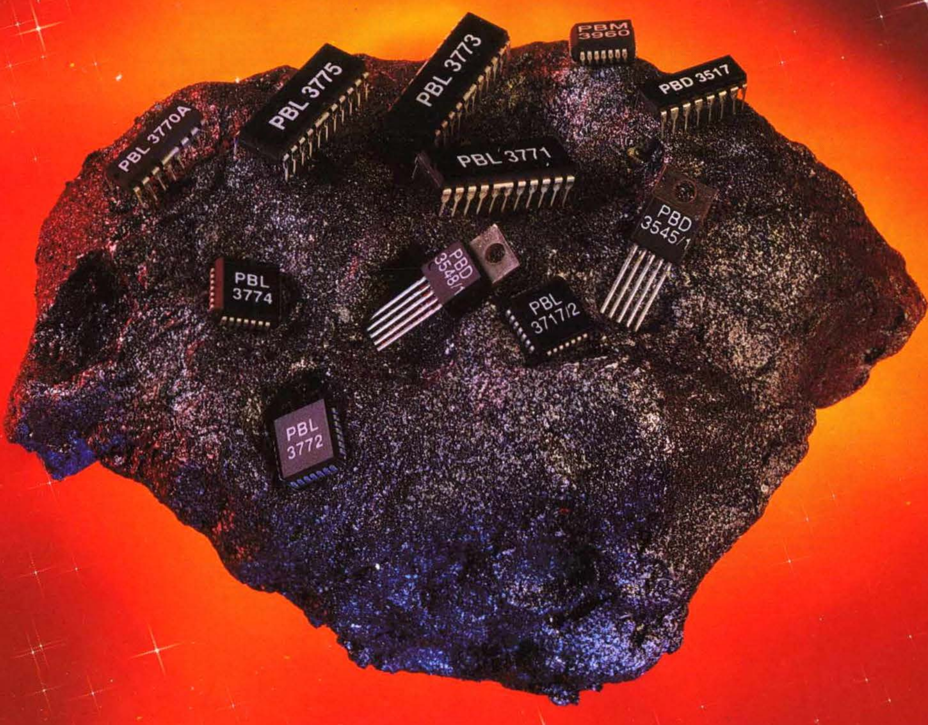
Industrial Circuits Databook and Stepper Motor Control Handbook



ERICSSON

Industrial Circuits Databook

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Life support and nuclear policy

Ericsson Components does not authorize or warrant any of its products for use in life support systems or nuclear facility applications, without the specific written consent of Ericsson Components.

Life support systems are equipment intended to support or sustain life, and whose failure to perform, when properly used in accordance with instructions provided, can be reasonably expected to result in personal injury or death.

Examples of nuclear facility applications are applications in a nuclear plant, or any device designed or used in connection with the handling, processing, packaging, preparation, utilization, fabrication, alloying, storing or disposal of fissionable material or waste thereof.

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General & Ordering Information

Engineers around the world have come to rely on Ericsson Components for state-of-the-art integrated driver solutions for motor control applications.

Since the introduction of the first fully integrated chopper stepper motor driver in 1982, our PBL 3717 has become the most widely used device for driving stepper motors in such applications as printers, hard-disk drives, fax-machines and small robotics.

The original chopper architecture of the PBL 3717 has been further refined and today, Ericsson Components offers a wide range of versatile stepper motor drivers including chip sets for precision microstepping applications. Most drivers are available in a surface mountable "Power PLCC" package.

This handbook has been written to assist our customers in broadening their knowledge about the theory of stepper motors, how the characteristics of a stepper motor system are affected by various driving methods and how to apply Ericsson Components' circuits for best overall performance. It is the first handbook focusing specifically on Stepper motor driver ICs and their applications.

We hope this applications handbook will be as much a "standard" as the PBL 3717 has become throughout the world and that it will provide a useful reference for all engineers involved in the design of stepper motor driver systems.

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Selection Guide

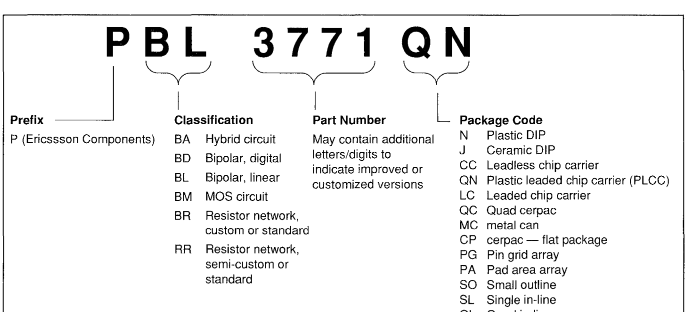
Part Number	Features	Technology	Package
Stepper motor controller and driver			
PBD 3517	• Unipolar driver, one circuit drives one motor • Half and full-step operations • Bilevel drive mode • I_{out} = 2 x 500 mA maximum	Bipolar	16-pin DIP 16-pin SO
Stepper motor drivers			
PBL 3717	Replaced by PBL 3717/2		16-pin Batwing DIP
PBL 3717/2	• Switched mode (chopper) bipolar constant current drive • Analog & digital current control • I_{out} = 1.2 A maximum	Bipolar	16-pin Batwing DIP 28-pin Power PLCC
PBL 3770	• Replaced by PBL 3770A		16-pin Batwing DIP
PBL 3770A	• Switched mode (chopper) bipolar constant current drive • Analog & digital current control • Low power dissipation • I_{out} = 1.8 A maximum	Bipolar	16-pin Batwing DIP 28-pin Power PLCC
PBL 3771	• Dual chopper driver, one circuit drives one motor • High microstepping accuracy • Selectable fast/slow current decay for improved high-speed microstepping • I_{out} = 700 mA maximum	Bipolar	22-pin Batwing DIP 28-pin Power PLCC
PBL 3772	• Dual chopper driver, one circuit drives one motor • High microstepping accuracy • 0 to +85°C temperature range • Low power dissipation • I_{out} = 1.2 A maximum	Bipolar	22-pin Batwing DIP 28-pin Power PLCC
PBL 3773	• Dual chopper driver, one circuit drives one motor • Few external components • -40 to +85°C temperature range • High impedance current control inputs for flexible microstepping • I_{out} = 850 mA maximum	Bipolar	22-pin Batwing DIP 28-pin Power PLCC
PBL 3774	• Dual chopper driver, one circuit drives one motor • -40 to +85 °C temperature range • Disable input for easy half-stepping • I_{out} = 1.2 A maximum	Bipolar	22-pin Batwing DIP 28-pin Power PLCC
PBL 3775	• Dual chopper driver, one circuit drives one motor • Few external components • -40 to +85°C temperature range • I_{out} = 850 mA maximum	Bipolar	22-pin Batwing DIP 28-pin Power PLCC
Microstepping controller			
PBM 3960	• Dual 7-bit + sign DAC • High-speed microprocessor interface • Programmable fast current decay control • Buffered DAC outputs, 0.0 - 3.0 V output voltage	CMOS	22-pin DIP 28-pin PLCC

Part Number	Features	Technology	Package
DC brushless motor controller			
PBM 3961	• PWM speed control • Integrated commutation for 3-phase, Hall-sensored motors • Direct drive of external power MOSFETs or bipolar transistors • On-chip PI speed regulator • Lock-at-speed indication	CMOS	16-pin DIP 16-pin SO 28-pin PLCC
Universal intelligent drivers			
PBD 3544	• Replaced by PBD 3548/1		5-p TO220
PBD 3545/1	• Low side driver • Short circuit and thermal protection with Error output for diagnosis • Open circuit detection • -40 to +85°C temperature range • I_{out} = 2 A continuously, V_{CC} = 45 V maximum	Bipolar	5-pin TO-220 28-pin Power PLCC
PBD 3548/1	• High side driver • Short circuit and thermal protection with Error output for diagnosis • Open circuit detection • -40 to +85°C temperature range • I_{out} = 2 A continuously, V_{CC} = 45 V maximum	Bipolar	5-pin TO-220 28-pin Power PLCC
Darlington drivers			
PBD 3523	7 X —Part is discontinued but may be available in limited quantities.		16-p CerDIP
PBD 3538	8 X —Part is discontinued but may be available in limited quantities.		18-p CerDIP

Ordering Information

Ericsson Components products are designated by a product code. Product codes will normally start with a "P" (a few older products may start with an "R"). Custom circuits may have special designations but will always carry an Ericsson Components identification code as well.

Below is an example of a product code. When ordering, please use the full code including the package designation suffix consisting of one or two letters.



Device Handling

All Ericsson Components ICs are designed and fabricated with protection diodes to reduce the risk of damage due to Electrostatic Discharge (ESD). However, in certain cases such as in high impedance nodes in analog ICs, ESD protection diodes could disturb normal circuit function and consequently, great care should be taken when handling all IC products.

Elimination or reduction of ESD risks can be accomplished as follows.

- Ground all handling equipment
- Ground all handling personnel with a conductive bracelet through a 1 MΩ resistor to ground.
- Clothes and shoes made of certain insulating materials (such as nylon) should be avoided. Natural materials such as cotton does not generate static discharge to the same extent and should always be used.
- Relative humidity should be kept at a level as high as possible; 50% is generally considered sufficient.
- Devices should never be removed from their carriers (normally antistatic, plastic tubes) until ready for insertion into PC boards.
- If removed from the container, always put the IC on plastic conductive foam. Alternatively, wrap the circuit in aluminum foil to protect it during handling.

Controller and driver

PBD 3517—Stepper motor controller and driver
PBD 3517 is intended to drive a four phase unipolar stepper motor. It is a complete phase logic generator/driver on a chip, requiring very few external components in a basic setup. Motor performance (higher torque at higher stepping rates) can be increased by operating in the bi-level drive mode. This means that a high voltage pulse from a secondary supply (V_{SS}) is applied to the motor winding at the beginning of a step, in order to give a rapid rise of current.

Figure 1 shows a unipolar stepper motor drive application using the bilevel drive mode of the PBD 3517. For normal operation V_{SS}, R_T, C_T, D1 and D2 are omitted.

Drive circuits

PBL 3717/2, PBL 3770A
The PBL 3717/2 and PBL 3770A Stepper Motor ICs are switch-mode (chopper) drivers feeding a constant current into one winding of a stepper motor. The current direction is controlled by the Phase input. Current level is selected high (100%), medium (60%), low (20%) and off (0%) via the I_0 and I_1 inputs. Furthermore, the output current can be continuously controlled by changing the voltage at the V_R pin, normally within the range 0 to 5 Volts. The output current is defined according to the following equation:

$$I_M = K \times (0.083 \times V_R) \div R_S \quad [A]$$

where K is the current level selected via the I_0 and I_1 inputs, K=1 for 100%, K=0.6 for 60% and K=0.2 for 20% current level.

Applications
The basic configuration is shown in figure 2. Signals to the logic inputs are normally generated by a microprocessor. In systems using a single pulse train as the step signal, the PBD 3517 Stepper Motor Driver can derive the control signals for full and half stepping operations, as shown in the schematic diagram in figure 3.

Dual channel drivers

The dual channel stepper motor driver family PBL 3771 to 3775 are fixed frequency switched mode (chopper), constant current driver ICs with two channels, one for each winding of a two-phase stepper motor. All circuits are especially developed for microstepping operation, but with various spe-

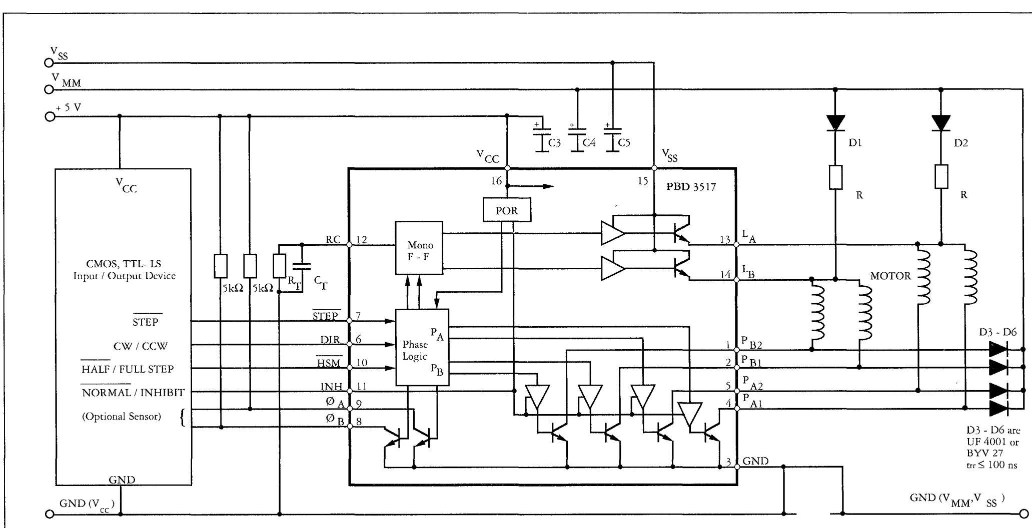


Figure 1. Typical unipolar stepper motor drive application with PBD 3517.

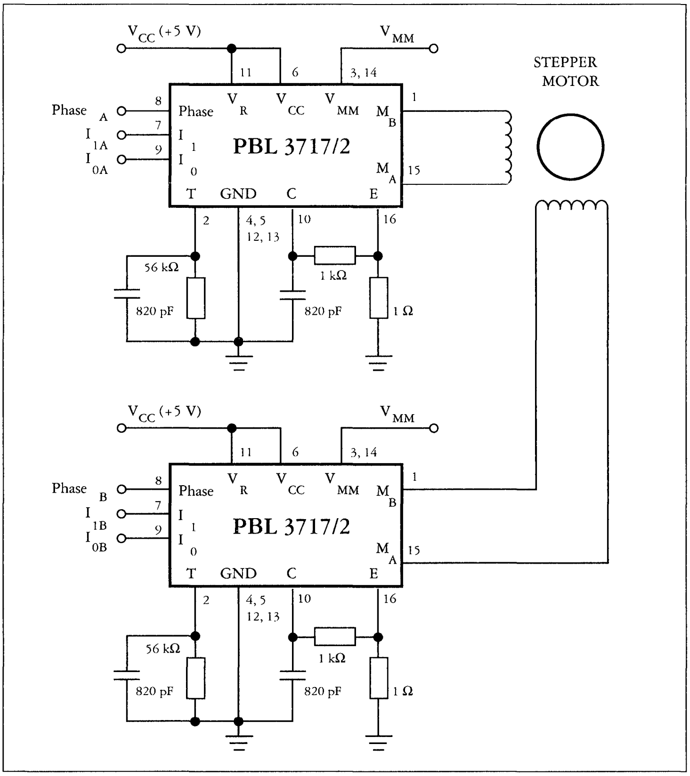
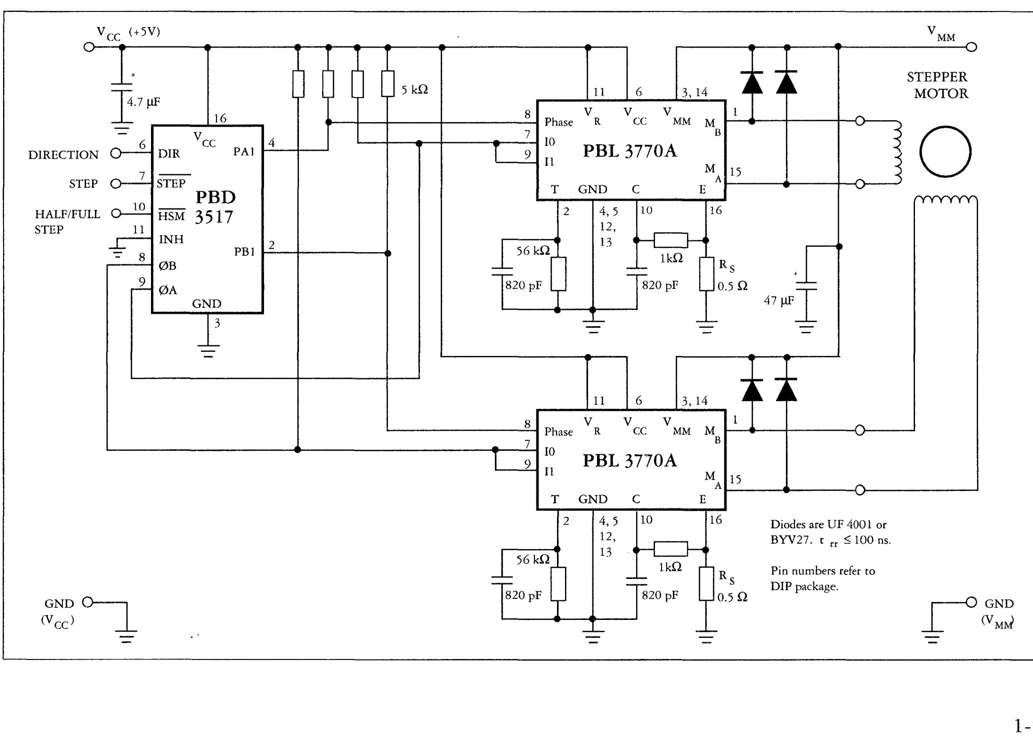


Figure 2. Typical stepper motor driver application with PBL 3717/2.

Figure 3. Stepper motor driver application with PBD 3517 used as a phase logic generator for 2 x PBL 3770A.



cial features for cost effective implemenation in different applications and current ranges.

PBL 3771—advanced microstepping driver

PBL 3771 offers a special logic function used to select slow or fast current decay during the off time of the chopping cycle. The fast current decay feature minimizes "current dragging" when driving a sinewave shaped current through the motor winding and results in less noise and better dynamic positioning accuracy at high stepping rates.

Figure 5 shows the basic configuration of the PBL 3771. In the figure, the PBL 3960 is used to generate the correct microstepping sequence. For full- or half-stepping, another generator can be used. For examples, see the halfstepping application note.

The output stages of the PBL 3771 include recirculation diodes, and have an output current capability of 650 mA in microstepping "sine/cosine drive" mode. PBL 3771 is available in 22-pin batwing DIP or in 28-pin power PLCC package.

PBM 3960—Microstepping Controller

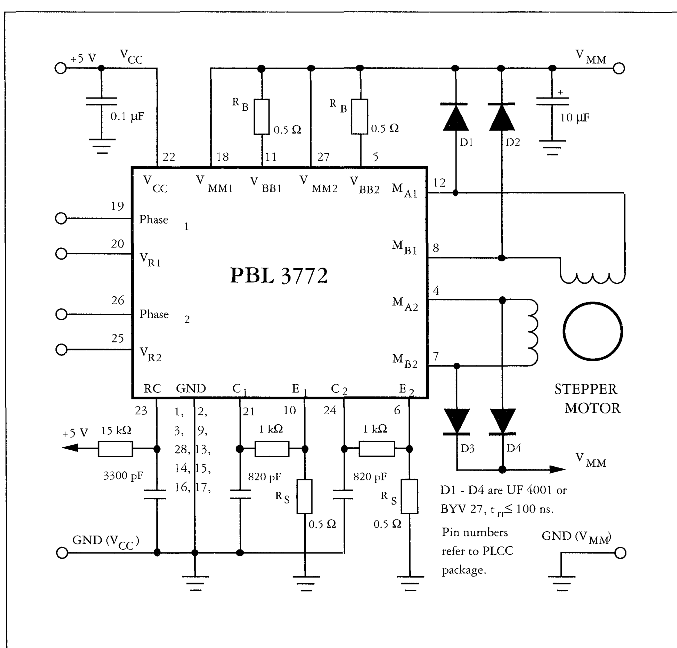
PBM 3960 is a dual 7-bit + sign, Digital-to-Analog Converter (DAC) especially developed to be used together with the dual drivers such as PBL 3771 in microstepping applications. PBM 3960 is a stand-alone, low-impedance voltage-output dual DAC that runs off a single +5 V supply, and includes automatic fast/slow current decay control in conjunction with the PBL 3771. PBM 3960 is packaged in 22-pin DIP or in 28-pin PLCC package.

A complete microstepping driver system consists of PBL 3771 + PBM 3960 and only eight passive components, see figure 5. A microprocessor is usually used for generation of the proper control and data codes required for microstepping. Figure 6 shows the typical block diagram of an application without a microprocessor.

PBL 3772—powerful microstepping driver

PBL 3772 is optimized for good microstepping performance and has very low power dissipation. Using external recirculation diodes, and external dropping resistors for reducing the

Figure 4. Typical stepper motor driver application with PBL 3772.



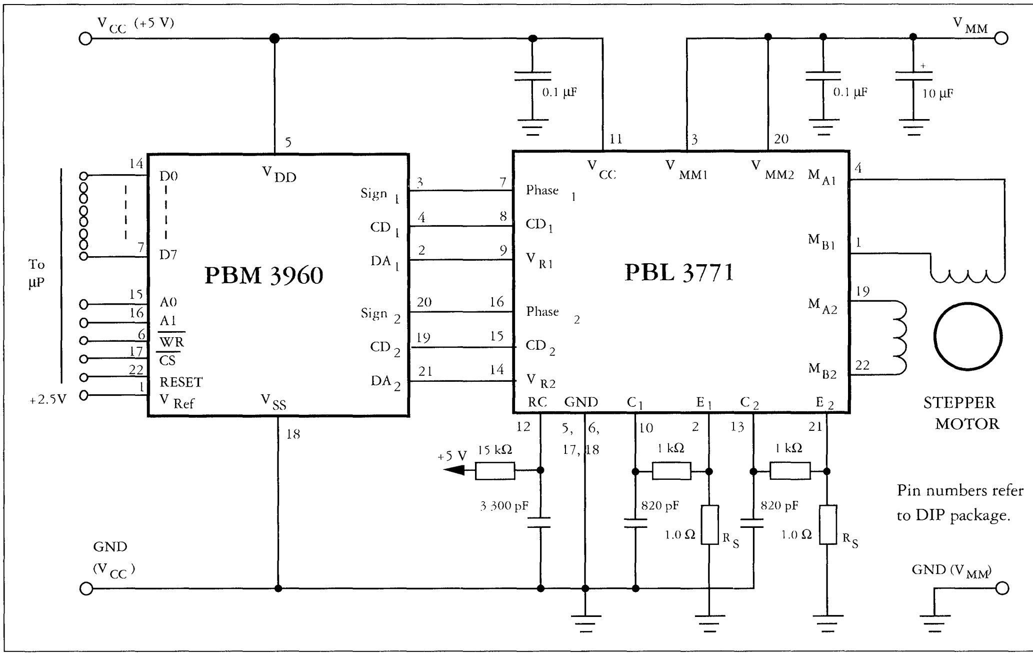


Figure 5. Typical microstepping application in a microprocessor based system.

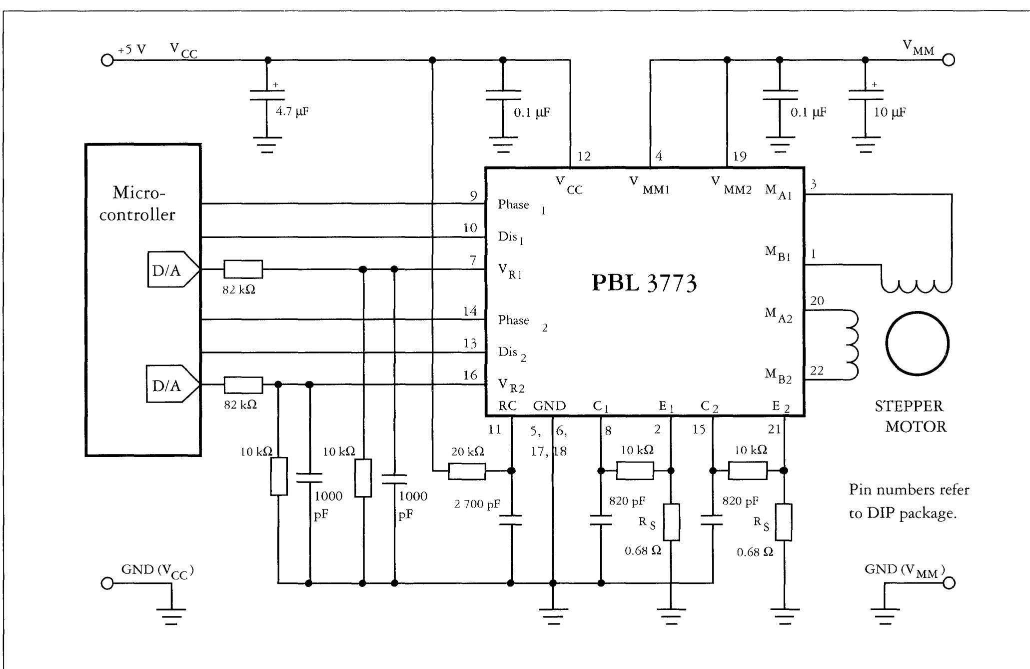


Figure 6. Microstepping system where a microcontroller including DACs provides analog current control voltages as well as digital signals to the PBL 3773.

saturation voltage in the output stages, the internal power dissipation is reduced to a minimum.

Continuous output current capability is 1.0 A per channel at ambient temperatures up to +85°C, using only a PCB copper ground plane for heat sinking.

Figure 4 shows the basic configuration of the PBL 3772, which can be controlled by a dual DAC such as the PBM 3960.

PBL 3773 and PBL 3775—versatile drivers with few external components

The PBL 3773 was developed for microstepping and half-stepping applications using the internal DACs of low cost microcontrollers as the voltage reference source. The voltage reference inputs are high impedance to enable simple interfacing to unbuffered DACs via high resistive attenuators in microstepping systems, see figure 6.

The PBL 3775 has an internal voltage divider at the voltage reference input. Reference voltage range is 0 – 5 V, making it similar to the PBL 3717/2 and PBL 3770A stepper motor drivers.

Both PBL 3773 and PBL 3775 have internal recirculation diodes. An internal digital filter eliminates external filtering components in the current sensing loop thus minimizing parts

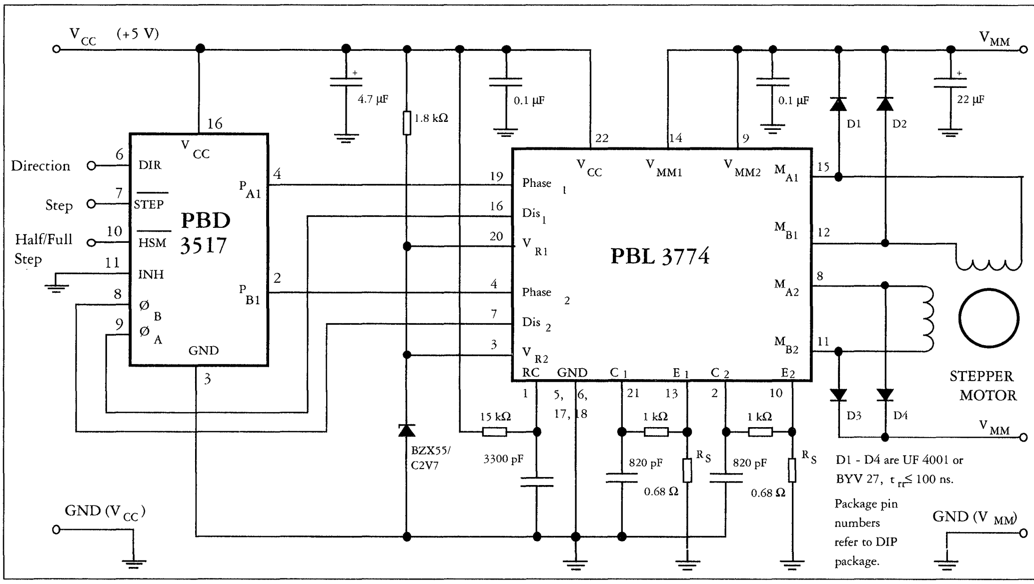


Figure 7. Typical stepper motor driver application with PBL 3774.

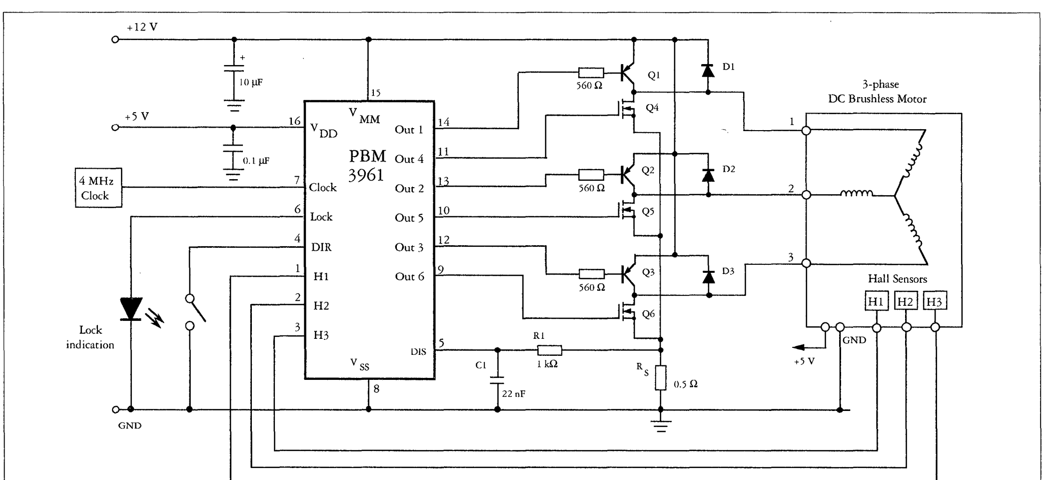


Figure 8. Typical application. Q1-Q3 are PNP power transistors and Q4-Q6 are N-channel power MOSFETs.

count. The operating temperature range is specified from -40°C to +85°C, making these circuits particularly suitable for automotive and industrial applications.

Conventional full/half stepping control is facilitated by a Disable input that turns off the output stage entirely.

Current capability is 750 mA continuously per channel.

PBL 3774—dual channel driver with extended temperature range.
The PBL 3774 is developed primarily for microstepping applications and has been provided with a Disable input for simple half-stepping control. Figure 7 shows a typical half-stepping application using PBD 3517 as a step generator. The operating temperature range is specified to -40°C to +85°C, making the circuit particularly suitable for automotive and industrial applications. Current capability is 1.0 A continuously per channel. The circuit is available in both DIP and power PLCC package.

DC Brushless Motor Controller

PBM 3961
PBM 3961 is a CMOS control circuit for three phase DC Brushless (Hall) motors in constant speed applications The IC and a minimum number of external components provide all necessary functions to start, drive control and break a three phase DC Brushless motor. Figure 8 shows a typical application diagram.

Closed-loop PI (proportional-integrating) speed control implemented with digital-only signal processing makes the circuit insensitive to component tolerances and aging. No external resistors/capacitors are required to stabilize the control-loop.

The circuit, which connects to external power MOS-FET transistors, uses PWM (Pulse-Width Modulation) techniques to control the motor speed, thus minimizing power losses and heat-sinking requirements. A level-sensitive disable input with hysteresis, can be used for current-limiting during start up. A special feature is a correct speed output, signalling when the actual motor speed is within ±0.7% of the correct value. The circuit is packaged in 16-pin plastic DIP, 28-pin PLCC or 16-pin SO package.

Universal Intelligent Drivers

PBD 3545/1, PBD 3548/1
Ericsson Components offers a family of truly smart drivers for inductive load control in industrial and automotive applications. The 2 A/45 V Universal Drivers, PBD 3545/1 and PBD 3548/1 offer "intelligent" power-control at a fraction of the cost of discrete implementations.

PBD 3545/1 and PBD 3548/1 are complementary drivers with equivalent functions and similar data. PDB 3545/1 is a low side (sink) driver and PBD 3548/1 is a high side (source) driver. Extensive electrical protection makes the drivers virtually indestructible when driving such loads as solenoids, relays or resistive loads.

The circuits are packaged in a 5-pin TO-220 power package or a 28-pin power PLCC package. The circuits incorporate complete short-circuit and over-temperature protection as well as load monitoring circuitry with an Error output for diagnosis. The protection circuitry is capable of detecting short circuit output to either V_{CC} or GND, and open circuit

Typical applications with PBD 3545/1 and PBD 3548/1 are shown in figures 9 and 10. The output stage contains a power transistor and two clamping diodes which are used for inductive transient suppression. The input pin can be connected by a pull-up resistor to a logic supply voltage or to the V_{CC} supply voltage when driven from an open collector outputs or opto-couplers. To prevent switching transients affecting the internal logic, a high quality decoupling capacitor of minimum 6.8 µF should be connected close to the V_{CC} and GND pins.

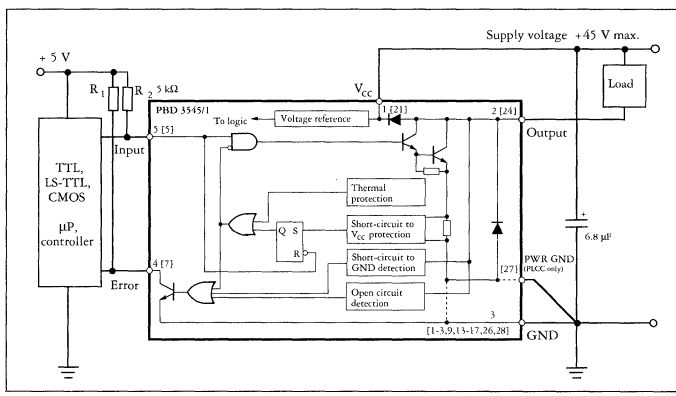


Figure 9. Block diagram and typical application of the PBD 3545/1 Sink Driver.

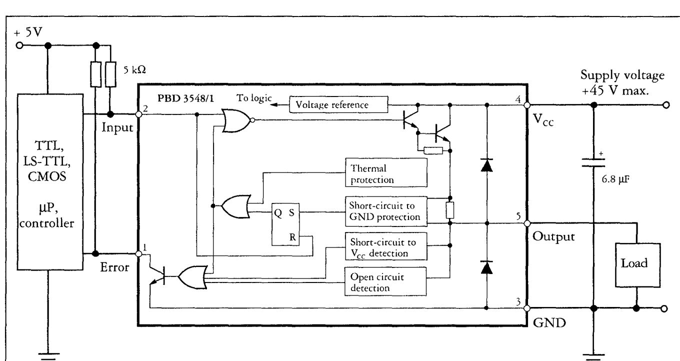


Figure 10. Block diagram and typical application of the PBD 3548/1 Source Driver.

Quality Assurance

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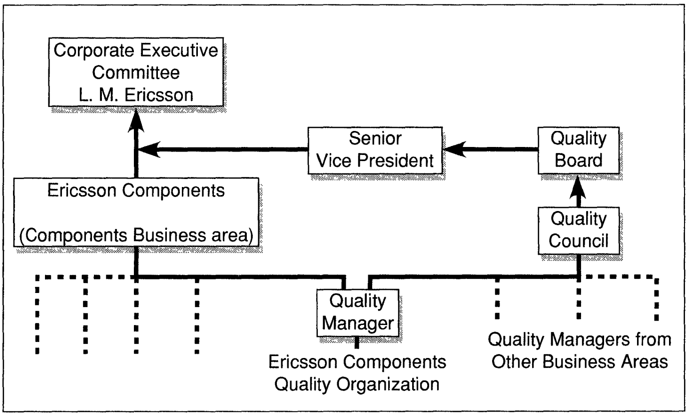


Figure 1. Quality reporting structure within Ericsson.

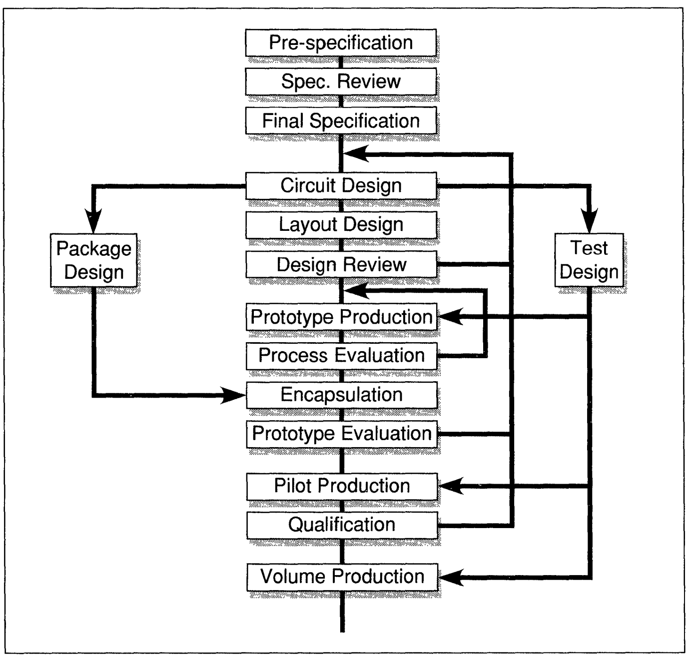


Figure 2. New product design flow.

Ericsson is organized in seven business areas; Ericsson Components AB is the main company within the components business area.

An overall quality policy, common to all business areas, is defined by the Ericsson Corporate Executive Committee.

"Our Company name shall be the symbol of overall quality.

"Our understanding of customer needs, and the error-free operation of our products are lasting factors which ensure the development and future of the Company.

"The quality of our products and services shall be the main reason our customers prefer to rely on us.

"Quality is everyone's concern."

Total operating quality is a fundamental part of Ericsson's overall strategy. A common Quality System for the entire Ericsson Group (Ericsson Quality System, EQS) is based on the international standard ISO 9000-9004.

Ericsson's Quality Board, which reports to the Corporate Executive Committee, has the overall responsibility for strategic and long-term quality policies within the Ericsson group of companies.

The Quality Manager of Ericsson Components is a member of Ericsson's Quality Council which coordinates quality matters in all business areas.

It is the responsibility of the Quality Manager to manage the quality organization within Ericsson Components AB, and to monitor and report the status of the quality work to the management.

As a complement to the extensive work directly related to product quality, Ericsson Components has also resources designated to assure the quality of external services, internal efficiency as well as to develop and maintain quality in our business processes.

Ericsson Components has a long tradition of delivering high quality electronic devices to demanding telecommunications and professional electronics customers.

Product reliability is assured by strict implementation of internationally accepted quality control measures. Our Quality Department defines quality control procedures and audits the implementation of our Quality System within the organization.

Advanced equipment is used throughout production to check important fabrication steps and to perform ongoing monitoring of critical process parameters.

Outgoing quality is assured by 100% final test, as well as 100% Lot Acceptance Testing, following sampling plans and procedures defined in IEC 410 (ISO 2059, MIL-STD 105) and MIL-M-38510F app. B.

Designing for Quality

Product reliability begins with building quality into the design. The work on a new product is organized in phases. In order to build in quality, the result of each phase is reviewed, evaluated and documented before the next phase is started.

Ericsson Components uses strict design and layout rules when a new circuit is designed. Unless a new product calls for specially-designed components, we only use fully-characterized processes and building elements when a new circuit is developed.

To prevent failures, due to metal migration, current density in internal aluminium paths is generally not allowed to exceed 5×10^5 A/cm^2.

All circuits must be designed to withstand minimum 500 V electrostatic discharge (ESD). (Test circuit according to MIL-STD-883, Method 3015). Many ICs are characterized at higher voltages, up to and in excess of 2000 V.

Circuit design makes use of the latest computer simulation tools, and the progress is constantly monitored in design review meetings with the Quality Department.

Advanced CAD software performs automatic design rule check (DRC) on the final layout. Before a new design is released for pre-production, sample lots are extensively characterized across and beyond its specified temperature range.

Product Qualification

Before a product is released for volume production, it has to be qualified. This procedure has many purposes:

- It checks the stability of the manufacturing process, e.g. oxide stability, lack of mobile ions etc.

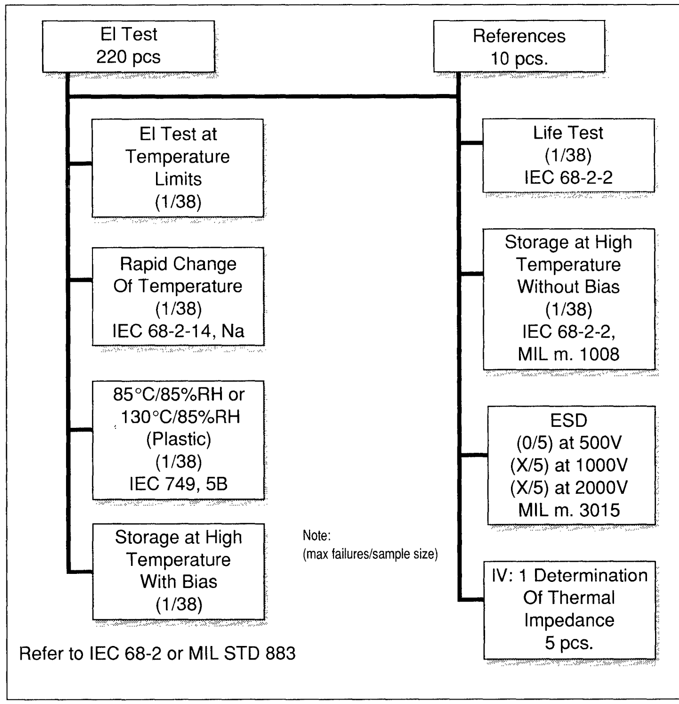


Figure 3. Flow chart, qualification of new chip design. Wafer process and assembly already qualified (all tests are in accordance with MIL-STD883 and IEC 68-2).

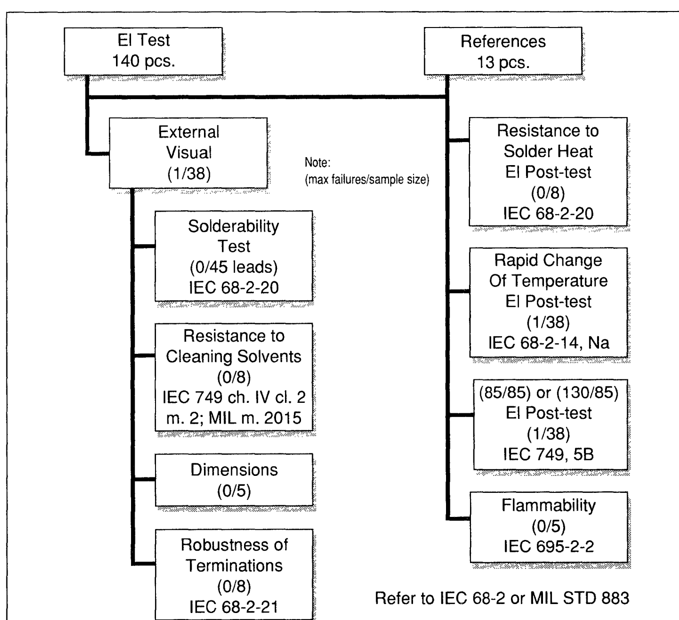


Figure 4. Qualification of new plastic packages.

- It checks the circuit layout for parasitic elements.
- It reveals weaknesses in the mechanical system consisting of chip, wire bonding, die attach and package.
- It gives a rough estimation of the operating lifetime and failure intensity one can expect from the circuit in a typical application.
- If needed, test time and sample size can be adjusted to meet specific demands from customers who wish to verify a certain failure intensity and/or lifetime under specific operating conditions.

Our standardized tests for new designs and packages are described in figures 3 through 5.

Production and Assembly Quality Assurance

Production quality is maintained in a number of ways.

All incoming materials are inspected according to our own specifications. Every manufacturing step is followed by inspections and process control monitors. The flowchart in Figure 8 shows the essential steps in bipolar production. MOS production, which takes place in a different fab, follows a similar flow. In-house mask and reticle production equipment guarantees full control over these important parts of semiconductor manufacturing and speeds up turnaround times. At the wafer probe level, we perform functional and AC/DC testing, as well as Process Monitoring test patterns on each wafer.

Assembly Q/A flow (see figures 6 and 7) follows strict procedures to guarantee highest possible outgoing quality. Inspections and quality monitoring follow MIL-STD 883 methods. Every package from subcontracted assembly houses is tested periodically in a Quality Conformance Program to monitor the assembly quality continu-

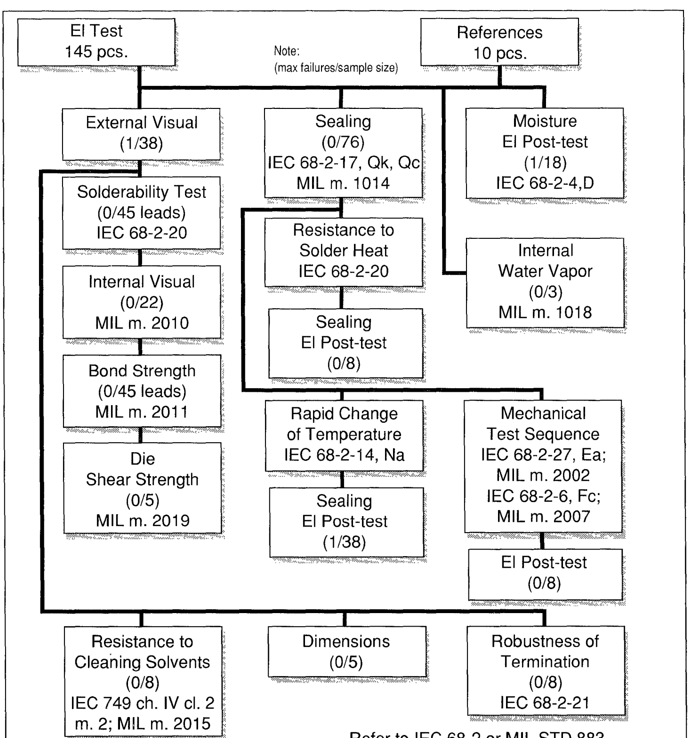


Figure 5. Qualifications of new hermetic packages.

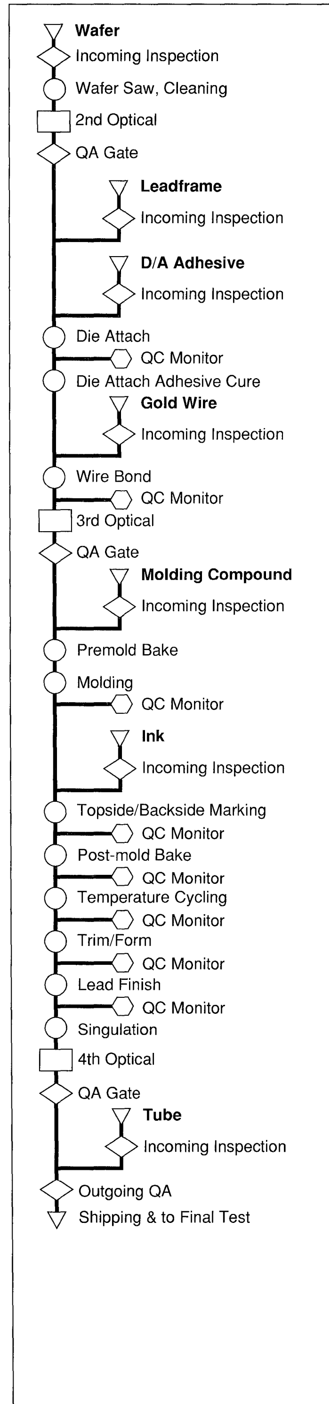


Figure 6. Plastic package QA flow.

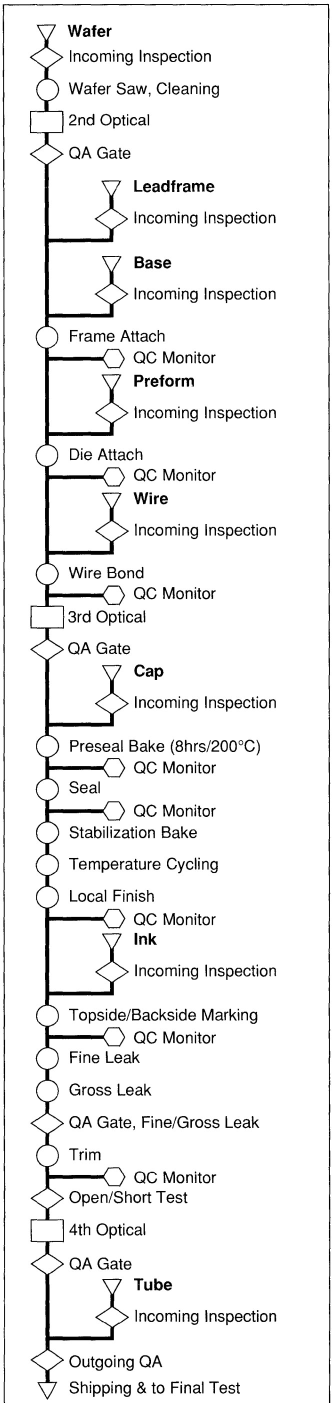


Figure 7. Ceramic package QA flow.

Table 1. Quality conformance test scheme.

Tests	Purpose	Periodicity
Group A	Final control of products to be delivered to customer	Each production lot
Group B	Control of encapsulation quality	Every 8th week
Group C	Control of chip-and encapsulation quality	Every 3rd or 6th month
Group D	Extended reliability tests	See product specification

The group B and C tests are performed on a selection of circuits that are representative for the different manufacturing processes, encapsulation and chip designs.

Test description			AQL level
Group A Inspection			
A1	External visual	Critical	0.15
		Major	0.4
		Minor	1.0
A2	Electrical function		0.065
A3	Static and dynamic el. parameters	(SLICs)	0.1
		(other circuits)	0.065
A4	El. function, static and dynamic parameters within temp. limits		LTPD 10

Test description		LTPD	Error/sample size
Group B Inspection			
B1	Dimensions		0/1
B2	Resistance to cleaning solvents	30	0/8
B3	Solderability	5	0/45 nr of leads
B4	Internal visual	50	0/5
	Bond strength	5	0/45 nr of bonds
	Die shear strength	50	0/5
B5	Sealing Fine leak	3	1/129
	Gross leak	3	1/129
B6	Rapid change of temp. (-65 – 150°C)	7	0/32
B7	Pressure cooker test	15	1/25
B8	Electrical test at temperature limits	10	2/52
Group C Inspection			
C1	Robustness of terminations	30	0/8
C2	Mechanical shock	50	0/5
	Vibration	50	0/5
C3	Resistance to solder heat	30	0/8
C4	Rapid change of temp. (-65 – 150°C)	10	1/38
C5	Moisture	20	1/18
C6	Life test 1000 h	10	1/38
C7	Internal water vapor		0/3
C8	Climatic test sequence: 85/85 or 130/85+bias	10	1/38
C9	Storage at high temperature with bias.	10	1/38

Group D Test

In some cases it is necessary to perform life tests, HTRB-tests etc. for a longer time in order to reveal failure mechanisms with activation energies lower than 0.7 eV. The number of circuits in the tests as well as the test times will be determined separately for each case.

ously. Final tests take place at our own facilities close to our design and quality departments for quickest failure analysis and corrective actions.

Quality Conformance Program

In order to assure a reliable production and a stable outgoing quality level, a quality conformance program has been put into operation. It consists of periodic tests of circuits from production, according to the scheme shown in table 1 on the following page.

Reliability Analysis

Reliability is the probability that a device will perform a required function under specific conditions for a specific period of time.

The reliability is described in quantitative terms by measuring the failure rate as a function of time. The failure rate distribution of a typical device follows approximately the "bathtub" curve shown in Figure 9.

Zone I covers the "infant mortality" period; the failure rate decreases with time. The predominant failure mechanism is related to assembly/mounting defects.

Zone II represents the "useful life" period, with low level of random failures, approximated with a constant failure rate.

Zone III is a possible wear-out period with increasing failure rate.

To assure low failure rate levels during service life time, Ericsson Components uses two groups of reliability tests:

a. Qualification tests are performed on all new designs before series production can be started. The purpose of the tests is to verify that the new product has an adequate operating life time under certain environmental conditions.

b. Quality conformance tests are performed on samples from the production. These tests are made to verify the reliability of the manufactured product.

Table 2 shows various test methods and how the tests results are interpreted with respect to different failure causes.

Most reliability testing means that the devices are subjected to higher stress levels than they normally experience in typical applications. The stress may take the form of temperature, voltage, humidity, etc. The acceleration factor can be calculated for failures caused by physical and chemical changes from the Arrhenius equation:

$$R = A \cdot \exp(-E_a / kT) \qquad [1]$$

R = acceleration rate

A = proportionality constant

E_a = activation energy (eV)

k = Bolzmann's constant (8.617×10^{-5} eV/degK)

T = absolute temperature (degK)

The activation energy is normally associated with a certain failure mechanism. Experimental values of activation energy range from 0.3 eV, typical of wear out phenomena only slightly

Table 2. Relationship between failure causes and analytical test methods

	Test method according to MIL-STD 883				
	B	B	B	H	H
Failure cause	**Solderability (2003.2)**	**Rapid change of temp. (1010.2)**	**Thermal Shock (1011.2)**	**Constant Accelleration (2001.2)**	**Mechanical Shock (2002.2)**
Bond Integrity		•	•	•	•
Cracked Chip		•	•		•
Internal Structural Defect					•
Contamination-/Contact-induced Short		•		•	•
Wire or Chip Breakage				•	•
Glass Crack	•	•	•		•
Lead Fatigue					
Contamination of Package Elements	•	•	•		
Thermal Fatigue		•			
Seal Integrity		•			
Seal Contamination				•	•
Leakage		•	•		
Package/Material Integrity	•	•	•		•

(P = applies to plastic package, H = applies to hermetic package, B = applies to both).

affected by temperature, to 1.5 eV for infant mortalities.

The temperature acceleration factor (F) by which the medium life is reduced when testing at high temperature is derived from the Arrhenius equation [1].

$$F = \exp[E_a/k(1 / T_{jo} - 1 / T_{jt})]$$

E_a = the activation energy (normally 0.7 - 0.9 eV)

T_{jo} = nominal junction temperature at operation (degrees Kelvin)

T_{jt} = junction temperature at test (Kelvin)

Test time should be chosen long enough to simulate the operating life.

$$\text{Test time} = \frac{\text{expected operating lifetime}}{\text{acceleration factor}}$$

The failure rate obtained from an exponential probability distribution is the number of failures observed on test divided by the number of device hours (sample size multiplied by test hours).

The failure rate is expressed in percent/1000 hours or FIT:s (failure in 10^9 hours). The mean time to failure (MTTF) is the reciprocal of the failure rate in hours. As the failure rate, derived from the sample, is only a point estimate of a much larger population, an upper confidence limit (UCL) is applied to the estimate using the chi-square (χ^2) distribution. The confidence limit assures that the population failure rate is no greater than a certain value at a specific probability level. The failure rate or test sample size can be calculated from the following equation:

$$\lambda_\alpha \leq \chi^2_{\alpha(2r+2)}/(2 \cdot n \cdot t \cdot F)$$

Table 3. Chi-square Distribution

Number of failures (r)	Degrees of freedom (2r + 2)	$\chi^2_{\alpha(2r+2)}$ Confidence, α 0.60	0.90
0	2	1.83	4.62
1	4	4.04	7.78
2	6	6.21	10.6
3	8	8.35	13.4
4	10	10.5	16.0
5	12	12.6	18.5
6	14	14.7	21.1
7	16	16.8	23.5
8	18	18.9	26.0
9	20	21.0	28.4

Test method according to MIL-STD 883

H	B	H	H	P	
Vibration, Variable Freq. (2007.1)	**Lead Fatigue (2004.2)**	**Moisture Resistance (1004.2)**	**Vibration Fatigue (2005.1)**	**+85°C/85%RH or +150°C/85%RH**	**Failure cause**
			•		Bond Integrity
					Cracked Chip
•					Internal Structural Defect
•			•		Contamination-/Contact-induced Short
•			•		Wire or Chip Breakage
	•				Glass Crack
	•				Lead Fatigue
				•	Contamination of Package Elements
					Thermal Fatigue
					Seal Integrity
•				•	Seal Contamination
	•	•			Leakage
		•		•	Package/Material Integrity

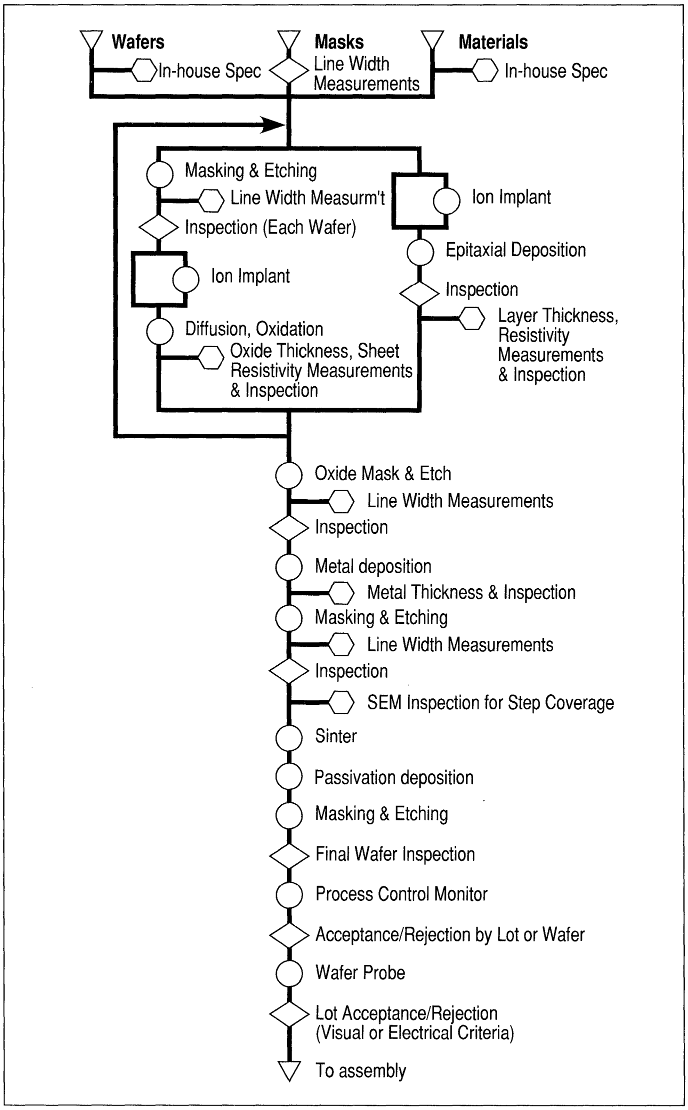


Figure 8. Bipolar production flow.

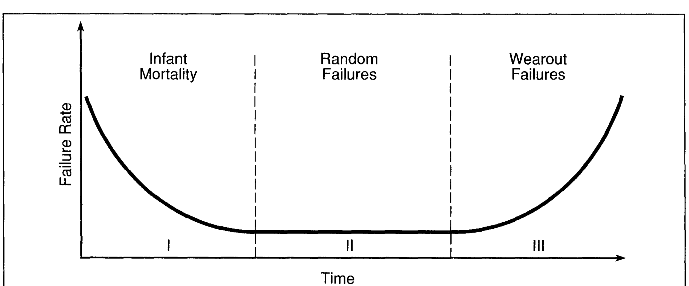


Figure 9. Failure rate distribution, "bathtub" curve.

λ_α = Failure rate in FITs

n = sample size

t = test time in hours

F = acceleration factor

r = number of failures

χ^2 = chi-square distribution with (2r + 2) degrees of freedom

α = confidence level

The value of χ^2 as a function of a and (2r + 2) can be obtained from table 3.

Failure analysis is our tool for reliability assurance. Using different failure analysis techniques to investigate the defective device, we can determine the failure mechanism and decide the right corrective actions.

Ericsson Components has access to an extensive range of failure analysis equipment. The most frequently used is the SEM (Scanning Electron Microscope) to inspect the surface and, via voltage contrast techniques, analyze voltage levels during operation. Other examples are the Auger electron spectrometer, used for analysis of surface contamination, and the Infrared microscope, used for thermal mapping.

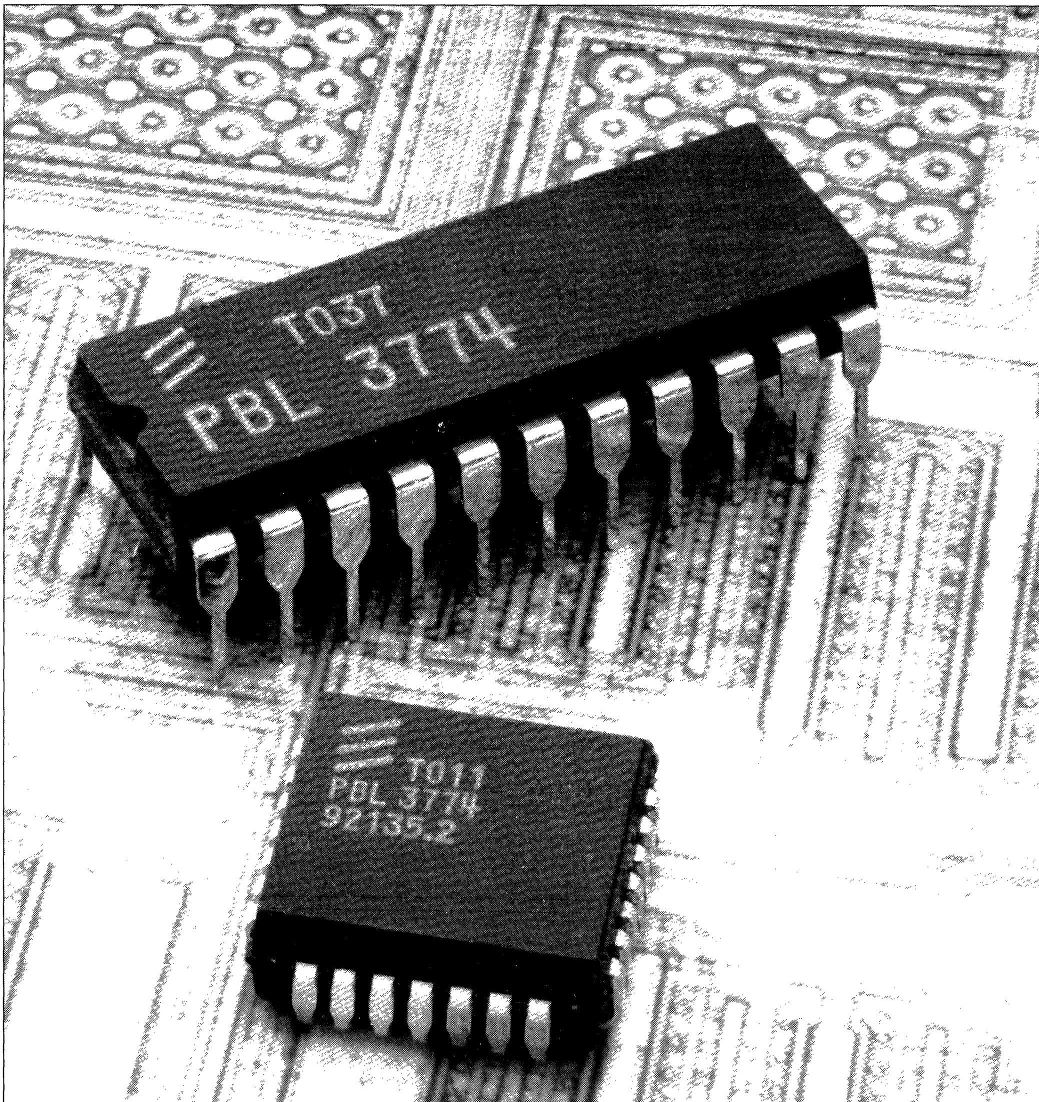
Packing

Ericsson Components' products are packaged for safe transportation. All devices are delivered in anti-static tubes for ESD protection and the packages are clearly marked to indicate ESD sensitivity. All boxes are marked with a product identification number, a production code, and the number of devices.

Traceability

All our produced circuits are marked with a production code and can be traced to assembly houses as well as to production year and week, ± one week. Our circuits are also marked with a production wafer lot number, which gives complete traceability

Industrial Circuit Datasheets



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May 1991

PBD 3517 Stepper Motor Drive Circuit

Description

PBD 3517 is a bipolar, monolithic, integrated circuit, intended to drive a stepper motor in a unipolar, bilevel way. Motor performance can be increased using a bilevel function without using a high power drop resistor.

One PBD 3517 and a minimum of external components form a complete control and drive unit for LS-TTL- or microprocessor-controlled stepper motor system for currents up to 500mA. The driver is suited for applications requiring least-posssible RFI.

Key Features

- LS-TTL-compatible inputs
- 2 × 350mA continuous-output current
- Half- and full-step mode generation
- All phase logic on chip
- Bilevel drive mode
- Voltage-doubling drive possibilities
- Half-step position-detection output
- Minimal RFI
- 16-pin plastic DIP package

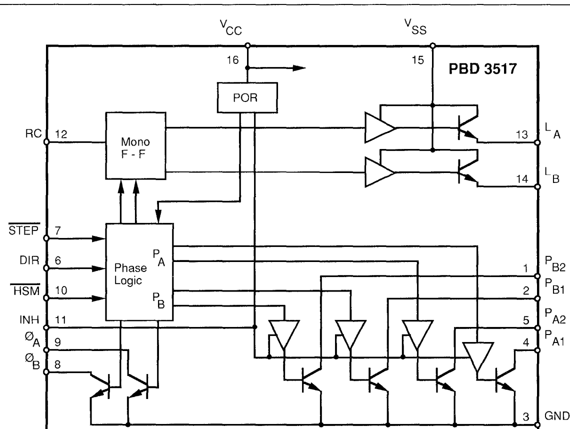
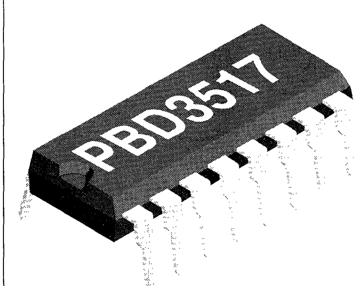


Figure 1. Block diagram.



16-pin plastic DIP

Maximum Ratings

Parameter	Symbol	Min	Max	Unit
Logic supply voltage	V_{CC}	0	7	V
Second supply voltage	V_{SS}	0	45	V
Phase output current	I_P	0	500	mA
Second-level output current	I_L	-500	0	mA
Logic input voltage	V_{In}	-0.3	6	V
Logic input current	I_{In}	-10		mA
The zero output current	$I_{\varnothing}$		6	mA
Junction temperature	T_J	0	+150	°C
Operating ambient temperature	T_{Amb}	0	+70	°C
Storage temperature	T_{Stg}	-55	+150	°C
Power dissipation (note 1)	P_d		1.6	W

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Supply voltage, logic	V_{CC}	4.75	5	5.25	V
Second-level supply voltage	V_{SS}	10		40	V
Phase output current	I_P	0		350	mA
Second-level output current	I_L	-350		0	mA
Ambient temperature	T_{Amb}	0		+70	°C
Set-up time (fig. 3)	t_s	400			ns
Step-pulse duration (fig. 3)	t_p	800			ns

Electrical Characteristics

Electrical characteristics at T_{Amb} = +25°C, V_{CC} = +5.0V, V_{MM} = +40V, V_{SS} = +40V unless otherwise specified

Parameter	Ref. Fig.	Conditions	Min	Typ	Max	Unit
Supply current, I_{CC}		INH = LOW		45	60	mA
		INH = HIGH		12		mA
Phase outputs						
Saturation voltage, $V_{PCE\ Sat}$		I_P = 350mA			0.85	V
Leakage current, I_{PL}		V_P = 0V			500	µA
Turn on, turn off, t_d					3	µs
Second-level outputs						
Saturation voltage, $V_{LCE\ Sat}$		I_L = -350mA			2.0	V
Leakage current, I_{LL}		V_L = 0V	-500			µA
On time, t_{On}		(note 2)	220	260	300	µs
Logic inputs						
Voltage level, HIGH, V_{IH}			2.0			V
Voltage level, LOW , V_{IL}					0.8	V
Input current, low level, I_{IL}		V_{In} = 0.4V	-400			µA
Input current, high level, I_{IH}		V_{In} = 2.4V			20	µA
Logic outputs						
Saturation voltage, $V_{\varnothing CE\ Sat}$		$I_{\varnothing}$ = 1.6mA			0.4	V

Notes

1. T_{Amb} = +25°C. Derates at 12.8mW/°C above 25°C.
2. R_T = 47kΩ, C_T = 10nF. $t_{On} = 0.55 \bullet R_T \bullet C_T$.

Figure 2. Test measurements.

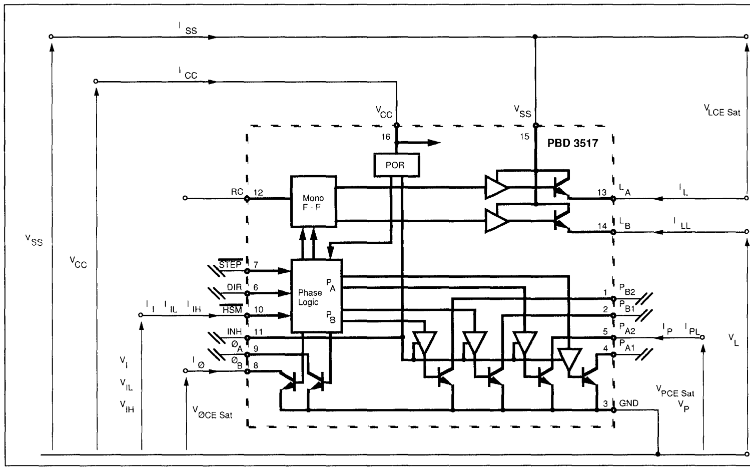
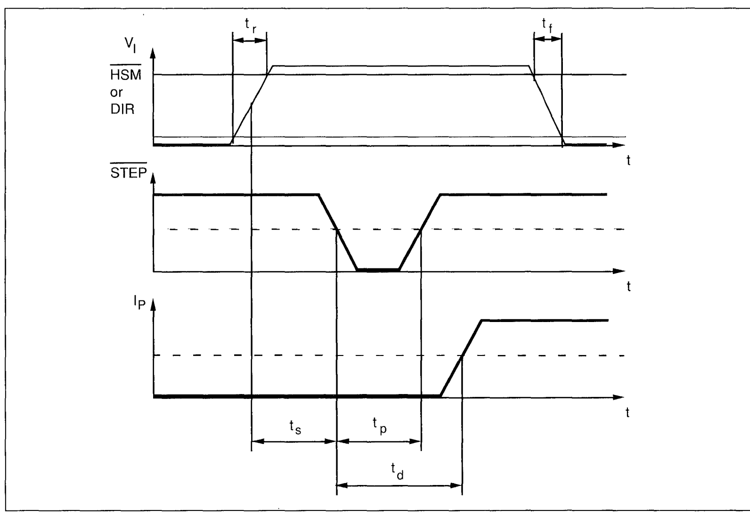


Figure 3. Timing diagram.



Diagrams

How to use the diagrams:

1. What is the maximum motor current in the application?
   - The ambient temperature sets the maximum allowable power dissipation in the IC, which relates to the motor currents and the duty cycle of the bilevel function. For PBD 3517, without any measures taken to reduce the chip temperature via heatsinks, the power dissipation vs. temperature follows the curve in figure 5.

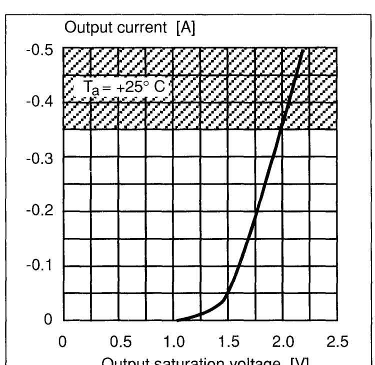


Figure 4. Typical I_L vs. $V_{LCE\ Sat}$ Second level output saturation.

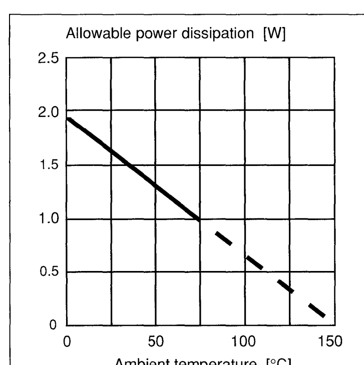


Figure 5. Typical P_D vs. T_a. Total power dissipation.

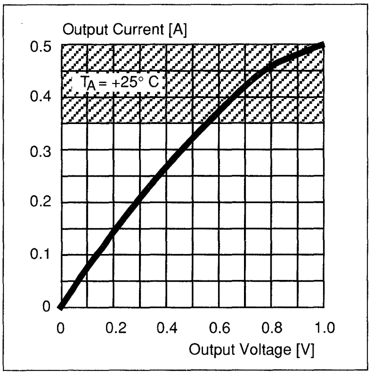


Figure 6. Typical I_P vs. $V_{PCE\,Sat}$. Phase output saturation.

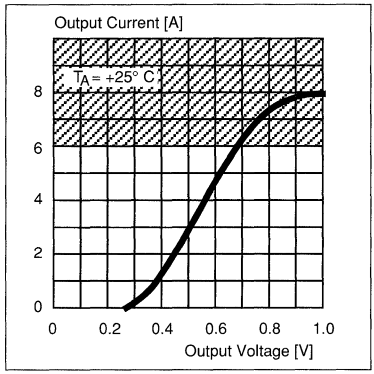


Figure 7. Typical $I_\varnothing$ vs. $V_{\varnothing CE\,Sat}$. "Zero output" saturation.

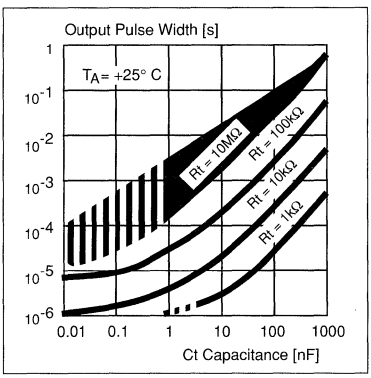


Figure 8. Typical t_{On} vs. C_T/R_T. Output pulse width vs. capacitance/resistance.

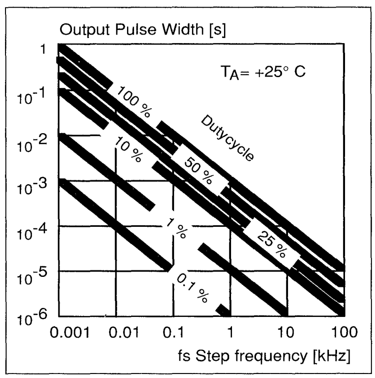


Figure 9. Typical t_{On} vs. f_s/dc. Output pulse width vs. step frequency/duty cycle.

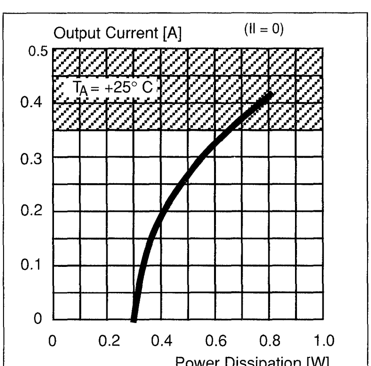


Figure 10. Typical P_{DP} vs. I_P. Power dissipation without second-level supply (includes 2 active outputs = FULL STEP).

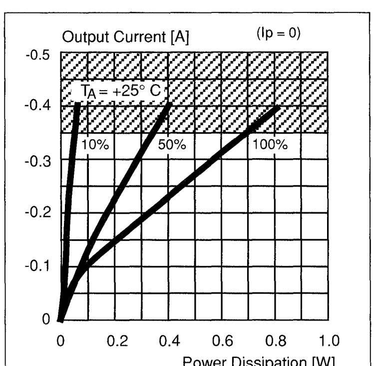


Figure 11. Typical P_{Dl} vs. I_l. Power dissipation in the bilevel pulse when raising to the I_l value. One active output.

- Figures 10 and 11 give the relationship between motor currents and their dissipations. The sum of these power dissipations must never exceed the previously-established value, or life expectancy will be drastically shortened.
- When no bilevel or voltage doubling is utilized, the maximum motor current can be found directly in figure 10.

2. How to choose timing components.
   - Figure 8 shows the relationship between C_T, R_T, and t_{On}. Care must be taken to keep the t_{On} time short, otherwise the current in the winding will rise to a value many times the rated current, causing an overheated IC or motor.
3. What is the maximum t_{On} pulse-width at a given frequency?
   - Figure 9 shows the relationship between duty cycle, pulse width, and step frequency. Check specifications for the valid operating area.
4. Figures 4, 6 and 7 show typical saturation voltages vs. output current levels for different output transistors.
5. Shaded areas represent operating conditions outside the safe operating area.

Functional Description

The circuit, PBD 3517, is a high-performance motor driver, intended to drive a stepper motor in a unipolar, bilevel way. Bilevel means that during the first time after a phase shift, the voltage across the motor is increased to a second voltage supply, V_{SS}, in order to obtain a more-rapid rise of current, see figure 12.

The current starts to rise toward a value which is many times greater than the rated winding current. This compensates for the loss in drive current and loss of torque due to the back emf of the motor.

After a short time, t_{On}, set by the monostable, the bilevel output is switched off and the winding current flows from the V_{MM} supply, which is chosen for rated winding current. How long this time must be to give any increase in performance is determined by V_{SS} voltage and motor data, the L/R time-constant.

In a low-voltage system, where high motor performance is needed, it is also possible to double the motor voltage by adding a few external components, see figure 14.

The time the circuit applies the higher voltage to the motor is controlled by a monostable flip-flop and determined by the timing components R_T and C_T.

The circuit can also drive a motor in traditional unipolar way.

An inhibit input (INH) is used to switch off the current completely.

Logic Inputs

All inputs are LS-TTL compatible. If any of the logic inputs are left open, the circuit will accept it as a HIGH level. PBD 3517 contains all phase logic necessary to control the motor in a proper way.

STEP — Stepping pulse

One step is generated for each negative edge of the STEP signal. In half-step mode, two pulses will be required to move one full step. Notice the set up time, t_s, of DIR and HSM signals. These signals must be latched during the negative edge of STEP, see timing diagram, figure 3.

DIR — Direction

DIR determines in which direction steps will be taken. Actual direction depends on motor and motor connections. DIR can be changed at any time, but not simultaneously with STEP, see timing diagram, figure 3.

HSM determines whether the motor will be controlled in full-step or half-step mode. When pulled low, a step-pulse will correspond to a half step of the motor. HSM can be changed at any time, but not simultaneously with STEP, see timing diagram, figure 3.

INH — Inhibit

A HIGH level on the INH input,turns off all phase outputs to reduce current consumption.

Reset

An internal Power-On Reset circuit connected to V_{cc} resets the phase logic and inhibits the outputs during power up,

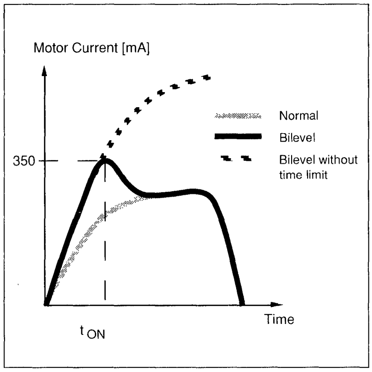


Figure 12. Motor current I_p.

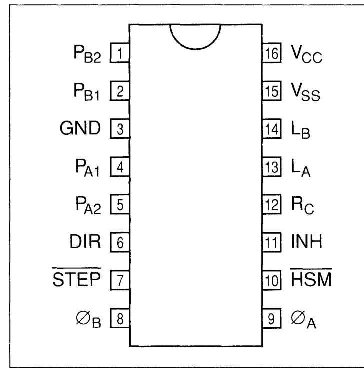


Figure 13. Pin configuration.

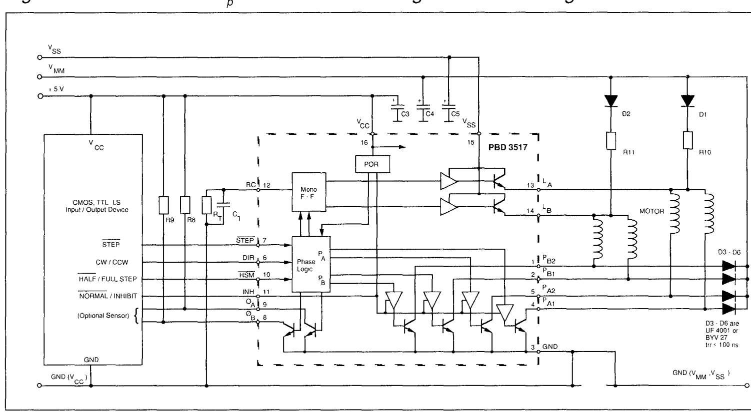


Figure 14. Typical Application.

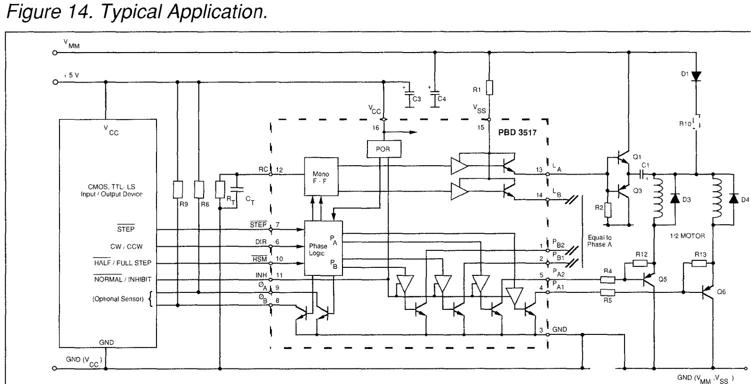


Figure 15. Voltage doubling with external transistors.

Purpose of external components

For figures 14 and 15. Note that "Larger than ..." is normally the vice versa of "Smaller than ... ."

Component	Purpose	Value	Larger than value	Smaller than value
D1, D2	Passes low power to motor and prevents high power from shorting through low power supply	I_f = 1A 1N4001, UF4001	Increases price	Decreases max current capability
D3 ... D6	Inductive current supressor	I_f = 1A	Increases price	Decreases current turn-off capability
		t_{rr} = 100nS e.g. BYV27 UF4001 RGPP10G RGPP30D	Slows down turn-off time. Voltage at anode might exceed voltage breakdown	Speeds up turn-off time.
R1	Base drive current limitter	R = 20ohm $P = R1\left(\frac{V_{mm}}{R_1 + R_2}\right)^2$	Slows down Q1's turn-on and Q4's turn-off time.	Speeds up Q1's turn-on and Q4's turn-off time.
R2, R3	Base discharge resistor	R = 240ohm $P = R1\left(\frac{V_{mm}}{R_1 + R_2}\right)^2$	Slows down Q1's turn-off and Q4's turn-on time.	Speeds up Q1's turn-off and Q4's turn-on time.
R4 ... R7	External transistor base driver	$R = \frac{V_{mm} - V_{be} - V_{ce}}{I_4 - \left(\frac{V_{be}}{R12}\right)}$ $P > (I_4)^2 \cdot R4$ Check hfe.	Decreases ext. transistor I_C max. Lowers 3517 power dissipation.	Increases ext. transistor I_C max. Increases 3517 power dissipation.
R8, R9	ØA, ØB pull-up resistors	R = 5ohm @ pull-up voltage = 5V. $P = \frac{(V_{CC})^2}{R}$	Increases noise sensitivity, worse logic-level definition Less stress on ØA, ØB output transistors	Increases noise immunity, better logic-level definition. Stress on ØA, ØB output transistors.
R10, R11	Limit max. motor current. Resistors may be omitted. (Check motor specifications first.)	$R = \frac{V_{mm} - V_{Motor} - V_{CESat}}{I_{Motor\ max}}$	Decreases motor current.	Increases motor current.
R12 ... R15	External transistor base discharge.	$R = \frac{V_{be}}{I_{12}} \approx 15\Omega$ $P > V_{be} \cdot I_{12}$	Slows down external transistor turn-off time. Lowers 3517 power dissipation	Speeds up external transistor turn-off time. Increases 3517 power dissipation
RT, CT	Sets L_A and L_B on time when triggered by STEP.	R = 47ohm, C = 10nf P < 250mW	Increases on time.	Decreases on time.
C1, C2	Stores the doubling voltage.	C = 100µF $V_C \geq$ 45V	Increases effective on-time during voltage doubling	Decreases effective on-time during voltage doubling.
C3 ... C5	Filtering of supply-voltage ripple and take-up of energy feedback from D3 ... D6	C ≥ 10 µF	Increases price, better filtering, decreases risk of IC breakdown	Decreases price, more compact solution.
		$V_{Rated} > V_{mm}, V_{ss}$ or V_{cc}	Increases price	Risk for capacitor breakdown.
Q1, Q2	Activation transistor of voltage doubling.	I_C as motor requires.	Increases price.	Decreases max I_m during voltage doubling.
Q3, Q4	Charging of voltage doubling capacitor	$I_C \leq \frac{(V_{mm} - V_f - V_{CE}) \cdot C1}{\left(\frac{1}{f_{Step}} - 0.55 \cdot R_T \cdot C_T\right)}$		
Q5 ... Q8	Motor current drive transistor.	I_C as motor requires. PNP power trans.	Increases max current capability.	Decreases max current capability.

to prevent false stepping.

Output Stages

The output stage consists of four open-collector transistors. The second high-voltage supply contains Darlington transistors.

Phase Outputs

The phase outputs are connected directly to the motor as shown in figure 14.

Bilevel Technique

The bilevel pulse generator consists of two monostables with a common RC network.

The internal phase logic generates a trigger pulse every time the phase changes state. The pulse triggers its own monostable which turns on the output transistors for a precise period of time:

$t_{On} = 0.55 \cdot C_T \cdot R_T$.

See pulse diagrams, figures 16 through 20.

Bipolar Phase Logic Output

The $Ø_A$ and $Ø_B$ outputs are generated from the phase logic and inform an external device if the A phase or the B phase current is internally inhibited. These outputs are intended to support if it is legal to correctly go from a half-step mode to a full-step mode without loosing positional information.

The PBD 3517 can act as a controller IC for 2 driver ICs, the PBL 3770A. Use P_{A1} and P_{B1} for phase control, and $Ø_A$ and $Ø_B$ for I_0 and I_1 control of current turn-off.

Applications Information

Logic inputs

If any of the logic inputs are left open, the circuit will treat it as a high-level input. Unused inputs should be connected to proper voltage levels in order to get the highest noise immunity.

Phase outputs

Phase outputs use a current-sinking method to drive the windings in a unipolar way. A common resistor in the center tap will limit the maximum motor current.

Fast free-wheeling diodes must be used to protect output transistors from inductive spikes. Alternative solutions are shown in figures 21 through 25 on pages

6 - 10.

Series diodes in V_{MM} supply, prevent V_{SS} voltage from shorting through the V_{MM} power supply. However, these may be omitted if no bilevel is used. The V_{SS} pin must not be connected to a lower voltage than V_{MM}, but can be left unconnected.

Zero outputs

$Ø_A$ and $Ø_B$, “zero A” and “zero B,” are open-collector outputs, which go high when the corresponding phase output is inhibited by the half-step-mode circuitry. A pull-up resistor should be used and connected to a suitable supply voltage (5 kohms for 5V logic). See “Bipolar phase logic output.”

Interference

To avoid interference problems, a good idea is to route separate ground leads to each power supply, where the only common point is at the 3517’s GND pin. Decoupling of V_{SS} and V_{MM} will improve performance. A 5 kohm pull-up resistor at logic inputs will improve level definitions, especially when driven by open-collector outputs.

Input and Output Signals for Different Drive Modes

The pulse diagrams, figures 16 through 20, show the necessary input signals and the resulting output signals for each drive mode.

On the left side are the input and output signals, the next column shows the state of each signal at the cursor position marked “C.”

STEP is shown with a 50% duty cycle, but can, of course, be with any duty cycle, as long as pulse time (t_p) is within specifications.

P_A and P_B are displayed with low level, showing current sinking.

L_A and L_B are displayed with high level, showing current sourcing.

User Hints

1. Never disconnect ICs or PC-boards when power is supplied.
2. If second supply is not used, disconnect and leave open V_{SS}, L_A, L_B, and RC. Preferably replace the V_{MM} supply diodes (D1, D2) with a straight connection.
3. Remember that excessive voltages

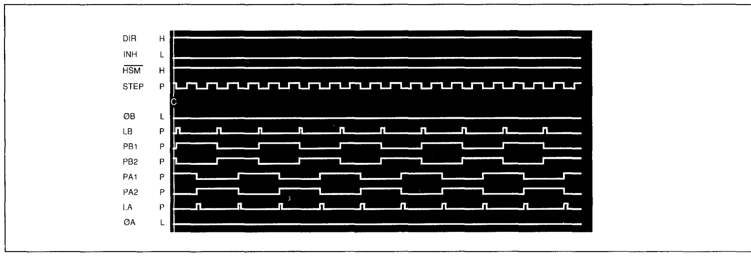


Figure 16. Full-step mode, forward. 4-step sequence. Gray-code +90° phase shift.

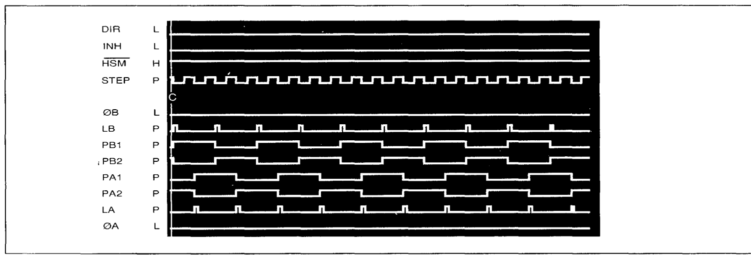


Figure 17. Full-step mode, reverse. 4-step sequence. Gray-code -90° phase shift.

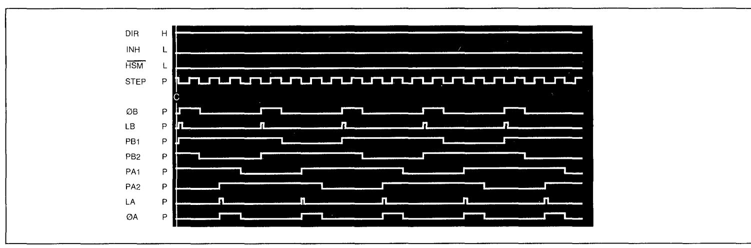


Figure 18. Half-step mode, forward. 8-step sequence.

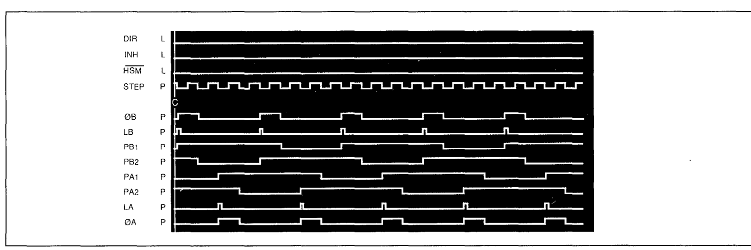


Figure 19. Half-step mode, reverse. 8-step sequence.

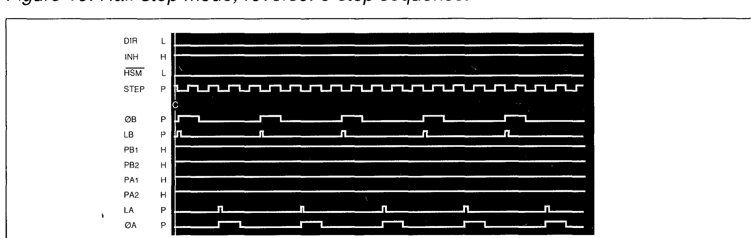


Figure 20. Half-step mode, inhibit.

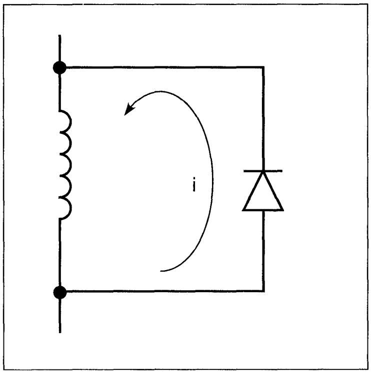


Figure 21. Diode turn-off circuit.

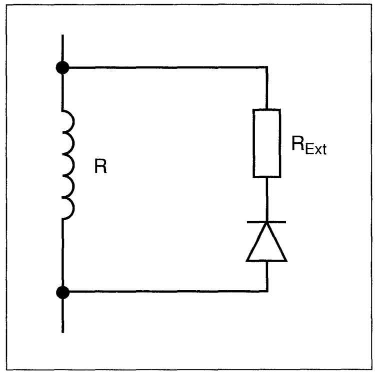


Figure 22. Resistance turn-off circuit.

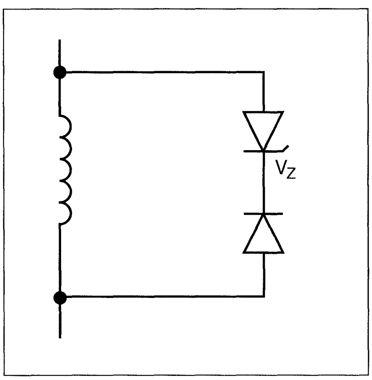


Figure 23. Zener dode turn-off circuit.

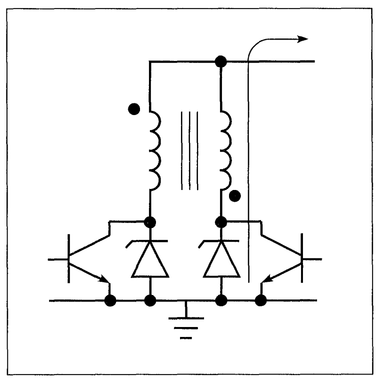


Figure 24. Power return turn-off circuit.

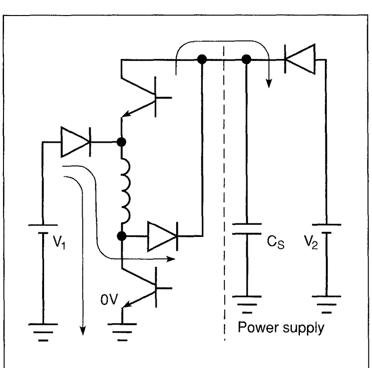


Figure 25. Power return turn-off circuit for bilevel .

might be generated by the motor, even though clamping diodes are used.

4. **Choice of motor.** Choose a motor that is rated for the current you need to establish desired torque. A high supply voltage will gain better stepping performance. If the motor is not specified for the V_{MM} voltage, a current limiting resistor will be necessary to connect in series with center tap. This changes the L/R time constant.

5. Never use L_A or L_B for continuous output at high currents. L_A and L_B on-time can be altered by changing the RC net. An alternative is to trigger the mono-flip-flop by taking a STEP and then externally pulling the RC pin (12) low (0V) for the desired on-time.

6. Avoid V_{MM} and V_{SS} power supplies with serial diodes (without filter capacitor) and/or common ground with V_{CC}. The common place for ground should be as close as possible to the IC's ground pin (pin 3).

7. To change actual motor rotation direction, exchange motor connections at P_{A1} and P_{A2} (or P_{B1} and P_{B2}).

8. **Half-stepping.** in the half-step mode, the power input to the motor alternates between one or two phase windings. In half-step mode, motor resonances are reduced. In a two-phase motor, the electrical phase shift between the windings is 90 degrees. The torque developed is the vector sum of the two windings energized. Therefore, when only one winding is energized, which is the case in half-step mode for every second step, the torque of the motor is reduced by approximately 30%. This causes a torque ripple.

9. **Ramping.** Every drive system has inertia which must be considered in the drive scheme. The rotor and load inertia plays a big role at higher speeds. Unlike the DC motor, the stepper motor is a synchronous motor and does not change speed due to load variations. Examination of typical stepper motors' torque versus speed curves indicates a sharp torque drop-off for the start-stop

without error curve. The reason for this is that the torque requirements increase by the cube of the speed change. As it can be seen, for good motor performance, controlled acceleration and deceleration should be considered.

Common Fault Conditions

- V_{MM} supply not connected, or V_{MM} supply not connected through diodes.
- The inhibit input not pulled low or floating. Inhibit is active high.
- A bipolar motor without a center tap is used. Exchange motor for unipolar version. Connect according to figure 14.
- External transistors connected without proper base-current supply resistor.
- Insufficient filtering capacitors used.
- Current restrictions exceeded.
- L_A and L_B used for continuous output at high currents. Use the RC network to set a proper duty cycle according to specifications, see figures 6 through 11.
- A common ground wire is used for all three power supplies. If possible, use separate ground leads for each supply to minimize power interference.

Drive Circuits

If high performance is to be achieved from a stepper motor, the phase must be energized rapidly when turned on and also de-energize rapidly when turned off. In other words, the phase current must increase/decrease rapidly at phase shift.

Phase Turn-off Considerations

When the winding current is turned off the induced high voltage spike will damage the drive circuits if not properly suppressed. Different turn-off circuits are used; e. g. :

Diode turn-off circuit (figure 21)

— Slow current decay

— Energy lost mainly in winding resistance

— Potential cooling problems.

Resistance T O C (figure 22)

— Somewhat faster current decay

— Energy lost mainly in R-Ext

— Potential cooling problems

Zener diode T O C (figure 23)

Relatively high V_Z gives:

— Relatively fast current decay

— Energy lost mainly in V_Z

— Potential cooling problems

Power return T O C for unipolar drive (figure 24)

Relatively high V_Z gives:

— Relatively fast current decay

— Energy returned to power supply

— Only small energy losses

— Winding leakage flux must be considered

— Potential cooling problems

Power return to T O C for bilevel drive (figure 25)

— Very fast current decay

— Energy returned to power supply

— Only small energy losses

— Winding leakage flux must be considered

Ordering Information

Package	Temp. range	Part No.
Plastic DIP	0 to 70°C	PBD3517N

IC4 (88079) A-Ue

Revised edition May 1991

ERICSSON

Ericsson Components AB
S-164 81 Kista-Stockholm
Telephone: (08) 757 50 00

ERICSSON

September 1989

PBL 3717/2 Stepper Motor Drive Circuit

Description

PBL 3717/2 is a bipolar monolithic circuit intended to control and drive the current in one winding of a stepper motor.

The circuit consists of a LS-TTL compatible logic input stage, a current sensor, a monostable multivibrator and a high power H-bridge output stage with built-in protection diodes.

Two PBL 3717/2 and a small number of external components form a complete control and drive unit for LS-TTL or microprocessor-controlled stepper motor systems.

- Half-step and full-step modes.
- Switched mode bipolar constant current drive
- Wide range of current control 5 — 1200 mA.
- Wide voltage range 10 — 45 V.
- Designed for unstabilized motor supply voltage.
- Current levels can be selected in steps or varied continuously.
- Thermal overload protection.
- Built-in recirculation diodes.

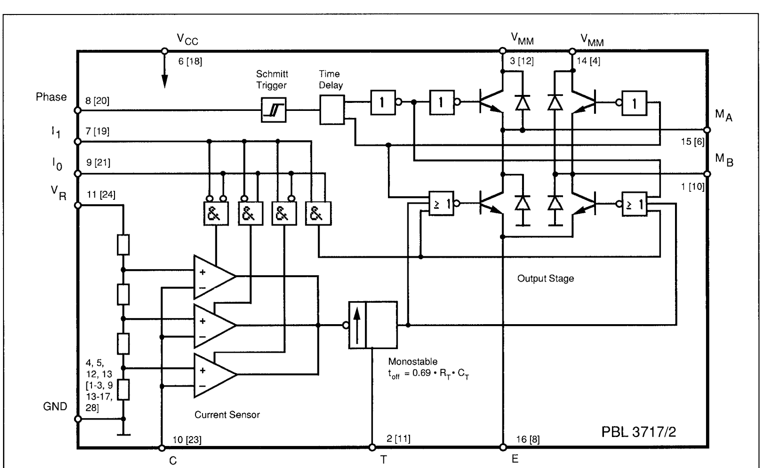
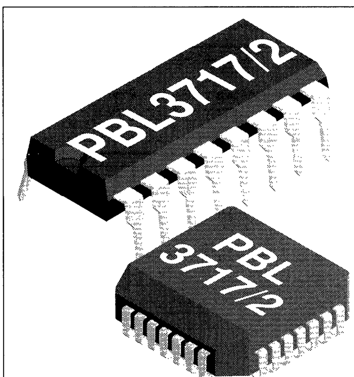


Figure 1. Block diagram



16-pin plastic batwing DIP
28-pin plastic PLCC package

Maximum Ratings

Parameter	Pin no. *	Symbol	Min	Max	Unit
Voltage					
Logic supply	6 [18]	V_{CC}	0	7	V
Motor supply	3, 14 [4, 12]	V_{MM}	0	45	V
Logic inputs	7, 8, 9 [19, 20, 21]	V_I	-0.3	6	V
Comparator input	10 [23]	V_C	-0.3	V_{CC}	V
Reference input	11 [24]	V_R	-0.3	15	V
Current					
Motor output current	1, 15 [6, 10]	I_M	-1.2	+1.2	A
Logic inputs	7, 8, 9 [19, 20, 21]	I_I	-10		mA
Analog inputs	10, 11 [23, 24]	I_A	-10		mA
Temperature					
Junction temperature		T_j		+150	°C
Operating ambient temperature		T_a	0	+70	°C
Storage temperature		T_s	-55	+150	°C

* [no] refers to PLCC package pin no.

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Logic supply voltage	V_{CC}	4.75	5	5.25	V
Motor supply voltage	V_{MM}	10		40	V
Motor output current	I_M	-1.0		+1.0	A
Ambient temperature	T_a	0		+70	°C
Rise time logic inputs	t_r			2	µs
Fall time logic inputs	t_f			2	µs

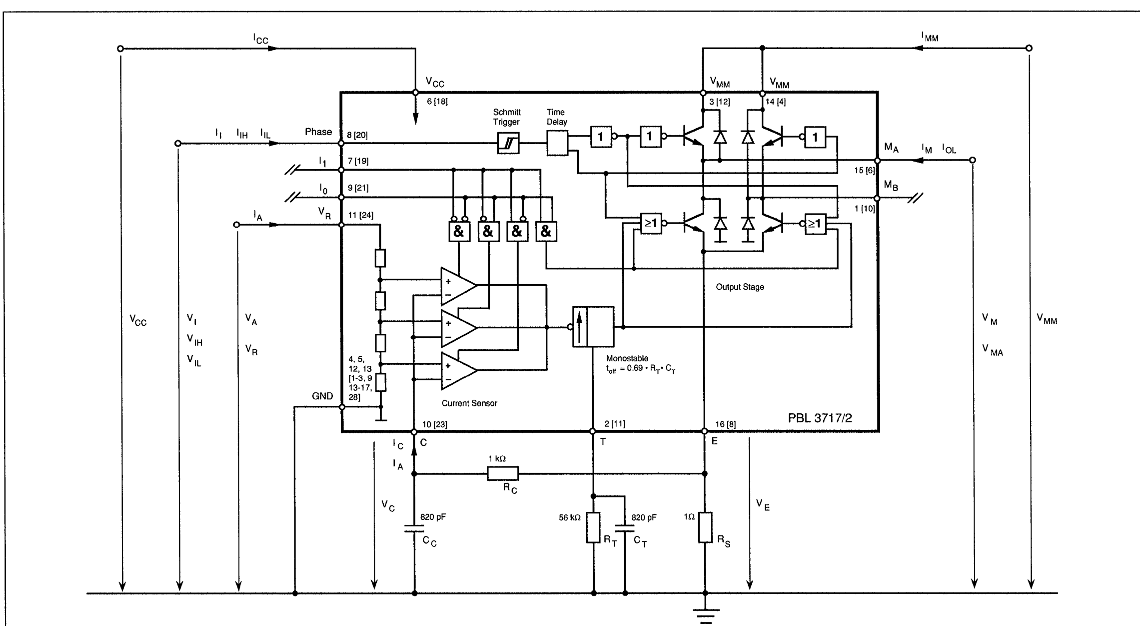


Figure 2. Definition of symbols.

Electrical Characteristics

Electrical characteristics over recommended operating conditions. C_T = 820 pF, R_T = 56 kohm.

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
General							
Supply current	I_{CC}	2				25	mA
Total power dissipation	P_D		f_s = 28 kHz, I_M = 0.5 A, V_{MM} = 36 V Note 2, 4.		1.4	1.7	W
			f_s = 28 kHz, I_M = 0.8 A, V_{MM} = 36 V Note 3, 4.		2.8	3.3	W
Turn-off delay	t_d	3	T_a = +25°C, $dV_C/dt \geq$ 50 mV/µs.		0.9	1.5	µs
Thermal shutdown junction temperature					170		°C
Logic Inputs							
Logic HIGH input voltage	V_{IH}	2		2.0			V
Logic LOW input voltage	V_{IL}	2				0.8	V
Logic HIGH input current	I_{IH}	2	V_I = 2.4 V			20	µA
Logic LOW input current	I_{IL}	2	V_I = 0.4 V	-0.4			mA
Reference Input							
Input resistance	R_R		T_a = +25°C		6.8		kohm
Comparator Inputs							
Threshold voltage	V_{CH}	2	V_R = 5.0 V, $I_0 = I_1$ = LOW	400	415	430	mV
Threshold voltage	V_{CM}	2	V_R = 5.0 V, I_0 = HIGH, I_1 = LOW	240	250	265	mV
Threshold voltage	V_{CL}	2	V_R = 5.0 V, I_0 = LOW, I_1 = HIGH	70	80	90	mV
Input current	I_C	2		-20			µA
Motor Outputs							
Lower transistor saturation voltage		2	I_M = 0.5 A		0.9	1.2	V
			I_M = 0.8 A		1.1	1.4	V
Lower diode forward voltage drop		2	I_M = 0.5 A		1.2	1.5	V
			I_M = 0.8 A		1.3	1.7	V
Upper transistor saturation voltage		2	I_M = 0.5 A		1.0	1.25	V
			I_M = 0.8 A		1.2	1.5	V
Upper diode forward voltage drop		2	I_M = 0.5 A		1.0	1.25	V
			I_M = 0.8 A		1.2	1.45	V
Output leakage current		2	$I_0 = I_1$ = HIGH, T_a = +25°C			100	µA
Monostable							
Cut off time	t_{off}	3	V_{MM} = 10 V, $t_{on} \geq$ 5 µs	27	31	35	µs

Thermal Characteristics

Parameter	Symbol	Ref. Fig.	Conditions	Min	Typ	Max	Unit
Thermal resistance	Rth_{j-c}		DIP package.		11		°C/W
	Rth_{j-a}	16	DIP package. Note 2.		40		°C/W
	Rth_{j-c}		PLCC package.		9		°C/W
	Rth_{j-a}	16	PLCC package. Note 2.		35		°C/W

Notes

1. All voltages are with respect to ground. Currents are positive into, negative out of specified terminal.
2. All ground pins soldered onto a 20 cm^2 PCB copper area with free air convection. T_a = +25°C.
3. DIP package with external heatsink (Staver V7) and minimal copper area. Typical Rth_{j-a} = 27.5°C/W. T_a = +25°C.
4. Not covered by final test program.

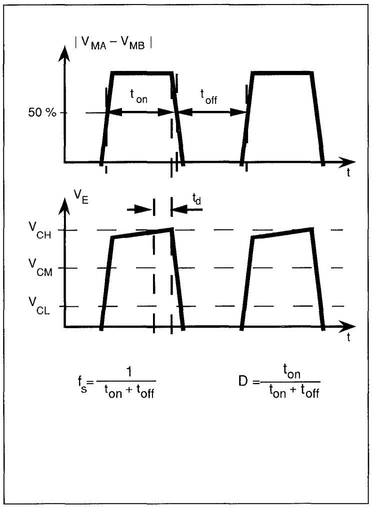


Figure 3. Definition of terms.

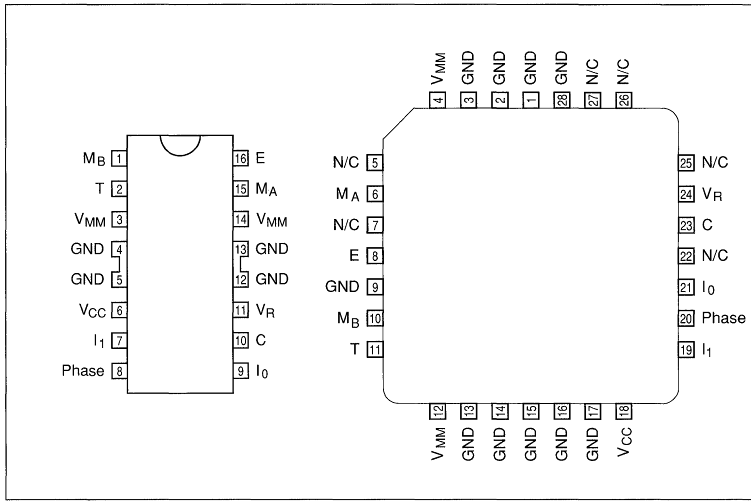


Figure 4. Pin configurations.

Functional Description

The PBL 3717/2 is intended to drive a bipolar constant current through one motor winding of a 2-phase stepper motor.

Current control is achieved through switched-mode regulation, see figure 5 and 6.

Three different current levels and zero current can be selected by the input logic.

The circuit contains the following functional blocks:

- Input logic
- Current sense
- Single-pulse generator
- Output stage

Input logic

Phase input. The phase input determines the direction of the current in the motor winding. High input forces the current from terminal M_A to M_B and low input from terminal M_B to M_A. A Schmitt trigger provides noise immunity and a delay circuit eliminates the risk of cross conduction in the output stage during a phase shift.

Half- and full-step operation is possible.

Current level selection. The status of I_0 and I_1 inputs determines the current level in the motor winding. Three fixed current levels can be selected according to the table below.

Motor current		I_0	I_1
High level	100%	L	L
Medium level	60%	H	L
Low level	20%	L	H
Zero current	0%	H	H

The specific values of the different current levels are determined by the reference voltage V_R together with the value of the sensing resistor R_S.

The peak motor current can be calculated as follows:

$i_m = (V_R \cdot 0.083) / R_S$ [A], at 100% level

$i_m = (V_R \cdot 0.050) / R_S$ [A], at 60% level

$i_m = (V_R \cdot 0.016) / R_S$ [A], at 20% level

The motor current can also be continuously varied by modulating the voltage reference input.

Current sensor

The current sensor contains a reference voltage divider and three comparators for measuring each of the selectable current levels. The motor current is sensed as a voltage drop across the current sensing resistor, R_S, and compared with one of the voltage references from the divider. When the two voltages are equal, the comparator triggers the single-pulse generator. Only one comparator at a time is activated by the input logic.

Single-pulse generator

The pulse generator is a monostable multivibrator triggered on the positive edge of the comparator output. The multivibrator output is high during the pulse time, t_{off}, which is determined by the timing components R_T and C_T.

$t_{off} = 0.69 \cdot R_T \cdot C_T$

The single pulse switches off the power feed to the motor winding, causing the winding to decrease during t_{off}.

If a new trigger signal should occur during t_{off}, it is ignored.

Output stage

The output stage contains four transistors and four diodes, connected in an H-bridge. The two sinking transistors are used to switch the power supplied to the motor winding, thus driving a constant current through the winding. See figures 5 and 6.

Overload protection

The circuit is equipped with a thermal shut-down function, which will limit the junction temperature. The output current will be reduced if the maximum permissible junction temperature is exceeded. It should be noted, however, that it is not short circuit protected.

Operation

When a voltage V_{MM} is applied across the motor winding, the current rise follows the equation:

$i_m = (V_{MM} / R) \cdot (1 - e^{-(R \cdot t)/L})$

R = Winding resistance

L = Winding inductance

t = time

(see figure 6, arrow 1)

The motor current appears across the external sensing resistor, R_S, as an analog voltage. This voltage is fed through a low-pass filter, $R_C C_C$, to the voltage comparator input (pin 10). At the moment the sensed voltage rises above the comparator threshold voltage, the monostable is triggered and its output turns off the conducting sink transistor.

The polarity across the motor winding reverses and the current is forced to circulate through the appropriate upper protection diode back through the source transistor (see figure 6, arrow 2).

After the monostable has timed out, the current has decayed and the analog voltage across the sensing resistor is below the comparator threshold level.

The sinking transistor then closes and the motor current starts to increase again, The cycle is repeated until the current is turned off via the logic inputs.

By reversing the logic level of the phase input (pin 8), both active transistors are turned off and the opposite pair turned on after a slight delay. When this happens, the current must first decay to zero before it can reverse. This current decay is steeper because the motor current is now forced to circulate back through the power supply and the appropriate sinking transistor protection diode. This causes higher reverse voltage build-up across the winding which results in a faster current decay (see figure 6, arrow 3).

For best speed performance of the stepper motor at half-step mode operation, the phase logic level should be changed at the same time the current-inhibiting signal is applied (see figure 2).

Heatsinking

The junction temperature of the chip highly effects the lifetime of the circuit. In high-current applications, the heatsinking must be carefully considered.

The $Rth_{j\text{-}a}$ of the PBL 3717/2 can be reduced by soldering the ground pins to a suitable copper ground plane on the printed circuit board (see figure 16) or by applying an external heatsink type V7 or V8, see figure 15.

The diagram in figure 14 shows the

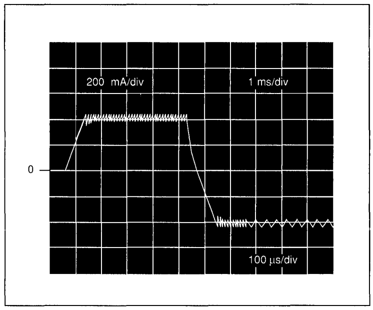


Figure 5. Motor current (I_M), Vertical : 200 mA/div, Horizontal: 1 ms/div, expanded part 100 µs/div.

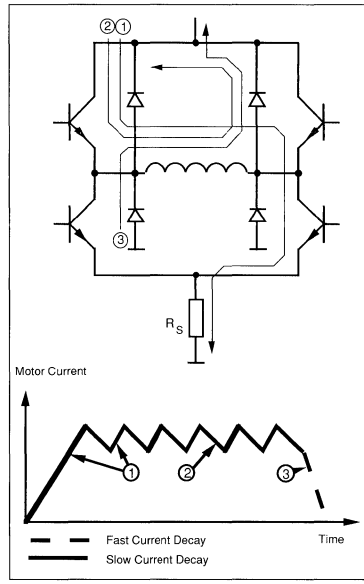


Figure 6. Output stage with current paths for fast and slow current decay.

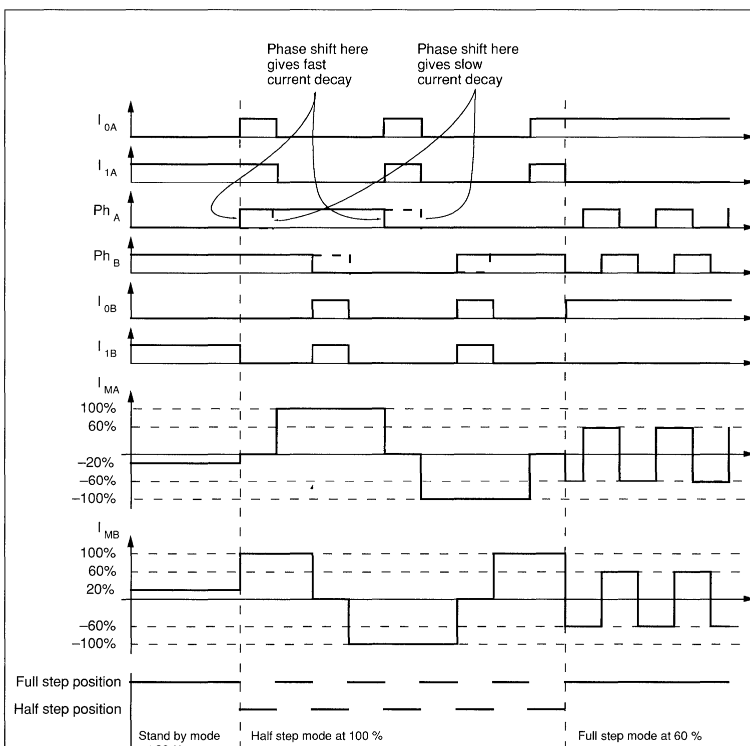


Figure 7. Principal operating sequence.

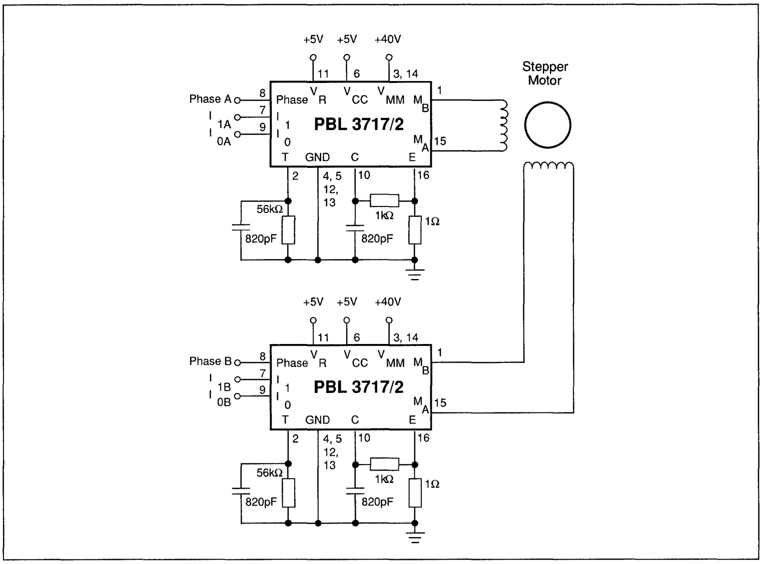


Figure 8. Typical stepper motor driver application with PBL 3717/2.

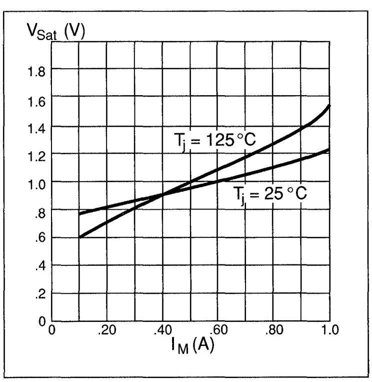


Figure 9. Typical source saturation vs. output current.

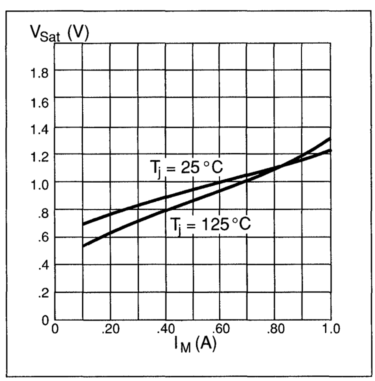


Figure 10. Typical sink saturation vs. output current.

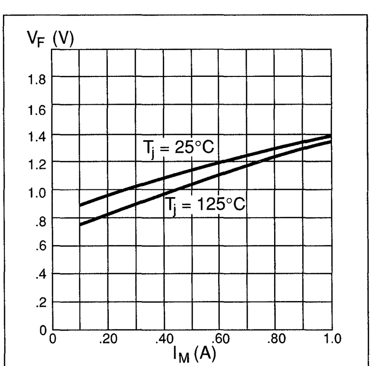


Figure 11. Typical lower diode voltage drop vs. recirculating current.

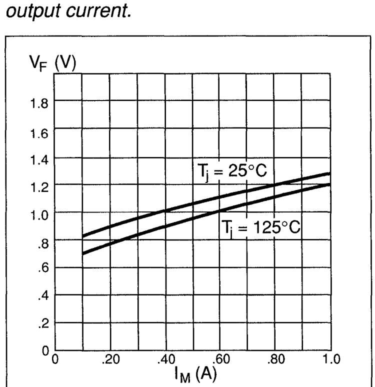


Figure 12. Typical upper diode voltage drop vs. recirculating current.

maximum permissible power dissipation versus the ambient temperature in °C, for heatsinks of the type V7, V8 or a 20 cm² copper area respectively. Any external heatsink or printed circuit board copper must be connected to electrical ground.

For motor currents higher than 500 mA, heatsinking is recommended to assure optimal reliability.

The diagrams in figures 13 and 14 can be used to determine the required heatsink of the circuit. In some systems, forced-air cooling may be available to reduce the temperature rise of the circuit.

Applications Information

Motor selection

Some stepper motors are not designed for continuous operation at maximum current. As the circuit drives a constant current through the motor, its temperature can increase, both at low- and high-speed operation.

Some stepper motors have such high core losses that they are not suited for switched-mode operation.

Interference

As the circuit operates with switched-mode current regulation, interference-generation problems can arise in some applications. A good measure is then to decouple the circuit with a 0.1 μF ceramic capacitor, located near the package across the power line V_{MM} and ground.

Also make sure that the V_R input is sufficiently decoupled. An electrolytic capacitor should be used in the +5 V rail, close to the circuit.

The ground leads between R_S, C_C and circuit GND should be kept as short as possible. This applies also to the leads connecting R_S and R_C to pin 16 and pin 10 respectively.

In order to minimize electromagnetic interference, it is recommended to route M_A and M_B leads in parallel on the printed circuit board directly to the terminal connector. The motor wires should be twisted in pairs, each phase separately, when installing the motor system.

Unused inputs

Unused inputs should be connected to proper voltage levels in order to obtain the highest possible noise immunity.

Ramping

A stepper motor is a synchronous motor and does not change its speed due to load variations. This means that the torque of the motor must be large enough to match the combined inertia of the motor and load for all operation modes. At speed changes, the requires torque increases by the square, and the required power by the cube of the speed change. Ramping, i.e., controlled acceleration or deceleration must then be considered to avoid motor pull-out.

V_{CC}, V_{MM}

The supply voltages, V_{CC} and V_{MM}, can be turned on or off in any order. Normal dV/dt values are assumed.

Before a driver circuit board is removed from its system, all supply voltages must be turned off to avoid destructive transients from being generated by the motor.

Analog control

As the current levels can be continuously controlled by modulating the V_R input, limited microstepping can be achieved.

Switching frequency

The motor inductance, together with the pulse time, t_{off}, determines the switching frequency of the current regulator. The choice of motor may then require other values on the R_T, C_T components than those recommended in figure7, to obtain a switching frequency above the audible range. Switching frequencies above 40 kHz are not recommended because the current regulation can be affected.

Sensor resistor

The R_S resistor should be of a non-inductive type, power resistor. A 1.0 ohm resistor, tolerance ≤ 1%, is a good choice for 415 mA max motor current at V_R = 5V.

Thepeak motor current, i_m, can be calculated by using the formulas:

$i_m = (V_R \cdot 0.083) / R_S$ [A], at 100% level

$i_m = (V_R \cdot 0.050) / R_S$ [A], at 60% level

$i_m = (V_R \cdot 0.016) / R_S$ [A], at 20% level

Ordering Information

Package	Temp. Range	Part No.
Plastic DIP	0 to 70°C	PBL 3717/2N
PLCC	0 to 70°C	PBL 3717/2QN

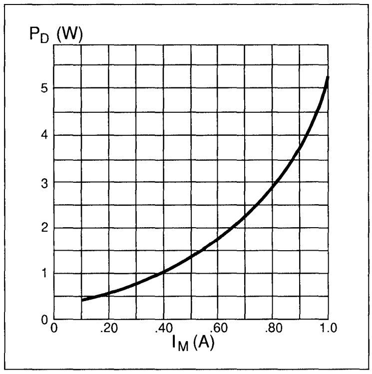


Figure 13. Typical power dissipation vs. motor current.

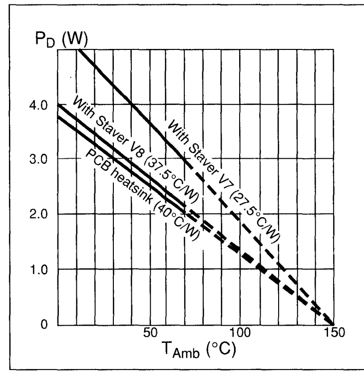


Figure 14. Allowable power dissipation vs. ambient temperature.

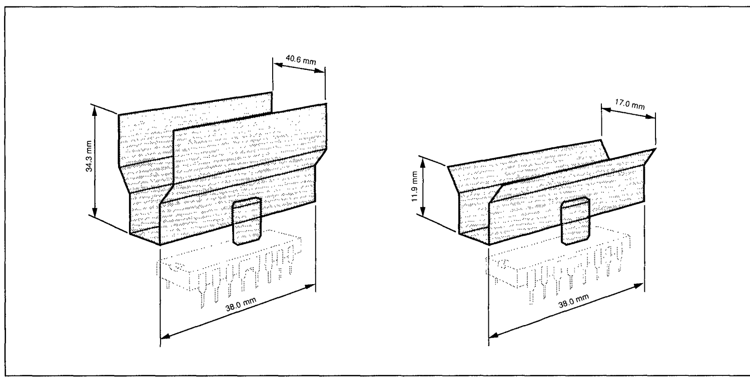


Figure 15. Heatsinks, Staver, type V7 and V8 by Columbia-Staver UK.

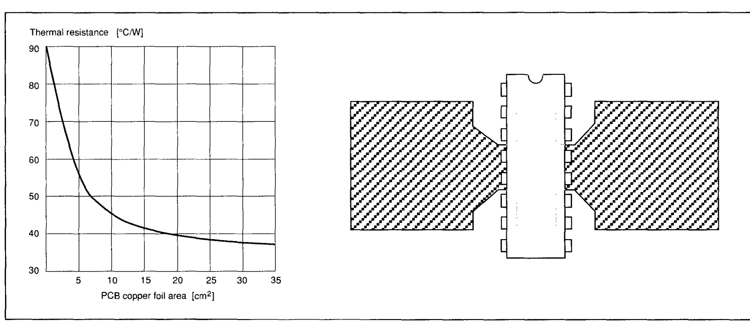


Figure 16. Copper foil used as a heatsink.

Description	DIP	PLCC
Rth_{j-c}, Junction to Case (Case = ground pin)	11°C/W	9°C/W
Rth_{j-a}, Junction to Ambient*	40°C/W	35°C/W

* For the DIP, the four ground pins soldered to a 20 cm² ground plane according to figure15. For the PLCC, all ground pins are soldered to a 20 cm² ground plane located as close as possible to the device and on both sides of a double sided PCB.

Table 1. Thermal resistance . Thermal resistance values are heavily dependant on location and shape of heatsinks.

Specifications subject to change without notice.

IC4 (88076) B-Ue
Revised edition April 1991.

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September 1989

PBL 3770A
High Performance Stepper Motor Drive Circuit

Description

PBL 3770A is a bipolar monolithic circuit intended to control and drive the current in one winding of a stepper motor. It is a high power version of PBL 3717 and special care has been taken to optimize the power handling capability without suffering in reliability.

The circuit consists of a LS-TTL compatible logic input stage, a current sensor, a monostable multivibrator and a high power H-bridge output stage. The circuit is pin-compatible with the PBL 3717 industry-standard driver.

Two PBL 3770A and a small number of external components form a complete control and drive unit for LS-TTL or microprocessor-controlled stepper motor systems.

Key Features

- Half-step and full-step operation.
- Switched mode bipolar constant current drive
- Wide range of current control 5 — 1800 mA.
- Wide voltage range 10 — 45 V.
- Designed for unstabilized motor supply voltage.
- Current levels can be selected in steps or varied continuously.
- Thermal overload protection.

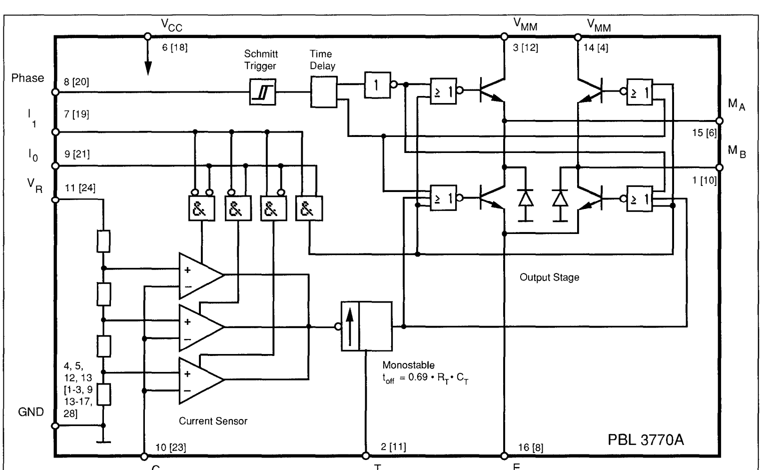
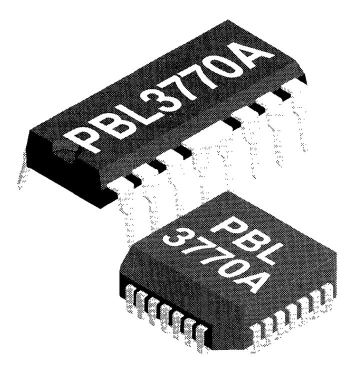


Figure 1. Block diagram.



16-pin plastic batwing DIP
28-pin plastic PLCC package

Maximum Ratings

Parameter	Pin no. *	Symbol	Min	Max	Unit
Voltage					
Logic supply	6 [18]	V_{CC}	0	7	V
Motor supply	3, 14 [4, 12]	V_{MM}	0	45	V
Logic inputs	7, 8, 9 [19, 20, 21]	V_I	-0.3	6	V
Comparator input	10 [23]	V_C	-0.3	V_{CC}	V
Reference input	11 [24]	V_R	-0.3	15	V
Current					
Motor output current	1, 15 [6, 10]	I_M	-1.8	+1.8	A
Logic inputs	7, 8, 9 [19, 20, 21]	I_I	-10		mA
Analog inputs	10, 11 [23, 24]	I_A	-10		mA
Temperature					
Junction temperature		T_j		+150	°C
Operating ambient temperature		T_a	0	+70	°C
Storage temperature		T_s	-55	+150	°C

* [no] refers to PLCC package pin no.

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Logic supply voltage	V_{CC}	4.75	5	5.25	V
Motor supply voltage	V_{MM}	10		40	V
Motor output current	I_M	-1.5		+1.5	A
Ambient temperature	T_a	0		+70	°C
Rise time logic inputs	t_r			2	µs
Fall time logic inputs	t_f			2	µs

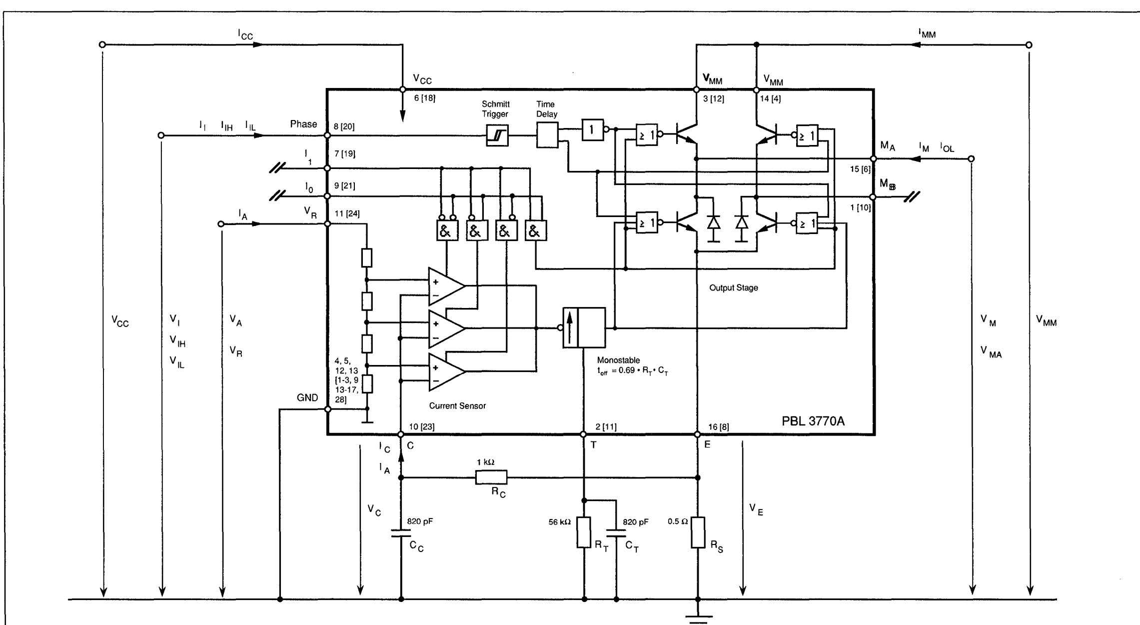


Figure 2. Definition of symbols.

Electrical Characteristics

Electrical characteristics over recommended operating conditions. C_T = 820 pF, R_T = 56 kohm.

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
General							
Supply current	I_{CC}	2	V_{MM} = 20 to 40 V, $I_0 = I_1$ = HIGH.		30	40	mA
			V_{MM} = 20 to 40 V, $I_0 = I_1$ = LOW, f_s = 23 kHz		48	65	mA
Total power dissipation	P_D		f_s = 28 kHz, I_M = 1.0 A, V_{MM} = 36 V Note 2, 4.		1.9	2.3	W
			f_s = 24 kHz, I_M = 1.0 A, V_{MM} = 12 V Note 2, 4.		1.7	2.1	W
			f_s = 28 kHz, I_M = 1.3 A, V_{MM} = 36 V Note 3, 4.		2.7	3.2	W
			f_s = 28 kHz, I_M = 1.5 A, V_{MM} = 36 V Note 3, 4.		3.5		W
Turn-off delay	t_d	3	T_a = +25°C, $dV_C/dt \geq$ 50 mV/µs.			2.5	µs
Thermal shutdown junction temperature					170		°C
Logic Inputs							
Logic HIGH input voltage	V_{IH}	2		2.0			V
Logic LOW input voltage	V_{IL}	2				0.8	V
Logic HIGH input current	I_{IH}	2	V_I = 2.4 V			20	µA
Logic LOW input current	I_{IL}	2	V_I = 0.4 V	-0.4			mA
Analog Inputs							
Comparator threshold voltage	V_{CH}	2	V_R = 5.0 V, $I_0 = I_1$ = LOW	400	415	430	mV
Comparator threshold voltage	V_{CM}	2	V_R = 5.0 V, I_0 = HIGH, I_1 = LOW	240	250	265	mV
Comparator threshold voltage	V_{CL}	2	V_R = 5.0 V, I_0 = LOW, I_1 = HIGH	70	80	90	mV
Input current	I_C	2		-20			µA
Motor Outputs							
Lower transistor saturation voltage			I_M = 1.0 A		0.5	0.8	V
			I_M = 1.3 A		0.8	1.3	V
Lower diode forward voltage drop			I_M = 1.0 A		1.3	1.6	V
			I_M = 1.3 A		1.5	1.8	V
Upper transistor saturation voltage			I_M = 1.0 A		1.1	1.3	V
			I_M = 1.3 A		1.3	1.6	V
Output leakage current			$I_0 = I_1$ = HIGH, T_a = +25°C			100	µA
Monostable							
Cut off time	t_{off}	3	V_{MM} = 10 V, $t_{on} \geq$ 5 µs	27	31	35	µs

Thermal Characteristics

Parameter	Symbol	Ref. Fig.	Conditions	Min	Typ	Max	Unit
Thermal resistance	Rth_{j-c}		DIP package.		11		°C/W
	Rth_{j-a}	15	DIP package. Note 2.		40		°C/W
	Rth_{j-c}		PLCC package.		9		°C/W
	Rth_{j-a}	15	PLCC package. Note 2.		35		°C/W

Notes

1. All voltages are with respect to ground. Currents are positive into, negative out of specified terminal.
2. All ground pins soldered onto a 20 cm² PCB copper area with free air convection. T_a = +25°C.
3. DIP package with external heatsink (Staver V7) and minimal copper area. Typical Rth_{j-a} = 27.5°C/W. T_a = +25°C.
4. Not covered by final test program.

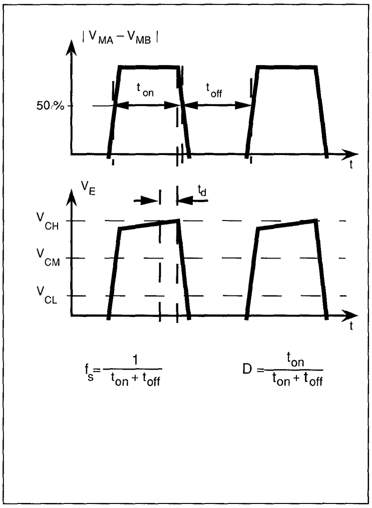


Figure 3. Definition of terms.

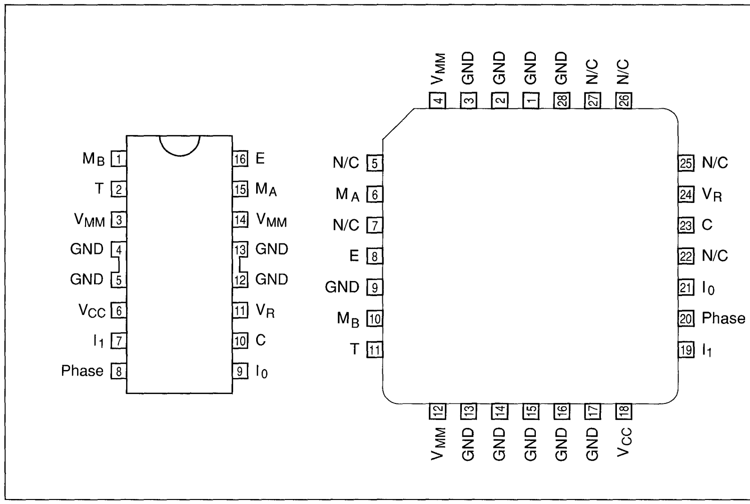


Figure 4. Pin configurations.

Functional Description

The PBL 3770A is intended to drive a bipolar constant current through one winding of a 2-phase stepper motor.

Current control is achieved through switched-mode regulation, see figure 5 and 6.

Three different current levels and zero current can be selected by the input logic.

The circuit contains the following functional blocks:

- Input logic
- Current sense
- Single-pulse generator
- Output stage

Input logic

Phase input. The phase input determines the direction of the current in the motor winding. High input forces the current from terminal M_A to M_B and low input from terminal M_B to M_A. A Schmitt trigger provides noise immunity and a delay circuit eliminates the risk of cross conduction in the output stage during a phase shift.

Half- and full-step operation is possible.

Current level selection. The status of I_0 and I_1 inputs determines the current level in the motor winding. Three fixed current levels can be selected according to the table below.

Motor current		I_0	I_1
High level	100%	L	L
Medium level	60%	H	L
Low level	20%	L	H
Zero current	0%	H	H

The specific values of the different current levels are determined by the reference voltage V_R together with the value of the sensing resistor R_S.

The peak motor current can be calculated as follows:

$i_m = (V_R \cdot 0.080) / R_S$ [A], at 100% level

The motor current can also be continuously varied by modulating the voltage reference input.

Current sensor

The current sensor contains a reference voltage divider and three comparators for measuring each of the selectable current levels. The motor current is sensed as a voltage drop across the current sensing resistor, R_S, and compared with one of the voltage references from the divider. When the two voltages are equal, the comparator triggers the single-pulse generator. Only one comparator at a time is activated by the input logic.

Single-pulse generator

The pulse generator is a monostable multivibrator triggered on the positive edge of the comparator output. The multivibrator output is high during the pulse time, t_{off}, which is determined by the timing components R_T and C_T.

$t_{off} = 0.69 \cdot R_T \cdot C_T$

The single pulse switches off the power feed to the motor winding, causing the winding to decrease during t_{off}.

If a new trigger signal should occur during t_{off}, it is ignored.

Output stage

The output stage contains four transistors and two diodes, connected in an H-bridge. Note that the upper recirculation diodes are connected to the circuit externally. The two sinking transistors are used to switch the power supplied to the motor winding, thus driving a constant current through the winding. See figures 5 and 6.

Overload protection

The circuit is equipped with a thermal shut-down function, which will limit the junction temperature. The output current will be reduced if the maximum permissible junction temperature is exceeded. It should be noted, however, that it is not short circuit protected.

Operation

When a voltage V_{MM} is applied across the motor winding, the current rise follows the equation:

$i_m = (V_{MM} / R) \cdot (1 - e^{-(R \cdot t) / L})$

R = Winding resistance

L = Winding inductance

t = time

(see figure 6, arrow 1)

The motor current appears across the external sensing resistor, R_S, as an analog voltage. This voltage is fed through a low-pass filter, $R_C C_C$, to the voltage comparator input (pin 10). At the moment the sensed voltage rises above the comparator threshold voltage, the monostable is triggered and its output turns off the conducting sink transistor.

The polarity across the motor winding reverses and the current is forced to circulate through the appropriate upper protection diode back through the source transistor (see figure 6, arrow 2).

After the monostable has timed out, the current has decayed and the analog voltage across the sensing resistor is below the comparator threshold level.

The sinking transistor then turns on and the motor current starts to increase again, The cycle is repeated until the current is turned off via the logic inputs.

When both I_1 and I_0 are high, all four transistors in the output H-bridge are turned off, which means that inductive current recirculates through two opposite free-wheeling diodes (see figure 6, arrow 3). this method of turning off the current results in a faster current decay than if only one transistor was turned off and will therefore improve speed performance in half-stepping mode.

Heatsinking

The junction temperature of the chip highly effects the lifetime of the circuit. In high-current applications, the heatsinking must be carefully considered.

The $Rth_{j\text{-}a}$ of the PBL 3770A can be reduced by soldering the ground pins to a suitable copper ground plane on the printed circuit board (see figure 14) or by applying an external heatsink type V7 or V8, see figure 14.

The diagram in figure 13 shows the maximum permissible power dissipation versus the ambient temperature in °C, for heatsinks of the type V7, V8, or a 20 cm^2 copper area respectively. Any external heatsink or printed circuit board copper must be connected to electrical ground.

For motor currents higher than approx 600 mA,some form of heatsinking is recommended to assure optimal

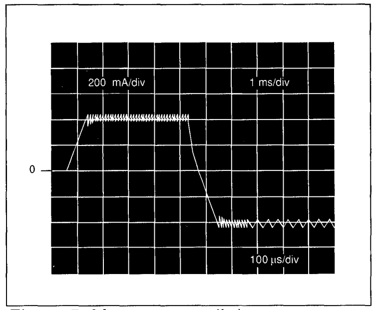


Figure 5. Motor current (I_M), Vertical : 200 mA/div, Horizontal: 1 ms/div, expanded part 100 µs/div.

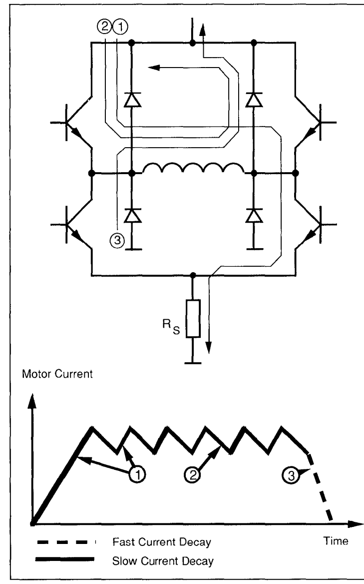


Figure 6. Output stage with current paths for fast and slow current decay.

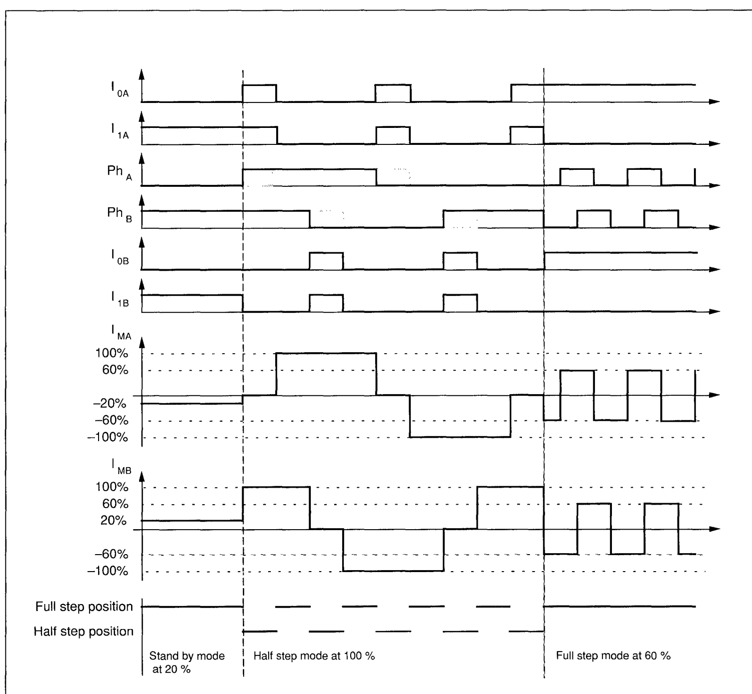


Figure 7. Principal operating sequence.

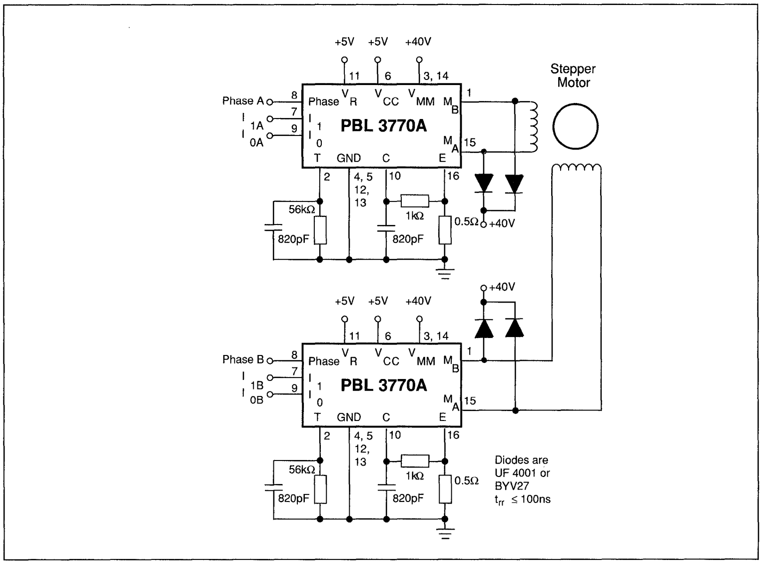


Figure 8. Typical stepper motor driver application with PBL 3770A.

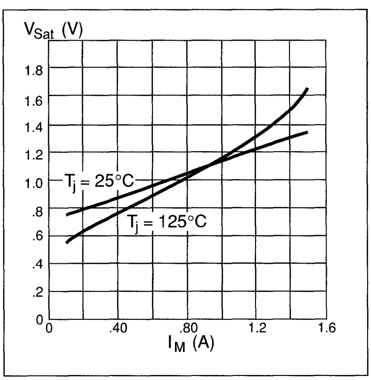


Figure 9. Typical source saturation vs. output current.

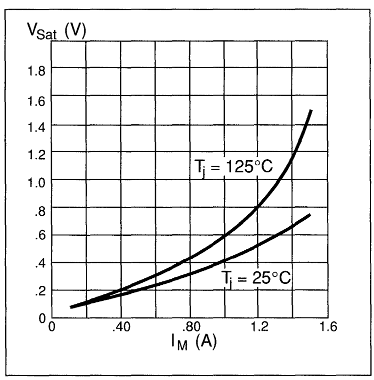


Figure 10. Typical sink saturation vs. output current.

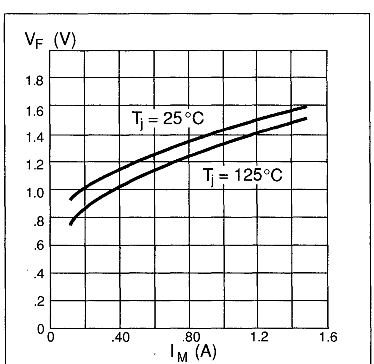


Figure 11. Typical lower diode voltage drop vs. recirculating current.

reliability.

The diagrams in figures 12 and 13 can be used to determine the required heatsinking of the circuit. In some systems, forced-air cooling may be available to reduce the temperature rise of the circuit.

Applications Information

Motor selection

Some stepper motors are not designed for continuous operation at maximum current. As the circuit drives a constant current through the motor, its temperature can increase, both at low- and high-speed operation.

Some stepper motors have such high core losses that they are not suited for switched-mode operation.

Interference

As the circuit operates with switched-mode current regulation, interference-generation problems can arise in some applications. A good measure is then to decouple the circuit with a 0.1 µF ceramic capacitor, located near the package across the power line V_{MM} and ground.

Also make sure that the V_{Ref} input is sufficiently decoupled. An electrolytic capacitor should be used in the +5 V rail, close to the circuit.

The ground leads between R_S, C_C and circuit GND should be kept as short as possible. This applies also to the leads connecting R_S and R_C to pin 16 and pin 10 respectively.

In order to minimize electromagnetic interference, it is recommended to route M_A and M_B leads in parallel on the printed circuit board directly to the terminal connector. The motor wires should be twisted in pairs, each phase separately, when installing the motor system.

Unused inputs

Unused inputs should be connected to proper voltage levels in order to obtain the highest possible noise immunity.

Ramping

A stepper motor is a synchronous motor and does not change its speed due to load variations. This means that the torque of the motor must be large enough to match the combined inertia of the motor and load for all operation modes. At speed changes, the requires torque increases by the square, and the required power by the cube of the speed change. Ramping, i.e., controlled acceleration or deceleration must then be considered to avoid motor pull-out.

V_{CC}, V_{MM}

The supply voltages, V_{CC} and V_{MM}, can be turned on or off in any order. Normal dv/dt values are assumed.

Before a driver circuit board is removed from its system, all supply voltages must be turned off to avoid destructive transients being generated by the motor.

Switching frequency

The motor inductance, together with the pulse time, t_{off}, determines the switching frequency of the current regulator. The choice of motor may then require other values on the R_T, C_T components than those recommended in figure 6, to obtain a switching frequency above the audible range. Switching frequencies above 40 kHz are not recommended because the current regulation can be affected.

Analog control

As the current levels can be continuously controlled by modulating the V_R input, limited microstepping can be achieved.

Sensor resistor

The R_S resistor should be of a non-inductive type power resistor. A 0.5 ohm resistor, tolerance ≤ 1%, is a good choice for 800 mA max motor current at V_R = 5V.

The peak motor current, i_m, can be calculated by using the formula:

$i_m = (V_R \cdot 0.080) / R_S$ [A], at 100% level

External recirculation diodes

Recirculation diodes must be connected across each motor terminal and the supply voltage, V_{MM}. The anodes shall be connected to the motor terminals and the cathodes to the V_{MM} voltage. Ultra-fast recovery diodes should be used for maximum performance and reliability.

Ordering Information

Package	Temp. range	Part No.
Plastic DIP	0 to 70°C	PBL3770AN
PLCC	0 to 70°C	PBL3770AQN

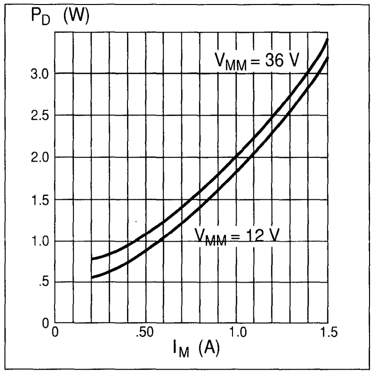


Figure 12. Typical power dissipation vs. motor current.

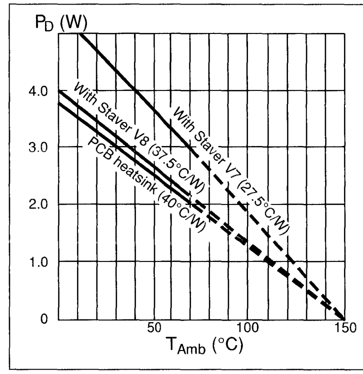


Figure 13. Allowable power dissipation vs. ambient temperature.

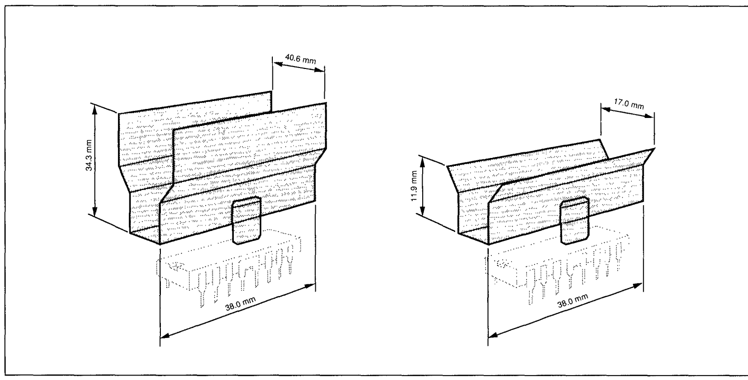


Figure 14. Heatsinks, Staver, type V7 and V8 by Columbia-Staver UK.

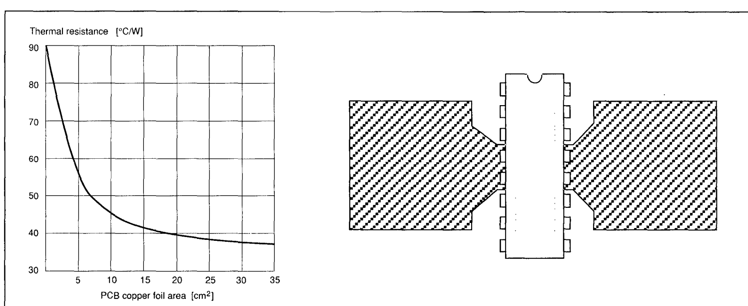


Figure 15. Copper foil used as a heatsink.

Description	DIP	PLCC
Rth_{j-c}, Junction to Case (Case = ground pin)	11°C/W	9°C/W
Rth_{j-a}, Junction to Ambient*	40°C/W	35°C/W

* For the DIP, the four ground pins soldered to a 20 cm² ground plane according to figure15. For the PLCC, all ground pins are soldered to a 20 cm² ground plane located as close as possible to the device and on both sides of a double sided PCB.

Table 1. Thermal resistance . Thermal resistance values are heavily dependant on location and shape of heatsinks.

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Revised edition April 1991.

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ERICSSON

September 1988

PBL 3771
Precision Stepper Motor Driver

Description

The PBL 3771 is a switch-mode, constant-current driver IC (chopper) with two channels, one for each winding of a two-phase stepper motor. The circuit is especially developed for use in microstepping applications in conjunction with the matching dual DAC (Digital-to-Analog Converter) PBM 3960. A complete driver system consists of these two ICs, a few passive components and a microprocessor for generation of the proper control and data codes required for microstepping.

The PBL 3771 contains a clock oscillator, which is common for both driver channels; a set of comparators and flip-flops implementing the switching control; and two H-bridges with internal recirculation diodes. Voltage supply requirements are +5 V for logic and +10 to +45 V for the motor. Maximum output current is 650 mA per channel.

A special logic function is used to select slow or fast current decay in the output stage for improved high-speed microstepping.

The close match between the two driver channels guarantees consistent output current ratios and motor positioning accuracy.

Key Features

- Dual chopper driver in a single package.
- 650 mA output current per channel.
- Close matching between channels for high microstepping accuracy.
- Selectable slow/fast current decay for improved high-speed microstepping.
- Improved low-level linearity.
- Specially matched to Dual DAC PBM 3960.
- Selection of packages, 22-pin "batwing" DIP or 28-lead PLCC with lead-frame for heat-sinking through PC board copper.

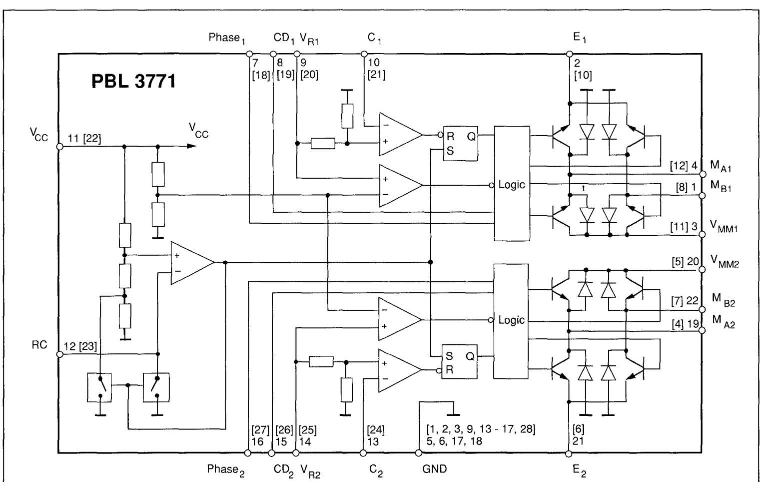
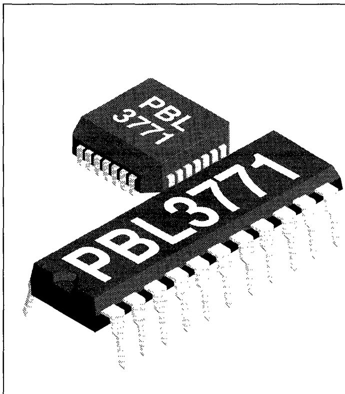


Figure 1. Block diagram.



28-pin PLCC package
22-pin plastic DIP package

Maximum Ratings

Parameter	Pin no. *	Symbol	Min	Max	Unit
Voltage					
Logic supply	11 [22]	V_{CC}	0	7	V
Motor supply	3, 20 [5, 11]	V_{MM}	0	45	V
Logic inputs	7, 8, 15, 16 [18-19, 26-27]	V_I	-0.3	6	V
Comparator inputs	10, 13 [21, 24]	V_C	-0.3	V_{CC}	V
Reference inputs	9, 14 [20, 25]	V_R	-0.3	7.5	V
Current					
Motor output current	1, 4, 19, 22 [4, 7, 8, 12]	I_M	-700	+700	mA
Logic inputs	7, 8, 15, 16 [18, 19, 26, 27]	I_I	-10		mA
Analog inputs	10, 13 [21, 24]	I_A	-10		mA
Oscillator charging current	12 [23]	I_{RC}		5	mA
Temperature					
Junction temperature		T_j		+150	°C
Operating ambient temperature		T_a	0	+70	°C
Storage temperature		T_s	-55	+150	°C

* [no] refers to PLCC package pin no.

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Logic supply voltage	V_{CC}	4.75	5	5.25	V
Motor supply voltage	V_{MM}	10		40	V
Motor output current **	I_M	-650		650	mA
Ambient temperature	T_a	0		70	°C
Rise time logic inputs	t_r			2	µs
Fall time logic inputs	t_f			2	µs
Oscillator timing resistor	R_T	2	15	20	kohms

** In microstepping mode, "sine/cosine" drive where $I_1 = 650 \cdot \cos(\theta)$ and $I_2 = 650 \cdot \sin(\theta)$ mA, otherwise 500 mA per channel both fully on.

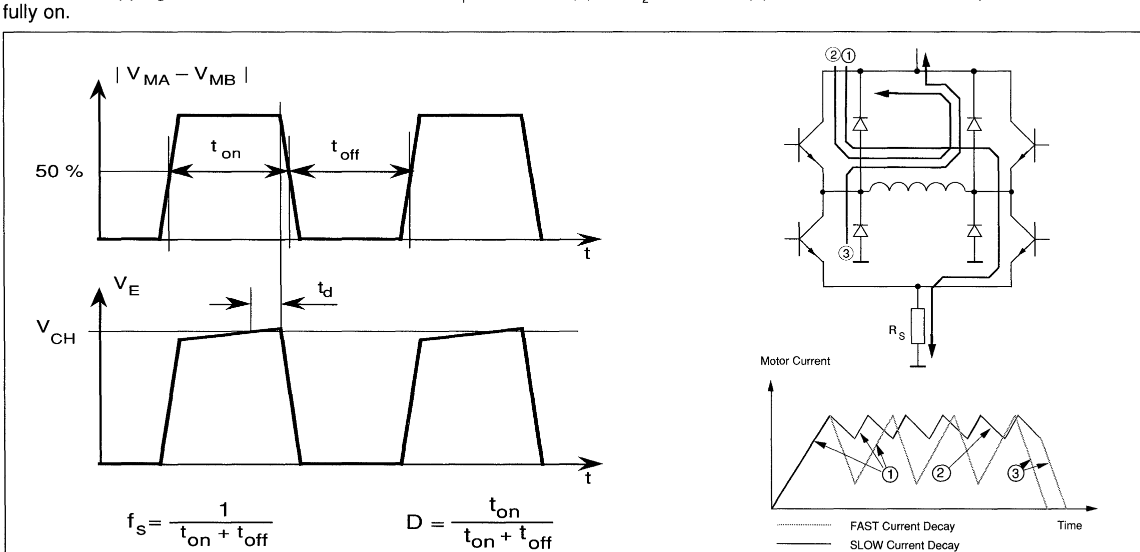


Figure 2. Definitions.

Electrical Characteristics

Electrical characteristics over recommended operating conditions.

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
General							
Supply current	I_{CC}				38	50	mA
Total power dissipation	P_D		V_{MM} = 40 V, I_{M1} = 450 mA, I_{M2} = 0 mA. Notes 2, 3.		1.4	1.6	W
			V_{MM} = 40 V, I_{M1} = I_{M2} = 318 mA. Notes 2, 3.		1.6	1.8	W
Turn-off delay	t_d	2	T_a = +25°C, $dV_C/dt \geq 50$ mV/µs. Note 3.		1.0	1.5	µs
Logic Inputs							
Logic HIGH input voltage	V_{IH}			2.0			V
Logic LOW input voltage	V_{IL}					0.8	V
Logic HIGH input current	I_{IH}		V_I = 2.4 V			20	µA
Logic LOW input current	I_{IL}		V_I = 0.4 V	-0.4			mA
Reference Inputs							
Input resistance	R_R		T_a = +25°C		5		kohms
Input current	I_R		T_a = +25°C, V_R = 2.5 V.		0.5	1.0	mA
Turn-off voltage	V_{TO}			20	29	38	mV
Comparator Inputs							
Threshold voltage	V_{CH}		R_C = 1 kohms, V_R = 2.5 V	430	450	470	mV
$\lvert V_{CH1} - V_{CH2} \rvert$ mismatch	$V_{CH,diff}$		R_C = 1 kohms		1		mV
Input current	I_C			-10		1	µA
Motor Outputs							
Lower transistor saturation voltage			I_M = 500 mA		1.0	1.20	V
Lower transistor leakage current			V_{MM} = 41 V, V_E = V_R = 0 V, V_C = V_{CC}			300	µA
Lower diode forward voltage drop			I_M = 500 mA		1.1	1.25	V
Upper transistor saturation voltage			I_M = 500 mA		1.2	1.35	V
Upper transistor leakage current			V_{MM} = 41 V, V_E = V_R = 0 V, V_C = V_{CC}			300	µA
Upper diode forward voltage drop			I_M = 500 mA		1.0	1.25	V
Chopper Oscillator							
Chopping frequency	f_s	2	C_T = 3300 pF, R_T = 15 kohms	25.0	26.5	28.0	kHz

Thermal Characteristics

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
Thermal resistance	Rth_{j-c}		DIP package.		11		°C/W
	Rth_{j-a}	5	DIP package. Note 2.		40		°C/W
	Rth_{j-c}		PLCC package.		9		°C/W
	Rth_{j-a}	5	PLCC package. Note 2.		35		°C/W

Notes

1. All voltages are with respect to ground. Currents are positive into, negative out of specified terminal.
2. All ground pins soldered onto a 20 cm^2 PCB copper area with free air convection.
3. Not covered by final test program.
4. Switching duty cycle D = 30%, f_S = 26.5 kHz.

Pin Description

Refer to figure 3.

DIP	PLCC	Symbol	Description
1	8	M_{B1}	Motor output B, channel 1. Motor current flows from M_{A1} to M_{B1} when Phase is HIGH.
2	10	E_1	Common emitter, channel 1. This pin connects to a sensing resistor to ground.
3	11	V_{MM1}	Motor supply voltage, channel 1, 10 to 40 V. V_{MM1} and V_{MM2} should be connected together.
4	12	M_{A1}	Motor output A, channel 1. Motor current flows from M_{A1} to M_{B1} when Phase is HIGH.
5, 17 6, 18	1, 2, 3, 9 13, 14 15, 16 17, 28		Ground and negative supply. Note: these pins are used thermally for heat-sinking. Make sure that all ground pins are soldered onto a suitably large copper ground plane for efficient heat sinking.
7	18	$Phase_1$	Controls the direction of motor current at outputs M_{A1} and M_{B1}. Motor current flows from M_{A1} to M_{B1} when $Phase_1$ is HIGH.
8	19	CD_1	Current decay control, channel 1. A logic HIGH on this input results in *slow* current decay, a LOW results in *fast* current decay, see "Functional Description."
9	20	V_{R1}	Reference voltage, channel 1. Controls the threshold voltage for the comparator and hence the output current. Input resistance is typically 2.5 kohms, ±20%.
10	21	C_1	Comparator input 1. This input senses the instantaneous voltage across the sensing resistor, filtered by an RC network. The threshold voltage for the comparator is (0.450 / 2.5) • V_{R1}, i.e. 450 mV at V_{R1} = 2.5 V.
11	22	V_{CC}	Logic voltage supply, nominally +5 V.
12	23	RC	Clock oscillator RC pin. Connect a 15 kohm resistor to V_{CC} and a 3300 pF capacitor to ground to obtain the nominal switching frequency of 26.5 kHz.
13	24	C_2	Comparator input 2. This input senses the instantaneous voltage across the sensing resistor, filtered by an RC network. The threshold voltage for the comparator is (0.450 / 2.5) • V_{R1}, i.e. 450 mV at V_{R1} = 2.5 V.
14	25	V_{R2}	Reference voltage, channel 2. Controls the threshold voltage for the comparator and hence the output current. Input resistance is typically 2.5 kohms, ±20%.

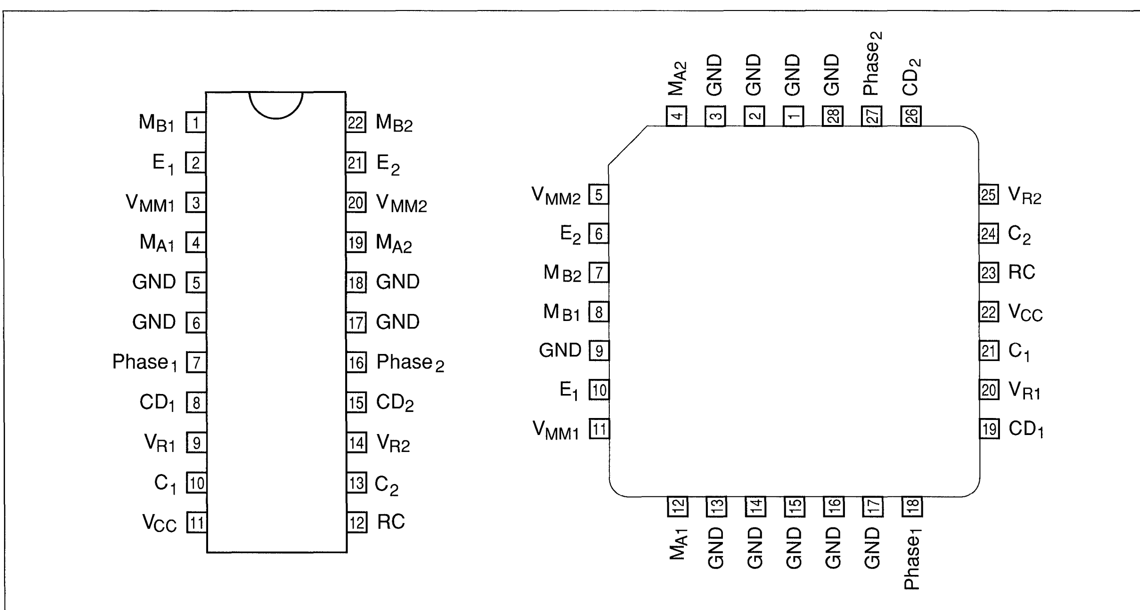


Figure 3. Pin configuration.

15	26	CD_2	Current decay control, channel 2. A logic HIGH on this input results in *slow* current decay, a LOW results in *fast* current decay, see “Functional Description.”
16	27	$Phase_2$	Controls the direction of motor current at outputs M_{A2} and M_{B2}. Motor current flows from M_{A2} to M_{B2} when $Phase_2$ is HIGH.
19	4	M_{A2}	Motor output A, channel 2. Motor current flows from M_{A2} to M_{B2} when Phase is HIGH.
20	5	V_{MM2}	Motor supply voltage, channel 2, 10 to 40 V. V_{MM1} and V_{MM2} should be connected together.
21	6	E_2	Common emitter, channel 2. This pin connects to a sensing resistor to ground.
22	7	M_{B2}	Motor output B, channel 2. Motor current flows from M_{A2} to M_{B2} when Phase is HIGH.

Functional Description

Each channel of the PBL 3771 consists of the following sections: an H-bridge output stage, capable of driving up to 650 mA continuous motor current (or 500 mA, both channels driven), a logic section that controls the output transistors, an S-R flip-flop, and two comparators. The oscillator is common to both channels.

Constant current control is achieved by switching the current to the windings. This is done by sensing the (peak) voltage across a current-sensing resistor, R_S, effectively connected in series with the motor winding, and feeding that voltage back to a comparator. When the motor current reaches a threshold level, determined by the voltage at the reference input, V_R, the comparator resets the flip-flop, which turns off the output transistors. The current decreases until the clock oscillator triggers the flip-flop, which turns on the output transistors again, and the cycle is repeated.

The current-decay rate during the turn-off portion of the switching cycle, can be selected fast or slow by the CD input.

In slow current-decay mode, only one of the lower transistors in the H-bridge (those closest to the negative supply) is switched on and off, while one of the upper transistors is held constantly on. During turn-off, the current recirculates through the upper transistor (which one depends on current direction) and the corresponding free-wheeling diode connected to V_{MM}, see figure 2.

In fast current decay mode, both the upper and lower transistors are switched. During the off-time, the freewheeling current is opposed by the supply voltage, causing a rapid discharge of energy in the winding.

Fast current decay may be required in half- and microstepping applications when rapid changes of motor current are necessary. Slow current decay, however, gives less current ripple, and should always be selected, if possible, to minimize core losses and switching noise.

Applications Information

Current control

The output current to the motor winding is mainly determined by the voltage at the reference input and the value of the sensing resistor, R_S.

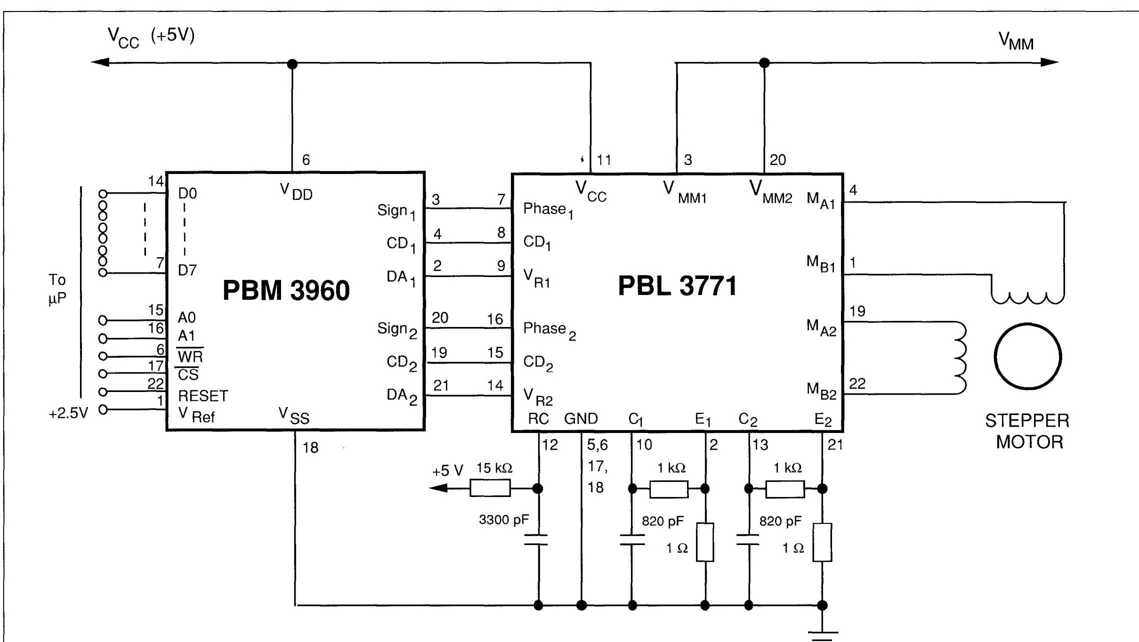


Figure 4. Microstepping system with PBM 3960 and PBL 3771.

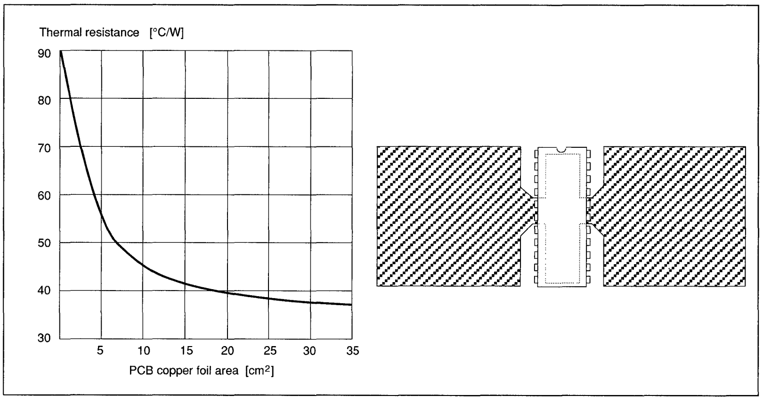


Figure 5. Thermal Resistance vs. PC Board copper area and suggested layout.

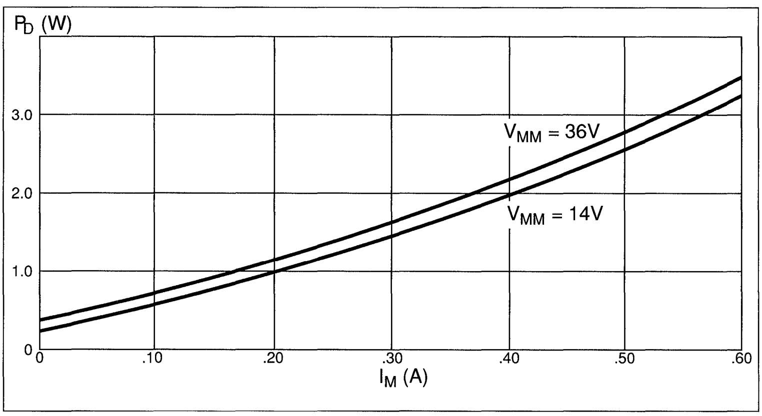


Figure 6. Power dissipation vs. motor current, both channels driven, T_a = 25°C.

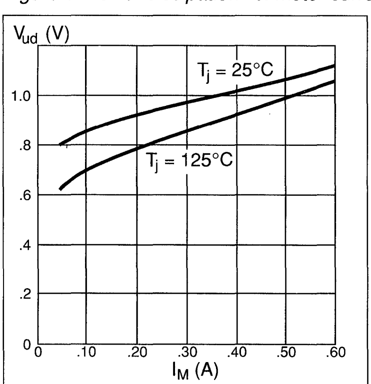


Figure 7. Typical upper diode voltage drop vs. recirculating current.

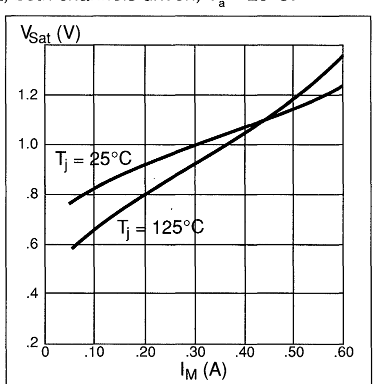


Figure 8. Typical source saturation voltage vs. output current.

Chopping frequency, winding inductance, and supply voltage will affect the current level, but to much less extent. Fast current decay setting will produce somewhat lower (average) current than slow current decay. The peak current through the sensing resistor (and motor winding) can be expressed as:

$I_{M,peak} = 0.18 \cdot (V_R / R_S)$ [A]

i.e., with a recommended value of 1 ohm for the sensing resistor, R_S, a 2.5 V reference voltage will produce an output current of approximately 450 mA. To improve noise immunity on the V_R input, the control range may be increased to 5 volts if R_S is correspondingly changed to 2 ohms.

External components

The voltage across the sensing resistor is fed back to the comparator via a low-pass filter section, to prevent erroneous switching due to switching transients. The recommended filter component values, 1 kohm and 820 pF, are suitable for a wide range of motors and operational conditions.

Since the low-pass filtering action introduces a small delay of the signal to the comparator, peak voltage across the sensing resistor, and hence the peak motor current, will reach a slightly higher level than the threshold, V_C, set by the reference voltage (V_C = 450 mV @ V_R = 2.5 V).

The time constant of the low-pass filter may therefore be reduced to minimize the delay and optimize low-current performance, especially if a low (12 V) supply voltage is used. Increasing the time constant may result in unstable switching.

The frequency of the clock oscillator is set by the R-C combination at pin RC. The recommended values give a nominal frequency of 26.5 kHz. A lower frequency will result in higher current ripple and may cause audible noise from the motor, while increasing the frequency results in higher switching losses and possibly increased iron losses in the motor.

The sensing resistor, R_S, should be selected for maximum motor current. The relationship between peak motor current, reference voltage and the value of R_S is described under "Current control" above. Be sure not to exceed the maximum output current which is 650 mA per channel (or 500 mA per channel, both channels fully on, see "Recommended Operating Conditions").

Motor selection

The PBL 3771 is designed for bipolar motors, i.e., motors that have only one winding per phase. A unipolar motor, having windings with a center tap, can also be used, see figure 11.

The chopping principle in the PBL 3771 is based on a constant frequency and a varying duty cycle. This scheme imposes certain restrictions on motor selection. Unstable chopping can occur if the chopping duty cycle exceeds approximately 50%. To avoid this, it is necessary to choose a motor with a low winding resistance. Low winding resistance means less inductance and will therefore enable higher stepping rates, however it also means less torque capability. A compromise has to be made.

Choose a motor with the lowest possible winding resistance that still gives the required torque and use as high supply voltage as possible without exceeding the maximum recommended 40 V. Check that the chopping duty cycle does not exceed 50% at maximum current.

Since the PBL 3771 produces a regulated, constant output current it is not necessary to use a motor that is rated at the same voltage as the actual supply voltage. Only rated current needs to be considered. Typical motors to be used together with the PBL 3771 have voltage ratings of 5 to 12 V, while the supply voltage usually ranges from 24 to 40 V.

General

Phase inputs. A logic HIGH on a SIGN input gives positive current flowing out from M_A into M_B. A logic LOW gives a current in the opposite direction.

Slow/fast current decay. A logic HIGH on the CD input gives slow current decay, a logic LOW gives fast current decay.

Heat sinking. Soldering the four center pins onto a free PCB copper area of 20 cm² (approx. 1.8" × 1.8", copper foil thickness = 35 μm) permits the circuit to operate with a maximum of 320 mA output current, both channels driving, at ambient temperatures up to +70°C. Consult figures 5 and 6 in order to determine the necessary copper area for heat sinking if higher currents are required.

Thermal shutdown. The circuit is equipped with a thermal shutdown function that reduces the output current at chip temperatures above +160°C.

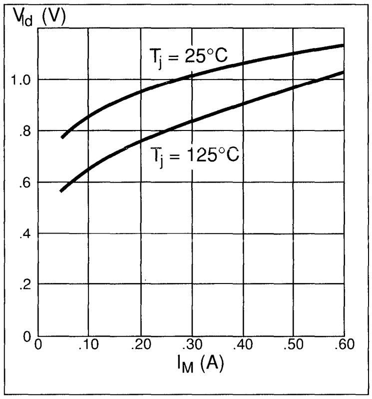


Figure 9. Typical lower diode voltage drop vs. recirculating current.

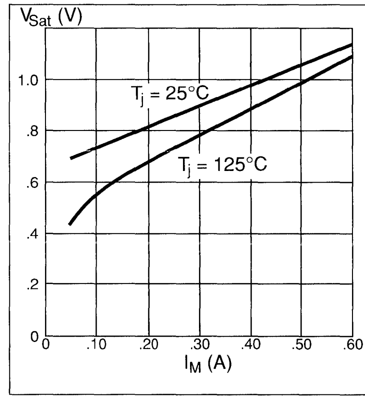


Figure 10. Typical sink saturation voltage vs. output current.

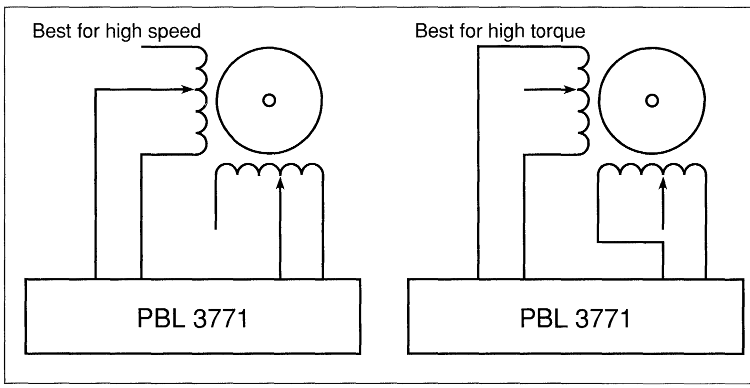


Figure 11. Connection of unipolar motors.

Description	DIP	PLCC
Rth_{j-c}, Junction to Case (Case = ground pin)	11°C/W	9°C/W
Rth_{j-a}, Junction to Ambient*	40°C/W	35°C/W

* For the DIP, the four ground pins soldered to a 20 cm² ground plane according to figure 5. For the PLCC, all ground pins are soldered to a 20 cm² ground plane located as close as possible to the device and on both sides of a double sided PCB.

Table 1. Thermal resistance . Thermal resistance values are heavily dependant on location and shape of heatsinks.

Ordering Information

Package	Temp. range	Part No.
Plastic DIP	0 to 70°C	PBL3771N
PLCC	0 to 70°C	PBL3771QN

Specifications subject to change without notice.

IC4 (88080) A-Ue
Revised edition April 1991.

ERICSSON

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PBL 3772
Dual Stepper Motor Driver

Description

The PBL 3772 is a switch-mode (chopper), constant-current driver IC with two channels, one for each winding of a two-phase stepper motor. The circuit is similar to Ericsson´s PBL 3771, but has been designed to generate a minimum amount of power dissipation and can deliver substantially more current to the stepper motor, up to 1 A continuously per channel. At 2 x 750 mA output current, power dissipation is only 1.8 W.

The circuit is designed for microstepping applications in conjunction with the matching dual DAC (Digital-to-Analog Converter) PBM 3960. A complete driver system consists of these two ICs, a few passive components and a microprocessor for generation of the proper control and data codes required for microstepping.

The PBL 3772 contains a clock oscillator, which is common for both driver channels, a set of comparators and flip-flops implementing the switching control, and two output H-bridges.

Voltage supply requirements are +5 V for logic and +10 to +45 V for the motor.

The close match between the two driver channels guarantees consistent output current ratios and motor positioning accuracy.

Key Features

- Dual chopper driver in a single package.
- 0°C to + 85°C operation.
- 1. 0 A continuous output current per channel.
- Very low power dissipation, 1.8 W at 2 x 750 mA output current.
- Close matching between channels for high microstepping accuracy.
- Specially matched to the Dual DAC PBM 3960.
- Plastic 22-pin batwing DIP package or 28-pin power PLCC with lead-frame for heat-sinking through PC board copper.

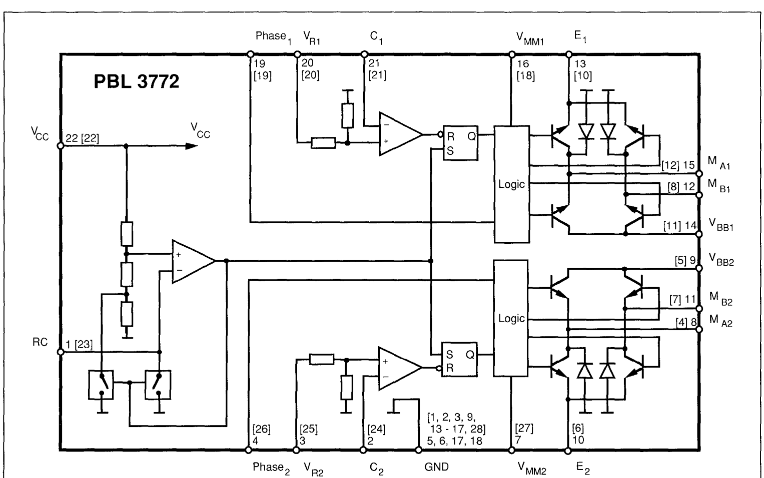
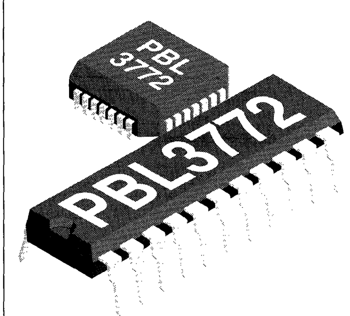


Figure 1. Block diagram.



28-pin PLCC package
22-pin plastic DIP package

Maximum Ratings

Parameter	Pin no.*	Symbol	Min	Max	Unit
Voltage					
Logic supply	22 [22]	V_{CC}	0	7	V
Motor supply	7, 16 [18, 27]	V_{MM}	0	45	V
Output stage supply	9, 14 [5, 11]	V_{BB}	0	45	V
Logic inputs	4, 19 [19, 26]	V_I	-0.3	6	V
Comparator inputs	2, 21 [21, 24]	V_C	-0.3	V_{CC}	V
Reference inputs	3, 20 [20, 25]	V_R	-0.3	7.5	V
Current					
Motor output current	8, 11, 12, 15 [4, 7, 8, 12]	I_M	-1200	+1200	mA
Logic inputs	4, 19 [19, 26]	I_I	-10		mA
Analog inputs	2, 3, 20, 21 [20, 21, 24, 25]	I_A	-10		mA
Temperature					
Junction temperature		T_J		+150	°C
Storage temperature		T_S	-55	+150	°C
Power Dissipation (Package Data)					
Power dissipation at T_{BW} = +25°C, DIP and PLCC package		P_D		5	W
Power dissipation at T_{BW} = +125°C, DIP package		P_D		2.2	W
Power dissipation at T_{BW} = +125°C, PLCC package		P_D		2.6	W

* Pin numers in brackets refer to PLCC package.

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Logic supply voltage	V_{CC}	4.75	5	5.25	V
Motor supply voltage	V_{MM}	10		40	V
Output stage supply voltage	V_{BB}	V_{MM} - 0.5		V_{MM}	V
Motor output current	I_M	-1000		+1000	mA
Operating ambient temperature	T_A	0		+85	°C
Rise and fall time, logic inputs	t_r, t_f			2	µs
Oscillator timing resistor	R_T	2	15	20	kohm

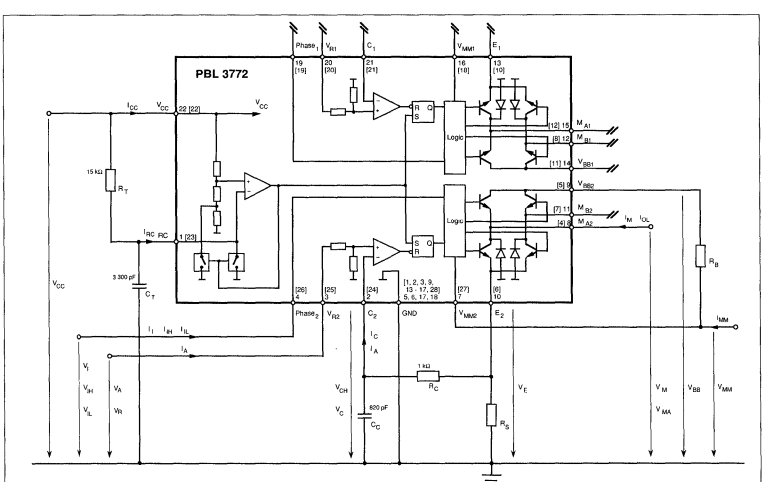


Figure 2. Definition of symbols.

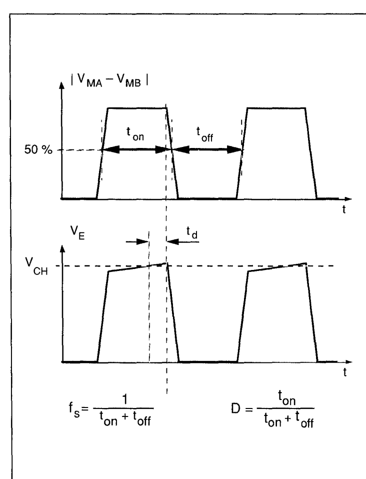


Figure 3. Definition of terms.

Electrical Characteristics

Electrical characteristics over recommended operating conditions, unless otherwise noted. 0°C ≤ T_J ≤ 125°C.

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
General							
Supply current	I_{CC}	2	Note 4.		60	75	mA
Total power dissipation	P_D	8	V_{MM} = 12 V, I_{M1} = I_{M2} = 750 mA. R_B = 0.68 ohm. Notes 2, 3, 4, 5.		1.8	2.1	W
Total power dissipation	P_D	8	V_{MM} = 12 V, I_{M1} = 1000 mA, I_{M2} = 0 mA. R_B = 0.47 ohm. Notes 2, 3, 4, 5.		1.8	2.2	W
Thermal shutdown junction temperature					160		°C
Turn-off delay	t_d	3	T_A = +25°C, $dV_C/dt \geq$ 50 mV/µs, I_M = 100 mA. Note 3.		1.4	2.0	µs
Logic Inputs							
Logic HIGH input voltage	V_{IH}	2		2.0			V
Logic LOW input voltage	V_{IL}	2				0.8	V
Logic HIGH input current	I_{IH}	2	V_I = 2.4 V			20	µA
Logic LOW input current	I_{IL}	2	V_I = 0.4 V	-0.4			mA
Comparator Inputs							
Threshold voltage	V_{CH}	2	R_C = 1 kohm, V_R = 2.50 V	430	450	470	mV
$\mid V_{CH1} - V_{CH2} \mid$ mismatch	$V_{CH,diff}$	2	R_C = 1 kohm		1		mV
Input current	I_C	2		-10		1	µA
Reference Inputs							
Input resistance	R_R		T_A = +25°C		5		kohm
Input current	I_R	2	V_R = 2.50 V		0.5	1.0	mA
Motor Outputs							
Lower transistor saturation voltage		11	I_M = 750 mA		0.6	0.9	V
Lower transistor leakage current		2	V_{MM} = 41 V, V_E = V_R = 0 V, V_C = V_{CC}			700	µA
Lower diode forward voltage drop		12	I_M = 750 mA		1.2	1.5	V
Upper transistor saturation voltage		13	I_M = 750 mA. R_B = 0.68 ohm. Note 5.		0.6	0.9	V
Upper transistor saturation voltage		13	I_M = 750 mA. R_B = 0.47 ohm. Note 3, 5.		0.8	1.1	V
Upper transistor leakage current		2	V_{MM} V_{BB} = 41 V, V_E = V_R = 0 V, V_C = V_{CC}			700	µA
Chopper Oscillator							
Chopping frequency	f_s	3	C_T = 3300 pF, R_T = 15 kohm	25.0	26.5	28.0	kHz

Thermal Characteristics

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
Thermal resistance	Rth_{J-BW}		DIP package.		11		°C/W
	Rth_{J-A}	14	DIP package. Note 2.		40		°C/W
	Rth_{J-BW}		PLCC package.		9		°C/W
	Rth_{J-A}	14	PLCC package. Note 2.		35		°C/W

Notes

1. All voltages are with respect to ground. Currents are positive into, negative out of specified terminal.
2. All ground pins soldered onto a 20 cm^2 PCB copper area with free air convection, T_A = +25°C.
3. Not covered by final test program.
4. Switching duty cycle D = 30%, f_s = 26.5 kHz.
5. External resistors R_B for lowering of saturation voltage.

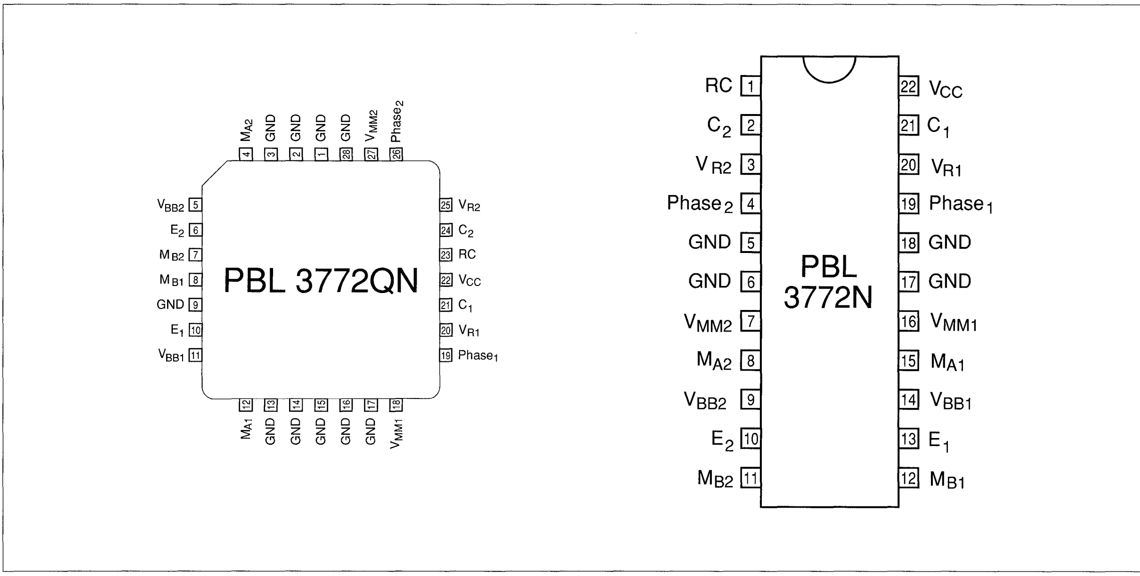


Figure 4. Pin configuration.

Pin Description

PLCC	DIP	Symbol	Description
[1-3, 9, 13-17 28]	5, 6 17, 18	GND	Ground and negative supply. Note: these pins are used thermally for heat-sinking. Make sure that all ground pins are soldered onto a suitably large copper ground plane for efficient heat sinking.
[4]	8	M_{A2}	Motor output A, channel 2. Motor current flows from M_{A2} to M_{B2} when $Phase_2$ is HIGH.
[5]	9	V_{BB2}	Collector of upper output transistor, channel 2. For lowest possible power dissipation, connect a series resistor R_B to V_{MM}. See Applications information, External components.
[6]	10	E_2	Common emitter, channel 2. This pin connects to a sensing resistor R_S to ground.
[7]	11	M_{B2}	Motor output B, channel 2. Motor current flows from M_{A2} to M_{B2} when $Phase_2$ is HIGH.
[8]	12	M_{B1}	Motor output B, channel 1. Motor current flows from M_{A1} to M_{B1} when $Phase_1$ is HIGH.
[10]	13	E_1	Common emitter, channel 1. This pin connects to a sensing resistor R_S to ground.
[11]	14	V_{BB1}	Collector of upper output transistor, channel 1. For lowest possible power dissipation, connect a series resistor R_B to V_{MM}. See Applications information, External components.
[12]	15	M_{A1}	Motor output A, channel 1. Motor current flows from M_{A1} to M_{B1} when Phase is HIGH.
[18]	16	V_{MM1}	Motor supply voltage, channel 1, +10 to +40 V. V_{MM1} and V_{MM2} should be connected together.
[19]	19	$Phase_1$	Controls the direction of motor current at outputs M_{A1} and M_{B1}. Motor current flows from M_{A1} to M_{B1} when $Phase_1$ is HIGH.
[20]	20	V_{R1}	Reference voltage, channel 1. Controls the threshold voltage for the comparator and hence the output current.
[21]	21	C_1	Comparator input channel 1. This input senses the instantaneous voltage across the sensing resistor, filtered by an RC network. The threshold voltage for the comparator is $V_{CH1} = 0.18 \cdot V_{R1}$ [V], i.e. 450 mV at $V_{R1} = 2.5$ V.
[22]	22	V_{CC}	Logic voltage supply, nominally +5 V.
[23]	1	RC	Clock oscillator RC pin. Connect a 15 kohm resistor to V_{CC} and a 3300 pF capacitor to ground to obtain the nominal switching frequency of 26.5 kHz.
[24]	2	C_2	Comparator input channel 2. This input senses the instantaneous voltage across the sensing resistor, filtered by an RC network. The threshold voltage for the comparator is $V_{CH2} = 0.18 \cdot V_{R2}$ [V], i.e. 450 mV at $V_{R2} = 2.5$ V.

[25]	3	V_{R2}	Reference voltage, channel 2. Controls the threshold voltage for the comparator and hence the output current.
[26]	4	$Phase_2$	Controls the direction of motor current at outputs M_{A2} and M_{B2}. Motor current flows from M_{A2} to M_{B2} when $Phase_2$ is HIGH.
[27]	7	V_{MM2}	Motor supply voltage, channel 2, +10 to +40 V.V_{MM1} and V_{MM2} should be connected together.

Functional Description

Each channel of the PBL 3772 consists of the following sections: an output H-bridge with four transistors, capable of driving up to 1 A continuous current to the motor winding; a logic section that controls the output transistors; an S-R flip-flop; and a comparator. The clock-oscillator is common to both channels.

Constant current control is achieved by switching the output current to the windings. This is done by sensing the peak current through the winding via a current-sensing resistor R_S, effectively connected in series with the motor winding during the turn-on period. As the current increases, a voltage develops across the sensing resistor, which is fed back to the comparator. At the predetermined level, defined by the voltage at the reference input V_R, the comparator resets the flip-flop, which turns off the output transistors. The current decreases until the clock oscillator triggers the flip-flop, which turns on the output transistors again, and the cycle is repeated.

The current paths during turn-on, turn-off and phase shift are shown in figure 5. Note that the upper recirculation diodes are connected to the circuit externally.

Applications Information

Current control

The output current to the motor winding is determined by the voltage at the reference input and the sensing resistor, R_S.

Chopping frequency, winding inductance and supply voltage also affect the current, but to much less extent.

The peak current through the sensing resistor (and motor winding) can be expressed as:

$I_{M,peak} = 0.18 \cdot (V_R / R_S)$ [A]

i.e., with a recommended value of 0.47 ohm for the sensing resistor R_S, a 2.5 V reference voltage will produce an output current of approximately 0.96 A. To improve noise immunity on the V_R input, the control range may be increased to 5 V if R_S is correspondingly changed to 1 ohm.

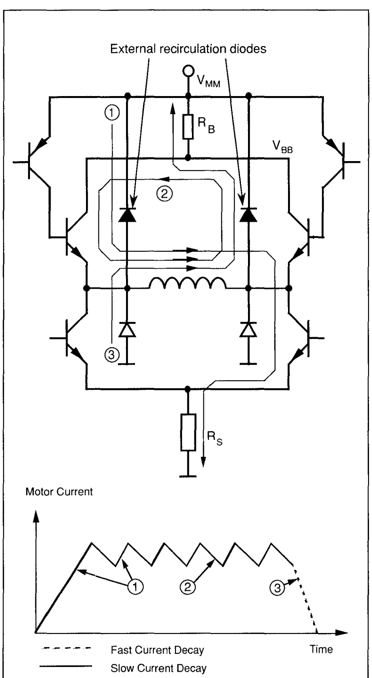


Figure 5. Output stage with current paths during turn-on, turn-off and phase shift.

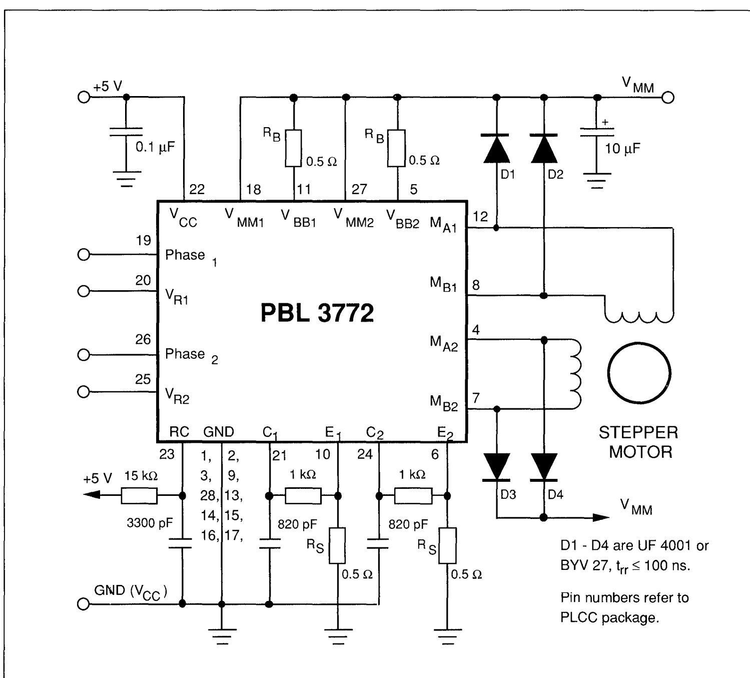


Figure 6. Typical stepper motor driver application with PBL 3772.

External components

The PBL 3772 exhibits substantially less power dissipation than most other comparable stepper motor driver ICs on the market. This has been achieved by creating an external voltage drop in series with the upper transistor in the output H-bridge, see figure 5. The voltage drop reduces the collector-emitter saturation voltage of the internal transistor, which can greatly reduce power dissipation of the IC itself. The series resistor, designated R_B, shall be selected for about 0.5 V voltage drop at the maximum output current. In an application with an output current of 1000 mA (peak), a 0.47 ohm, ½ W resistor is the best choice.

In low current applications where power dissipation is not a critcal factor, the R_B resistor can of course be omitted, and the V_{MM} and V_{BB} pins (pins 5, 11, 18, 27) can all be connected directly to the motor supply voltage V_{MM}.

Contributing to the low power dissipation is the fact that the upper recirculation diodes in the output H-bridge are connected externally to the circuit. These diodes shall be of fast type, with a t_{rr} of less than 100 ns. Common types are UF4001 or BYV27.

A low pass filter in series with the comparator input prevents erroneous switching due to switching transients. The recommended filter component values, 1 kohm and 820 pF, are suitable for a wide range of motors and operational conditions.

Since the low-pass filtering action introduces a small delay of the signal to the comparator, peak voltage across the sensing resistor, and hence the peak motor current, will reach a slightly higher level than than what is defined by the comparator threshold, V_{CH}, set by the reference input V_R (V_{CH} = 450 mV at V_R= 2.5 V).

The time constant of the low-pass filter may therefore be reduced to minimize the delay and optimize low-current performance. Increasing the time constant may result in unstable switching. The time constant should be adjusted by changing the C_C value.

The frequency of the clock oscillator is set by the R_T-C_T timing components at the RC pin. The recommended values result in a clock frequency (= switching frequency) of 26.5 kHz. A lower frequency will result in higher current ripple, but may improve low-current level linearity. A higher clock frequency reduces current ripple, but increases the switching losses in the IC and possibly the iron losses in the motor. If the clock frequency needs to be changed, the C_T capacitor value should be adjusted. The recommended R_T resistor value is 15 kohm.

The sensing resistor R_S, should be selected for maximum motor current. The relationship between peak motor current, reference voltage and the value of R_S is described under Current control above. Be sure not to exceed the maximum output current which is 1.2 A peak when only one channel is activated. Or recommended output current, which is 1.0 A peak, when both channels is activated.

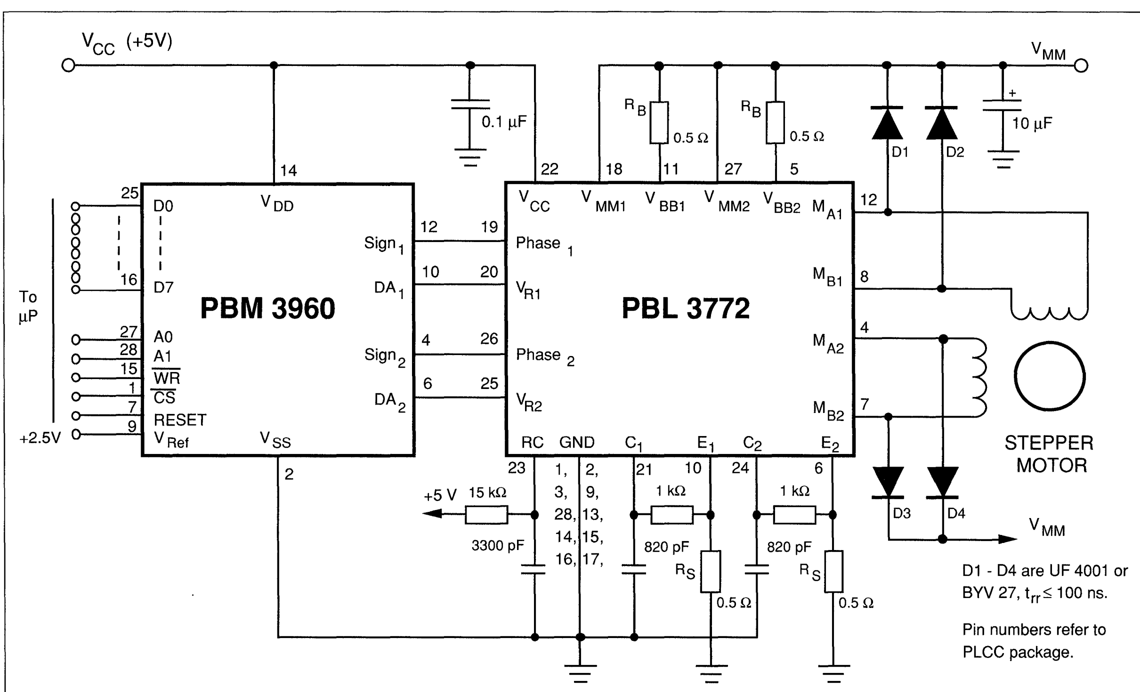


Figure 7. Microstepping system with PBM 3960 and PBL 3772.

Motor selection

The PBL 3772 is designed for two-phase bipolar stepper motors, i.e., motors that have only one winding per phase.

The chopping principle of the PBL 3772 is based on a constant frequency and a varying duty cycle. This scheme imposes certain restrictions on motor selection. Unstable chopping can occur if the chopping duty cycle exceeds approximately 50%. See figure 3 for definitions. To avoid this, it is necessary to choose a motor with a low winding resistance and inductance, i.e. windings with a few turns.

It is not possible to use a motor that is rated for the same voltage as the actual supply voltage. Only rated current needs to be considered.Typical motors to be used together with the PBL 3772 have a voltage rating of 1 to 6 V, while the supply voltage usually ranges from 12 to 40 V.

Low inductance, especially in combination with a high supply voltage, enables high stepping rates. However, to give the same torque capability at low speed, a reduced number of turns in the winding must be compensated by a higher current. A compromise has to be made.

Choose a motor with the lowest possible winding resistance that still gives the required torque, and use as high supply voltage as possible, without exceeding the maximum recommended 40 V. Check that the chopping duty cycle does not exceed 50% at maximum current.

General

Phase inputs. A logic HIGH on a Phase input gives a current flowing from pin M_A into pin M_B. A logic LOW gives a current flow in the opposite direction. A time delay prevents cross conduction in the H-bridge when changing the Phase input.

Heat sinking. Soldering the batwing ground leads onto a copper ground plane of 20 cm² (approx. 1.8" x 1.8"), copper foil thickness 35 µm, permits the circuit to operate with 750 mA output current, both channels driving, at ambient

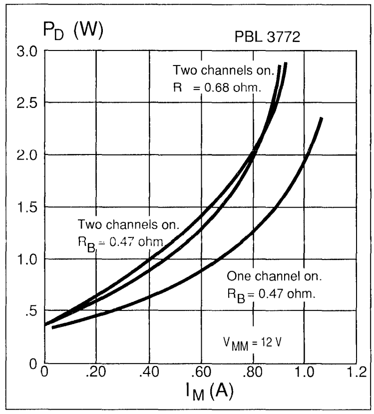


Figure 8. Power dissipation vs. motor current. T_a = 25°C.

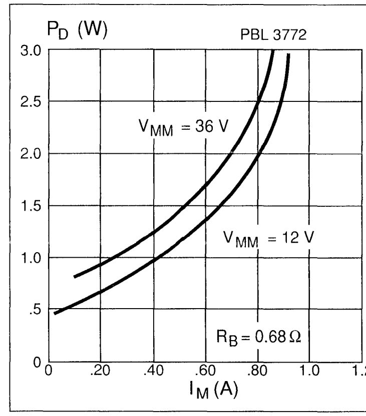


Figure 9. Power dissipation vs. motor current, both channels on. T_a = 25°C.

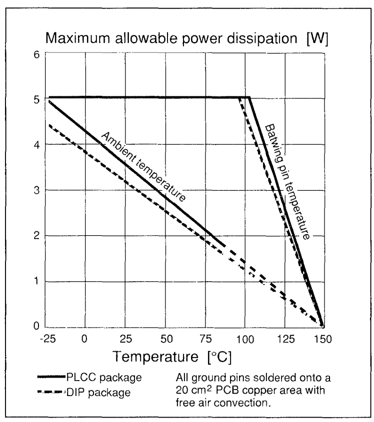


Figure 10. Maximum allowable power dissipation vs. temperature.

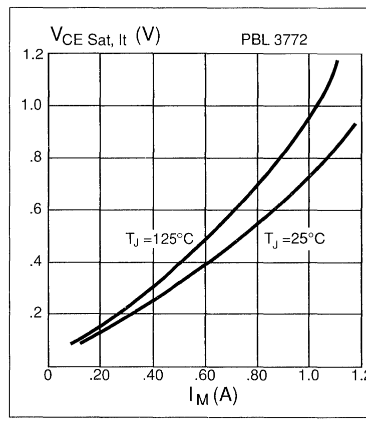


Figure 11. Typical lower transistor saturation voltage vs. output current.

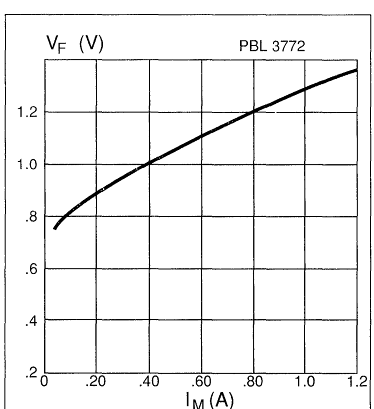


Figure 12. Typical lower diode voltage drop vs. recirculating current.

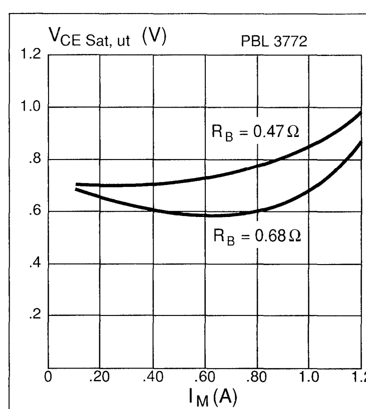


Figure 13. Typical upper transistor saturation voltage vs. output current.

temperatures up to 70°C. Consult figures 8, 9, 10 and 14 in order to determine the necessary copper ground plane area for heat sinking at higher current levels.

Thermal shutdown. The circuit is equipped with a thermal shutdown function that turns the output off at chip temperatures above 160°C. Normal operation is resumed when the temperature has decreased about 20°C.

Ordering Information

Package	Temp. range	Part No.
Plastic DIP	0°C to + 85°C	PBL3772N
PLCC	0°C to + 85°C	PBL3772QN

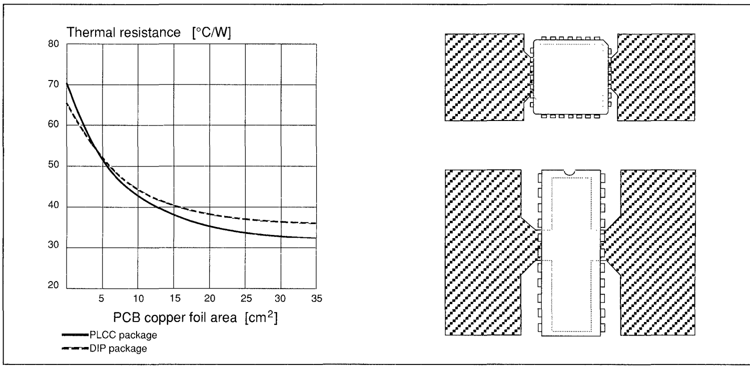


Figure 14. Typical thermal resistance vs. PC Board copper area and suggested layout.

Specifications subject to change without notice.
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April 1991

PBL 3773
Dual Stepper Motor Driver

Description

The PBL 3773 is a switch-mode (chopper), constant-current driver IC with two channels, one for each winding of a two-phase stepper motor. The circuit is similar to Ericsson´s PBL 3771 and PBL 3772. While all Dual stepper motor drivers are optimized for microstepping applications, PBL 3773 is equipped with a Disable input to simplify half-stepping operation.

The circuit is well suited for microstepping applications. The current control inputs are low current, high impedance inputs, which allows the use of unbuffered Digital-to-Analog converters or external high resistive resistor divider networks.

The PBL 3773 contains a clock oscillator, which is common for both driver channels, a set of comparators and flip-flops implementing the switching control, and two output H-bridges, including recirculation diodes.

Voltage supply requirements are +5 V for logic and +10 to +45 V for the motor.

The close match between the two driver channels guarantees consistent output current ratios and motor positioning accuracy.

Key Features

- Dual chopper driver in a single package.
- –40° C to +85° C operation.
- 750 mA continuous output current per channel.
- Low power dissipation, 2.0 W at 2 x 500 mA output current
- Close matching between channels for high microstepping accuracy
- High impedance current control inputs
- Digital filter on chip eliminates external filtering components.
- Plastic 22-pin batwing DIP package or 28-pin power PLCC with lead-frame for heat-sinking through PC board copper.

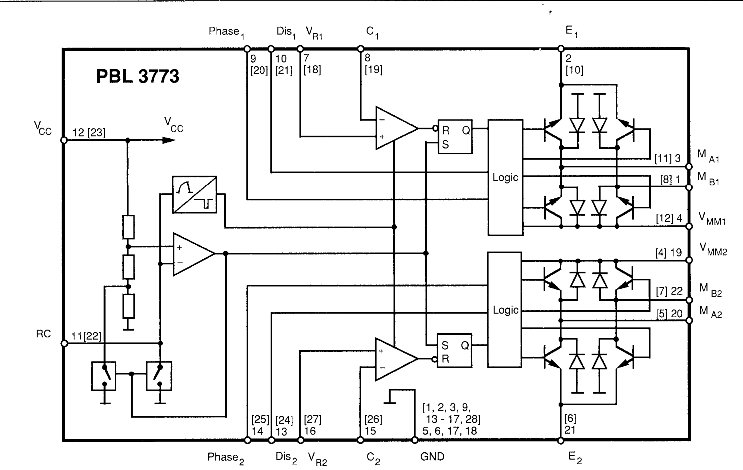
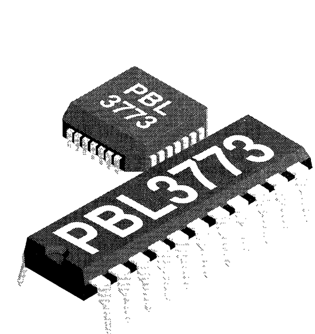


Figure 1. Block diagram.



28-pin PLCC package
22-pin plastic DIP package

Maximum Ratings

Parameter	Pin no.*	Symbol	Min	Max	Unit
Voltage					
Logic supply	12 [23]	V_{CC}	0	7	V
Motor supply	4, 19 [4, 12]	V_{MM}	0	45	V
Logic inputs	9, 10, 13, 14 [20, 21, 24, 25]	V_I	-0.3	6	V
Analog inputs	7, 8, 15, 16 [18, 19, 26, 27]	V_A	-0.3	V_{CC}	V
Current					
Motor output current	1, 3, 20, 22 [5, 7, 8, 11]	I_M	-850	+850	mA
Logic inputs	9, 10, 13, 14 [20, 21, 24, 25]	I_I	-10		mA
Analog inputs	7, 8, 15, 16 [18, 19, 26, 27]	I_A	-10		mA
Temperature					
Junction temperature		T_J		+150	°C
Storage temperature		T_S	-55	+150	°C
Power Dissipation (Package Data)					
Power dissipation at T_{BW} = +25°C, DIP and PLCC package		P_D		5	W
Power dissipation at T_{BW} = +125°C, DIP package		P_D		2.2	W
Power dissipation at T_{BW} = +125°C, PLCC package		P_D		2.6	W

* Pin numbers in brackets refer to PLCC package.

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Logic supply voltage	V_{CC}	4.75	5	5.25	V
Motor supply voltage	V_{MM}	10		40	V
Output emitter voltage	V_E			1.0	V
Motor output current	I_M	-750		+750	mA
Operating ambient temperature	T_A	-40		+85	°C
Rise and fall time logic inputs	t_r, t_f			2	µs
Oscillator timing resistor	R_T	2	12	20	kohm

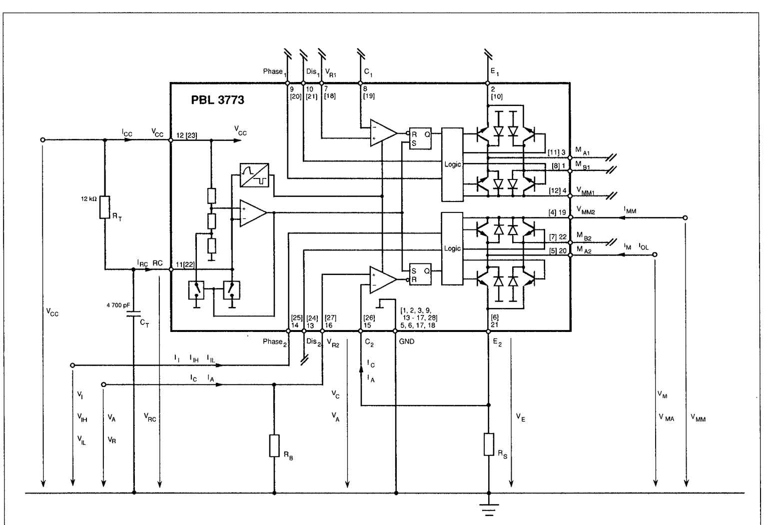


Figure 2. Definition of symbols.

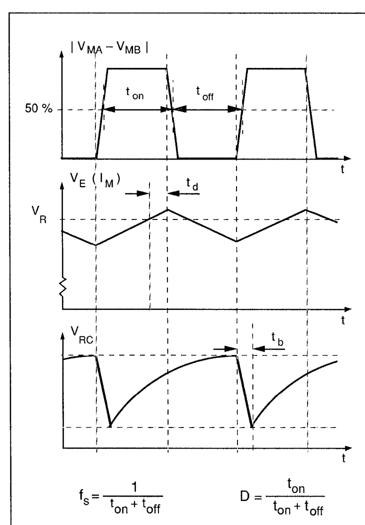


Figure 3. Definition of terms.

Electrical Characteristics

Electrical characteristics over recommended operating conditions, unless otherwise noted. -20°C ≤ T_j ≤ +125°C.

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
General							
Supply current	I_{CC}	2	Note 4.		55	70	mA
Supply current	I_{CC}	2	$Dis_1 = Dis_2$ = HIGH.		7	10	mA
Total power dissipation	P_D	8	V_{MM} = 24 V, $I_{M1} = I_{M2}$ = 500 mA. Notes 2, 3, 4.		2.0	2.3	W
Total power dissipation	P_D	8	V_{MM} = 24 V, I_{M1} = 700 mA, I_{M2} = 0 mA. Notes 2, 3, 4.		1.7	2.0	W
Thermal shutdown junction temperature					160		°C
Turn-off delay	t_d	3	T_A = +25°C, dV_C/dt ≥ 50 mV/µs, I_M = 100 mA. Note 3. (one channel on).		1.1	2.0	µs
Logic Inputs							
Logic HIGH input voltage	V_{IH}	2		2.0			V
Logic LOW input voltage	V_{IL}	2				0.6	V
Logic HIGH input current	I_{IH}	2	V_I = 2.4 V			20	µA
Logic LOW input current	I_{IL}	2	V_I = 0.4 V	-0.2	-0.1		mA
Analog Inputs							
Input current	I_A	2		-0.5	-0.2		µA
$\vert V_{C1} - V_{C2} \vert$ mismatch	$V_{C,diff}$	2	R_B = 1 kΩ. Note 3.		1		mV
Motor Outputs							
Lower transistor saturation voltage		10	I_M = 500 mA		0.4	0.8	V
Lower transistor leakage current		2	V_{MM}=41 V, T_A = +25°C. $Dis_1 = Dis_2$ = HIGH.			100	µA
Lower diode forward voltage drop		11	I_M = 500 mA		1.1	1.3	V
Upper transistor saturation voltage		12	I_M = 500 mA.		1.1	1.4	V
Upper diode forward voltage drop		13	I_M = 500 mA.		1.1	1.4	V
Upper transistor leakage current		2	V_{MM}=41 V, T_A = +25°C. $Dis_1 = Dis_2$ = HIGH.			100	µA
Chopper Oscillator							
Chopping frequency	f_s	3	C_T = 4 700 pF, R_T = 12 kohm	21.5	23.0	24.5	kHz
Digital filter blanking time	t_b	3	C_T = 4 700 pF. Note 3.		1.0		µs

Thermal Characteristics

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
Thermal resistance	Rth_{J-BW}		DIP package.		11		°C/W
	Rth_{J-A}	14	DIP package. Note 2.		40		°C/W
	Rth_{J-BW}		PLCC package.		9		°C/W
	Rth_{J-A}	14	PLCC package. Note 2.		35		°C/W

Notes

1. All voltages are with respect to ground. Currents are positive into, negative out of specified terminal.
2. All ground pins soldered onto a 20 cm² PCB copper area with free air convection, T_A = +25°C.
3. Not covered by final test program.
4. Switching duty cycle D = 30%, f_s = 23.0 kHz.

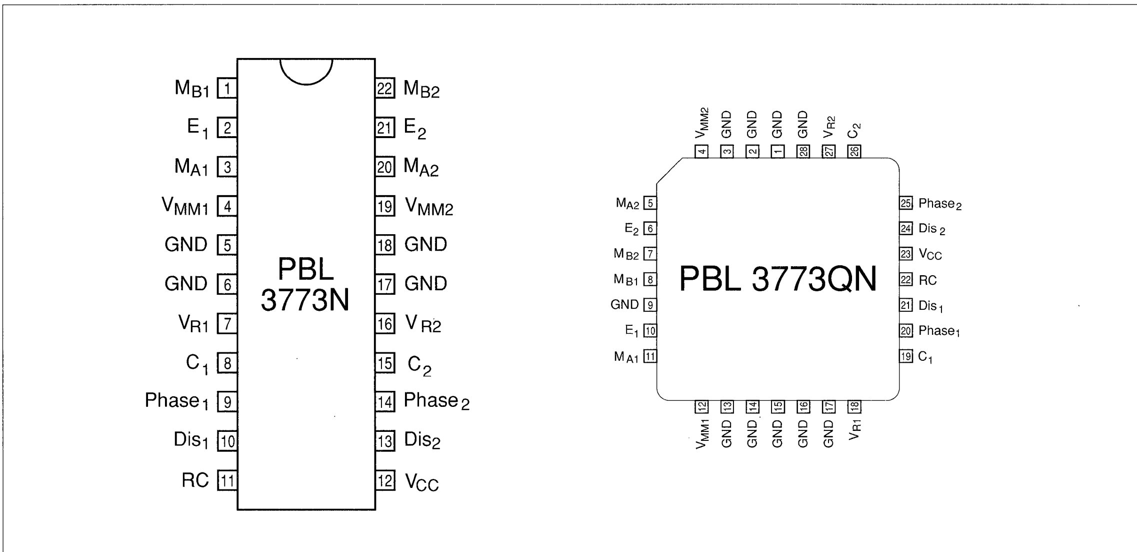


Figure 4. Pin configuration.

Pin Description

DIP	PLCC	Symbol	Description
1	[8]	M_{B1}	Motor output B, channel 1. Motor current flows from M_{A1} to M_{B1} when $Phase_1$ is HIGH.
2	[10]	E_1	Common emitter, channel 1. This pin connects to a sensing resistor R_S to ground.
3	[11]	M_{A1}	Motor output A, channel 1. Motor current flows from M_{A1} to M_{B1} when Phase is HIGH.
4	[12]	V_{MM1}	Motor supply voltage, channel 1, +10 to +40 V. V_{MM1} and V_{MM2} should be connected together.
5, 6, 17, 18	[1-3, 9, 13-17, 28]	GND	Ground and negative supply. Note: these pins are used thermally for heat-sinking. Make sure that all ground pins are soldered onto a suitably large copper ground plane for efficient heat sinking.
7	[18]	V_{R1}	Reference voltage, channel 1. Controls the comparator threshold voltage and hence the output current.
8	[19]	C_1	Comparator input channel 1. This input senses the instantaneous voltage across the sensing resistor, filtered by the internal digital filter or an optional external RC network.
9	[20]	$Phase_1$	Controls the direction of motor current at outputs M_{A1} and M_{B1}. Motor current flows from M_{A1} to M_{B1} when $Phase_1$ is HIGH.
10	[21]	Dis_1	Disable input for channel 1. When HIGH, all four output transistors are turned off, which results in a rapidly decreasing output current to zero.
11	[22]	RC	Clock oscillator RC pin. Connect a 12 kohm resistor to V_{CC} and a 4 700 pF capacitor to ground to obtain the nominal switching frequency of 23.0 kHz and a digital filter blanking time of 1.0 µs.
12	[23]	V_{CC}	Logic supply voltage, nominally +5 V.
13	[24]	Dis_2	Disable input for channel 2. When HIGH, all four output transistors are turned off, which results in a rapidly decreasing output current to zero.
14	[25]	$Phase_2$	Controls the direction of motor current at outputs M_{A2} and M_{B2}. Motor current flows from M_{A2} to M_{B2} when $Phase_2$ is HIGH.
15	[26]	C_2	Comparator input channel 2. This input senses the instantaneous voltage across the sensing resistor, filtered by the internal digital filter or an optional external RC network.
16	[27]	V_{R2}	Reference voltage, channel 2. Controls the comparator threshold voltage and hence the output current.
19	[4]	V_{MM2}	Motor supply voltage, channel 2, +10 to +40 V.V_{MM1} and V_{MM2} should be connected together.
20	[5]	M_{A2}	Motor output A, channel 2. Motor current flows from M_{A2} to M_{B2} when $Phase_2$ is HIGH.
21	[6]	E_2	Common emitter, channel 2. This pin connects to a sensing resistor R_S to ground.
22	[7]	M_{B2}	Motor output B, channel 2. Motor current flows from M_{A2} to M_{B2} when $Phase_2$ is HIGH.

Functional Description

Each channel of the PBL 3773 consists of the following sections: an output H-bridge with four transistors and four recirculation diodes, capable of driving up to 750 mA continuous current to the motor winding, a logic section that controls the output transistors, an S-R flip-flop, and a comparator. The clock-oscillator is common to both channels.

Constant current control is achieved by switching the output current to the windings. This is done by sensing the peak current through the winding via a current-sensing resistor R_S, effectively connected in series with the motor winding. As the current increases, a voltage develops across the sensing resistor, which is fed back to the comparator. At the predetermined level, defined by the voltage at the reference input V_R, the comparator resets the flip-flop, which turns off the upper output transistor. The turn-off function of the two channels works independently of each other. The current decreases until the clock oscillator triggers the flip-flops of both channels simultaneously, which turns on the output transistors again, and the cycle is repeated.

To prevent erroneous switching due to switching transients at turn-on, the PBL 3773 includes a digital filter. The clock oscillator provides a blanking pulse which is used for digital filtering of the voltage transient across the current sensing resistor during turn-on.

The current paths during turn-on, turn-off and phase shift are shown in figure 5.

Applications Information

Current control.

The regulated output current level to the motor winding is determined by the voltage at the reference input and the value of the sensing resistor, R_S. The peak current through the sensing resistor (and the motor winding) can be expressed as:

$I_{M,peak} = V_R / R_S$ [A]

With a recommended value of 0.5 ohm for the sensing resistor R_S, a 0.25 V reference voltage will produce an output current of approximately 0.5 A. R_S should be selected for maximum motor current. Be shure not to exceed the absolute maximum output current which is 850 mA. Chopping frequency, winding inductance and supply voltage also affect the current, but to much less extent.

To improve noise immunity on the comparator inputs (V_R and C), the control range may be increased to 0.5 V if R_S is correspondingly changed to 1 ohm for a maximum output current of 0.5 A.

For accurate current regulation, the sensing resistor should be a 0.5 - 1.0 W precision resistor, i. e. less than 1% tolerance and low temperature coefficient.

Current sense filtering.

At turn-on a current spike occurs, due to the recovery of the recirculation diodes and the capacitance of the motor winding. To prevent this spike from reseting the flip-flops through the current sensing comparators, the clock oscillator generates a blanking pulse at turn-on. The blanking pulse disables the comparators for a short time. Thereby any voltage transient across the sensing

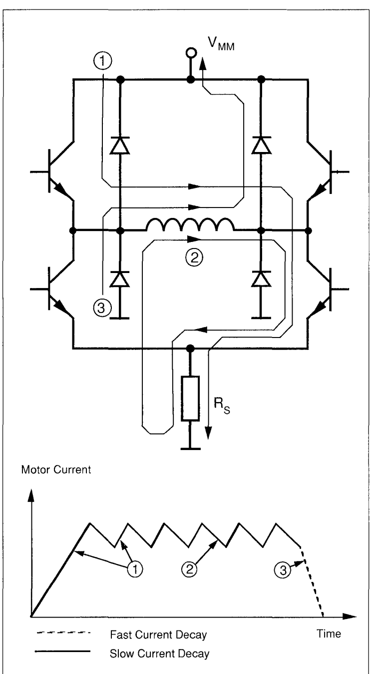


Figure 5. Output stage with current paths during turn-on, turn-off and phase shift.

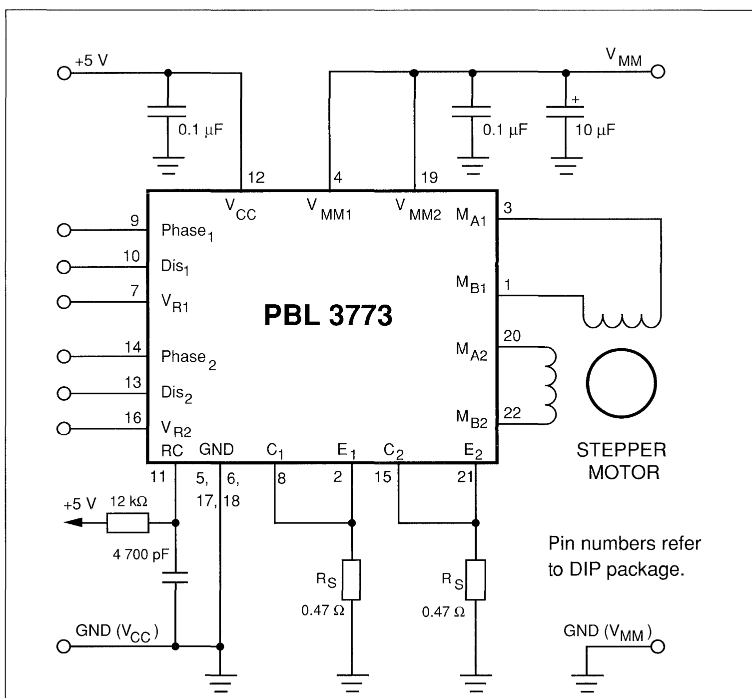


Figure 6. Typical stepper motor driver application with PBL 3773.

resistor will be ignored during the blanking time.

Choose the blanking pulse time to be longer than the duration of the switching transients by selecting a proper C_T value. The time is calculated as:

$t_b = 210 \cdot C_T$ [s]

As the C_T value may vary from approximately 2 200 pF to 33 000 pF, a blanking time ranging from 0.5 µs to 7 µs is possible. Nominal value is 4 700 pF, which gives a blanking time of 1.0 µs.

As the filtering action introduces a small delay, the peak value across the sensing resistor, and hence the peak motor current, will reach a slightly higher level than what is defined by the reference voltage. The filtering delay also limits the minimum possible output current. As the output will be on for a short time each cycle, equal to the digital filtering blanking time plus additional internal delays, an amount of current will flow through the winding. Typically this current is 1-10 % of the maximum output current set by R_S.

When optimizing low current performance, the filtering may be done by adding an external low pass filter in series with the comparator C input, see figure 7. In this case the digital blanking time should be as short as possible. The recommended filter component values are 10 kohm and 820 p. Lowering the switching frequency also helps reducing the minimum output current.

To create an absolute zero current, the Dis input should be HIGH.

Switching frequency.

The frequency of the clock oscillator is set by the timing components R_T and C_T at the RC-pin. As C_T sets the digital filter blanking time, the clock oscillator frequency is adjusted by R_T. The value of R_T is limited to 2 - 20 kohm. The frequency is approximately calculated as:

$f_s = 1 / (0.77 \cdot R_T \cdot C_T)$

Nominal component values of 12 kohm and 4 700 pF results in a clock frequency of 23.0 kHz. A lower frequency will result in higher current ripple, but may improve low level linearity. A higher clock frequency reduces current ripple, but increases the switching losses in the IC and possibly the iron losses in the motor.

Phase inputs.

A logic HIGH on a Phase input gives a current flowing from pin M_A into pin M_B. A logic LOW gives a current flow in the opposite direction. A time delay prevents cross conduction in the H-bridge when changing the Phase input.

Dis (Disable) inputs.

A logic HIGH on the Dis inputs will turn off all four transistors of the output H-bridge, which results in a rapidly decreasing output current to zero.

V_R (Reference) inputs.

The comparator inputs of PBL 3773 (V_R and C) are high impedance, low current inputs (typically -0.2 µA). This gives a great deal of flexibility in selecting a suitable voltage divider network to interface to different types of Digital-to-Analog converters. Unbuffered DACs are preferably interfaced by a high resistive divider network (typ. 100 kohm), while for buffered DACs a low resistive network (typ. 5 kohm) is recommended. A filter capacitor in conjunction with the resistor network will improve noise rejection. A typical filter time constant is 10 µs. See figure 7. In basic full and half-stepping applications, the reference voltage is easily divided from the V_{CC} supply voltage.

Interference.

Due to the switching operation of PBL 3773, noise and transients are generated and coupled into adjacent circuitry. To reduce potential interference there are a few basic rules to follow:

- Use separate ground leads for power ground (the ground connection of R_S), the ground leads of PBL 3773, and the ground of external analog and digital circuitry. The grounds should be connected together close to the GND pins of PBL 3773.
- Decouple the supply voltages close to the PBL 3773 circuit. Use a ceramic capacitor in parallel with an electrolytic type for both V_{CC} and V_{MM}. Route the power supply lines close together.
- Do not place sensitive circuits close to the driver. Avoid physical current loops, and place the driver close to both the motor and the power supply connector. The motor leads could preferably be twisted or shielded.

Motor selection.

The PBL 3773 is designed for two-phase bipolar stepper motors, i.e. motors that have only one winding per phase.

The chopping principle of the PBL 3773 is based on a constant frequency and a varying duty cycle. This scheme imposes certain restrictions on motor

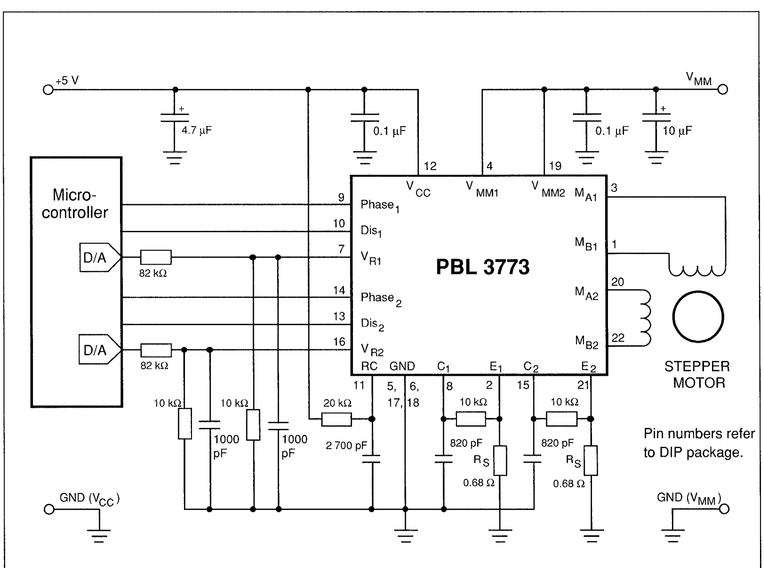


Figure 7. Microstepping system where a microcontroller including DACs provides analog current control voltages as well as digital signals to the PBL 3773.

selection. Unstable chopping can occur if the chopping duty cycle exceeds approximately 50%. See figure 3 for definitions. To avoid this, it is necessary to choose a motor with a low winding resistance and inductance, i.e. windings with a few turns.

It is not possible to use a motor that is rated for the same voltage as the actual supply voltage. Only rated current needs to be considered. Typical motors to be used together with the PBL 3773 have a voltage rating of 1 to 6 V, while the supply voltage usually ranges from 12 to 40 V.

Low inductance, especially in combination with a high supply voltage, enables high stepping rates. However, to give the same torque capability at low speed, the reduced number of turns in the winding in the low resistive, low inductive motor must be compensated by a higher current. A compromise has to be made. Choose a motor with the lowest possible winding resistance and inductance, that still gives the required torque, and use as high supply voltage as possible, without exceeding the maximum recommended 40 V. Check that the chopping duty cycle does not exceed 50% at maximum current.

Heat sinking.

PBL 3773 is a power IC, packaged in a power DIP or PLCC package. The ground leads of the package (the batwing) are thermally connected to the chip. External heatsinking is achieved by soldering the ground leads onto a copper ground plane on the PCB.

Maximum continuous output current is heavily dependent on the heatsinking and ambient temperature. Consult figures 8, 9 and 14 to determine the necessary heatsink, or to find the maximum output current under varying conditions.

A copper area of 20 cm² (approx. 1.8" x 1.8"), copper foil thickness 35 µm on a 1.6 mm epoxy PCB, permits the circuit to operate at 2 x 450 mA output current, at ambient temperatures up to 85°C.

Thermal shutdown.

The circuit is equipped with a thermal shutdown function that turns the outputs off at a chip (junction) temperature above 160°C. Normal operation is resumed when the temperature has decreased about 20°C.

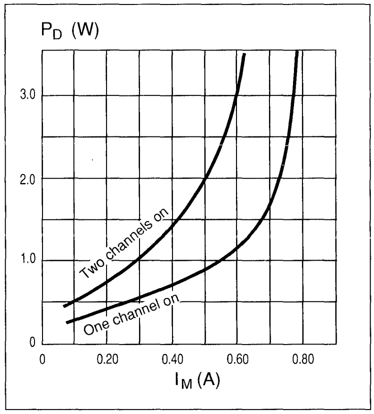


Figure 8. Typical power dissipation vs. motor current. T_a = 25°C.

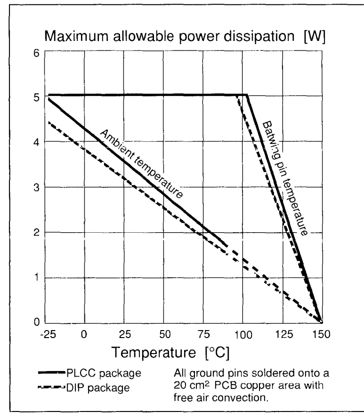


Figure 9. Maximum allowable power dissipation.

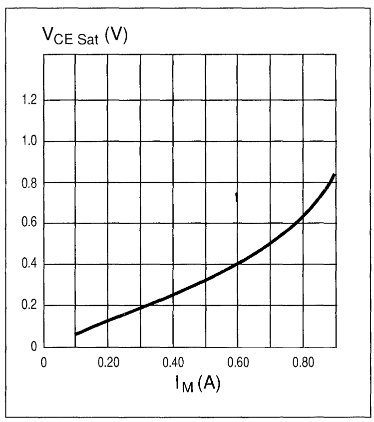


Figure 10. Typical lower transistor saturation voltage vs. output current.

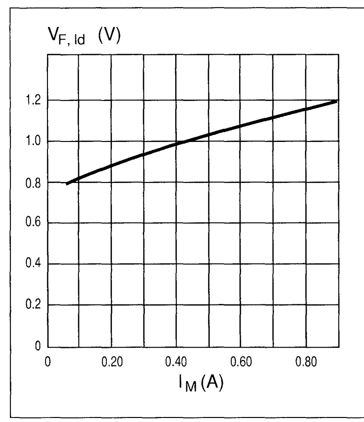


Figure 11. Typical lower diode voltage drop vs. recirculating current.

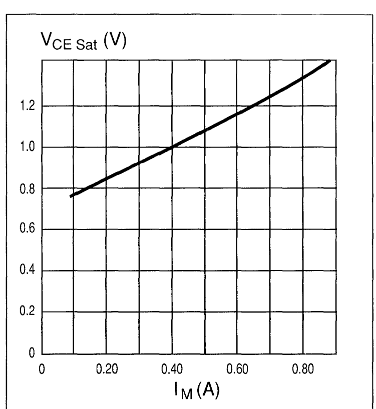


Figure 12. Typical upper transistor saturation voltage vs. output current.

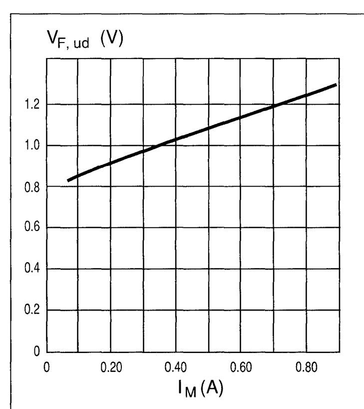


Figure 13. Typical upper diode voltage drop vs. recirculating current.

Programming.

Figure 15 shows the different input and output sequences for full-step, half-step and modified halfstep operations.

Full-step mode. Both windings are energized at all the time with the same current, $I_{M1} = I_{M2}$. To make the motor take one step, the current direction (and the magnetic field direction) in one phase is reversed. The next step is then taken when the other phase current reverses. The current changes go through a sequence of four different states which equal four full steps until the initial state is reached again.

Half-step mode. In the half-step mode, the current in one winding is brought to zero before a complete current reversal is made. The motor will then have taken two half steps equalling one full step in rotary movement. The cycle is repeated, but on the other phase. A total of eight states are sequenced until the initial state is reached again.

Half-step mode can overcome potential resonance problems. Resonances appear as a sudden loss of torque at one or more distinct stepping rates and must be avoided so as not to loose control of the motor´s shaft position.

One disadvantage with the half-step mode is the reduced torque in the half step positions, in which current flows through one winding only. The torque in this position is approximately 70 % of the full step position torque.

Modified half-step mode. The torque variations in half step mode will be eliminated if the current is increased about 1.4 times in the halfstep position. A constant torque will further reduce resonances and mechanical noise, resulting in better performance, life expectancy and reliability of the mechanical system.

Modifying the current levels must be done by bringing the reference voltage up (or down) from its nominal value correspondingly. This can be done by using DACs or simple resistor divider networks. The PBL 3773 is designed to handle about 1.4 times higher current in one channel on mode, for example 2 x 500 mA in the full-step position, and 1 x 700 mA in the half-step position.

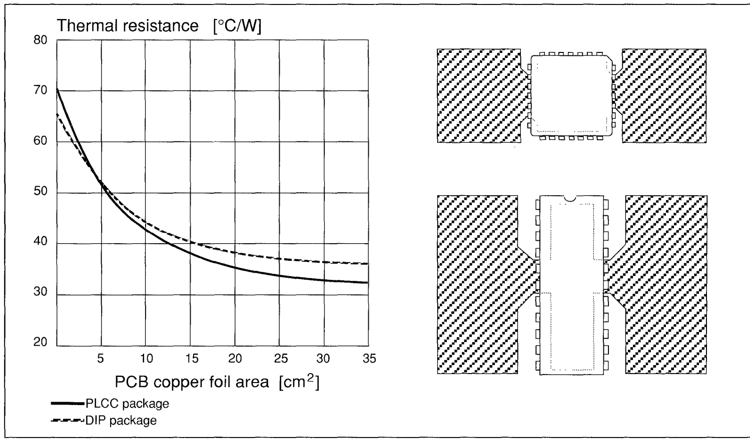


Figure 14. Typical thermal resistance vs. PC Board copper area and suggested layout.

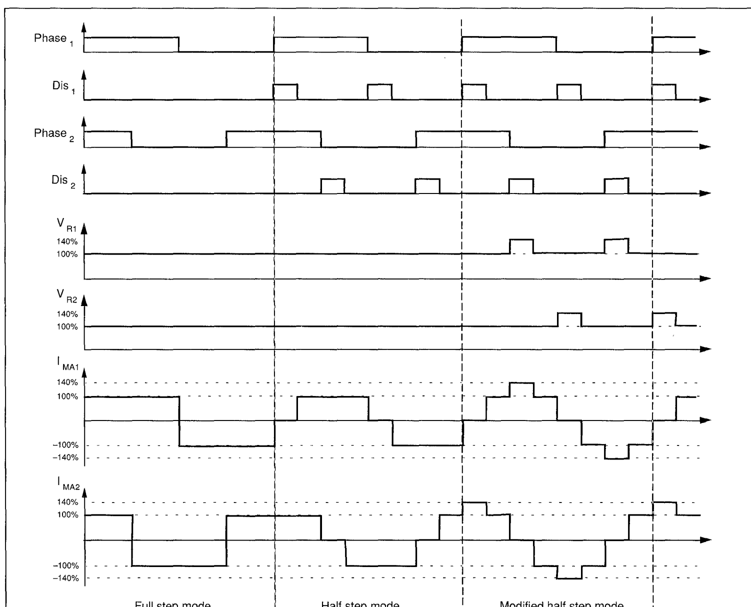


Figure 15. Stepping modes.

ERICSSON

Ericsson Components AB
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Telephone: (08) 757 50 00

Ordering Information

Package	Temp. range	Part No.
Plastic DIP	-40 to +85°C	PBL3773N
PLCC	-40 to +85°C	PBL3773QN

PBL 3774
Dual Stepper Motor Driver

Description

The PBL 3774 is a switch-mode (chopper), constant-current driver IC with two channels, one for each winding of a two-phase stepper motor. The circuit is similar to Ericsson´s PBL 3771 and PBL 3772. While all Dual stepper motor drivers are optimized for microstepping applications, the PBL 3774 is equipped with a TTL level compatible Disable input to simplify half-stepping operation.

The circuit is well suited for microstepping applications together with the matching dual DAC (Digital-to-Analog Converter) PBM 3960. A complete driver system consists of these two ICs, a few passive components and a microprocessor for generation of the proper control and data codes required for microstepping.

In full/halfstepping applications, Ericsson Compnent's PBL 3517 can be used as a phase generator (translator) to derive the necessary signals for the PBL 3774.

The PBL 3774 contains a clock oscillator, which is common for both driver channels, a set of comparators and flip-flops implementing the switching control, and two output H-bridges.

Voltage supply requirements are +5 V for logic and +10 to +45 V for the motor.

The close match between the two driver channels guarantees consistent output current ratios and motor positioning accuracy.

Key Features

- Dual chopper driver in a single package.
- -40° C to +85° C operation.
- 1. 0 A continuous output current per channel.
- Low power dissipation, 2.6 W at 2 x 750 mA output current.
- Close matching between channels for high microstepping accuracy.
- Specially matched to the Dual DAC PBM 3960.
- Plastic 22-pin batwing DIP package or 28-pin power PLCC package with lead-frame for heatsinking through PC board copper.

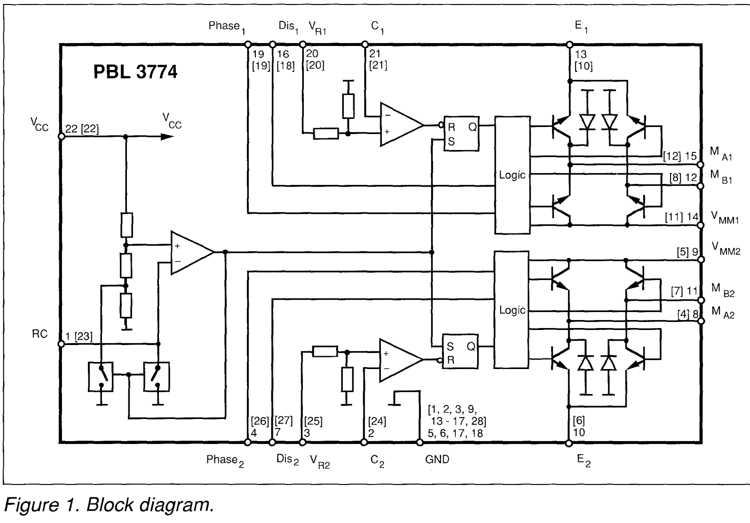
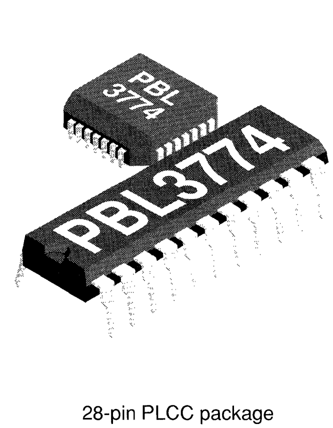


Figure 1. Block diagram.



28-pin PLCC package
22-pin plastic DIP package

Maximum Ratings

Parameter	Pin no. *	Symbol	Min	Max	Unit
Voltage					
Logic supply	22, [22]	V_{CC}	0	7	V
Motor supply	9, 14, [5, 11]	V_{MM}	0	45	V
Logic inputs	4, 7, 16, 19, [18, 19, 26, 27]	V_I	-0.3	6	V
Comparator inputs	2, 21, [21, 24]	V_C	-0.3	V_{CC}	V
Reference inputs	3, 20, [20, 25]	V_R	-0.3	7.5	V
Current					
Motor output current	8, 11, 12, 15, [4, 7, 8, 12]	I_M	-1200	+1200	mA
Logic inputs	4, 7, 16, 19, [18, 19, 26, 27]	I_I	-10		mA
Analog inputs	2, 3, 20, 21, [20, 21, 24, 25]	I_A	-10		mA
Temperature					
Junction temperature		T_J		+150	°C
Storage temperature		T_S	-55	+150	°C
Power Dissipation (Package Data)					
Power dissipation at T_{BW} = +25°C, DIP and PLCC package		P_D		5	W
Power dissipation at T_{BW} = +125°C, DIP package		P_D		2.2	W
Power dissipation at T_{BW} = +125°C, PLCC package		P_D		2.6	W

* Pin numbers in brackets refer to PLCC package.

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Logic supply voltage	V_{CC}	4.75	5	5.25	V
Motor supply voltage	V_{MM}	10		40	V
Motor output current	I_M	-1000		+1000	mA
Operating ambient temperature	T_A	- 40		+85	°C
Rise and fall time, logic inputs	t_r, t_f			2	µs
Oscillator timing resistor	R_T	2	15	20	kohm

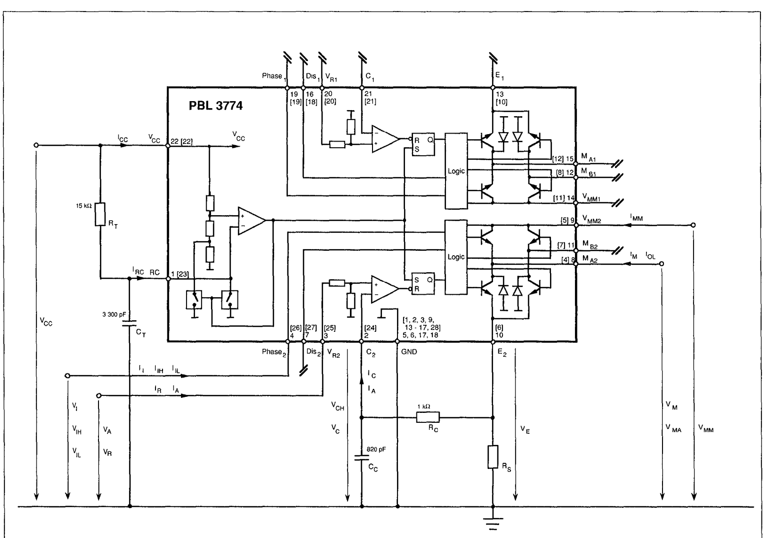


Figure 2. Definition of symbols.

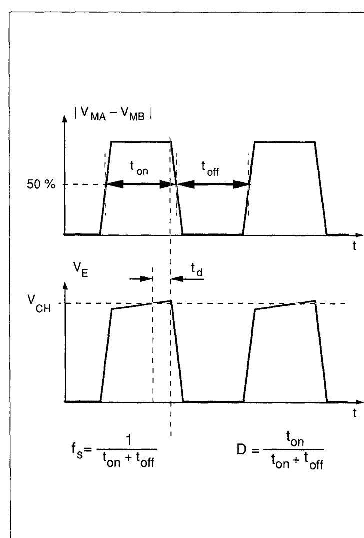


Figure 3. Definition of terms.

Electrical Characteristics

Electrical characteristics over recommended operating conditions unless otherwise noted, - 40°C ≤ T_J ≤ +125°C.

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
General							
Supply current	I_{CC}	2	Note 4.		60	75	mA
Total power dissipation	P_D		V_{MM} = 12 V, I_{M1} = I_{M2} = 750 mA. Notes 2, 3, 4.		2.6	2.9	W
Total power dissipation	P_D		V_{MM} = 12 V, I_{M1} = 1000 mA, I_{M2} = 0 mA. Notes 2, 3, 4.		2.6	2.9	W
Thermal shutdown junction temperature					160		°C
Turn-off delay	t_d	3	T_A = +25°C, dV_C/dt ≥ 50 mV/µs. I_M = 100 mA. Note 3.		1.4	2.0	µs
Logic Inputs							
Logic HIGH input voltage	V_{IH}	2		2.0			V
Logic LOW input voltage	V_{IL}	2				0.8	V
Logic HIGH input current	I_{IH}	2	V_I = 2.4 V			20	µA
Logic LOW input current	I_{IL}	2	V_I = 0.4 V	-0.4			mA
Comparator Inputs							
Threshold voltage	V_{CH}	2	R_C = 1 kohm, V_R = 2.50 V	430	450	470	mV
| V_{CH1} - V_{CH2} | mismatch	$V_{CH,diff}$	2	R_C = 1 kohm		1		mV
Input current	I_C	2		-10		1	µA
Reference Inputs							
Input resistance	R_R	2	T_A = +25°C		5		kohm
Input current	I_R	2	V_R = 2.5 V		0.5	1.0	mA
Motor Outputs							
Lower transistor saturation voltage		10	I_M = 750 mA		0.6	0.9	V
Lower transistor leakage current		2	V_{MM} = 41 V, V_E = V_R = 0 V, V_C = V_{CC}			700	µA
Lower diode forward voltage drop		11	I_M = 750 mA		1.2	1.5	V
Upper transistor saturation voltage		12	I_M = 750 mA.		1.1	1.4	V
Upper transistor leakage current		2	V_{MM} = 41 V, V_E = V_R = 0 V, V_C = V_{CC}			700	µA
Chopper Oscillator							
Chopping frequency	f_s	3	C_T = 3300 pF, R_T = 15 kohm	25.0	26.5	28.0	kHz

Thermal Characteristics

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
Thermal resistance	Rth_{J-BW}		DIP package.		11		°C/W
	Rth_{J-A}	13	DIP package. Note 2.		40		°C/W
	Rth_{J-BW}		PLCC package.		9		°C/W
	Rth_{J-A}	13	PLCC package. Note 2.		35		°C/W

Notes

1. All voltages are with respect to ground. Currents are positive into, negative out of specified terminal.
2. All ground pins soldered onto a 20 cm^2 PCB copper area with free air convection, T_A = +25°C.
3. Not covered by final test program.
4. Switching duty cycle D = 30%, f_s = 26.5 kHz.

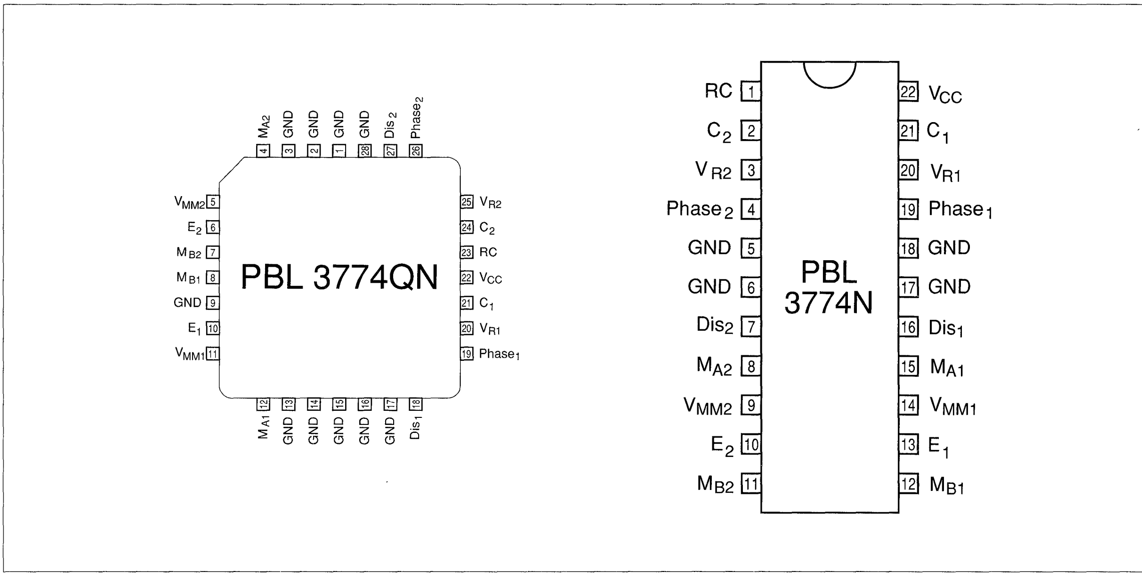


Figure 4. Pin configuration.

Pin Description

PLCC	DIP	Symbol	Description
[1-3, 9, 13-17 28]	5, 6 17, 18	GND	Ground and negative supply. Note: these pins are used thermally for heat-sinking. Make sure that all ground pins are soldered onto a suitably large copper ground plane for efficient heat sinking.
[4]	8	M_{A2}	Motor output A, channel 2. Motor current flows from M_{A2} to M_{B2} when $Phase_2$ is HIGH.
[5]	9	V_{MM2}	Motor supply voltage, channel 2, +10 to +40 V.V_{MM1} and V_{MM2} should be connected together.
[6]	10	E_2	Common emitter, channel 2. This pin connects to a sensing resistor R_S to ground.
[7]	11	M_{B2}	Motor output B, channel 2. Motor current flows from M_{A2} to M_{B2} when $Phase_2$ is HIGH.
[8]	12	M_{B1}	Motor output B, channel 1. Motor current flows from M_{A1} to M_{B1} when $Phase_1$ is HIGH.
[10]	13	E_1	Common emitter, channel 1. This pin connects to a sensing resistor R_S to ground.
[11]	14	V_{MM1}	Motor supply voltage, channel 1, +10 to +40 V. V_{MM1} and V_{MM2} should be connected together.
[12]	15	M_{A1}	Motor output A, channel 1. Motor current flows from M_{A1} to M_{B1} when Phase is HIGH.
[18]	16	Dis_1	Disable input (TTL level compatible) for channel 1. When HIGH, all four output transistors are turned off, which results in a rapidly decreasing output current to zero.
[19]	19	$Phase_1$	Controls the direction of motor current at outputs M_{A1} and M_{B1}. Motor current flows from M_{A1} to M_{B1} when $Phase_1$ is HIGH.
[20]	20	V_{R1}	Reference voltage, channel 1. Controls the threshold voltage for the comparator and hence the output current.
[21]	21	C_1	Comparator input channel 1. This input senses the instantaneous voltage across the sensing resistor, filtered by an RC network. The threshold voltage for the comparator is $V_{CH1} = 0.18 \cdot V_{R1}$ [V], i.e. 450 mV at $V_{R1} = 2.5$ V.
[22]	22	V_{CC}	Logic voltage supply, nominally +5 V.
[23]	1	RC	Clock oscillator RC pin. Connect a 15 kohm resistor to V_{CC} and a 3300 pF capacitor to ground to obtain the nominal switching frequency of 26.5 kHz.
[24]	2	C_2	Comparator input channel 2. This input senses the instantaneous voltage across the sensing resistor, filtered by an RC network. The threshold voltage for the comparator is $V_{CH2} = 0.18 \cdot V_{R2}$ [V], i.e. 450 mV at $V_{R2} = 2.5$ V.

PLCC	DIP	Symbol	Description
[25]	3	V_{R2}	Reference voltage, channel 2. Controls the threshold voltage for the comparator and hence the output current.
[26]	4	$Phase_2$	Controls the direction of motor current at outputs M_{A2} and M_{B2}. Motor current flows from M_{A2} to M_{B2} when $Phase_2$ is HIGH.
[27]	7	Dis_2	Disable input (TTL level compatible) for channel 2. When HIGH, all four output transistors are turned off, which results in a rapidly decreasing output current to zero.

Functional Description

Each channel of the PBL 3774 consists of the following sections: an output H-bridge with four transistors, capable of driving up to 1 A continuous current to the motor winding; a logic section that controls the output transistors; an S-R flip-flop; and a comparator. The clock-oscillator is common to both channels.

Constant current control is achieved by switching the output current to the windings. This is done by sensing the peak current through the winding via a resistor, R_S, effectively connected in series with the motor winding during the turn-on period. As the current increases, a voltage develops across the resistor, and is fed back to the comparator. At the predetermined level defined by the voltage at the reference input V_R, the comparator resets the flip-flop, turning off the output transistors. The current decreases until the clock oscillator triggers the flip-flop, turning on the output transistors, and the cycle is repeated.

The current paths during turn-on, turn-off and phase shift are shown in figure 5. Note that the upper recirculation diodes are connected to the circuit externally.

Applications Information

Current control

The output current to the motor is determined by the voltage at the reference input and value of sensing resistor, R_S.

Chopping frequency, winding inductance and supply voltage also affect the current, but to much less extent. The output current can be switched off completely by a HIGH input level at the Disable input (Dis1 and Dis2 for respective channels). When Disable goes HIGH, all four transistors in the output stage are switched off, and the output current rapidly drops to zero ("fast current decay" – see figure 5).

The peak motor current through the sensing resistor and the motor winding can be expressed as:

$I_{M,peak} = 0.18 \cdot (V_R / R_S)$ [A]

A 2.5 V reference voltage and a 0.47 ohm sensing resistor will produce an output current level of approximately 0.96 A.

To improve noise immunity at the V_R input, the voltage control range can be increased to 5 V if R_S is correspondingly changed (for example to 1 ohm for 0.90 A max output current).

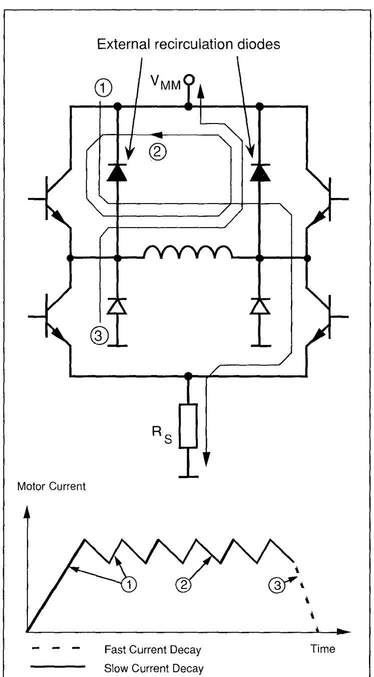


Figure 5. Output stage with current paths during turn-on, turn-off and phase shift.

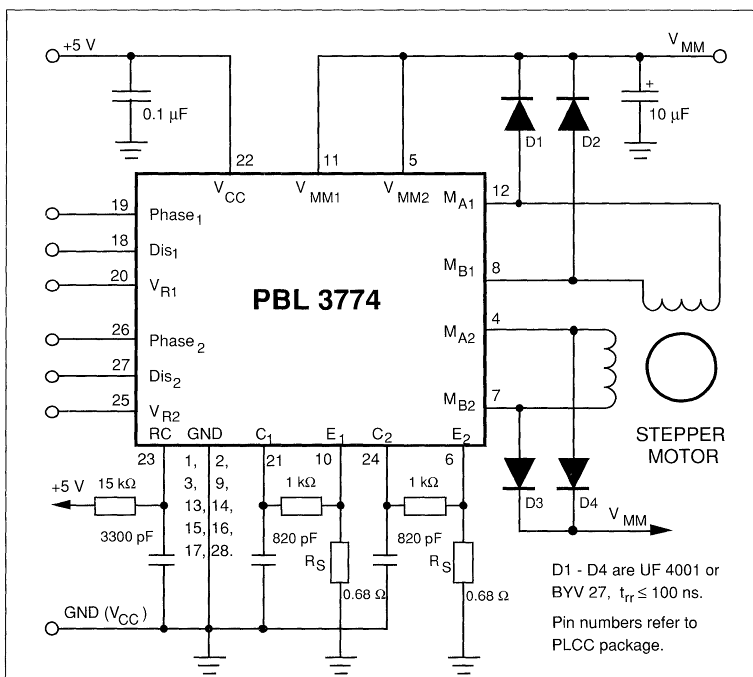


Figure 6. Typical stepper motor driver application with PBL 3774.

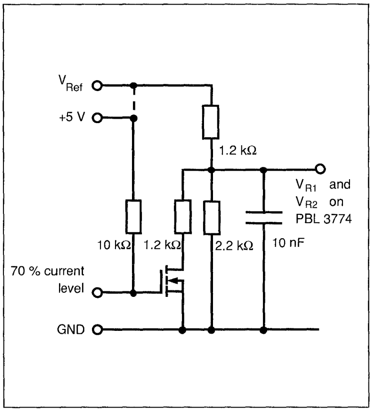


Figure 7. Reduction of reference voltage at the V_R pin of PBL 3774.

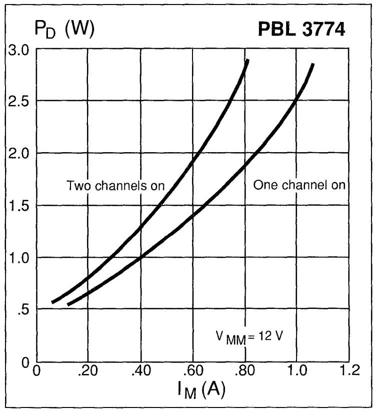


Figure 8. Power dissipation vs. motor current, T_A = 25°C.

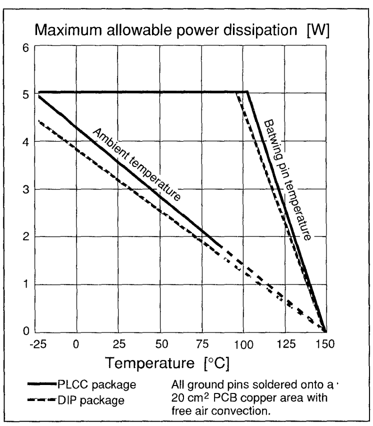


Figure 9. Maximum allowable continuous power dissipation vs. temperature.

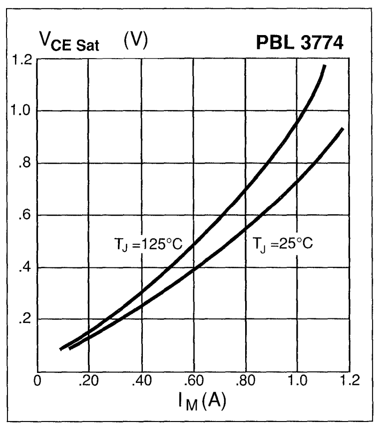


Figure 10. Typical lower transistor saturation voltage vs. output current.

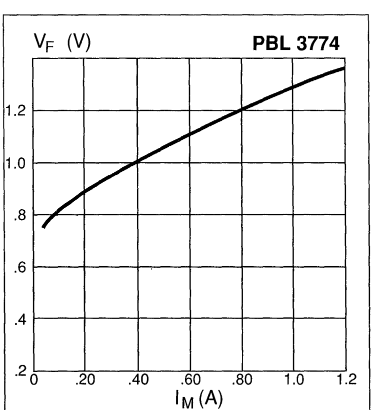


Figure 11. Typical lower diode voltage drop vs. recirculating current.

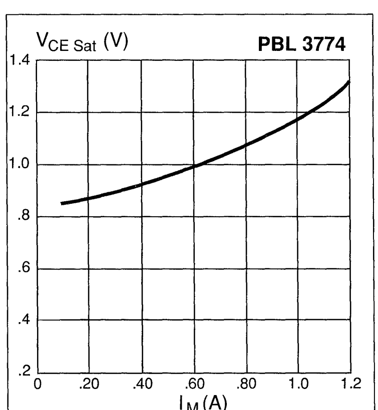


Figure 12. Typical upper transistor saturation voltage vs. output current.

External components.

For the device to function properly, four external free-wheeling diodes must be connected, as in figure 6. The diodes should be of fast type with a reverse recovery time of less than 100 ns. Commonly used types are UF4001 or BYV27.

A low pass filter in series with the comparator input prevents erroneous switching due to switching transients.The recommended filter component values, 1 kohm and 820 pF, are suitable for a wide range of motors and operational conditions.

Since the low-pass filtering action introduces a small delay of the signal to the comparator, peak voltage across the sensing resistor, and hence the peak motor current, will reach a slightly higher level than what is defined by the comparator threshold, V_{CH}, set by the reference input V_R (V_{CH} = 450 mV at V_R= 2.5 V).

The time constant of the low-pass filter may therefore be reduced to minimize the delay and optimize low-current performance. Increasing the time constant may result in unstable switching. The time constant should be adjusted by changing the C_C value.

The frequency of the clock oscillator is set by the R_T-C_T timing components at the RC pin. The recommended values result in a clock frequency (= switching frequency) of 26.5 kHz. A lower frequency will result in higher current ripple, but may improve low-current level linearity. A higher clock frequency reduces current ripple, but increases the switching losses in the IC and possibly increased iron losses in the motor. If the clock frequency needs to be changed, the C_T capacitor value should be adjusted. The recommended R_T resistor value is 15 kohm.

The sensing resistor R_S, should be selected for maximum motor current. The relationship between peak motor current, reference voltage and the value of R_S is described under Current control above. Be sure not to exceed the maximum output current which is 1.2 A peak when only one channel is activated.Or recommended output current, which is 1.0 A peak, when both channels is activated.

Motor selection.

The PBL 3774 is designed for two-phase bipolar stepper motors, i.e. motors that have only one winding per phase.

The chopping principle of the PBL 3774 is based on a constant frequency and a varying duty cycle. This scheme imposes certain restrictions on motor selection. Unstable chopping can occur if the chopping duty cycle exceeds approximately 50%. See figure 3 for definitions. To avoid this, it is necessary to choose a motor with a low winding resistance and inductance, i.e. windings with a few turns.

It is not possible to use a motor that is rated for the same voltage as the actual supply voltage. Only rated current needs to be considered. Typical motors to be used together with the PBL 3774 have a voltage rating of 1 to 6 V, while the supply voltage usually ranges from 12 to 40 V.

Low inductance, especially in combination with a high supply voltage, enables high stepping rates. However, to give the same torque capability at low speed, the reduced number of turns in the winding of the low resistive, low inductive motor must be compensated by a higher current. A compromise has to be made. Choose a motor with the lowest possible winding resistance and inductance, that still gives the required torque, and use as high supply voltage as possible, without exceeding the maximum recommended 40 V. Check that the chopping duty cycle does not exceed 50% at maximum current.

General.

Phase inputs. A logic HIGH on a Phase input gives a current flowing from pin M_A into M_B. A logic LOW gives a current flow in the opposite direction. A time delay prevents cross conduction in the H-bridge when changing the Phase input.

Heat sinking. Soldering the batwing ground leads onto a copper ground plane of 20 cm² (approx. 1.8" x 1.8"), copper foil thickness 35 µm, permits the circuit to operate with 650 mA output current, both channels driving, at ambient temperatures up to 70°C. Consult figures 8, 9 and 13 in order to determine the necessary copper ground plane area for heat sinking at higher current levels.

Thermal shutdown. The circuit is equipped with a thermal shutdown function that turns the output off at temperatures above 160°C. Normal operation is resumed when the temperature has decreased about 20 °C.

Programming.

Figure 14 shows the different input and output sequences for full-step, half-step and modified halfstep operations.

Full-step mode. Both windings are energized at all the time with the same current, $I_{M1} = I_{M2}$. To make the motor take one step, the current direction (and the magnetic field direction) in one phase is reversed. The next step is then taken when the other phase current reverses. The current changes go through a sequence of four different states which equal four full steps until the initial state is reached again.

Half-step mode. In the half-step mode, the current in one winding is brought to zero before a complete current reversal is made. The motor will then have taken two half steps equalling one full step in rotary movement. The cycle is repeated, but on the other phase. A total of eight states are sequenced until the initial state is reached again.

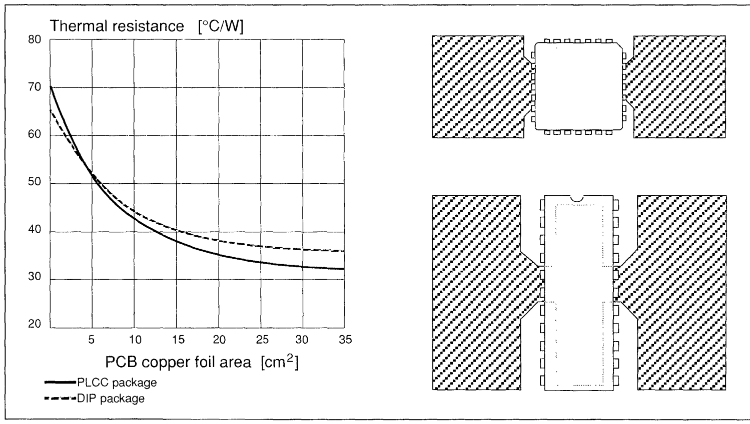


Figure 13. Typical thermal resistance vs. PC Board copper area and suggested layout.

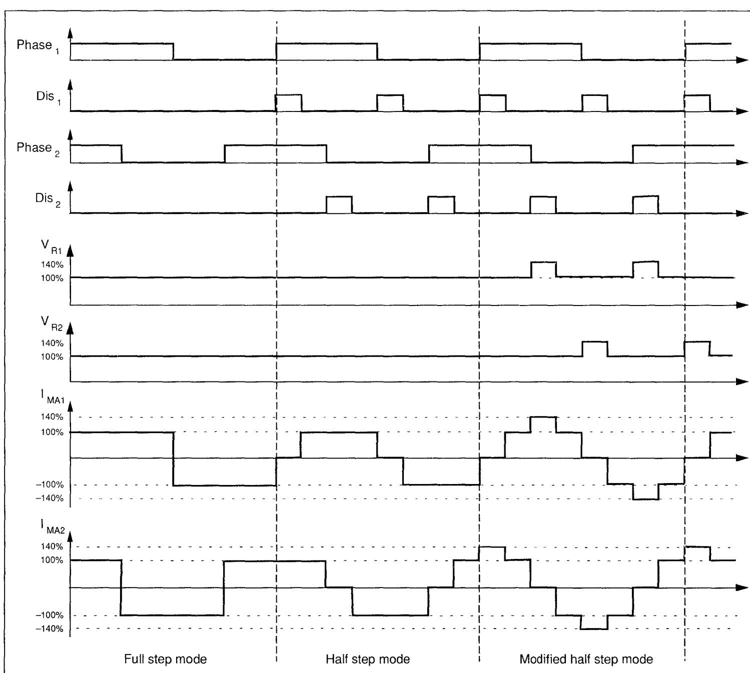


Figure 14. Stepping modes.

Half-step mode can overcome potential resonance problems. Resonances appear as a sudden loss of torque at one or more distinct stepping rates and must be avoided so as not to loose control of the motor´s shaft position.

One disadvantage with the half-step mode is the reduced torque in the half step positions, in which current flows through one winding only. The torque in this position is approximately 70 % of the full step position torque.

Modified half-step mode. The torque variations in half step mode will be eliminated if the current is increased about 1.4 times in the halfstep position. A constant torque will further reduce resonances and mechanical noise, resulting in better performance, life expectancy and reliability of the mechanical system.

Modifying the current levels must be done by bringing the reference voltage up (or down) from its nominal value correspondingly. This can be done by using DACs or simple resistor divider networks, as shown in figure 7.

The PBL 3774 is designed to handle about 1.4 times higher current in one channel on mode, for example 700 mA per winding in the full-step position, and 1000 mA in the half-step position.

Ordering Information

Package	Temp. range	Part No.
Plastic DIP	- 40 to 85°C	PBL3774N
PLCC	- 40 to 85°C	PBL3774QN

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May 1991

PBL 3775
Dual Stepper Motor Driver (Preliminary Data)

Description

The PBL 3775 is a switch-mode (chopper), constant-current driver IC with two channels, one for each winding of a two-phase stepper motor. The circuit is similar to Ericsson´s PBL 3773 . While several of Ericsson´s Dual stepper motor drivers are optimized for micro-stepping applications, PBL 3775 is equipped with a Disable input to simplify half-stepping operation.

The circuit is well suited for microstepping applications in conjunction with the matching Dual DAC (Digital-to-ANalog Converter) PBM 3960. A complete driver system consists of these two ICs,a few passive components and a microprocessor for generation of the control and data codes required for microstepping.

The PBL 3775 contains a clock oscillator, which is common for both driver channels, a set of comparators and flip-flops implementing the switching control, and two output H-bridges, including recirculation diodes.

Voltage supply requirements are +5 V for logic and +10 to +45 V for the motor.

The close match between the two driver channels guarantees consistent output current ratios and motor positioning accuracy.

Key Features

- Dual chopper driver in a single package.
- –40°C to +85°C operation.
- 750 mA continuous output current per channel.
- Low power dissipation, 2.0 W at 2 x 500 mA output current
- Close matching between channels for high microstepping accuracy
- Specially matched to the Dual DAC PBM 3960.
- Digital filter on chip eliminates external filtering components.
- Plastic 22-pin batwing DIP package or 28-pin power PLCC with lead-frame for heat-sinking through PC board copper.

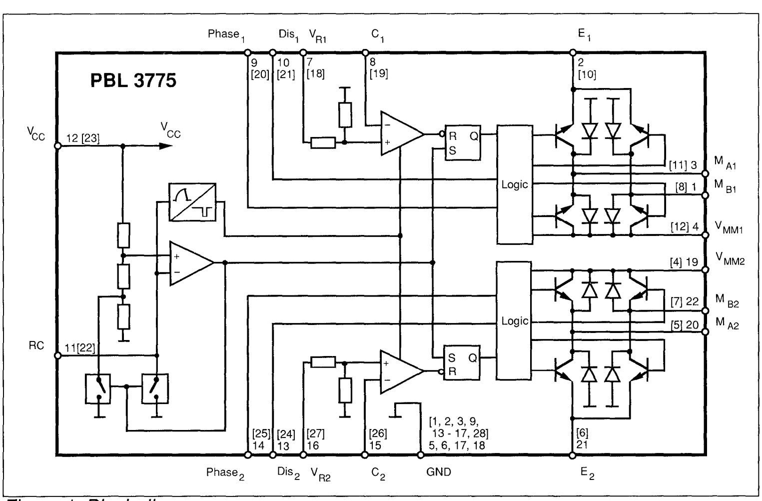
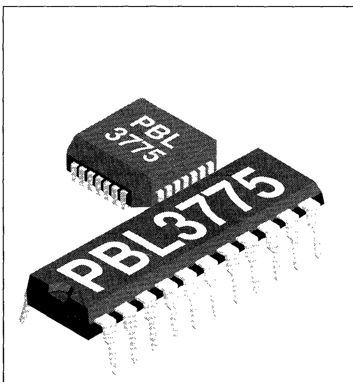


Figure 1. Block diagram.



28-pin PLCC package
22-pin plastic DIP package

Maximum Ratings

Parameter	Pin no.*	Symbol	Min	Max	Unit
Voltage					
Logic supply	12 [23]	V_{CC}	0	7	V
Motor supply	4, 19 [4, 12]	V_{MM}	0	45	V
Logic inputs	9, 10, 13, 14 [20, 21, 24, 25]	V_I	-0.3	6	V
Analog inputs	7, 8, 15, 16 [18, 19, 26, 27]	V_A	-0.3	V_{CC}	V
Current					
Motor output current	1, 3, 20, 22 [5, 7, 8, 11]	I_M	-850	+850	mA
Logic inputs	9, 10, 13, 14 [20, 21, 24, 25]	I_I	-10		mA
Analog inputs	7, 8, 15, 16 [18, 19, 26, 27]	I_A	-10		mA
Temperature					
Junction temperature		T_J		+150	°C
Storage temperature		T_S	-55	+150	°C
Power Dissipation (Package Data)					
Power dissipation at T_{BW} = +25°C, DIP and PLCC package		P_D		5	W
Power dissipation at T_{BW} = +125°C, DIP package		P_D		2.2	W
Power dissipation at T_{BW} = +125°C, PLCC package		P_D		2.6	W

* Pin numbers in brackets refer to PLCC package.

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Logic supply voltage	V_{CC}	4.75	5	5.25	V
Motor supply voltage	V_{MM}	10		40	V
Output emitter voltage	V_E			1.0	V
Motor output current	I_M	-750		+750	mA
Operating ambient temperature	T_A	-20		+85	°C
Rise and fall time logic inputs	t_r, t_f			2	µs
Oscillator timing resistor	R_T	2	12	20	kohm

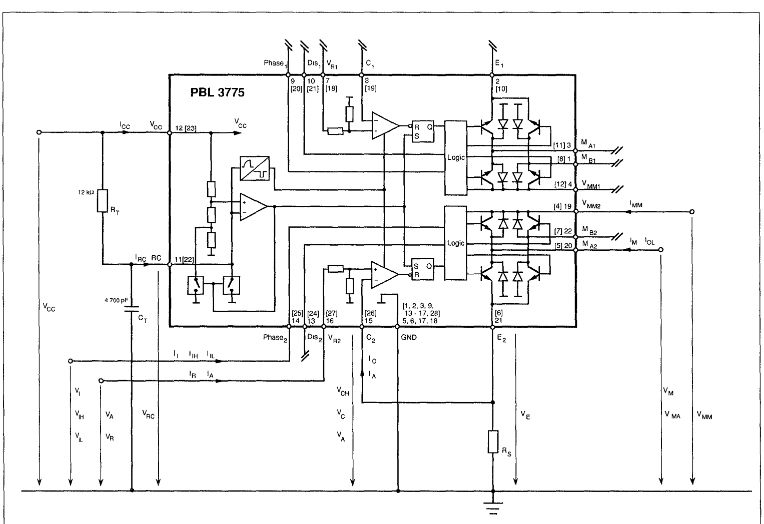


Figure 2. Definition of symbols.

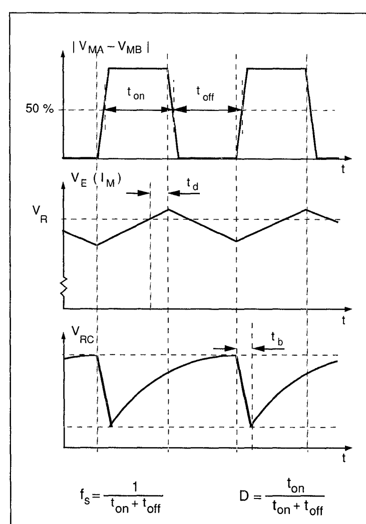


Figure 3. Definition of terms.

Electrical Characteristics

Electrical characteristics over recommended operating conditions, unless otherwise noted. -20°C ≤ T_j ≤ +125°C.

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
General							
Supply current	I_{CC}	2	Note 4.		55	70	mA
Supply current	I_{CC}	2	Dis_1= Dis_2= HIGH.		7	10	mA
Total power dissipation	P_D	8	V_{MM}= 24 V, I_{M1}= I_{M2}= 500 mA. Notes 2, 3, 4.		2.0	2.3	W
Total power dissipation	P_D	8	V_{MM}= 24 V, I_{M1}= 700 mA, I_{M2}= 0 mA. Notes 2, 3, 4.		1.7	2.0	W
Thermal shutdown junction temperature					160		°C
Turn-off delay	t_d	3	T_A = +25°C, dV_C/dt ≥ 50 mV/µs, I_M = 100 mA. Note 3.		1.1	2.0	µs
Logic Inputs							
Logic HIGH input voltage	V_{IH}	2		2.0			V
Logic LOW input voltage	V_{IL}	2				0.6	V
Logic HIGH input current	I_{IH}	2	V_I = 2.4 V			20	µA
Logic LOW input current	I_{IL}	2	V_I = 0.4 V	-0.2	-0.1		mA
Analog Inputs							
Input current	I_A	2	V_r= 5 V		500		µA
$\|V_{C1}—V_{C2}\|$ mismatch	V_{Cdiff}	2			1		mV
Motor Outputs							
Lower transistor saturation voltage		10	I_M = 500 mA		0.4	0.8	V
Lower transistor leakage current		2	V_{MM}=41 V,T_A = +25°C. Dis_1= Dis_2= HIGH.			100	µA
Lower diode forward voltage drop		11	I_M = 500 mA		1.1	1.3	V
Upper transistor saturation voltage		12	I_M = 500 mA.		1.1	1.4	V
Upper diode forward voltage drop		13	I_M = 500 mA.		1.1	1.4	V
Upper transistor leakage current		2	V_{MM}=41 V,T_A = +25°C. Dis_1= Dis_2= HIGH.			100	µA
Chopper Oscillator							
Chopping frequency	f_s	3	C_T = 4 700 pF, R_T = 12 kohm	21.5	23.0	24.5	kHz
Digital filter blanking time	t_b	3	C_T = 4 700 pF. Note 3.		1.0		µs

Thermal Characteristics

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
Thermal resistance	Rth_{J-BW}		DIP package.		11		°C/W
	Rth_{J-A}	14	DIP package. Note 2.		40		°C/W
	Rth_{J-BW}		PLCC package.		9		°C/W
	Rth_{J-A}	14	PLCC package. Note 2.		35		°C/W

Notes

1. All voltages are with respect to ground. Currents are positive into, negative out of specified terminal.
2. All ground pins soldered onto a 20 cm^2 PCB copper area with free air convection, T_A = +25°C.
3. Not covered by final test program.
4. Switching duty cycle D = 30%, f_s = 23.0 kHz.

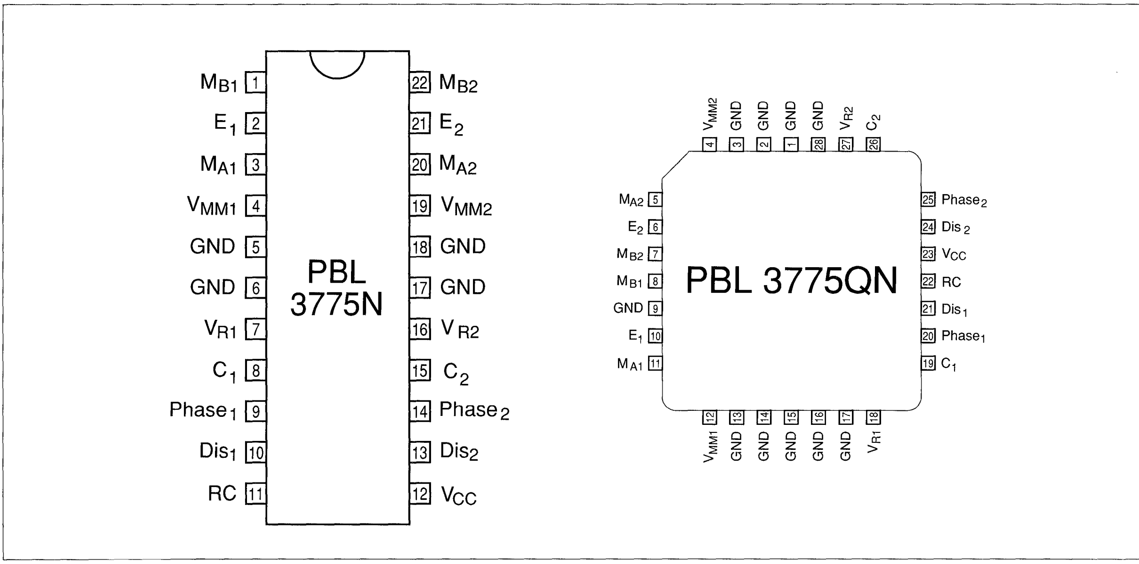


Figure 4. Pin configuration.

Pin Description

DIP	PLCC	Symbol	Description
1	[8]	M_{B1}	Motor output B, channel 1. Motor current flows from M_{A1} to M_{B1} when Phase$_1$ is HIGH.
2	[10]	E_1	Common emitter, channel 1. This pin connects to a sensing resistor R_S to ground.
3	[11]	M_{A1}	Motor output A, channel 1. Motor current flows from M_{A1} to M_{B1} when Phase is HIGH.
4	[12]	V_{MM1}	Motor supply voltage, channel 1, +10 to +40 V. V_{MM1} and V_{MM2} should be connected together.
5, 6, 17, 18	[1-3, 9, 13-17, 28]	GND	Ground and negative supply. Note: these pins are used thermally for heat-sinking. Make sure that all ground pins are soldered onto a suitably large copper ground plane for efficient heat sinking.
7	[18]	V_{R1}	Reference voltage, channel 1. Controls the comparator threshold voltage and hence the output current.
8	[19]	C_1	Comparator input channel 1. This input senses the instantaneous voltage across the sensing resistor, filtered by the internal digital filter or an optionalexternal RC network.
9	[20]	Phase$_1$	Controls the direction of motor current at outputs M_{A1} and M_{B1}. Motor current flows from M_{A1} to M_{B1} when Phase$_1$ is HIGH.
10	[21]	Dis$_1$	Disable input for channel 1. When HIGH, all four output transistors are turned off, which results in a rapidly decreasing output current to zero.
11	[22]	RC	Clock oscillator RC pin. Connect a 12 kohm resistor to V_{CC} and a 4 700 pF capacitor to ground to obtain the nominal switching frequency of 23.0 kHz and a digital filter blanking time of 1.8 µs.
12	[23]	V_{CC}	Logic voltage supply, nominally +5 V.
13	[24]	Dis$_2$	Disable input for channel 2. When HIGH, all four output transistors are turned off, which results in a rapidly decreasing output current to zero.
14	[25]	Phase$_2$	Controls the direction of motor current at outputs M_{A2} and M_{B2}. Motor current flows from M_{A2} to M_{B2} when Phase$_2$ is HIGH.
15	[26]	C_2	Comparator input channel 2. This input senses the instantaneous voltage across the sensing resistor, filtered by the internal digital filter or an optional external RC network.
16	[27]	V_{R2}	Reference voltage, channel 2. Controls the comparator threshold voltage and hence the output current.
19	[4]	V_{MM2}	Motor supply voltage, channel 2, +10 to +40 V.V_{MM1} and V_{MM2} should be connected together.
20	[5]	M_{A2}	Motor output A, channel 2. Motor current flows from M_{A2} to M_{B2} when Phase$_2$ is HIGH.
21	[6]	E_2	Common emitter, channel 2. This pin connects to a sensing resistor R_S to ground.
22	[7]	M_{B2}	Motor output B, channel 2. Motor current flows from M_{A2} to M_{B2} when Phase$_2$ is HIGH.

Functional Description

Each channel of the PBL 3775 consists of the following sections: an output H-bridge with four transistors and four recirculation diodes, capable of driving up to 750 mA continuous current to the motor winding, a logic section that controls the output transistors, an S-R flip-flop, and a comparator. The clock-oscillator is common to both channels.

Constant current control is achieved by switching the output current to the windings. This is done by sensing the peak current through the winding via a current-sensing resistor R_S, effectively connected in series with the motor winding. As the current increases, a voltage develops across the sensing resistor, which is fed back to the comparator. At the predetermined level, defined by the voltage at the reference input V_R, the comparator resets the flip-flop, which turns off the upper output transistor. The turn-off of one channel is independent of the other channel. The current decreases until the clock oscillator triggers the flip-flops of both channels simultaneously, which turns on the output transistors again, and the cycle is repeated.

To prevent erroneous switching due to switching transients at turn-on, the PBL 3775 includes a digital filter. The clock oscillator provides a blanking pulse which is used for digital filtering of the voltage transient across the current sensing resistor during turn-on.

The current paths during turn-on, turn-off and phase shift are shown in figure 5.

Applications Information

Current control.

The regulated output current level to the motor winding is determined by the voltage at the reference input and the value of the sensing resistor, R_S. The peak current through the sensing resistor (and the motor winding) can be expressed as:

$I_{M,peak} = 0.1 \cdot V_R / R_S$ [A]

With a recommended value of 0.5 ohm for the sensing resistor R_S, a 2.5 V reference voltage will produce an output current of approximately 0.5 A. R_S should be selected for maximum motor current. Be shure not to exceed the absolute maximum output current which is 850 mA. Chopping frequency, winding inductance and supply voltage also affect the current, but to much less extent.

For accurate current regulation, the sensing resistor should be a 0.5 - 1.0 W precision resistor, i. e. less than 1% tolerance and low temperature coefficient.

Current sense filtering.

At turn-on a current spike occurs, due to the recovery of the recirculation diodes and the capacitance of the motor winding. To prevent this spike from reseting the flip-flops through the current sensing comparators, the clock oscillator generates a blanking pulse at turn-on. The blanking pulse pulse disables the comparators for a short time. Thereby any voltage transient across the sensing resistor will be ignored during the blanking time.

Choose the blanking pulse time to be longer than the duration of the switching transients by selecting a proper C_T value.

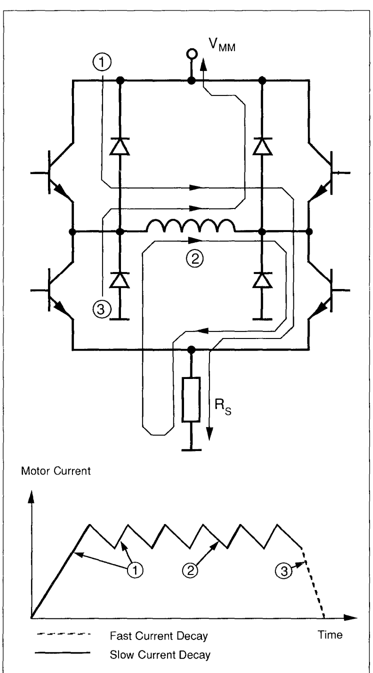


Figure 5. Output stage with current paths during turn-on, turn-off and phase shift.

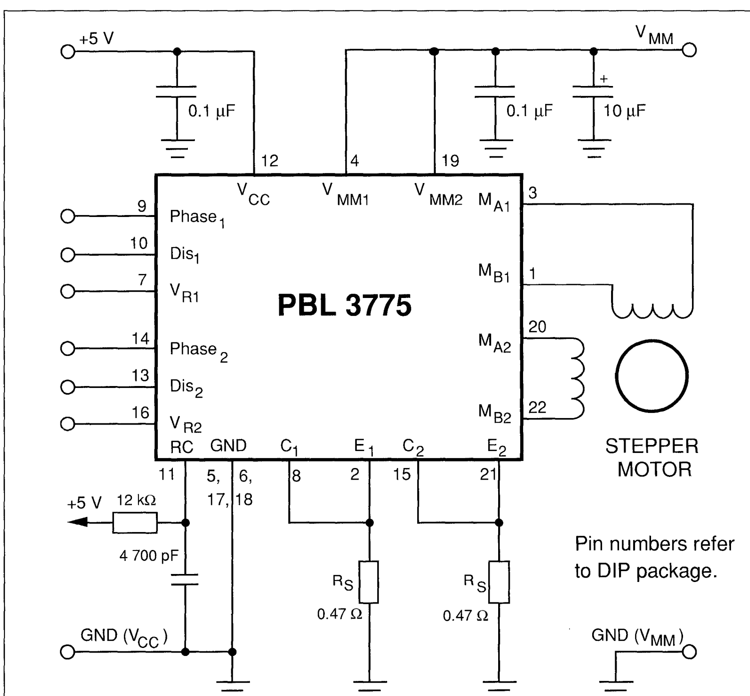


Figure 6. Typical stepper motor driver application with PBL 3775.

The time is calculated as:

$t_b = 380 \cdot C_T$ [s]

As the C_T value may vary from approximately 2 200 pF to 33 000 pF, a blanking time ranging from 0.8 µs to 13 µs is possible. Nominal value is 4 700 pF, which gives a blanking time of 1.8 µs.

As the filtering action introduces a small delay, the peak value across the sensing resistor, and hence the peak motor current, will reach a slightly higher level than what is defined by the reference voltage. The filtering delay also limits the minimum possible output current. As the output will be on for a short time each cycle, equal to the digital filtering blanking time plus additional internal delays, an amount of current will flow through the winding. Typically this current is 1-10 % of the maximum output current set by R_S.

When optimizing low current performance, the filtering may be done by adding an external low pass filter in series with the comparator C input, see figure 7. In this case the digital blanking time should be as short as possible. The recommended filter component values are 10 kohm and 820 p. Lowering the switching frequency also helps reducing the minimum output current.

To create an absolute zero current, the Dis input should be HIGH.

Switching frequency.

The frequency of the clock oscillator is set by the timing components R_T and C_T at the RC-pin. As C_T sets the digital filter blanking time, the clock oscillator frequency is adjusted by R_T. The value of R_T is limited to 2 - 20 kohm. The frequency is approximately calculated as:

$f_s = 1 / (0.77 \cdot R_T \cdot C_T)$

Nominal component values of 12 kohm and 4 700 pF results in a clock frequency of 23.0 kHz. A lower frequency will result in higher current ripple, but may improve low level linearity. A higher clock frequency reduces current ripple, but increases the switching losses in the IC and possibly the iron losses in the motor.

Phase inputs.

A logic HIGH on a Phase input gives a current flowing from pin M_A into pin M_B. A logic LOW gives a current flow in the opposite direction. A time delay prevents cross conduction in the H-bridge when changing the Phase input.

Dis (Disable) inputs.

A logic HIGH on the Dis inputs will turn off all four transistors of the output H-bridge, which results in a rapidly decreasing output current to zero.

V_R (Reference) inputs.

The Vref inputs of the PBL 3775 have a voltage divider with a ratio of 1 to 10 to reduce the external reference voltage to an adequate level. The divider consists of closely matched resistors . Nominal input reference voltage is 5 V.

Interference.

Due to the switching operation of PBL 3775, noise and transients are generated and coupled into adjacent circuitry. To reduce potential interference there are a few basic rules to follow:

- Use separate ground leads for power ground (the ground connection of R_S), the ground leads of PBL 3775, and the ground of external analog and digital circuitry. The grounds should be connected together close to the GND pins of PBL 3775.
- Decouple the supply voltages close to the PBL 3775 circuit. Use a ceramic capacitor in parallel with an electrolytic type for both V_{CC} and V_{MM}. Route the power supply lines close together.
- Do not place sensitive circuits close to the driver. Avoid physical current loops, and place the driver close to both the motor and the power supply connector. The motor leads could preferably be twisted or shielded.

Motor selection.

The PBL 3775 is designed for two-phase bipolar stepper motors, i.e. motors that have only one winding per phase.

The chopping principle of the PBL 3775 is based on a constant frequency and a varying duty cycle. This scheme imposes certain restrictions on motor selection. Unstable chopping can occur if the chopping duty cycle exceeds approximately 50%. See figure 3 for definitions. To avoid this, it is necessary to choose a motor with a low winding resistance and inductance, i.e. windings with a few turns.

It is not possible to use a motor that is rated for the same voltage as the actual supply voltage. Only rated current needs to be considered. Typical motors to be used together with the PBL 3775 have a voltage rating of 1 to 6 V, while the supply voltage usually ranges from 12 to 40 V.

Low inductance, especially in combination with a high supply voltage, enables high stepping rates. However, to

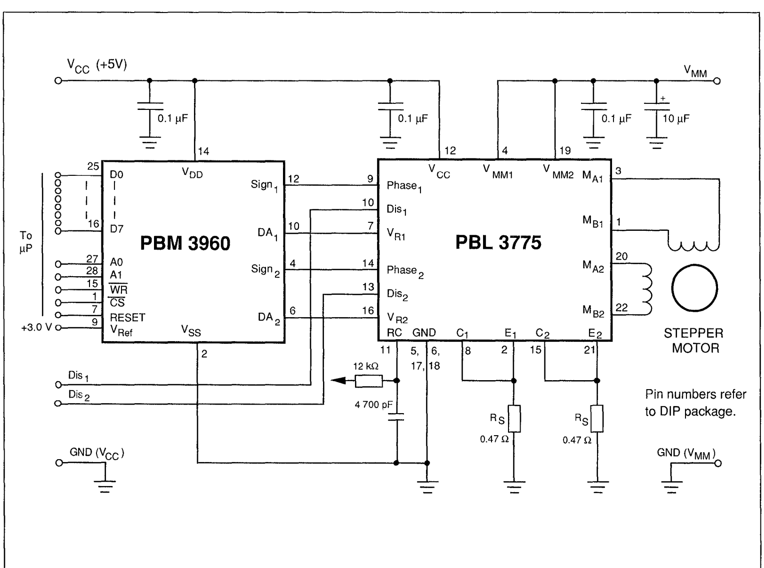


Figure 7. Microstepping system where a microcontroller including DACs provides analog current control voltages as well as digital signals to the PBL 3775.

give the same torque capability at low speed, the reduced number of turns in the winding in the low resistive, low inductive motor must be compensated by a higher current. A compromise has to be made. Choose a motor with the lowest possible winding resistance and inductance, that still gives the required torque, and use as high supply voltage as possible, without exceeding the maximum recommended 40 V. Check that the chopping duty cycle does not exceed 50% at maximum current.

Heat sinking.

PBL 3775 is a power IC, packaged in a power DIP or PLCC package. The ground leads of the package (the batwing) are thermally connected to the chip. External heatsinking is achieved by soldering the ground leads onto a copper ground plane on the PCB.

Maximum continuous output current is heavily dependent on the heatsinking and ambient temperature. Consult figures 8, 9 and 14 to determine the necessary heatsink, or to find the maximum output current under varying conditions.

A copper area of 20 cm² (approx. 1.8" x 1.8"), copper foil thickness 35 μm on a 1.6 mm epoxy PCB, permits the circuit to operate at 2 x 450 mA output current, at ambient temperatures up to 85°C.

Thermal shutdown.

The circuit is equipped with a thermal shutdown function that turns the outputs off at a chip (junction) temperature above 160°C. Normal operation is resumed when the temperature has decreased about 20°C.

Programming.

Figure 15 shows the different input and output sequences for full-step, half-step and modified halfstep operations. **Full-step mode.** Both windings are energized at all the time with the same current, $I_{M1} = I_{M2}$. To make the motor take one step, the current direction (and the magnetic field direction) in one phase is reversed. The next step is then taken when the other phase current reverses. The current changes go through a sequence of four different states which equal four full steps until the initial state is reached again.

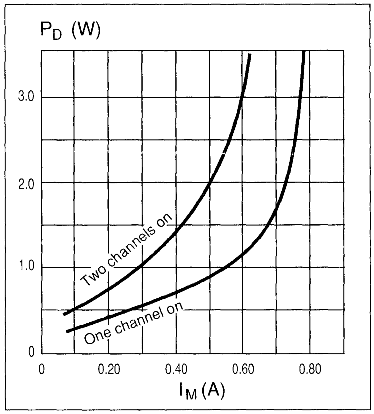


Figure 8. Power dissipation vs. motor current. T_a = 25°C.

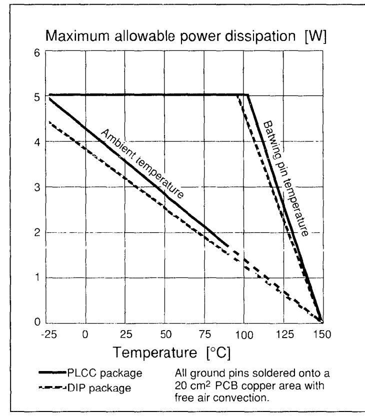


Figure 9. Maximum allowable power dissipation.

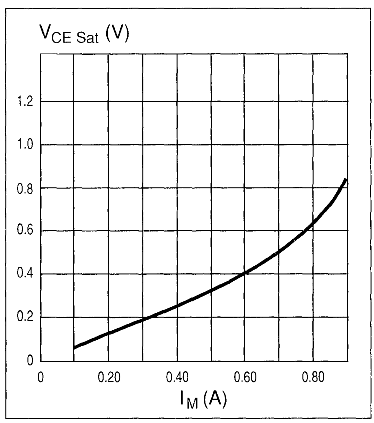


Figure 10. Typical lower transistor saturation voltage vs. output current.

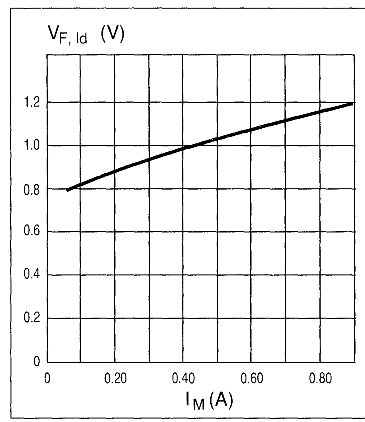


Figure 11. Typical lower diode voltage drop vs. recirculating current.

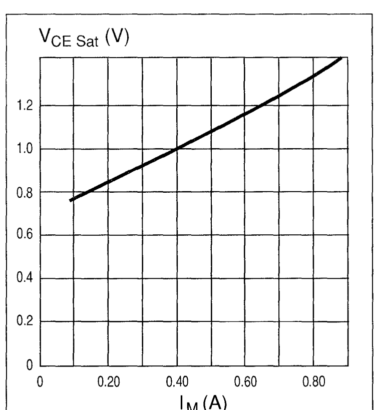


Figure 12. Typical upper transistor saturation voltage vs. output current.

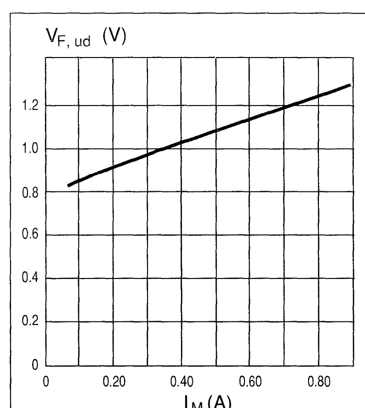


Figure 13. Typical upper diode voltage drop vs. recirculating current.

Half-step mode. In the half-step mode, the current in one winding is brought to zero before a complete current reversal is made. The motor will then have taken two half steps equalling one full step in rotary movement. The cycle is repeated, but on the other phase. A total of eight states are sequenced until the initial state is reached again.

Half-step mode can overcome potential resonance problems. Resonances appear as a sudden loss of torque at one or more distinct stepping rates and must be avoided so as not to loose control of the motor´s shaft position.

One disadvantage with the half-step mode is the reduced torque in the half step positions, in which current flows through one winding only. The torque in this position is approximately 70 % of the full step position torque.

Modified half-step mode. The torque variations in half step mode will be eliminated if the current is increased about 1.4 times in the halfstep position. A constant torque will further reduce resonances and mechanical noise, resulting in better performance, life expectancy and reliability of the mechanical system.

Modifying the current levels must be done by bringing the reference voltage up (or down) from its nominal value correspondingly. This can be done by using DACs or simple resistor divider networks. The PBL 3775 is designed to handle about 1.4 times higher current in one channel on mode, for example 2 x 500 mA in the full-step position, and 1 x 700 mA in the half-step position.

Ordering Information

Package	Temp. range	Part No.
Plastic DIP	-40 to +85°C	PBL3775N
PLCC	-40 to +85°C	PBL3775QN

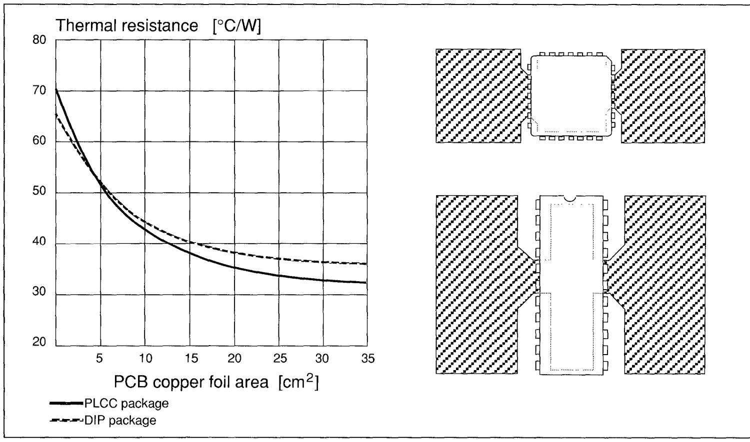


Figure 14. Typical thermal resistance vs. PC Board copper area and suggested layout.

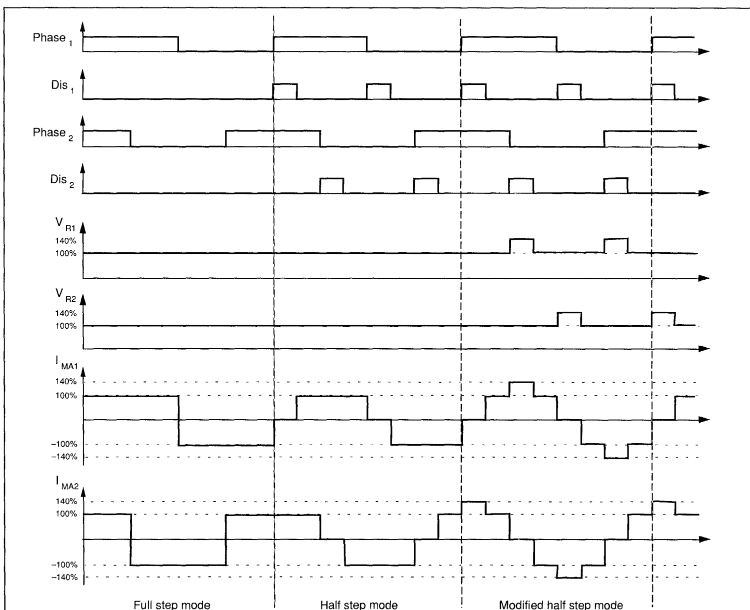


Figure 15. Stepping modes.

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September 1988

PBM 3960
Microstepping Controller/ Dual Digital-to-Analog Converter

Description

PBM 3960 is a dual 7-bit+sign, Digital-to-Analog Converter (DAC) especially developed to be used together with the PBL 3771, Precision Stepper Motor driver in microstepping applications. The circuit has a set of input registers connected to an 8-bit data port for easy interfacing directly to a microprocessor. Two registers are used to store the data for each seven-bit DAC, the eigth bit being a sign bit (sign/magnitude coding). A second set of registers are used for automatic fast/slow current decay control in conjunction with the PBL 3771, a feature that greatly improves high-speed microstepping performance. The PBM 3960 is fabricated in a high-speed CMOS process.

Key Features

- Analog control voltages from 3 V down to 0.0 V.
- High-speed microprocessor interface.
- Automatic fast/slow current decay control.
- Full -scale error ±1 LSB.
- Interfaces directly with TTL levels and CMOS devices.
- Fast conversion speed, 3 µs.
- Matches PBL 3771.

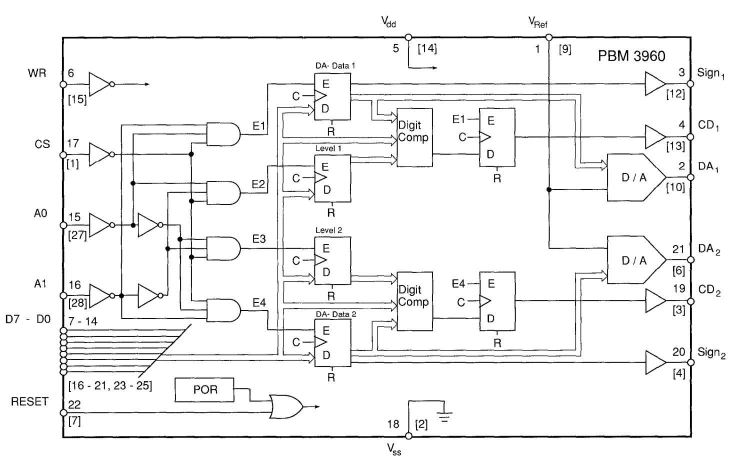
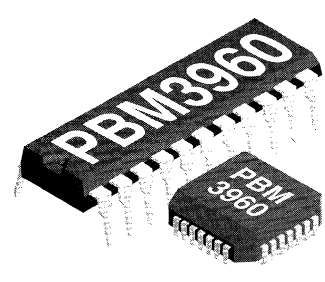


Figure 1. Block Diagram



22-pin plastic DIP
28-pin plastic PLCC

Maximum Ratings

Parameter	Pin no. *	Symbol	Min	Max	Unit
Voltage					
Supply	5 [14]	V_{DD}		6	V
Logic inputs	6- 17 [1, 15-17,19-21, 23-25, 27-28]	V_I	-0.3	V_{DD}+ 0.3	V
Reference input	1 [9]	V_{Ref}	-0.3	V_{DD}+ 0.3	V
Current					
Logic inputs	6- 17 [1, 15-17,19-21, 23-25, 27-28]	I_I	-0.4	+0.4	mA
Temperature					
Storage temperature		T_s	-55	+150	°C
Ambient operating temperature		T_a	0	+70	°C

* [no] refers to PLCC package pin no.

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Supply voltage	V_{DD}	4.75	5.0	5.25	V
Reference voltage	V_{Ref}	0	2.5	3.0	V
Rise and fall time of WR	t_r, t_f			1	µs

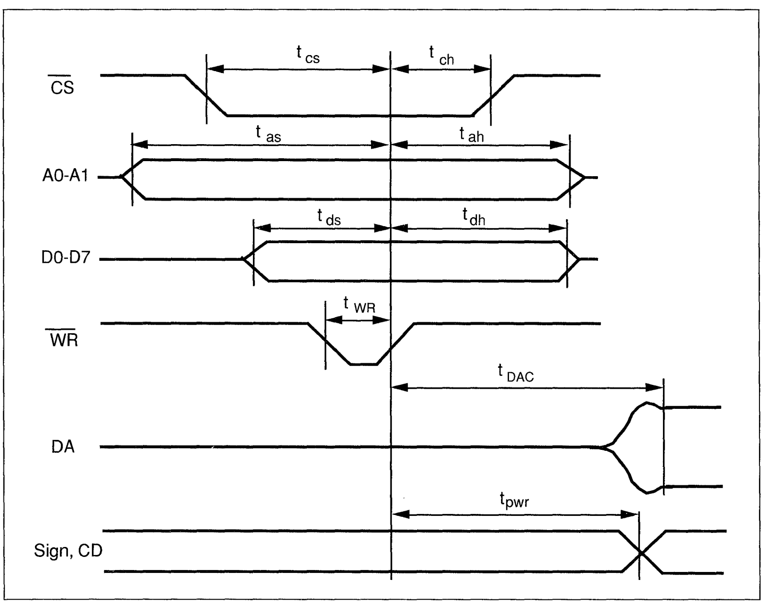


Figure 2. Timing.

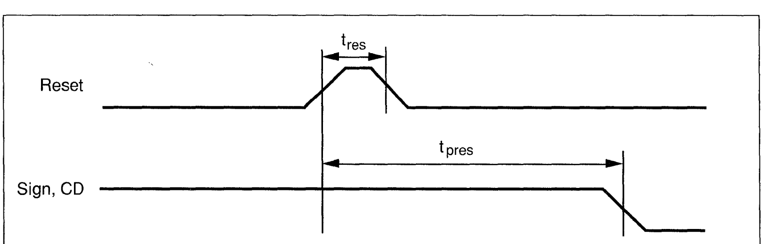


Figure 3. Timing of Reset.

Electrical Characteristics

Electrical characteristics over recommended operating conditions.

Parameter	Symbol	Ref. fig	Conditions	Min	Typ	Max	Unit
Logic Inputs							
Reset logic HIGH input voltage	V_{IHR}			3.5			V
Reset logic LOW input voltage	V_{ILR}					0.1	V
Logic HIGH input voltage	V_{IH}			2.0			V
Logic LOW input voltage	V_{IL}					0.8	V
Reset input current	I_{IR}		$V_{SS} < V_{IR} < V_{DD}$	-0.01		1	mA
Input current, other inputs	I_I		$V_{SS} < V_I < V_{DD}$	-1		1	µA
Input capacitance					3		pF
Internal Timing Characteristics							
Address setup time	t_{as}	2	Valid for A0, A1	70			ns
Data setup time	t_{ds}	2	Valid for D0 - D7	70			ns
Chip select setup time	t_{cs}	2		80			ns
Address hold time	t_{ah}	2				0	ns
Data hold time	t_{dh}	2				0	ns
Chip select hold time	t_{ch}	2				0	ns
Write cycle length	t_{WR}	2		60			ns
Reset cycle lenght	t_{Res}	3		90			ns
Reference Input							
Input resistance	R_{Ref}			6	9		kohm
Logic Outputs							
Logic HIGH output current	I_{OH}		$V_O = 2.4$ V		-13	-4	mA
Logic LOW output current	I_{OL}		$V_O = 0.4$ V	1.7	5		mA
Write propagation delay	t_{pWR}	2	From positive edge of WR. Outputs valid, $C_{load} = 120$ pF		30	110	ns
Reset propagation delay	t_{pRes}	3	From positive edge of Reset to outputs valid, $C_{load} = 120$ pF		60	170	ns
DAC Outputs			Reset open, $V_{Ref} = 2.5$ V				
Nominal output voltage	V_{DA}			0		V_{Ref}- 1LSB	V
Resolution					7		Bits
Offset error		7			0.2	0.5	LSB
Gain error		7			0.1	0.5	LSB
Endpoint nonlinearity		7			0.2	0.5	LSB
Differential nonlinearity		5, 6			0.2	0.5	LSB
Load error			(V_{DA}, unloaded - V_{DA}, loaded) $R_{load} = 2.5$ kΩ, Code 127 to DAC		0.1	0.5	LSB
Power supply sensitivity			Code 127 to DAC 4.75 V < V_{DD} < 5.25 V		0.1	0.3	LSB
Conversion speed	t_{DAC}	2	For a full-scale transition to ±0.5 LSB of final value, $R_{load} = 2.5$ kohm, $C_{load} = 50$ pF.		3	10	µs

Pin Descriptions

Refer to figure 4.

DIP	PLCC	Symbol	Description
1	9	V_{Ref}	Voltage reference supply pin, 2.5 V nominal (3.0 V maximum)
2	10	DA_1	Digital-to-Analog 1, voltage output. Output between 0.0 V and V_{ref} - 1 LSB.
3	12	$Sign_1$	Sign 1, TTL/CMOS level. To be connected directly to PBL 3771Phase input. Databit D7 is transfered non inverted from PBM 3960 data input.
4	13	CD_1	Current Decay 1, TTL/CMOS level. The signal is automatically generated when decay level is programmed. LOW level = fast current decay.
5	14	V_{DD}	Voltage Drain-Drain, logic supply voltage. Normally +5 V.
6	15	$\overline{WR}$	Write, TTL/CMOS level, input for writing to internal registers. Data is clocked into flip flops on positive edge.
7	16	D7	Data 7, TTL/CMOS level, input to set data bit 7 in data word.
8	17	D6	Data 6, TTL/CMOS level, input to set data bit 6 in data word.
9	19	D5	Data 5, TTL/CMOS level, input to set data bit 5 in data word.
10	20	D4	Data 4, TTL/CMOS level, input to set data bit 4 in data word.
11	21	D3	Data 3, TTL/CMOS level, input to set data bit 3 in data word.
12	23	D2	Data 2, TTL/CMOS level, input to set data bit 2 in data word.
13	24	D1	Data 1, TTL/CMOS level, input to set data bit 1 in data word.
14	25	D0	Data 0, TTL/CMOS level, input to set data bit 0 in data word.
15	27	A0	Address 0, TTL/CMOS level, input to select data transfer, A0 selects between cannel 1 (A0 = LOW) and channel 2 (A0 = HIGH).
16	28	A1	Address 1, TTL/CMOS level, input to select data transfer. A1 selects between normal D/A register programming (A1 = LOW) and decay level register programming (A1 = HIGH).
17	1	$\overline{CS}$	Chip Select, TTL/CMOS level, input to select chip and activate data transfer from data inputs. LOW level = chip is selected.
18	2	V_{SS}	Voltage Source-Source. Ground pin, 0 V reference for all signals and measurements unless otherwise noted.

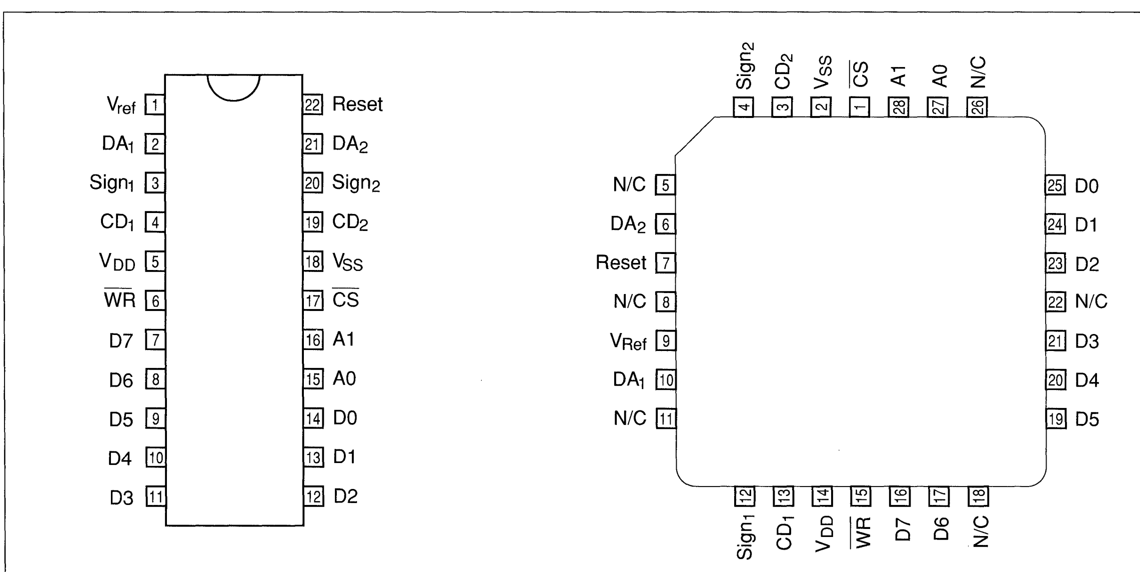


Figure 4. Pin configuration.

DIP	PLCC	Symbol	Description
19	3	CD_2	Current Decay 2, TTL/CMOS level. The signal is automatically generated when decay level is programmed. LOW level = fast current decay .
20	4	$Sign_2$	Sign 2. TTL/CMOS level. To be connected directly to PBL 3771 sign input. Data bit D7 is transfered non-inverted from PBM 3960 data input.
21	6	DA_2	Digital-to-Analog 2, voltage output. Output between 0.0 V and V_{ref} - 1 LSB.
22	7	Reset	Reset, digital input resetting internal registers. HIGH level = Reset, $V_{Res} \geq 3.5$ V = HIGH level. Pulled low internally.
	5		Not Connected
	8		Not Connected
	11		Not Connected
	18		Not Connected
	22		Not Connected
	26		Not Connected

Definition of Terms

Resolution

Resolution is defined as the reciprocal of the number of discrete steps in the DAC output. It is directly related to the number of switches or bits within the DAC. For example, PBM 3960 has 2^7, or 128, output levels and therefor has 7 bits resolution. Remember that this is not equal to the number of microsteps available.

Linearity Error

Linearity error is the maximum deviation from a straight line passing through the end points of the DAC transfer characteristic. It is measured after adjusting for zero and full scale. Linearity error is a parameter intrinsic to the device and cannot be externally adjusted.

Power Supply Sensitivity

Power supply sensitivity is a measure of the effect of power supply changes on the DAC full-scale output.

Settling Time

Full-scale current settling time requires zero-to-full-scale or full-scale-to-zero output change. Settling time is the time required from a code transition until the DAC output reaches within $\pm ^1/_2$LSB of the final output value.

Full-scale Error

Full-scale error is a measure of the output error between an ideal DAC and the actual device output.

Differential Non-linearity

The difference between any two consecutive codes in the transfer curve from the theoretical 1LSB, is differential non-linearity

Monotonic

If the output of a DAC increases for increasing digital input code, then the DAC is monotonic. A 7-bit DAC which is monotonic to 7 bits simply means that increasing digital input codes will produce an increasing analog output. PBM 3960 is monotonic to 7 bits.

Functional Description

Each DAC channel contains two registers, a digital comparator, a flip flop, and a D/A converter. A block diagram is shown on the first page. One of the registers stores the current level, below which, fast current decay is initiated. The status of the CD outputs determines a fast or slow current decay to be used in the driver.

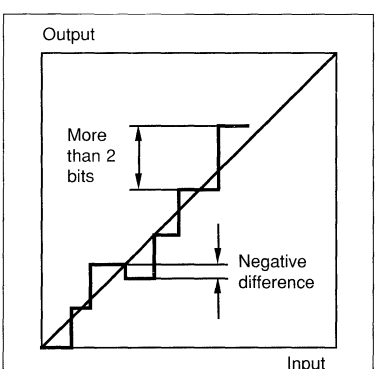


Figure 5. Errors in D/A conversion. Differential non-linearity of more than 1 bit, output is non-monotonic.

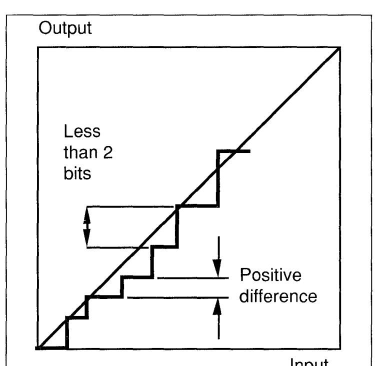


Figure 6. Errors in D/A conversion. Differential non-linearity of less than 1 bit, output is monotonic.

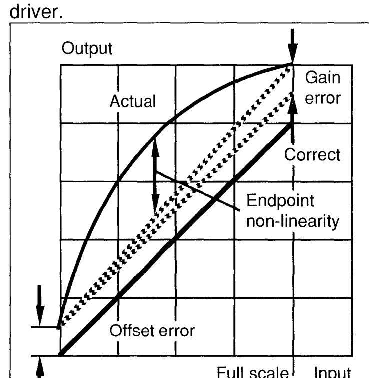


Figure 7. Errors in D/A conversion. Non-linearity, gain and offset errors.

The digital comparator compares each new value with the previous one and the value for the preset level for fast current decay. If the new value is strictly lower than both of the others, a fast current decay condition exists. The flip flop sets the CD output. The CD output is updated each time a new value is loaded into the D/A register. The fast current decay signals are used by the driver circuit, PBL 3771, to change the current control scheme of the output stages. This is to avoid motor current dragging which occurs at high stepping rates and during the negative current slopes, as illustrated in figure 9. Eight different levels for initiation of fast current decay can be selected.

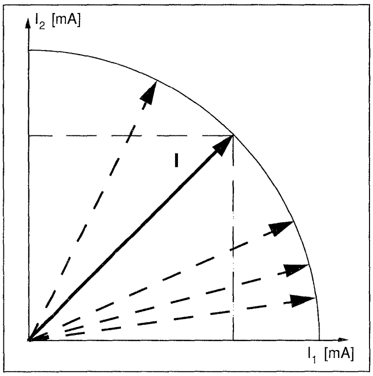


Figure 8a. Assuming that torque is proportional to the current in resp. winding it is possible to draw figure 8b.

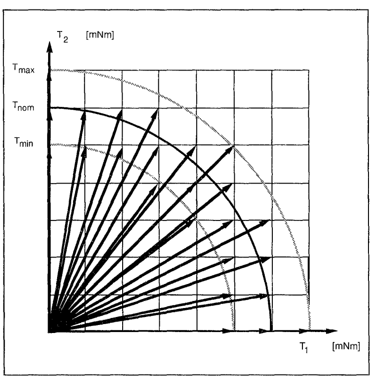


Figure 8b. An example of accessible positions with a given torque deviation/ fullstep. Note that 1:st µstep sets highest resolution. Data points are exaggerated for illustration purpose. TNom = code 127.

The sign outputs generate the phase shifts, i.e., they reverse the current direction in the phase windings.

Data Bus Interface

PBM 3960 is designed to be compatible with 8-bit microprocessors such as the 6800, 6801, 6803, 6808, 6809, 8051, 8085, Z80 and other popular types and their 16/32 bit counter parts in 8 bit data mode. The data bus interface consists of 8 data bits, write signal, chip select, and two address pins. All inputs are TTL-compatible (except reset). The two address pins control data transfer to the four internal D-type registers. Data is transferred according to figure 10 and on the positive edge of the write signal.

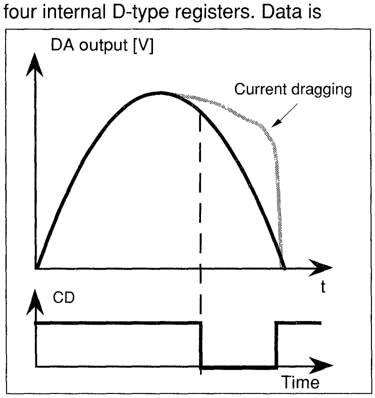


Figure 9. Motor current dragging at high step rates and current decay influence. Fast current decay will make it possible for the current to follow the ideal sine curve. Output shown without sign shift.

$\overline{CS}$	A0	A1	Data Transfer
0	0	0	D7 —> Sign1, (D6—D0) —> (Q61—Q01), New value —> CD1
0	0	1	(D6—D4) —> (L61—L41)
0	1	0	D7 —> Sign2, (D6—D0) —> (Q62—Q02), New value —> CD2
0	1	1	(D6—D4) —> (L62—L42)
1	X	X	No Transfer

Figure 10. Table showing how data is transfered inside PBM 3960.

Current Direction, $Sign_1$ & $Sign_2$

These bits are transferred from D_7 when writing in the respective DA register. A_0 and A_1 must be set according to the data transfer table in figure 10.

Current Decay, CD_1 & CD_2

CD_1 and CD_2 are two active low signals (LOW = fast current decay). CD_1 is active if the previous value of DA-Data1 is strictly larger than the new value of DA-Data1 and the value of the level register LEVEL1 ($L_{61} \ldots L_{41}$) is strictly larger than the new value of DA-Data1. CD_1 is updated every time a new value is loaded into DA-Data1. The logic definition of CD_1 is:

$$CD_1 = \text{NOT}\{[(D_6 \ldots D_0) < (Q_{61} \ldots Q_{01})] \text{ AND}[(D_6 \ldots D_4) < (L_{61} \ldots L_{41})]\}$$

Where ($D_6 \ldots D_0$) is the new value being sent to DA-Data1 and ($Q_{61} \ldots Q_{01}$) is DA-Data1's old value. ($L_{61} \ldots L_{41}$) are the three bits for setting the current decay level at LEVEL1.

The logic definition of CD_2 is analog to CD_1:

$$CD_2 = \text{NOT}\{[(D_6 \ldots D_0) < (Q_{62} \ldots Q_{02})] \text{ AND}[(D_6 \ldots D_4) < (L_{62} \ldots L_{42})]\}$$

Where ($L_{62} \ldots L_{42}$) is the level programmed in channel 2's level register. ($D_6 \ldots D_0$) and ($Q_{62} \ldots Q_{02}$) are the new and old values of DA-Data2.

The two level registers, LEVEL1 and LEVEL2, consist of three flip flops each and they are compared against the three most significant bits of the DA-Data value, sign bit excluded.

DA_1 and DA_2

These are the two outputs of DAC1 and DAC2. Input to the DACs are internal data bus ($Q_{61} \ldots Q_{01}$) and ($Q_{62} \ldots Q_{02}$).

Reference Voltage V_{Ref}

V_{Ref} is the analog input for the two DACs. Special care in layout, gives a very low voltage drop from pin to resistor. Any V_{Ref} between 0.0 V and V_{DD} can be applied, but output might be non-linear above 3.0 V.

Power-on Reset

This function automatically resets all internal flip flops at power-on. This results in V_{SS} voltage at both DAC outputs and all

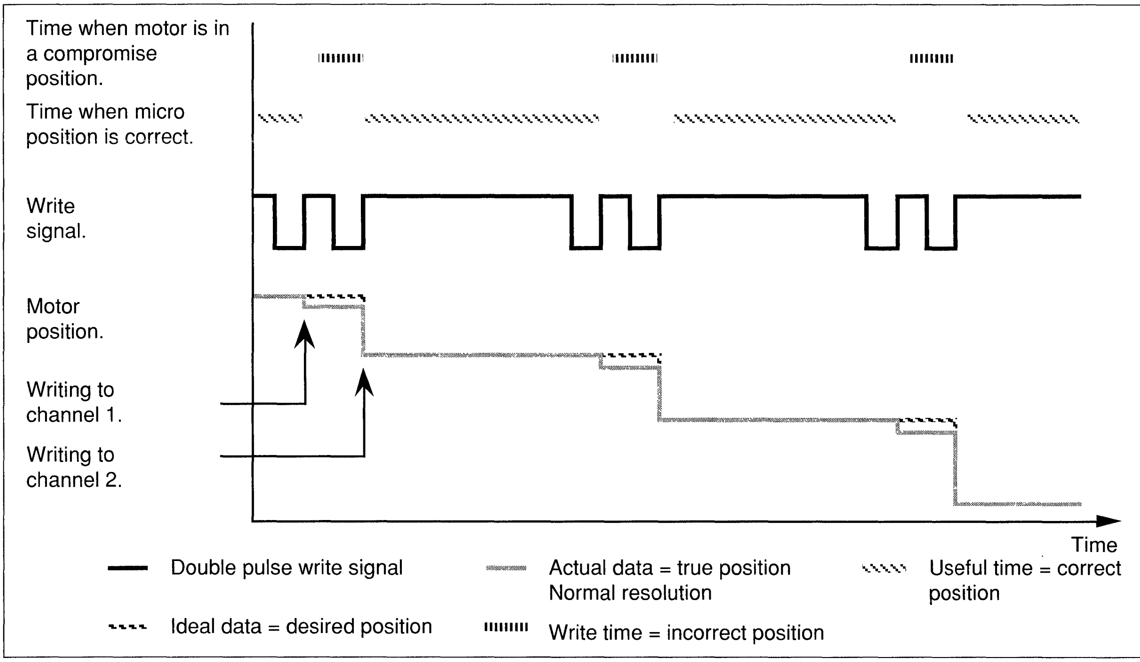


Figure 11. Double pulse programming, in- and output signals.

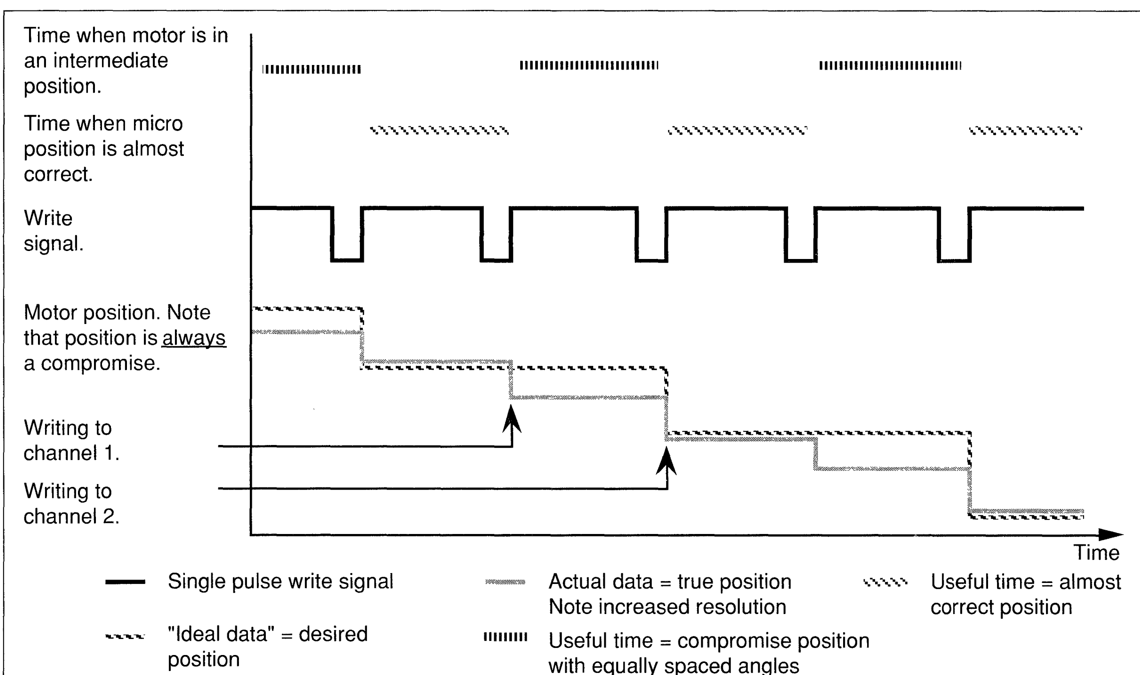


Figure 12. Single pulse programming, in- and output signals.

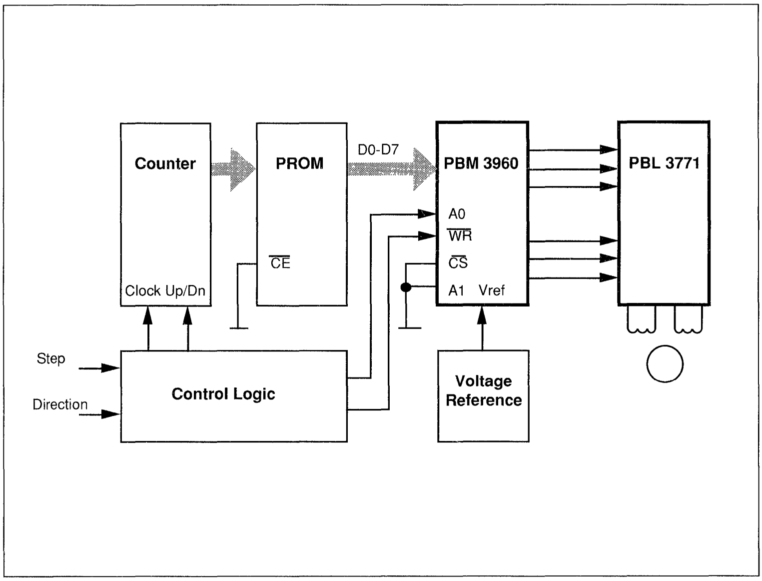


Figure 13. Typical blockdiagram of an application without a microprocessor. Available as testboard, TB 307i.

digital outputs.

Reset

If Reset is not used, leave it disconnected. Reset can be used to measure leakage currents from V_{DD}.

Applications Information

How Many Microsteps?

The number of true microsteps that can be obtained depends upon many different variables, such as the number of data bits in the Digital-to-Analog converter, errors in the converter, acceptable torque ripple, single- or double-pulse programming, the motor's electrical, mechanical and magnetic characteristics, etc. Many limits can be found in the motor's ability to perform properly; overcome friction, repeatability, torque linearity, etc. It is important to realize that the number of current levels, 128 (2^7), is *not* the number of steps available. 128 is the number of current levels (reference voltage levels) available from each driver stage. Combining a current level in one

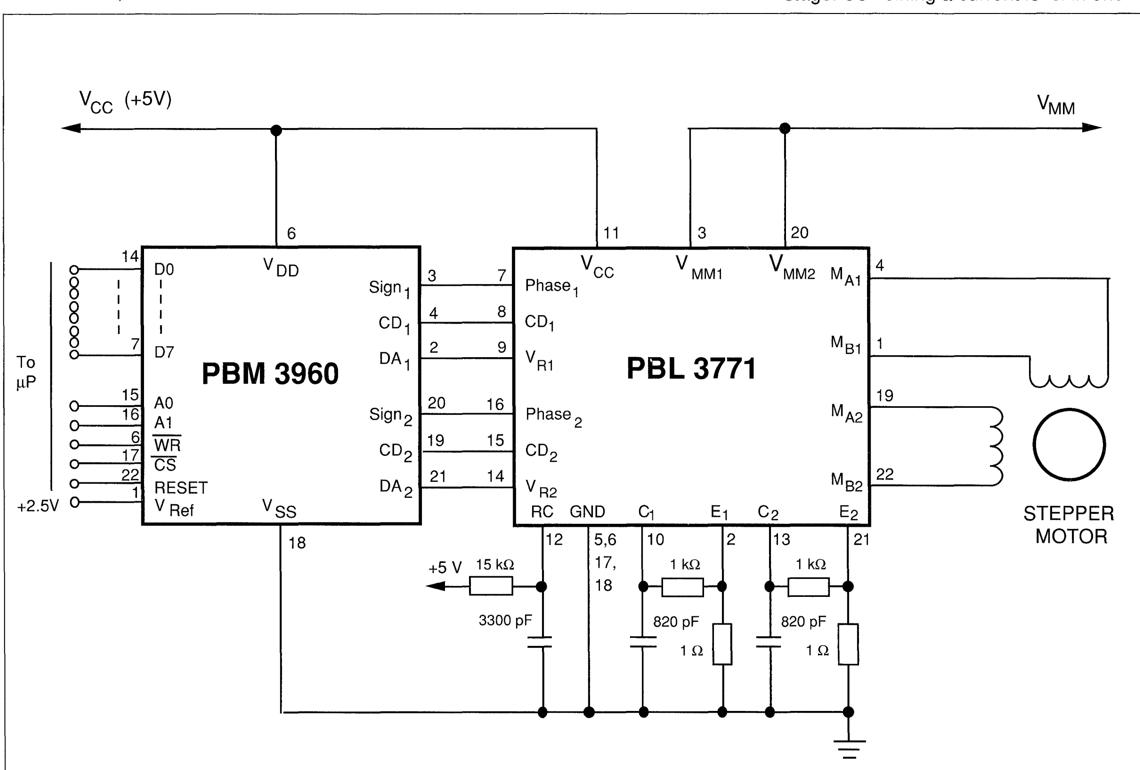


Figure 14. Typical application in a microprocessor based system.

winding with any of 128 other current levels in the other winding will make up 128 current levels. So expanding this, it is possible to get 16,384 (128 • 128) combinations of different current levels in the two windings. Remember that these 16,384 micro-positions are not all useful, the torque will vary from 100% to 0% and some of the options will make up the same position. For instance, if the current level in one winding is OFF (0%) you can still vary the current in the other winding in 128 levels. All of these combinations will give you the same position *but* a varying torque.

Typical Application

The microstepper solution can be used in a system with or without a microprocessor.

Without a microprocessor, a counter addresses a ROM where appropriate step data is stored. Step and Direction are the input signals which represent clock and up / down of counter. This is the ideal solution for a system where there is no microprocessor or it is heavily loaded with other tasks.

With a microprocessor, data is stored in ROM / RAM area or each step is successively calculated. PBM 3960 is connected like any peripheral addressable device. All parts of stepping can be tailored for specific damping needs etc. This is the ideal solution for a system where there is an available microprocessor with extra capacity and low cost is more essential than simplicity. See typical application, figure 14.

User Hints

Never disconnect ICs or PC Boards when power is supplied.

Choose a motor that is rated for the current you need to establish desired torque. A high supply voltage will gain better stepping performance even if the motor is not rated for the V_{MM} voltage, the current regulation in PBL 3771 will take care of it. A normal stepper motor might give satisfactory result, but while microstepping, a "microstepping-adapted" motor is recommended. This type of motor has smoother motion due to two major differences, the stator / rotor teeth relationship is non-equal and the static torque is lower.

The PBM 3960 can handle programs which generate microsteps at a desired resolution as well as quarter stepping, half stepping, full stepping, and wave drive.

Fast or Slow Current Decay?

There is a difference between static and dynamic operation of which the actual application must decide upon when to use fast or slow current decay. Generally slow decay is used when stepping at slow speeds. This will give the benefits of low current ripple in the drive stage, a precise and high overall average current, and normal current increase on the positive edge of the sine-cosine curves. Fast current decay is used at higher speeds to avoid current dragging with lost positions and incorrect step angles as a result.

Ramping

Every drive system has inertia which must be considered in the drive system. The rotor and load inertia play a big role at higher speeds. Unlike the DC motor, the stepper motor is a synchronous motor and does not change its speed due to load variations. Examining a typical stepper motor's torque-versus-speed curve indicates a sharp torque drop-off for the "start-stop without error" curve. The reason for this is that the torque requirements increase by the cube of the speed change. For good motor performance, controlled acceleration and deceleration should be considered even though microstepping will improve overall performance.

Programming PBM 3960

There are basically two different ways of programming the PBM 3960. They are called "single-pulse programming" and "double-pulse programming." Writing to the device can only be accomplished by addressing one register at a time. When taking one step, at least two registers are normally updated. Accordingly there must be a certain time delay between writing to the first and the second register. This programming necessity gives some special stepping advantages.

Double-pulse Programming

The normal way is to send two write pulses to the device, with the correct addressing in between, keeping the delay between the pulses as short as possible. Write signals will look as illustrated in figure12. The advantages are:

- low torque ripple
- correct step angles between each set of double pulses
- short compromise position between the two step pulses
- normal microstep resolution

Single-pulse Programming

A different approach is to send one pulse at a time with an equally-spaced duty cycle. This can easily be accomplished and any two adjacent data will make up a microstep position. Write signals will look as in figure 13. The advantages are:

- higher microstep resolution
- smoother motion

The disadvantages are:

- higher torque ripple
- copromise positions with almost-correct step angles

Ordering Information

Package	Temp. Range	Part No.
Plastic DIP	0 to 70°C	PBM3960N
PLCC	0 to 70°C	PBM3960QN

IC4 (88084) A-Ue

ERICSSON

Ericsson Components AB
S-164 81 Kista-Stockholm, Sweden
Telephone: (08) 757 50 00

May 1991

PBD 3545/1 Universal Sink Driver

Description

PBD 3545/1 is a bipolar universal high-current highly-protected low side driver with transparent input and 2 A continuous-current sink capability. A high-level input activates the output.

The driver is equipped with extensive electrical protection, such as overcurrent protection and thermal protection, which makes the device viritually indestructible.
Furthermore it can detect open circuit and short circuit to ground.

A special feature is the Error indicating output function pin which signals to the host system if the protection or the load check functions is activated.

Typical loads are solenoids, relays or resistive loads.

The PBD 3545/1 and PBD 3548/1 are complementary drivers and have similar data.

Key features

- 2 A continuous-output current
- Short circuit to V_{CC} protection
- Error signal to host system
- Open circuit detection
- Short circuit to ground detection
- Thermal protection
- Built-in protection diodes
- LS-TTL, CMOS, and supply voltage compatible input
- ESD protected
- 5-pin TO-220 package, or 28-lead power PLCC with lead-frame for heat-sinking through PC board copper.

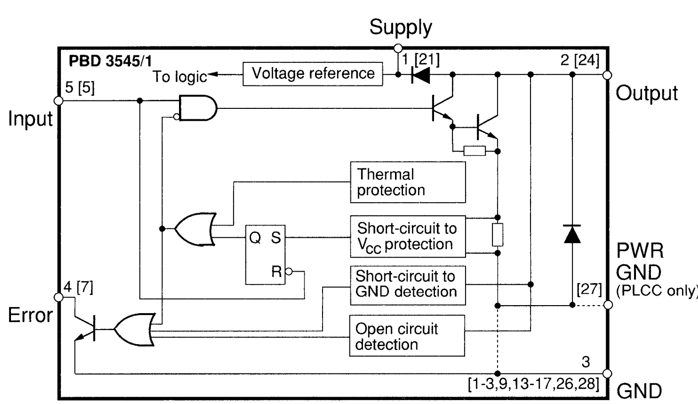
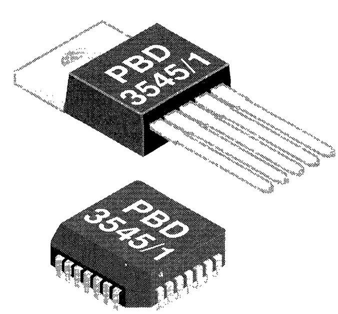


Figure 1. Block Diagram. Pin number in brackets refer to PLCC package.



TO-220 5-pin package
28-pin PLCC package

Maximum Ratings

Parameter	Pin no.	Symbol	Min	Max	Unit
Voltage					
Supply voltage	1 [21]	V_{CC}	0	45	V
Logic input voltage	5 [5]	V_{IN}	-0.3	V_{CC}	V
Current					
Logic input current	5 [5]	I_{IN}	-10		mA
Continuous DC Operation output current	2 [24]	I_{OUT}		2.0	A
Error output current	4 [7]	I_{ERR}		10	mA
Temperature					
Operating junction temperature (internally limited)		T_J		+140	°C
Storage temperature		T_S	-55	+150	°C
Power Dissipation (Package Data)					
Power dissipation at T_{Case} = 85°C, TO-220 package		P_D		11	W
Power dissipation at T_{Case} = 85°C, PLCC package		P_D		5	W
ESD					
ESD tolerance (Note 2)			2000		V

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Supply voltage	V_{CC}	4.75		40	V
Output current	I_{OUT}			2.0	A
Operating ambient temperature	T_A	-40		+85	°C
Error output current	I_{Err}		5	8	mA

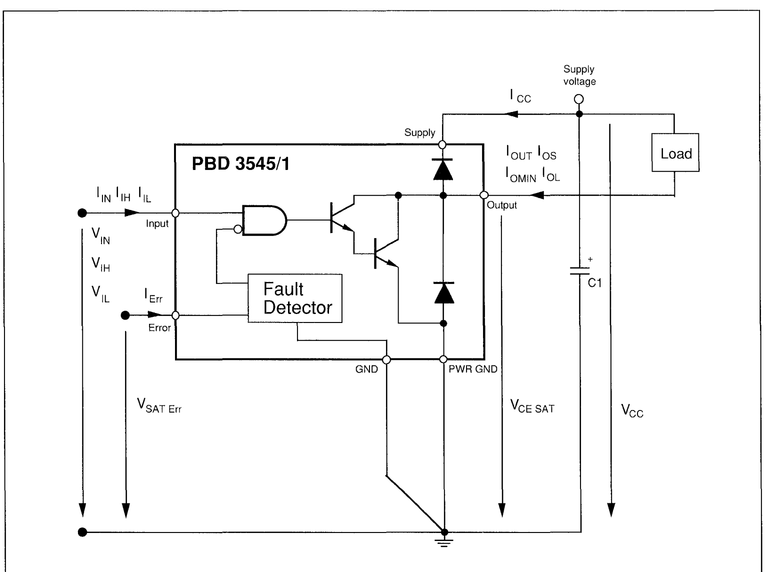


Figure 2. Definition of symbols.

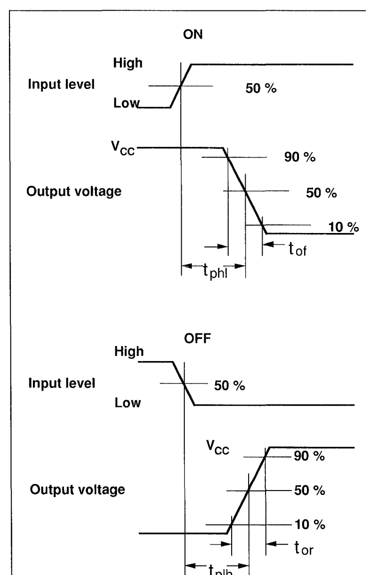


Figure 3. Timing diagram, input vs. output. V_{CC} = 24V.

Electrical Characteristics

At 5 V ≤ V_{CC} ≤ 40 V, -40°C ≤ T_J ≤ +100°C. Typical values are given at V_{CC} = 24 V, T_J = 25°C.

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
General							
Supply currrent	I_{CC}	2,7	0 ≤ V_{IN} ≤ 0.8	1.5	4	7	mA
Thermal shutdown	T_{JS}			+120	+130	+140	°C
Thermal shutdown release	T_{JSR}			+110	+120	+130	°C
Logic input							
High level input voltage	V_{IH}	2		2.0		V_{CC}	V
Low level input voltage	V_{IL}	2		-0.3		0.8	V
High level input current	I_{IH}	2,9	2.0 ≤ V_{IN} ≤ V_{CC}		9	20	µA
Low level input current	I_{IH}	2,9	0 ≤ V_{IN} ≤ 0.8	-400			µA
Outputs							
Error output saturation voltage	$V_{Err\ SAT}$	2,10	I_{Err} = 5 mA		0.2	1	V
Output saturation voltage	$V_{CE\ SAT}$	2,11	I_{OUT} = 2 A		1.4	1.8	V
Output current shutdown	I_{OS}	2,5,14	2.0 ≤ V_{IN} ≤ V_{CC}	2.0	3.2	4.5	A
Output current (not detected as open circuit)	I_{OMIN}	2,5	2.0 ≤ V_{IN} ≤ V_{CC}	0.5	2	8	mA
Output leakage current	I_{OL}	2,12	0 V≤ V_{IN} ≤0.8 V. Output = 0 V	-8	-6	-2	µA
Clamping diode forward voltage		8	I_F = 2.0 A		1.5	1.8	V
Timing							
Propagation time		3	I_{OUT} = 2 A				
Output high to low (50%),	t_{phl}				1.5	3.0	µs
Output low to high (50%),	t_{plh}				0.5	1.0	µs
Rise time (10 to 90%),	t_{or}	3			0.2	0.5	µs
Fall time (90 to 10%),	t_{of}	3			0.2	0.5	µs

Thermal Charateristics

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
Thermal resistance	Rth_{J-C}	21	TO-220 package, junction to case		5		°C/W
	Rth_{J-A}	21	TO-220 package, junction to ambient		60		°C/W
	Rth_{J-BW}	20	PLCC package, junction to batwing		10		°C/W
	Rth_{J-A}	20,22	PLCC package, note 3.		35		°C/W

Note 1. Currents are defined positive if flowing into, and negative if flowing out of a terminal. Voltages are defined between terminal and ground.
Note 2. ESD testing according to Human Body Model (C_{Zap} = 100 pF, R_{Zap} = 1500 Ω)
Note 3. All ground pins soldered onto a 20 cm^2 PCB copper area with free air convection, T_A = +25°C.

Pin Description

TO-220	PLCC	Symbol	Description
1	[21]	Supply	Supply voltage. Nominally 5 V to 40 V.
2	[24]	Output	Output pin. Current flows from supply through the load into the pin. Nominal current is 8 mA to 2 A.
3	[1-3,9, 13-17,26,28]	GND	Ground supply. Note: for PLCC these pins are used thermally for heat sinking. Make sure that all pins are soldered onto a suitably large copper ground for efficient heat sinking.
	[27]	PWR GND	Power ground pin. In the PLCC package, the emitter of the output transistor including the protection diode are bonded to a separate pin.
4	[7]	Error	Error indicating pin. Sinks current to ground if the protection and/or detection circuitry is activated. Note: the current must be externally limited to 8 mA.
5	[5]	Input	TTL compatible input. A LOW input signal turns the output transistor off and a HIGH input turns it on. If the input is left open it will be detected as low level.
	[4,6,8,10-12 18-20,22,23,25]	NC	No connection. Pins are not bonded to the chip and may therefore be soldered to any PC board trace for efficient heat sinking.

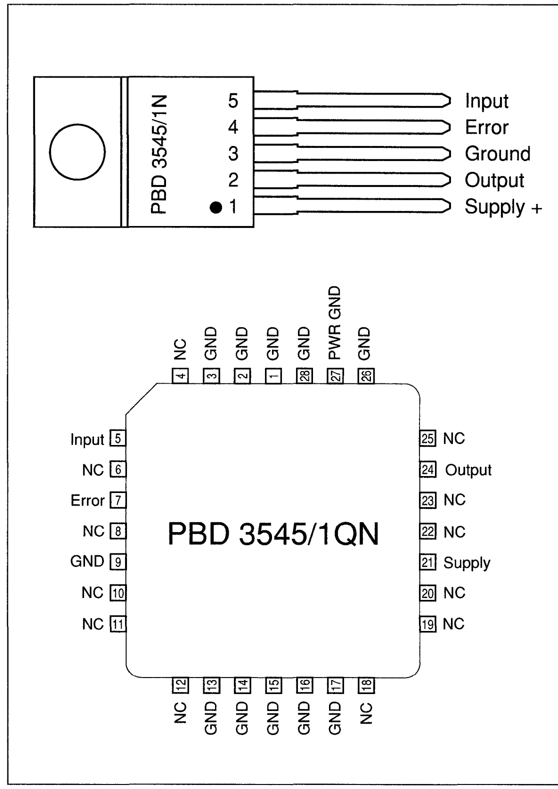


Figure 4. Pin descriptions.

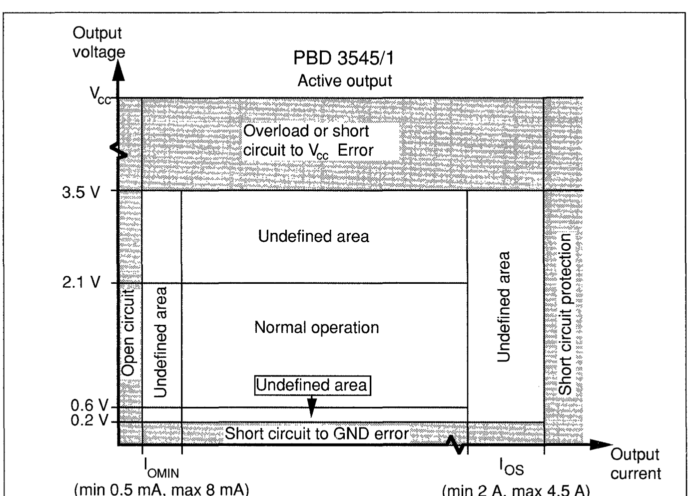


Figure 5. Error state vs. output voltage and output current, active output ($2.0 \leq V_{IN} \leq V_{CC}$), $5\ V < V_{CC} < 40\ V$, $-40°C < T_J < +100°C$.

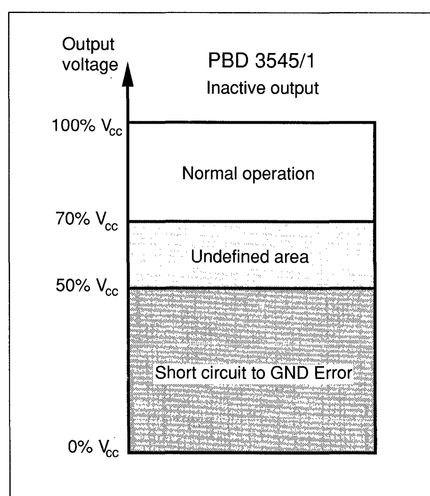


Figure 6. Error state vs. output voltage, inactive output ($0\ V \leq V_{IN} \leq 0.8\ V$), $5\ V \leq V_{CC} \leq 40\ V$, $-40°C < T_J < +100°C$.

Typical performance characeristics

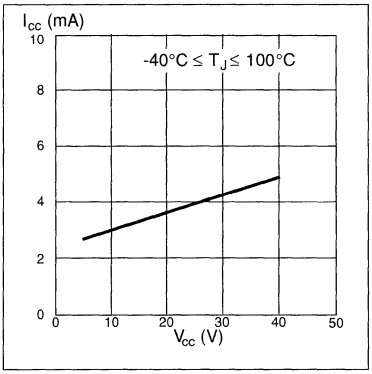


Figure 7. Current consumption vs. supply voltage at 0 V ≤ V_{in} ≤ 0.8 V.

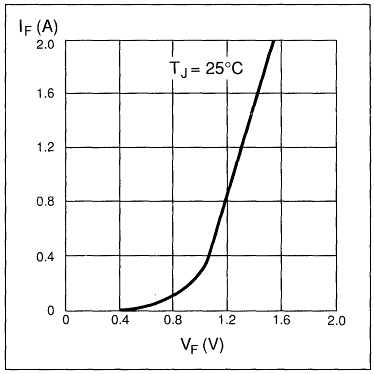


Figure 8. Diode forward voltage drop vs. forward current.

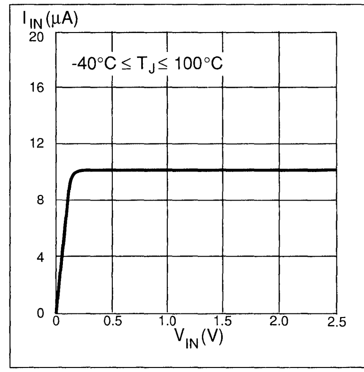


Figure 9. Input current vs. input voltage. 5 V ≤ V_{CC} ≤ 40 V.

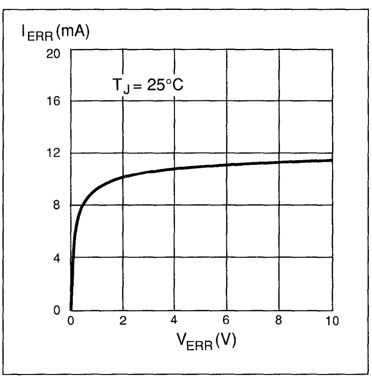


Figure 10. Error output saturation voltage vs. error current. V_{CC} = 24 V.

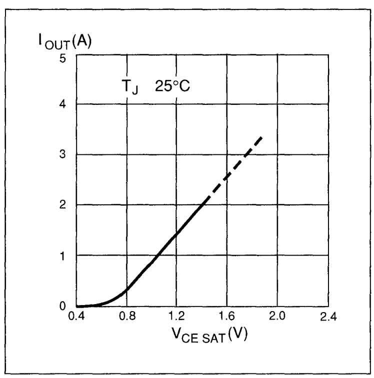


Figure 11. Output saturation voltage vs. output current. 5 V < V_{CC} < 40 V.

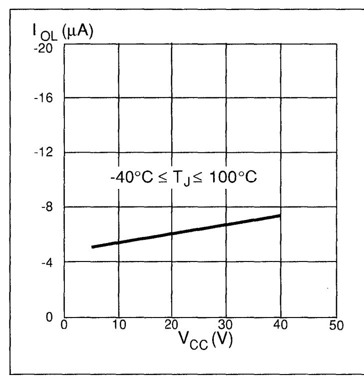


Figure 12. Output leakage current vs. supply voltage. 0 V ≤ V_{IN} ≤ 0.8 V. Output = 0 V.

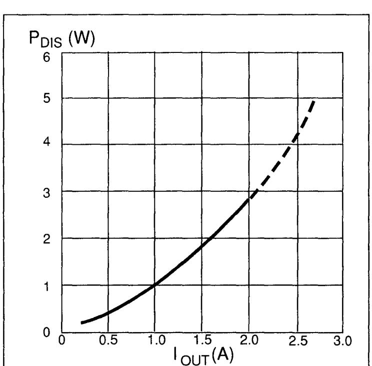


Figure 13. Power dissipation vs. output current.

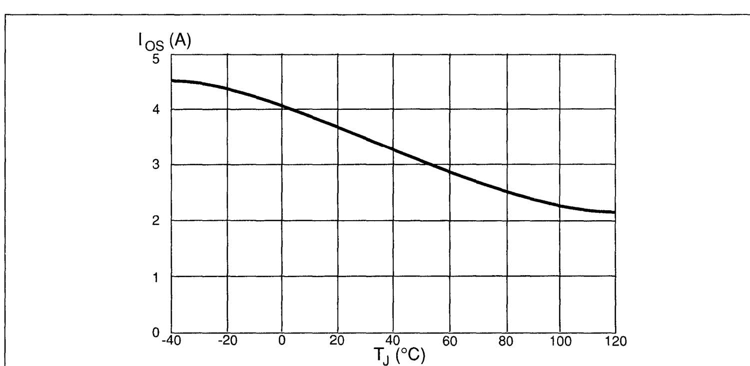


Figure 14. Output current shut-down vs. chip temperature. 5 V ≤ V_{CC} ≤ 40 V.

Functional Description

The circuit PBD 3545/1 is a low side driver capable of driving resistive or inductive loads not exceeding 2 A.

The driver has an error indicating function which generates an Error output signal when a fault condition has occurred.

The circuits PBD 3545/1 and PBD 3548/1 are complementary drivers with equivalent functions and similar data. PDB 3545/1 is a sink driver and PBD 3548/1 is a source driver.

Input stage

The output stage is switched on and off according to the status of the input. HIGH level activates the output. If the input is left open, the circuit will accept it as a LOW level.

Output stage

The output stage contains a power transistor and two clamping diodes. The diodes are used for terminating line transients from inductive loads. If the driver is inactive and the output is shorted to GND the driver will leake maximum 8 μA. See figure 12.

Protection circutry

The circuit contains two protection circuits:

- Overload and Short circuit protection
- Thermal protection

The overload and short circuit protection will be activated at I_{out}= 3.5 A typically at T_J= +25°C, see figure 14.

The output will be turned off immediately and latched to a high-impedance state after an overload or short circuit has been detected.

A logic-level change at the input will reset the internal error latch. If the fault still is present at turn-on, the circuit will once again turn the output off.

Due to a slight delay in the circuit, a high current transient will occur when the output is shorted to V_{cc}. This current transient may reach 8 A during 5 μs. Consequently, switching at high frequencies with a shorted output may destroy the circuit. If a short circuit condition is detected, stop switching the input and remove fault condition.

Thermal protection

The output of PDB 3545/1 is equipped with a thermal shut-down function, which limits the junction temperature to typically +130°C. The output will be turned off until the junction temperature has decreased to approximately 120°C.

Error functions

The Error indicating signal occurs on a separate pin. The complete error table is shown in figure 17.

The following conditions generate an error signal:
When the driver is activated and at least one of the following conditions has

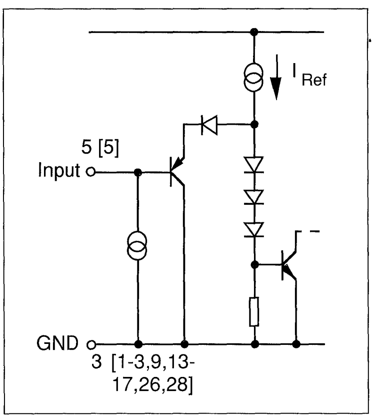


Figure 15. Input stage.

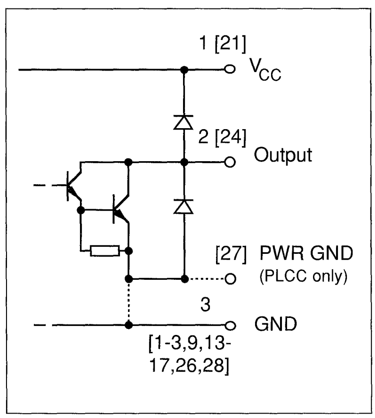


Figure 16. Output stage.

Fault condition	Input	Output	Error LOW=ERROR HIGH=Normal	How to resume normal operation
Normal	0 LOW	1 OFF	1 HIGH	——
	1 HIGH	0 ON	1 HIGH	——
V_{OUT} Short to GND	0 LOW	1 OFF	0 LOW	Remove fault condition.
	1 HIGH	0 ON	0 LOW	Remove fault condition.
V_{OUT} Short to V_{CC}	0 LOW	1 OFF	1 HIGH	——
	1 HIGH	1 OFF	0 LOW	Turn off and on after fault condition is removed.
Open load	0 LOW	1 OFF	1 HIGH	——
	1 HIGH	0 ON	0 LOW	Attach proper load to output or turn off the driver.
Over temperature	0 LOW	1 OFF	1 HIGH	——
T_J=130 °C	1 HIGH	1 OFF	0 LOW	Temperature is reduced to approx 120°C, or turn off the driver.

Figure 17. Error table.

occurred:

- thermal overload
- short circuit to GND
- short circuit to V_{CC}
- open circuit

An output current less than 8 mA might be detected as “open circuit”. Output currents larger than 8 mA and less than 2 A will definitely not generate an error. The normal operational area is shown in figure 5.

Also when the driver is inactivated an Error indication can occur. That is if the output is shorted to GND. In figure 6 short circuit to GND Error state versus output voltage is shown.

When the Error-detection function is activated, the Error output is capable of sinking 8 mA, supporting direct connection of an LED. The current has to be externally limited by a series resistor.

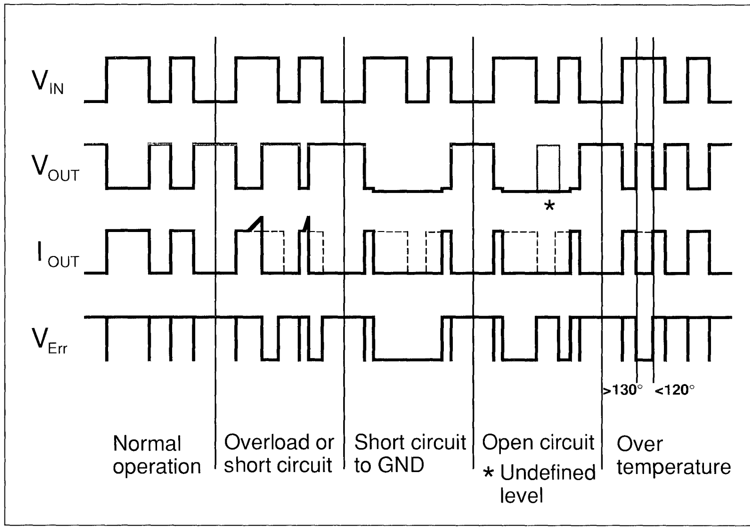


Figure 18. Signal diagram

Signal diagrams

The signal diagram in figure 18 shows the input signal and the resulting output signals for each error mode. For details, se error table, figure 17.

V_{IN} = Input voltage. Active = HIGH.

V_{OUT} = Output voltage.

I_{OUT} = Output current from driver.

V_{ERR} = Error output voltage. Error = LOW.

Applications Information

Important application areas are:

- Programmable logic control systems.
- Security systems.
- Relay control.
- Hydraulic valves.
- Intelligent interfaces between microprocessors and loads.
- Vehicle control systems.
- Robot techniques.
- Dashboard information systems.
- Print head drivers.
- High-current stepper motor drivers with security aspects.

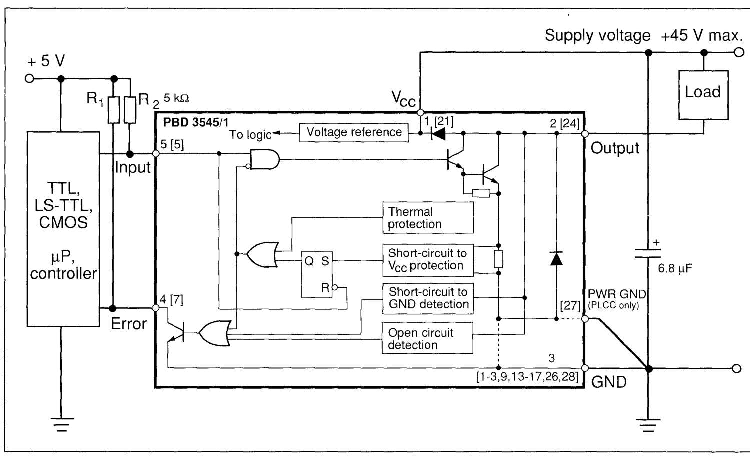


Figure 19. Typical application. Pin numbers refer to TO 220 package.

Transient protection

1. Keep V_{CC} and GND leads as short as possible. Use different supplies if possible.

2. Connect a filter capacitor close to the circuit. Recommended filter capacitor between V_{CC} and GND is 6.8 µF, of tantalum type. A ceramic capacitor in parallel will improve high frequency decoupling. Typical values range from 0.002 µF to 0.1 µF. In an application having a highly stable supply and short power leads to the driver a low leakage electrolytic type can be used, which is less expensive.

3. Connect Input and Error via pull-up resistors to the appropriate logic supply level or V_{CC} to obtain highest noise immunity. Se figure 19. The resistor R_1 limits the current into the Error indicating pin. This current must not exeed 8 mA. R_2 is a pull-up resistor which improves noise immunity at the Input. Pull-up current should not exeed the sinking capacity of the controlling device output.

4. If several supply voltages are to be used, prefere a supply having separate ground leads. In this case the logic ground and the power ground should be connected together at only one point, the ground pin of the driver.

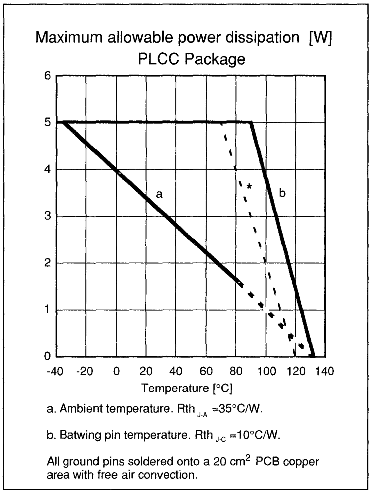


Figure 20. Maximum allowable power dissipation. PLCC package.

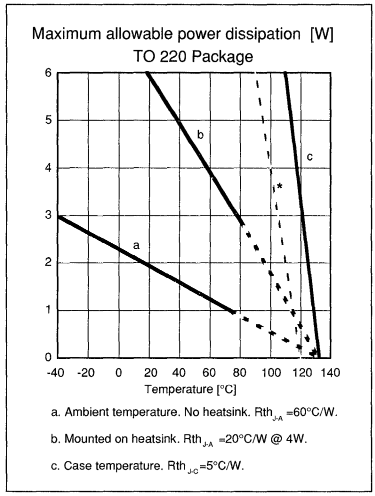


Figure 21. Maximum allowable power dissipation. TO 220 package.

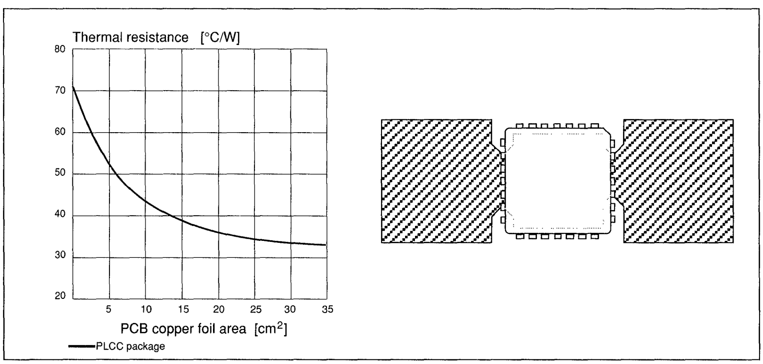


Figure 22. Typical thermal resistance vs. PC board copper area and suggested layout.

Switch mode applications

The internal diodes are normally sufficient for clamping of transients caused by inductive load turn off. External diodes may be necessary in PWM/switch mode applications, and when the terminals are externally accessible and thereby exposed to an electrically noisy environment. Recommended diodes are BYV27/100, BYV98/100, UF4001 or similar types with a t_{rr} < 100 ns and $I_F \geq 1$ A.

Error indication signal

When the circuit is switched on/off, a short pulse (t_{Err}<10 µS for resistive loads) is generated at the Error output. This is a correct detection of an incorrect level during the rise and fall times of the output voltage. Consequently the Error output should not be detected when switching on and off. An alternative is to low-pass filter at the Error output at around 100 kHz.

Heat sinking

PBD 3545/1N is packaged in a 5-pin TO 220 power package. The circuit GND is connected to the heat sink tab. External heatsinking is achieved by mounting the package to a heat sink.

The circuit is also avaible in a 28 pin power PLCC package. In the PLCC package the circuit ground is connected to the lead frame batwing. External heatsinking is achieved by soldering the ground leads onto a copper ground plane. Note: The power ground pin (PWR GND) should also be connected to the ground plane.

Maximum continuous output current is heavily dependant on the heatsinking applied and ambient temperature. Consult figures 13, 20, 21 and 22 to determine the maximum output current under varying conditions.

Ordering Information

Package	Temp. range	Part No.
TO-220	-40 to +85°C	PBD 3545/1N
PLCC	-40 to +85°C	PBD 3545/1QN

Specifications subject to change without notice.
IC4 (88081) A-Ue

Revised edition May 1991

ERICSSON

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PBD 3548/1
Universal Source Driver

Description

PBD 3548/1 is a bipolar universal high-current highly-protected high side driver with transparent input and 2 A continuous-current source capability. A low-level input activates the output.

The driver is equipped with extensive electrical protection, such as overcurrent protection and thermal protection, which makes the device viritually indestructible. Furthermore it can detect open circuit and short circuit to V_{CC}.

A special feature is the Error indicating output function pin which signals to the host system if the protection or the load check functions is activated.

Typical loads are solenoids, relays or resistive loads.

The PBD 3548/1 and PBD 3545/1 are complementary drivers and have similar data.

Key features

- 2 A continuous-output current
- Short circuit to ground protection
- Error signal to host system
- Open circuit detection
- Short circuit to V_{CC} detection
- Thermal protection
- Built-in protection diodes
- LS-TTL, CMOS, and supply voltage compatible input
- ESD protected
- 5-pin TO-220 package, or 28-lead power PLCC with lead-frame for heat-sinking through PC board copper.

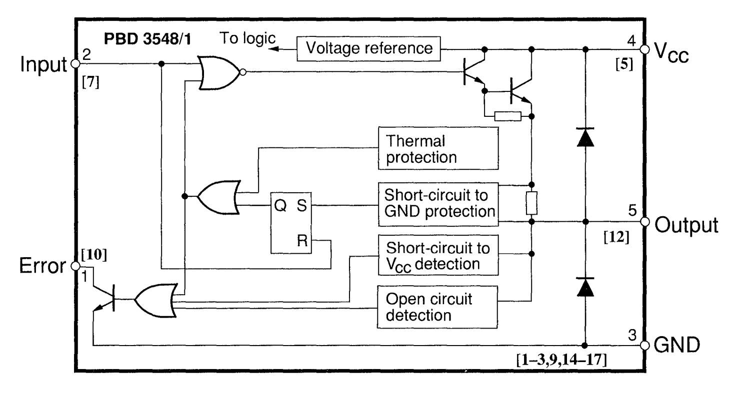
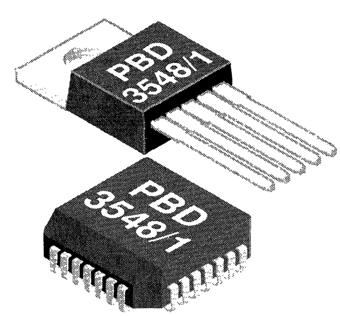


Figure 1. Block Diagram. Pin number in brackets refer to PLCC package.



TO-220 5-pin package
28-pin PLCC package

Maximum Ratings

Parameter	Pin no.* (note 1)	Symbol	Min	Max	Unit
Voltage					
Supply voltage	1 [21]	V_{CC}	0	45	V
Logic input voltage	5 [5]	V_{In}	-0.3	V_{CC}	V
Current					
Logic input current	5 [5]	I_{In}	-10		mA
Continuous DC Operation output current	2 [24]	I_{Out}	-2		A
Error output current	4 [7]	I_{Err}		10	mA
Temperature					
Operating junction temperature (internally limited)		T_J		+140	°C
Storage temperature		T_{Stg}	-55	+150	°C
Power Dissipation (Package Data)					
Power dissipation at T_{Case} = 85°C, TO-220 package		P_D		11	W
Power dissipation at T_{Case} = 85°C, PLCC package		P_D		5	W
ESD					
ESD tolerance (Note 2)			2000		V

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Supply voltage	V_{CC}	4.75		40	V
Output current	I_{Out}	-2			A
Operating ambient temperature	T_{Amb}	-40		+85	°C
Error output current	I_{Err}		5	8	mA

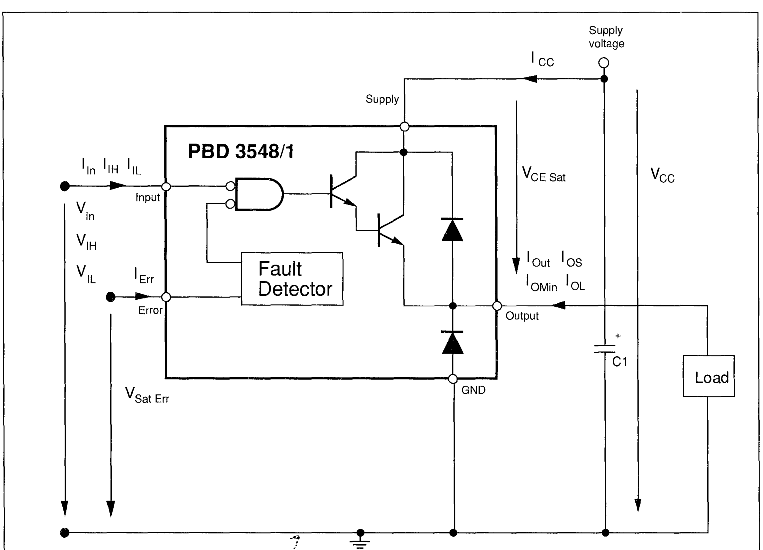


Figure 2. Definition of symbols.

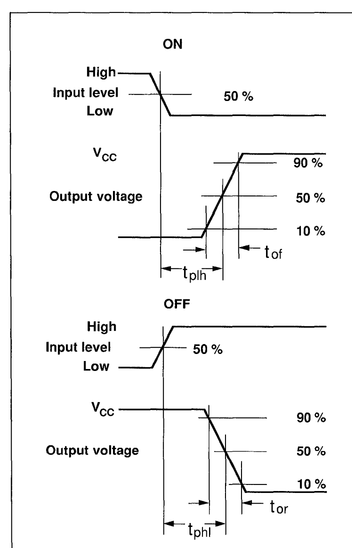


Figure 3. Timing diagram, input vs. output. V_{CC} = 24V.

Electrical Characteristics

At 5 V ≤ V_{CC} ≤ 40 V, -40°C ≤ T_J ≤ +100°C. Typical values are given at V_{CC} = 24 V, T_J = 25°C.

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
General							
Supply currrent	I_{CC}	2,7	2.0 ≤ V_{IN} ≤ V_{CC}	1.5	4	7	mA
Thermal shutdown	T_{JS}			+120	+130	+140	°C
Thermal shutdown release	T_{JSR}			+110	+120	+130	°C
Logic input							
High level input voltage	V_{IH}	2		2.0		V_{CC}	V
Low level input voltage	V_{IL}	2		-0.3		0.8	V
High level input current	I_{IH}	2,9	2.0 ≤ V_{IN} ≤ V_{CC}			20	µA
Low level input current	I_{IH}	2,9	0 ≤ V_{IN} ≤ 0.8	-400	-4		µA
Outputs							
Error output saturation voltage	$V_{Err\ SAT}$	2,10	I_{Err} = 5 mA		0.2	1	V
Output saturation voltage	$V_{CE\ SAT}$	2,11	I_{OUT} = -2 A		1.9	2.4	V
Output current shutdown	I_{OS}	2,5,14	0 ≤ V_{IN} ≤ 0.8 V	-5.0	-3.5	-2.0	A
Output current (not detected as open circuit)	I_{OMIN}	2,5	0 ≤ V_{IN} ≤ 0.8 V	-8	-3	-1	mA
Output leakage current	I_{OL}	2,12	2.0 ≤ V_{IN} ≤ V_{CC}. Output = V_{CC}	-2	-6	-8	µA
Clamping diode forward voltage		8	I_F = 2.0 A		1.5	1.8	V
Timing							
Propagation time		3	I_{OUT} = - 2 A				
Output low to high (50%),	t_{plh}				0.6	1.0	µs
Output high to low (50%),	t_{phl}				0.5	1.0	µs
Rise time (10 to 90%),	t_{or}	3			0.6	1.0	µs
Fall time (90 to 10%),	t_{of}	3			0.2	0.4	µs

Thermal Charateristics

Parameter	Symbol	Ref fig.	Conditions	Min	Typ	Max	Unit
Thermal resistance	Rth_{J-C}	21	TO-220 package, junction to case		5		°C/W
	Rth_{J-A}	21	TO-220 package, junction to ambient		60		°C/W
	Rth_{J-BW}	20	PLCC package, junction to batwing		10		°C/W
	Rth_{J-A}	20,22	PLCC package. Note 3.		35		°C/W

Notes: 1. Currents are defined positive if flowing into, and negative if flowing out of a terminal. Voltages are defined between terminal and ground.

2. ESD testing according to Human Body Model (C_{Zap} = 100 pF, R_{Zap} = 1500 Ω)

3. All gound pins soldered onto a 20 cm² PCB copper area with free air convection, T_A = + 25°C.

Pin Description

TO-220	PLCC	Symbol	Description
1	[5]	Error	Error indicating pin. Sinks current to ground if the protection and/or detection circuitry is activated. Note: the current must be externally limited to 8 mA.
2	[7]	Input	TTL compatible input. A HIGH input signal turns the output transistor off and a LOW input turns it on. If the input is left open it will be detected as high level.
3	[1-3,9 13-17, 28]	GND	Ground supply. Note: for PLCC these pins are used thermally for heat sinking. Make sure that all pins are soldered onto a suitably large copper ground for efficient heat sinking.
4	[10]	Supply	Supply voltage. Nominally 5 V to 40 V.
5	[12]	Output	Output pin. Current flows out from this pin through the load to GND. Nominal current is 8 mA to 2 A.
	[4,6,8,11, 18-27]	NC	No connection. Pins are not bonded to the chip and may therefore be soldered to any PC board trace for efficient heat sinking.

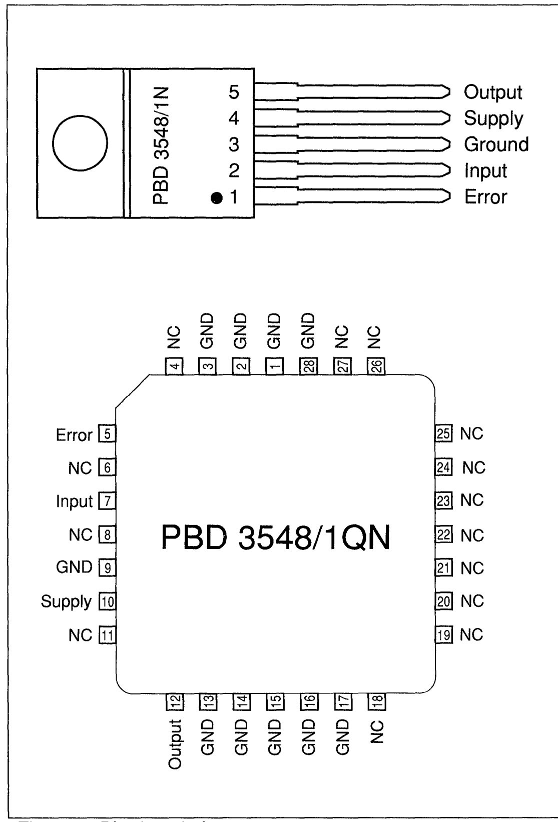


Figure 4. Pin descriptions.

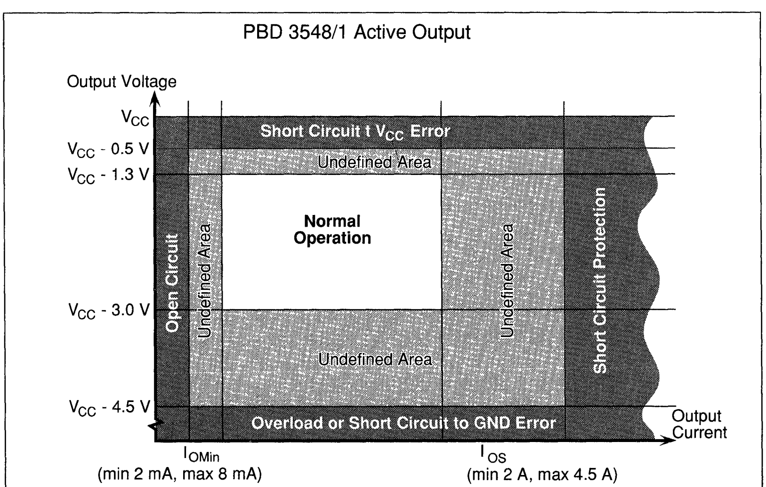


Figure 5. Error state vs. output voltage and output current, active output ($0V \leq V_{IN} \leq 0.8$ V, 5 V < V_{CC} < 40 V and -40°C <+T_J>+100°C)

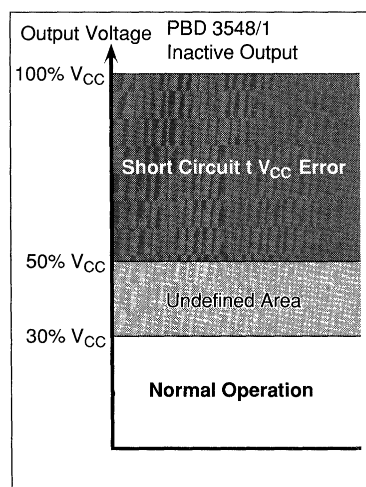


Figure 6. Error state vs. output voltage, inactive output (2.0 V ≤ V_{IN} ≤ V_{CC}, 5 V ≤ V_{CC} ≤ 40 V and -40°C <T_J<+100°C).

Typical performance characteristics

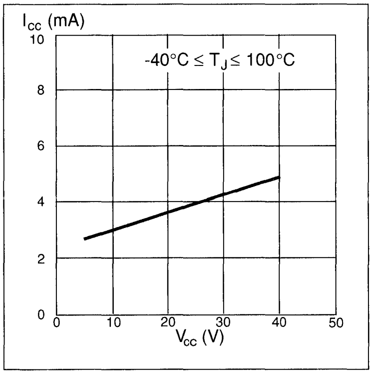


Figure 7. Current consumption vs. supply voltage at 2 V ≤ V_{in} ≤ V_{CC}V.

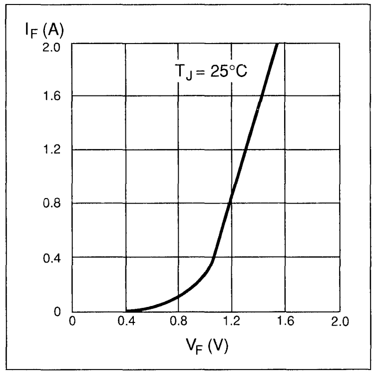


Figure 8. Diode forward voltage drop vs. forward current.

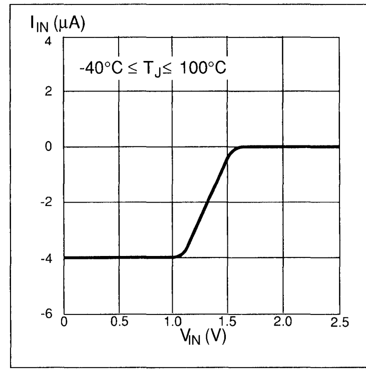


Figure 9. Input current vs. input voltage. 5 V ≤ V_{CC} ≤ 40 V.

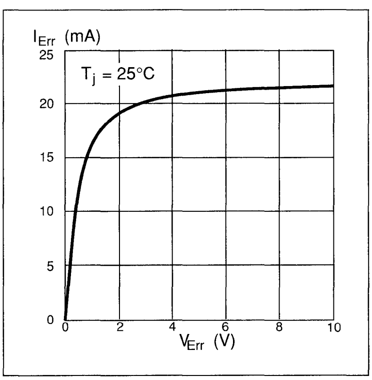


Figure 10. Error output saturation voltage vs. error current. V_{CC} = 24 V.

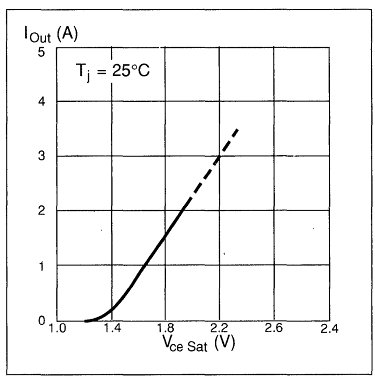


Figure 11. Output saturation voltage vs. output current. 5 V < V_{CC} < 40 V.

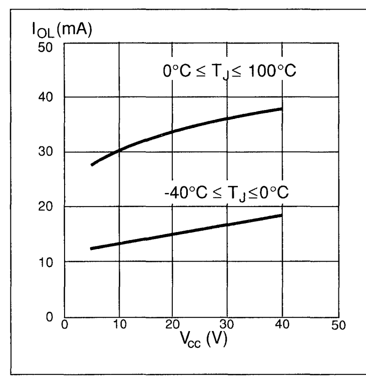


Figure 12. Output leakage current vs. supply voltage. 2.0 V ≤ V_{IN} ≤ V_{CC}. Output = V_{CC}.

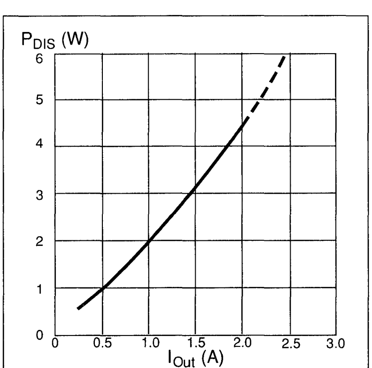


Figure 13. Power dissipation vs. output current.

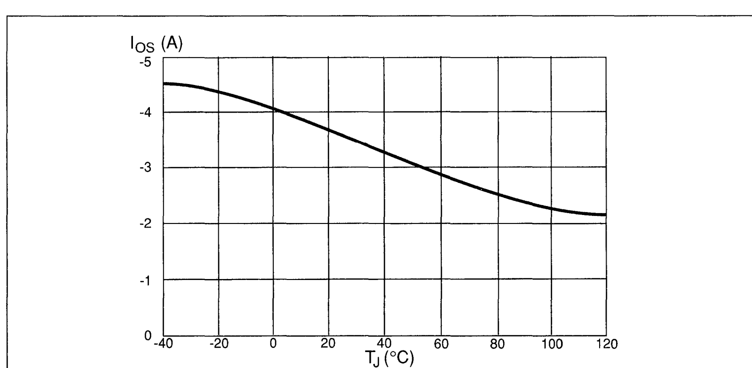


Figure 14. Output current shut-down vs. chip temperature. 5 V ≤ V_{CC} ≤ 40 V.

Functional Description

The circuit PBD 3548/1 is a high side driver capable of driving resistive or inductive loads not exceeding 2 A.

The driver has an error indicating function which generates an Error output signal when a fault condition has occurred.

The circuits PBD 3548/1 and PBD 3545/1 are complementary drivers with equivalent functions and similar data. PBD 3548/1 is a source driver and PDB 3545/1 is a sink driver.

Input stage

The output stage is switched on and off according to the status of the input. LOW level activates the output. If the input is left open, the circuit will accept it as a HIGH level.

Output stage

The output stage contains a power transistor and two clamping diodes. The diodes are used for terminating line transients from inductive loads. If the driver is inactive and the output is shorted to V_{CC} the driver will leak a maximum of 40 mA. See figure 12.

Protection circuitry

The circuit contains two protection circuits:

- Overload and Short circuit protection
- Thermal protection

The overload and short circuit protection will be activated at I_{out}= 3.5 A typically at T_J= +25°C, see figure 14.

The output will be turned off immediately and latched to a high-impedance state after an overload or short circuit has been detected.

A logic-level change at the input will reset the internal error latch. If the fault still is present at turn-on, the circuit will once again turn the output off.

Due to a slight delay in the circuit, a high current transient will occur when the output is shorted to GND. This current transient may reach 8 A during 5 µs. Consequently, switching at high frequencies with a shorted output may destroy the circuit. If a short circuit condition is detected, stop switching the input and remove fault condition.

Thermal protection

The output of PDB 3548/1 is equipped with a thermal shut-down function, which limits the junction temperature to typically +130°C. The output will be turned off until the junction temperature has decreased to approximately 120°C.

Error functions

The Error indicating signal occurs on a separate pin. The complete error table is shown in figure 17.

The following conditions generate an error signal:

When the driver is activated and at least one of the following conditions has occurred:

- thermal overload
- short circuit to GND
- short circuit to V_{CC}
- open circuit

An output current less than 8 mA might be detected as "open circuit". Output currents larger than 8 mA and less than 2 A will definitely not generate an error. The normal operational area is shown in figure 5.

Also when the driver is inactivated an Error indication can occur. That is if the output is shorted to V_{CC}. In figure 6 short circuit to V_{CC} Error state versus output voltage is shown.

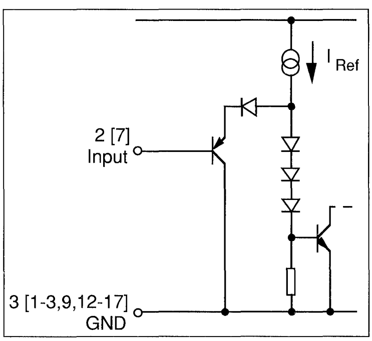


Figure 15. Input stage.

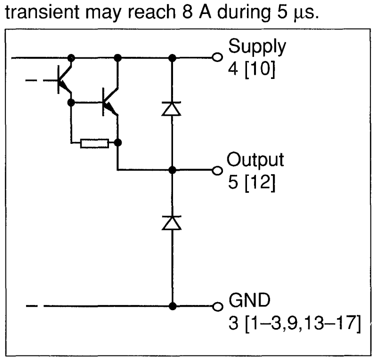


Figure 16. Output stage.

Fault condition	Input	Output	Error LOW=ERROR HIGH=Normal	How to resume normal operation
Normal	0 LOW	1 ON	1 HIGH	——
	1 HIGH	0 OFF	1 HIGH	——
V_{OUT} Short to V_{CC}	0 LOW	1 ON	0 LOW	Remove fault condition.
	1 HIGH	0 OFF	0 LOW	Remove fault condition.
V_{OUT} Short to GND	0 LOW	0 OFF	0 LOW	Turn off and on after fault condition is removed.
	1 HIGH	0 OFF	1 HIGH	——
Open load	0 LOW	1 ON	0 LOW	Attach proper load to output or turn off the driver.
	1 HIGH	0 OFF	1 HIGH	——
Over temperature	0 LOW	0 OFF	0 LOW	Temperature is reduced to approx 120°C, or turn off the driver.
T_J=130 °C	1 HIGH	0 OFF	1 HIGH	——

Figure 17. Error table.

When the Error-detection function is activated, the Error output is capable of sinking 8 mA, supporting direct connection of an LED. The current has to be externally limited by a series resistor.

Signal diagrams

The signal diagram in figure 18 shows the input signal and the resulting output signals for each error mode. For details, se error table, figure 17.

V_{In} = Input voltage. Active = LOW.

V_{Out} = Output voltage.

I_{Out} = Output current from driver.

V_{Err} = Error output voltage. Error = LOW.

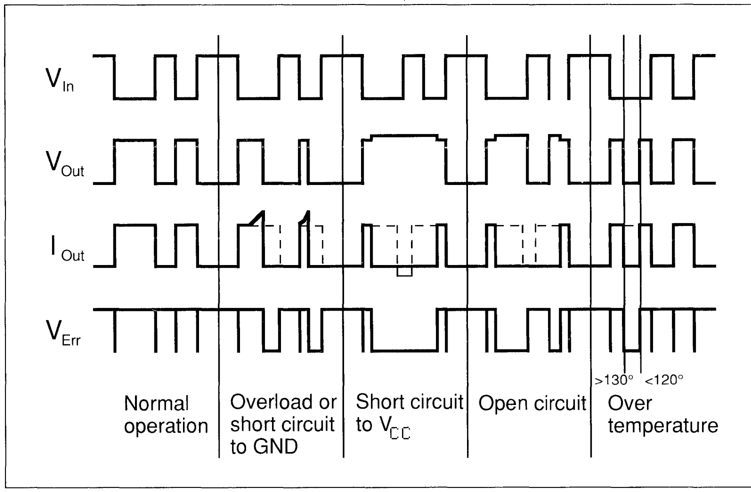


Figure 18. Signal diagram

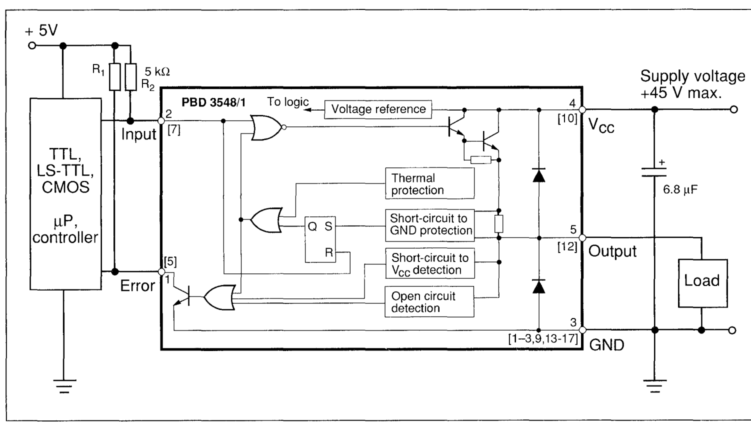


Figure 19. Typical application. Pin numbers refer to TO 220 package.

Applications Information

Important application areas are:

- Programmable logic control systems.
- Security systems.
- Relay control.
- Hydraulic valves.
- Intelligent interfaces between microprocessors and loads.
- Vehicle control systems.
- Robot techniques.
- Dashboard information systems.
- Print head drivers.
- High-current stepper motor drivers with security aspects.

Transient protection

1. Keep V_{CC} and GND leads as short as possible. Use different supplies if possible.
2. Connect a filter capacitor close to the circuit. Recommended filter capacitor between V_{CC} and GND is 6.8 µF, of tantalum type. A ceramic capacitor in parallel will improve high frequency decoupling. Typical values range from 0.002 µF to 0.1 µF. In an application having a highly stable supply and short power leads to the driver a low leakage electrolytic type can be used, which is less expensive.
3. Connect Input and Error via pull-up resistors to the appropriate logic supply level or V_{CC} to obtain highest noise immunity. Se figure 19. The resistor R_1 limits the current into the Error indicating pin. This current must not exceed 8 mA. R_2 is a pull-up resistor which improves noise immunity at the Input. Pull-up current should not exceed the sinking capacity of the controlling device output.
4. If several supply voltages are to be used, prefer a supply having separate ground leads. In this case the logic ground and the power ground should be connected together at only one point, the ground pin of the driver.

Switch mode applications

The internal diodes are normally sufficient for clamping of transients caused by inductive load turn off. External diodes may be necessary in PWM/switch mode applications, and when the terminals are externally accessible and thereby exposed to an electrically noisy environment. Recommended diodes are BYV27/100, BYV98/100, UF4001 or similar types with a t_{rr} < 100 ns and $I_F \geq 1$ A.

Error indication signal

When the circuit is switched on/off, a short pulse (t_{Err}<10 µS for resistive loads) is generated at the Error output. This is a correct detection of an incorrect level during the rise and fall times of the output voltage. Consequently the Error output should not be detected when switching on and off. An alternative is to low-pass filter at the Error output at around 100 kHz.

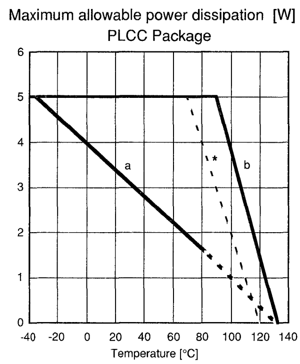


Figure 20. Maximum allowable power dissipation. PLCC package.

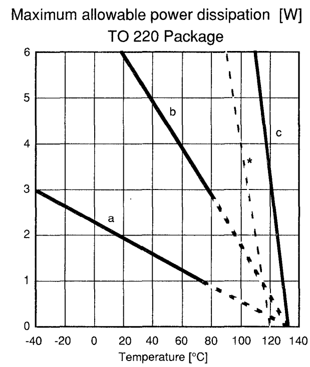


Figure 21. Maximum allowable power dissipation. TO 220 package.

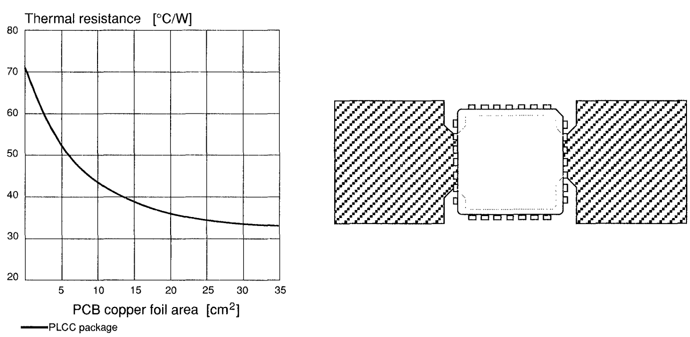


Figure 22. Typical thermal resistance vs. PC board copper area and suggested layout.

Heat sinking

PBD 3548/1N is packaged in a 5-pin TO 220 power package. The circuit GND is connected to the heat sink tab. External heatsinking is achieved by mounting the package to a heat sink.

The circuit is also available in a 28 pin power PLCC package. In the PLCC package the circuit ground is connected to the lead frame batwing. External heatsinking is achieved by soldering the ground leads onto a copper ground plane. Note: The power ground pin (PWR GND) should also be connected to the ground plane.

Maximum continuous output current is heavily dependent on the heatsinking applied and ambient temperature. Consult figures 13, 20, 21 and 22 to determine the maximum output current under varying conditions.

Ordering Information

Package	Temp. range	Part No.
TO-220	-40 to +85°C	PBD 3548/1N
PLCC	-40 to +85°C	PBD 3548/1QN

IC4 (88082) A-Ue

Revised edition May 1991

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September 1988

PBM 3961 DC Brushless Motor Controller

Description

PBM 3961 is a C-MOS control circuit for constant speed applications. The IC and a minimum number of external components provide all necessary functions to start, drive, control and break a three phase, four pole DC Brushless motor. Closed-loop PI (proportional-integrating) control implemented with digital-only signal processing makes the circuit insensitive to component tolerances and aging. No external resistors/ capacitors are required what so ever to stabilize the control-loop. The circuit, which connects to external power MOS-transistors, uses PWM (pulse-width modulation) techniques to control the motor speed, thus minimizing power losses and heat-sinking requirements. A level-sensitive disable input with hysteresis, can be used for current-limiting during start up. A special feature is a correct-speed signal, signalling when the actual motor speed is within ±0.7% of the correct value. The circuit is packaged in 16 pin plastic DIP or SO 16 package.

Key Features

- Current limitation
- Lock-at-speed indication
- Direction control
- Digital filters - requires no external compensation components
- Direct interface to Hall sensors (TTL level)
- 16 pin plastic DIP-package or SO 16

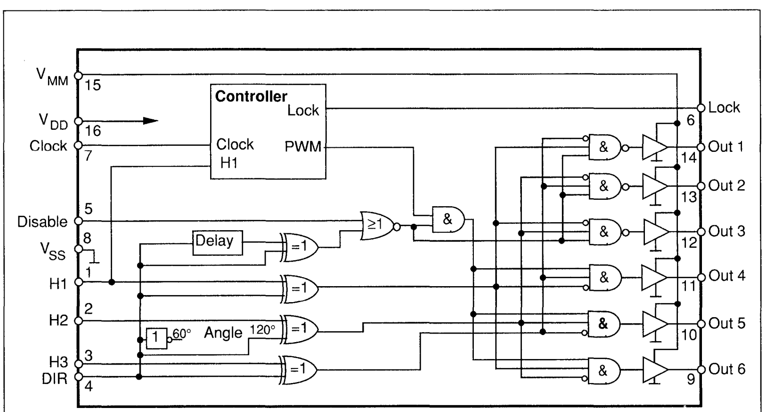
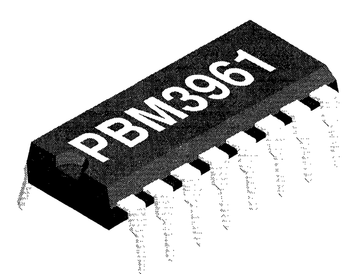


Figure 1. Block diagram.



16-pin plastic DIP

Maximum Ratings

Parameter	Pin no.	Symbol	Min	Max	Unit
Voltage					
Motor supply	15	V_{MM}	0	14	V
Logic supply	16	V_{DD}	0	6	V
Logic inputs	1-5, 7	V_I	-0.3	V_{DD}+0.3	V
Current					
Logic inputs	1-5, 7	I_I	-0.5	+0.5	mA rms
Temperature					
Storage temperature		T_s	-55	150	°C
Ambient operating temperature		T_a	0	70	°C

Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Motor supply voltage	V_{MM}	V_{DD}		12	V
Logic supply voltage	V_{DD}	4.75	5.0	5.25	V
Ambient temperature	T_a	0	25	70	°C
System clock frequency	f_C	2		8	MHz

Electrical Characteristics

Electrical characteristics over recommended operating conditions, V_{MM} = 12 V.

Parameter	Symbol	Ref. fig.	Conditions	Min	Typ	Max	Unit
Logic inputs							
Logic high	V_{IH}		Valid for H1, H2, H3, Clock, Dir		1.8	2.0	V
Logic high Disable	V_{IHD}				1.2	1.5	V
Logic low	V_{IL}		Valid for H1, H2, H3, Clock, Dir	0.8	1.0		V
Logic low Disable	V_{ILD}			0.8	1.0		V
Input DC-current	I_I		$V_{SS} < V_I < V_{DD}$, valid for Clock, Dis.	-1		1	µA
Input DC-current	I_{IH}		V_I = 1.5 V, valid for H1, H2, H3, Dir.	-750		-150	µA
Input capacitance	C_I				5		pF
Outputs							
Output current Low, Lock	I_{OL}		V_O = 0.4 V	4	16		mA
Output current High, Lock	I_{OH}		V_O = 2.4 V		-20	-8	mA
Output current Low, Out1-6	I_{OutL}		V_{Out} = 1.0 V	20	50		mA
Output current High, Out1-6	I_{OutH}		V_{Out} = 11.0 V		-30	-12	mA
Timing Characteristics							
Clock period time,	t_{cp}	2a		125	250	1000	ns
Clock High time,	t_{ch}	2a		60			ns
Clock Low time,	t_{cl}	2a		60			ns
Clock transition time,	t_{ct}	2a				20	ns
PWM period,	t_{pwp}	2b			$128 \cdot t_{cp}$		
Propagation delay,	t_{dHall}	3a	H1-3 to Out=90% of final value, C_{Load}=1 nF.		200	500	ns
Propagation delay,	t_{dDis}	3b 3c	Disable or Dir to Out=90% of final value, C_{Load}=1 nF.		200	500	ns
Disable time when Dir toggles	t_{tDis}	3b		$64 \cdot t_{cp}$		$128 \cdot t_{cp}$	ns

Figure 2. Timing diagram

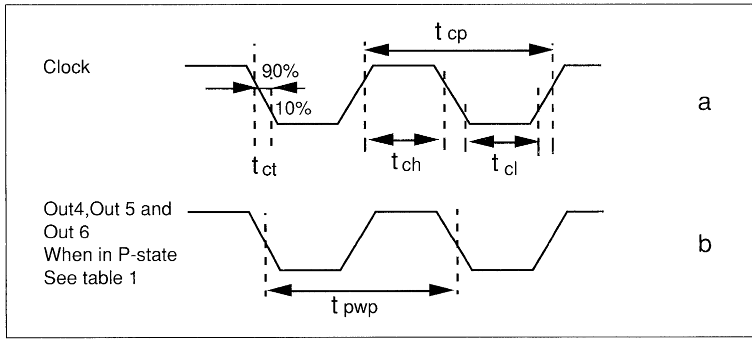
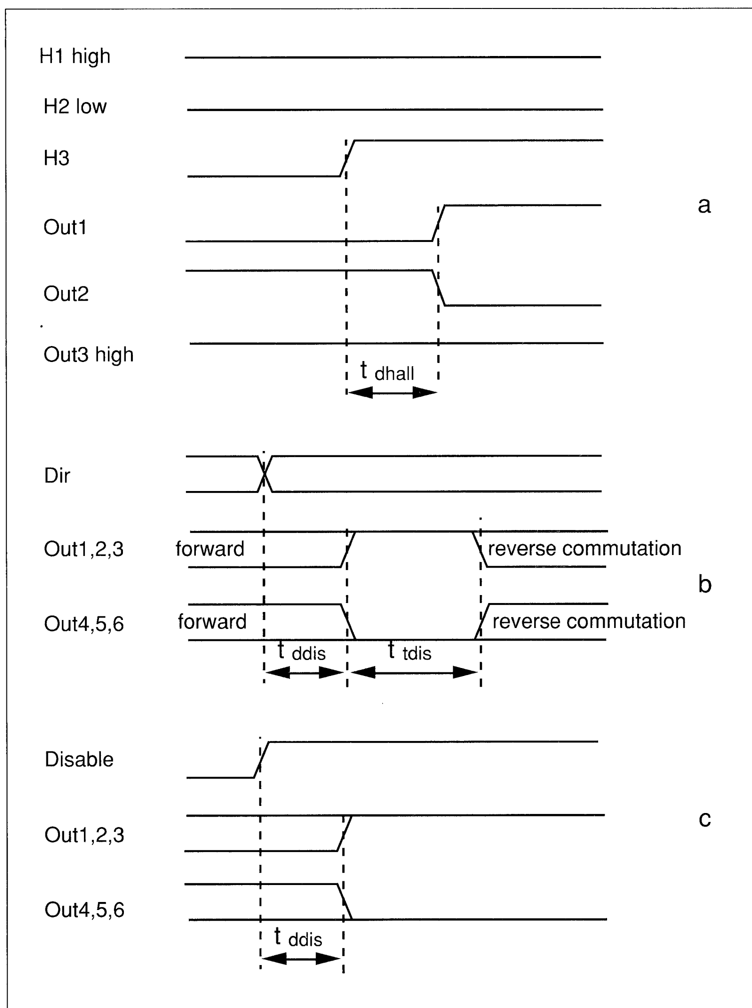


Figure 3. Timing diagram.



Pin Descriptions

Refer to figure 6 (16-pin dual-in-line package)

Pin	Symbol	Description
1	H1	Hall element 1
2	H2	Hall element 2
3	H3	Hall element 3
4	Dir	Controls the direction of the motor. Can also be used for braking together with the disable input.
5	Disable	A high level turns the drive stage into a high impedance mode (tri-state).
6	Lock	Indicates that the motor runs at correct speed 3600 rpm (60 Hz) ±0.7 % at a reference frequency of 4 MHz.
7	Clock	Reference frequency for the control loop (4 MHz).
8	V_{SS}	Ground supply - 0 Volt
9	Out 6	Controls an external n channel transistor - Winding 3.
10	Out 5	Controls an external n channel transistor - Winding 2.
11	Out 4	Controls an external n channel transistor - Winding 1.
12	Out 3	Controls an external p channel transistor - Winding 3.
13	Out 2	Controls an external p channel transistor - Winding 2.
14	Out 1	Controls an external p channel transistor - Winding 1.
15	V_{MM}	Motor voltage - normally the same voltage as applied to the motor.
16	V_{DD}	Logic supply voltage

The inputs H1, H2, H3 and Dir have internal pull-up transistors.

The circuit has a metal mask choice ANGLE in the communication logic. It is possible to choose between:

1. A motor with hall elements placed with 120 degrees electrical angle.
2. A motor with hall elements placed with 60 degrees electrical angle.

The choice in this version is 120 degrees.

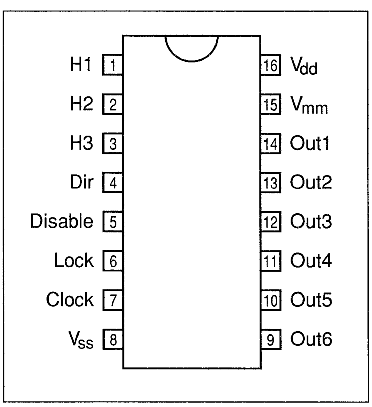


Figure 4. Pin configuration.

Functional Description

The circuit PBM 3961 is a complete control system for constant speed motor applications. The circuit handles commutation, pulse width modulation and speed regulation of a 4-pole, 3-phase DC Brushless motor running at constant speed.

The IC requires six external MOS transistors and an external clock reference. The IC is optimized for a 3600 rpm disc drive motor using a 4 MHz reference clock. Best performance will be achieved between 1800 and 7200 rpm depending on motor load and V_{MM} voltage. The external MOS transistors are controlled by pulse width modulation.

This is done by measuring the frequency at one of the three hall elements inside the motor. This signal is fed into the circuit which will control the duty cycle of the pulse width modulated signals to the drive stage. The duty cycle regulates the speed of the motor to the correct value.

The correct motor speed is the clock frequency divided by 66688, if the motor is a 4-pole, 3-phase, Y or delta wound DC Brushless motor. The speed will be approximately 60 r.p.s if a 4 MHz Clock frequency is used. (When the motor runs at 60 r.p.s. the frequency of the hall element input H1 will be 120 Hz for a 4-pole motor.)

The disable input is used to limit the start-up current. A current sensing resistor will be needed to accomplish this, see typical application.

Inputs

The logic inputs H1, H2, H3, Disable, Dir and Clock forms the basic data for the output logic. H1, H2 and H3 are the signals from the hall elements inside the motor. These signals contains the information about the position of the rotor and are fed to three EXOR gates. If Dir is low (forward) the outputs of the EXOR-gates will follow the H signals. If Dir is set high the outputs of the gates will be the inverted H signals which will lead to reverse commutation. The input logic also contains a delay function to avoid the output to cross-conduct while the direction of the motor is changed. As Dir changes state the drive stage is in tristate for between 64 and 128 clock cycles (16-32 µs when 4 MHz at Clock).

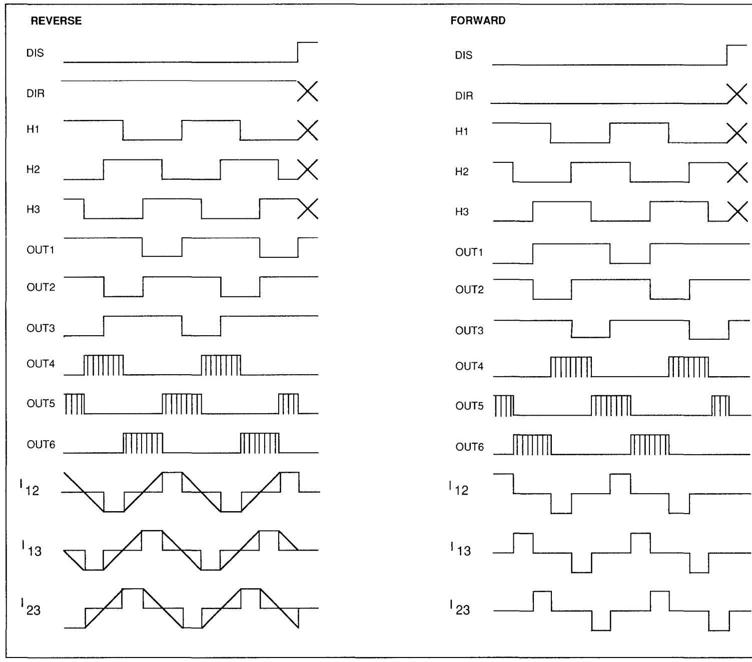


Figure 5. Voltage and current waveforms.

Disable Conditions as below	Dir	H1	H2	H3	Out1	Out2	Out3	Out4	Out5	Out6
HIGH	X	X	X	X	1	1	1	0	0	0
LOW	0	0	0	0	1	1	1	0	0	0
LOW	0	0	0	1	1	0	1	P	0	0
LOW	0	0	1	0	1	1	0	0	P	0
LOW	0	0	1	1	1	1	0	P	0	0
LOW	0	1	0	0	0	1	1	0	0	P
LOW	0	1	0	1	1	0	1	0	0	P
LOW	0	1	1	0	0	1	1	0	P	0
LOW	0	1	1	1	1	1	1	0	0	0
LOW	1	0	0	0	1	1	1	0	0	0
LOW	1	0	0	1	0	1	1	0	P	0
LOW	1	0	1	0	1	0	1	0	0	P
LOW	1	0	1	1	0	1	1	0	0	P
LOW	1	1	0	0	1	1	0	P	0	0
LOW	1	1	0	1	1	1	0	0	P	0
LOW	1	1	1	0	1	0	1	P	0	0
LOW	1	1	1	1	1	1	1	0	0	0

X = 1 or 0; P = Pulse width modulated signal.
There are two different ways to turn the external drive stage into tristate mode:
1. The voltage level at the Disable pin exceeds V_{IHD}
2. The voltage level at the V_{MM} input is below typically $V_{DD}/2$

Table 1. Commutation.

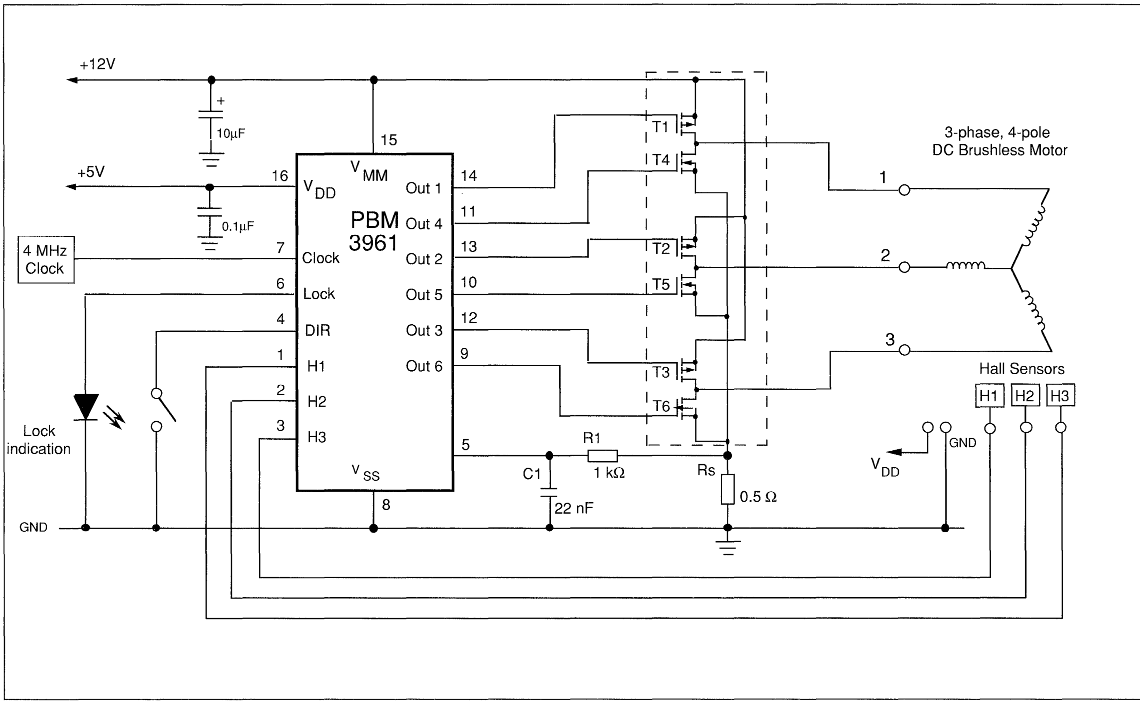


Figure 6. Typical application, T1 — T6 are P and N channel power MOS FETs.

Controller

H1 is fed to the controller and indicates the actual speed of the motor. The controller will compare the frequency of the H1 signal with the clock reference.

If the motor runs at the correct speed ±0.7% the output lock is set high. H1 signal is filtered internally to avoid that a single false speed value turns lock low. The frequency of the pulse width modulated signal is the clock frequency divided by 128.

Outputs

The logic in front of the outputs Out1-Out6 are for comutation e. i. decides in which of the motor windings current should flow, and in what direction. Commutation is performed according to table 1.

During normal operation the N-channel transistors in the external drive stage are pulse width modulated, since they are usually faster than the p-channel devices. The current is slowly decreased via a diode and a conducting p-channel device. This drive method ensures that there is only a small current ripple.

When disable is high, energy is fed back from the motor to the power supply via two diodes. This makes the current decay fast.

Ordering Information

Package	Temp. Range	Part No.
Plastic DIP	0 to 70°C	PBM3961N

Specifications subject to change without notice.

IC4 (88083) A-Ue

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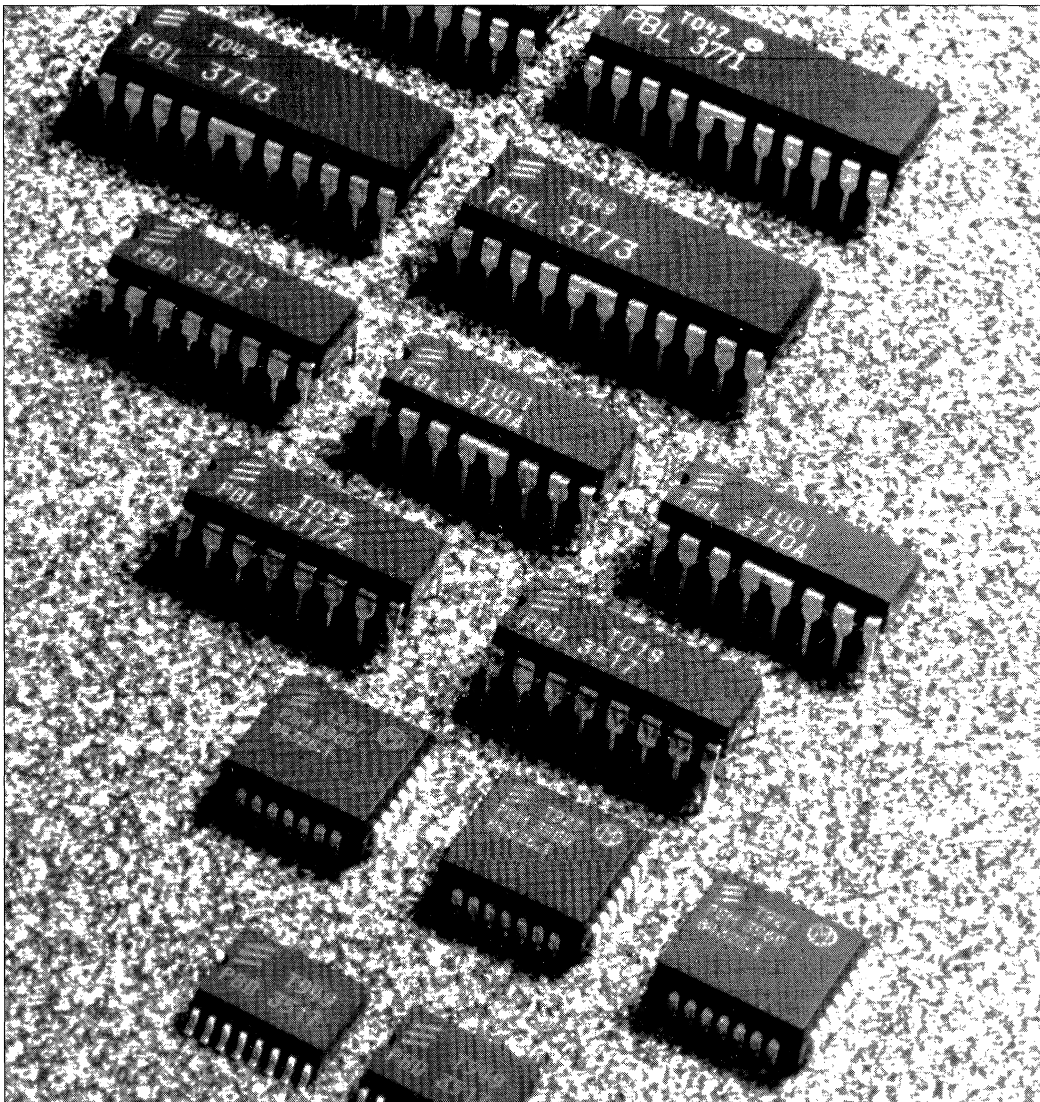
IC Package Mechanical Specifications



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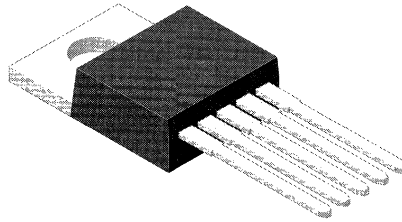
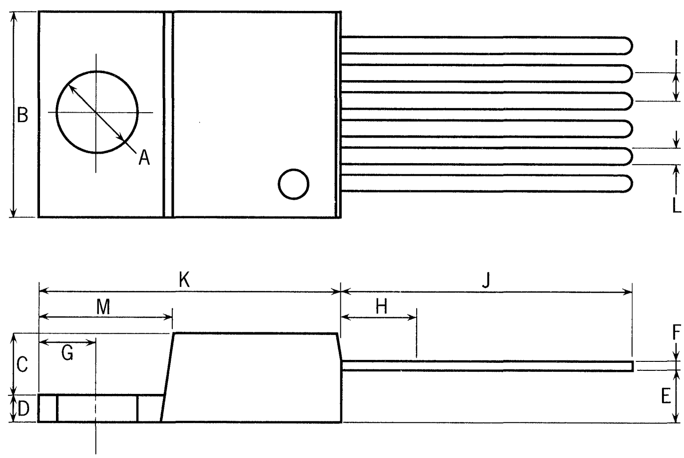
5-lead TO-220

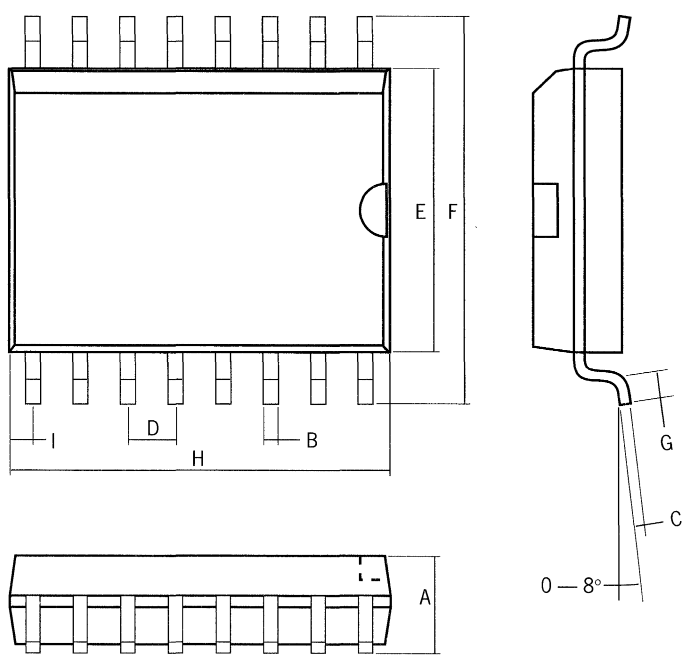
dim.	millimeters min.	max.	inches min.	max.
A	3.53	3.91	0.139	0.154
B	9.66	10.66	0.380	0.420
C	3.55	4.80	0.140	0.189
D	1.05	1.39	0.041	0.055
E	2.04	2.92	0.080	0.155
F	0.38	0.50	0.015	0.020
G	2.54	3.05	0.100	0.120
H		3.00		0.118
I	1.50	1.90	0.059	0.075
J	12.50	14.50	0.492	0.571
K	14.32	15.52	0.564	0.611
L	0.81	0.95	0.032	0.037
M	5.85	6.85	0.230	0.270

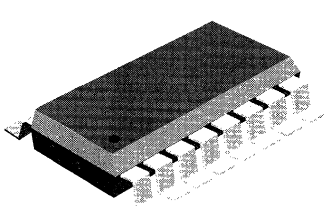




16-lead small outline package

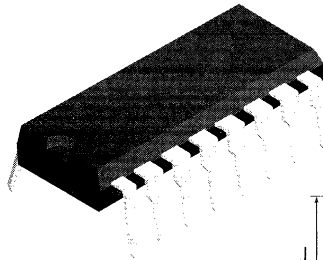
dim.	millimeters min.	max.	inches min.	max.
A	2.35	2.65	0.093	0.104
B	0.33	0.51	0.013	0.020
C	0.23	0.32	0.009	0.012
D	1.27 typical		0.050 typical	
E	7.40	7.60	0.291	0.299
F	10.00	10.65	0.394	0.419
G	0.40	1.27	0.016	0.050
H	10.10	10.50	0.397	0.460
I	0.66		0.026	

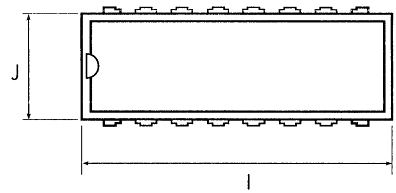


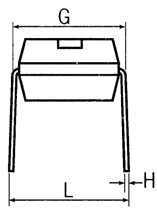


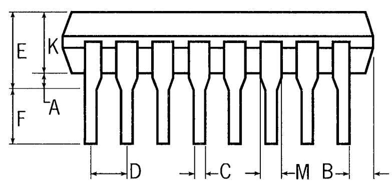
16-pin dual in-line package

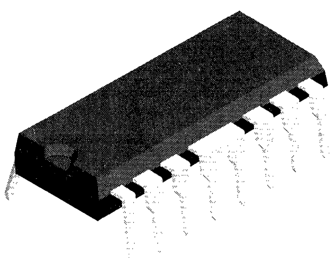
dim.	millimeters min.	millimeters max.	inches min.	inches max.
A	0.39		0.015	
B	0.13		0.005	
C	0.36	0.56	0.014	0.022
D	2.54 typical		0.100 typical	
E		5.33		0.210
F	2.93	4.06	0.115	0.160
G	7.62	8.25	0.300	0.325
H	0.20	0.38	0.008	0.015
I	18.93	21.33	0.745	0.840
J	6.10	7.11	0.240	0.280
K	2.93	4.95	0.115	0.195
L		10.92		0.430
M	1.15	1.77	0.045	0.070

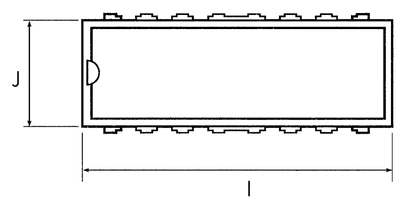


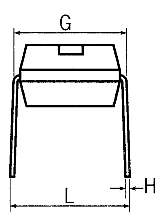


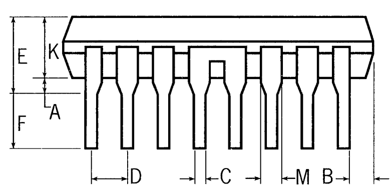






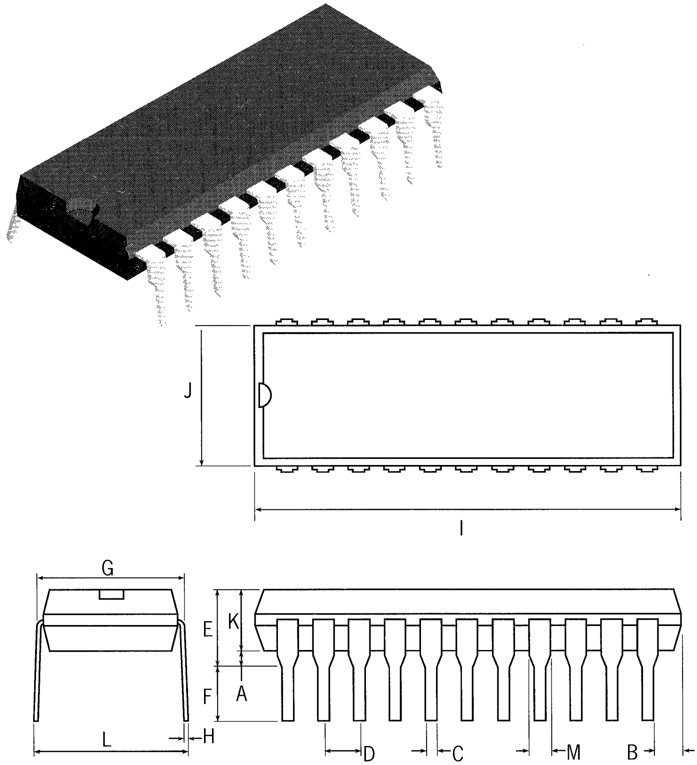


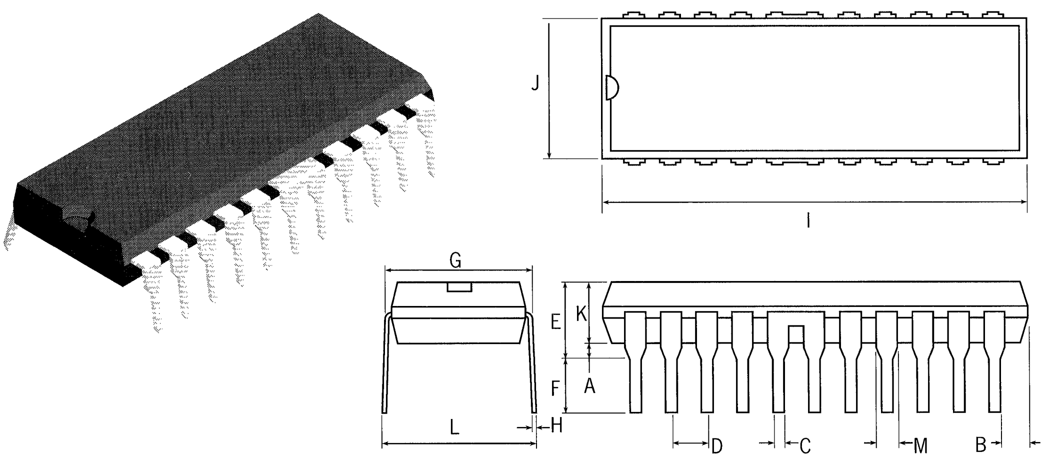




22-pin dual in-line package

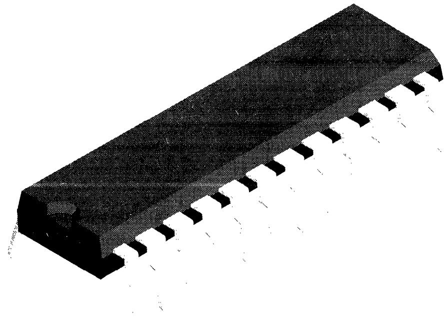
dim.	millimeters min.	max.	inches min.	max.
A	0.39		0.015	
B	0.13		0.005	
C	0.36	0.56	0.014	0.022
D	2.54 typical		0.100 typical	
E		5.33		0.210
F	2.93	4.06	0.115	0.160
G	9.91	10.79	0.390	0.425
H	0.20	0.38	0.008	0.015
I	26.67	28.44	1.050	1.120
J	8.39	9.65	0.330	0.380
K	3.18	4.95	0.125	0.195
L		12.70		0.500
M	0.77	1.77	0.030	0.070
N	0.56	1.17	0.022	0.046

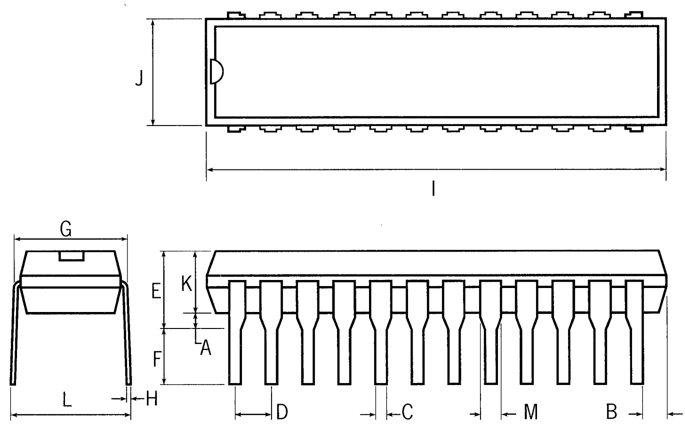




24-pin dual in-line package

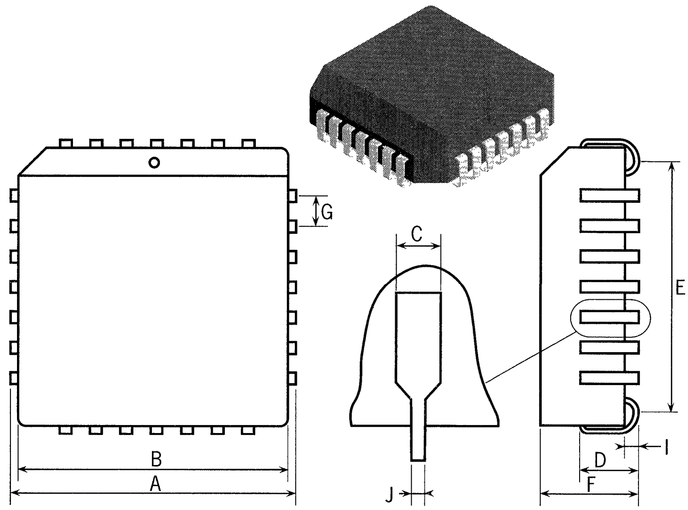
dim.	millimeters min.	max.	inches min.	max.
A	0.39		0.015	
B	0.13		0.005	
C	0.36	0.56	0.014	0.022
D	2.54 typical		0.100 typical	
E		5.33		0.210
F	2.93	4.06	0.115	0.160
G	7.62	8.25	0.300	0.325
H	0.20	0.38	0.008	0.015
I	28.60	32.30	1.125	1.275
J	6.10	7.11	0.240	0.280
K	2.93	4.95	0.115	0.195
L		10.92		0.430
M	1.15	1.77	0.045	0.070



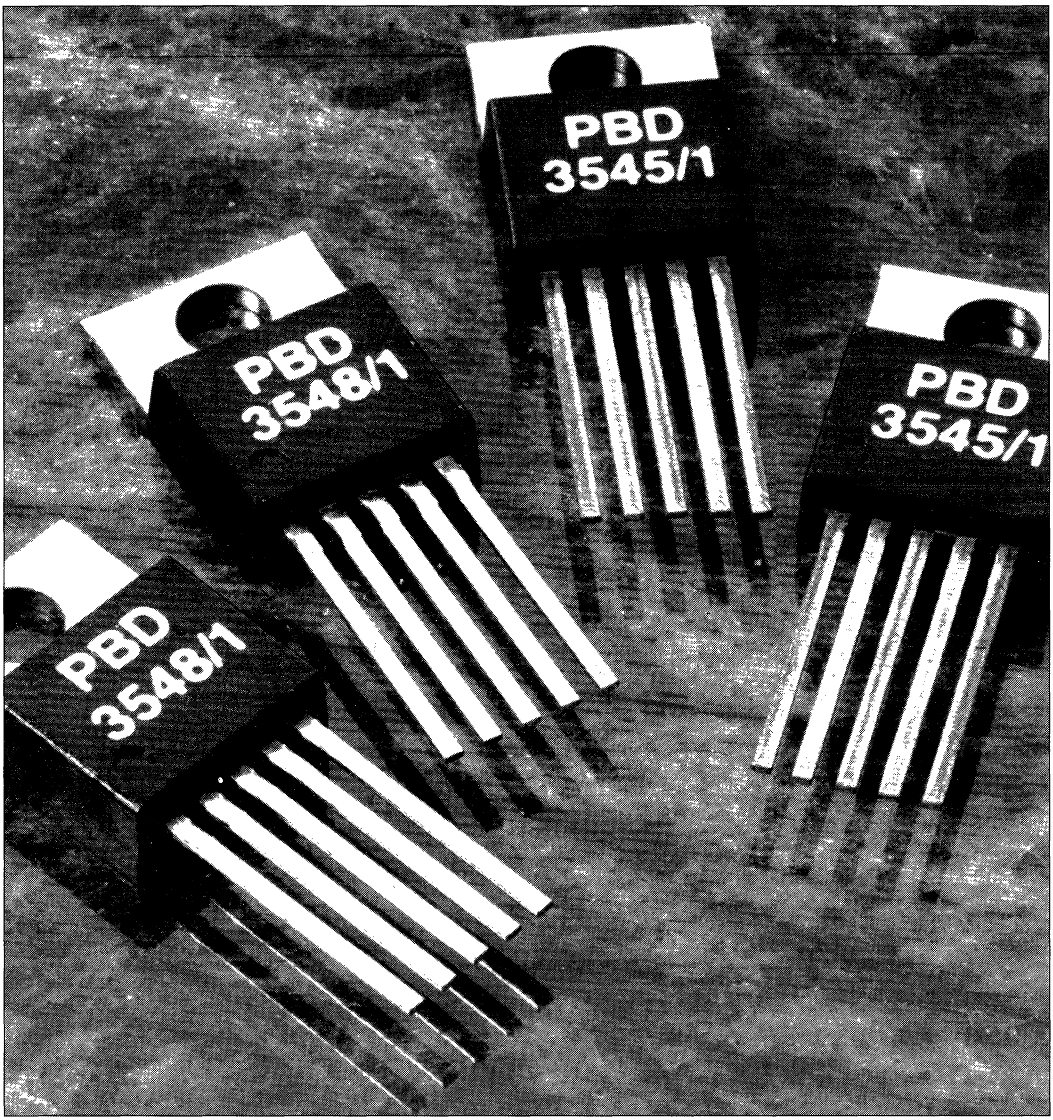


28-lead PLCC package

dim.	millimeters min.	millimeters max.	inches min.	inches max.
A	12.32	12.57	0.485	0.495
B	11.43	11.58	0.450	0.456
C	0.66	0.81	0.026	0.032
D	2.29	3.04	0.090	0.120
E	9.91	10.92	0.390	0.430
F	4.20	4.57	0.165	0.180
G	1.27 typical		0.050 typical	
I	0.51		0.020	
J	0.33	0.53	0.013	0.027



Intellligent Power Driver Application Notes



ERICSSON

Industrial Circuits Application Note

Transient protection for the PBD 3545/1 and PBD 3548/1

The PBD 3545/1 and PBD 3548/1 general purpose drivers are equipped with a very fast short circuit protection circuitry for reliable SOA (Safe Operating Area) protection of the Darlington output transistor. It is a thyristor-like structure which gives a fast latching turn off of the output transistor. A short circuit at the output creates not only a current spike, but also a voltage transient. This voltage transient activates the fast short circuit protection.

The short circuit protection could also be activated by a voltage transient that is not caused by a short circuit. Strong transients at the V_{cc}, Output or GND terminals may trigger the short circuit protection. Therefore, proper layout and filtering is important in order to avoid false triggering of the short circuit protection.

In some cases this transient protection may be too sensitive, for example when heavy load currents are switched on and off by a mechanical switch or relay located close to the circuit.

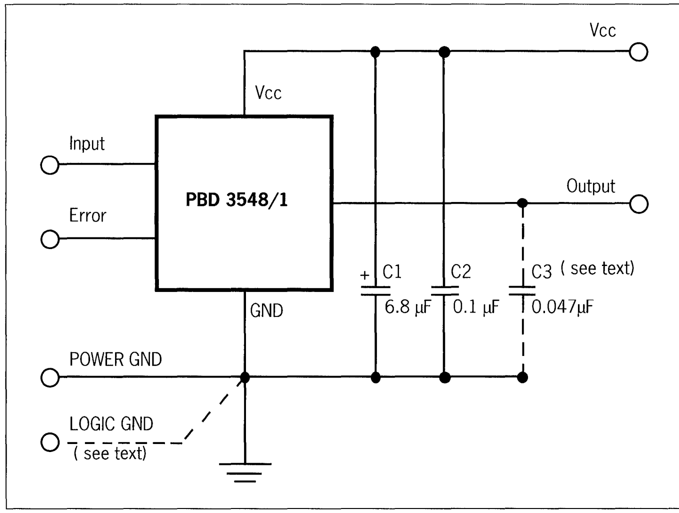


Figure 1. Basic decoupling in a typical application.

Design basics

Power supply and system layout:

Figure 1 shows a decoupling diagram which includes the minimum required decoupling components. In most applications this level of decoupling should be sufficient.

- Keep V_{cc} and GND leads as short and as low resistive possible.
- Use separate ground leads with only one common point at the ground pin of the driver.
- Use separate decoupling capacitors C1 and C2 placed as close as possible to the pins of the circuit. C1 is preferably an 6.8 µF tantalum type capacitor. In a application with a highly stable supply and short leads to the driver a low leakage electrolytic type can be used, which is less expensive. C2 is a ceramic type capacitor to improve high frequency decoupling. Typical value is 0.002 µF to 0.1 µF.

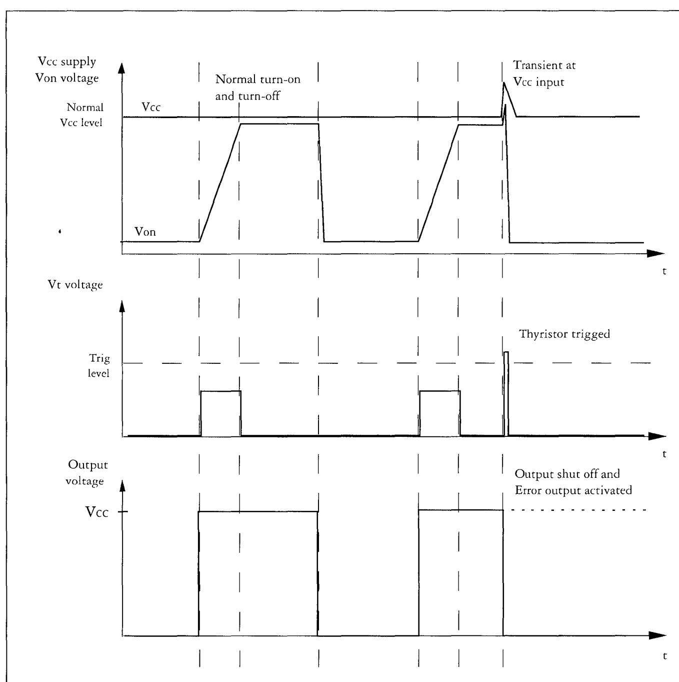
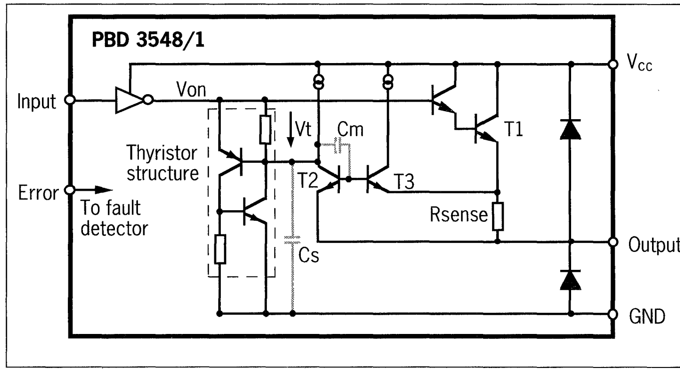


Figure 2. Waveforms at normal operation and at transient turn-off.

Figure 3. Schematic diagram of the fast short circuit protection.



Filtering:

An additional capacitor between output and GND may be necessary to reduce incoming transients at the output. The value will depend on the application, but it should be a ceramic type, typically ranging from 0.001 µF to 0.047 µF. Note that a too large total capacitance at the output (i.e. including stray capacitances and load capacitance), will cause the circuit to recognize the charging current at turn-on as a short circuit, and activate the short-circuit protection. Therefore, the value of C3 should be verified in the specific application to prevent this from occuring.

PBD 3548/1 extended Transient protection

The PBD 3548/1 source driver is more sensitive to incoming transients at the output pin than PBD 3545/1 sink driver. This is because 3548/1 has an emitter output and the current sensing resistor, R_{sense}, placed at the emitter. The PBD 3545/1 has a collector output and is therefore more tolerant to voltage transients at the output pin. If we look at figures 2 and 3 we can see how strong transients can possibly trigger the sensitive short circuit detection circuitry. A transient at V_{cc} can translate through the output transistor base drive circuit, increase Vt and trigger the thyristor. A transient

External components selection guide.

Ext. comp	Purpose	Typ. value
C1	Supply decoupling	6.8 µF tant.
C2	Supply HF decoupling	0.047 µF ceramic
C3	Supply filtering	100 µF
C4	Output filter	0.01 µF
C5	HF LC-filter	0.047 µF
C7	HF RC-filter	0.1 µF
D1	Clamping diode	UF4001, BYV27/100
L1		100 µH
L2		40 µH
R1		56 ohm

NOTE: These are typical values . The final values has to be verified from case to case.

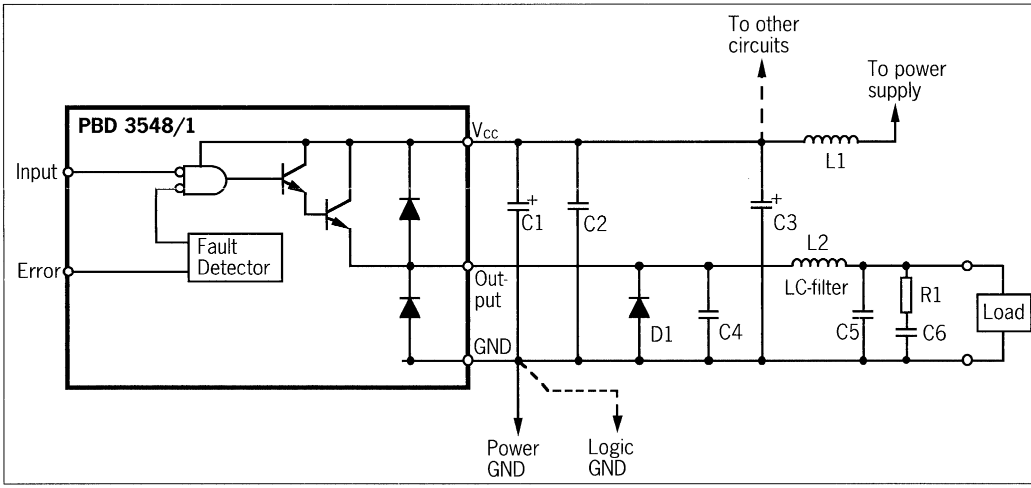


Figure 4. Circuit diagram showing worst case filtering arrangement for suppression of transients.

at the output can translate through T3 and Cm/T2 and triggers the thyristor.

The diagram in figure 4 shows a worst-case filtering arrangement for applications where a high degree of external noise can be expected. All of the components indicated in the figure are usually not required. Start with the basic configuration in figure 1 and apply additional filtering components based on a step by step evaluation in the same order as discussed in the text:

Power supply and system layout:

- Keep V_{cc} and GND leads as short and as low resistive as possible.
- If several supply voltages are to be used, prefer a supply with separate ground leads. In that case the logic ground and the power ground should be connected together at one point, the ground pin of the driver.
- An LC-filter (L1 & C3) at the power supply connection, or at the driver section of the PCB eliminates spikes and noise on the V_{cc} supply line. Several circuits may share a common filter. Typical values range from 10 – 1000 µH and 10 – 1000 µF. Higher values give better transient suppression, but at a higher cost.

Individual decoupling of each circuit:

- Connect a decoupling (filter) capacitor C1 between V_{cc} and GND, as close as possible to the pins of the circuit. A 6.8 µF tantalum or an equivalent low leakage, low impedance type capacitor is recommended .
- Each circuit must have an individual decoupling capacitor (C1). Even if several PBD 3548/1 or PBD 3545/1 are placed on the same PCB, they cannot share decoupling capacitors. However, the value of the capacitors may be decreased, for example to 3.3 µF
- A ceramic capacitor C2 in parallell with C1 improves high frequency decoupling. Typical values range from 0.002 µF to 0.1 µF.

Clamping:

- The internal diodes are normally sufficient for clamping of transients caused by inductive load turn off. External diodes may be necessary in PWM/switch mode applications, and when the output terminals are externally accessible and thereby exposed to an electrically noisy environment.
- A diode D1 between GND and Output will clamp negative transients at the Output to ground. The diode must be of switching type with very short recovery time and low forward voltage drop. Recommended type is UF4001, BYV27/100, BYV98/100 or similar types with a recovery time (trr) less than 100 ns and a forward current capability of 1 A or more.

Filtering:

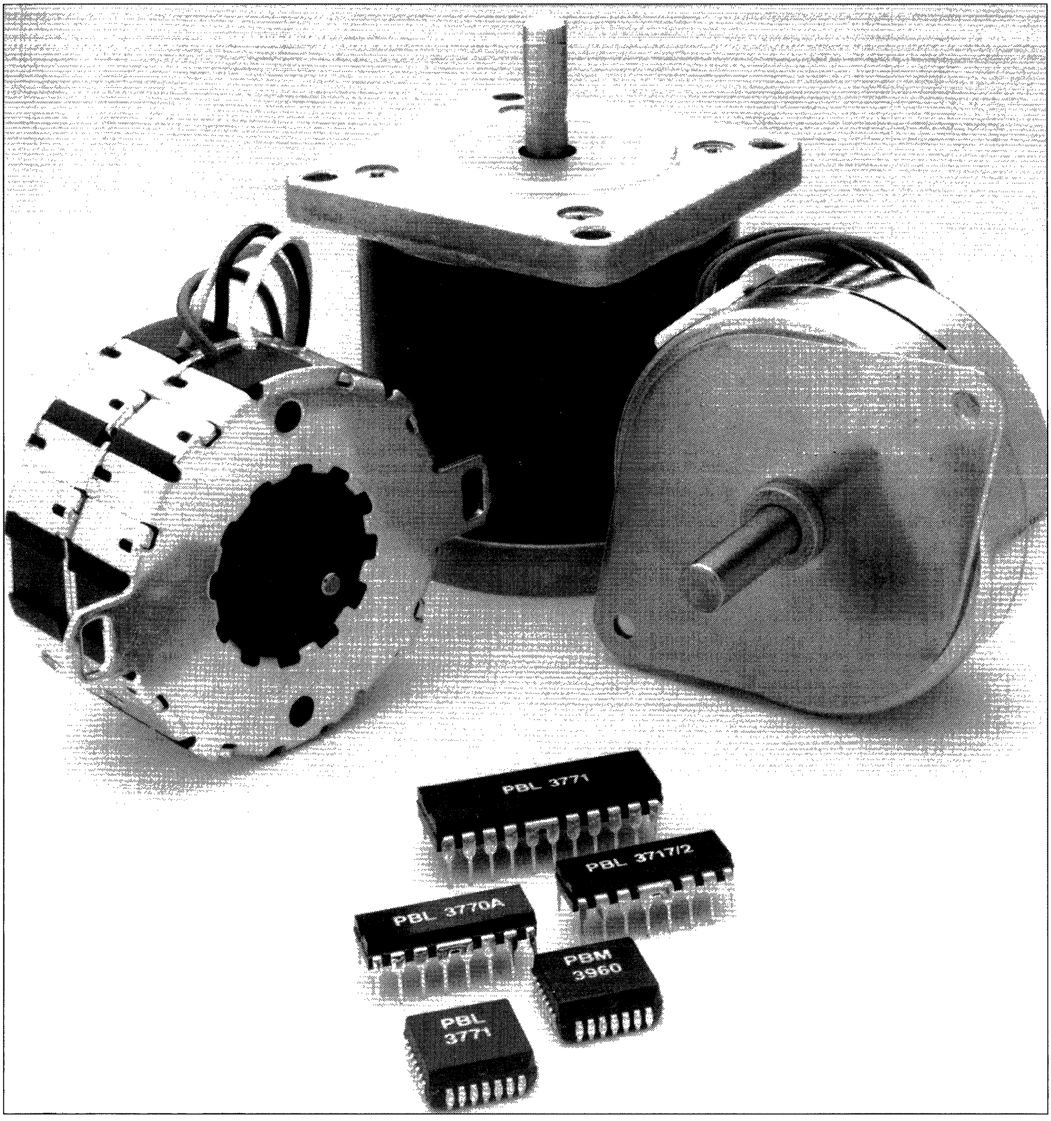
- Filtering of the Output, especially for externally accessible general purpose outputs, reduces transients caused by make and break of inductive loads. (i. e. RFI and EMI)
- A capacitor between Output - GND (C4). Typical values are 0.001 µF to 0.047 µF.
- An LC-filter (L2 and C5) will reduce RFI and ESD efficiently. Typical values range from 1 µH to 100 µH for the inductor and 0.01 µF to 0.1 µF for the capacitor.

  When using the LC-filter, the RC-filter R1 and C6 is needed to reduce oscillations which may occur at switch on and off. The values are chosen depending on the values of L2 and C5.

  If L2 is used, it is possible to drive large capcitive loads (>0.1 µF) and small lamps which have an inrush current.

  With the LC-filter at the output, short circuit will be detected slower than normally. Depending on the supply, voltage, switching frequency and inductor size, the circuit may not detect a short circuit condition at all. In such a case, the temperature shut down function will eventually turn off the circuit.

Stepper Motor Application Notes



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Industrial Circuits Application Note
Stepper Motor Basics

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

Stepper Motor Advantages and Disadvantages

Advantages

1. The rotation angle of the motor is proportional to the input pulse.
2. The motor has full torque at standstill (if the windings are energized)
3. Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 – 5% of a step and this error is non cumulative from one step to the next.
4. Excellent response to starting/stopping/reversing.
5. Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.
6. The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.
7. It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
8. A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

1. Resonances can occur if not properly controlled.
2. Not easy to operate at extremely high speeds.

Open Loop Operation

One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. Your position is known simply by keeping track of the input step pulses.

Stepper Motor Types

There are three basic stepper motor types. They are :

- Variable-reluctance
- Permanent-magnet
- Hybrid

Variable-reluctance (VR)

This type of stepper motor has been around for a long time. It is probably the easiest to understand from a structural point of view. Figure 1 shows a cross section of a typical V.R. stepper motor. This type of motor consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles.

Permanent Magnet (PM)

Often referred to as a "tin can" or "canstock" motor the permanent magnet step motor is a low cost and low resolution type motor with typical step angles of 7.5° to 15°. (48 – 24 steps/revolution) PM motors as the

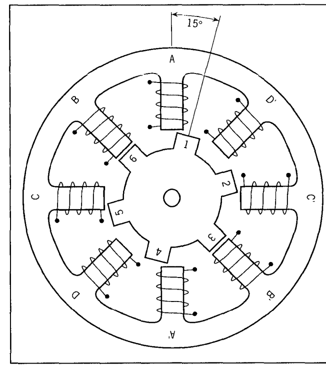


Figure 1. Cross-section of a variable-reluctance (VR) motor.

name implies have permanent magnets added to the motor structure. The rotor no longer has teeth as with the VR motor. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and because of this the PM motor exhibits improved torque characteristics when compared with the VR type.

Hybrid (HB)

The hybrid stepper motor is more expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the HB stepper motor range from 3.6° to 0.9° (100 – 400 steps per revolution). The hybrid stepper motor combines the best features of both the PM and VR type stepper motors. The rotor is multi-toothed like the VR motor and contains an axially magnetized concentric magnet around its shaft. The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the airgap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types.

The two most commonly used types of stepper motors are the permanent magnet and the hybrid types. If a designer is not sure which type will best fit his applications requirements he should first evaluate the PM type as it is normally several times less expensive. If not then the hybrid motor may be the right choice.

Size and Power

In addition to being classified by their step angle stepper motors are also classified according to frame sizes which correspond to the diameter of the body of the motor. For instance a size 11 stepper motor has a body diameter of approximately 1.1 inches. Likewise a size 23 stepper motor has a body diameter of 2.3 inches (58 mm), etc. The body length may however, vary from motor to motor within the same frame size classification. As a general rule the available torque output from a motor of a particular frame size will increase with increased body length.

Power levels for IC-driven stepper motors typically range from below a watt for very small motors up to 10 – 20 watts for larger motors. The maximum power dissipation level or thermal limits of the motor are seldom clearly stated in the motor manufacturers data. To determine this we must apply the relationship P = V × I. For example, a size 23 step motor may be rated at 6V and 1A per phase. Therefore, with two phases energized the motor has a rated power dissipation of 12 watts. It is normal practice to rate a stepper motor at the power dissipation level where the motor case rises 65°C above the ambient in still air. Therefore, if the motor can be mounted to a heatsink it is often possible to increase the allowable power dissipation level. This is important as the motor is designed to be and should be used at its maximum power dissipation ,to be efficient from a size/output power/cost point of view.

When to Use a Stepper Motor

A stepper motor can be a good choice whenever controlled movement is required. They can be used to advantage in applications where you need to control rotation angle, speed , position and synchronism. Because of the inherent advantages listed previously, stepper motors have found their place in many different applications. Some of these include printers, plotters, high-end office equipment, hard disk drives, medical equipment, fax machines, automotive and many more.

The Rotating Magnetic Field

When a phase winding of a stepper motor is energized with current a magnetic flux is developed in the stator. The direction of this flux is determined by the "Right Hand Rule" which states:

"If the coil is grasped in the right hand with the fingers pointing in the direction of the current in the winding (the thumb is extended at a 90° angle to the fingers), then the thumb will point in the direction of the magnetic field."

Figure 2 shows the magnetic flux path developed when phase B is energized with winding current in the direction shown. The rotor then aligns itself so that the flux opposition is minimized. In this case the motor would rotate clockwise so that its south pole aligns with the north pole of the stator B at position 2 and its north pole aligns with the south pole of stator B at position 6. To get the motor to rotate we can now see that we must provide a sequence of energizing the stator windings in such a fashion that provides a rotating magnetic flux field which the rotor follows due to magnetic attraction.

Torque Generation

The torque produced by a stepper motor depends on several factors.

- The step rate
- The drive current in the windings
- The drive design or type

In a stepper motor a torque is developed when the magnetic fluxes of the rotor and stator are displaced from each other. The stator is made up of a high permeability magnetic material. The presence of this high permeability material causes the magnetic flux to be confined for the most part to the paths defined by the stator structure in the same fashion that currents are confined to the conductors of an electronic circuit. This serves to concentrate the flux at the stator poles. The torque output produced by the motor is proportional to the intensity of the magnetic flux generated when the winding is energized.

The basic relationship which defines the intensity of the magnetic flux is defined by:

$H = (N \times i) \div l$ where:

N = The number of winding turns

i = current

H = Magnetic field intensity

l = Magnetic flux path length

This relationship shows that the magnetic flux intensity and consequently the torque is proportional to the number of winding turns and the current and inversely proportional to the length of the magnetic flux path. From this basic relationship one can see that the same frame size stepper motor could have very different torque output capabilities simply by changing the winding parameters. More detailed information on how the winding parameters affect the output capability of the motor can be found in the application note entitled "Drive Circuit Basics".

Phases, Poles and Stepping Angles

Usually stepper motors have two phases, but three- and five-phase motors also exist.

A bipolar motor with two phases has one winding/phase and a unipolar motor has one winding, with a center tap per phase. Sometimes the unipolar stepper motor is referred to as a "four-phase motor", even though it only has two phases.

Motors that have two separate windings per phase also exist—these can be driven in either bipolar or unipolar mode.

A pole can be defined as one of the regions in a magnetized body where the magnetic flux density is concentrated. Both the rotor and the stator of a step motor have poles. Figure 2 contains a simplified picture of a two-phase stepper motor having 2 poles (or 1 pole pairs) for each phase on the stator, and 2 poles (one pole pair) on the rotor. In reality several more poles are added to both the rotor and stator structure in order to increase the number of steps per revolution of the motor, or in other words to provide a smaller basic (full step) stepping angle. The permanent magnet stepper motor contains an equal number of rotor and stator pole pairs. Typically the PM motor has 12 pole pairs. The stator has 12 pole pairs per phase. The hybrid type stepper motor has a rotor with teeth. The rotor is split into two parts, separated by a permanant magnet—making half of the teeth south poles and half north poles.The number of pole pairs is equal to the number of teeth on one of the rotor halves. The stator of a hybrid motor also has teeth to build up a higher number of equivalent poles (smaller pole pitch, number of equivalent poles = 360/teeth pitch) compared to the main poles, on which the winding coils are wound. Usually 4 main poles are used for 3.6 hybrids and 8 for 1.8- and 0.9-degree types.

It is the relationship between the number of rotor poles and the equivalent stator poles, and the number the number of phases that determines the full-step angle of a stepper motor.

Step angle = $360 \div (N_{Ph} \times Ph) = 360/N$

N_{Ph} = Number of equivalent poles per phase = number of rotor poles

Ph = Number of phases

N = Total number of poles for all phases together

If the rotor and stator tooth pitch is unequal, a more-complicated relationship exists.

Stepping Modes

The following are the most common drive modes.

- Wave Drive (1 phase on)
- Full Step Drive (2 phases on)
- Half Step Drive (1 & 2 phases on)
- Microstepping (Continuously varying motor currents)

For the following discussions please refer to the figure 3.

In Wave Drive only one winding is energized at any given time. The stator is energized according to the sequence A → B → $\overline{A}$ → $\overline{B}$ and the rotor steps from position 8 → 2 → 4 → 6. For unipolar and bipolar wound motors with the same winding parameters this excitation mode would result in the same mechanical position. The disadvantage of this drive mode is that in the unipolar wound motor you are only using 25% and in the bipolar motor only 50% of the total motor winding at any given time. This means that you are not getting the maximum torque output from the motor

In Full Step Drive you are energizing two phases at any given time. The stator is energized according to the sequence AB → $\overline{A}$B → $\overline{A}\overline{B}$ → A$\overline{B}$ and the rotor steps from position 1 → 3 → 5 → 7 . Full step mode results in the same angular movement as 1 phase on drive but the mechanical position is offset by one half of a full step. The torque output of the unipolar wound motor is lower than the bipolar motor (for motors with the same winding parameters) since the unipolar motor

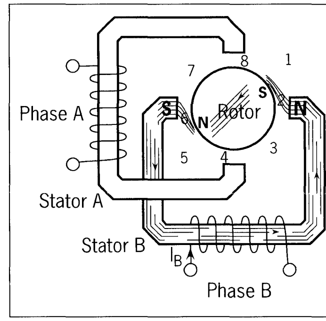
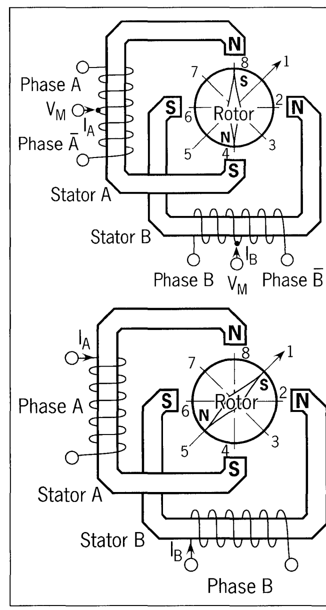


Figure 2. Magnetic flux path through a two-pole stepper motor with a lag between the rotor and stator.



Unipolar and bipolar wound stepper motors.

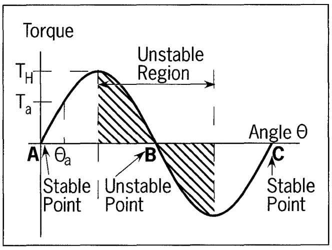


Figure 4. Torque vs. rotor angular position.

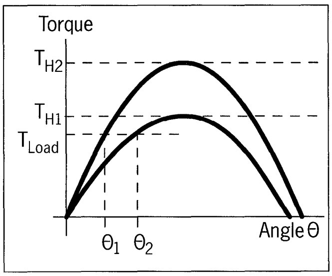


Figure 5. Torque vs. rotor angle position at different holding torque.

uses only 50% of the available winding while the bipolar motor uses the entire winding.

Half Step Drive combines both wave and full step (1&2 phases on) drive modes. Every second step only one phase is energized and during the other steps one phase on each stator. The stator is energized according to the sequence AB → B → $\overline{A}$B → $\overline{A}$ → $\overline{A}\overline{B}$ → $\overline{B}$ → A$\overline{B}$ → A and the rotor steps from position 1 → 2 → 3 → 4 → 5 → 6 → 7 → 8. This results in angular movements that are half of those in 1- or 2-phases-on drive modes. Half stepping can reduce a phenomena referred to as resonance which can be experienced in 1- or 2-phases-on drive modes.

The excitation sequences for the above drive modes are summarized in Table 1.

In Microstepping Drive the currents in the windings are continuously varying to be able to break up one full step into many smaller discrete steps. More information on microstepping can be found in the microstepping chapter.

Torque vs, Angle Characteristics

The torque vs angle characteristics of a stepper motor are the relationship between the displacement of the rotor and the torque which applied to the rotor shaft when the stepper motor is energized at its rated voltage. An ideal stepper motor has a sinusoidal torque vs displacement characteristic as shown in figure 4.

Positions A and C represent stable equilibrium points when no external force or load is applied to the rotor shaft. When you apply an external force T_a to the motor shaft you in essence create an angular displacement, Θ_a. This angular displacement, Θ_a, is referred to as a lead or lag angle depending on wether the motor is actively accelerating or decelerating. When the rotor stops with an applied load it will come to rest at the position defined by this displacement angle. The motor develops a torque, T_a, in opposition to the applied external force in order to balance the load. As the load is increased the displacement angle also increases until it reaches the maximum holding torque, T_h, of the motor. Once T_h is exceeded the motor enters an unstable region. In this region a torque is the opposite direction is created and the rotor jumps over the unstable point to the next stable point.

The displacement angle is determined by the following relationship:

$$X = (Z \div 2\pi) \times sin(T_a \div T_h) \quad \text{where:}$$

Z = rotor tooth pitch

T_a = Load torque

T_h = Motors rated holding torque

X = Displacement angle.

Therefore if you have a problem with the step angle error of the loaded motor at rest you can improve this by changing the "stiffness" of the motor. This is done by increasing the holding torque of the motor. We can see this effect shown in the figure 5. Increasing the holding torque for a constant load causes a shift in the lag angle from Q_2 to Q_1.

Step Angle Accuracy

One reason why the stepper motor has achieved such popularity as a positioning device is its accuracy and repeatability. Typically stepper motors will have a step angle accuracy of 3 – 5% of one step. This error is also noncumulative from step to step. The accuracy of the stepper motor is mainly a function of the mechanical precision

Table 1. Excitation sequences for different drive modes

	Wave Drive				Normal full step				Half-step drive							
Phase	1	2	3	4	1	2	3	4	1	2	3	4	5	6	7	8
A	•				•			•	•						•	•
B		•			•	•			•	•	•					
$\overline{A}$			•			•	•				•	•	•			
$\overline{B}$				•			•	•					•	•	•	

of its parts and assembly. Figure 6 shows a typical plot of the positional accuracy of a stepper motor.

Step Position Error
The maximum positive or negative position error caused when the motor has rotated one step from the previous holding position.

Step position error = measured step angle - theoretical angle

Positional Error
The motor is stepped N times from an initial position (N = 360°/step angle) and the angle from the initial position is measured at each step position. If the angle from the initial position to the N-step position is Θ_N and the error is $\Delta\Theta_N$ where:

$\Delta\Theta_N = \Delta\Theta_N$ - (step angle) $\times$ N.

The positional error is the difference of the maximum and minimum but is usually expressed with a ± sign. That is:

positional error = $\pm\frac{1}{2}(\Delta\Theta_{Max} - \Delta\Theta_{Min})$

Hysteresis Positional Error
The values obtained from the measurement of positional errors in both directions.

Mechanical Parameters, Load, Friction, Inertia

The performance of a stepper motor system (driver and motor) is also highly dependent on the mechanical parameters of the load. The load is defined as what the motor drives. It is typically frictional, inertial or a combination of the two.

Friction is the resistance to motion due to the unevenness of surfaces which rub together. Friction is constant with velocity. A minimum torque level is required throughout the step in over to overcome this friction (at least equal to the friction). Increasing a frictional load lowers the top speed, lowers the acceleration and increases the positional error. The converse is true if the frictional load is lowered

Inertia is the resistance to changes in speed. A high inertial load requires a high inertial starting torque and the same would apply for braking. Increasing an inertial load will increase speed stability, increase the amount of time it takes to reach a desired speed and decrease the maximum self start pulse rate. The converse is again true if the inertia is decreased.

The rotor oscillations of a stepper motor will vary with the amount of friction and inertia load. Because of this relationship unwanted rotor oscillations can be reduced by mechanical damping means however it is more often simpler to reduce these unwanted oscillations by electrical damping methods such as switch from full step drive to half step drive.

Torque vs, Speed Characteristics

The torque vs speed characteristics are the key to selecting the right motor and drive method for a specific application. These characteristics are dependent upon (change with) the motor, excitation mode and type of driver or drive method. A typical "speed – torque curve" is shown in figure 7.

To get a better understanding of this curve it is useful to define the different aspect of this curve.

Holding torque
The maximum torque produced by the motor at standstill.

Pull-In Curve
The pull-in curve defines a area refered to as the start stop region. This is the maximum frequency at which the motor can start/stop instantaneously, with a load applied, without loss of synchronism.

Maximum Start Rate
The maximum starting step frequency with no load applied.

Pull-Out Curve
The pull-out curve defines an area refered to as the slew region. It defines the maximum frequency at which the motor can operate without losing synchronism. Since this region is outside the pull-in area the motor must ramped (accelerated or decelerated) into this region.

Maximum Slew Rate
The maximum operating frequency of the motor with no load applied.

The pull-in characteristics vary also depending on the load. The larger the load inertia the smaller the pull-in area.

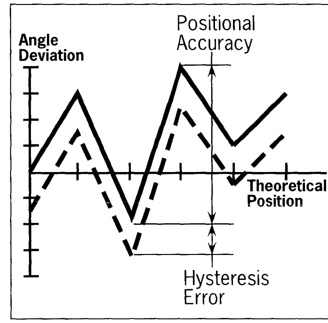


Figure 6. Positional accuracy of a stepper motor.

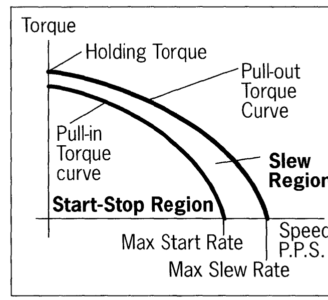


Figure 7. Torque vs. speed characteristics of a stepper motor.

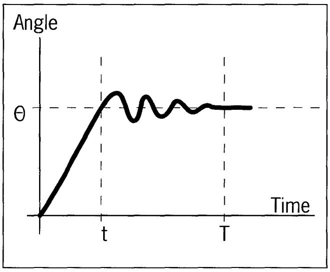


Figure 8. Single step response vs. time.

We can see from the shape of the curve that the step rate affects the torque output capability of stepper motor The decreasing torque output as the speed increases is caused by the fact that at high speeds the inductance of the motor is the dominant circuit element.

The shape of the speed - torque curve can change quite dramatically depending on the type of driver used. The bipolar chopper type drivers which Ericsson Components produces will maximum the speed - torque performance from a given motor. Most motor manufacturers provide these speed - torque curves for their motors. It is important to understand what driver type or drive method the motor manufacturer used in developing their curves as the torque vs. speed characteristics of an given motor can vary significantly depending on the drive method used.

Single Step Response and Resonances

The single-step response characteristics of a stepper motor is shown in figure 8.

When one step pulse is applied to a stepper motor the rotor behaves in a manner as defined by the above curve. The step time t is the time it takes the motor shaft to rotate one step angle once the first step pulse is applied. This step time is highly dependent on the ratio of torque to inertia (load) as well as the type of driver used.

Since the torque is a function of the displacement it follows that the acceleration will also be. Therefore, when moving in large step increments a high torque is developed and consequently a high acceleration. This can cause overshots and ringing as shown. The settling time T is the time it takes these oscillations or ringing to cease. In certain applications this phenomena can be undesirable. It is possible to reduce or eliminate this behaviour by microstepping the stepper motor. For more information on microstepping please consult the microstepping note.

Stepper motors can often exhibit a phenomena refered to as resonance at certain step rates. This can be seen as a sudden loss or drop in torque at certain speeds which can result in missed steps or loss of synchronism. It occurs when the input step pulse rate coincides with the natural oscillation frequency of the rotor. Often there is a resonance area around the 100 – 200 pps region and also one in the high step pulse rate region. The resonance phenomena of a stepper motor comes from its basic construction and therefore it is not possible to eliminate it completely. It is also dependent upon the load conditions. It can be reduced by driving the motor in half or microstepping modes.

Industrial Circuits Application Note

Drive circuit basics

For a given size of a stepper motor, a limited space is available for the windings. In the process of optimizing a stepper motor drive system, an efficient utilization of the available winding space as well as a matching of driver and winding parameters are of great importance.

This chapter discusses the basic electrical characteristics of a stepper motor winding. Special attention is given to driving configurations and current control methods.

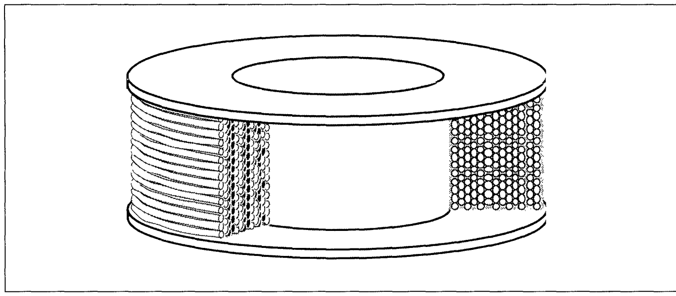


Figure 1. Winding of a typical Permanent Magnet stepper motor.

Winding resistance and inductance.

The windings of a stepper motor are made up of several turns of copper wire. The wire is wound on plastic bobbin, which allows separate manufacturing of the winding, the stator and other mechanical parts. At a final stage of production the bobbin is mounted around the stator poles. Resistance and inductance and are two inherent physical properties of a winding, or any coil. These two basic factors also limit the possible performance of the motor.

The resistance of the windings is responsible for the major share of the power loss and heat up of the motor. Size and thermal characteristics of the winding and the motor limit the maximum allowable power dissipated in the winding. The power loss is given by:

$P_R = R \cdot I_M^2$

It is important to note that a motor should be used at its maximum power dissipation to be efficient. If a motor is running below its power dissipation limit, it means that it could be replaced by a smaller size motor, which most probably is less expensive

Inductance makes the motor winding oppose current changes, and there-

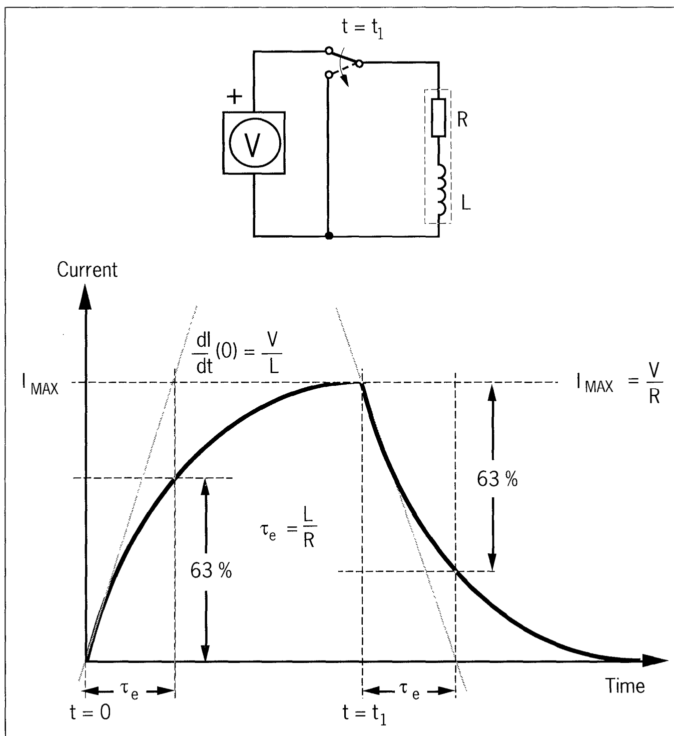


Figure 2. Current wave form in an inductive–resistive circuit.

How are the motor winding parameters affected by the number of turns and the wire diameter?

The crossectional area of the winding is A. The resistance of the winding as a function of the number of turns is found by the following idealized calculation:

$R = \rho \cdot l / a$ where:

$a = A / n$, the cross-sectional area of the wire;
wire length $l = 2 \cdot \pi \cdot r \cdot n$; ρ is the resistivity of copper.

$$R = \rho \cdot 2 \cdot \pi \cdot r \cdot n / (A / n) = 2 \cdot \pi \cdot \rho \cdot r \cdot n^2 / A \approx n^2$$

The resistance is proportional to the square of the number of wire turns.

Inductance is calculated as (simplified):

$$L = 2 \cdot \pi \cdot r^2 \cdot n^2 \approx n^2$$

The inductance is proportional to the square of the number of wire turns.

To calculate the current rating we use the condition of constant power disspation:

$$P_R = R \cdot I_M{}^2$$

which leads to:

$$I_M = \sqrt{P_R / R} \approx \sqrt{P_R / n^2} \approx 1 / n$$

Current is inversely proportional to the number of turns.

Torque is proportional to the flux F, which is proportional to the number of amperetums in the winding:

$$T \approx \Phi \approx n \cdot I_M \approx n \cdot (1 / n) = \text{constant.}$$

Torque is constant at a constant power dissipation level, regardless of the number of turns.

Rated voltage is:

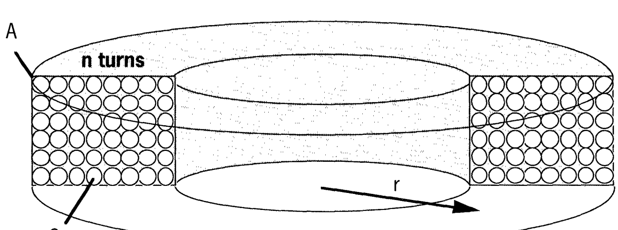
$$V_M = R \cdot I_M \approx n^2 \cdot (1 / n) \approx n$$

Rated voltage is proportional to the number of turns.

Finally, the electrical time constant is:

$$\tau_e = L / R \approx n^2 / n^2 = \text{constant}$$

The time constant is not affected by the number of turns.



fore limits high speed operation. Figure 2 shows the electrical characteristics of an inductive–resistive circuit. When a voltage is connected to the winding the current rises according to the equation

$$I(t) = (V/R) \cdot (1 - e^{-t \cdot R/L})$$

Initially the current increases at a rate of

$$\delta I / \delta t \, (0) = V/L$$

The rise rate decreases as the current approaches the final level:

$$I_{MAX} = V/R$$

The value of $\tau_e = L/R$ is defined as the electrical time constant of the circuit. τ_e is the time until the current reaches 63% ($1 - 1/e$) of its final value.

When the inductive–resistive circuit is disconnected and shorted at the instant $t = t_1$, the current starts to decrease:

$$I(t) = (V/R) \cdot e^{-(t-t_1) \cdot R/L}$$

at an initial rate of

$$I(t) = - V/L$$

When a square wave voltage is applied to the winding, which is the case when fullstepping a stepper motor, the current waveform will be smoothed. Figure 4 shows the current at three different frequencies. Above a certain frequency (B) the current never reaches its maximum value (C). As the torque of the motor is approximately proportional to the current, the maximum torque will be reduced as the stepping frequency increases.

To overcome the inductance and gain high speed performance of the motor two possibilities exist: Increase the current rise rate and/or decrease the time constant. As an increased resistance always results in an increased power loss, it is preferably the ratio V/L that should be increased to gain high speed performance.

To drive current through the winding, we should:

- use as high voltage as possible
- keep the inductance low.

Accordingly, a low inductance/resistance motor has a higher current rating. As the maximum current is limited by the driver, we find that high performance is highly dependant on the choice of driver.

The limiting factor of the motor is the power dissipation, and not the current itself. To utilize the motor efficiently, power dissipation should be at the maximum allowed level.

Basic winding parameters and dimensioning.

Under the conditions of a constant maximum allowable power dissipation P_R and a given winding space, i. e. a given copper volume, the only parameter that could be altered is the number of wire turns, or correspondingly, the wire diameter. See the fact box, *"How are the winding parameters affected by the number of turns and the wire diameter?"* on previous page.

Drive circuit schemes.

The stepper motor driver circuit has two major tasks:

- To change the current and flux direction in the phase windings
- To drive a controllable amount of current through the windings, and enabling as short current rise and fall times as possible for good high speed performance.

Flux direction control.

Stepping of the stepper motor requires a change of the flux direction, independently in each phase. The direction change is done by changing the current direction, and may be done in two different ways, using a bipolar or a unipolar drive. Figure 5 shows the two schemes. Only one of the two phases is shown as the two phases are identical.

Bipolar drive.

Bipolar drive refers to the principle where the current direction in one winding is changed by shifting the voltage polarity across the winding terminals. To change polarity a total of four switches are needed, forming an H-bride.

The bipolar drive method requires one winding per phase. A two-phase motor will have two windings and accordingly four connecting leads.

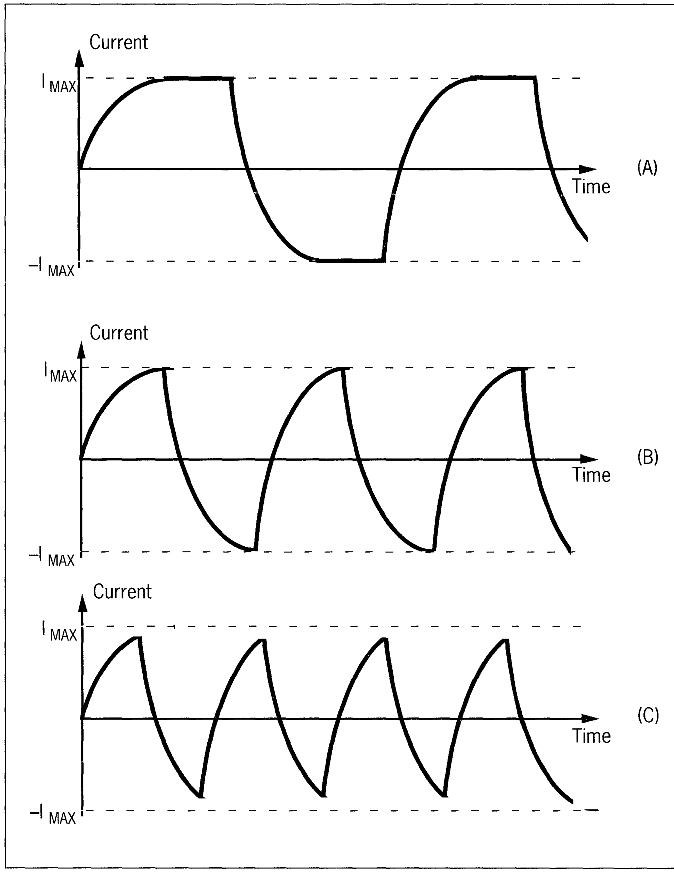


Figure 4. Current wave form in an inductive–resistive circuit.

Unipolar drive.

The unipolar drive principle requires a winding with a center-tap, or two separate windings per phase. Flux direction is reversed by moving the current from one half of the winding to the other half. This method requires only two switches per phase. On the other hand, the unipolar drive utilizes only half the available copper volume of the winding. The power loss in the winding is therefore twice the loss of a bipolar drive at the same output power.

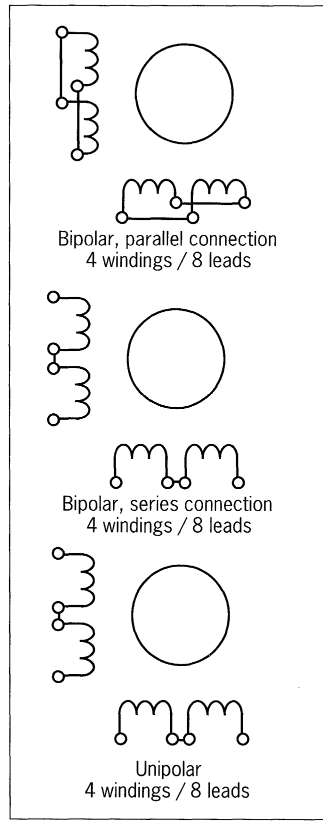


Figure 8. Different winding configurations for bipolar and unipolar drive using an 8-lead motor.

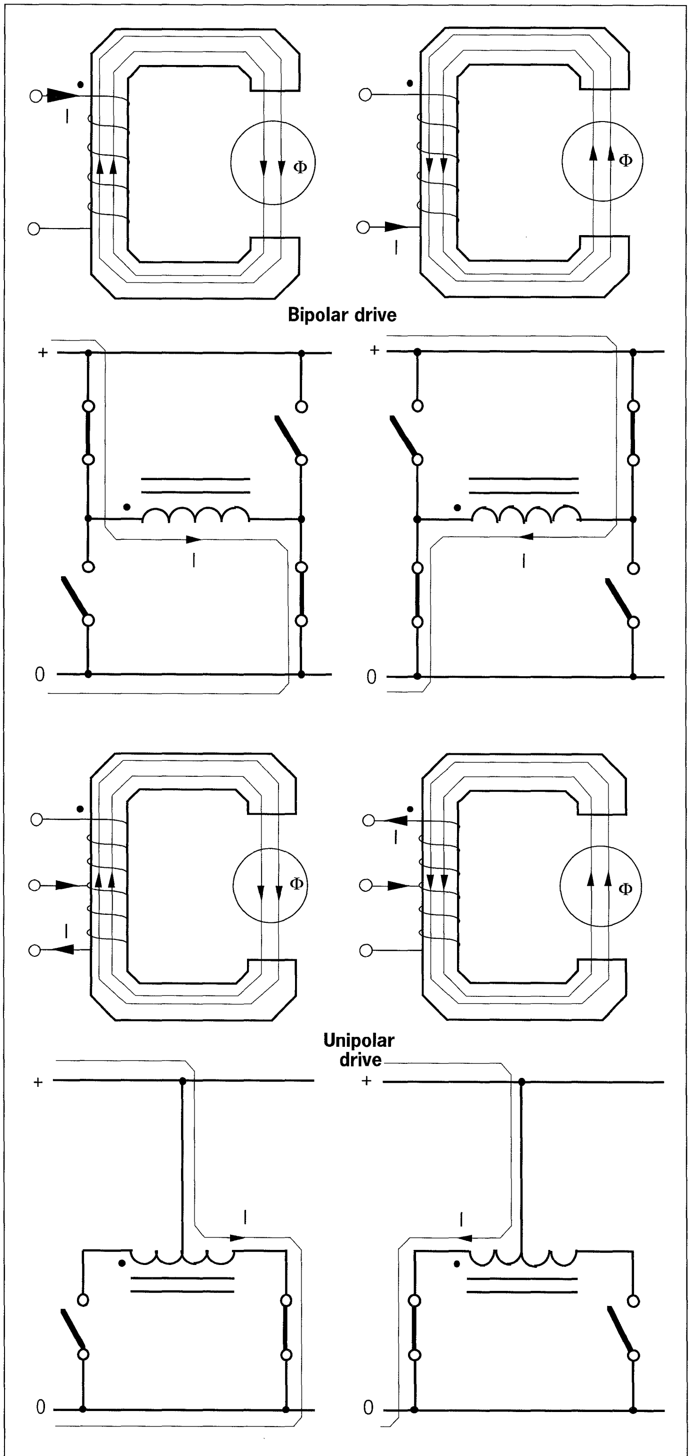


Figure 5. Bipolar and unipolar drive schemes to control the current and the flux direction in the phase winding.

The unipolar, centerttapped motor has three leads per phase, totally six leads for a two-phase motor. A motor having two separate windings per phase is usually referred to as an 8-lead motor. It may be connected both as a unipolar or a bipolar motor, see figure 8.

Current control.

To control the torque as well as to limit the power dissipation in the winding resistance, the current must be controlled or limited. Furthermore, when half stepping a zero current level is needed, while microstepping requires a continuously variable current.

Two principles to limit the current are described here, the resistance limited drive and the chopper drive. Any of the methods may be realized as a bipolar or unipolar driver.

Resistance limitation of the current (L/R drive).

In this basic method the current is limited by supply voltage and the resistance of the winding, and if necessary, an additional external resistance (dropping resistor):

$I_M = V_{supply} / (R + R_{ext})$

If the nominal motor voltage is the same as the supply voltage, R_{ext} is excluded.

For a given motor, high speed performance is increased by increasing the supply voltage. An increased supply voltage in the resistance limited drive must be accompanied by an additional resistor (R_{ext}) in series with the winding to limit the current to the previous level. The time constant:

$\tau_e = L / (R + R_{ext})$

decreases, which shortens the current rise time. See figure 6. The penalty using this method is the power loss in the additional external resistors. Usually several watts has to be dissipated - and supplied. Spacious power resistors, heat removal considerations and a space consuming power supply reduce costeffectivenes and limits L/R drive scheme to small motors, rated around 1- 2 Watts.

The bilevel L/R-drive.

The bilevel L/R-drive provides a solution to the power waste using dropping resistors. In the beginning of

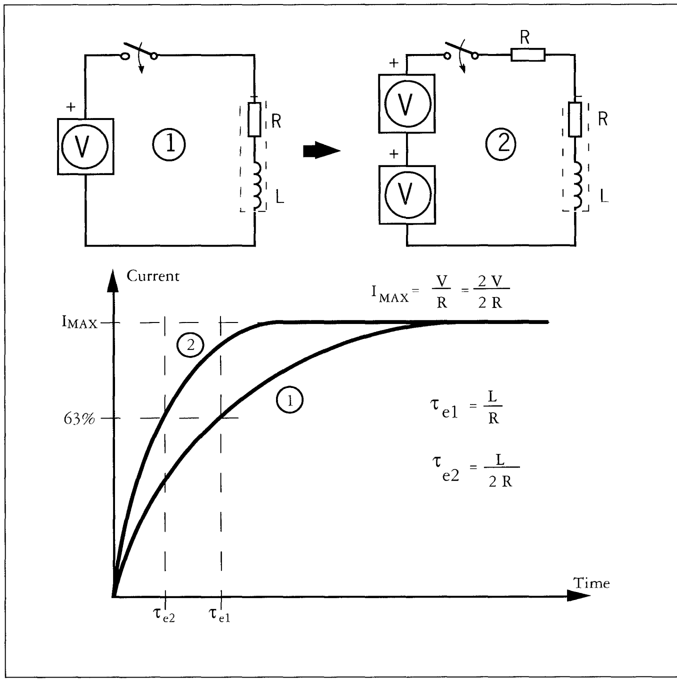


Figure 6. Resistance limitation of the current.

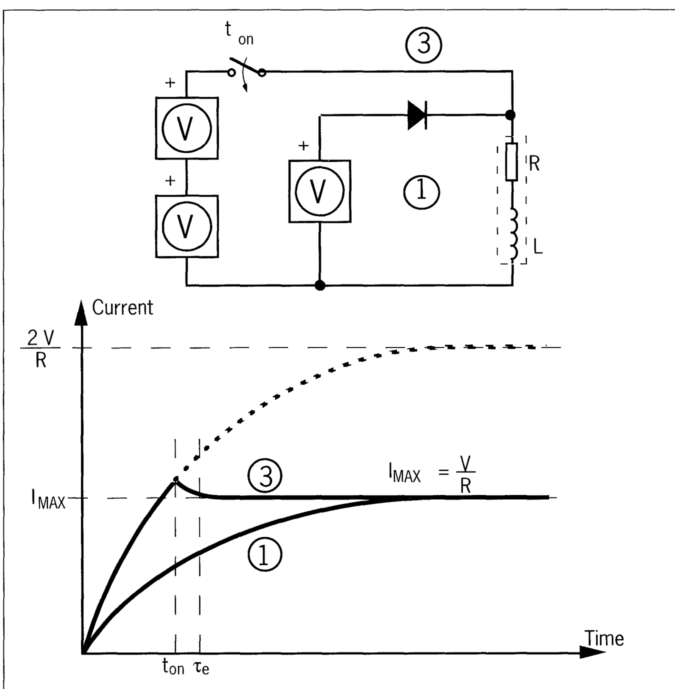


Figure 7. The bilevel drive.

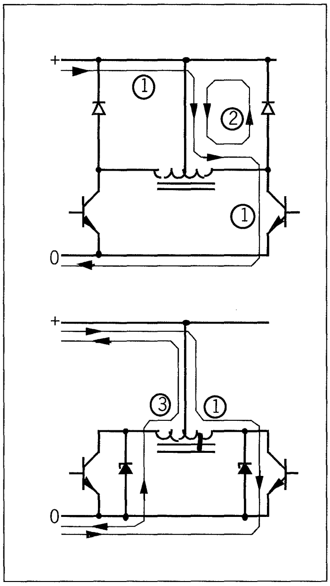


Figure 10. Current paths in the unipolar driver.

the current build-up period, the winding is connected to a secondary high voltage supply. After a short time, when the current has reached its nominal level, the second level supply is disconnected. Figure 7 explains further. The disadvantage of bilevel drive is the need of a second level power supply. In some applications where 5 V and 12 V/24 V are available, it may be a cost effective solution, but, if not available, it is a costly method. It is possible to use voltage doubling techniques as well.

Current paths.
Another very important consideration is current paths at turn-off and at phase shift. The inductive nature of the winding demands that a current path always exists. When using transistors as switches, diodes have to be added to enable current flow in both directions across the switch. For the bipolar driver four diodes, one for each switch, provide current paths according to figure 9. Note that there are two ways to turn the current off, either by turning all transistors off (path 3), or turn just one of the two conducting transistors off (path 2). The former gives a fast current decay as the energy stored in the winding inductance is discharged at a high voltage, V_{supply}. The latter gives a slow current decay as the counter voltage is only

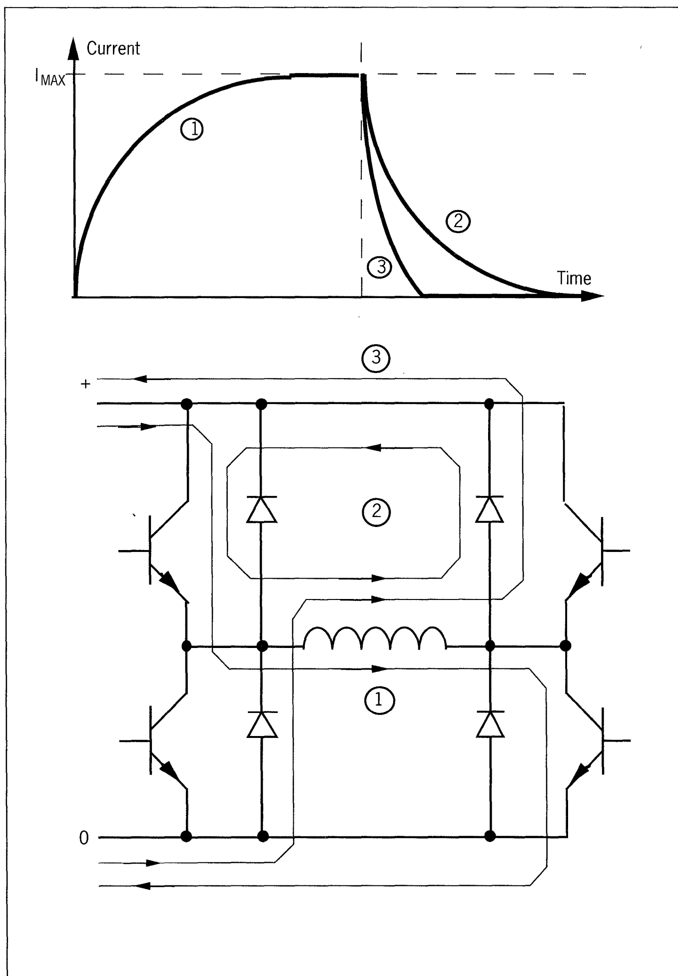


Figure 9. Current paths in the bipolar driver.

two diode voltage drops and the resistive voltage drop across the winding resistance. At phase shift the current will decay rapidly as both conducting transistors are turned off. For high speed halfstepping a rapid decay to zero in the half step position is important.

The unipolar driver is somewhat more complicated when it comes to current paths. The reason being the full coupling between the two halves of each phase winding, except for a small amount of leakage inductance. Figure 10 shows some possible schemes. Because of the coupling, large voltage transients—at least twice the supply voltage—occurs when switching on and off. The transistor switches must be rated at a much higher voltage than the supply voltage. The leakage inductance will also cause transients. Therefore the switching transistors has to be protected by snubber networks or zener diodes.

Chopper control.

The chopper driver provides an optimal solution both to current control and fast current build-up and reversal. The basic idea is to use a supply voltage which is several times higher than the nominal voltage of the motor. The current rise rate, which initially is V/L, is thereby possible to increase substantially. The ratio V_M/V_{supply} is called the overdrive ratio. By controlling the duty cycle of the chopper, an average voltage and an average current equal to the nominal motor voltage and current are created. The chopper is usually configured for constant current regulation, see figures 11- 13.

Constant current regulation is achieved by switching the output current to the windings. This is done by sensing the peak current through the winding via a current-sensing resistor, effectively connected in series with the motor winding. As the current increases, a voltage develops across the sensing resistor, which is fed back to the comparator. At the predetermined level, defined by the voltage at the reference input, the comparator resets the flip-flop, which turns off the output transistor. The current decreases until the clock oscillator triggers the flip-flops, which turns on the output transistor again, and the cycle is repeated.

The advantage of the constant current control is a precise control of the developed torque, regardless of power supply voltage variations. It also gives the shortest possible current build-up and reversal time. Power dissipation is minimized, as well as supply current. Supply current is not the same as the motor current in a copper drive. It is the motor current multiplied by the dutycycle, at standstill typically

$$I_{supply} = I_M \cdot (V_M/V_{supply})$$

Figure 13 shows an H-bridge configured as a constant current chopper. Depending on how the H-bridge is switched during the turn-off period, the current will either recirculate through one transistor and one diode (path 2), giving the slow current de-

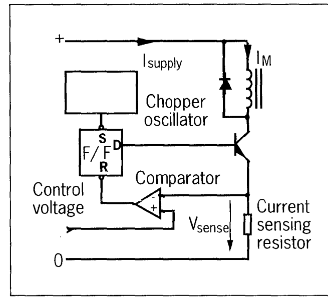


Figure 11. A simplified schematic shows the principle of constant current chopper regulation.

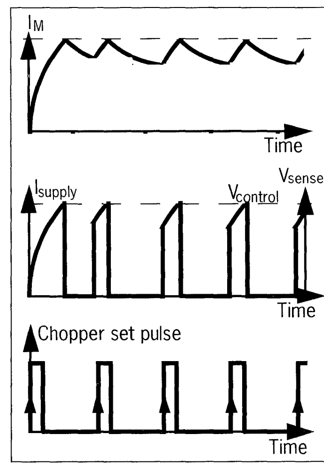


Figure 12. Current waveform in the basic chopper circuit.

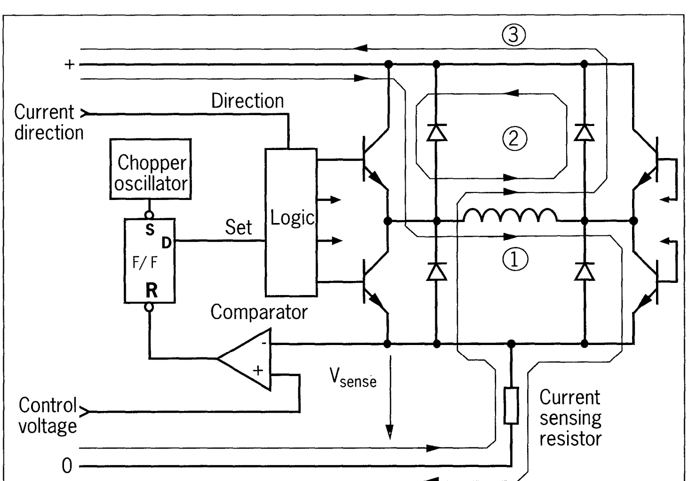


Figure 13. An H-bridge configured as a constant current chopper.

cay, or recirculate back through the power supply (path 3). The advantage of feeding the power back to the power supply is the fast current decay and the ability to quickly reduce to a lower current level. One example is when microstepping at a negative slope, which may be impossible to follow if the current decay rate is lower than the slope demands. The disadvantage with fast current decay is the increased current ripple, which can cause iron losses in the motor. Further discussion about the concept of fast/ slow current decay can be found in the half stepping techinques and microstepping chapter.

Industrial Circuit Application Note

Stepper motor and driver selection

Stepper motors are used in many different types of applications this makes it difficult to recommend a general step-by-step design flow chart. The design process is more an iterative process, involving experience, calculation and experimentation. The purpose of this application note is to show how system performance is affected by motor and driver selection. Some popular motors and drivers are dealt with, as well as the importance of the gearing between the motor and the load.

Limits to system performance

Torque and output power

The output torque and power from a stepper motor are functions of the motor size, motor heat sinking, working duty cycle, motor winding, and the type of driver used. In applications with low damping, the usable torque from the stepper motor can be drastically reduced by resonances.

In data sheets for stepper motors, the pull-in and pull-out torque are given, as functions of stepping rate, for different types of motor and driver combinations. The pull-in torque curve shows the maximum friction torque with which, the motor can start, at different stepping rates, without losing any step. In an actual application, this curve has to be modified to account for the load inertia.

The pull-out curve is of more interest, because it shows the total available torque when the motor runs at constant speed at a given frequency. In an application, this torque is used for overcoming the load fiction torque and for accelerating the load and motor inertia.

One problem when selecting the right motor type and size is the big influence that the driver has on the output torque and power. The difference in output torque, power, and system efficiency for a 7.5-degree 57mm PM stepper is illustrated in figure 1. In both cases the winding and driver combination have been designed to drive the maximum current through the winding at stand still without exceeding the maximum 7-watt power dissipation for this type of motor.

From the chart, we see that the output power of the motor can be increased by a factor of six, through the use of a bipolar constant current driver, compared to the basic unipolar

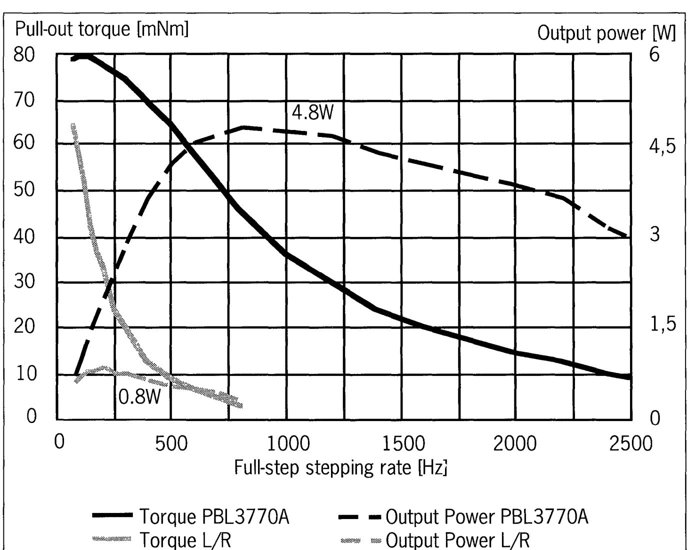


Figure 1. Pull-out torque and output power for a 57mm PM stepper driven by a unipolar L/R-driver and a PBL3770A bipolar constant current driver.

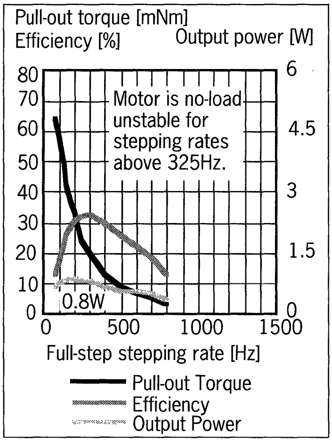


Figure 2. Performance curves for a 100ohm unipolar 57mm PM-motor driven by a 20V L/R constant voltage driver.

L/R-driver. The increased output power is a function of both the increased overall pull-out torque and the increased stepping frequency range.

As we can see from the figure, the maximum output power is available at relatively high stepping rates, compared to the maximum pull-in frequency, for this type of motor (approximately 150 to 400Hz, for zero-load inertia, depending on driver circuit). This fact, which is true for most stepper applications, shows that, to be able to get a high-performance stepper motor system, we have to use ramping up/down when we start and stop the motor and load. The use of ramping opens up stepper motors for power output applications, and does not limit the usage of steppers to low-performing low-output power systems.

Damping and resonances

In applications with low system damping, the available output torque and power can be drastically reduced by resonance. Resonances in stepper motor systems can arise at low-, mid-, and high stepping rates. As a rule, *constant current drivers* have the most problems with resonances in the low-frequency region. These resonances can often be eliminated by using half-stepping or microstepping. *Constant voltage drivers* normally have problems with resonances at medium and/or high frequencies. At these frequencies, neither half- nor microstepping can reduce the resonances. This limits the usage of this type of drivers at medium and high frequencies to driving high-damping loads.

Damping also depends on the motor type—PM-motors have higher damping than hybrids, due to slide bearing friction and magnetic losses.

Some driver and motor combinations have such low damping, at certain stepping rates, that they do not run without a high-damping load. This condition is known as no-load instability.

Resolution and positioning accuracy

The resolution of a stepper motor system is affected by several factors—the stepper motor full-step length, the selected driver mode (full-step, half-step or microstepping), and the gear rate. This means that there are several different combinations which can be used to get the desired resolution. Because of this, the resolution problem of a stepper design can normally be dealt with after the motor size and driver type have been established.

Design time

Even though customization of step motors is possible, it requires both engineering time and time for manufacturing stepper motor samples. Using a more-flexible driver circuit, like the chopper constant current driver can

Table 1. Unipolar constant voltage driver attributes

Features

- Low electronic component cost.
- For small motors very low cost transistor arrays can be used.
- Low electrical noise level.

Drawbacks

- Lowest motor output power.
- Maximum power dissipation at stand still.
- Higher motor cost and larger size for the same output power as from other drives.
- Driver transistors have to withstand twice the maximum supply voltage.
- Windings must be designed for the used supply voltage.
- Regulated power supply normally required.
- Holding torque depends on supply voltage and motor temperature.
- Large torque ripple when driven in half-step mode.

Applications.

- Low speed and low power applications were the motor mainly is used to produce a torque.
- Normally only used with small size motors.

make it possible to select a standard motor with no performance loss.

Cost

In high-volume applications, the major cost is the hardware—including power supply, driver, wiring, motor, and gearing. In this case, the engineering cost is less important. In many applications, it is possible to lower the total system cost and increase the performance by using a more-complex driver (with a slightly higher cost) and less-costly motor and power supply.

In low- and medium-volume applications, the engineering cost becomes a larger part of the total cost. In this case the flexibility and high integration of a constant current driver can help save engineering time and cost.

Dynamic characteristics

In applications were the stepper must move from one position to another then stop in the shortest possible time, the settling time becomes a very important factor. If the system is designed properly, the settling time can be kept to a minimum—if not, the settling time can easily require several hundred milliseconds.

To get good dynamic behavior in an open loop system, it is important to have the correct gear rate and precise control of the motor running and holding torque. With well-designed gearing, it is possible to handle variations in both load inertia and friction.

Performance of drivers

In the following section, the performance of some commonly-used driver configurations are compared when they drive a 57mm 7.5-degree PM-stepper motor. Driving voltage/currents are selected so the stand-still motor losses are kept at maximum rated 7 W. The performance curves show the pull-out torque, output power (at the motor shaft), and the system efficiency. Efficiency is defined as the mechanical output power from the motor divided by the input power to the driver. For each driver, features and drawbacks are also listed.

Unipolar constant voltage

This is the classic low-end driver. It offers the lowest price for the driver electronics—only four transistors are used. To drive small-sized motors, a transistor array of ULN2003 or similar type can be used. For mid-sized motors, power darlington transistors, or transistor arrays can be used. In figure 2, the performance of this type of driver is shown. A motor winding with 100 ohm phase resistance has been selected. This gives good control of winding current and low losses in power transistors. With this driver, the motor has problems with no-load instabilities at stepping rates above 325Hz.

Unipolar L/nR constant voltage

This driver is similar to the unipolar constant voltage but has external series resistors in series with the motor windings. This driver can be configured with different L/R ratios. L/2R means that the total resistance is equal to two times the motor's internal resistance. A higher L/R-ratio increases high-stepping-rate output

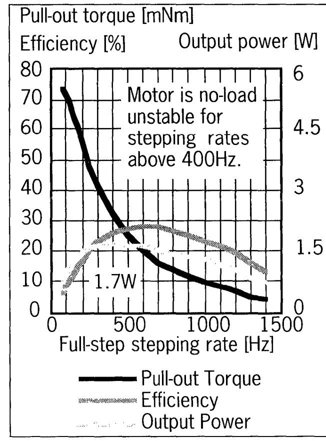


Figure 3. Performance curves for a 100ohm unipolar 57mm PM-motor driven by a 40V L/2R constant-voltage driver (2 × 100ohm external series resistors).

Table 2. Unipolar L/NR constant voltage driver attributes

Features

- Low component cost
- Low electrical noise level.

Drawbacks

- Low or very low efficiency. Lower efficiency the higher R_{ext}/R ratio.
- Problems with heat dissipation from the series resistors.
- Maximum power dissipation at stand still increase by the L/nR ratio compared to the normal L/R driver.
- Large torque ripple in half step mode.
- Holding torque depends on supply voltage and winding temperature.

Applications.

- Low and medium speed and low power applications.

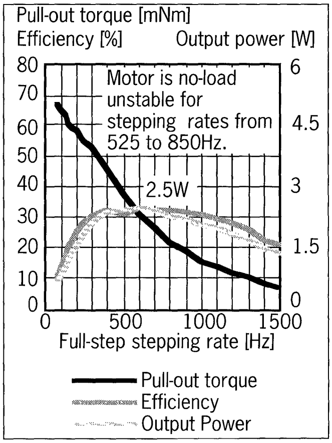


Figure 4. Performance curves for a 100ohm unipolar 57mm PM-motor driven by a 40/20V Bi-level constant-voltage driver (High-voltage-on time = 4ms).

torque, but reduces the system efficiency. Figure 3 shows the performance of this driver in the L/2R-mode, driving the same 100 ohm unipolar motor.

Compared to the L/R-driver we now gain higher output torque and power. The maximum output power has doubled, but the peak system efficiency has decreased.

This drive also shows the no-load instability, here for stepping rates above 400Hz. This limits the applications, at high frequencies, to driving high-damping loads or to operating in ramp up/down applications, were the motor does not run at constant speed. It is possible to ramp through unstable frequencies, and use the full pull-out torque (with normal safety margin) if the motor only runs a limited number of steps in the unstable range.

Unipolar timed Bi-level

This driver uses two voltage levels to increase motor utilization. At every step taken, the voltage across the winding is raised, for a short time, to a higher level compared to the nominal voltage used at stand still. During the remaining time, the nominal voltage is used. This driver can also be configured in the "run/stop" bi-level mode, were the high voltage is used while the motor is stepped and the low voltage is used at stand still. This driver can also be combined with L/nR-series resistors to give higher flexibility in selecting stand-by holding torque. Ericsson's PBD 3517 is a fully-integrated, bi-level driver intended for use with small-sized motors. In figure 4, the performance of the L/2R driver is shown while driving the same 100-

Table 3. Unipolar timed bi-level driver attributes

Features

- Medium electronic component cost
- Medium electrical noice level.

Drawbacks

- Timing circuit or extra CPU overhead needed to control high voltage on time.
- 6 power transistors needed compared to 4 for the standard and L/nR unipolar drives.
- If large high to low driving voltage ratio is used the control off holding torque and step accuracy becomes difficult as a result of variations in winding currents.
- Holding torque depends on winding temperature and supply voltage.

Applications.

- Low to medium speed and low to medium power applications.

Table 4. Unipolar constant current driver attributes

Features

- Nearly the same high speed torque as bipolar chopper drive.
- Uses 6 power transistors compared to 8 for bipolar constant current.
- Half stepping without torque ripple possible.

Drawbacks

- Only 70% of holding and low speed torque compared to bipolar constant current.
- Power transistors have to withstand twice the maximum supply voltage.
- Winding leakage inductance have to be considered when snubbing circuit is designed.
- 6 lead wires add cost and space for motor connectors and flexible cables.

Applications.

- High speed and medium power applications.

ohm unipolar PM stepper. The torque curve for a given motor is a function of both the high-voltage level and the high-voltage-on time. In this example the high voltage is 40V (2 times the nominal voltage) and the high voltage on time is 4ms. Compared to the original L/R-driver, the maximum output power is three times higher. Compared to the L/nR-driver, the efficiency is higher—and is not decreased by losses in series resistors as the ratio U_{high}/U_{nom} is increased. This driver also has problems with no-load instability, but in this case only the mid frequencies are affected. If used in a ramp up/down application, this does not cause any problems, if the constant speed is selected in the stable area above 850Hz.

Unipolar constant current
This driver gives the best performance of the unipolar drives—but it is lower than for the bipolar chopper driver. The efficiency is reduced as a result of higher resistive losses caused by using only half of the windings at a time. At higher frequencies, power losses caused by leakage inductance and snubbing circuits also appear.

Bipolar constant current
The highest output power and motor utilization for a given motor is achieved with the bipolar constant current driver. DC-losses is kept at a minimum due to maximum utilization of the copper in the winding and no power losses from leakage inductance and snubbing circuits since every winding only consists of one part.

In figure 5, the performance for this type of driver is shown driving the same type 57mm PM-motor. Here a motor with a constant-current-adapted winding resistance of 3.75 ohms has been selected. The winding current is selected to give the same resistive losses in the winding at stand still as

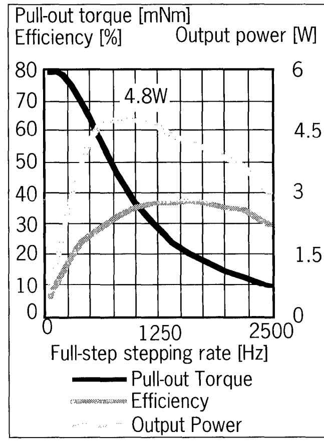


Figure 5. Performance curves for a 3.75ohm bipolar 57mm PM-motor driven by PBL3770A constant-current driver (Chopper voltage 20V, winding current 960mA).

Table 5. Bipolar constant current driver attributes

Features

- Maximum motor utilisation and high efficiency.
- Maximum torque at low and high stepping rates.
- Low losses stand bye mode possible.
- 8-lead motors can be configured for 3 different operating currents.
- No snubbing circuits required and current turn off can be selected for fast (return to power supply) or slow.
- Highly integrated drivers available, second sourced drives also available.

Drawbacks

- 8 power transistors needed to drive a motor.
- Problems with electrical noise and interference can occur.
- Power losses in current sensing resistors.

Applications.

- For small and medium size motors highly integrated drivers are available.
- High speed and high power applications.

Table 6. Bipolar constant current microstepping driver attributes

Features

- Same as for the bipolar constant current, plus:
- Resonance free movement on low step rates.
- Increased stop position resolution.

Drawbacks

- Same as for the bipolar constant current, plus:
- Higher cost for the current control electronics than for normal bipolar drive.

Applications.

- For small and medium size motors highly integrated drivers are available.
- High speed and high power applications.
- Applications were increased resolution is required.
- Applications were resonance free low speed characteristics is needed.

for the unipolar drives tested above. From the chart, we can see the increase of output power, maximum stepping rate, and system efficiency. Due to the better utilization of the winding, the holding torque is also raised.

The no-load instabilities in the mid- and high-stepping rate regions are no longer present. This increases the flexibility in selecting constant-speed running frequencies. However, a resonance at 100Hz is present. In a ramp up/down application, this does not cause any problems as long as this frequency is not used as constant speed frequency.

During the last 10 years, progress in IC-technology has made it possible to develop fully-integrated bipolar constant-current drivers, making this type of driver cost-effective for driving small- and medium-sized motors.

Bipolar constant current microstepping
This is an improved version of the basic full- and half- stepping bipolar constant-current driver. Here, the winding currents form a sine/cosine pair. This greatly improves low-frequency stepping by eliminating overshot movements, ringing, and resonances. Performance at medium- and high-stepping rates are close to that of full- and half-stepping.

This driver uses the same power stage as the bipolar constant-current driver, but extra electronics for setting the sine/cosine current levels are used. Microstepping can be used with different microstep lengths. A shorter step length than 1⁄32 of a full-step normally does not make any further improvement in the motor's motion. With most microstepping controllers, is it also possible to run the normal full- and half-step modes.

Microstepping can also increase motor resolution and step accuracy.

General driver aspects

Power supply design
For all drivers of constant-voltage type, regulated power supplies are normally required. This means that the over-all system efficiency will decrease further, compared to the values shown in the figures above, due to losses in the power supply. This will increase transformer cost and heating problems. If unregulated supplies are used, large variations of holding and running torques occurs, thus making stop-time minimizing more difficult or impossible. An unregulated power supply for a constant voltage driver also affects the motor power dissipation making good motor utilization impossible.

For a constant-current driver, it is normally possible to use an unregulated supply voltage. The motor current, and thereby also holding torque and power dissipation, is controlled by the driver itself. The pull-out torque at high stepping rates is affected by the supply voltage but at low step rates, its influence is small.

It is difficult to calculate the power consumption for a particular application. The best way to get this information is to make a prototype and measure the driver input current under different driving conditions. Remember that the power consumption depends on input voltage, current levels (if constant current mode), load, motor temperature, duty cycle and so on.

Snubbing and current turn off circuits.
To assure trouble-free functioning of all unipolar drives, especially when larger size motors are used, the winding and current turn-off circuit has to be properly-designed.

It is important that a unipolar winding is bifilar wound—this means the two wires that build up the coil on each motor pole are wounded in parallel. This way, the leakage inductance is kept to a minimum, even though the energy stored in the winding has to be taken care of (or moved to the other winding half) when the current is turned off. This is done by a current-turn-off circuit or a snubbing circuit. If the current-turn-off circuit works on the principle of current commutation from one winding half to the other, the energy stored in the leakage inductance is handled by a snubbing circuit.

In the case of bipolar drive, separate snubbering circuits are never needed, since the windings only consist of one part each and no leakage inductance can occur. The current-turn-off circuit is of four diodes in opposition to the four power transistors in the H-bridge.

Hysteresis losses in motors
With some low-inductance motors, chopper-type drivers can generate increased iron losses, caused by the winding current ripple. To minimize this problem, use a high chopping frequency and do not use a lower inductance than needed to get maximum-required step rate—it is also possible to use a lower chopping voltage. In most applications, the hysteresis loss related to the chopping current ripple is low compared to the hysteresis loss related to the stepping current changes. If chopping current ripple is kept at or below 10% of the nominal current, this normally doesn't cause a problem.

Interference problems
For all chopper-type drives, the increased risk of different interference problems has to be considered. Separate and wide grounding lines, as well as physical separation from sensitive electronics on the PCB, can help to avoid interference. Stepper lead wires should also be separated from sensitive signal wires to reduce capacitive and inductive coupling. In a chopper application the capacitive coupling of the chopped voltage (this is a square wave signal with the amplitude equal to the supply voltage and the frequency equal to the chopping frequency) present at the motor lead wires can cause serious problems if not handled.

Performance of motors

The maximum output torque and power from a stepper motor is limited by the power losses of the motor. For low stepping rates, most of the losses are related to resistive losses in the motor winding. At higher stepping rates the hysteresis and eddy-current losses become the major ones. Especially for low-cost tin-can PM-steppers, these losses can be high—because of the absence of laminations and the use of low performing magnetic materials of the stator and rotor flow path.

From the above driver comparisons, we can see that the maximum torque, efficiency, and output power from a given motor is achieved with the bipolar chopper driver. We will now examine the performance of some commonly-used stepper motor types when they are driven with a bipolar chopper drive.

A drop in performance, similar that of the 57mm PM-motor used above, can be expected when other types of drivers are used.

57mm PM motor

PM-motors are a cost-effective alternative in many low- and medium-performing applications. The motors uses slide bearings and a simple mechanical design to keep cost low. Compared to hybrid motors, the life expectancy is shorter, step accuracy and efficiency is lower. The slide bearing can also cause problems if a belt drive is applied directly to the motor shaft.

The 57mm PM-motor is. for instance, suitable to use as paper feed and carriage drive motor in medium-performance matrix or daisy printers and in typewriters. Other applications are fax machines, sewing machines, valve controls, and plotters.

Other popular PM-motor sizes are 35mm and 42mm. 20mm, 25mm and 63mm motors are also common PM motor sizes. The 20mm motor is popular as a head driver in 3½" floppy-disk drive applications. Commonly-available full-step angles are 7.5 and 15 degrees but others are also available (9, 11.25, and 18 degrees, for examples).

In figure 6, the performance of this motor is shown again. The power loss is plotted as a function of the stepping frequency. This motor is rated at 7 watts maximum power dissipation. The chart shows the power dissipation of the motor and driver together. At low step rates about a 3W-loss in the two PBL 3770A circuits can be expected, as well as an additional 1W in the current sensing resistors and approximately 1W in the external diodes. At higher stepping rates, the driver losses decrease as the winding current decreases and the switching stops. At low step rates this gives a 7-watt loss in the motor. At higher step rates, the total loss decreases indicating the ability to get a higher output power without exceeding the maximum allowed motor losses of 7W. If a lower duty cycle or better heat sinking is applied to this motor a peak output power of at least 10W can be achieved.

PM-motors have one advantage over hybrid motors, they have a higher internal damping and offer, in some applications, a more-noise-free operation than the hybrid motors.

42mm square motor

This motor is normally manufactures with 3.6-, 1.8- and 0.9-degree step angle. Step accuracy is ±3% to ±7% of a full-step. The motor uses ball-bearings to maintain the very small air-gap required for high efficiency.

This type of stepper motor is available from many manufacturers at a reasonable price, but the price is higher than the PM-motors. The main feature of this type of motor, compared to the 57mm PM-motor, is higher efficiency and step accuracy. In many applications, the ball-bearings offer higher life expectancy and make the design of the gearing and mechanics easier. This type of stepper became very popular some years ago as head driver for 5¼" floppy and hard disk drives. It is suitable as a carriage driver for printers and plotters, and for driving the print wheel in typewriters and daisy wheel printers. It is also a competitor to the small-sized PM-motors, if the application requires higher efficiency or ball-bearings

Figure 7 shows the performance of a 25-ohm bipolar 3.6-degree 42mm square motor driven by a constant-current driver. The current level is selected to give 4W resistive losses at stand still. This motor type is rated for 4 to 6W losses depending on manufacturer. Compared to the 57mm PM motor in figure 6, nearly doubled system efficiency is the most interesting difference. From the power losses curve, we see that at higher stepping rates the losses decrease. This indicates that an even-higher high-frequency performance can be achieved with a higher chopping voltage or with a lower-inductance winding.

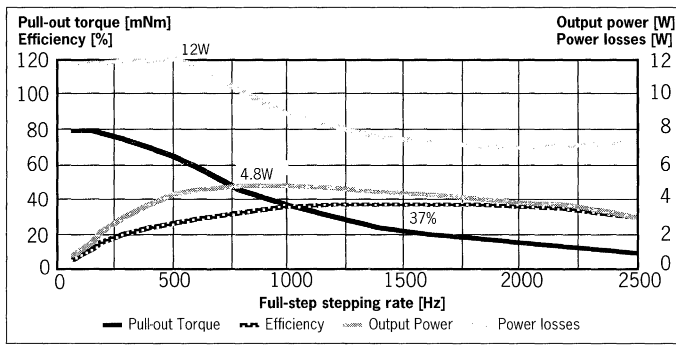


Figure 6. Performance curves for a 3.75ohm bipolar 57mm PM-motor driven by PBL3770A constant-current driver. Power losses in motor and driver are also shown (Chopper voltage 20V, winding current 960mA).

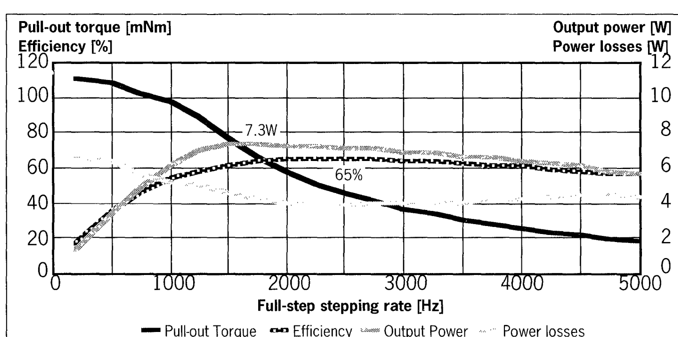


Figure 7. Performance curves for a 25ohm bipolar 42mm square hybrid stepper driven by PBL3770A constant-current driver (Chopper voltage 40V, winding current 280mA).

57mm (size 23) hybrid motor
This type of hybrid stepper motor is normally available with a 1.8- and 0.9-degree step angle and in a number of different lengths from 40mm to 100mm. This motor is more expensive than the two other types described above. On the other hand, a much higher torque and output power is available.

The performance of this motor type is plotted in figure 10. A motor with 5-degree step angle, 2.8-ohm bipolar winding and with 42mm length has been selected. This is the smallest motor size of this class. The 5-degrees step angle is interesting when high shaft speed is more important than high holding torque.

The diagram shows the same high-efficiency as for the 42mm square motor, but four-times-higher output power. A maximum of over 30W is achieved in the area of 3000 to 3500Hz. At high step rates, the power losses of the motor is approximately 12W (including driver 16W). This is acceptable with normal cooling of the motor and 100% duty cycle. At low step rates, the losses decrease and at standstill the losses are only 3W. This shows the ability to increase the motor current to get even higher output torque and power at low step rates. On the other hand, decreasing the low frequency torque can be a way of decreasing noise levels and vibrations in applications where the load friction torque consumes a larger part of the motor torque than the load inertia.

This motor is suitable for paper handling and carriage driving in high-performance printers and plotters, or industrial motion control. The 5-degree stepper, with performance shown in figure 8, is suitable for driving the print mechanism of laser printers. PBL3770A is a suitable driver for this size of stepper motor.

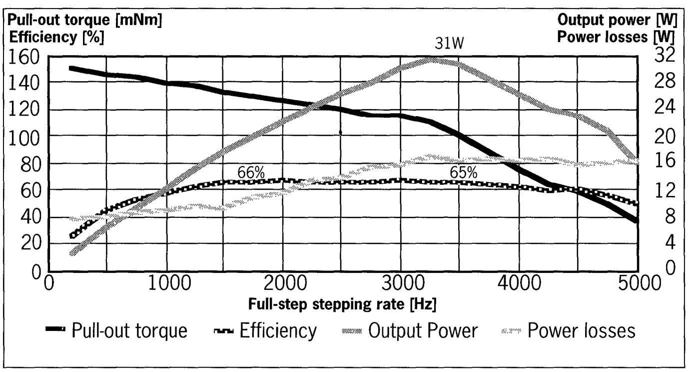


Figure 8. Performance curves for a 2.8ohm bipolar 57mm hybrid stepper (length 42mm) driven by PBL3770A constant-current driver (Chopper voltage 40V, winding current 750mA).

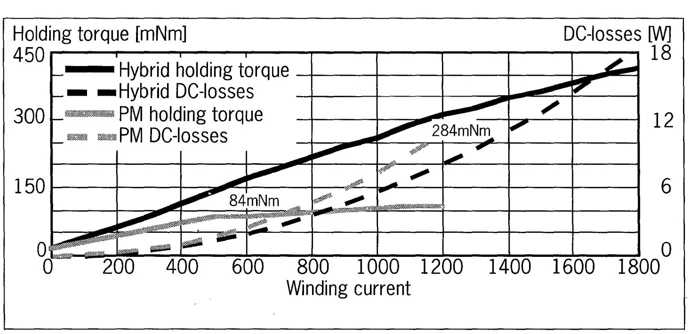


Figure 9. Holding torque and DC-loss as functions of winding currents for a 57mm PM motor and for a 57mm hybrid motor.

Power losses and holding torque
The limiting factor in high-performance stepper motor designs is the stepper power dissipation.

Stepper motor manufacturers often specify the stepper motor windings by the maximum-allowed power disipation at stand still. This gives the nominal winding voltage and current levels. In an application, the optimum performance often is achieved at different voltage and current levels. In figure 9, the holding torques of the 57mm PM and 57mm hybrid motors, described above, are plotted as functions of the the 2-phase-on current, as are the resistive power losses in the windings.

From the diagram, we can see that for the PM-motor, the holding torque curve shows a knee at 600mA—indicating that magnetic saturation starts to occur at this current level, even though the resistive losses in the winding is only 3W, compared to the specified 7W. This indicates that using the specified current level of 960mA does not give the optimum performance on low stepping rates.

Figure 10 shows the affect on motor and drivier performance when the winding current is decreased to 480mA. (50% of the value used in figure 6.) Comparing figure 6 and 10 shows the improved low-frequency performance. Low-speed losses are decreased to less than 50% and low-speed torque only dropps to 80%. In the high-stepping-rate region, only a small loss in torque apears. In figure 13 another combination of driving current and voltage is used to increase the output power to 5.5W with the same maximum losses as in figure 6. Now the losses occur where they are more motivated at the stepping rate where the maximum output power appears.

For the hybrid motor, we see that the winding currents can be increased beyond the maximum rating without causing too much saturation effect. In figure 8, the torque from this motor shows a relativly-flat torque characteristic for stepping rates below 3kHz. This is a result of the 750mA current level not using the full low-speed capabilities of this motor. Increased current will raise the output torque at low speeds and make the region with maximum output power wider (towards low frequencies), but it will only increase the peak output power marginally.

Designing a system

Analyzing the load
When designing a stepper motor system, the first question to ask is "What are the characteristics of the load?" Too often, this question is given too little consideration. To get the best performance, it is important to do an analysis before selecting motor and driver and before designing the transmission and mechanical system.

Friction or inertia loads
If the system will have high dynamic performance, (high acceleration/ retardation), then most of the output torque from the motor will be used to accelerate the system's inertia. To get the maximum performance from this type of system, the gear rate should normally be designed so that the load inertia seen by the motor is close to the motor internal inertia. The load inertia seen by the motor is:

$J_{lm} = J_l \div G_r^2$ where:

J_l = load inertia without gearing

G_r = the gear rate.

A friction torque is reduced by the factor $1/G_r$ by a gear mechanism.

Friction torque/load power consumption
To select the right motor size and driver type, it is necessary to calculate or measure the load friction torque. For most type of loads, this is fairly constant at different speeds, which makes measuring easy. If the system involves a linear motion, a spring scale can be used—and for a rotating system, a torque watch can be used. From the measured force or torque, and information about the maximum speed of the motion, the maximum-needed load power can be calculated:

$P[W] = v[m/s] \times F[N]$
for linear systems and
$P[W] = \omega[radians/s] \times T[Nm]$
for rotating systems.

Another way of estimating the load power consumption is to replace the motor or motor and gearbox with a DC-motor with known current-to-torque function and drive the motor at the desired speed while measuring the current consumption. If this technique is used, it is possible to measure the power consumption at different speeds.

Damping
As noted earlier, the usable torque from a stepper motor can decrease at certain stepping rates due to resonances. At which step rates, and to what extent, this torque reduction appears depends on the application damping and inertia. The damping of the driver also influence the torque reduction.

Resonances at low stepping rates can normally be reduced by lowering driver current and voltage levels, or by selecting half- or microstepping mode drivers. At medium step rates the constant-current drivers normally have the least problems with resonances, but here the characteristics of the load have large impact.

Low system inertia normally creates fewer problems with resonances. However, in some applications, an increased inertia can be used to move a resonance to a lower frequency.

Selecting concept
After analyzing the load, we know the output power needed, the maximum and minimum stepping rates, and the resolution needed.

Depending on the importance of the different demands and the ability to fulfill them, the designer has a range of options in combining motor gearing and driver in a system.

The design is normally an iterative process, with calculation and experimentation. If highest-performance or lowest-cost for a given performance is essential, it is a good idea to compare a few different combinations of motor driver and gearing.

A higher-step-rate driver and a smaller motor, together with a suitable gearing, often gives better performance —in efficiency and output power— than a large motor driving the load directly.

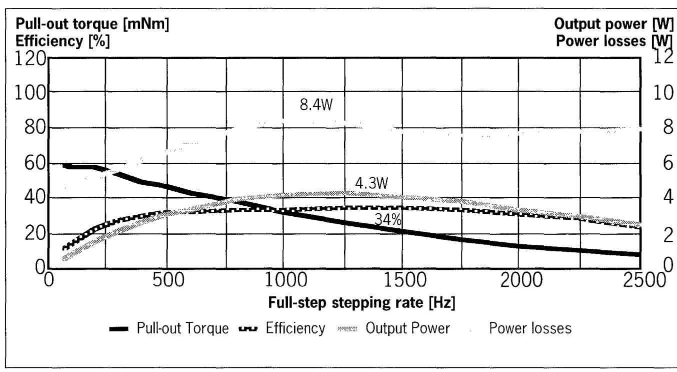


Figure 10. Performance curves for a 3.75ohm bipolar 57mm PM-motor driven by PBL3770A constant-current driver. (Chopper voltage 20V, winding current 480mA).

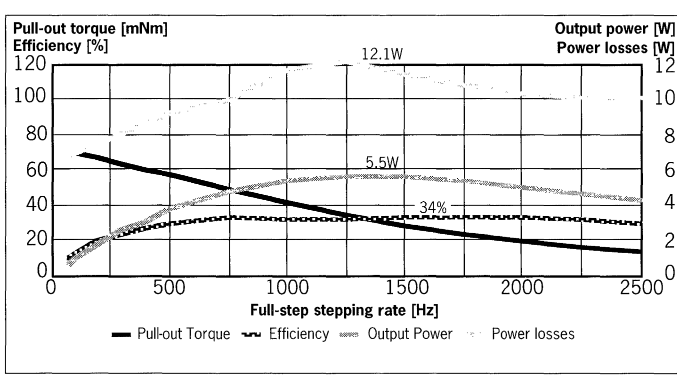


Figure 11. Performance curves for a 3.75ohm bipolar 57mm PM-motor driven by PBL3770A constant-current driver. (Chopper voltage 25V, winding current 600mA).

Motor selection

Output power
This is the most important design criteria in getting the best price/ performance of a stepper motor system. Compare the power requirements of the load with the data given above, or with the data in the manufacturer's data sheet. If the manufacturer's data sheet is used be aware of the big differences in performance of the stepper motors due to different drivers. Also remember that measuring stepper motor pull-out and pull-in torque is tricky. The measurement is easily influenced by inertia and resonances in the measuring system, and the inertia and damping of the application is normally different. As a result, the pull-out curves in the data sheet are not always valid for an actual application.

Mechanical aspects
The physical dimension and weight of the motor are important criteria when a motor is selected. Often the choice of a smaller motor can make a compact mechanical design easier. A smaller motor can also, if the motor is in a moving part of the mechanism, make the design of the motion system easier.

In applications where long life expectancy is needed, motors with ball bearings are required. Hybrid motors use ball-bearings as a standard (to maintain the narrow air-gap), but small-sized PM motors usually use slide bearings. PM motors, with ball bearing as an option, are supplied by some manufacturers—but the additional cost for this is rather high.

If the motor drives a belt gearing or a belt transmission directly, ball bearings are strongly recommended. This ensures proper lifetime and reduces torque loss due to bearing friction caused by the belt tension.

Cost
The motor cost depends on motor type and size. Winding type and resistance do not affect the cost. As a rule, hybrid motors are more expensive than PM-motors. The motor cost normally increases with motor size. Another factor that influences the motor cost is the production volumes of a certain motor and the number of manufacturers of that motor. This means that many times a "popular" type and size motor is the best choice even if the motor output power is a little higher than required.

Customizing the motor
In medium- and high-volume applications, it is possible to customize the motor. Most manufacturers offers customization on the following items.

Shaft	Single- or double-sided Length Pinions
Winding	Resistance Inductance
Rotor	Type of magnets hybrid air-gap distance
Lead wires	Length Connector

From some manufacturers, other parameters such as shaft diameter, bearing types, mounting flange can be customized but this is normally applicable only in high-volume applications.

Driver design

Selecting driver type
The performance curves at the beginning show the effect of the driver on the system. If only low stepping rates are used and the use of gearing is not a solution, the unipolar L/R-driver offers the lowest cost for the electronics for a given output torque.

As demand for output power from the stepper increases, more-effective drivers offer the best price performance ratio. The best motor utilization is achieved with the bipolar constant current driver and this driver is the obvious choice for all high-power applications.

For applications in the low- and medium-power range, several alternatives exists. If system efficiency is important, then the bipolar constant current driver is the best choice. This driver offers higher flexibility in selecting the motor winding, since both the chopper voltage and the current in the winding can be changed to get the desired pull-out torque curve from the motor. Power-supply design gets easier and power-supply losses decrease since regulated supply normally is not needed for constant current drivers.

If minimum cost for the driver electronics is the most important design criteria, rather than the over all system performance, then the different unipolar driver can be the best choice.

Selecting driver mode
FULL-STEP MODE: This is the basic stepper driving mode, it offers the simplest control electronics and it is recommended for high- and medium-frequency operation. At these frequencies, the inertia of the motor and the load smooth out the torque, resulting in less vibration and noise compared to low-speed operation.
HALF-STEP MODE: Half stepping with 140% 1-phase-on current gives smoother movement at low step rates compared to full stepping and can be used to lower resonances at low speeds. Half stepping also doubles the system resolution. Observe that for most steppers, the step accuracy specification only is valid for 2-phase-on positions. The accuracy is lower and the stop-position hysteresis is larger for 1-phase-on positions.

Figure 12 shows the effects on performance of the 57mm PM-motor when half stepping is applied to this motor. Compared to to full stepping (reffer to **figure** 10 for the same driving conditions), a slightly-higher torque at low speed and a small decrease at higher step rates. The main advantage is the lowered noise and vibrations at low stepping rates. If maximum performance at both low and high step rates is essential, a switch to full-step mode can be done at a suitable frequency. Change the stepping mode this way will also lowers CPU-time requirement (step rate reduced by 50% at high speeds) if the system use a microprocessor as control unit.
MICROSTEPPING: The smoothest movements at low frequencies is achieved with microstepping. Higher resolution is also offered. If resonance-free movement at low step rates is important, the microstepping driver is the best choice. Microstepping can also be used to increase stop position accuracy beyond the normal motor limits.

Designing the winding

For a constant current chopper type driver the winding design depends on the desired output power, maximum operation frequency, and chopper voltage. A simplified design method, which in most cases when high output power is important, gives a good results is described below.

EMF selection

A good design criteria for winding design is the EMF (electromotive force) of the winding The optimum motor performance efficiency and output power is achieved close to the step frequency where the EMF peak value is equal to the driving voltage (chopper voltage in the case of constant current drive). As an example, the 42mm square motor, with performance as shown in figure 7, has an EMF constant of 20mV/Hz (full-step frequency) With a 40-volt chopping voltage, this gives a optimum stepping rate of 2kHz. From figure 7, we see that at 2kHz both the efficiency and the output power are at their maximum values. To design a winding for 20 volts, with a maximum output at the same stepping rate, a winding with 10mV/Hz EMF constant should be used. This winding will have half the number of turns and thus ¼ of the resistance and inductance of the original winding. To get the same holding torque and low-frequency performance the winding current has to be raised to twice the original value.

It is not possible to increase the optimum stepping rate for a motor to very high values since then hysteris loss and rotor leakage inductance will decrease the efficiency.

The EMF constant for a motor is measured by conecting the motor winding to an osciloscope and rotating the rotor at a constant speed (by means of a DC-motor for instance) and measuring the peak value and the frequency of the generated signal. The generated frequency corresponds to a four-times-higher full-stepping rate. From this the EMF constant can be calculated.

Figure 13 shows the affect on the torque and output power of the 42mm hybrid motor when the chopping voltage is decreased. From the figure,

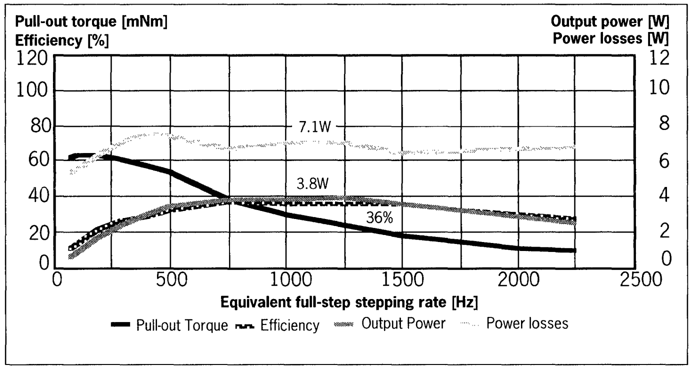


Figure 12. Performance curves for a 3.75ohm bipolar 57mm PM-motor driven by PBL3770A constant-current driver. (Half-step mode fast current decay. Chopper voltage 20V, 2-phase-on current 480mA).

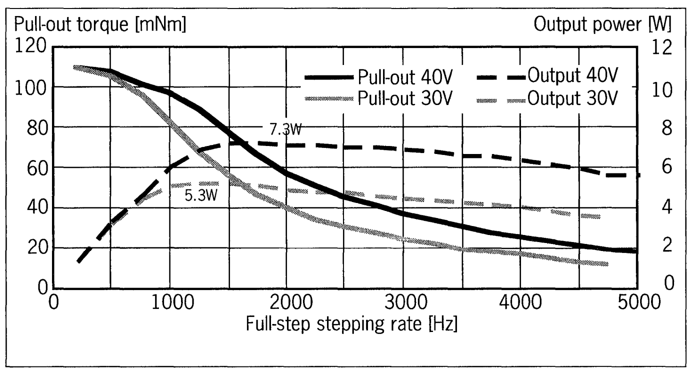


Figure 13. Performance as a function of chopper voltage for a 25ohm bipolar 42mm square hybrid stepper driven by PBL3770A constant-current driver (Chopper voltage 40/30V, winding current 280mA).

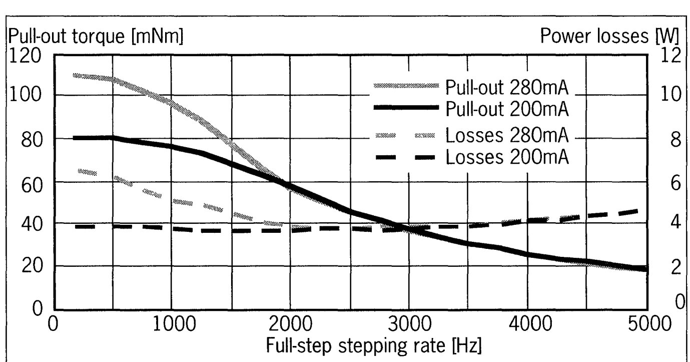


Figure 14. Performance as a function of winding current for a 25ohm bipolar 42mm square hybrid stepper driven by PBL3770A constant-current driver (Chopper voltage 40V, winding current 280/200mA).

we can see that the optimum operating frequency moves from approximatly 2kHz to 1.5kHz when the chopping voltage is decreased from 40 to 30 volts. Using the EMF-rule we get the same result:

20mV/Hz × 1.5kHz = 30 Volts.

Selecting the current level

In a constant-current driver the driver-current level mainly affects the torque at the low frequencies. Depending on the load torque demand (friction and inertia) as a function of stepping rate, it is often a good idea to reduce the current level to get a more-flat torque characteristics from the motor. This normally decrease resonances and power losses and allows a lower-rated driver circuit.

In **Figure** 14, the effect of decreased winding current is shown—from the curve we can see that only the low and medium frequencies are affected by the lower current. Power losses at low step rates have also decreased. The peak output power, however, is not affected as the torque at 2kHz is not decreased.

Summing up

The unipolar L/R-driver offers the lowest cost for the electronics for a given output torque, if the step rate is low.

As demand for output power from the stepper increases, more effective drivers offers the best price performance ratio. The best motor utilization is achieved with the bipolar constant current driver and this driver is the obvious choice for all high-power applications.

Half stepping techniques

By operating a stepper motor in half stepping mode it is possible to improve system performance in regard to higher resolution and reduction of resonances. It is also possible to reduce torque variations to achieve an even smoother motion and more precise positioning by modifying the half step mode. The electronics and programming, as well as the theoretical background involved in generating the necessary signals for half stepping using Ericsson's stepper motor drivers are described in this application note.

The rotating magnetic field.

The basic principle of driving the stepper motor is to generate a rotating magnetic field to which the rotor aligns. The rotating field is generated in the stator by currents in the two phase windings (see figure 1). The direction and the magnitude of the magnetic field is described in a vector diagram (see figure 2). To create a two dimensional vector at least two coordinates have to be controlled—the X- and the Y-axis coorinates. In the following these X and Y axes are also referred to as the stator axes.
The two windings in figure 1 generate a magnetic flux which is aligned to the two stator axis. The current ratio between the two windings gives the total magnetic field vector it is direction and the length of the vector represents the added magnetic flux amplitude. These vectors is shown both in figure 1 and 2. The torque at the shaft (axis) is proportional to the magnetic field.

Referring to figure 1: If phase A and B are energized, the rotor can step from position 1 to position 3, 5, 7 and so on in either direction, depending on the magnetic flux direction which is controlled by the current direction in the two windings. This drive is normally referred to as "two-phase-on" drive. If only one stator coil is energized at a time the rotor can step from position 2 to 4, 6, 8 and so on. This drive mode is referred to as "one-phase-on" drive. Both of these two drive modes will result in full stepping, but the full step positions are shifted one half of a full step.

Half stepping

If these two drive modes are combined and correct sequences are fed into the windings the rotor can be made to align at all positions i.e. 1, 2, 3, 4, and so on. This is referred to as "half-step mode".

Figure 3 describes the current time diagram, it includes input signals and a current direction table as well as the magnetic field direction.

The first part shows the two-phase-on drive where the motor steps from pos 1 to 3, 5, 7. In the second part of the diagram, a half step sequence is fed into the windings.

Compared to full-step drive, half-step drive gives some major advantages:

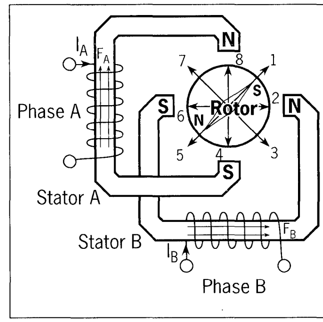


Figure 1. Two phase stepper motor

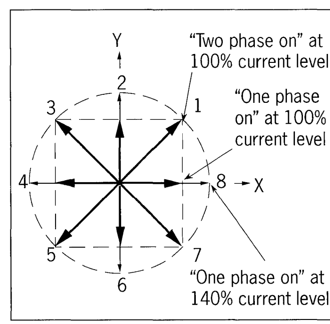


Figure 2. Direction and amplitude of the magnetic field.

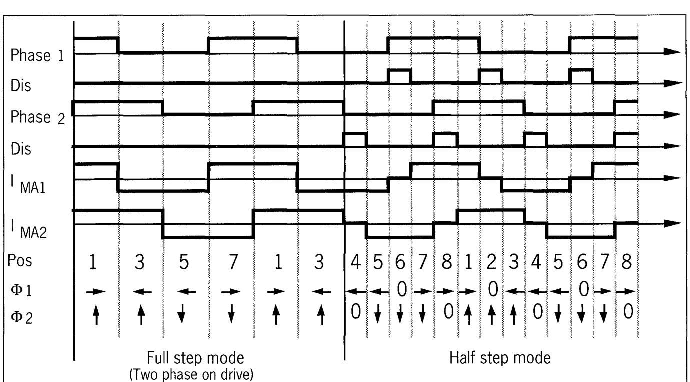


Figure 3. Input signals, output current and magnetic field direction for the different rotor positions in figure 1.

- Higher resolution (without use of a more expensive motor with higher number of steps).
- Less problems with resonance phenomena. Resonances appear as a sudden loss of torque at one or more stepping rates.

Half stepping usually overcomes these resonance problems.

However a disadvantage with half-step drive is a significant torque variation. The reason is the torque in one-phase-on positions is about 70% of the two-phase-on positions' torque. This variation can cause vibrations and/or mechanical noise, though less than in full-step drive mode.

Modified half stepping (constant torque mode)

The way to deal with this torque variation problem is to increase the one-phase-on position torque, to achieve a constant torque over all positions. This can be done if the current level is increased to approximately 140% of the nominal two-phase-on current, in the half-step positions (i.e. 2, 4, 6, 8 in figures 1 and 2).

This is done by changing the value of Rs and/or Vref. The currents in the two-phase-on positions are then reduced by changing the Vref. Some circuits (like the PBL 3717/2 and PBL 3770A) have the ability to set different current levels internally via the I_0, I_1 logical inputs. These inputs set the current to 100%, 60%, 20% and 0% of the maximum current. Note that 140% current level is a theoretical figure. If the application demands very accurate torque and/or the smoothest-possible drive, the relative current levels between full- and half-step positions may have to be adjusted, depending on the type of motor and step rate used.

Since the current is increased every half step, the total power dissipation as well as the torque is kept at a constant level (the same level as in full-step mode of 100% current). Increasing the current to 140% is obviously not always possible without exceeding maximum current or P_D ratings of the driver circuit.

However, when using Ericsson's dual-channel drivers, this is not a problem. The performance of the driver is limited by the package and the allowable power dissipation. When both channels are on, a certain amount of power is dissipated, and, if one of the channels is shut off, the power dissipation is reduced by 50%. The other channel is therefore allowed to dissipate more power and consequently drive more current.

Single drivers can be selected to match the highest current level needed, i.e. the 140% current level, in one-phase-on position, since they can not share the package power handling capability.

Current decay

It is very important to consider the current behaviour when entering the one-phase-on position. Especially when using half-step drive. To force the rotor into one-phase-on position the current

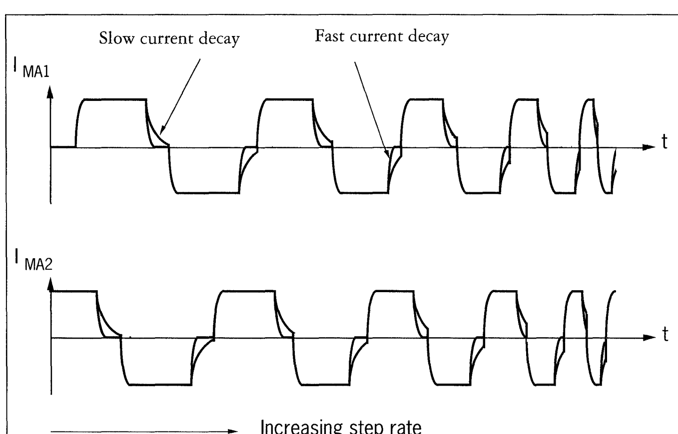


Figure 4. Fast and slow current decay effects on the motor current vs. increasing step rate.

through the non-energized coil should be brought to zero as quickly as possible. Often fast current decay will result in a reduction of the vibrations and resonances. But the performance achieved is very much dependent on the application (mechanical damping, the lag between the rotor position and the magnetic field and so on). Fast current decay will "tighten up" the control of the magnetic field versus the input phase.

By current decay, we are referring to the current change which occurs when de-energizing the coil completely after a phase shift, not the current decay during constant current switching. Generally the current decay time is dependent on the voltage into which the winding discharges its stored magnetic energy. Forcing the remaining current to flow back into the power supply, which is the highest available voltage in the application, results in the fastest possible current decay.

Figure 3 shows an idealized picture of the motor current. A more-realistic picture is illustrated in figure 4. At high step rates, it is obvious that the motor current will not reach zero in the one-phase-on position if the current decay is slow, instead the motor current will be smoothed and look more and more like a distorted sine wave. The result is a significant loss of torque at high stepping rates.

In an H-bridge arrangement the current decay can be controlled by switching the transistors on and off in the right sequence. Referring to figure 5, path 1 is enabled when feeding current through the winding. Transistors Q1 and Q4 are conducting, Q2 and Q3 are shut off. Switching the output off can be done in two ways with different results.

If only Q4 is switched off, the current is forced to follow path 2. This means slow current decay—as the current is opposed only by the forward voltage drop of one diode. The major share of the stored magnetic energy is dissipated in the resistance of the motor winding. This switching method is usually used in constant-current switching. (Also referred to as two-quadrant drive).

An alternative is to shut both Q1 and Q4 off, i.e. all four transistors are shut off. This means the current is forced to flow through two diodes and

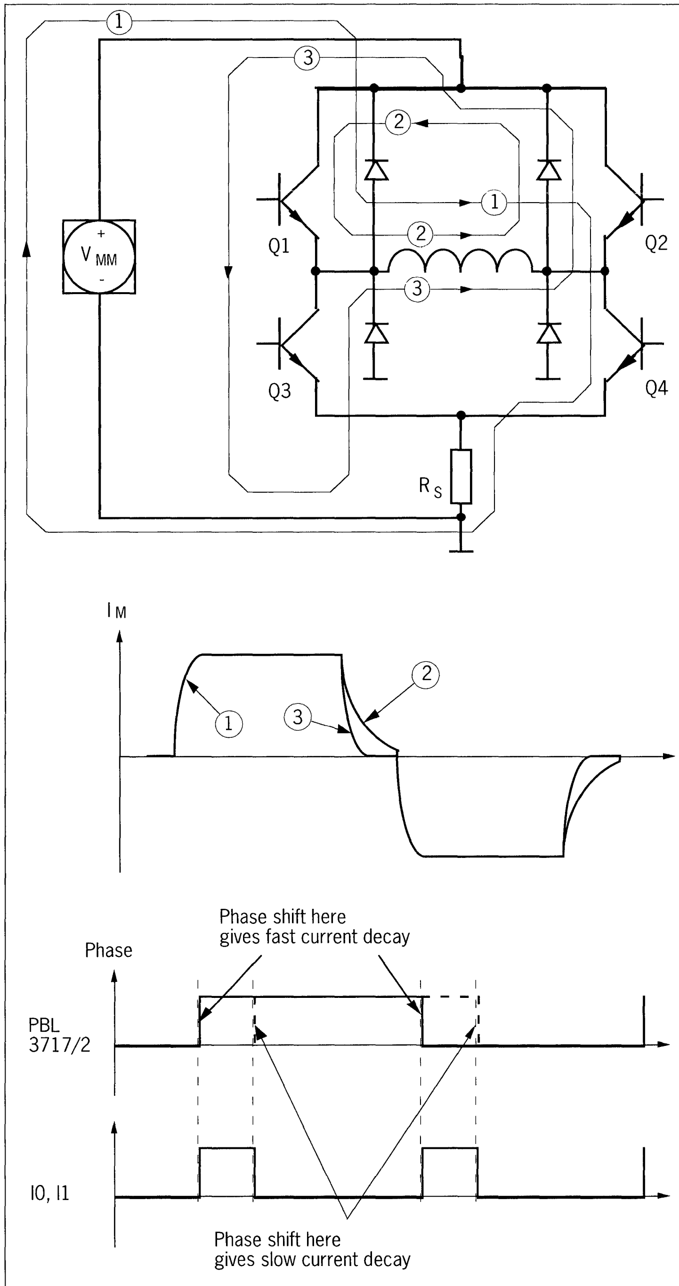


Figure 5. Output stage with current paths at turn-on, turn off and phase shift. Current behaviour at different current paths.

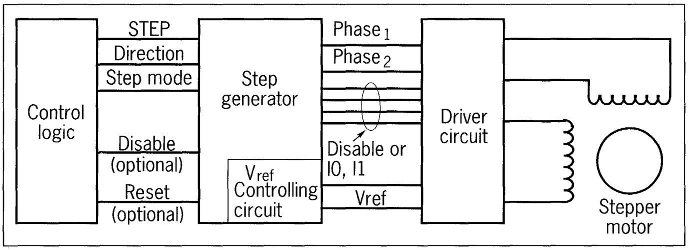
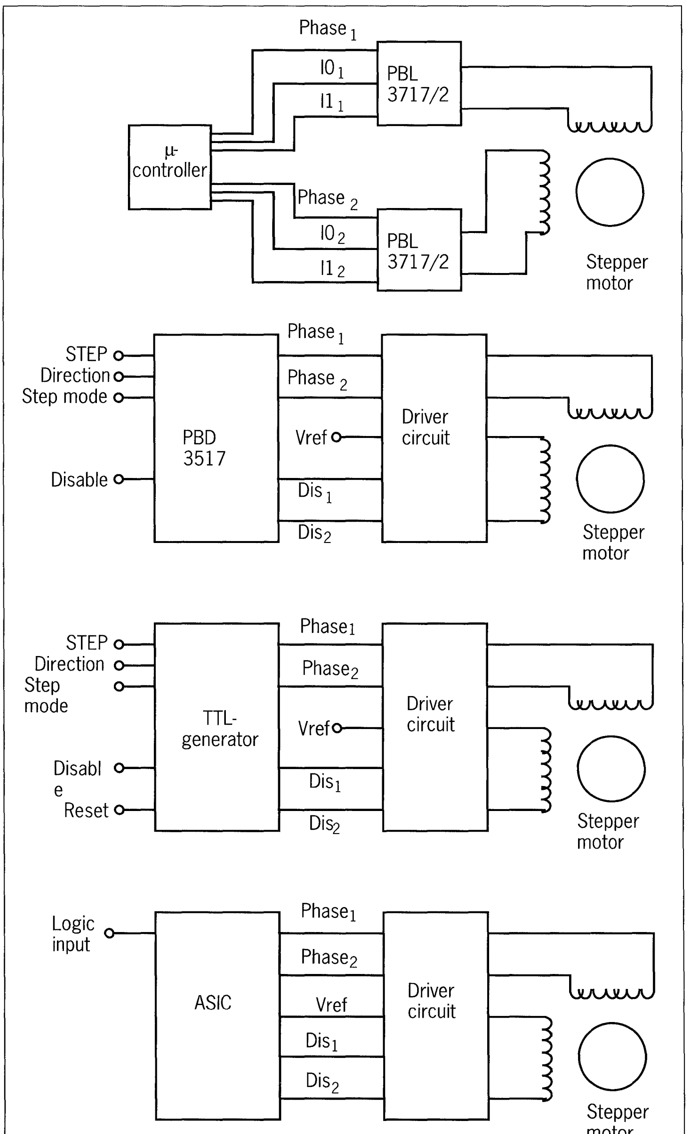


Figure 6. Definition of input and output controlling signals needed.



the motor supply, against the supply voltage (path 3 in figure 5). This results in fast current decay. When current is recirculating in path 3, transistors Q2 and Q3 may be turned on with very little effect on the recirculating current. However, when the current is brought to zero, the current will start to flow in the opposite direction, i.e. a complete phase shift occurs. (Also referred to as four-quadrant drive).

Note: In modified half step mode the fast current decay is only applicable on the current decay from 70% level to zero current. The current decay between 100% and 70% current level will always be slow, because the only change made is lowering of Vref and this will not affect the current decay.

Different circuits have different input signals to obtain fast current decay:

- PBL 3717/2. The current is brought to zero by bringing I0 and I1 high, which turns off the two lower transistors Q3 and Q4. Fast current decay is achieved by simultaneously shifting the phase input which turns off the previously conducting upper transistor Q1 or Q2 (see figure 5).
- PBL 3770A turns off all four transistors when I0=I1=1.
- PBL 3771 turns the output transistors off when the V_R pin is brought to zero.
- PBL 3772 controls the current decay via proper phase shift. See PBL 3717/2.
- PBL 3773/74/75 have a separate disable pin which turns all four transistors at the output off.

Generating the half step sequence

The step sequence is generated by a step generator which can be created in various ways. Some different step generators are presented—the intent is to give some ideas, not to present a complete list—other designs can be found by a designer, which may be application specific or even general solutions.

Figure 7. Examples of stepper motor driver/generator configurations.

A block design defining the input and output pins of the step generator is shown in figure 6.

Input signals to the step generator are:

- STEP. The stepping clock signal.
- Direction. A logic input controlling the stepping direction (rotation) of the motor.
- Step mode. This is a logic input which chooses between full-, half-, and modified-half-step drive mode

The output signals from the step generator are defined by the chosen driver circuit. Phase 1 and 2 are always needed, but the remaining signals depend on driver and drive mode used.

- V_{R1}, V_{R2}. These are the reference voltage inputs. They set, together with the current regulation circuit in the driver, the amount of current in the motor windings. To achieve modified-half-step drive, by changing Vref, a control circuit is usually necessary.

Drivers like the PBL 3717/2 and PBL 3770A have internally-generated current levels, which could be used in half-/modified-half-stepping modes. These levels are controlled via logic control inputs I_0 I_1.

Some examples of stepper motor driver/generator configurations are illustrated in figure 7. More details are given later.

- A software step sequence generator in a microcontroller.
- A TTL step sequence generator, designed using a few standard components.
- PBD 3517 unipolar stepper motor driver can be used as a stepping sequence generator.
- An ASIC circuit can be used to generate the step sequence. This is a space saving solution which can be made application specific.

The choice between these different ways of implementing a half-/modi-

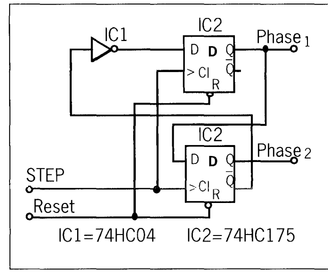


Figure 9. One direction TTL full step generator.

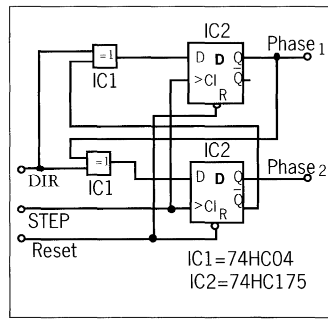
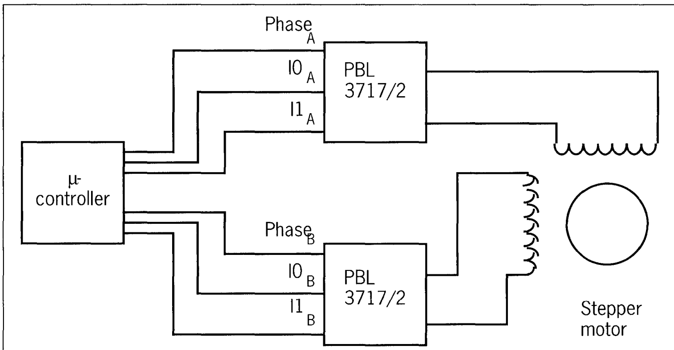


Figure 10. Two direction TTL full step generator.



Phase A	1 1 1 1	0 0 0 0	X 1 1 1	X 0 0 0	X 1 1 1	X 0 0 0
Phase B	1 1 0 0	0 0 1 1	1 1 X 0	0 0 X 1	1 1 X 0	0 0 X 1
I_{0A}	0 0 0 0	0 0 0 0	1 0 0 0	1 0 0 0	1 1 0 1	1 1 0 1
I_{1A}	0 0 0 0	0 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0
I_{0B}	0 0 0 0	0 0 0 0	0 0 1 0	0 0 1 0	0 1 1 1	0 1 1 1
I_{1B}	0 0 0 0	0 0 0 0	0 0 1 0	0 0 1 0	0 0 1 0	0 0 1 0
	Full step mode		Half step mode		Modified half step mode	

X=1 when the bit map is used in ➡ direction (for example CW)
X=0 when the bit map is used in ⬅ direction (for example CCW)

Figure 8. Two PBL 3717/2 controlled by a microprocessor and an output bit map. Note, the change in the digital sequence when changing direction. TheX values in the figure will generate fast current decay; reverse X-polarity to get slow current decay.

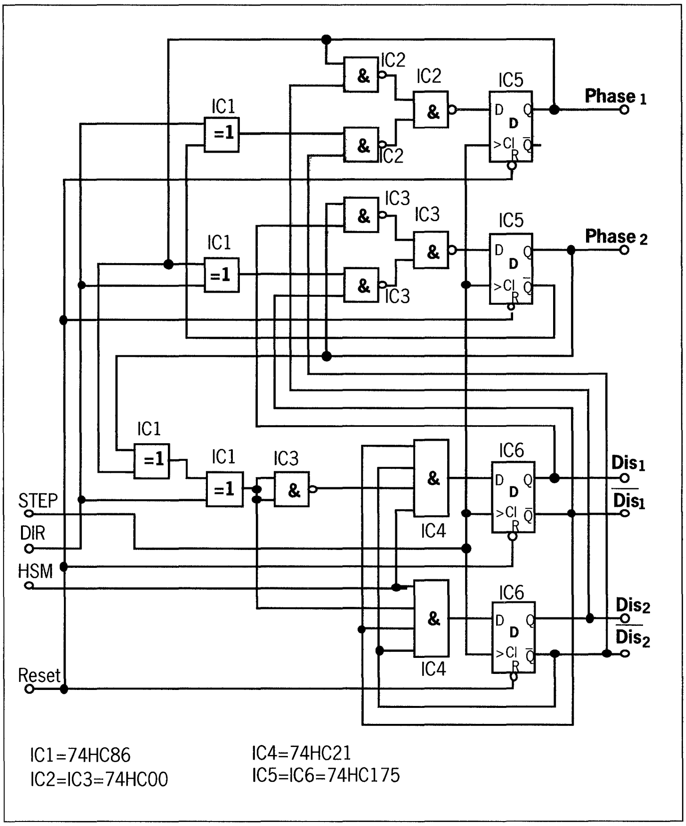


Figure 11. Two direction TTL full and half/modified half step generator.

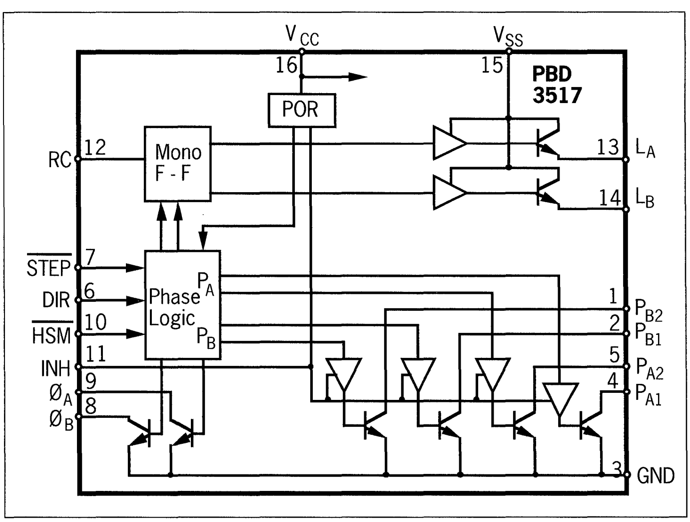


Figure 12. PBD 3517 block diagram.

fied-half-step sequence generator has to be made considering economy, space and already-existing logic functions.

Microcontroller as half step generator

A microcontroller is an easy way to achieve the half step control sequence. The price for a simple microcontroller is resonably low, which means that it is cost effective in many applications. Furthermore, it is very easy to change the control signals using the software.

There are several ways to use the microcontroller output. One is to attach the driver inputs to the outputs of the controller (see figure 8) and let the controller send something like the digital sequence illustrated in the figure anmd access the drivers via the database. Another way is to use a latch.

Some microcontrollers have D/A converters on-chip which makes it possible to use the controller to generate and control the V_R input along with the other inputs. This gives the ability to achieve a half-step sequence with highly accurate torque.

Full step TTL-generator

A full-step TTL generator is easy to implement. A basic design is shown in figure 9. Only two D-flip-flops and one inverter are used. This design does not allow a change of stepping direction. Changing the actual rotational direction of the shaft is easily done by switching the phase outputs to one coil of the stepper motor. Only a step-signal is necessary to control the generator and the motor will take a step for each one of the pulses on the input STEP signal.

If the ablity to change the rotational direction via logic signals is necessary, the design in figure 10 can be used. Here two TTL-circuits are needed. Depending on the state of the logic direction signal the motor will run in either direction.

The reset signal sets the logic outputs to zero. Note: the actual motor shaft position is not reset to a specific position and the windings are fully energized.

Half step TTL-generator

An extended TTL-generator, which can generate control signals for full step, half step and modified half step, is shown in figure 11. In some step modes and with some drivers it might

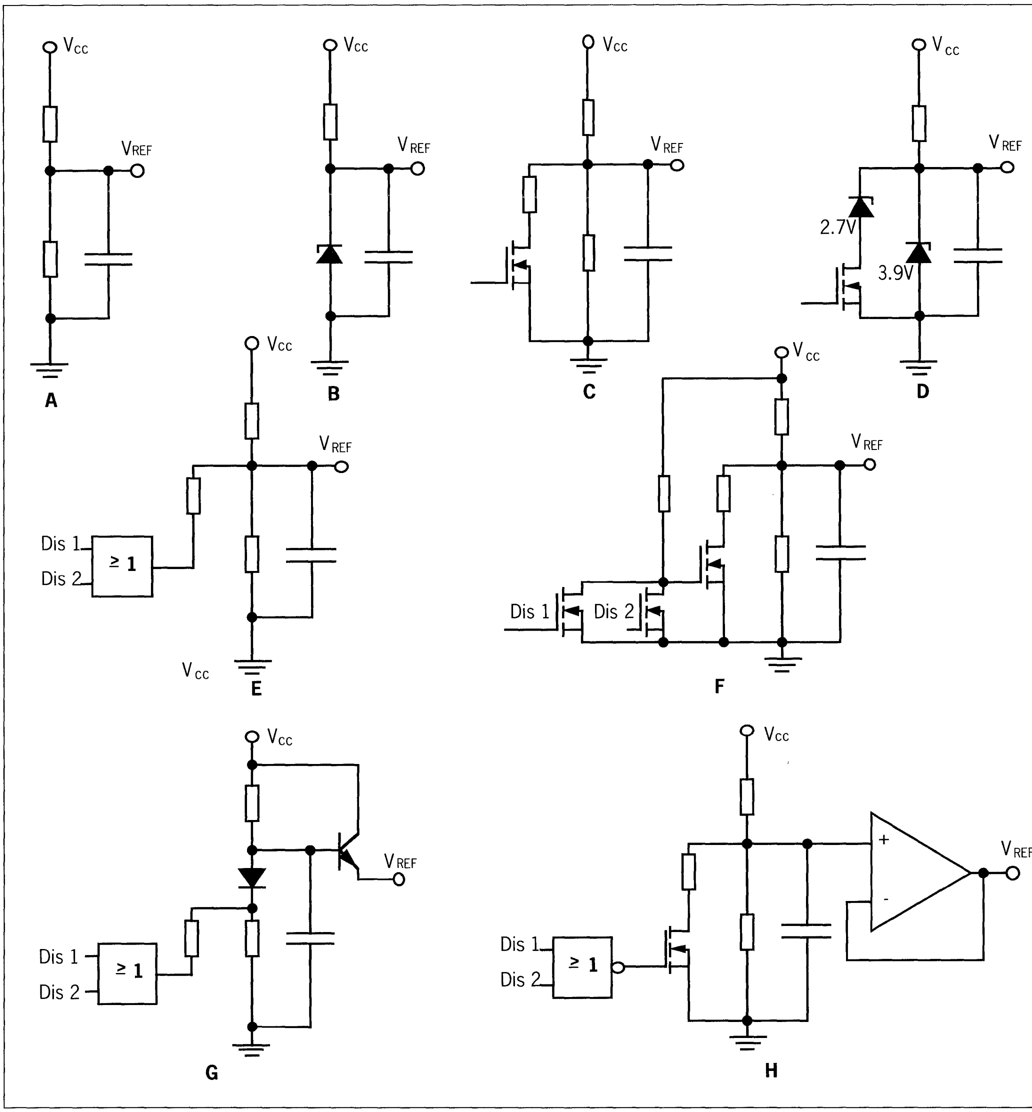


Figure 13. Examples of different voltage reference circuits.

be necessary to add a few components, such as voltage controlling circuits when using modified-half-step mode. The inputs in this case are step, direction and half-step mode.

As in the full-step TTL-generator above, the reset signal only sets the logic outputs to a well defined specific state. A current-disable function can be added by adding a few logic functions.

PBD 3517 as a half step generator
The PBD 3517 unipolar stepper motor driver can be used as a half-step generator (see figure 12). It should only be used with PBL 3770A, PBL 3773, PBL 3774 and PBL 3775. PBD 3517 is not suitable to control PBL 3717/2, because no fast current decay is generated when entering the one-phase-on position.

PBL 3770A has the fast current decay function built in via the I_0, I_1 inputs. In PBL 3773/74/75 the disable pins turns the output transistors off which causes fast current decay.

ASIC
If an ASIC circuit (PAL, PLD, Semicustom and so on) is used in the application, it will be well-suited to include the step generator. This is a

very economical way of implementing the step generator, since it will occupy very little space on the ASIC chip.

Voltage reference control circuits

As discussed earlier, modified half-stepping operation requires a changing current level.

In one-phase-on positions, the current has to be about 40% higher than two-phase-on positions. Or conversely, the total current level could be brought up to the 140% level and reduced to the 100% level in the two-phase-on positions. This method is described in the following text.

To increase the total current level, the current-sensing resistor value should be lowered accordingly. When using the stepper motor drivers which have 2.5 V as nominal reference voltage, it is possible to raise the V_{ref} to increase the motor current. Or you may use a combination of lowering R_s and increasing V_{ref}. Do not exceed the maximum allowable current of the driver. Assuming V_{cc} (5 V) is used as reference voltage source, the controllable reference voltage will range well below V_{cc}.

The input reference voltage range differs within the Ericsson stepper motor driver family.

PBL 3717/2, PBL 3770A and PBL 3775 have an input range of 0 – 5 V. This range is not possible when using Vcc as Vref source. To compensate for the reduced voltage range, the current sensing resistor must be lowered even more to maintain the current level.

When using PBL3717/2 and PBL3770A the internal 60% current levels can be used to lower the current level in the two-phase-on position. In this case an external reference circuit is not necessary, Vcc can be used directly.

PBL 3771, -72 and -74 have a nominal Vref of 2.5 V, which makes it easier to generate a suitable Vref from Vcc. These circuits have no I_0, I_1 inputs, therefore the current reduction in full-step positions has to be generated via the Vref input when using modified-half-step mode. Different kinds of V_{ref} controlling circuits are shown in figure 13.

The comparator inputs of PBL 3773 (VR and C) are of high impedance and low current (typically -0.2 µA). This gives a great deal of flexibility in selecting a suitable voltage divider network.

When using a microcontroller to generate the step sequence, it is natural to use a DAC to generate the V_{ref}. This is probably the best solution because it gives ability to easily change the Vref with software.

Figure 13 illustrates a variety of voltage reference circuits that can be used, depending of the drive mode and the driver circuits used. A and B are two types of stable reference circuits.

A. Ordinary voltage divider circuit. Using only a few components, but relying on the accuracy and stability of Vcc. Note, the V_R input resistance of the Ericsson stepper motor circuit has a tolerance of about 20% at 25°C and is temperature dependent.

B. Another way is to use a zener diode to set the voltage reference. Compared to A the zener diode solution reduces the influence of the varying internal resistance. Zener diodes however are available only in a few discrete values below 5 V. Also note the indistinct zener knee and relatively high internal resistance for zener diodes at this voltage range.

Some voltage reference controling circuits intended for modified half step drive are illustrated in fig C-H. In this drive mode the V_{ref} voltage has to shift between two different levels.

C. This circuit uses a MOS FET device to switch a resistor in parallel with the voltage divider, and thereby causes a reference voltage change. A capacitor at the output improves noise rejection.

D. By using Zener diodes instead of resistors, the influence of the internal resistance can be reduced. Note the zener limitations in circuit B.

E. When using the TTL-controller or the PBD 3517, this reference circuit can be used to change the reference voltage. To reduce the influence of the input resistance, the current through the voltage divider has to be fairly high. Make sure the gate can sink the current needed. It is possible to parallel two or more gates to increase the current sink capability. Note that the gate has to be of open-drain or open-collector type.

F. This circuit uses three FET-transistors to form an OR function. The voltage-setting circuit is a straight forward voltage divider. A capacitor on the output improves noise rejection.

G. This is a recommended reference voltage controlling circuit. It is an ordinary voltage divider that can switch between two levels when a resistor is added in parallel with the lower resistor. Since a buffer is added at the output the current needed is fairly small. This means, the switching device can be a TTL or a CMOS gate (open drain or open collector type). The buffer is a transistor used in open emitter mode. To compensate for the base emitter temperature dependence a diode is added in the voltage divider.

H. This reference controlling circuit uses an operational amplifier as a buffer. The voltage-setting circuit is a switchable voltage divider. A MOS transistor in conjunction with a NOR gate is used for switching. Any other voltage setting circuit can be used with an operational amplifier as buffer.

Modified half step using TTL-generator and PBL 3717/2 or PBL 3770A

This application (figure 14) uses the previously described TTL-generator (see figure 11) to generate the nessesary phase signals. To set the relative current levels between the "two phase on" position and the "one phase on" position, the internal current limiting function is used. This function is controlled via the I_0, I_1 inputs.

The internal current limiting function can control the output current in four levels 100 %, 60 %, 20 % and off. In this application the 100 % and 60 % current levels are used. These levels are not optimal since the current in the "two phase on" position should be 70 % of the current in the "one step on" position. The 60 % level is used which is often adequate.

The reset signal sets the flip-flops in a defined state. This state does not shut the motor current off. To be able to turn the current off the design in figure 15 can be added to the TTL-generator. It should be placed inside the dotted boundary in figure 14.

As a voltage reference V_{CC} (5 V) is used. PBL 3770A together with the choosen current sensing resistor, R_s = 0.5 Ω the motor current will be set to approximately 800 mA. PBL3717/2 uses a current sensing resistor R_S = 1 Ω, which gives a motor current of approximately 415 mA. These current levels can of course be changed, within the power limit, according to the application.

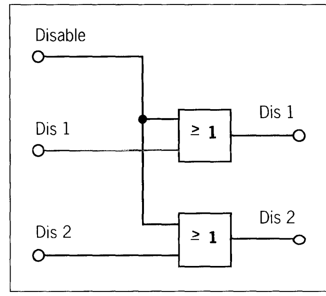


Figure 15. Motor current disable circuit. To be included in figure 14.

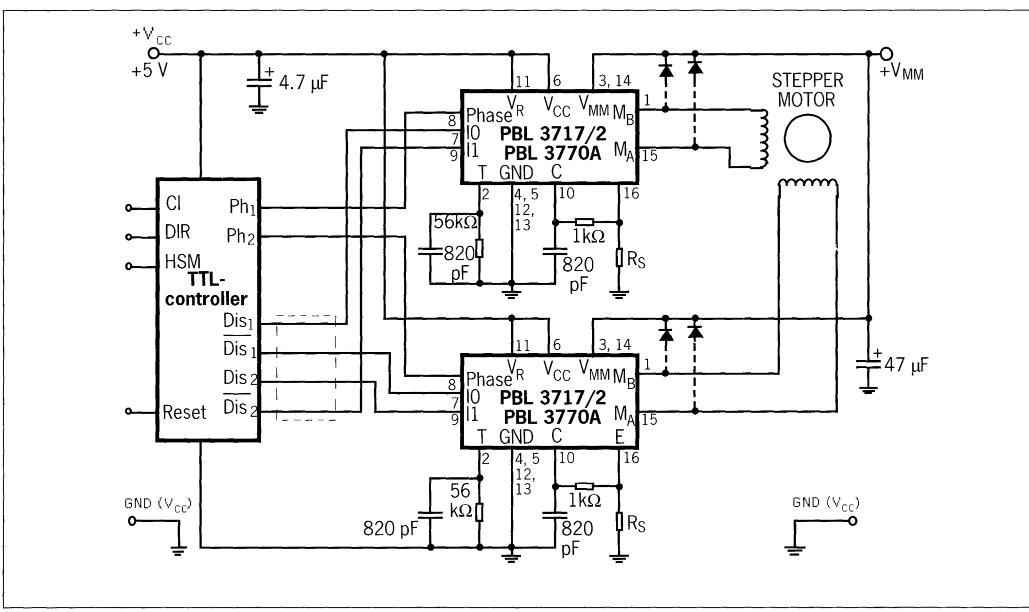


Figure 14. Typical application using a TTL controller and two PBL 3717/2 or two PBL 3770A.

Half/modified half step using TTL-generator and PBL 3774.

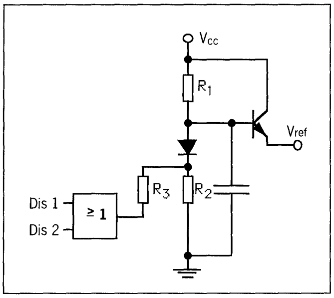


Figure 17. Voltage reference circuit to achieve modified half stepping in the application in figure 16.

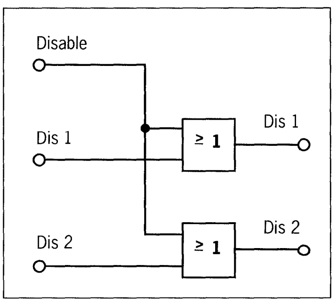


Figure 18. Motor current disable circuit. To be included in figure 16.

The TTL-controller shown previously (see figure 11) can be used to control the PBL 3774 dual stepper motor driver circuit.

By using the disable inputs of the PBL 3774 it is easy to achieve a half stepping function (see figure 18). To generate the necessary reference voltage a zenerdiode of 2.7 V is used. In the diagram a resistor of 0.68 Ω is used for current sensing. This resistor together with the reference voltage gives a peak current of 0.71 A.

To obtain modified half-stepping, a reference voltage switching circuit has to be added.

The voltage reference circuit uses the V_{cc} (5 V) as input. To achieve the two voltage levels the voltage divider G, presented in the reference voltage circuit chapter (is used, see figure 17). This reference circuit uses a voltage divider R1 and R2 to generate the reference voltage. By adding resistor R3 in parallel with R2 a change of voltage is achieved. A transistor used as a buffer reduces the influence of the input impedance. It also makes it possible to choose relatively high values of the resistors (R1, R2 and R3) to reduce current consumption.This makes it possible to use an open drain or open collector NAND gate as a switch. The diode will reduce the temperature dependence of the base emitter junction at the transistor. The motor current is easily set by changing the sensing resistor values.

The reset input at the controller resets only the internal flip-flops and does not disable the motor current. To make it possible to disable the motor current the simple circuit shown in figure 18 has to be added to the diagram in figure 16. This circuit is made up of two OR-gates. When the Disable input is high both Dis inputs at the driver are high and the currents in both windings are shut off.

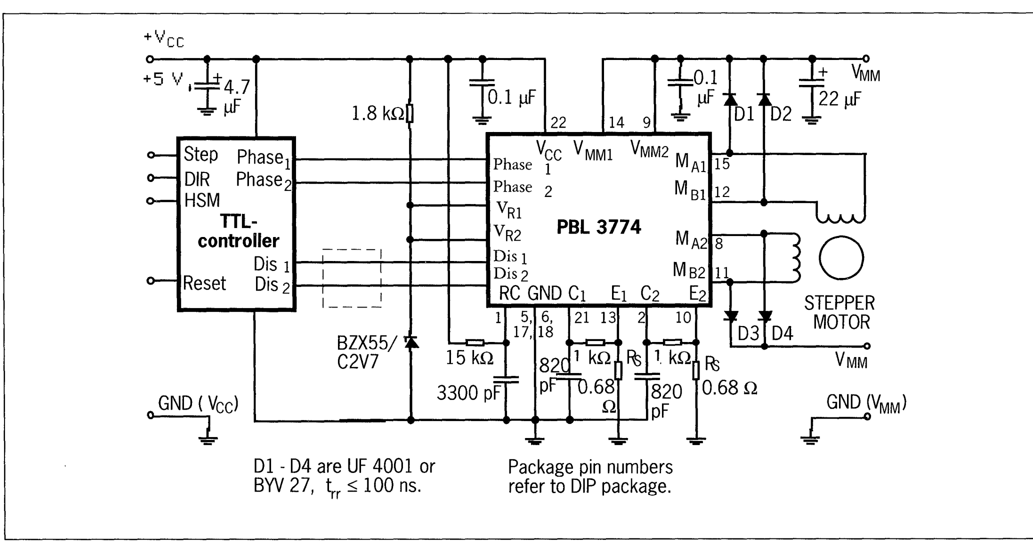


Figure 16. Typical application using a TTL controller and PBL 3774.

Half stepping using PBL 3770A as driver and PBD 3517 as controller.

With this configuration it is easy to achieve half stepping. The unipolar stepper motor driver PBD 3517 can be used as a step controller. Not all of the stepper motor driver circuits are perfectly sutable to function toghether with PBD 3517 (see the Generating step sequence chapter).

Figure 19 shows an application where the PBD 3517 controls and generates the step sequence for two PBD 3770A. The PBD 3517 includes both a full step and a half step sequence generator and the choice between the two is easily made via the logic input, Full/Half step.'The Directon input controlls the rotational direction of the motor shaft. The Step input controls the step rate.

The ØA and ØB outputs of the PBD 3517 are used as current controlling signals for the PBL 3770A (I_0 and I_1) pins (see figure 19). The phase inputs are controlled directly from the PA1 and PB1 outputs of the PBD 3517. Since the utputs from PBD 3517 are open collector outputs pull-up resistors are needed.

With a current sensing resistor (R_s) of 0.5 Ω a motor current of 800 mA is achieved. Note : The PBL 3770A has fast current decay if both I_0 and I_1 are brought to logic high. This is because all four output transistor are shut off.

To achieve modified half stepping the logic circuit in figure 20 has to be incorporated. I_0, I_1 are used to lower the current in the "two phase on" positions. This will result in lowering the current to 60%. This is not optimum but will be accurate enough in most cases. Furthermore this includes a disable function which turns the outputs off.

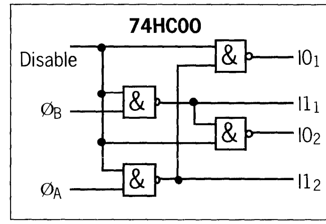


Figure 20. Circuit to achieve modified half stepping in the application in figure 19.

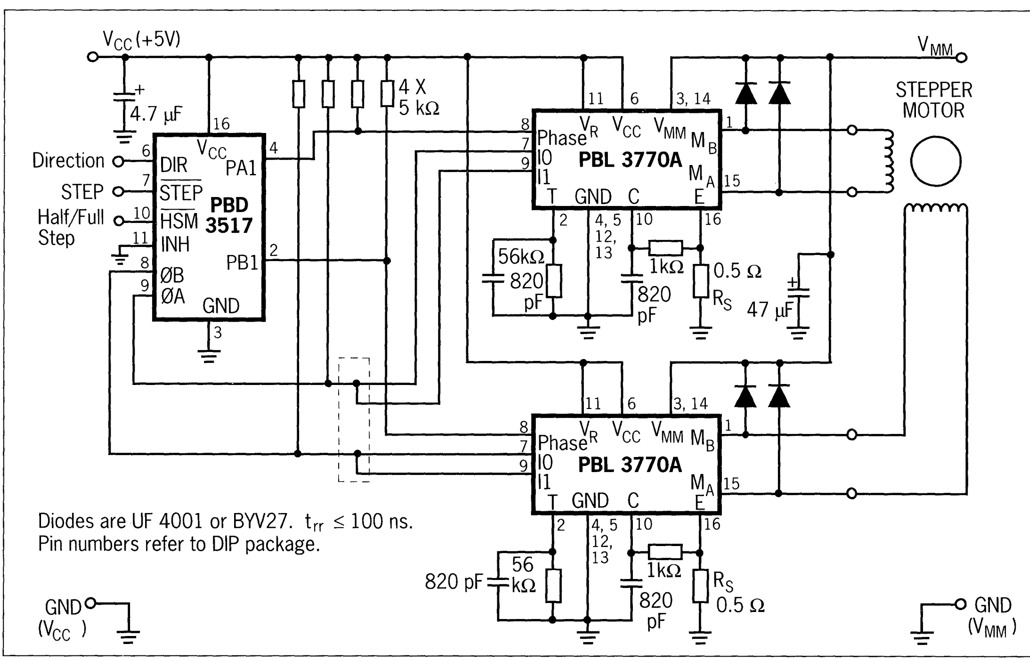


Figure 19. Typical application using PBL 3770A as driver circuit and PBD 3517 as controller circuit.

Half stepping using PBL 3774 as driver and PBD 3517 as controller

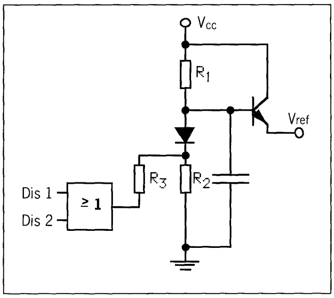


Figure 22. Voltage reference circuit to achieve modified half stepping in the application in figure 21.

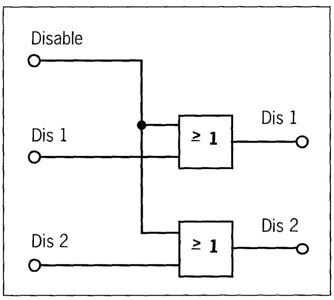


Figure 23. Motor current dsiable circuit. To be included in figure 21.

With this configuration it is easy to achieve half stepping. The unipolar stepper motor driver PBD 3517 can be used as a step controller. Not all of the stepper motor driver circuits are perfectly sutable to function together with PBD 3517 (see the Generating step sequence chapter).

Figure 21 shows the diagram wired for half stepping. To generate the neccesary reference voltage a zener diode of 2.7 V is used. In the diagram a resistor of 0.68 Ω is used for current sensing. This resistor together with the reference voltage gives a peak current of 0.71 A.

To achieve modified half stepping the reference voltage must shift between two levels. The higher level at "one phase on" and the lower level at "two phase on".

The voltage reference circuit uses the V_{cc} (5 V) as input. To achieve the two voltage levels the voltage divider G, presented in the reference voltage circuit chapter, is used (see figure 22).

This reference circuit uses a voltage divider R1 and R2 to generate the reference voltage. By adding a resistor R3 in parallel with R2 a change of voltage is achieved. A transistor used as a buffer reduces the influence of the input impedance. It also makes it possible to choose relatively high values of the resistors (R1, R2 and R3) to reduce current consumtion.This makes it possible to use an open drain or open collector NAND gate as a switch. The diode will reduce the temperature dependence of the base emitter junction at the transistor.

The motor current is easily set by changing the sensing resistor values.

To make it possible to disable the motor current, a simple circuit shown in figure 23 has to be added to the diagram in figure 21. This circuit is made of two OR-gates. When the Disable input is high both Dis inputs at the driver are high and the currents in both windings are shut off.

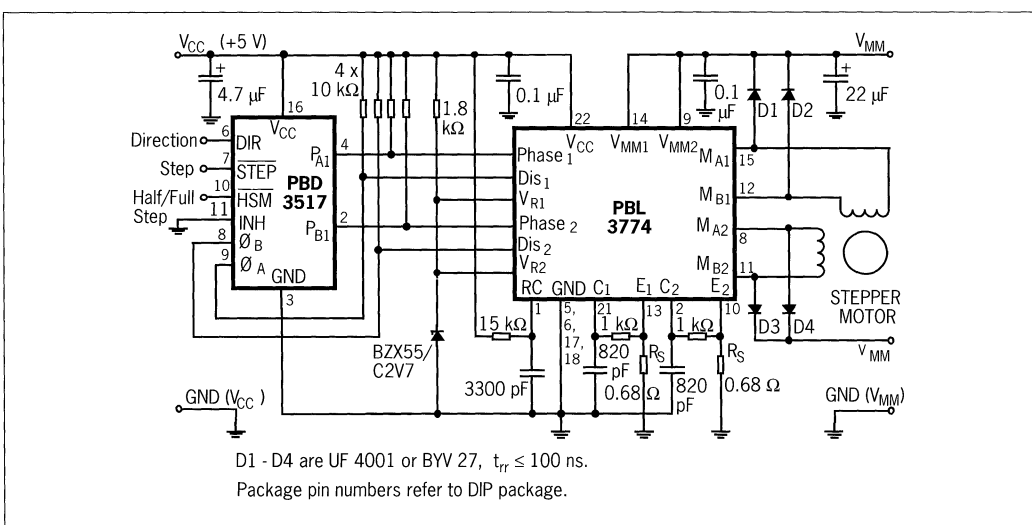


Figure 21. Typical application using PBL 3774 as driver circuit and PBD 3517 as controller circuit.

Industrial Circuits Application Note

Microstepping

This application note discusses microstepping and the increased system performance that it offers. Some of the most important factors that limit microstepping performance, as well as methods of overcoming these limitations, are discussed. It is assumed that the reader is somewhat familiar with stepper motor driving and the torque generation principles of a stepper motor. If not, chapter 1 and 2 of this book can be read to get the background information necessary.

What is microstepping

Microstepping is a way of moving the stator flux of a stepper more smoothly than in full- or half-step drive modes. This results in less vibration, and makes noiseless stepping possible down to 0 Hz. It also makes smaller step angles and better positioning possible.

There are a lot of different microstepping modes, with step lengths from 1/3-full-step down to 1/32-full-step—or even less. Theoretically it is possible to use non-integer fractions of a full-step, but this is often impractical.

A stepper motor is a synchronous electrical motor. This means that the rotor's stable stop position is in synchronization with the stator flux. The rotor is made to rotate by rotating the stator flux, thus making the rotor move towards the new stable stop position. The torque (T) developed by the motor is a function of the holding torque (T_H) and the distance between the stator flux (f_s) and the rotor position (f_r).

$$T = T_H \times sin(f_s - f_r)$$

where f_s and f_r are given in electrical degrees.

The relationship between electrical and mechanical angles is given by the formula:

$$f_{el} = (n \div 4) \times f_{mech}$$

where n is the number of full-steps per revolution.

When a stepper is driven in full-step and half-step modes the stator flux is rotated 90 and 45 electrical degrees, respectively every step of the motor. From the formula above we see that a pulsing torque is developed by the motor (see figure 1a, which also shows the speed ripple caused by the torque ripple). The reason for this is that $f_s - f_r$ is not constant in time due to the discontinuous motion of f_s.

Generating a stator flux that rotates 90 or 45 degrees at a time is simple, just two current levels are required I_{on} and 0. This can be done easily with all type of drivers. For a given direction of the stator flux, the current levels corresponding to that direction are calculated from the formulas:

$$I_A = I_{peak} \times sin(f_s)$$
$$I_B = I_{peak} \times cos(f_s)$$

By combining the I_{on} and 0 values in the two windings we can achieve 8 different combinations of winding currents. This gives us the 8 normal 1- and 2-phase-on stop positions corresponding to the flux directions 0, 45, ..., 315 electrical degrees (see figure 2a).

If we have a driver which can generate any current level from 0 to 141% of the nominal 2-phase-on current for the motor, it is possible to create a rotating flux which can stop at any desired electrical position (see figure 2b). It is therefore also possible to select any electrical stepping angle—1/4-full-step (15 electrical degrees), 1/8-full-step or 1/32-full-step (2.8 electrical degrees) for instance. Not only can the direction of flux be varied, but also the amplitude.

From the torque development formula, we can now see that the effect of microstepping is that the rotor will have a much smoother movement on low frequencies because the stator flux, which controls the stable rotor stop position, is moved in a more-continuous way, compared to full and half-step modes, (see figure 1b).

With frequencies above 2 to 3 times the system's natural frequency, micro-

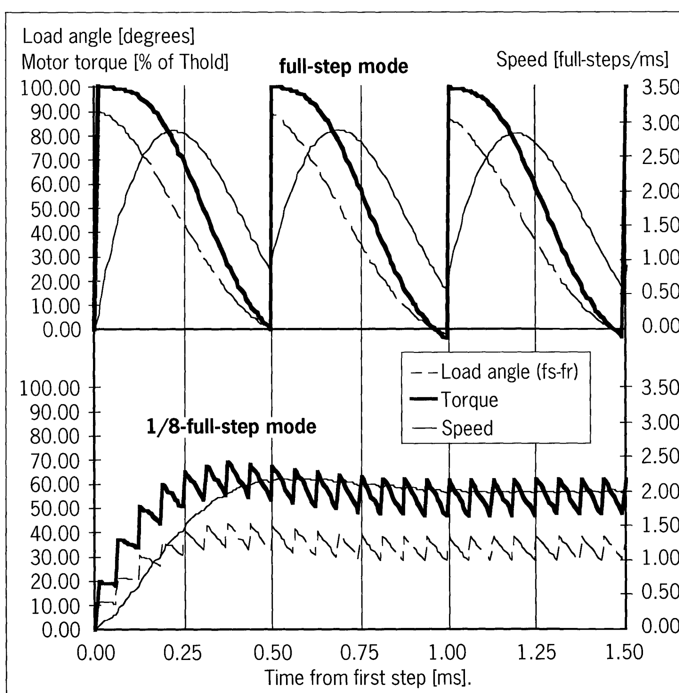


Figure 1. (A)—torque and speed ripple as function of load angle, full-step mode. (B)—torque and speed ripple as function of load angle, microstepping 1/8-full-step mode.

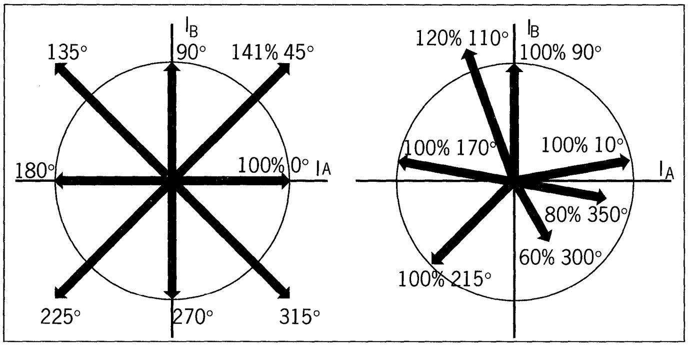


Figure 2. (A)—flux directions for normal half and full-step stop positions. Length is proportional to holding torque. (B)—microstepping flux directions. Direction and length are variable.

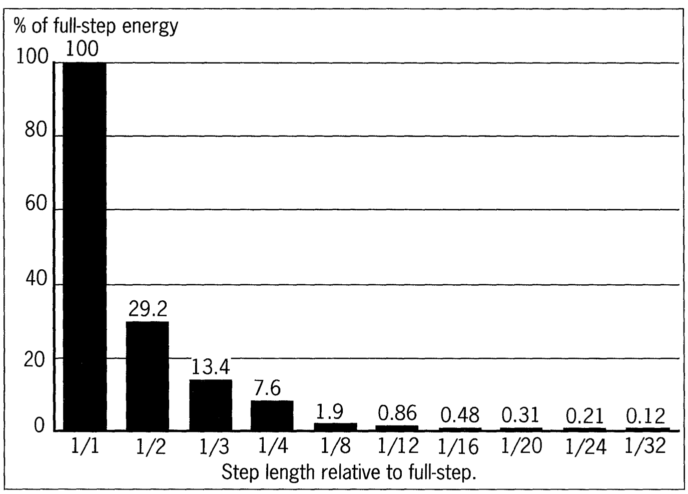


Figure 3. Relative excitation energy as function of electrical step length.

stepping has only a small effect on the rotor movement compared to full-stepping. The reason for this is the filtering effect of the rotor and load inertia. A stepper motor system acts as a low pass filter.

Why microstepping

In many applications microstepping can increase system performance, and lower system complexity and cost, compared to full- and half-step driving techniques. Microstepping can be used to solve noise and resonance problems, and to increase step accuracy and resolution.

Running at resonance frequencies

The natural frequency, F_0 (Hz), of a stepper motor system is determined by the rotor and load inertia, $J_T = J_R + J_L$ (Kgm^2), holding torque, T_H (Nm), (with the selected driving mode and current levels) and number of full-steps per revolution (n).

$$F_0 = (n \times T_H \div J_T)^{0.5} \div 4\pi$$

If the system damping is low there is an obvious risk of losing steps or generating noise when the motor is operated at or around the resonance frequency. Depending on motor type, total inertia, and damping; this problems can also appear at or close to integer multiples and fractions of F_0, that is: …, $F_0/4$, $F_0/3$, $F_0/2$, $2F_0$, $3F_0$, $4F_0$, … . Normally the frequencies closest to F_0 gives the most problems.

When a non-microstepping driver is used, the main cause of these resonances is that the stator flux is moved in a discontinuous way, 90 or 45 (full-step and half-step mode) electrical degrees at a time. This causes a pulsing energy flow to the rotor. The pulsations excite the resonance. The energy transferred to the rotor, when a single step is taken, is in the worst case (no load friction) equal to:

$$(4T_H \div n) \times [1 - \cos(f_e)]$$

T_H and n are as above and f_e = electrical step angle, 90 degrees for full-step, 45 degrees for half-step. This shows that using half-steps instead of full-steps reduce the excitation energy to approximately 29% of the full-step energy. If we move to microstepping $1/32$-full-step mode only 0.1% of the full-step energy remains (see figure 3).

It appears that, by using microstepping techniques, this excitation energy can be lowered to such a low level that all resonances are fully eliminated.

Unfortunately this is only true for an ideal stepper motor. In reality there are also other sources that excite the system resonances. Never the less, using microstepping will improve the movement in almost all applications—and in many cases microstepping will alone give a sufficient reduction of the noise and vibrations to satisfy the application.

Extending the dynamic range towards lower frequencies

When running a stepper motor at low frequencies. in half- or full-step mode. the movement becomes discontinuous, shows a great deal of ringing, and generates noise and vibrations. The stepping frequencies where this happens are below the system's natural frequency. Here microstepping offers a easy and safe way to extend noiseless stepping frequencies down towards 0Hz. Normally it is not necessary to use smaller steps than 1/32-full-step. With this small electrical step angle the energy transferred to the rotor/electrical step is only 0.1% of the full-step energy, as described above, and is so small that it is easily absorbed by the internal motor friction—so no ringing or overshot is generated by the stepping (see figure 4). The deviation of the microstepping positions from a straight line is due to the use of uncompensated sine/cosine profiles.

Electronic "gearbox"

In some applications, where small relative movements or higher step resolution are required, microstepping can replace a mechanical gearbox. In many applications, this is often a better and less-complex solution—even if a larger motor has to be used. To get the best results in this type of application careful motor selection and development of customized sine/cosine profiles are recommended.

Improved step accuracy

Microstepping can also be used to increase stepper motor position accuracy beyond the manufacturer's specification. One way to do this is as follows. Design a microprocessor based microstepping system. Use the motor at 2-phase-on stop positions, $|I_a| = |I_b|$ (these are normally the most accurate rotor stop positions). Use a factory calibration process (manual or automatic) to store a correction value for each stop position on every motor used. The correction value is used to output "adjusted" full-step positions to the motor (see figure 5b). The adjusted positions have slightly changed current levels in the windings to compensate for the position deviations at the original stop positions (see figure 5a). This technique can be used when optimum step accuracy is the most important design criteria.

If this technique is used, the system has to use a rotor home position indicator to synchronize the rotor with the compensation profile.

System complexity

Even though the electronics for generating microstepping is more complex than electronics for full- and half-stepping, the total system complexity including motor, gearbox and transmission is less complex and costs less in many applications. Microstepping can

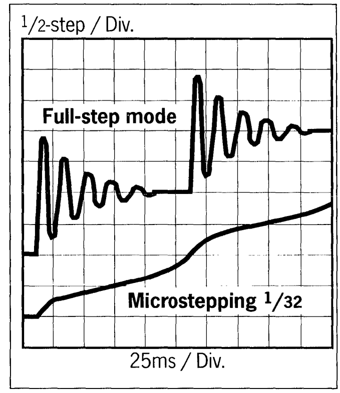


Figure 4. Rotor position as function of stepping mode.

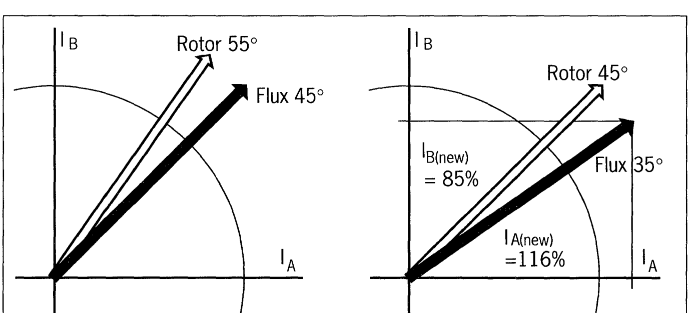


Figure 5. (A)—rotor and flux directions at original full-step position. (B)—rotor and flux directions at adjusted full-step position.

replace or simplify gearboxes and mechanics for damping of noise and vibrations. Also motor selection becomes easier and more flexible.

In a microprocessor,based microstepping application it is possible to use software and PWM-timers or D/A-converters internal to the microprocessor to replace an external microstepping controller to achieve lowest possible microstepping hardware cost. It is then possible to achieve the same hardware cost as in full- and half-step systems for similar motor sizes.

What affects microstepping performance

In theory, microstepping is quite simple, and theoretically, the technique solves all resonance, vibration and noise problems in a stepper motor system.

In reality, a lot of different phenomena arise which set limits for the system performance. Some are related to the driver and others to the motor. If a high-precision controller/driver combination such as PBM3960 and PBL3771 or equivalent are used, then the errors associated with the driver are negligible when compared with those associated with most available motors.

Step accuracy

In the manufacturers' stepper motor data sheets, the step accuracy is normally given. Step accuracy can be given absolute (±1.0 degree, as an example) or relative (±5% of one full-step). Normally step accuracy is only specified for 2-phase-on stop positions. (Here a 2-phase-on stop position means a position with the same current level in both windings. A position with different current levels, or none, in the windings is a microstep position.) This means that the manufacturer does not tell anything about the motor behavior when the motor is used in a microstepping application. Optimizing a motor for high full-step positioning accuracy and holding torque normally reduces microstepping accuracy.

One important effect of the 2-phase-on step accuracy is shown by the following example. Consider a microstepping design, using 1/32-full-step mode with a 7.5-degree PM-stepper motor. One microstep theoretically corresponds to 7.5 ÷ 32 = 0.23°. For this type of motor a step accuracy of ±1 degree is common. This means that if the motor home position is calibrated at a randomly-selected 2-phase-on position (which can be positioned anywhere within ±1 degree from the theoretically-correct home position) the maximum deviation of the rotor at another 2-phase-on position can be [1-(-1)] / 0.23 = 8.5 microsteps from its theoretical position. This fact has to be considered when microstepping is used in applications were absolute positioning is essential. A technique to solve this problem is described previously under "Improved step accuracy".

Sine/cosine conformity

Most actual stepper motors do not have an ideal sine/cosine behavior (a stepper with idealized sine/cosine behavior will rotate with a absolute constant speed when a sine/cosine current pair is applied to the windings). Mainly due to varying air gap area, air gap distance and magnetic hysteresis the flux vector direction and magnitude—and therefore the microstepping stop positions and the microstepping holding torque—deviate from the ideal sine/cosine behavior. The deviations are dependent upon rotor and stator-tooth shape, and the type of material used in the construction.

Some motors are optimized for high holding torque or increased step accuracy at 2-phase-on stop positions. This can be done by shaping the teeth in such a way that a extra high flux is achieved at the 2-phase-on positions. This type of optimized motors should be avoided in microstepping applications because there large deviations from the sine/cosine behavior. The closer the motor conforms to the sine/cosine behavior the better performance in a microstepping application.

The deviations can be divided into two parts: of the amplitude of the flux vector (influences the microstepping holding torque), and of the direction of the flux vector (effects the microstepping stop positions).

Microstepping position ripple

When a stepper is used in a microstepping application, the microstepping stop positions are affected by the sine/cosine conformity. The difference between the theoretical and actual microstepping stop positions is called microstepping position ripple. It is defined as the average deviation, for all full-step cycles over a full revolution, of the actual microstep stop positions from the theoretical, when a sine/cosine current wave form is applied to the motor windings (see figure 6). The microstepping position ripple is a median value over the whole revolution. This means that it is not a function of the normal 2-phase-on step accuracy. To calculate the total microstepping accuracy, the microstepping position ripple has to be added to the 2-phase-on accuracy.

The effect of the microstepping position ripple is that, when a motor is driven with an uncompensated sine/cosine profile, the rotor movement will show a varying speed over the full-step cycle—in other words, the microsteps will vary in length. Microstep lengths from ½ to 3 times the nominal are not uncommon when a microstep length of 1/32-full-step is used (see figure 7).

In microstepping applications, this is most common phenomena that excites the systems resonances.

Microstepping holding torque ripple

The magnitude of the magnetic flux will also deviate from the theoretical value when microstepping is applied to a stepper motor. This is referred to as microstepping holding torque ripple. The nominal holding torque is theoretically independent of the flux direction when the motor is driven with a sine/cosine current wave form. The theoretical holding torque is calculated from the formula:

$$T_H = k \times (I_A^2 + I_B^2)^{0.5}$$

If I_A and I_B are sine/cosine pair then T_H is independent of flux direction.

The magnitude of the microstepping holding torque ripple, which is a function of the nominal stator and rotor-tooth geometry, is normally in the range 10 to 30% of the nominal 2-phase-on holding torque. Most motors are optimized for highest holding torque at the 2-phase-on positions (see figure 8).

The microstepping holding torque ripple is an average value for all full-step cycles over one full revolution and should not be confused with the motor-tolerance-dependent 2-phase-on holding torque ripple. When a stepper is stopped at different 2-phase-on positions the holding torque normally differs up to ±10% of the nominal holding torque. These variations are caused by mechanical tolerances in the rotor/stator geometry of the motor and would be zero for a geometrically correct motor.

Hysteresis

The stop-position hysteresis of a stepper motor is mainly affected by the magnetic hysteresis, but also partly by the friction of the rotor bearing. If we measure the microstep stop positions, first by rotating the motor in CW direction and then in the CCW direction the hysteresis will clearly show (see figure 6).

The magnetic flux in the air gap is theoretically proportional to the number of turns in the winding (n) and the winding current (I).

$$F_A = k_f \times n \times I$$

Because of the hysteresis of the magnetic materials in the rotor and stator flux path, this is not quite true. When hystereses are involved, the present flux is a function of the present winding current and the flux history (see figure 9). The H value is directly proportional to the winding current, but to determine the flux it is also necessary to know the previous H-values (the flux history). In applications where positioning accuracy is important, it is some times necessary to use an over-shot movement so as to always have the hysteresis on the same side and thereby not create any additional positioning error.

In a high-resolution microstepping application, the hysteresis can be several times the nominal microstep length.

When the total positioning accuracy of a stepper motor system is calculated, it is important to know if the hysteresis is included in the step accuracy given in the motor data sheet.

Torque ripple

When the stepper motor is stepped in full- or half-step mode, there will be a pulsing torque developed by the motor. This pulsing torque has the same mean value as the load friction torque, but can in some applications have a peak value 20 or more times as high as the average value. This is the main cause of noise and resonances in stepper motor systems. This phenomena is also known as torque ripple. In an

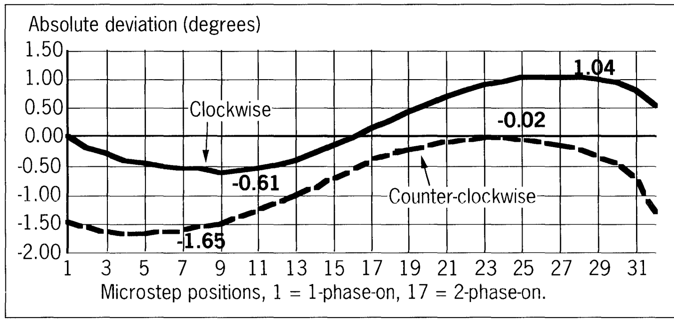


Figure 6. Microstepping position ripple for a 57mm 7.5 degree PM stepper. CW ripple = 1.04 - (-0.61) = 1.65 degrees = 22%.

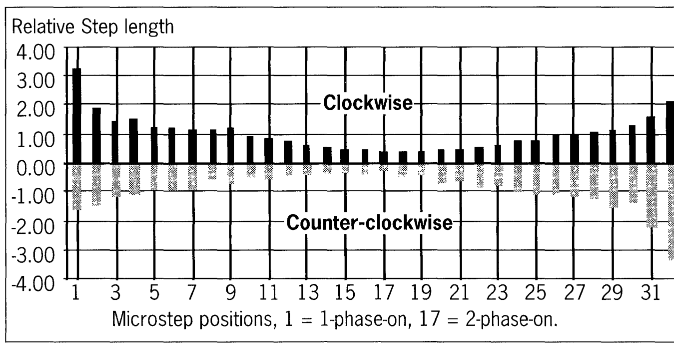


Figure 7. 57mm PM-stepper relative microstep length as function of stop position, 1/32-full-step mode.

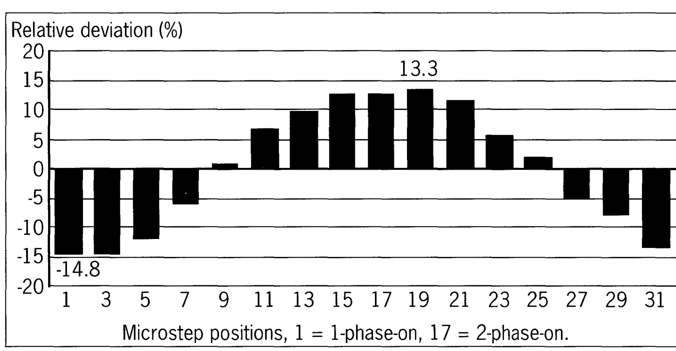


Figure 8. Microstepping holding torque ripple for a 57mm PM stepper. Ripple = 13.3 - -14.8 = 28.1%.

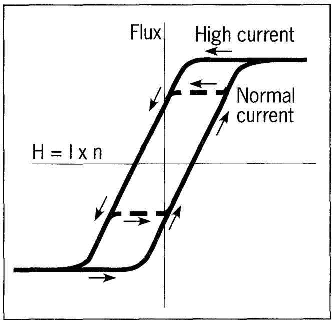


Figure 9. Flux as function of flux history and H-value when two different current levels are applied to the winding.

ideal stepper motor, the torque ripple is a function of the holding torque, the stepping method, and the load angle (f_l). The load angle, or rotor lag, is defined as the median deviation between the electrical stator flux and the rotor position measured in electrical degrees.

In a real application the torque ripple is also affected by the sine/cosine conformity of the stepper and driver used.

When microstepping is used to reduce noise in a stepper application, it is important to know the dominant source that excites the resonances. The formulas below show that a high precision controller driver combination such as PBM3960 and PBL3771 reduces the errors associated with the driver/controller to a negligible level compared to most motors.

Microstep-length-related torque ripple

If we drive an ideal stepper motor with an ideal and continuous sine/cosine current wave form then the torque ripple will be zero. If we instead use sine/cosine microstepping, the torque ripple will be a function of the motor holding torque (T_H) the microstep length (f_e) and the average load angle (f_l). This assumes that the rotor speed is constant—which is a good approximation for a simple model. We can now calculate the torque ripple associated with the microstepping length.

$$T_{Rfe} = T_H \times \frac{f_e \times \pi}{180} \times cos(f_l)$$

f_e and f_l given in electrical degrees.

Motor sine/cosine conformity related torque ripple

In an actual design, the motor is not ideal and, as mentioned above, we have two types of deviations from the sine/cosine behavior. Let us now calculate the torque ripple associated with these deviations. For an approximation, we still consider the rotor speed as constant.

First, assume the microstepping position ripple equals zero and drive the motor with ideal sine/cosine current curves (no driving-mode-related torque ripple). We can now calculate the torque ripple associated with microstepping holding torque ripple (T_{mhtr}).

$$T_{Rmhtr} = T_{mhtr} \times sin(f_l)$$

Next assume the microstepping holding torque ripple equals zero and, still using ideal sine/cosine current wave forms, calculate the torque ripple associated with the microstepping position ripple (f_{mpr}).

$$T_{Rmpr} = T_H \times [(f_{mpr} \times \pi)/180] \times cos(f_l)$$

f_{mpr} and f_l given in electrical degrees.

Motor tolerance related torque ripple

The 2-phase-on step accuracy and holding torque variations of the motor also generate a torque ripple. Usually the effect from these errors can be ignored because they are not cyclic but random, or if cyclic not periodic on full-step cycles. This makes the risk that these errors will excite the system resonance lower. If necessary, the torque ripple associated with these errors can be calculated in a similar way to the microstepping errors related to the motor. To minimize these type of errors use a high quality motor with small internal geometric tolerances.

Driver related torque ripple

When we use an non-ideal driver, the driver will also contribute to the torque ripple. This contribution can be separated into one microstepping position ripple and one microstepping holding torque ripple, in the same way as for the motor. Depending on the type of motor and driver used, either the driver or motor errors will dominate. If Ericsson's high-precision microstepping controller and driver are used, then the errors associated to the driver normally can be ignored (both the driver microstepping position and holding torque ripple are less than 1%). If other types of drivers, or if high-precision microstepping motors, are used then the best way of estimating the total system (driver and motor) error is to measure the microstepping holding torque ripple and microstepping position ripple of the motor and driver combination together. If the driver-related error can not be ignored, it can be calculated in the same way as the errors related to the motor. One part concerning the flux vector position and one concerning the magnitude of the flux.

Comparing the different torque ripple sources

We can now compare the magnitude of the torque ripple generated by the different sources. As we can see from the formulas above, we also have to take the average load angle (f_l) into consideration. This means that, depending on whether we have a high or low friction load in the system, the different error mechanisms will generate different amounts of torque ripple. We will study three different cases. First, with zero load angle—this system can be a good approximation for many low-friction-load systems. Second, 12-degree load angle (21% of available torque used)—this is a normal value for many medium performing systems. Third, a 49-degrees load angle (75% of available torque used) —this is close to the maximum practically-available torque under the best driving conditions and can be used for a high performance motor drive. Table 1 compares the torque ripple from the different sources under different conditions, also torque ripples calculated for 6- and 30-degree load angles.

Measuring microstepping performance

To develop compensated sine/cosine current profiles in a systematic manner, we need to measure the microstepping position ripple, and in some applications, the microstepping holding torque ripple.

Measuring microstepping position ripple

To measure the stop position ripple use a microstepping controller/driver (Ericsson TB307I for an example)—make sure that the same chopping voltage, current levels, current decay mode and chopping frequency are used as the in the final application. Use a high-precision miniature coupling to fix a high-precision, low-friction, optical encoder to the stepper motor shaft to measure the rotor stop positions. If possible, use two couplings in series separated by a 50 – 100 mm axle (see figure 10).

Be careful with the mechanical set-up—misalignment of the motor and encoder shafts will affect the measurement accuracy.

First, microstep the motor in the CW direction for at least one full-step distance. Continue in the CW direction to the next 1-phase-on stop position. Reset the rotor position measurement. Move the rotor one microstep in the CW direction. Note the new stable stop position. Continue in this way until the stator flux has moved 4 full-step positions (360 electrical degrees) in the CW direction. Now rotate the flux an additional full-step distance without noting the stop positions (this is to allow the flux hysteresis to build up on positions not measured). Change the direction to CCW and microstep the flux back to the last measured flux stop position, note the CCW stop position. Continue microstepping the motor in the CCW direction and note all the CCW stop positions.

Calculate the CW and CCW deviations from the theoretical stop positions. Plot the deviations in a graph. From the graph, we can read the hysteresis and the CW and CCW microstepping position ripple as functions of the flux direction for the microstep positions (see figure 11). Observe the cyclisity, the deviation repeats every 90 electrical degrees. This is a result of the sine/cosine 90-degree symmetry. Calculate the average deviation of the four cycles to get a more-accurate measurement result. The curve in figure 6 is calculated from figure 11 in this way. This data is the input for calculating compensated sine/cosine profiles. To get even-more-accurate data the deviations can be measured for a integer multiple of 4 full-step cycles. For the best results, use all the full-step cycles in one whole revolution.

Measuring microstepping holding torque ripple

To measure the holding torque ripple as a function of the microstepping stop positions, a microstepping driver and a torque watch or torque sensor are needed. Measure the holding torque as a function of the flux direction (see figure 12). Calculate the torque ripple from the measurements by subtracting the average value. Figure 8 is calculated from figure 12 in this way. The microstepping position ripple is a full-step cyclic function. For best accuracy measure as many cycles as possible.

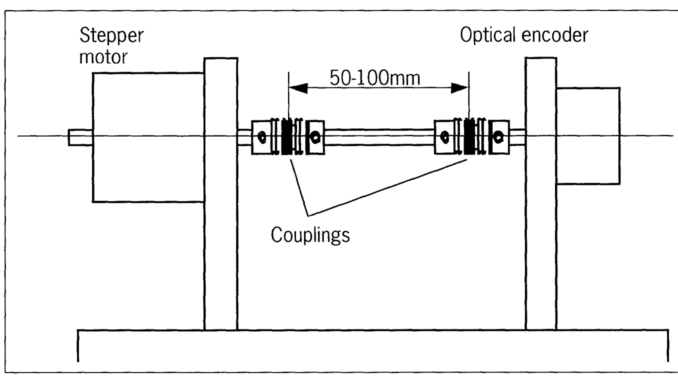


Figure 10. Suggested set-up for measuring microstepping position ripple.

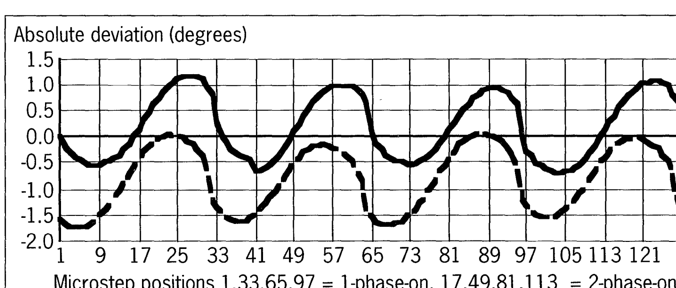


Figure 11. Microstepping position ripple for 4 full-step cycles for a 57mm 7.5 degree PM stepper.

Table 1. Absolute torque ripple as function of driving conditions and different torque ripple sources.

Conditions		**Torque ripple [mNm]**				
Mean load angle [degrees]		0	6	12	30	49
Friction torque [% of T_{hold}]		0	10	21	50	75
Driver mode microstepping length						
1/1-stepping	90.0	157	156	154	136	103
1/2-stepping	45.0	79	78	77	68	52
1/8-stepping	**11.3**	**20**	**20**	**19**	**17**	**13**
1/16-stepping	5.6	10	10	10	9	6
1/32-stepping	2.9	5	5	5	4	3
Motor microstepping holding torque ripple						
5% (5mNm)	0.05	0	1	1	3	4
10% (10mNm)	0.10	0	1	2	5	8
20% (20mNm)	0.20	0	2	4	10	15
30% (30mNm)	**0.30**	**0**	**3**	**6**	**15**	**23**
40% (40mNm)	0.40	0	4	8	20	30
Motor microstepping position ripple						
5% (0.38 deg.)	0.05	8	8	8	7	5
10% (0.75 deg.)	0.10	16	16	15	14	10
20% (1.5 deg.)	0.20	31	31	31	27	21
30% (2.25 deg.)	**0.30**	**47**	**47**	**46**	**41**	**31**
40% (3.9 deg.)	0.40	63	62	61	54	41
Driver microstepping holding torque ripple						
1% (1mNm)	**0.01**	**0**	**0**	**0**	**1**	**1**
2% (2mNm)	0.02	0	0	0	1	2
5% (5mNm)	0.05	0	1	1	3	4
10% (10mNm)	0.10	0	1	2	5	8
Driver microstepping position ripple						
1% (0.9 el. deg.)	**0.01**	**2**	**2**	**2**	**1**	**1**
2% (1.8 el. deg.)	0.02	3	3	3	3	2
5% (4.5 el. deg.)	0.05	8	8	8	7	5

Values are calculated for a 7.5 degree 57mm PM-motor with 100mNm holding torque. Typical values are shown in bold type.

For a 3.6 degree stepper, there are 25 stable stop positions with the same flux direction. It is possible to measure all of them without changing the flux direction. Make sure you measure the holding torque in the same mechanical direction for all stop positions and, if only a few positions are measured, measure the same mechanical stop position at all flux stop positions to get the best measurement accuracy.

The results of these measurements are the input data for calculating microstepping holding torque compensated sine/cosine current profiles.

Designing compensated sine/cosine profiles

From the discussion above, we see that there are many motor-specific parameters that affect the microstepping performance in an application. In fact, if no actions are taken, the motor will always limit the performance. Theoretically, microstepping is done with sine/cosine current wave forms, but the flexibility of the PBM3960 microstepping controller allows for easy modification of the current profile. Adding a microprocessor to the control also makes handling of hysteresis and CW/CCW-unsymmetry a matter of software.

The sine/cosine conformity is mainly dependent upon the rotor/stator geometry and the material used in the construction. For most motors, the deviations among the individuals are relatively small compared to the average deviations from the theoretical values. This makes designing compensated sine/cosine current profiles an effective way of improving microstepping performance in a specific design.

Microstepping position ripple compensation

The compensated sine/cosine profile is calculated from the measured microstepping position ripple profile. Use the measured deviations at the different applied flux directions to interpolate new flux directions with zero deviation. Use these new flux directions to build the compensated sine/cosine profile. Now measure the microstepping position ripple with the compensated current profiles driving the motor. If necessary make further modifications to the current profile; and repeat the measurement until an acceptable result is obtained. Figure 13 shows the microstepping position ripple for the motor measured in figure 11 and 6 after applying compensated sine/cosine profiles to the motor. In figure 14 the full-step cycle average value is plotted. The compensated curve is a "first try", to get a even better result the procedure can be repeated with the new measured data as input.

If the application requires bidirectional rotation of the rotor, calculate different compensated profiles for the CW and CCW directions. In some applications it is possible to use the average CW and CCW deviation curve for both CW and CCW directions. Depending on the motor hysteresis level, this gives a somewhat less precise compensation.

The above method gives the best result when the rotor speed is low. When the speed is increased, the flux history of the motor is influenced by the rotor EMF, so the measured stop positions are not the correct ones. In these cases an experimental compromise between the uncompensated sine/cosine profile and the position-ripple-compensated profile normally gives the best result.

Holding torque ripple compensation
Normally, in applications were the friction load torque is low compared to the motor holding torque, no compensation for microstepping holding torque ripple is necessary (see table 1). The primary source of resonance excitation is the microstepping position ripple.

If compensation for holding torque is required it can be applied alone or together with the stop position compensation.

Use the measured microstepping-dependent holding torque to calculate the new current levels.

$I_{new} = I_{old} \times (T_{Hnom} \div T_{Hmeasured})$

This is applied to both winding currents.

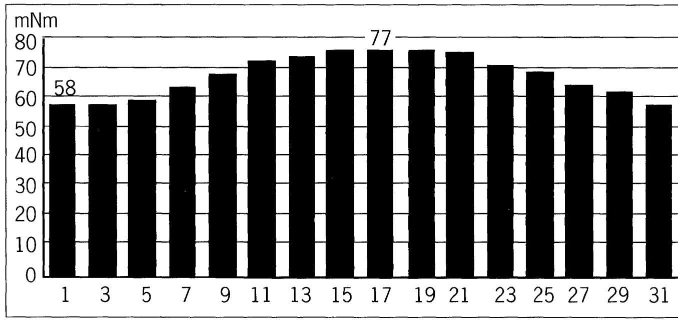


Figure 12. Microstepping holding torque for a 57mm PM stepper.

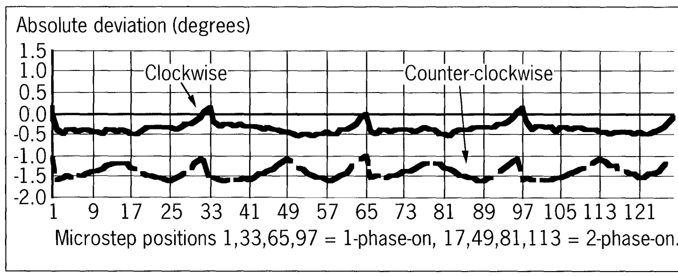


Figure 13. Sine/cosine CW compensated microstepping position ripple for 4 full-step cycles for a 57mm 7.5 degree PM stepper

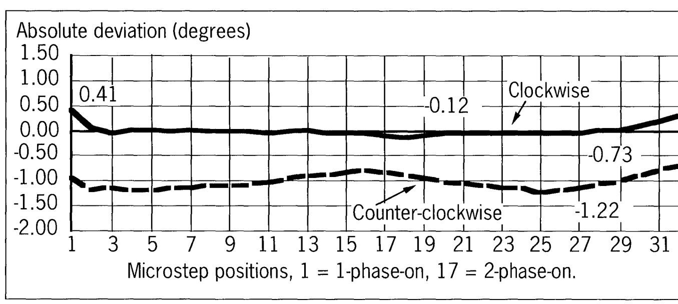


Figure 14. Sine/cosine compensated microstepping position ripple for a 57mm 7.5° PM stepper. CW ripple = 0.41 - -0.12 = 0.53 degrees =7% compared to 22% for uncompensated.

Industrial Circuits Application Note

Solving RFI and noise problems with PBL 3717 and PBL 3770A

The PBL 3717 and PBL 3770A are chopper (switch-mode) type stepper motor drivers. Due to the operation of these circuits, electromagnetic as well as capacitively coupled noise can be generated by the ICs during switching and may be radiated via surrounding wires and PCB copper tracks.

Magnetic noise is generated by loops on the PCB and couples into nearby circuitry in the same fashion as a transformer couples power between two windings. The general method to avoid magnetically coupled noise is to route supply rails close to each other on the PCB and to make current loops as physically small as possible.

Capacitive noise is coupled between adjacent copper tracks or components/ component leads on the PC board. Especially sensitive situations are when two tracks run in parallel on each side of a board or on nearby layers. Capacitively coupled noise may be eliminated by introducing ground planes between power rails and low level circuitry on multilayer boards. Separating low level circuitry from power circuits by guarding or screening may also be needed.

To reduce potential interference when using the PBL 3770A (or the PBL 3717/2), there are a few basic rules to follow. Please refer to the figure 1 and the points of discussions indicated by numbers 1 through 7.

1. Recirculating current path
During the turn-off mode of the IC (a complete description of the operation of the PBL 3717/3770A can be found in the data sheets) the motor current recirculates through the external free-wheeling diodes as indicated by the magnetic field which can induce noise voltage in adjacent circuitry. To reduce potential problems, the recirculation diodes should be located as close to the IC as possible.

2. Filtering of power supply rails
An LC filter in the positive supply rail reduces noise that may be spread to other circuits. Suitable values are: inductor, 10 - 100 µH; and capacitor, 10 µF + 0.1 µF. The LC filter should be located as close to the circuit as possible, and the capacitor connected to power ground.

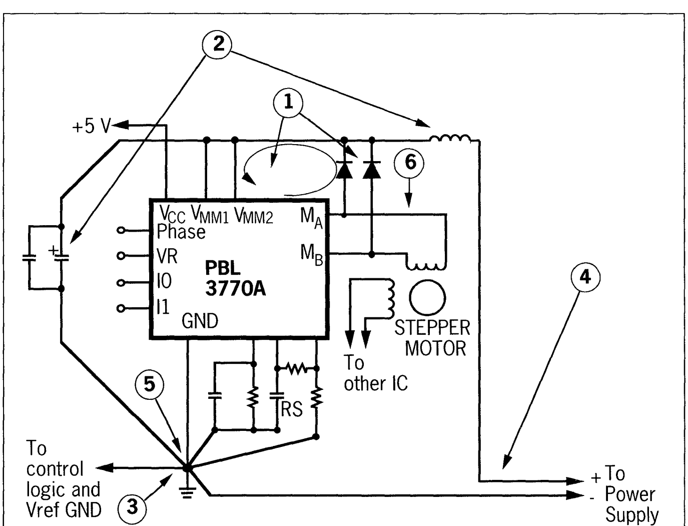


Figure 1. Circuit showing proper printed circuit board layout design.

3. Grounding

It is essential to understand that the power ground of the circuit is at the point where the sensing resistor RS connects to the negative supply. Thus, this ground connection should be separated from all other ground returns, especially those of sensitive low-level circuits. Signal ground is at the ground pins of the stepper motor driver circuit, and should be connected to a common ground point, preferably close to the power connector on the PC board.

4. Power supply connection

To minimize magnetic interference from the power supply rails, the positive supply and the power ground return copper tracks should be routed closely to each other on the PC board. Compare this to the "twisted wire" technique. Best result will be achieved if the two tracks run in parallel in separate layers on a multilayer PCB.

5. Signal ground

Ground reference for the logic inputs, the reference voltage ladder resistor network and the current selection comparators, are all connected to the ground pins of the device (see data sheet for pin-out diagrams for DIP and PLCC packages respectively).

This ground should be connected to the same logic ground as the control logic which drive the logic inputs (Phase, I0 and I1). This is also the ground of the voltage reference, usually the +5 V rail.

There are two important aspects of the signal ground:

1. During phase shift (when Phase changes state) the motor current will flow through signal ground and cause ground current transients. This means that the signal ground path on the PCB must be kept as short and low impedance as possible to avoid noise that can be capacitively coupled to sensitive circuits.
2. It is imperative that the ground of control logic and the signal ground of the stepper motor IC are at equal ground potential. Different ground potentials can result in permanent damage of the ESD protection diodes at the logic inputs of the stepper motor IC.

6. Motor leads

The motors leads should be wired for minimal interference. Shielding may reduce noise further. RC or LC filtering of the motor outputs may be needed in severe cases. Rule of thumb: Cut-off frequency of filter shall be at least 10 times chopper frequency.

Industrial Circuits Application Note

Thermal Management

Ericsson's stepper motor ICs are power ICs encapsulated in Dual in Line and PLCC (Plastic Leaded Chip Carrier) packages. The silicon die is directly bonded to a heat-spreading lead-frame for efficient heat-transfer to an external heat sink, or to a copper ground plane on the printed circuit board.

Determining the needed amount of PCB copper area for heat sinking is a simple procedure, following a few basic guidelines.

1. Establish a value of the circuit's power dissipation, P_D. Graphs showing typical power dissipation vs. output current are found in our data sheets.
2. Specify maximum operating ambient temperature, T_A.
3. Specify maximum junction temperature, T_J , the temperature of the chip at maximum operating current. No strict rules exist— typically one should design for a maximum continuous junction temperature of 100°C to 130°C. Maximum rating is 150°C.

The maximum value of thermal resistance junction-to-ambient, Rth_{J-A}, can now be calculated as follows:

$$Rth_{J-A} = (T_J - T_A) / P_D$$

The graph in figure 1 shows thermal resistance junction-to-ambient vs. the area of a copper ground plane of a PC board. Use this graph to determine the area required to achieve the value of the thermal resistance as calculated.

Figure 2 summarizes the output current capability of Ericsson's stepper motor drivers for various levels of heat sinking.

In order to verify the thermal design, it is useful to make an estimate of the real chip temperature. This is done by attaching a thermocouple or some other miniature temperature sensor right onto the batwing ground pins of the IC under test, and measuring the temperature of the batwing pin (T_{BW}). The chip (junction) temperature can now be calculated:

$$T_J = T_{BW} + P_D \times Rth_{J-BW}$$

where Rth_{J-BW} is the thermal resistance from junction to the batwing pin.

Rth_{J-BW} is 9°C/W for the PLCC package and 11°C/W for the DIP package.

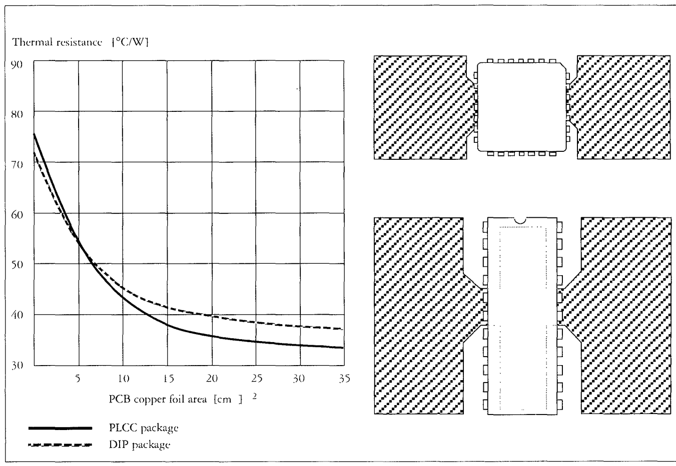


Figure 1. Typical thermal resistance vs. PC Board copper area and suggested layout.

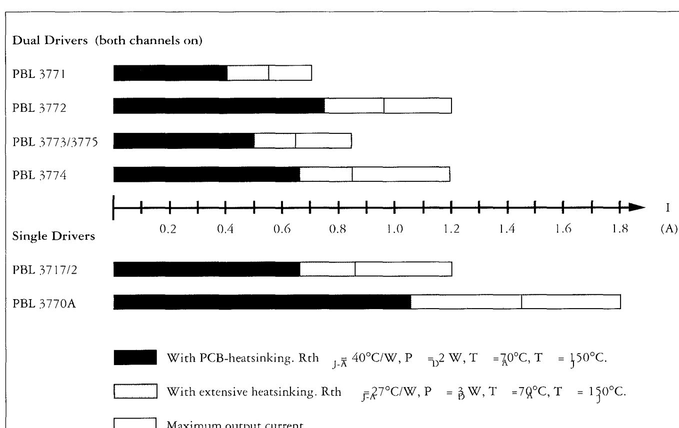


Figure 2. Output current capability for Ericsson's stepper motor driver ICs.

Synchronization of single-channel stepper motor drivers reduces noise and interference

In most applications, a non-synchronized operation causes no problems.
However, in some cases the switching of the two channels interfere, causing audible noise and vibrations from the motor. By synchronizing the switching in the two channels, interference and noise will be cancelled.

Synchronization of Ericsson´s stepper motor drivers

The single channel stepper motor drivers 3717/2 and 3770A are not synchronized in the typical application of fig. 1, i.e. the PWM switching of one channel is totally independent of the other cannel. Note that the Dual channel drivers (3771, 3772, 3773, 3774 and 3775) all are synchronized by design. The basic operation of the PWM switching is described in the data sheet of of each circuit.

Improvements by synchronization

From the electrical point of view, synchronization 180° out of phase gives some major improvements. With two channels free-running, the peak supply current will be the sum of the current in the two channels, as shown in figure 2. When synchronized 180° out of phase, the two channels will never be on at the same time. Peak supply current is then equal to the peak value of one channel. Higher-order harmonics will also be significantly reduced in amplitude. This means a reduced need for power supply filtering, or better filtering from the same filtering components. Magnetically coupled noise to nearby circuitry will also be reduced as the peak current and higher order harmonics are reduced.

The design

Fig. 3 shows the timing diagram during synchronized operation.

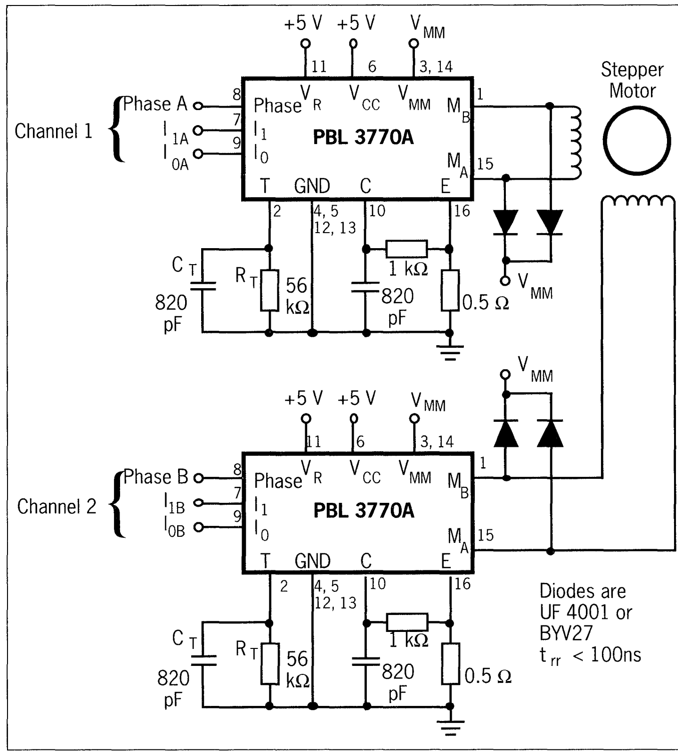


Figure 1. Typical stepper motor driver application with PBL 3770A.

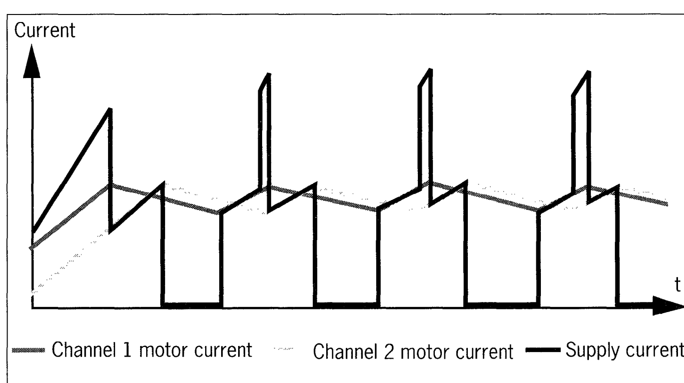


Figure 2. Typical supply current with two channels free-running.

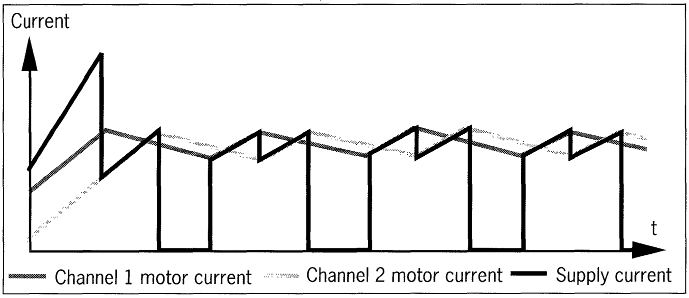


Figure 3. Timing diagram with two channels during synchronized operation.

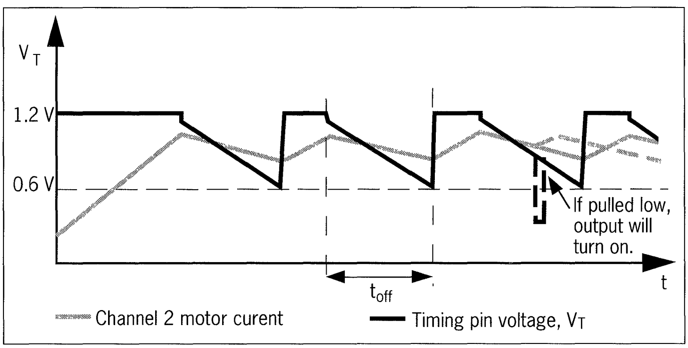


Figure 4. Motor current and V_T voltage vs. time.

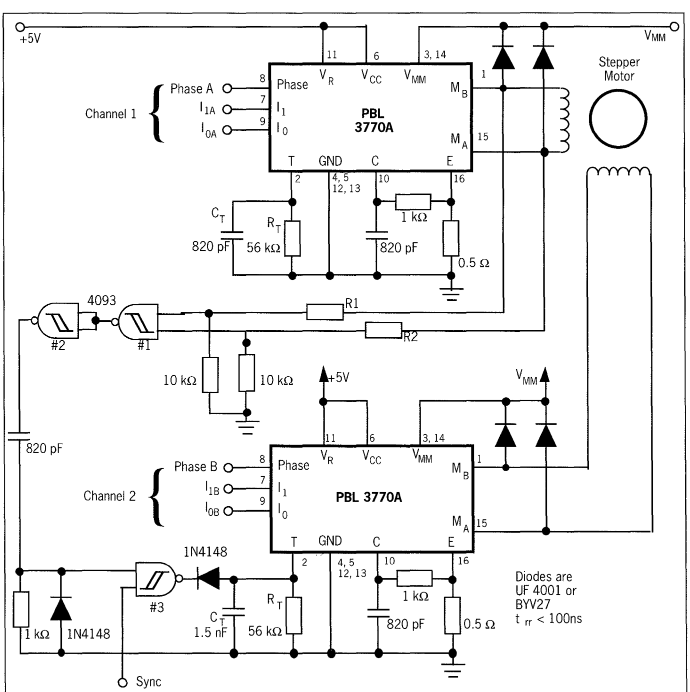


Figure 5. Two PBL 3770A in synchronized operation using a master/slave configuration.

Channel 1 is designated the master, and channel 2 the slave. When synchronized, the off-time of the slave will not be controlled by the internal monostable flip-flop, but by the turn-off of the master. By increasing the timing capacitor value C_T (and thereby increasing the off-timeof the slave), the master will always give the turn-on trigger pulse before the monostable. As long as the total duty cycle (the sum of channel 1 & 2 duty cycles), are less than 100%, the two channel will never be turned on simultaneously.

The operation of the monostable flip-flop is shown in fig 4. In the motor current output-on state, the V_T voltage is constantly kept at about 1.2 V at the T (Timing) pin. When the motor peak current is reached, the monostable flip-flop is triggered, and V_T decreases as C_T discharges through R_T. At V_T=0.6 V a comparator resets the monostable flip-flop, and turns the output on again. An external sinking output connected to the T-pin could discharge C_T in a very short time, and induce an immediate turn-on.

The circuit diagram is shown in figure 5. A 4093 CMOS Schmitt trigger NAND-gate and some external components form an edge detector to generate the sync pulses.

Gate #1 detects the off-state of channel 1. The voltage divider resistor network including R1 and R2 reduces the input voltage swing to equal the 4093 supply voltage. If V_{MM} is below 15 V, 4093 can be fed by V_{MM}, and the voltage divider network could be omitted.

In the off-state both M_{A1} and M_{A2} are high (=V_{MM}) giving a low output of gate #1. Gate #2 inverts the signal, and sends it through a high pass filter, acting as a positive edge detector. For each positive transition of gate #2 (occurring when channel 1 is turned off), a short negative pulse is generated at the output of gate #3. The other input of gate #3 (Sync) may be used as a disable input. The diode at the output of gate #3 makes it a sinking output. At each negative pulse at gate #3 output, the C_T capacitor of 1.5 nF is discharged, and the output of the driver accordingly turned on.

Industrial Circuits Application Note

High current drive using 4 X PBL 3770A

The absolute max current provided from Ericsson's stepper motor drivers is 1.8 A (PBL 3770A). Sometimes higher-current drive capability is needed. A solution which can give up to 3 A total current/phase is described in this chapter. This is accomplished by using a stepper motor with two separate windings for each phase. Each winding is controlled by a PBL 3770A and the drivers in one phase are driven in parallel. This increases the total current drive capability in each phase to approximately 3 A. Any of Ericsson's stepper motor drivers including the dual drivers can be used similarly.

Basic design

This design (see figure 3) consists of four PBL 3770A in a standard configuration (see the datasheet) and a PBD 3517 as a step sequence generator. This application can perform full and half step.

For V_{ref}, either the 5 V supply (V_{cc}) or a separately generated reference voltage is used. (A separately generated V_{ref} is usually more accurate). Using R_s=0.33 Ω and V_r=5.0 V results in a motor current of approx. 1200 mA for each driver which gives 2.4 A in each phase (100% level). The motor current can be changed either by changing the V_r and/or the R_s.

To achieve modified half stepping the circuit in figure 1 is included instead of the transistors and resistors within the dotted boundary in figure 3. The added logic circuit uses the I0, I1 inputs to switch between the 100% and 60% current levels.

These two basic paralleling circuits may work well in certain well defined situations. High frequent interference may occur which will cause audible noise from the motor. This interferent noise is a result of the unsynchronized constant current switching in the driver circuits. The motor acts as a non-linear mixer and all kinds of frequencies may occur. Therefore the motor choice is important when using this unsynchronized design. Unsynchronized switching will also load the supply with high current transients.

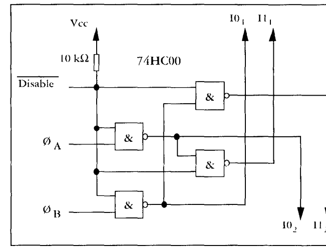


Figure 1. Logic circuit which, when added to design in figure 3, allows it to perform modified-half-step driving.

Synchronization

Synchronization of the current switching can be used to reduce and in some cases eliminate noise and to put a smoother load on the supply. The synchronization can be done in different ways. In this application a master/slave sync. can not be used since one phase will be completely off when using half stepping. An external oscillator will control all four drive circuits. (see figure 2). In Ericsson's dual stepper motor drivers, the oscillator is still running when the motor current is disabled (via the Dis input or by bringing V_{ref} to zero), making it possible to use a master/slave configuration.

The driver circuits are synchronized in pairs to get a "smooth" load on the supply. That is, the two drivers in one phase switch in parallel and the two motor phases are 180° out of phase. It

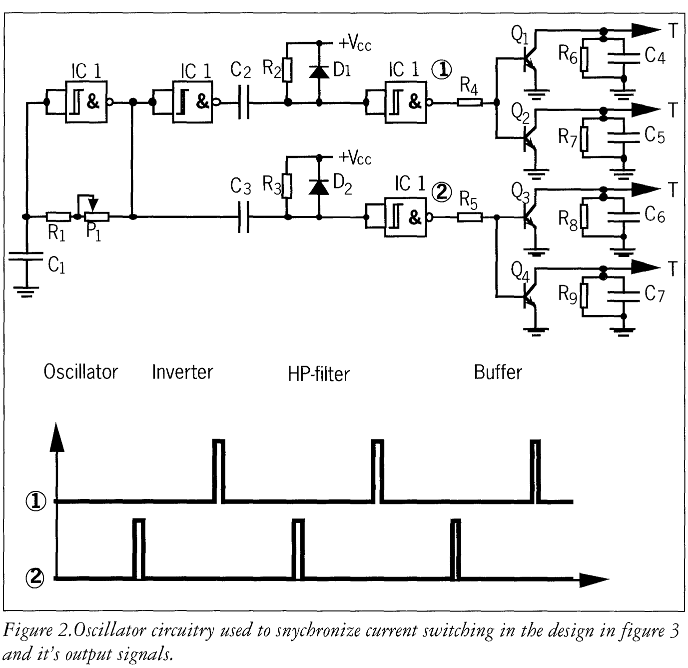


Figure 2.Oscillator circuitry used to snychronize current switching in the design in figure 3 and it's output signals.

Table 1. Value of components used in Figure 2

Symbol	Value
R_1	68 KΩ
R_2, R_3	1 KΩ
R_4, R_5	100 Ω
R_6, R_7, R_8, R_9	56 KΩ
C_1,C_2, C_3, C_4 C_5, C_6, C_7	820 pF
P_1	50K trim
IC_1	4093
Q_1, Q_2, Q_3, Q_4	BC547 or equivalent
D_1, D_2	IN4148 or equivalent

is also possible to sync one driver in each phase in parallel and the other two drivers 180° out of phase. (See the *Synchronization* application note).

The external oscillator tested in this application is shown in figure 3. A 4093 CMOS Schmitt trigger NAND-gate and some external components form an oscillator with two outputs. The outputs are 180° out of phase and by HF-filtering and Schmitt trigger buffers short positive pulses are generated(see figure 3). The T inputs of the PBL 3770A are controlled via a standard NPN transistor. See the *Synchronization* application note for information about how the PBL 3770A is controlled via the T inputs. The resistor and capacitor at the T-input are still needed to suppress interference.

Conclusion

The interference between the current switching and cause of this the noise from the motor is drastically reduced. The supply current is smooth without any transients.

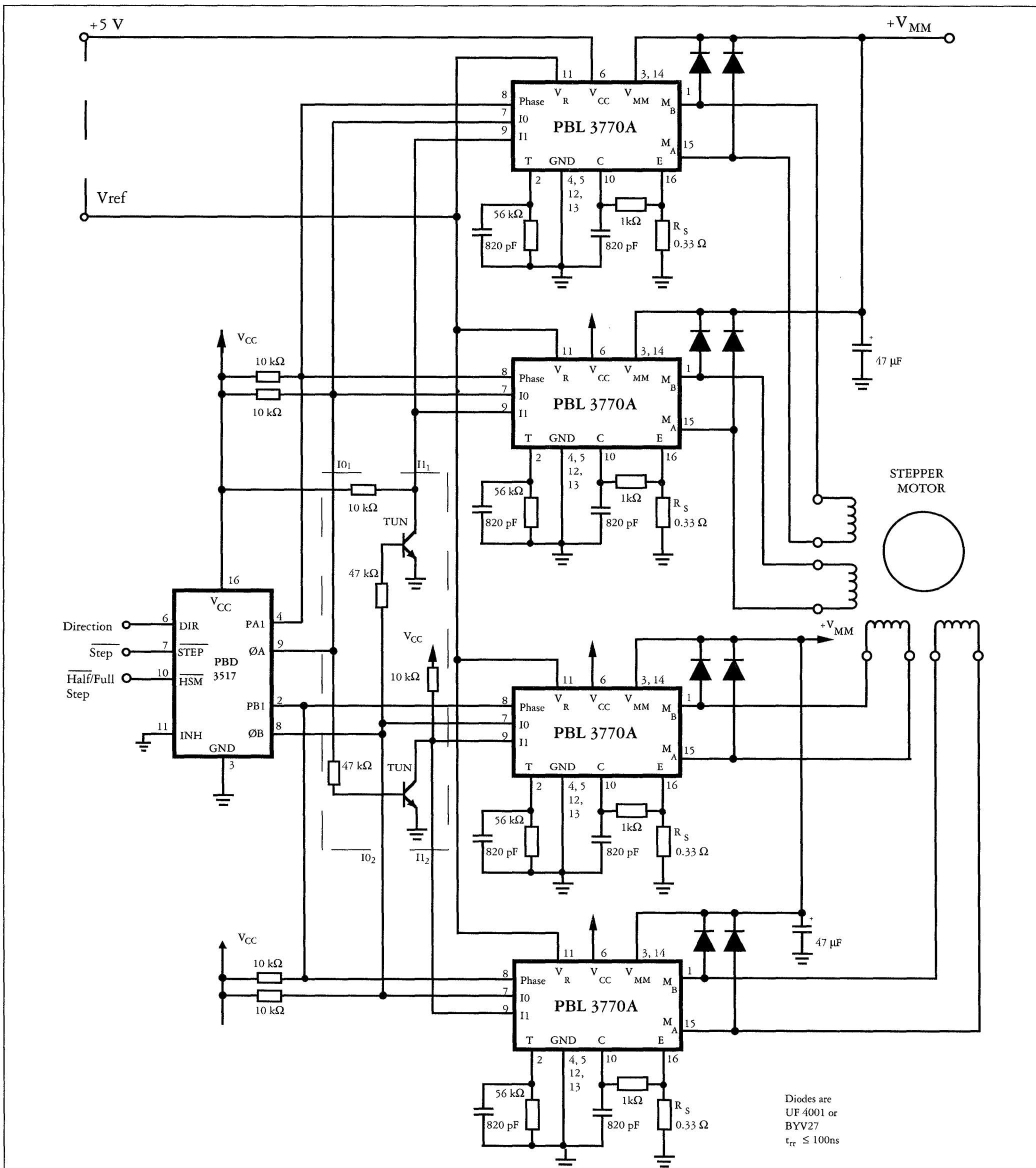
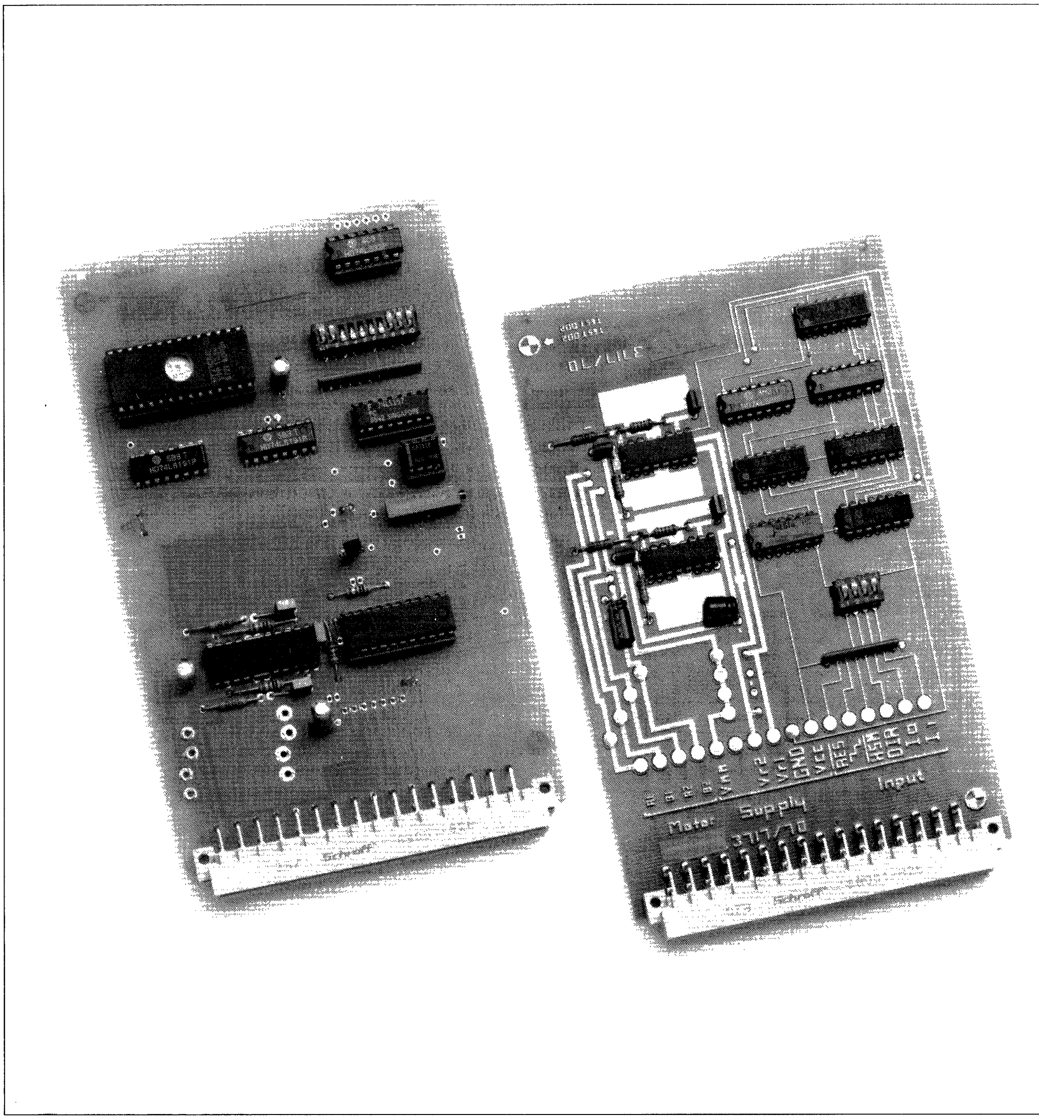


Figure 3. High-current design (2.5 A/Phase) using four PBL 3770A.

Stepper Motor Driver Testboard



ERICSSON

TB3021/3031
Test Board for PBL 3717/2 and PBL 3770A

Test Board 3021 offers a short cut to get acquainted with Ericsson's bipolar, stepper motor drivers. The board includes all necessary electronics for driving one motor in full step or half step mode. The board can be used as a ready made solution for production or as a test support for easy evaluation. No heatsink is necessary for currents up to 500 mA.

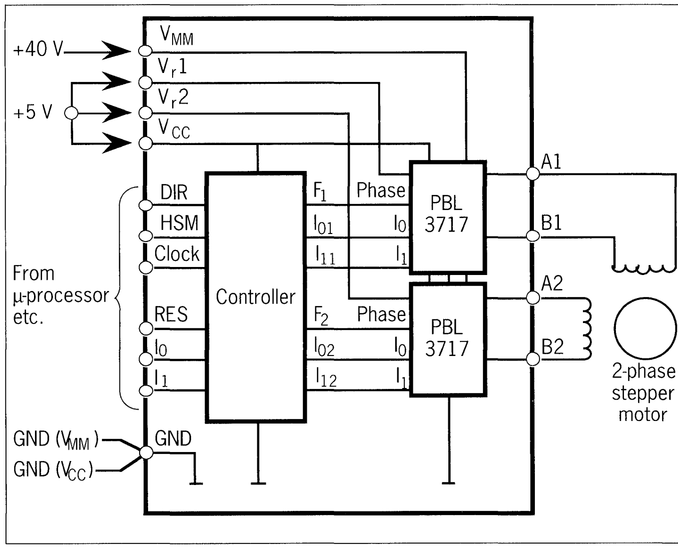


Figure 1. Typical application.

Key features

- LS-TTl compatible inputs
- Bipolar switched mode drive
- Half and full step mode generation
- Translator on board
- Three digitally selectable current levels
- Zero current
- Unstabilized motor supply voltage can be used
- Thermal overload protection
- Motor phase status reset function
- Analogically selectable current levels

Functional Description

The function of the board is to drive a bipolar constant current through each motor winding in a 2 phase motor. The constant current is generated through switch mode regulation. There is a choice of three different current levels with the two logic input 10 and 11.

The current can also be switched of completely.

All inputs are TTL compatible. DIR, $\overline{\text{HSM}}$, CLOCK, and $\overline{\text{RES}}$ have input buffers with Schmitt triggers.

V_r1, V_r2—Reference inputs
Total current level control. The analog reference voltage on V_r1 and V_r2 defines the "100%" overall current in the corresponding winding. Normally V_r1 and V_r2 should be connected to the V_{cc} supply. You can also adjust R9 and R10 to achieve proper current.

Calculation of the motor current:

I_m is motor current

V_r is reference voltage and

K is the factor corresponding to the digitally selected current level.

$I_m = k \times V_r$ (mA)

$k_{high} = 84$

$K_{medium} = 50$

$k_{low} = 16$

Logic inputs
If any of the logic inputs are left open, the board will accept it as a HIGH level. There is a 10 kohm pull-up resistor at each input to obtain higher noise immunity.

$\overline{\text{RES}}$—Reset
A reset is executed when the $\overline{\text{RES}}$ input is pulled low. This will set the motor in a defined status, which corresponds to logic zero on both PHASE signals to the PBL 3717 circuits.

CLOCK—Stepping pulse
One step is generated for each positive edge of the CLOCK signal. for HALF step mode two pulses will be needed to take a FULL step. DIR and $\overline{\text{HSM}}$ must be latched during the positive edge of CLOCK.

$\overline{\text{HSM}}$—Half Step Mode
Half step mode is selected when the $\overline{\text{HSM}}$ input is at low level.

DIR—Direction
The direction of motor rotation is selected by DIR. Actual direction depends on motor and motor connections.

I_0, I_1—Current level selection
The motor current is digitally controlled by I_0 and I_1.

Motor current		I_0	I_1
High	100%	L	L
Medium	60%	H	L
Low	20%	L	H
Off	0%	H	H

Overload protection
The drivers of PBL 3717 are equipped with a thermal shut-down function, which will limit the junction temperature. The output current will stabilize at a level giving the thermal shut down temperature. It should be noted however, that it is not permitted to shortcircuit the outputs.

Table 1. Maximum Ratings

Supply voltage	
Logic supply, V_{cc}	7V
Motor supply, V_{mm}	45V
Input voltage	
Logic inputs	6V
Analog inputs, V_r	15V
Input Current	
Logic inputs	-10mA
Output current	
Motor windings, I_m	±1A
Temperatures	
Operating ambient temperature range, T_{Amb}	0°C to +70°C
Storage temperature, T_{Stg}	-55°C to +150°C

Maximum ratings over operating free-air temperature range (unless otherwise noted). Currents are defined positive if flowing into and negative if flowing out of a terminal, voltage are defined between the terminal and ground.

Output Stages
The output stages contains four Darlington transistors and four diodes, connected as an H-bridge. The two sinking transistors are used to switch the power supplied to the motor winding, thus driving a constant current through the winding.

Application Notes

Motor selection hints
Some stepper motors are not designed for continuous operation at maximum current. As the circuit drives a constant current through the motor, its temperature might increase exceedingly, both at low and high speed operation.

Some motors have such high core losses that they are not suited for switched mode current drive.

Unused inputs
Unused inputs should be connected to the proper voltage level in order to get the highest noise immunity.

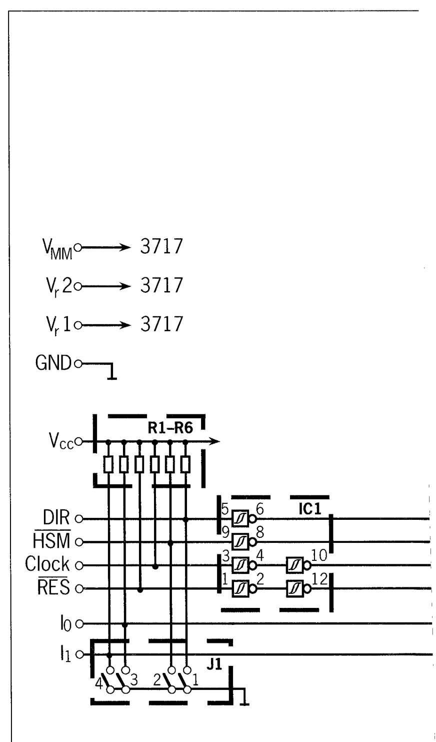


Figure 2. Block diagram.

Grounding can be done on-board with the DIP switches. However, an on-board grounded input must NOT be connected externally, TTL short-circuit might occur.

Optional connections

The PCB is also valid for evaluation of the PBL 3770 circuit. The following substitutions should be made:

- IC8, IC9 — PBL 3770 must be in place instead of PBL 3717
- R9, R10 — The 1 ohm resistors can be substituted with 0.5 ohm (2%) resistors for high current at V_r = 5.0 V. There is linear relationship between motor current and the resistance.
- D1-D4 — Fast recovery diodes must be in place, with their cathodes toward V_{mm}. T_{rr} < = 100 nS. E.g. BYV 27/100, BYW 98/100 or UF 4001.

Note that this configuration can be ordered as an alternative test board: Test board 3031.

- C5, C6 — Can be inserted on board for filtering of V_r voltages.

Note that the V_r connections preferably should be connected to the proper voltage at the female DIN/EURO connector, in order to have fully compatible equipment.

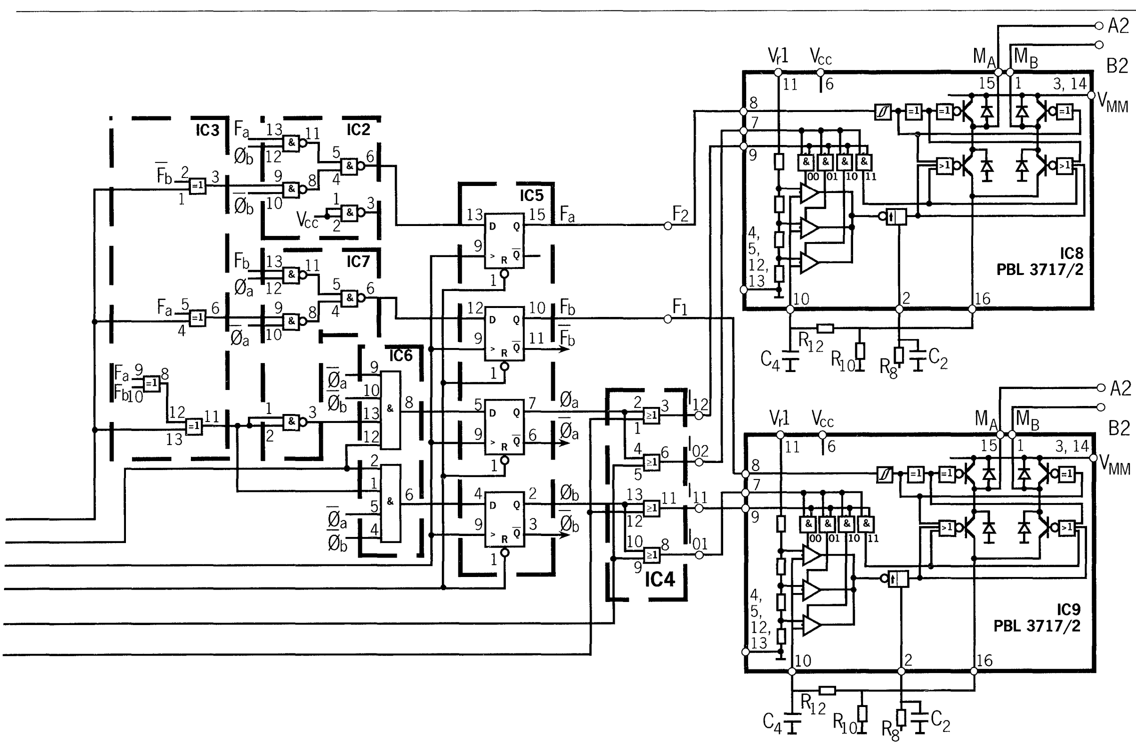
Although, for test purposes, a jumper can be soldered close to IC8, this will connect V_r1 and V_r2 to V_{cc}, to eliminate the need of a third power supply (I_m – 420 mA).

Table 2. Thermal Data

Parameter	Min	Typ	Max	Unit
Thermal resistance, junction-case, $R_{th\ j\text{-}case}$		11		°C/W
Thermal resistance, junction-ambient, $R_{th\ j\text{-}amb}$		45		°C/W

Table 3. Recommended operating conditions

Parameter	Min	Typ	Max	Unit
Supply voltage, V_{cc}	4.75	5.0	5.25	V
Supply voltage, V_{mm}	10		40	V
Output current, I_m	20		800	mA
Ambient temperature, T_{Amb}	0		+70	°C



Predrilled holes are supplied for a screw terminal, paralleled with the DIN/EURO connector, 5 mm spacing.

Common fault conditions

- V_r1 and/or V_r2 not connected to proper voltage.
- Both I_0 and I_1 at high level.
- External input signal connected and DIP switch in ON position.
- Noise at inputs due to long wires without totempole drivers.
- Improper connection of motor windings.

User hints

1. Never disconnect ICs or cards when power is supplied.
2. Do not make unnecessary connections on board, as this can make it incompatible with other test boards.
3. For external input signals turn the appropriate DIL switch to OFF (open). This prevents TTL short-circuits.
4. Preferably, connections to the female DIN/EURO connector should be made to the "c" rail only.
5. Pin 22 on DIN/EURO can be used for special purposes as long as compatibility is not expected.
6. For motor currents higher than 500 mA, use a test board with PBL 3770 or use a heat sink, STAVER V7 or equivalent.
7. Avoid V_{mm} power supply with serial diodes and/or common ground with V_{cc}.
8. To change actual rotation direction, swap motor connection A1 and B1 only.
9. Do not measure motor current through the V_{mm} supply, but use a current probe or use an oscilloscope and measure the voltage across the R9 and the R10 resistors. The current will be: I = V/R.

Mechanical Data

Dimensions:
160 mm x 100 mm x 12 mm (excluding DIN/EURO connector).

Table 4. Connection example

DIN/EURO	Marking	Description
32	A1	Motor winding 1
30	B1	Motor winding 1
28	A2	Motor winding 2
26	B2	Motor winding 2
24	V_{MM}	Motor supply Voltage
22		Not connected
20	V_r2	Reference voltage 2
18	V_r1	Reference voltage 1
16	GND	Ground
14	V_{cc}	Logic supply voltage
12	$\overline{RES}$	Reset
10	CLOCK	Clock/Step
08	$\overline{HSM}$	Half step mode
06	DIR	Direction
04	I_0	I_0
02	I_1	I_1

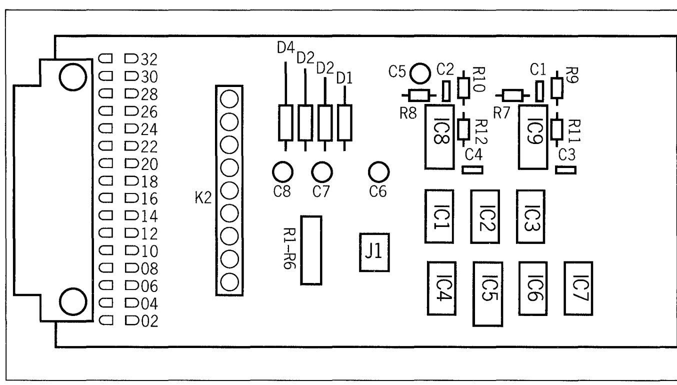


Figure 3. PC board layout

Table 5. Component List

No.	Component	No.	Component	No.	Component
ICI	74LS14	R1–R6	10kΩ × 6 (-8}	C7, C8	not mounted
IC2, IC7	74LS00	R7, R8	56 kΩ	D1–D4	not mounted
IC3	74LS86	R9, R10	1 Ω ±2%	J1	4-pole DIP switch
IC4	74LS32	R11, R12	1 kΩ		
IC5	74LS175	C1–C4	820 pF 10%	K1	DIN/EURO connector 32-pole/even/male
IC6	74LS21	C5	10 µF / 63 V		
IC8, IC9	PBL 3717	C6	47 µF / 10 V	K2	not mounted

TB370I Testboard for microstepping with PBL 3771 and PBM 3960

The testboard TB3071 offers a short cut to get familiar with microstepping. It is a complete system to drive a bipolar stepper motor in microstep mode and for comparison half and full-step modes. As you learn about microstepping the testboard offers more advanced facilities to cope with different motors, resonances and running the testboard from your microprocessor system. The testboard is built around the PBM3960 microstepping controller and PBL3771 precision stepper motor driver.

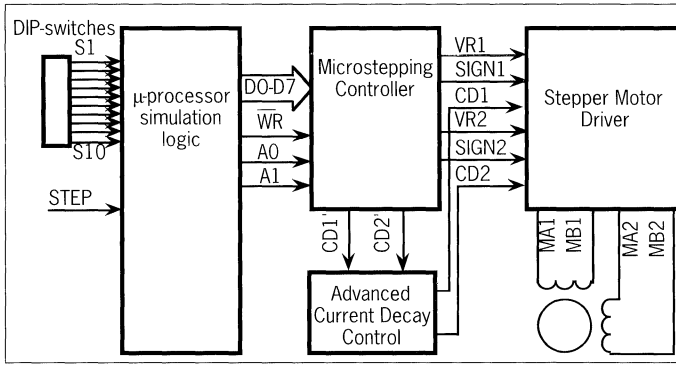


Figure 1. TB307i block diagram.

Quick start

To run the testboard you need the following things. One pulse generator, 1Hz to 1MHz, with TTL output levels. One +5 volt power supply, capable of delivering 200mA. One power supply for the motor voltage, preferable variable output from 10 to 40V DC, maximum output current 1 Ampere or more. The testboard 32-pole matching Euro-connector. Some electrical wires and connectors. A bipolar stepper motor with rated current 0.35 to 0.65 ampere and rated voltage less than 20 volts. The nominal drive current is 450mA one phase on and 320mA two phases on. With a simple modification you can adapt the testboard for any current up to 650mA.

Connections

Turn power supplies off (make this as a habit when connecting and disconnecting motor and power supplies) so you do not damage the testboard.

Disconnect the 32-pole matching connector from the testboard and connect it with appropriate connectors for motor, power supplies and pulse generator. The connections shall be in accordance to table 1.

Set the all DIP-switches except S7 to ON, set S7 to OFF. If necessary check the jumper settings. These should set as delivered from the factory.

Table 1. Basic connections

Pin	Symbol	Description
12A	Step	Connect the TTL-level signal from the pulse generator to this pin. Ground from pulse generator is connected to pin 16A. Connect it directly to the pin and not to the power supply. This minimizes electrical noise problems.
14C	V_{CC}	Logic supply voltage. Connect to +5 volt supply positive terminal. Less than 200mA needed.
16A	V_{SS}	Logic GND. Connect to 5 volt supply negative terminal.
16C	GND	Motor GND. Connect to motor power supply negative terminal. Motor and logic ground are internally connected on the testboard and shall be separated on the power supplies to minimize ground voltage noise problems.
24C	V_{MM}	Stepper motor chopper voltage. Connect to motor supply positive line. Normally +10 to +40 Volt, The supply voltage should be at least twice the nominal motor voltage to ensure good current regulation. Supply current depends on motor type, selected current level and stepping frequency but is normally less than 1 Ampere.
26C	M_{B2}	Connect to motor winding 2 terminal B.
28C	M_{A2}	Connect to motor winding 2 terminal A.
30C	M_{B1}	Connect to motor winding 1 terminal B.
32C	M_{A1}	Connect to motor winding 1 terminal A

Table 2. Jumpers

Pos	Factory	Function
J1	Mounted	The jumper controls the CS (chip select) signal to the PBM3960. It is normally mounted but should be removed if the CS signal is to be controlled from the Euro-connector.
J2	Mounted	This jumper together with J3 can be replaced with a resistor or a potentiometer to rise the reference voltage to the PBM3960 thus rising the motor current. Normally the jumper is mounted.
J3	Removed	See J2. Normally removed.
J4	Removed	This jumper together with J5 can be used to by-pass the LM311 circuit. To do this install both jumpers and remove IC7 from its socket. Normally removed.
J5	Removed	See J4. Normally removed.

Table 3. Stepping sequences

Block	BA2 (S10)	BA1 (S9)	BA0 (S8)	Description*
0	ON	ON	ON	Standard 1/32-step sine/cosine. I_{peak} = 450mA.
1	ON	ON	OFF	Modified sine/cosine 1. I_{peak} = 450mA.
2	ON	OFF	ON	Modified sine/cosine 2. I_{peak} = 450mA.
3	ON	OFF	OFF	Full step both phases on. $I_{phase1} = I_{phase2}$ = 320mA.
4	OFF	ON	ON	Half step. $I_{phaseon}$ = 320mA and $I_{phaseoff}$ = 0.
5	OFF	ON	OFF	Linear ramp. Here is a linear ramp profile with all the codes for both DACs in the PBM3960. The motor moves forth and back one full step. The peak current is 450mA.
6	OFF	OFF	ON	Another linear ramp profile but with every fourth DAC-value used. The peak current is 450mA.
7	OFF	OFF	OFF	Damping test. This sequence moves the motor back and forth one full step. It uses full-step and with two different microstep movements. Connect a high resolution precision potentiometer to the motor shaft and observe the position signal on an oscilloscope. Note the change in settling time.

(Current levels refer to unmodified testboard with R_s = 1 ohm and V_{ref} = 2.5V)

Table 4. Test points

Pos	Symbol	Function
TP1	MAX/MIN	The signal can be used when using the testboard to develop a customized current wave form to find the beginning or end in the EPROM data block under test. This point is low when Step is low and the counter is equal 0 and is counting up or when step is low and the counter is counting down and is equal to FFH.
TP2	TRIG	This is the MSB of the 8-bit counter. This signal is synchronised with the current wave forms and can be used as a trigger. On cycle corresponds to one full data block output from the EPROM.

Factory set-up is described in table 2. This setup runs the testboard in the basic mode. Microstepping 1/32-step, sine/cosine current curves and slow current decay. When running the testboard in this mode the potentiometer P1 setting has no effect.

Check that all connections are OK. Turn the power on in the following order. First logic supply, then motor supply and last pulse generator. Change the pulse generator frequency to examine the motor behaviour at different stepping frequencies. The direction of rotation can be changed with the DIP-switch S3. If the motor doesnot rotate at any frequency, turn power off and check the DIP-switches, jumpers and wiring once more. Ensure that the motor winding is correct and correctly connected.

Comparisons of stepping methods
Microstepping greatly improves stepping at low frequencies and in most cases also at frequencies around the system resonance frequency. When the motor is running correctly the following experiments give a briefing about microstepping.

Smooth movements on low step frequencies.
Select full-step mode (set BA2, BA1, BA0 to ON, OFF, OFF) run the motor at a low frequency, 250Hz for instance, (this corresponds to approximately 4Hz full-step frequency). Notice the rotor movement. To make this easier you can fix a pointer to the motor shaft or even better use a high precision potentiometer and an oscilloscope. Now change to half-step mode (BA setting according to table 3). Finally switch to microstepping. This clearly shows the benefits of using microstepping when running a stepper at low frequencies. Examine the differences at other low frequencies. Notice that no matter how low of step rates you set there will be no noise problems with microstepping. This is due to the low amount of energy transferred to the motor per microstep.

Checking motor sine/cosine conformity
To achieve the smoothest possible microstep movements at the lowest frequencies it is almost always necessary to develop a customized sine/cosine current profile. The profile compensates for the motor sine/cosine devia-

tion. If microstepping position ripple is of less importance and microstepping is used only for reduction of noise the standard sine/cosine profile usually does the job. The EPROM on the testboard contains in addition to the standard sine / cosine profiles two customized sine/cosine profiles.

Run the motor at a very low frequency 50Hz, for instance. Set the standard sine/cosine profile and observe the rotor movement. Use a pointer or potentiometer to observe the movement more clearly. If the velocity ripple is too large for the actual application use a more microstepping adapted motor or develop a customized sine/cosine current profile. Switch to the modified sine/cosine profiles to see if this improves the movement. Refer to the microstepping application note for more information on how to develop a customized current profile.

Damping resonances at motor resonance frequency.
Find the system resonance and run the motor at this frequency. By holding the motor in your hand it is possible to compare the resonance amplitude when running the motor in micro, half and full-step modes. Also check the influence of the chopper voltage and winding currents on the resonance amplitude.

More methods of damping resonances are described in "Advanced facilities"

Modifying the testboard

Modifying current levels
The nominal motor currents are shown in table 2. This is valid with R4 = R7 = 1ohm and V_{ref} = 2.50 volt.

There are two ways of changing the motor current levels. The easiest is by changing the current sense resistors R4 and R7. The motor currents are in accordance to the following formula:

$$I_{new} = I_{nominal} \times (1 / R_{new}).$$

It is also possible to change the current levels by changing the reference voltage. This can be done in several different ways.

Remove IC8 (TL431) precision shunt regulator and connect a variable voltage 0 – 5 V (0 – 3 V recommended) to jumper J2. The current will be

$$I_{new} = I_{nominal} \times (V_{refnew} / 2.5).$$

The new current can be in the range of 0 to $2 \times I_{nom}$.

Mount a 5.1k resistor at position J3 and replace J2 with a 0 to 3k resistor The current will be:

$$I_{new} = I_{nominal} \times \frac{2.5 \times (RJ2+RJ3)}{RJ3}$$

Table 5. DIP-switch settings

Pos	Symbol	Factory	Function when S2 is ON	Function when S2 is OFF
S1	A0	ON	Don't care.	A0 address to PBM3960. ON selects current decay register for channel 1. OFF selects channel 2.
S2	MODE	ON	Selects normal stepping mode.	Selects load current decay level mode.
S3	DIR	ON	Selects direction of motor rotation. ON = counter up counting. Actual rotation direction depends on motor winding and EPROM contents.	Don't care.
S4	L4	ON	Don't care.	Selects data to be sent to current decay level registers bits L41 and L42 ON = 0.
S5	L5	ON	Don't care.	Selects data to be sent to current decay level registers bits L51 and L52 ON = 0.
S6	L6	ON	Don't care.	Selects data to be sent to current decay level registers bits L61 and L62 ON = 0.
S7	/WR	OFF	Always OFF.	Normally OFF. By toggling this switch a write pulse is generated to the PBM3960. This can be used to update the level registers.
S8	BA0	ON	Block address 0. LSB to selects EPROM data block. Connected to EPROM address line A8. ON = A8 low.	Don't care.
S9	BA1	ON	Block address 1. Selects EPROM data block. Connected to EPROM address line A9. ON = A9 low.	Don't care.
S10	BA2	ON	Block address 2. MSB to select EPROM data block. Connected to EPROM address line A10. ON = A10 low.	Don't care.

The current can in this case be changed from $I_{nominal}$ to $1.6 \times I_{nominal}$

It is also possible to replace J2 and J3 with a 10k potentiometer Connect the center tap to the node common for J2 and J3. The current can in this case be set to a value from I_{nom} to approximately $1.8 \times I_{nom}$

It is possible to combine both changes in R_s and V_{ref} to achieve the preferred current range.

In all cases were V_{ref} is changed, values above 3 volt will derate the PBM3960 DAC accuracy. This causes increased current wave form distortion.

Don't set a higher current than 650 mA despite of method used. 650 mA is the maximum-allowed driver current (one phase on). If more than 500mA is used the driver has to be equipped with a heat sink.

Adding external diodes

In some applications lower driver and motor losses and improved current regulation can be achieved by adding external switching diodes. Diodes can be mounted on the testboard in position D1 to D4. Use a fast switching diode type UF4001, BYW27 or equivalent.

Functional description

The testboard can be devided into four blocks, see figure 1. Microprocessor simulation logic, microstepping controller, precision stepper motor driver and advanced current decay control logic.

Microprocessor simulation

This block sends the control signals normally sent by a microprocessor to the microstepping controller. Inputs to the block are the 10 DIP-switches S1 to S10 and the Step signal in the Euro-connector (pin 12A). During normal operation the current level in one of the motor windings is updated at every Step pulse (single pulse programming). This means that two Step pulses are required to update both winding currents and make the motor turn what's normally called one microstep. In this mode it is possible to change the motor direction of rotation by operating the dip-switch S3.

This block can also generate the signals required to program the current decay levels.

Table 6. 32-pole Euro-Connector

Pin	Symbol	Dir	Description
2A	A0	In	Normally not connected. Address line A0 to PBM3960. Used when TB307I is interfaced to a microprocessor.
2C	A1	In	Normally not connected. Address line A1. Same as A0.
4A	D1	In	Normally not connected. Data line D1 to PBM3960. Used when TB307I is interfaced to a microprocessor.
4C	D0	In	Normally not connected. Data line D0. Same as D1.
6A	D3	In	Normally not connected. Data line D3. Same as D1.
6C	D2	In	Normally not connected. Data line D2. Same as D1.
8A	D5	In	Normally not connected. Data line D5. Same as D1.
8C	D4	In	Normally not connected. Data line D4. Same as D1.
10A	D7	In	Normally not connected. Data line D7. Same as D1.
10C	D6	In	Normally not connected. Data line D6. Same as D1.
12A	Step	In	A positive transition on this pin outputs the next current level to one of the motor windings. To take one microstep new current levels to both windings are needed therefore the motor takes ½ microstep per input pulse. When TB307I is connected to a microprocessor this pin is the $\overline{\text{WR}}$ signal to the PBM3960.
12C	/CS	In	Normally not connected. Can be used as chip select signal to the PBM3960 when interfaced to a microprocessor. If used jumper J1 has to be removed. This is a active low input.
14A	RESET	In	Normally not connected. This is a active high input to reset the PBM3960. The signal is internally pulled down to GND so normally no connection is necessary.
14C	VCC	In	Logic supply voltage connect to +5 Volt. Less than 200mA needed.
16A	VSS	In	Logic GND. Connect to logic supply ground.
16C	GND	In	Motor GND. Connect to motor supply ground. Motor and logic ground are internally connected and shall be separated on the power supplies to minimize ground voltage noise levels.
18A	CD1	I/O	Normally not connected. Current decay channel 1. Test point or CD1 input to PBL3771 if PBM3960 is removed.
18C	DA1	I/O	Normally not connected. Analog DA channel 1 output from PBM3960 and referents voltage input channel 1 to PBL3771. Can be used as test point or as set value input to PBM3771 if PBL3960 is removed.
20A	CD2	I/O	Normally not connected. Current decay channel 2. Test point or CD2 input to PBL3771 if PBM3960 is removed.
20C	DA2	I/O	Normally not connected. Analog DA channel 2 output from PBM3960 and referents voltage input channel 2 to PBL3771. Can be used as test point or as set value input to PBM3771 if PBL3960 is removed.
22A	SIGN1	I/O	Normally not connected. Test point for SIGN1 output from PBL3960 or if PBL3960 is removed SIGN1 input to PBM3771.

Pin	Symbol	Dir	Description
22C	SIGN2	I/O	Normally not connected. Test point for SIGN2 output from PBL3960 or if PβL3960 is removed SIGN2 input to PBM3771.
24A	NC		No internal connection.
24C	VMM	In	Stepper motor driver chopper voltage. Connect to motor supply positive line. Normally +10 to +40 Volt. Supply current depends on motor type and selected current level but is normally less than 1 Ampere.
26A	NC		No internal connection.
26C	MB2	Out	Connect to motor winding 2. This pin sources current when SIGN2 = high.
28A	NC		No internal connection.
28C	MA2	Out	Connect to motor winding 2. This pin sinks current when SIGN2 = high.
30A	NC		No internal connection.
30C	MB1	Out	Connect to motor winding 1. This pin sources current when SIGN1 = high.
32A	NC		No internal connection.
32C	MA1	Out	Connect to motor winding 1. This pin sources current when SIGN1 = high.

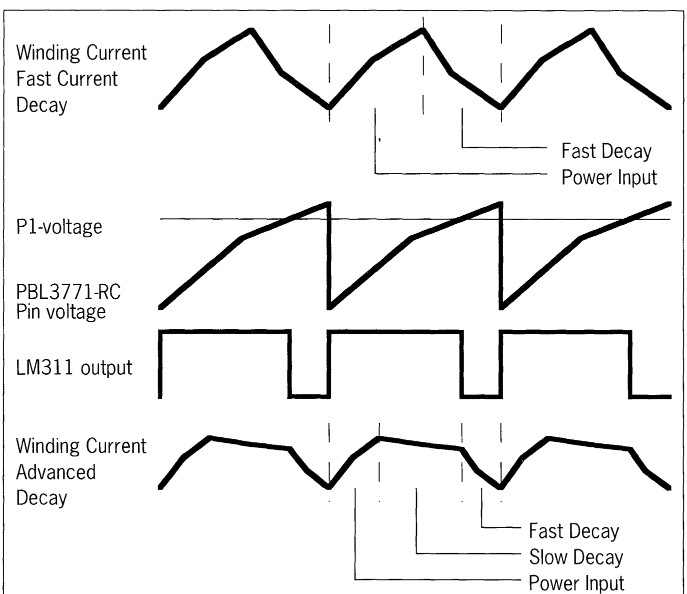


Figure 2. TB307i advanced current decay control.

An eight bit counter, built up of two four bit counters (74LS191, IC1 and IC2), generates a 256 step sequence at the outputs A_{IC1}, B_{IC1}, ..., D_{IC2}. This is sent as an eight bit wide address (A0 to A7) to the EPROM (2764, IC3). The counter increments (DIR DIP-switch in position ON) or decrements (DIR = OFF) the address at every positive transition on the Step input. When the EPROM input address line A0 is low the EPROM outputs data associated to driver channel 1. When A0 is high data associated to channel 2 is output from the EPROM. This means that 128 consecutive 2-byte entities in the EPROM make up one microstep cycle which is equivalent to 360 electrical degrees or 4 full-steps. The dip-switches S8,S9 and S10 are directly connected to the EPROM address lines A8, A9 and A10 respectively. This makes it possible to select 1 of 8 different microstep sequences (blocks) without changing the EPROM contents.

By changing the MODE DIP-switch (S2) to the OFF state the logic changes from the stepping mode to the output current decay level mode. In this mode the selector (74LS257, IC4) changes the signals on the outputs D4, D5, D6 and A0 from being connected to the EPROM to being connected to the DIP-switches L4, L5, L6 and A0.

Microstepping controller.
This block converts the digital signals from the EPROM into two analog signals VR_1 and VR_2 which control the current levels in the two motor windings. It also generates the digital signals SIGN1 and SIGN2 to control the direction of the current in the windings. The basic control signals for current decay are also generated here. The block contains the PBM3960 micro stepping controller and a precision 2.5 volt reference. The reference voltage is connected to the reference input of the PBM3960 which generates the above signals internally.

When the MODE DIP-switch (S2) is in the OFF position it is possible to load the current decay level registers of the PBL3960. L4, L5 and L6 select the data to load and A0 selects which current decay register to update. To make writing to the registers possible, the clock on the Step input must be running or the DIP-switch S7 must be toggled once per register.

Refer to the PBM3960 data sheet for more information.

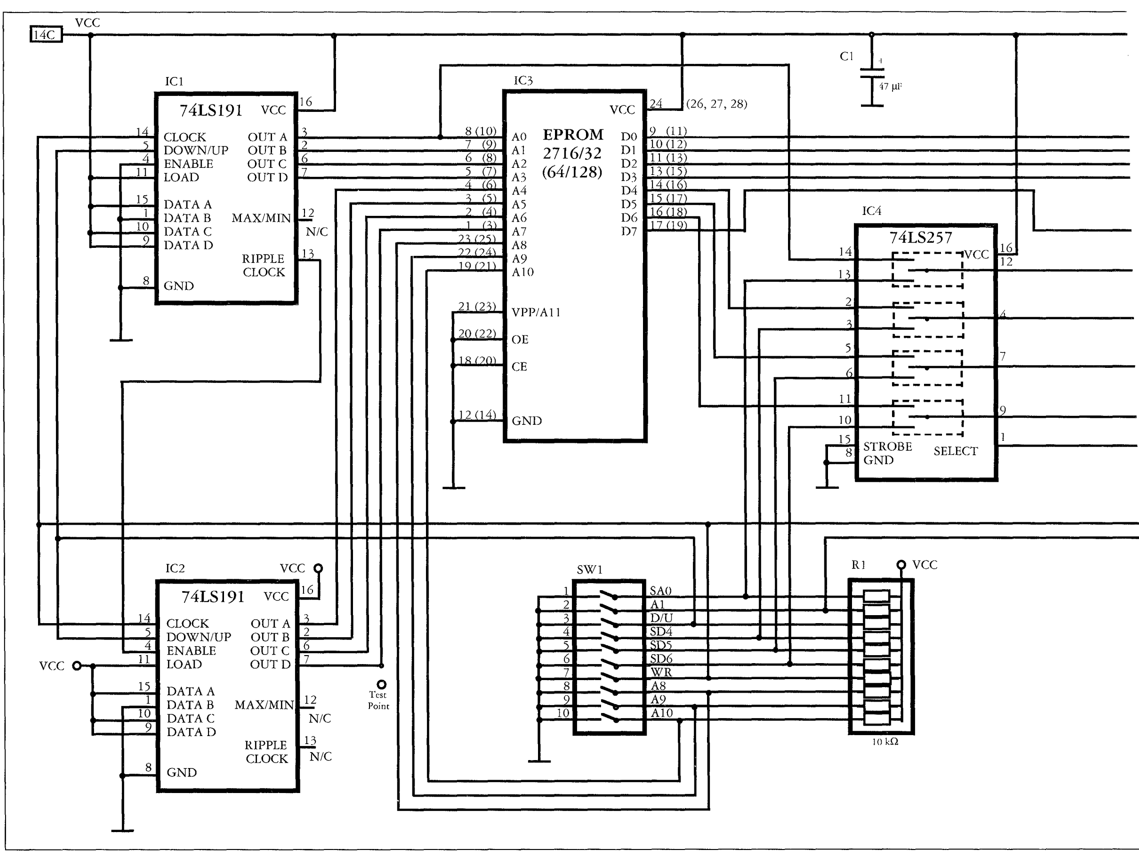
Stepper motor driver
The driver controls the winding currents in accordance to the analog and digital input signals. The current control is switch-mode constant-current (chopper) to minimize driver power losses. The chopping is controlled by a fixed frequency PWM method. The driver is implemented with the PBL3771 precision stepping motor driver. Only a few external components are used to set the current levels and switching frequency. The output currents are a function of the analog input signals VR_1 and VR_2, the current sensing resistors R_{S1} and R_{S2} (R4 respectively R7) and the SIGN1 and SIGN2 inputs. $|I_1| = (VR_1 \cdot R_{S1})$. When SIGN1 = 1 the current flows from the M_{A1} terminal to the M_{B1} terminal. The equivalent is valid for I_2. For more information on the precision stepper motor driver PBL3771 refer to the device data sheet.

Advanced current decay control
This is an optional block which can be used to improve the current regulation. If not used it can be disabled by turning the potentiometer P1 to the CCW end point or by dismounting IC7 and installing the jumpers J4 and J5. If no fast current decay level has been programmed to the level registers the circuit won¥t effect the driver operation.

The function of the improved current decay circuit is as follows. The comparator LM311 (IC9) compares a variable voltage set by P1 with the RC-terminal saw tooth voltage generated by the PBL3771 driver. The saw tooth signal is synchronised with the chopper control. One period on the saw tooth signal corresponds to one PWM period. By setting P1 to a voltage between $0.2V_{CC}$ and $0.64V_{CC}$, 0 to 100% of the PWM period can be enabled for fast current decay. $V_{CC} = 0.64$ gives 100% fast decay. Refer to “Advanced facilities” and figure 2 for more information on this topic.

Advanced facilities

Using fast current decay
When driving a stepper motor especially on frequencies around and above the system resonance frequency, problems with current dragging can occur. At the same time mechanical resonances and acoustic noise can also be present.



Often it is possible to lower resonances and noise by eliminating the current dragging. The PBM3960 controller can lower or fully eliminate the current dragging by use of fast current decay. The PBM3960 only enables fast current decay when the desired amplitude of the winding current is decreasing. In this way the overall current ripple can be kept at a lower level. The amount of fast current decay to be applied is controlled by programming the current decay level registers of the PBM3960.

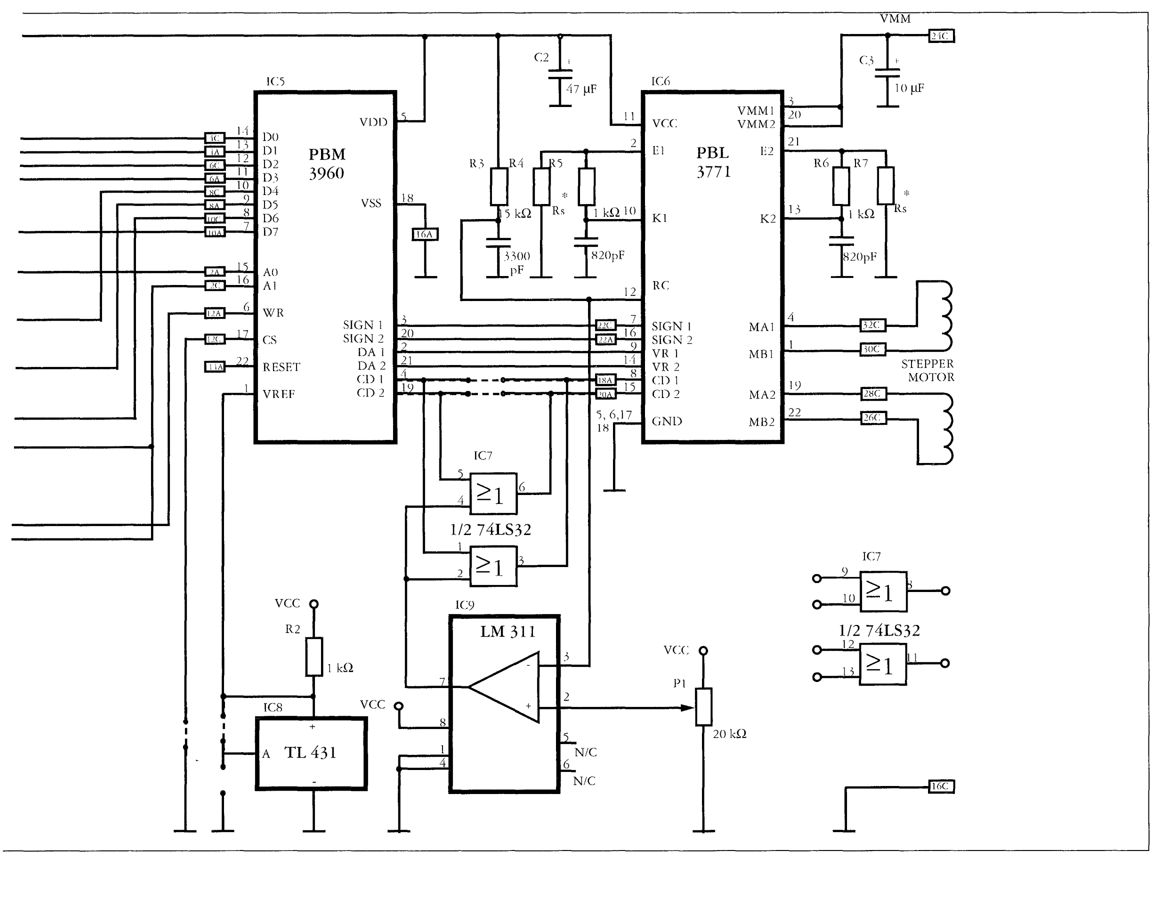
It is possible to program eight different values of current decay to each of the two level registers (one register for each winding). Normally the same values are used for both registers. 7 gives maximum fast current decay and 0 gives no fast current decay.

To program both registers to the same value do as follows. Set the DIP-switches L4,L5 and L6 (S4, S5 and S6) to the desired value, ON = 0, S4 = LSB. With the pulse generator running and connected to the Step input, set the MODE DIP-switch (S2) to the OFF position. Now one of the level registers has been written to. Switch the A0 DIP-switch (S1) to its other position to program the other level register. Return the MODE switch to its ON position to return to normal stepping mode. Compare the new current wave forms with the old to see the effect. For more information on current decay control refer to PBM3960 data sheet. To reset the current decay function program the level registers to 0 or turn power off and on again.

Advanced current decay control
Programming the current decay as above can with some combinations of decay levels motor types and windings result in increased current ripple and distortion of the current wave form. These problem can be eliminated by applying advanced current decay control. On the testboard this is done with the LM311 circuit mentioned earlier. The LM311 circuit works as follows.

With normal current decay one PWM cycle is divided into two phases first the power input phase and thereafter either a freewheeling phase (slow current decay) or an energy return phase (fast current decay), see figure 2.

When slow decay is applied the winding is theoretically short-circuited by the driver circuit. The winding current is in this case a function of the winding inductance, resistance and the EMF generated by the rotor movement. The energy stored in the winding inductance and rotor movement is slowly transferred to heat in the winding resistance. This has a damping effect on rotor oscillations.



When fast current decay is selected then the driver connects the winding in opposition to the power supply. In this case the excessive energy in the winding and rotor is quickly removed thus eliminating the current dragging. But, if too much energy is removed the winding current ripple will increase. This will cause switching noise, increased power losses, current wave form distortion and in some cases also increased resonances.

The LM311 circuit combines fast and slow current decay into a three phase PWM-cycle, see figure 2. Firstly a power input phase, secondly a slow current decay phase and lastly a fast current decay phase. This three phase PWM-cycle replaces the normal fast current decay cycle. By setting the voltage level on potentiometer P1 the maximum length of the fast current decay phase can be set thus lowering the current ripple and eliminating the problems associated with this.

To select the optimum P1 setting first you must fully enable fast current decay from the PBM3960. Then the current decay can be controlled by the LM311-circuit. Turn P1 to the CCW end point then the LM311-circuit fully disables the fast current decay. Run the motor at different frequencies to find frequencies with noise and resonance problems. Run the motor at the worst resonance and turn P1 to the optimum position where the smoothest movement of the rotor occurs. In some applications the smoothest movement is achieved with PBM3960 fast current decay only partially enabled. Now check the motor movements on all frequencies used in the application. In some cases the P1 setting has to be a compromise between several frequencies which cause problems.

For an actual design use the optimum output voltage from P1 to design a voltage divider to avoid the cost and adjustment procedure of potentiometer P1. Use 1% resistors and connect the divider to V_{CC} and GND to get the best performance. The amplitude and offset of the saw tooth signal is referred to V_{CC} and GND and are within 1% from the theoretical values ($0.2V_{CC}$ and $0.64V_{CC}$) so a small tolerance on the fast current decay phase can be achieved.

Modifying the current wave forms
By changing the data stored in the EPROM it is possible to generate different current wave forms. For instance it is possible to modify the sine/cosine curves to get minimum microstepping position ripple. It is also possible to generate microstepping sequences with other step lengths. The following lengths are possible 1/32 (default microstep), 1/16, 1/8, 1/4, 1/2, and 1/1 (full-step). For all sequences all the 128 2-byte entities of the EPROM have to be programmed due to the 8-bit counter driving the EPROM. It is a good idea to stretch all sequences to a 128-step sequence to get the same motor speed independently of the step length. This is done by repeating every 2-byte entity 2, 4, 8, 16 or 32 times when not 1/32 stepping mode is used.

The 2-byte entities contain the two 7-bit DA-data register data and 1-bit sign data for the two DACs in the PBM3960. DAC 1 data is stored on even addresses and DAC 2 data on odd addresses. Bits 0 to 6 set the amplitude of the current and bit 7 sets the sign (direction).

One data block stores one sequence and occupies 256 consecutive addresses in the EPROM. It is possible to access 8 different blocks with the DIP-switches BA0,BA1 and BA2 therefore only 2k-byte of the EPROM can be used without modifying the testboard.

It is possible to use EPROMs of the types 2764, 27128 and 27256 and their CMOS versions. When 2764 is used the blocks should be placed on address 0 to 7FFH. For 27128 address 2000H to 27FFH and for 27256 address 6000H to 67FFH should be used. The address lines A11 and A12 are hardwired to GND and A13 and A14 to V_{CC}.

Connecting the testboard to a microprocessor
It is possible to connect the testboard to your own microprocessor system. Access to all control signals is possible through the 32-pole Euro-connector. To avoid conflicting signals it is necessary to remove the EPROM (IC3) and the selector (IC4). The DIP-switches MODE and $\overline{WR}$ (S2 and S7) should be in their OFF positions. You also have to remove the jumper J1 if you want to use the chip select input. There will be 10kohm pull-up resistors connected to the $\overline{WR}$ and A1 signals.

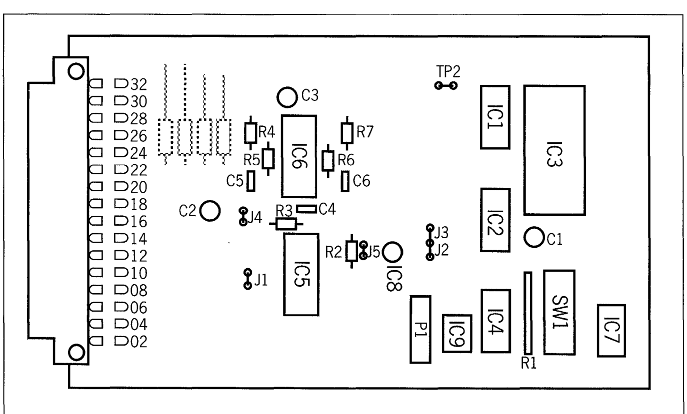


Figure 4. PC board layout.

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