MAGNETIC BUBBLE MEMORY TESTING

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Magnetic bubble devices are made by growing a magnetic garnet film on a nonmagnetic garnet substrate. With no external magnetic field, a maze-like pattern of magnetic domains appears in the film such that the entire sample is magnetically neutral (Fig 1). In the presence of a perpendicular external magnetic field (bias field), the regions of polarity opposite to that of the applied field shrink. A proper bias field, usually created by small permanent magnets which are part of the package, forms small cylindrical regions called bubbles.

The bubbles move in the film under the influence of small magnetic field parallel to the plane of the film. In present devices, a Permalloy pattern deposited on the garnet film controls this movement (bubble propagation). The bubbles move in accord with the changing magnetic poles produced in the Permalloy pattern by a rotating in-plane magnetic field (drive field). Fig 2 shows a common pattern of alternating T's and bars and the corresponding bubble movement as the field rotates. Two orthogonal magnetic coils wound around the device produce the rotating field. The switching of bubbles between alternate propagation paths, the generation of bubbles and the replication of bubbles for a non-destructive read are accomplished by producing localized magnetic fields on the device with current carrying conductor loops. The presence of bubbles is detected by the magneto-resistive effect of the bubble passing under a conductor carrying a small amount of current. The data in bubble memory devices is represented by the presence or absence of a bubble in each of the propagation positions. The presence of a bubble indicates a binary 1 and the absence of a bubble indicates a binary 0. Access to the device is by a serial data stream.

One common device organization called the major-minor loop device (Fig 3), consists of a "major" propagation loop which provides access to a number of minor loops. The minor loops contain a large number of propagation elements and form actual data storage region of the bubble device. The major loop contains the bubble generation and detection functions. Data is accessed in a block or page which consists of one bit position from each of the minor loops. Various functions are needed to control a bubble device. Transfer gates are used to transfer bubbles between the major and minor loops. The generator creates bubbles to form the data pattern. The replicator element can either make a copy of the bubble for detection purposes or simply transfer the bubble to the detector area to remove it from the device before new data are generated.

Many methods are currently used to package bubble memory devices. To obtain the greatest bit density designers package several bubble devices within one magnet structure. How-

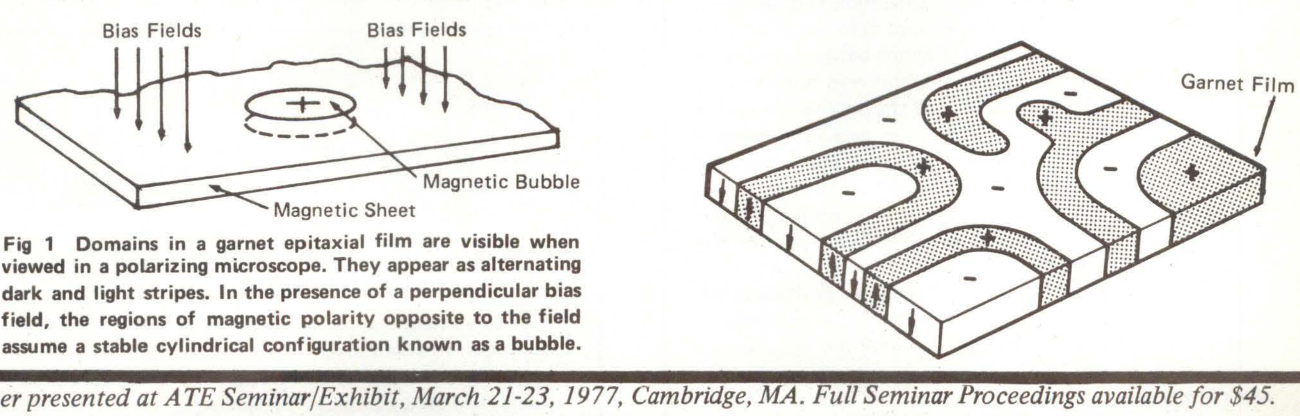

Fig 1 Domains in a garnet epitaxial film are visible when viewed in a polarizing microscope. They appear as alternating dark and light stripes. In the presence of a perpendicular bias field, the regions of magnetic polarity opposite to the field assume a stable cylindrical configuration known as a bubble.

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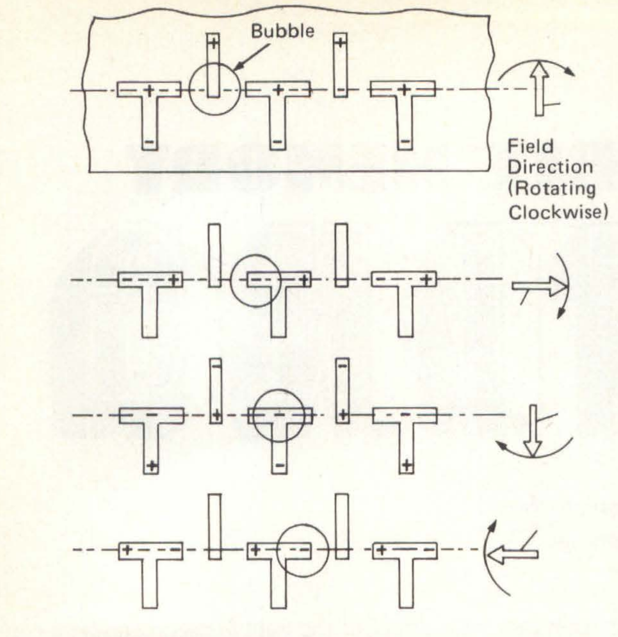

Fig 2 T-Bar Propagation Circuit. The rotating magnetic field in the plane of the garnet film induces magnetic poles in the Permalloy film. The changing magnetic poles cause the bubble to move.

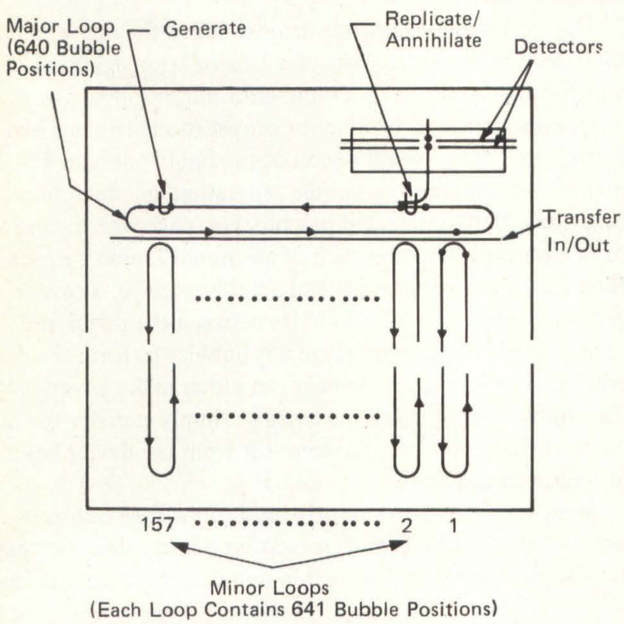

Fig 3 Major loop contains bubble generation and detection functions; Minor loops are the storage area of the device. Transfer gates cause the bubbles to switch between the major and minor loops. Sequencing for a bubble read function is as follows: The drive field is started and the bubbles are moved until the proper block is at the transfer gate. The block is transferred to the major loop and propagated to the replicator where a copy is made of each bubble for detection purposes. The block continues around the major loop until it reaches the transfer gate again where it is transferred back into the minor loops. The number of steps in the major loop is arranged so that the bubbles return to the same position in the minor loops that they came from. The write operation is similar except that the replicator transfers the bubbles out of the major loop and the generator produces a new bubble data pattern.

ever, to minimize cost, a single device can be mounted within a small magnetshield arrangement to form a 14-pin dual inline package. The characteristics of such a module are given in Table I. For testing purposes the magnetic bias field can be altered by wrapping a small coil around the magnetic shield. Drive field coils are operated with a triangular current waveform. Current in the two coils is 90 degrees out of phase to produce the rotating field (Fig 4). The bubble motion can be started and stopped by controlling the drive field as shown in Fig 4. Bubble memories are non-volatile and data can be stored indefinitely since the module contains protection from stray magnetic fields. Fig 5 summarizes the physical and electrical features of magnetic bubble memory operation.

Table 1
Module Characteristics

Useful capacity	92304	Bits
Useful block size	144	Bits
Minor loop size	641	Bits
Percent redundant storage	8.3	%
Drive field frequency	100	KHz
Data rate	50	Kb/s
Average access time (first bit)	4	ms
Size	1.0 x 1.1 x 0.4	"
Pin count	14	Pins
Weight	20	gm
Max. external magnetic field	40	Oe
Operating temperature	0 to 70	°C
Nonvolatile storage temp.	-40 to 85	°C

Two factors reflect device performance. The first is the amount of allowable variation in the magnetic bias field. This magnetic bias margin and its size indicates how well the device will work over a range of electrical, mechanical and environmental variations. The second performance criteria is the number of bad minor loops. With current device technology, perfect devices are difficult to produce. To make a cost effective memory system, 13 of the 157 minor loops on a 100 kilobit device are allowed to be inoperative.

the test system hardware and software

TI's computer-based test system consists of a Texas Instruments 990 minicomputer, a microprogrammed bubble memory controller, and various standard computer peripherals (Fig 6). In addition, a programmable bias field power supply and a programmable function amplitude unit are interfaced

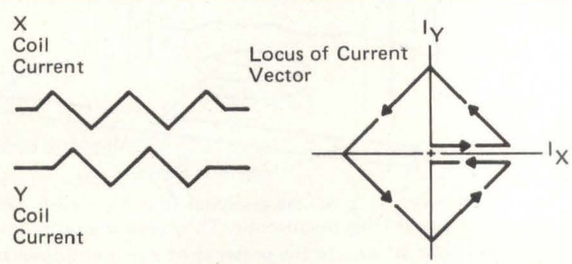

Fig 4 Drive field may be stopped and started as indicated to provide non-volatile storage. The device is mounted at a slight angle within the bias magnet structure to provide a small holding field on the propagation elements.

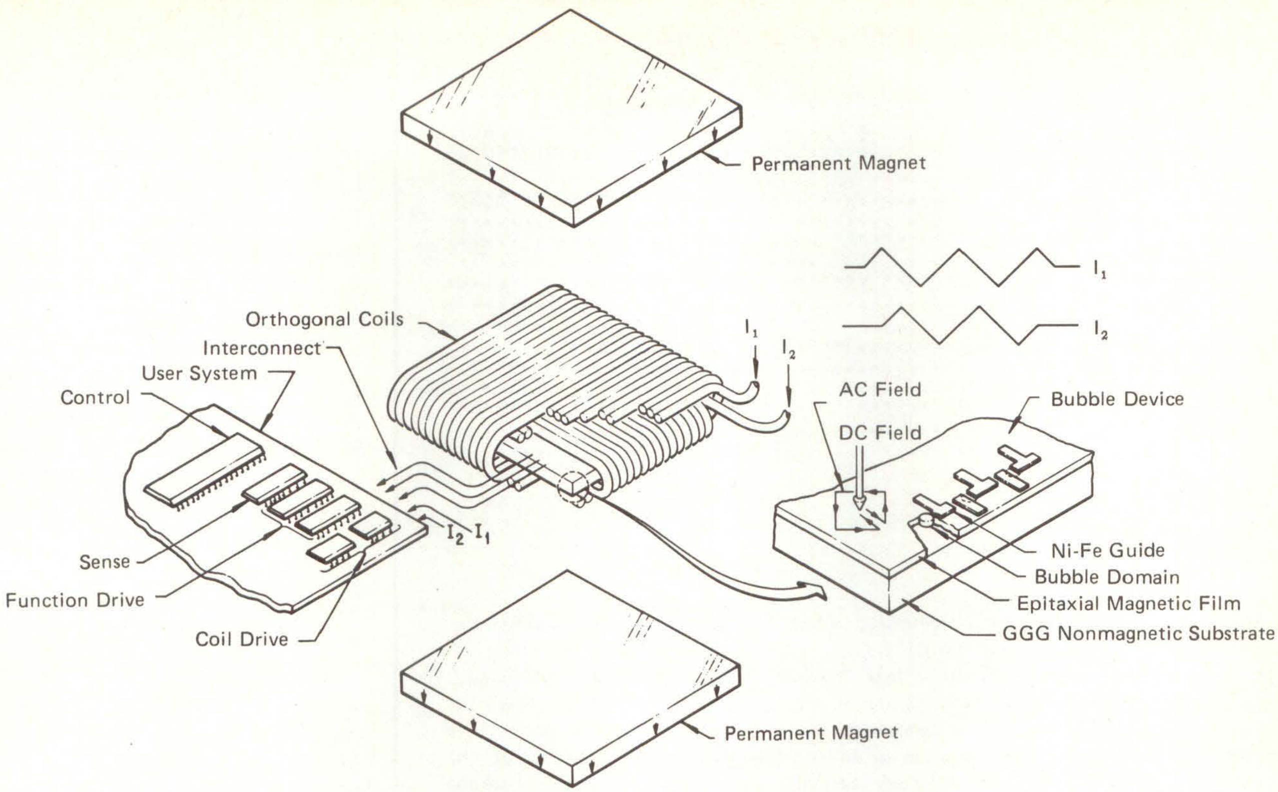

Fig 5 Various components needed for bubble memory operation.

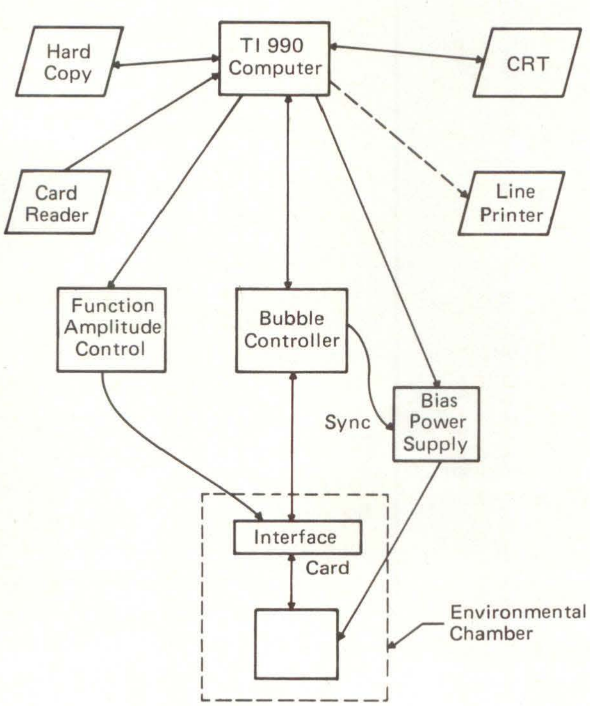

Fig 6 Block diagram of the bubble memory test system

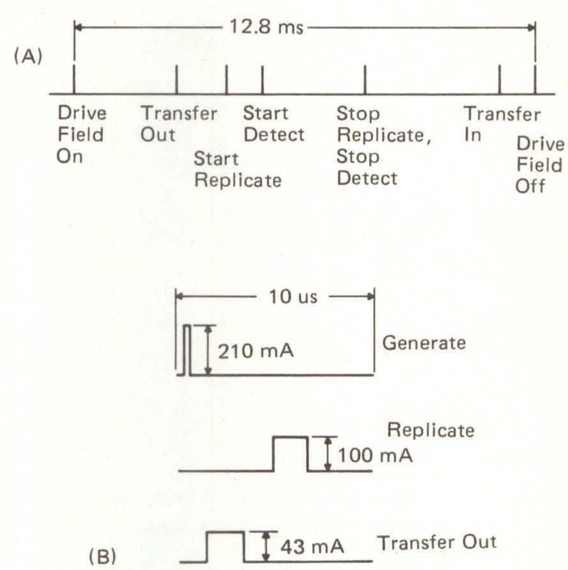

Fig 7 Bubble memory functions must occur during the proper drive cycles (A). The bubble controller contains counters to keep track of which block is at the transfer gate and to count the intervals between functions. During the drive field cycles when a function is enabled, the function current must be precisely controlled (B). This is done digitally in the test system controller. Amplitude, duration and position within the field cycle are all controllable by the test program.

```
CHARACTERIZATION TEST 10DEC76 10:55:32
MODULE  B6-8-9 TPB25   TEMP -42

FUNCTION TIMING 10DEC76 10:55:36  MODULE   B6-8-9 TPB25   AT  -42 DEG C
                          1         2         3         4         5         6
 LE DUR FUNC 0123456789012345678901234567890123456789012345678901234567890123
 32, 18  ADV ................................******************..............
 48, 18  BDV **..............................................****************
 0,  18  CDV ******************..............................................
 16, 18  DDV ................******************..............................
 2,  2   GEN ..**............................................................
 23, 30  ANH .......................******************************...........
 0,  1   STR *...............................................................
 33, 6   REP .................................******.........................
 31, 17  XIN ...............................*****************................
 9,  9   CLP .........*********..............................................
 14, 1   STB ..............*.................................................
 0,  64  DET ****************************************************************
 8,  11  XOT ........***********.............................................
 42, 5   RWC ..........................................*****.................
 FIELD PHASE 0               90              180              270             0

FUNCTION AMPLITUDES AT TEMP -42
GEN= 337   ANH= 60   REP= 146   XIN= 30   XOT= 43
```

Fig 8a Excerpt of output from the characterization test. This printer listing is the actual test result of a 100 Kbit bubble device at -40°C. The test was done with a 200KHz drive field. All bias setting and margins listed are in the units of Oersteds *10 (thus 25 means 2.5 Oersteds). Function position (LE) and duration (DUR) are given in 64ths of the drive field cycle. Bias values represent the deviation from the permanent magnet setting and can be either positive or negative. Function amplitudes are given in miliamperes. Readout gives timings of the functions within the drive field cycle. Asterisks represent the portion of the cycle where the function is on. Function amplitudes, compensated for temperature, are also listed.

MAJOR LOOP ERROR TEST   TEMP -42 10DEC76 10:55:43
NUMBER OF READS = 20

BIAS	MISSING BUBBLES	EXTRA BUBBLES	TOTAL ERRORS
-60	400	0	400
-50	400	0	400
-40	383	1	384
-30	350	0	350
-20	0	0	0
-10	0	0	0
0	0	0	0
10	0	0	0
20	0	0	0
30	0	0	0
40	0	0	0
50	0	0	0
60	0	0	0
70	0	0	0
80	0	0	0
90	0	0	0
100	0	0	0
110	0	0	0
120	0	0	0
130	177	0	177
140	400	0	400

Fig 8b Bias margin test of the major loop. In this test the bubbles are kept in the major loop to eliminate transfer and minor loop errors from the test. The margin can be seen to be 16 Oersteds.

```
MASK BIAS LOW -28   HIGH 110   MARGIN 138
SELF GENERATION TEST   TEMP -44 10DEC76 10:56:17BIAS=  40
MASK   0000 0000 0800 0000 0000 0000 0000 0004 0000 0007  NBIT 2
```

Fig 8c The minor loop mask is determined. This device has 2 bad minor loops over a 13.8 Oersted bias range. The bits in the last word of the mask are not from the device since a block contains 157 bits.

to the test system. The bubble memory controller performs all of the bubble memory timing operations. Test programs, written in a high-level test language, usually include some degree of data reduction and often include procedures to produce graphical output on the hard-copy terminal or line printer. The CRT terminal is used for high speed data display and operator control. A card reader is used for the system load and the input of test programs.

The operation of bubble memories can be broken into two levels of control. To sequence the bubbles properly, the control functions must be enabled during prescribed cycles of the rotating drive field. One level of control counts cycles of the rotating field to access the required page of data correctly (Fig 7a). The bubble memory controller contains a programmable sequencer which performs this operation. The program can accept commands from the host computer, start the drive field, count the required intervals for the device architecture and the required page and stop the drive field when the bubbles have returned to the minor loops. This program can be loaded or modified by the host computer so that different bubble device architectures may be tested. An assembler for the controller was implemented by using the macro capabilities of the IBM 370 assembler to define the various controller instructions. An output formatter was written to make the resultant listing and load deck easier to use. The microcode for a typical device architecture consists of about 125 instructions. Ease of programmability using an assembly language has simplified the system changes required to test new device architectures.

Each of the function currents must be accurately timed within the drive field cycle (Fig 7b). A function timing RAM divides the drive field cycle into 64 discrete intervals. The function RAM operates as a recycling shift register with one track or channel for each of the bubble functions. Each of the channels contains a set of logical ones in that period of the bubble cycle where the function is to be turned on. The programmable portion of the controller enables the output of the appropriate channel during the proper field cycle. The contents of the function timing RAM may be changed by the test program so that timing tolerances may be

```
GEN  NOMINAL LE 2   DUR 2   AMP 337
 LE     LOW    HIGH  MARGIN
 0      -52     179   231
 1      -51     181   232
 2      -53     183   236
 3      -49     179   228
 4      -43     180   223
 5      -48     181   229
 6      -44     179   223
 7      -41     182   223
 8      -38     182   220
 9      -31     181   212
 10     -32     179   211
                   -60                 40                  140
                   :                   :                   :
         5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
 0                    L                                            H
 1                    L                                             H
 2                    L                                             H
 3                     L                                           H
 4                      L                                           H
 5                     L                                            H
 6                      L                                          H
 7                      L                                           H
 8                       L                                          H
 9                        L                                         H
 10                       L                                        H
         5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
MODULE  86-8-9 TPB25   TEMP -43 10DEC76 10:56:34


GEN  NOMINAL LE 2   DUR 2   AMP 337
 DUR    LOW    HIGH  MARGIN
 1      -50     180   230
 2      -47     180   227
 3      -39     180   219
 4      -34     180   214
 5      -15     180   195
                   -60                 40                  140
                   :                   :                   :
         5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
 1                    L                                             H
 2                     L                                            H
 3                       L                                          H
 4                        L                                         H
 5                           L                                      H
         5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
MODULE  86-8-9 TPB25   TEMP -43 10DEC76 10:56:42


GEN  NOMINAL LE 2   DUR 2   AMP 337
AMP     LOW    HIGH  MARGIN
 277    -50     82    132
 287    -48     181   229
 297    -47     180   227
 307    -52     181   233
 317    -52     181   233
 327    -51     181   232
 337    -46     181   227
 347    -39     177   216
 357    -47     179   226
 367    -45     179   224
 377    -45     181   226
                   -60                 40                  140
                   :                   :                   :
         5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
 277                  L                         H
 287                   L                                            H
 297                   L                                            H
 307                  L                                             H
 317                  L                                             H
 327                  L                                             H
 337                   L                                            H
 347                     L                                         H
 357                   L                                           H
 367                   L                                           H
 377                   L                                            H
         5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
MODULE  86-8-9 TPB25   TEMP -42 10DEC76 10:56:57
```

Fig 8d The bias margin of the generate function is shown as the position, duration and amplitude change. Results are listed in both tabular and graphical form.

CIRCLE 44▶

```
XIN  NOMINAL LE 31   DUR 17   AMP 30
LE      LOW   HIGH  MARGIN
21     40      40   0
23     40      40   0
25     40      40   0
27     -25     104  129
29     -55     146  201
31     -54     148  202
33     -53     147  200
35     -56     147  203
37     -51     147  198
39     -37     148  185
41     -20     147  167
43     -10     147  157
                   -60                  40                  140
                    :                   :                   :
          5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
21
23
25
27                         L                        H
29                   L                                       H
31                    L                                      H
33                    L                                      H
35                   L                                       H
37                    L                                      H
39                       L                                   H
41                          L                                H
43                            L                              H
          5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
MODULE  86-8-9 TPB25   TEMP -44 10DEC76 10:58:53

XIN  NOMINAL LE 31   DUR 17   AMP 30
DUR     LOW   HIGH  MARGIN
11     40      40   0
12     40      40   0
13     9       106  97
14     -52     133  185
15     -52     146  198
16     -54     147  201
17     -54     147  201
18     -55     146  201
19     -56     149  205
20     -57     145  202
21     -56     145  201
                   -60                  40                  140
                    :                   :                   :
          5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
11
12
13                                L                  H
14                    L                                   H
15                    L                                      H
16                    L                                      H
17                    L                                      H
18                   L                                       H
19                   L                                       H
20                   L                                       H
21                   L                                       H
          5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
MODULE  86-8-9 TPB25   TEMP -43 10DEC76 10:59:10

XIN  NOMINAL LE 31   DUR 17   AMP 30
AMP     LOW   HIGH  MARGIN
18     -21     143  164
20     -42     145  187
22     -52     147  199
24     -56     144  200
26     -53     148  201
28     -55     147  202
30     -55     148  203
32     -57     147  204
34     -56     146  202
36     -54     148  202
38     -53     147  200
                   -60                  40                  140
                    :                   :                   :
          5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
18                          L                               H
20                      L                                    H
22                    L                                      H
24                   L                                      H
26                    L                                      H
28                   L                                       H
30                   L                                       H
32                   L                                       H
34                   L                                       H
36                    L                                      H
38                    L                                      H
          5.4.3.2.1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
MODULE  86-8-9 TPB25   TEMP -43 10DEC76 10:59:28
```

Fig 8e Similar to (8d) for the transfer in function.

studied. Bubble memory function current amplitudes can be controlled by the 990 minicomputer with a one millampere resolution, allowing the design of test programs which can easily determine the sensitivity of bubble operation to current amplitude changes.

As mentioned earlier, small coils are wound around the magnetic shield so that the bias field may be changed for testing purposes. These coils are attached to a computer-controlled power supply to provide high-speed control of the bias field to a 0.1 Oersted resolution. In addition, this power supply can be programmed to provide narrow current pulses to test the bias sensitivity of individual propagation elements on the device. These pulses can have a duration as small as 20 microseconds which corresponds to two drive field cycles at 100 KHz drive frequency.

The bubble test language (BTL) was designed to be similar to BASIC, providing a language simple to use but comprehensive enough to support changing test methods. Simplicity is needed to reduce the test programming effort; however, more powerful language features are occasionally required. BTL is a table driven interpretive test language which allows quick additions to the set of valid statements as well as fast changes to any existing statement type. BTL has proven capable of the adaptation needed as our test techniques have improved.

Each BTL statement consists of a verb and a number of parameters. The language contains no keywords outside of the verb field. There is no limit to the number of characters in a variable name, allowing the use of meaningful names. Alphanumeric labels are used rather than line numbers so that programs can be made more readable. Extensions to the normal set of arithmetic operators is made possible by the use of the '#' character as an operator prefix. Thus the relational operators used in 'IF' statements are of the form #EQ or #GT. Output print formatting specifications are included in the list of variables to be printed and default specifications allow the formatting to be optional.

For instance the statement: PRINT A will print the variable A in a decimal

```
MAJOR LOOP PROPAGATION
                  DELAY   LOW    HIGH   MARGIN
                   100    -54     171    225
                   100    -54     173    227
                   100    -55     170    225
                   100    -56     170    226
                   100    -55     169    224
MINOR LOOP PROPAGATION - MASK BITS=  2
                  DELAY   LOW    HIGH   MARGIN
                   100    -59     141    200
                   100    -60     139    199
                   100    -61     139    200
                   100    -62     138    200
                   100    -61     137    198
COMPOSITE MAJOR LOOP
                          LOW    HIGH   MARGIN
                          -50     115    165
                          -58     115    173
                          -57     116    173
                          -55     115    170
                          -56     115    171
COMPOSITE MINOR LOOP - MASK BITS =  2
                          LOW    HIGH   MARGIN
                          -61     117    178
                          -55     116    171
                          -61     117    178
                          -57     111    168
                          -58     114    172
```

Fig 8f Propagation and composite margins. Each test is repeated 5 times. Minor loop composite includes propagation and all device functions.

```
           -60                 40                  140
            :                   :                   :
          1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
GENP 0                LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
GENP 2               NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
GENP 4                 HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
GEND 1                LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
GEND 2                 NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
GEND 3                  HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
GENA 317              LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
GENA 337               NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
GENA 357               HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
ANNP 21               LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
ANNP 23                 NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
ANNP 25                HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
ANND 28                 LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
ANND 30                NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
ANND 32                HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
ANNA 40               LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
ANNA 60               NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
ANNA 80               HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
REPP 31                 LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
REPP 33                 NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
REPP 35                HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
REPD 9                LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
REPD 10               NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
REPD 11                HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
REPA 126              LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
REPA 146                NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
REPA 166             HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
XINP 29              LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
XINP 31              NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
XINP 33              HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
XIND 15                LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
XIND 17              NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
XIND 19              HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
XINA 28              LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
XINA 30              NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
XINA 34              HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
XOTP 6               LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
XOTP 8               NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
XOTP 10              HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
XOTD 10              LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
XOTD 11              NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
XOTD 12             HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
XOTA 41              LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
XOTA 43              NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
XOTA 45              HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
MAJP 1               LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
MINP 1              LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
MAJC 1               LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
MINC 1               LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
          1.0.9.8.7.6.5.4.3.2.1.0.1.2.3.4.5.6.7.8.9.0.1.2.3.4.5.
END OF TEST 11:02:09    TEMP -43 MODULE   B6-8-9 TPB25
```

Fig 8g A summary of the test results giving margin bar graphs for 3 values of each variable parameter.

Watch for the July and August Issues

Patent activity data — who is patenting what and with what intensity — provides you with an important vector that helps you determine directions of technological developments. In May, we reported the patent status of magnetic bubble memories; in July, we will report on the patent status of floppy disks; and in August, we'll have a patent report on 14 types of memory systems other than magnetic bubble.

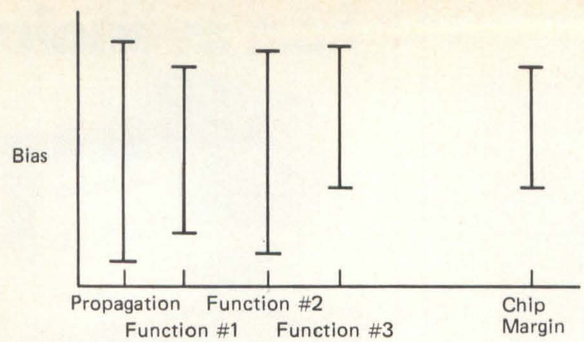

Fig 9 Example — comparison of function bias margins

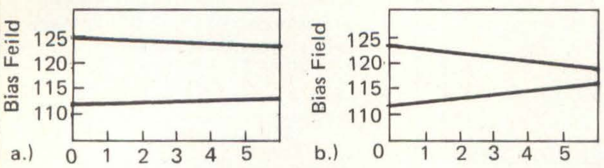

Fig 10 Bias field margin as a function of log number of propagation steps can also be interpreted as MTTF at a bias field setting. (A) A good device has a small longevity slope giving a large MTTF for much of the bias margin. (B) A poor device has a steeper longevity slope giving a larger region of poor MTTF despite a similar bias margin for a short test.

format. If a hexadecimal format is desired, the operator #HEX may be used; PRINT #HEX,A.

If a data pattern needs to be printed from an array, the number of elements will follow the operator; PRINT #HEX 5, B. The language was thus designed to allow more complicated statements when added power is needed.

A 'DEVICE' statement in the language allows the program to acquire the device architecture specifications at execution time so that programs can be written independent of a particular device design. This allows us to test various developmental devices without a full-time test programming effort. The language contains special statements to perform bubble I/O. To test the sensitivity of the device to various data patterns, the language contains pattern I/O statements with automatic data comparison during reading. A method is provided to test an individual device in a memory subsystem where the data from many devices is multiplexed together.

Test language programs have been written to provide a variety of tests; 5 typical programs are;

- **Diddle Program** is used for module set-up and semi-module or system checkout. Data is written to and read from the device and displayed on the CRT screen. Many test parameters may be controlled to get a 'feel' for device performance.
- **Characterization Test** produces "Schmoo" plots of bias margin as a function of the amplitude, position and duration of each device function. Overall device and propagation margins are also tested (Fig 9).
- **Long Term Error Test** determines a device mask by doing a large number of reads of a once-written device. A mask may be entered and the accuracy of the mask may be checked over long periods of time.
- **General Longevity** performs 8 different functional sequences, each of which can be repeated 10^N times for N between 1 and 8. The maximum bias margin for data storage without error is a function of N for any of the test sequences.
- **Radar Longevity** determines the bias margin of small sections of the propagation path for 10^M steps where M is between 1 and 4. The bias field pulse width is 80 microseconds. The major loop, minor loop or detect path may be tested.

bubble device testing

Because of its importance, much of the current testing procedure inspects the change in bias margin as some other testing variable changes. If the magnetic bias field is too large, bubbles will tend to collapse and disappear. If the field is too small, the bubbles will become too large for one storage location and will 'strip out' during propagation. For current devices with a nominal bias field of about 120 Oersteds, the margin may vary from 8 to 20 Oersteds. To ensure the most reliable operation of the device, this margin should be as large as possible. In general, each Permalloy element and each bubble function has its own operating margin. These margins do not fully overlap (Fig 9). The overall operating margin is the intersection of the margins of all of the functions. Advanced testing techniques such as the Radar Longevity Program allow us to test the operating margin of each device element. Thus we can correct the device design and detect mask defects as well as identify individual device defects.

The final production test of a bubble memory must determine which minor loops are defective. The system using the bubble device will not place bubbles into these minor loops and data read from the loops is not used. These bad loops comprise the bubble device redundancy mask. The bubble system processes all data through a mask operation when either writing or reading. It is important to determine an accurate mask so that no additional bad loops will appear during use. Most of the bad minor loops are easy to detect by simply writing data into every minor loop and reading it back. These types of failures have two symptoms: either data will disappear when written or data will be read when none is written. Errors associated with pattern sensitivity and the leaking of bubbles from one minor loop to another are types of errors that are harder to detect. These types of problems increase the difficulty of testing and, more importantly, the time required to accurately test a device.

Another factor in bubble operation which can affect the mask determination is the longevity effect. It has been shown that during propagation a bubble has a finite probability of self-collapse (disappearing). This probability is near zero at the midpoint of the bias range and increases as the upper or lower bias limits are reached (Fig 10). Due to device defects, this error probability may be increased in a minor loop although that loop is not found to be bad during a short test. Two actions may need to be taken to minimize any problems by this effect: First, the operating bias setting must be chosen at a point which promises the best longevity results, and second, a longevity test may have to be performed as a part of the final test to find loops with a bad longevity curve. The effects of the longevity curve on long term device operation and the impact to testing are still being studied (Fig 11).

Although bubble device bias margin is the range of perpendicular magnetic field over which the device will operate, a statement of bias margin must also include data on the length and nature of the test. A less demanding test will discover that a device has a wider margin than a longer, more complicated test because of a combination of factors including longevity effects and bubble-bubble interaction.

Our first testing showed that each minor loop appeared to have its own bias margin. Most of the loops on the device will appear quite similar but occasionally some are encountered with very narrow margins. Thus one problem in assigning a redundancy mask is the interaction of device margin and the number of loops masked. As we improved processing and reduced device and mask defects, we were able to identify several of the bubble functions as being limiting factors the bias margin. Since the functions use peculiar propagation elements and entail the alignment of a conductor mask to carry the function current, this came as little surprise. A concentrated effort was begun to characterize the bubble functions (references 5,7). We found that device design changes and process improvements could increase the function bias margin and increase the timing and amplitude tolerances. We also found that several functions would need amplitude compensation to operate reliably over a 0 – 70°C temperature range.

Bias margin and mask are affected by the data pattern used in testing. This pattern sensitivity or loading factor is due to bubble-bubble interaction. In general, about 3 Oersteds must be subtraced from a "simply determined" margin to account for loading effects.

Due to the changes in magnetic properties of the garnet film the optimal bias field value will change with temperature (Fig 12), introducing the concept of magnet tracking. To achieve device operation or even simple data retention over a range of temperatures, the temperature characteristics of the bias magnet must match that of the film. For some garnet material compositions a matching magnet material is difficult to find. Device/magnet tracking mismatch also adds to the mask determination problem and places more emphasis on maximizing the device bias margin.

The test system approach that we have developed has proven comprehensive enough for our current laboratory and production efforts. The information learned from our characterization effort is being applied to device improvements and refinement of production test techniques. Our current results show that the time required for production testing needs to be reduced.

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