magnetic bubble memories

past • present • future

A BENWILL/TECHNOCAST REPORT

Magnetic bubbles are single wall domains assuming the shape of right circular cylinders in a sheet of magnetic material, typically a rare earth orthoferrite, characterized by a preferred or easy axis of magnetization perpendicular to the plane of the sheet. The axis can be defined as a negative direction of magnetization out of the plane of the sheet while magnetic bubbles have a positive direction of magnetization normal to the sheet.

Magnetic fields move or propagate magnetic bubbles in the magnetic sheet. Since binary information can be represented by either different size bubbles, circulation direction of domain wall magnetization, or the presence and absence of bubble domains, all of which can correspond to a binary "1" or "0". Magnetic bubbles make excellent shift register or memory applications.

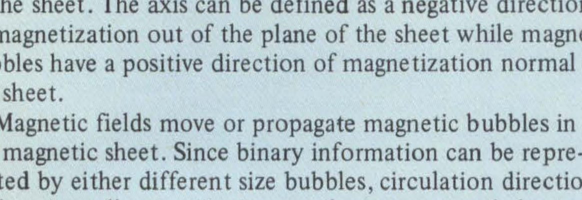


Fig 1a Encircled plus sign represents a domain in a magnetic sheet. The circle in the plane of the sheet represents the encompassing single wall of the domain.

The first patent suggesting magnetic bubbles for memory applications was granted to Bell Telephone Laboratories in 1969 (1). The potential of this new technology to provide low cost, high capacity memories, quickly realized, is reflected in recent patent activity. Over 53% of the U.S. patents in this technology have been granted during the most recent three year period, 1974-76 (estimated).

In terms of numbers of U.S. patents granted, the foreign activity in magnetic bubble memories, for the period 1974-76 (estimated) is only slightly less than the all technology foreign share average of 35.4%. About 31% of all U.S. patents in the area have been granted to foreign residents over the period 1974-76 (estimated). The country table shows, by patent grant date and patent application date, the country distribution of the patents in this field that were granted to foreign residents. *(See Table 1)*

description of the technology

Magnetic bubbles are usually formed in thin sheets of certain magnetic oxides. A basic requirement for formation of bubbles is that the sheet material possesses uniaxial magnetic anistropy with the easy direction of magnetization perpendicular to the plane of the sheet, achievable in crystals or orthoferrite, hexagonal ferrites and synthetic garnets. Another requirement is that the material be able to support a bubble of small diameter to make large density memories possible. Synthetic garnets seem to possess the most desirable characteristics for bubble memory applications since they have the capability to support the smallest stable bubble size at high mobility rates.

Magnetic bubbles are shaped by applying a biasing magnetic field perpendicular to the plane of the sheet. Increasing this field causes the natural serpentine domains of the sheet to shrink until most of them disappear. However, a few domains will shrink to a stable cylindrical volume or "bubble" of polarity opposite to the rest of the sheet, as shown in Fig 1a. These bubbles are stable over a variation of approximately 30% of the biasing field. However, if the bias is increased above critical strength, these stable bubbles will also collapse and be annihilated. Fig 1b shows the evolution of propogate structures.

Magnetic bubble propagation or movement is achieved by creating an unbalanced force on the bubble which drives it in the desired direction. This may be done by creating, in the vicinity of the bubbles, localized magnetic fields which, by magnetic attraction or repulsion, cause the bubble to propagate.

Basically, two methods are available for producing such fields: conductor-access and field-access. In the conductor-access technique, small current carrying loops are deposited on the sheet and the loops are sequentially energized by three phase currents. In the field-access approach, permalloy (soft magnetic material) patterns are deposited on the sheet and a transverse in-plane rotating field is used to change the magnetic polarities of these patterns to cause the bubbles to follow the changing pole patterns from input to output position. Three often used permalloy patterns are the chevron, T-I bar and Y-I bar configuration.

Fig 2 illustrates the propagation of a bubble using a permalloy T-bar pattern for supporting a pole pattern changing in response to a rotating transverse field in the plane of the sheet. To perform the necessary memory operations of writing, reading and erasing, the magnetic bubbles must, respectively, be generated, sensed and annihilated.

In addition to generation by nucleation, bubbles can be created by stretching a seed bubble and separating it into two bubbles, accomplished using permalloy patterns and the appropriate fields or current. In a typical bubble generator, the seed bubble rotates around a permalloy disc under the influence of a rotating driving field (patents 3, 4). As the bubble rotates, it is stretched by attraction to an adjacent T-bar pattern. When the field is in an upward direction, repulsion by the lower portion of the disc collapses the center of the domain leaving the seed bubble and a newly generated bubble.

A number of methods are available for bubble sensing: electromagnetic induction, Hall effect, optical sensing and magnetoresistance effect.

• In the electromagnetic induction method, the moving bubble acts as a magnetic dipole and induces a small voltage in a pickup coil. • In the Hall effect, a probe generates a voltage output at right angles to the direction of a direct sense current. • In optical sensing, the detector reacts to a change in the intensity of light when a bubble is observed through a polarizer. • In the magnetoresistive effect, the presence of a bubble lowers the resistance of a permalloy segment, providing a usable output signal.

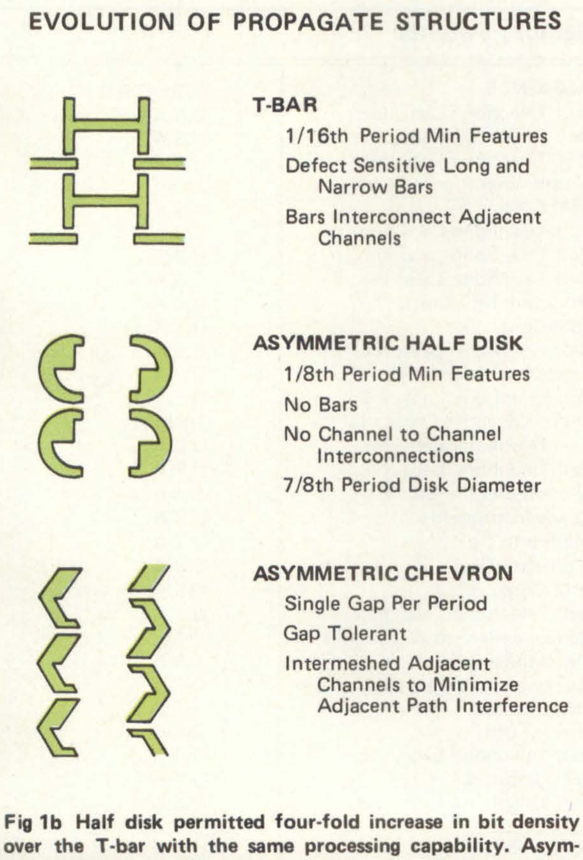


Fig 1b Half disk permitted four-fold increase in bit density over the T-bar with the same processing capability. Asymmetrical chevron adds another factor of improvement. The T-bar with 2 "gaps" per propogate period has been replaced in most labs by more efficient single gap structures. BTL uses the half-disk and its successor, the asymmetric chevron. *(From A.H. Bobech, Development of Bubble Memory Devices, Electro 77.)*

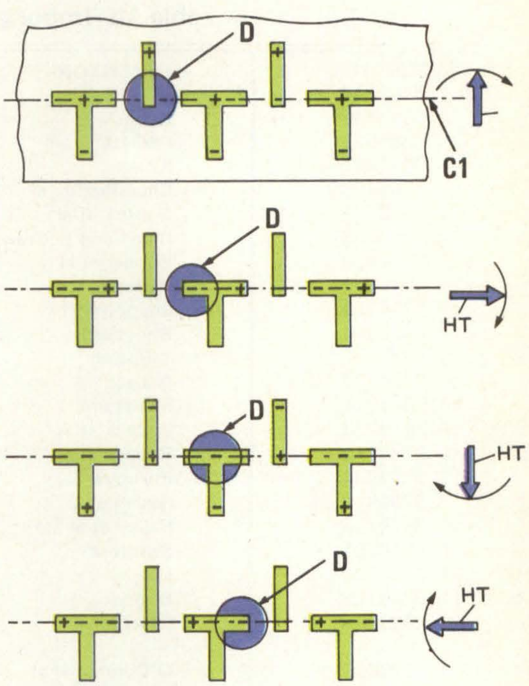


Fig 2. The transverse field, HT, rotates clockwise through 360 creating pole concentrations on the T-bar pattern. A domain, D, may occupy each position along the broken line, identified by the channel notation, C1, where a minus sign is shown. Minus signs represent the most intense pole concentration to which the domains are attracted. As the field rotates, the poles of the T-bar change according to the position of field HT, causing the domain D to be attracted to the minus sign and thus move to the right. Note that the same domain would move to the left if the transverse field is rotated counter clockwise.

Bubbles which are no longer to be used must be annihilated by increasing the bias field so that the total field exceeds the domain collapse threshold. The bias field can be increased by either applying an external current pulse or by inducing a collapsing field in a permalloy segment.

thrust of technology

Magnetic material limitations have presented significant obstacles to commercial realization of magnetic bubble devices. For example, very pure materials are necessary. Domains of less than 1 micron diameter, needed to obtain good memory density (up to 10^{10} bit/in^2), required that material imperfections affecting nucleation or propagation be smaller than the domain itself. This problem has been overcome through discovery of magnetic amorphous materials that do not contain structural imperfections that would impede the movement and nucleation of magnetic domains in the composition (patent 5).

Attempts to reduce stable bubble size at usual operating temperature have posed further problems. Operation near the magnetic reorientation temperature reduces bubble size but results in high magnetostriction, complicating both fabrication and operation. Operation near the reorientation temperature also results in a large temperature dependence of bubble size which in turn requires close temperature control. With garnet compositions, this temperature dependency can be reduced by partial substitution of the composition by Eu, Gd, Tb, Dy, Ho, Er or Tm ions in the dodecahedral sites (patent 6).

Yet another problem involving magnetic material limitations relates to finding materials that permit a required mobility, defined as an inherent speed factor of the magnetic medium. This factor, when multiplied by the applied field in the material results in a "velocity" term.

Table 1a Country Distribution of Patents

	By Patent Application Filing Date									Total	By Patent Grant Date										Total
	1965	66	67	68	69	70	71	72	73	65-73	1967	68	69	70	71	72	73	74	75	76E	67-76E
Total Patents	1	3	11	17	19	36	69	80	46	282			5	25	21	55	71	74	58	68	377
United States	1	3	11	17	19	35	60	52	36	234			5	25	21	51	55	55	42	52	306
Total Foreign						1	9	28	10	48						4	16	19	16	16	71
Japan						1	2	18	5	26						1	11	8	8	8	36
Netherlands								3	1	4								4	1	8	13
Canada							5	3	1	9						3	2	3	2		10
United Kingdom							2	3		5							3	2			5
Finland																			3		3
Switzerland								3	1	2								1	1		2
Germany									1	1								1			1
Italy									1	1									1		1

Table 1b Important Bubble Memory Patents

PATENT NO.	INVENTOR	ASSIGNEE	COUNTRY
1. 3460116	Bobeck et al	Bell Telephone Labs, Inc.	U.S.A.
2. 3543347	Bobeck	Bell Telephone Labs, Inc.	U.S.A.
3. 3555527	Perneski	Bell Telephone Labs, Inc.	U.S.A.
4. 3820091	Kohara	Nippon Electric Co., Ltd.	Japan
5. 3965463	Chaudhari et al	IBM Corp.	U.S.A.
6. 3646529	Bobeck et al	Bell Telephone Labs, Inc.	U.S.A.
7. 3964035	Blank and LeCraw	Bell Telephone Labs, Inc.	U.S.A.
8. 3886533	Bonner et al	Bell Telephone Labs, Inc.	U.S.A.
9. 3946372	Henry et al	Rockwell Int'l Corp.	U.S.A.
10. 3899779	Malozemoff	IBM Corp.	U.S.A.
11. 3618054	Bonyhard	Bell Telephone Labs, Inc.	U.S.A.
12. 3838407	Juliussen	Texas Instruments Inc.	U.S.A.
13. 3676870	Bobeck	Bell Telephone Labs, Inc.	U.S.A.
14. 3944991	Murakami	Nippon Electric Co., Ltd.	Japan
15. 3810133	Bobeck et al	Bell Telephone Labs, Inc.	U.S.A.
16. 3703712	Bobeck et al	Bell Telephone Labs, Inc.	U.S.A.
17. 3737882	Furuoya	Nippon Electric Co., Ltd.	Japan
18. 3909810	Naden et al	Texas Instruments	U.S.A.
19. 3879716	Bailey et al	Monsanto Co.	U.S.A.
20. 3940751	Sandfort	Monsanto Co.	U.S.A.
21. 3925768	Lin	IBM Corp.	U.S.A.
22. 3713119	Bobeck	Bell Telephone Labs, Inc.	U.S.A.
23. 3927398	Dimyan	Canadian Patents & Development Ltd.	U.S.A.
24. 3827036	O'Donnell et al	Rockwell Int'l Corp.	U.S.A.
25. 3763478	Yoshizawa et al	Hitachi Ltd.	Japan
26. 3943497	Yoshizawa	Hitachi Ltd.	Japan
27. 3934235	Bobeck et al	Bell Telephone Labs, Inc.	U.S.A.
28. 3946373	Moolenbeek et al	GTE Labs Inc.	U.S.A.
29. 3713120	Bobeck et al	Bell Telephone Labs, Inc.	U.S.A.
30. 3736419	Almasi et al	IBM Corp.	U.S.A.
31. 3953840	Cutler et al	Hewlett-Packard Co.	U.S.A.
32. 3840865	Holtzberg et al	IBM Corp.	U.S.A.
33. 3909809	Kinsner	Canadian Patents & Development Ltd.	U.S.A.
34. 3842407	Argyle	IBM Corp.	U.S.A.
35. 3936883	Heckler Jr.	Ampex Corp.	U.S.A.
36. 3798607	Minnick et al	Monsanto Co.	U.S.A.

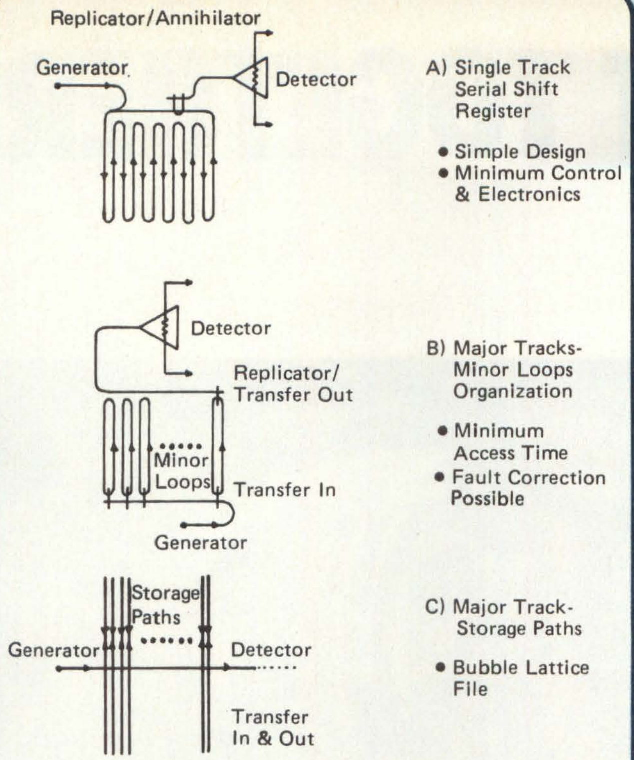
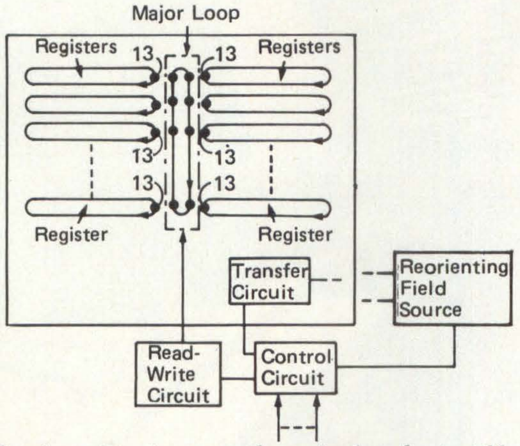


Fig 3a Field access chip organizations fall into three categories. Specific functions of bubble propagation, generation, detection and replication are generally used in serial shift register bubble chips. Advantages are a minimum of interface electronics, simple control logic and a relatively simple chip design. The main disadvantage is the access time although this is entirely adequate, for example, in an application such as voice storage. For applications requiring improved performmance the major/minor loop configuration isthe most frequent choice. Average access time with a 100kHz rotating field is 3.1 msec, a value comparable to that of a fixed head disk memory. This improvement in performance is obtained with an attendant increase in bubble chip complexity, interface electronics and control logic. (From A.H. Bobeck, Development of Bubble Memory Devices, Electro 77).



Popular major-minor type of organization of patent 11.

Fig 3b Memories of this type store information permanently in recirculating loops called minor loops. The information is selectively transferred to an accessing loop, called a major loop, where bubble generation, annihilation and sense operations occur through the use of an input-output circuit. The arrangement is such that the minor loops are a number of parallel channels to which the major loop is perpendicular. Subsequent to the generation or sense operation, information in the major loop is returned, via the transfer positions designated by numeral 13, to the minor loops for storage. Not only does this type of organization eliminate unnecessary external connections but it also reduce the ancillary control and utilization circuitry required.

This problem was overcome when a critically defined class of garnet compositions were found with sufficient high velocity to permit rapid movement of domain walls which results in high access rates. These compositions are characterized by the presence of europium in the crystallographic dodecahedral site and a reltively low magnetic movement contribution by the iron sublattices (patent 7). Garnet materials that exhibit both a high mobility and low temperature dependence of magnetization result from partial substitution of silicon or germanium for iron (patent 8).

While garnet materials have presently been found to be the most suitable for bubble memory applications, they form a domain that exhibits distinctly different behavior. These domains are called "hard bubbles". Hard bubbles have low mobilities and propagate at an angle to the applied bias field gradient. In addition, they strongly resist collapse, making them difficult to annihilate. Hard bubble suppression can be accomplished by selecting a composition based upon a characteristic temperature above which the bubbles are not generated (patent 9). However, a magnetic bubble system has been devised in which both hard and soft bubbles are used for the representation of information (patent 10).

One of the more important aspects of any memory unit is its organization. An efficient organization provides high packing density and fast access times. Many organizations have been presented, but one of the most popular is the major-minor type (patent 11), shown in Fig 3.

A number of modifications and improvements have been made to the basic major-minor configuration. For instance, one organization includes a major loop which does not close on itself, but which does pass each of the minor loops in the same order to provide two locations in each minor loop for bubble transfer (patent 12). Another configuration uses each transfer location by a conductor loop to ensure that a domain moves to the desired receiving positions and can later be returned to its original position (patent 13).

Still another major-minor loop memory is affected by selectively controlling the passage of bubbles through at least two gates provided between a bubble generator and the major loop in a two dimensionsal array (patent 14). A first gate of each memory in a selected row is conditioned for writing while a second gate in a selected column is conditioned in accordance with the data to be inserted. This arrangement permits new data to be inserted only into the memory of the array that is located at the intersection of the selected row and column. The result is the prevention, in a two-dimensional array, of an unnecessary transfer of bubbles in the major loops of an unselected magnetic domain memory unit. In some configurations a replication rather than a transfer operation is used, obviating the necessity of returning information to the minor loops and thus improving data rates (patent 15).

Mass memory units have been developed using a number of major-minor loop memories in an array. One such unit is operated in a word-organized block access fasion with noise cancellation detection (patent 16). Another magnetic domain memory, having a number of storage channels with major-minor loops, can be written into by one domain generating source, and read-out via one domain detecting means, without any relative time loss resulting from the distance of the storage channel from the detecting or generating means (patent 17). A redundancy bubble memory system has been developed which is composed of data chips having a major-minor loop organization and a flag chip which will prevent faulty loops from being read and used for data storage (patent 18).

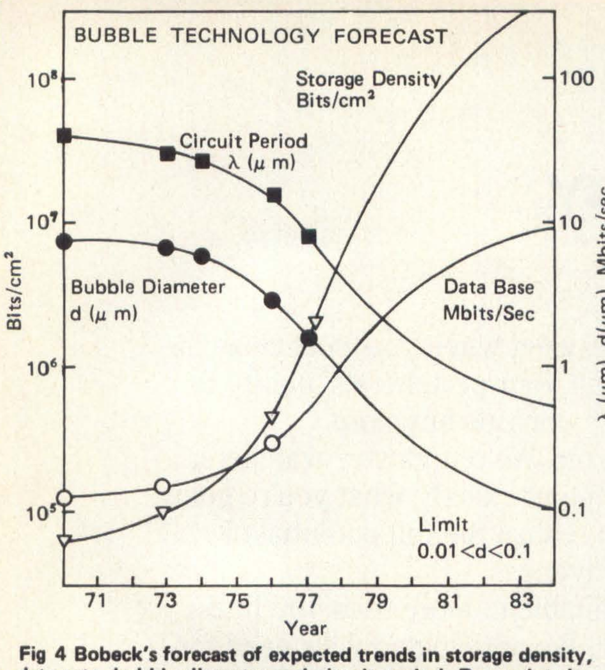


Fig 4 Bobeck's forecast of expected trends in storage density, data rate, bubble diameter and circuit period. Datapoints indicate achievements to date.

The need to propagate bubbles in one or more recirculating minor loops without operating other loops has led to the development of different types of propagating circuits. One such circuit is a mutually exclusive closed loop field-accessed type which uses a magnetic bubble overlay circuit element nicknamed the "crow-foot". This element has a straight bar or stem portion with a pair of angled arms in the form of staggered barb-like projections (patent 19). These "crow-foot" circuit elements can be used to build closed loop paths with parallel sides that propagate bubbles in opposite directions with the same set of pulsed drive fields (patent 20).

All propagation structures mentioned so far have gapped permalloy patterns; however, these patterns are characterized by a number of disadvantages. For one, the bubble diameter must be substantially larger than the gap width in order to traverse it. In addition, a bubble must be elevated to a higher energy state to traverse a gap which renders it momentarily less stable. To overcome these problems, a double-sided gapless propagation structure was developed. Propagation is achieved by using two identical disc circuits on opposite sides of the bubble material displaced from each other by one-half of periodicity (patent 21).

Other propagation structures have been disclosed. For example, enhanced operating characteristics are obtained if the extremes of the permalloy patterns are of enlarged geometry to concentrate flux (patent 22). Further examples are propagation structures consisting of magnetic material bars positioned over the bubble supporting material (patent 23). While yet in another example, a propagation circuit is defind by grooves extending partially into a thin film of magnetic bubble material (patent 24).

In propagating magnetic domains through the use of permalloy patterns and in plane rotating fields, power consumption of the driving circuits which produce such fields is of primary importance. The circuit for creating rotating magnetic fields commonly includes a pair of coils which are positioned perpendicular to each other and an AC current source for supplying current to these coils. A separate current is supplied to each of the coils which are 90 degrees out of phase. The total effect of the individual magnetic fields from the current in each coil is a rotating magnetic field vector which extends throughout a region into which the bubble memory is disposed. A driving system which reduces power consumption is formed by connecting resonating capacitors to the two coils that form the field (patent 25).

In a large bubble memory system which is divided into smaller memory elements, reduction of power consumption can be achieved by providing each smaller memory element with its own driving coils which are adapted to be selectively energized only when a memory-refer is made (patent 26).

Bubble memories are known to be nonvolatile. That is to say, bubble memories retain information even when a power failure occurs. It is important, however, to ensure the in-plane field stops and starts in the same reorientation to avoid loss of information. A reactive-coupled pair of tuned circuits can be used to drive a magnetic bubble memory. Refresh pulses can then be extracted conveniently from the parallel tuned circuits to ensure the same reorientation (patent 27). Another control circuit which insures such reorientation uses a DC current supplying circuit along with the AC current source at the beginning and end of the operating mode (patent 28).

Another difficult problem facing practical implementation of magnetic bubble devices is sensing the bubble. Despite ėfforts to minimize bubble readout or sensing by incorporating logic in the memory to enhance the informational content of each bit, a reliable sensing unit is still necessary. The basic problem is the small magnetic field associated with a single miniscule magnetic bubble. This field is barely distinguishable from the background noise which, by itself, represents the absence of a bubble. The magnetoresistive effect is perhaps the most effective method of bubble detection. A relatively large output signal can be achieved from an expanded magnetic domain by a relatively long magnetoresistance element in the path of the domain (patent 29). Noise cancellation is possible through the use of two magnetoresistive sensing elements

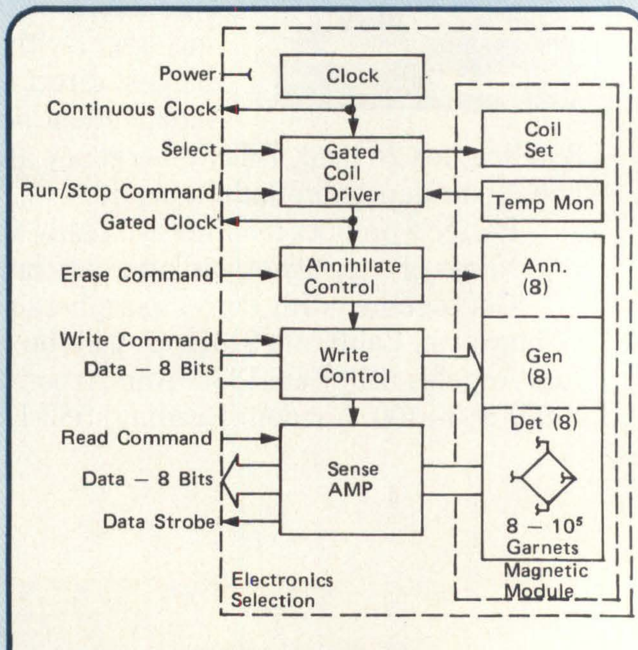


Fig 5 POS Block Diagram

whose combined voltage or current output is constant in the absence of a bubble domain (patent 30). In this respect, a differential detection device connected to a pair of adjacent permalloy columns is used to determine the presence or abasence of a bubble (patent 31).

Alternate methods of sensing the magnetic bubble have been investigated. In one case, detection of the domain is accomplished by using tunnel junctions in which the Fermi level of one or both the electrodes is changed due to the bubble (patent 32). Sensing can also be accomplished by first converting the energy associated with a bubble into mechanical energy, and secondly by converting the mechanical energy to electrical energy to indicate the presence of a domain (patent 33). In yet another sensor, the magnetic bubble is oscillated in size to cause a change in the self-conductance of a conductor loop which is used as the oscillator (patent 34).

technology trends

A little over 10 years ago – in October 1967 – the first article on the device applications of magnetic bubbles appeared in the Bell System's technical journal. It was authored by A.H. Bobeck, a frequent contributor to advances in magnetic bubble state-of-the-art. Since that time, magnetic bubble memory development has grown rapidly and will unquestionably continue to do so. Magnetic bubbles, like CCD memories, can find application in both central processor units and in-line bulk memories. Unlike CCD memories, however, this technology is expected to replace magnetic drum and disk memories. Magnetic bubbles, more versatile, are now used to write and read digitized signals of audio, Video and digital data as described in patent 35. And patent 36 describes a relatively recent magnetic bubble computer.

Last month at Electro '77, Bobeck, still at Bell Laboratories in Murray Hill, NJ contributed another paper on the development of bubble memory devices. He pointed out that Rockwell and BTL/WE have announced memory systems based on serial bubble shift register chips. And Hitachi, Fujitsu, NEC, Philips, HP, TI, Rockwell, Univac and BTL are among those developing designs based on major-minor organizations. Texas Instruments has pioneered the "fault tolerant approach" to memory system architecture.

Bobeck's extrapolation of the rate at which the bit storage density has increased from 1973 to 1977 forecasts that bit density 5×10^7 bit per cm^2 and 4×10^8 bits per cm^2 would be reached in 1980 and 1985 respectively. The latter implies a bubble diameter of 0.1 μm still considerably greater than the theoretical limit of approximately 0.01 μm. Advances into mid-1980 could be made with routine extensions of the presently used epitaxial garnet films and bubble circuitry. Bobeck reported that the anticipated limitation is expected to be in circuit patenting, and systems such as electronic beam exposure systems will require continued evolution to meet these needs. Single mask, self-structuring and lattice circuits may ease the lithographic requirements.

Bobeck forecasts that bubble chips with 10^8 bit capacity should be state-of-the-art by 1985. But he cautions that we need not wait that long for something useful to materialize for single chip packages equivalent in capacity to the floppy disk should appear this year and multi-chip packages of 10^7 bits or greater should be commonplace by 1979.

Bell Laboratories in Whippany, NJ is developing another bubble data storage system to meet the requirements for low-cost, non-volatile memory in micro processor-based systems. At Electro,'77 J.E. Williams reviewed the first Bell System application of magnetic bubbles in their 13A announcement system with emphasis on how they solved several long standing problems with recorded voice announcement systems. His paper describes a low cost, 272 kbit sequential memory system (Serial Bubble Store) and illustrates magnetic bubbles applied to satisfy requirements for nonvolatile, electrically alterable sequential memory.

Table 2 Solid State Data Recorder Characteristics

Capacity	104,857,600 Bits
Format	
Serial	1-4 channels
Parallel	1, 8-Bit Byte
Data Rate/Channel	1.2 MHz
Max. Data Rate	2.4 MHz
Interface	TTL
Voltage	28V ± 4V
Power	103 Watts max. @ 100% duty cycle and Linearly variable with duty cycle and data rate
Volume	600 $in^3 \approx 0.01$ cu. meter
Weight	40 lbs. ≈ 18.2 kg.

Table 3 POS/8 Characteristics

Capacity	819,200 bits
Format	Endless loop/byte parallel
Data Rate	100K Bytes/sec 800K Bits/sec
Interface	TTL
Voltages	+5, –5, +32V, ±2%
Power Dissipation	29W max. @ 100% duty cycle and linearly variable with duty cycle
Volume	50 cu. in. ≈ 820 c.c.
Temperature	0°to 50°C
Weight	2.5 lbs. ≈ 1.14 kg.

systems applications

One of the major driving forces in developing bubble technology has been the needs of the U.S. National Aeronautical and Space Administration (NASA). Wm. C. Mavity of Rockwell International's Autonetics Group, reports that they are now designing for NASA Langley Research Center a space qualifiable 10^8 bit recorder which has the characteristics of Table 2. Composed of four basic modules, it contains 50 million bits. Completing the memory is one module for logic, timing, and control and one for the power supply. The "memory cell" which contains a bias structure/drive coil set and 16 chips, contains 1,638,000 bits. The complete memory contains 64 cells and has an estimated MTBF of 40,000 hours. Should any cell fail, the system loses only 1.5 percent of its capacity. Thus the usability of the memory extends far beyond the 40,000 hours. Among the features implemented are reconfiguration capabilities for one to four independent organizations (one memory of 100 million bits to 4 memories of 25 million bits), dual buses throughout, override of failed cells in steps of 1.5 percent of capacity, and full status monitoring. The flexibility of the system architecture allows the design to be utilized for over 95 percent of the missions now using a number of different recorders. Present schedules expect the first unit to be operational in early 1978. Full utilization is anticipated by users in 1979.

For the potential user who wants laboratory "hands-on" experience with bubbles, Mavity reported that Rockwell is now producing an 8 x 10^5 bit recorder organized as an endless loop of 10^5, eight-bit bytes. In addition to its usefulness as a technology proof article, it has direct application as the operating mass memory for microprocessor or microcomputer systems. Characteristics of this memory, the POS/8, are shown in Table 3. Of particular interest is the varied possibilities of power consumption. The peak power shown will completely fill or empty the memory in one second. In most situations the memory will be operated in bursts. When idle, the memory dissipates no power. The duty cycle of actual operation is an improtant item to linearly factor into long-term power dissipation, especially in applications utilizing a battery power supply. For many applications the duty cycle is much less than one percent.

A block diagram of the memory is shown in Fig 4. The operation of the memory is straightforward. Enabling the select line brings the memory to operational readiness and starts the clock. Start/stop set to true starts data circulating and enables a gated clock that occurs at the beginning of each cycle. Coincident "trues" on combinations of Read, Write, and/or Erase causes data to be placed on the Data Out bus with strobe, data to be written from the Data In bus, or data to be erased from the memory. As an endless loop of data the addressing is left to the user to format. Fixed, variable, or unique block addressing via data header or counters, can be implemented. A complete description of the memory and details on testing and achieved margins can be found in the recent paper by Ypma and Swanson.

pos/8 applications

In industrial applications the memory finds application as a large (relatively) memory for a desktop calculator where larger or many varied programs could be permanently stored for day to day use. The electronic notebook or electronic routebook could also utilize the POS/8 units. The routebook is of interest as it can be programmed each evening for the route a field sales representative would cover the next day. Order, inventory, and return information can be collected for use by the home office. Also in this general recorder application area would be a configuration where daily transaction records of commercial sales would be contained at a terminal via a POS/8. The POS/8 memory would provide the basic record that allows reconstruction of transactions in the event of system outages more central to the accounting function.

The POS/8 is the ideal operating mass memory for a mircroprocessor. Its usage is shown in Fig 6. In many instances the need for program ROMs is eliminated as the POS/8 can be bootstrapped during start-up and then program swaps can be utilized for operating programs. The multi-level hierarchies of many larger computer systems can now be implemented in a microprocessor system. Expensive main memory capacity can be reduced and replaced by inexpensive bubble secondary storage where access is controlled via a swapping algorithm. Many applications will continue to use flexible disks and cassettes for off-line storage. But a solid state secondary bulk memory, provided by bubbles, allows full system utilization with no concern for the maintenance of moving parts. The design is sufficiently flexible to allow unique user adaptation.

Fig 6 Microprocessor Application

One of the most interesting system applications is the stand alone terminal for small retail business firms. The one register operation of shoe stores, restaurants, "Mom & Pop" groceries, etc., will require non-volatile, on-line storage in their terminals. Price table lookup, transaction, and inventory control can be included in the terminal function via the secondary storage.

The automated office of the future will require on-line, high usage, non-volatile mass storage that, for reliability reasons, is best implemented in a solid-state technology. One can envision that the office typewriter will be soon replaced by the office terminal – complete with video display, keyboard, and prenter. Memos in process, appointment calendars, telephone and address records, travel arrangements, etc., will all be incorporated and it will be imperative to be able to swap data bases with the speed of a push button, Mavity emphasized.

The quickly growing personal computing technology will similarly require secondary storage that bubbles can provide – as will the other terminal applications based on the microprocessor.

controller considerations for the pos/8

Since the POS/8 is essentially an endless loop of 102, 400 eight-bit bytes operating at a fixed frequency of 100 KHz, the user can choose among many sets of options in organizing his data and usage. He can then design an appropriate controller to interface the POS/8 to his system.

The initial decision concerns the basic operating modes. Some users may want an incremental recorder where the unit is started, cycled once for reading or writing, and then stopped. Others may require a Block Record mode where the memory is started, cycled for a burst transfer, and then stopped. A sub-decision in this mode is whether the block length is fixed via hardware design or variable via software control. Also to be considered is the basic transfer method, i.e., via Programmed Input/Output where software moves data through the microprocessor or via Direct Memory Access (DMA) where non-CPU hardware functions as the transfer controller.

Another set of decisions must be made in organizing the data or blocks. Since the memory is an endless loop it may be desirable to have an overall index mark entered via software. In basic serial recorders they may not be necessary as the presence of a non-all-zero byte may be sufficient if the memory is not totally filled. In block oriented usage where ASCII is used there are definitive characters for Start of Data, End of Block, etc. that are sufficient. In those applications not using ASCII there are many other possibilities for record identification. Among them are counting cycles from an index mark, establishing a start-of-record (SOR) mark (8 bits) which is forbidden data; SOR followed by address or key word (a known combination of characters); or SOR, keyword and block length. If the memory is divided into fixed blocks an SOR character can also be identified by the repeatability of the character every known block length. In this form the SOR can also be valid data with extremely low probability of misidentification.

In a block record system the user can also consider the addition of useful non-data characters to add features such as Longitudinal Party, Cyclic redundancy codes, write protection codes, supervisor key codes, etc. Some users may want this information sent to the using hardware, others may want it stripped and only valid "data" sent as in mapping or swapping into memory.

The above mentioned features make two requirements on the overall system application. First, data storage efficiency is decreased when non-data bytes are stored with the data. For example, if data is formatted in 256 byte blocks, the POS/8 can store 400 blocks. If an index mark is required, 399 blocks plus some slack are available. If each block had an address of 3 bytes (enough bits to code binary 400) appended to it; 395 blocks + 95 bytes (used for the memory index) would result. A memory block could be formatted as shown in Figure 7. This configuration allows SOR, address, data, Check Code and two null characters. The null characters are required only in the case where the memory is stopped at those points in the record. This results in a 268 character block. The memory could contain 382 blocks with 24 characters left over for an index pattern. A data efficiency of 95.5 percent results.

The second requirement is that the decision making or intelligence in the controller must be high speed. A bipolar bit slice processor and discrete hardware could do the job.

A more exhaustive discussion of controllers for the POS/8 can be found in the recent paper by Norton.

Mavity believes that future generations of bubble products are assured by the technical accomplishments to date in the research laboratories. Advances are being made to not only make the first generation of products even more cost effective, but also to show proofs of second generation technology

Here are Mavity's basic rules-of-thumb that can be used to assist in defining a technology generation:

• Bubble film thickness is approximately 0.8 of the bubble

Texas Instrument's First in Commercial Market

In the meantime, Texas Instruments has applied their TBM 0103 magnetic bubble memory to two data terminals trademarked Silent 700. Claiming them to be the first known commericial application of bubble memories in the computer industry, each terminal comes standard with 20,000 bytes of non-volatile bubble memory storage expandable to 80,000 bytes in 20,000-byte increments.

The memory data terminals combine TI Silent 700 experience with the advantages of magnetic bubbles to bring electronic data storage to terminals which heretofore required the use of larger, more expensive media such as cassettes, paper tape or floppy discs. The 763 or 765 terminal can access any indexed record in memory in less than 15 milliseconds, compared to a search time from several seconds to several minutes for a cassette system. If the data location in the 763 or 765 memory is not known (not indexed), the character string search speed is 1000 characters per second, about four times the speed of a cassette search. Compared to a floppy disc, the bubble memory indexed record access time is more than ten times faster, but total data transfer rates are lower.

Fig 7 Designed for portable use, TI's 765 terminal includes a carrying case and built-in acoustic coupler. Table-top version, the 763, is designed for office applications not requiring portability.

TI said that applications for the new terminals include timesharing, real estate inquiry, newspaper reporting, wholesale and retail order entry and credit verification, and insurance inquiry. TI also explained that any application can use data entry during daily use, off-line from the host computer. The stored data then can be transmitted to the home office computer over standard telephone lines at a speed of 30 characters per second (300 baud) via the built-in acoustic coupler on the 765 terminal, or at 120 characters per second (1200 baud) with either terminal when connected to an external modem. This off-line data entry and transmission speed reduces computer connect time and telephone line charges compared to on-line keyboard data entry.

At only 17 pounds, the Model 765 Portable Memory Terminal is a fully capable 30-cps terminal with a full ASCII keyboard, a built-in numeric cluster, a virtually silent thermal printer, acoustic coupler, carrying case and a powerful editing capability. TI added that the combination of a file management system and a powerful operator command mode provide excellent user flexibility. For example, an operator using the terminal's typewriter-like keyboard can select communications options, configure memory, and enter or edit text. The command mode also includes a self-test capability to minimize system downtime and reduce service calls.

Production deliveries of the new terminals are scheduled for the fourth quarter, 1977. Quantity one U.S. Domestic price with 20K bytes of bubble memory are $2995 for the Model 765 Portable Memory Terminal, and $2695 for the Model 763 Memory Send-Receive Terminal. Both terminals are expandable to 80K bytes of memory at $500 per 20K byte increment.

Table 4 Mavity's Bubble Memory Applications Matrix

Chip	Type I	Type II
Type	Serial Loop 100,000 Bits	Block Access 65,536 Bits
Memory System Size	100 kHz, 1/2S Access Time 1/4 in. x 1/4 in.	300 kHz, 1-mS Access Time, 1/4 in. x 1/4 in.
TYPE A	Solid State cartridge recorder	Smart Terminal Mass Memory
	Small, severe-environronment recorder	Distributed processing Memory
	Unattended data gatherer	Tactical message switching
$3x10^5 \rightarrow 3x10^6$	Microporcessor Mass Memory	Store and Forward Memory
TYPE B	Graphic display buffer	Minicomputer program and data file
	Re-entry test vehicle recorder	
$3x10^6 \rightarrow 3x10^7$	Interim STP experiment	Electronic Swapping Memory
TYPE C	Satellite data recorder	Fast auxiliary mass memory
$3x10^7 \rightarrow 3x10^8$		Electronic head-per-track disk
TYPE D $3x10^8 \rightarrow 3x10^9$	Second generation	Second generation

diameter they support.
- Bubbles should be constrained to be separated by approximately 4 to 4.5 bubble diameters.
- Conventional T-Bar storage elements require that the separation between elements, i.e., the gaps, be approximately 1/4 the bubble diameter.
- Conventional photo-lithography allows processing of a one micron gap.

Thus, 4 micron bubbles on 16 micron periods has been defined by Rockwell as its first generation technology. They have standardized on a chip size of (0.25 in).

The "gap tolerant" circuit elements reported separately by Gergis and Bonyhard, at the 1976 Joint Intermag/MMM conference allows gaps to be approximately 1/2 the bubble diameter. This property can be utilized to either relax the fabrication tolerance requirements or pack more bits/chip. In fact both are being done. Larger gaps allow more cost effective first generation products to evolve as volume production begins. These mask improvements for 4 micron bubbles are now in design.

Mavity feels that larger capacity chips will also be perfected based on several concepts. The concept of using block access chips composed of small loops which interconnect to an input/output track via replicate/transfer switches is well known. The major/minor loop chip was the first design using the principle. When the replication feature was added, the need for a major loop was negated. External ordering of data allowed for redundancy designs which further enhanced yield at the cost of electronics complexity. The concepts of gap tolerance, replication, and redundancy have recently been combined in the design of a one-million bit chip by Rockwell scientists.

Mavity says we can expect that these principles can be extended further to chips approaching 10 million bits capacity as techniques such as E-beam mask making and X-ray lithography are brought on-stream allowing sub-micron gaps to be fabricated. While systems using these advance design chips will not appear in the field until the early 1980's, it should be reassuring to all potential users that future generations of equipment will be forthcoming.