MAGNETIC FILMS - REVOLUTION IN COMPUTER MEMORIES

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SUMMARY

The development and application of magnetic thin films has been persued vigorously by a number of workers. Some of the practical results are tabulated seven years after the first reported work.

Advances in ferrite memory technology and difficulties in fabrication of film memories have delayed the widespread use of film memories. However, a number of experimental memory systems have demonstrated significant achievements in packing density, 200-900 bits per square inch; read-write cycle time of 100-200 nsec.; reliable nondestructive read out in an electrically alterable memory; in the use of high performance circuits and construction techniques giving an economical memory system.

Several film memories are in production or pilot production at the UNIVAC Division of Sperry Rand Corp. These are the small 128 word 1/2 microsecond film memory used in the "UNIVAC 1107" and the large 6656 word, nondestructive read out, electrically alterable film memory developed for the ADD (Aerospace Digital Development) Computer. Burroughs Corp. is using a small film memory in a military computer and is marketing a memory plane. Texas Instruments announced immediate availability of a memory plane pair at the August 1962 WESCON.

Magnetic thin films differ from ferrite memory elements in two important ways. The nickel-iron alloy used for thin films is deposited under conditions that cause a magnetic anisotropy and the film thinness and geometry is chosen to permit coherent rotational switching. The magnetic anisotropy makes possible the simple operating mode that is widely used, in which coherent rotational switching of the magnetization can be completed in several nanoseconds.

Film memory elements are usually operated with open instead of closed flux paths permitting simple wiring with printed circuits. The film elements are made in arrays of large numbers of bits or in continuous processes and can be economically tested. Large volume production and testing may be able to produce film memory bits for about one-tenth of a cent per bit.

Thin films rate highly in the characteristics required of an ideal memory element. They can be utilized economically, packaged very densely for severe environments, operated with low power, can be used in very fast memories, and operated in either a destructive or nondestructive read out mode.

All of the film memories disclosed to date use a word organized or linear select method of operation. Studies with feasibility models have shown that it should be possible to build large capacity magnetic film memory systems that are competitive with other systems.

Magnetic thin films have been successfully deposited on silver, aluminum, glass, copper and gold, by various workers, making great design flexibility possible. Present

research may result in higher bit density and low current operation that is compatible with integrated and molecular circuits. Further improvements in film properties and manufacturing uniformity may make coincident current selection practical while achieving coherent rotation. The combined impact of low cost, high speed, wide temperature range, low power and simple NDRO operation should result in a revolution in computer memories.

INTRODUCTION

Brief History

The potential usefulness of magnetic thin films has attracted a great deal of research and development effort. To the many people actively seeking practical applications, it is a little like chasing an attractive mirage which continually recedes as one approaches. The significant and steady improvements in ferrite memories and the practical problems of magnetic film elements are about equally responsible for this characteristic. Taking some risk of being premature, it is thought that a revolution in computer memories is now underway and that the extent and impact of that revolution will expand very rapidly. To be more specific, the change from individually formed, tested and wired elements to the deposition of large multi-bit arrays that are tested and laminated with their wiring as arrays, is a major advantage. At the same time it is troublesome because of the close control of uniformity that is necessary. In addition, the switching time of the magnetic film memory element is no longer of major significance in determining the memory cycle time or access time.

Since 1955 [1] when the first thin magnetic film work was reported, until about 1960, practical applications were almost nonexistant. In the last two years, relatively small, moderately fast thin film memories have been put to practical use at Lincoln Labs [2] in the TX-2 and FX-1 Computers and in the commercially available UNIVAC 1107 [3]. Outstanding because of its large size, 166,000 bits, the thin film memory used in the UNIVAC ADD (Aerospace Digital Development) Computer is relatively slow, but represents a milestone in thin film technology [4]. Its application of non-destructive read-out in an electronically alterable memory may be the cornerstone necessary to achieve the long sought breakthrough in practical application of film memories, although its physical realization may change in future designs.

Achievements of Some Film Memories

A number of experimental magnetic film memory systems have been built and their achievements reported. See Figures 1 and 2. This list is not intended to be comprehensive

COMPANY	LINCOLN LAB M. I. T.	IBM	NATIONAL CASH REGISTER	I. C. T.
IDENTIFICATION	FX-1 COMPUTER[2]	W. E. PROEBSTER[14]	D. A. MEIER[7]	E. M. BRADLEY[15]
DATE	FEB. 1962	FEB. 1962	MAY 1961	AUG. 1962
NO. OF WORDS	256	256	128	4096
NO. OF BITS/WORD	13	72	8	
ACCESS TIME		60 ns		
CYCLE TIME	370 ns	100 ns	200 ns	1000 ns
FILM	LONG RECTANGLE	RECTANGLES	CONTINUOUS CYLINDERS	CONTINUOUS FILM
SUBSTRATE	GLASS	SILVER, SiO	WIRE	ALUMINUM
DEPOSITION	VACUUM	VACUUM	ELECTROPLATED	VACUUM
NO. OF PLANES	1	1		
OPERATING MODE	DRO	DRO	DRO	DRO
ORGANIZATION	WORD SELECT	WORD SELECT	WORD SELECT	WORD SELECT
COMMENTS	OPERATING IN A COMPUTER	BASED ON INITIAL TESTS		

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Figure 1. Achievements of some experimental thin film memories.

IDENTIFICATION	ULTRA HIGH[6] SPEED MEMORY	FEASIBILITY MODEL	SEARCH[6]
DATE	AUG. 1962	JUNE 1962	JUNE 1962
NO. OF WORDS	1024	512	128
NO. OF BITS/WORD	24	32	24
ACCESS TIME	50 ns	200 ns	100 ns SEARCH
CYCLE TIME	100 ns	250 ns	100 ns SEARCH
FILMS	PAIRED RECTANGLES	RECTANGLES	BICORE CIRCLES
SUBSTRATE	GLASS	GLASS	GLASS
DEPOSITION	VACUUM	ELECTROPLATED	VACUUM
NO. OF PLANES	4	8	1
OPERATING MODE	DRO	DRO	SEARCH
ORGANIZATION	WORD SELECT	WORD SELECT	SEARCH
COMMENTS	OPERATING IN TEST MACHINE	BEING EXPANDED TO 4096 WORDS	

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Figure 2. Achievements of some UNIVAC experimental thin film memories.

and no particular inference is to be drawn from the omission of other film memory work. It is both interesting and worthwhile to examine these results and the problems that have been solved. A list of the principal problems would certainly include the following:

1. Magnetic film uniformity and reproducibility.
2. Connections to and interconnections between the magnetic film memory elements.
3. Memory packaging and organization suitable for large, fast memory systems.

The first problem has apparently been adequately solved by five or six companies. The second problem is probably the most vexing and most likely to resist a completely satisfactory solution. A technique, of limited usefulness, to minimize the interconnection problem is to place all film spots in a single plane. This technique seems to place a practical limit on the number of bits in a conveniently packaged memory of high speed.

The third problem has been partly solved by three companies, judging by hardware that is available. See Figure 3. One of these companies has announced memory planes for sale that use connectors similar to standard printed circuit edge connectors. These memory planes, or similar ones, are used in a military computer [5] built by the company. A second company announced the availability of memory planes at WESCON this year. The other company has two different memories in production or pilot production [6]. Several types of film memories are available as production items or, depending on the exact application, can be produced with a small amount of engineering design and integration [6]. These include destructive read-out and nondestructive read-out. One of these memories is a 128 word, 36 bit DRO memory capable of a 300 nsec. cycle time. A second memory consists of 6656 24-bit words of NDRO and 256 24-bit words of DRO with a 0.7 microsecond access time and a 3 microsecond cycle time. The NDRO memory is electrically alterable and is similar to the memory in the ADD Computer mentioned earlier.

One experimental thin film memory [7] uses a different alloy 97% Fe - 3% Ni and

COMPANY	UNIVAC	BURROUGHS	UNIVAC	TEXAS INSTRUMENTS
IDENTIFICATION	[3]	MEMORY PLANE	ADD[4]	MEMORY PLANE PAIR
NO. OF WORDS	128	128	6656	64
NO. OF BITS/WORD	36	24	24	18
ACCESS TIME	330ns		700ns	
CYCLE TIME	670ns	200ns *	3000ns	200ns
FILMS	CIRCLES	RECTANGLES	BICORE CIRCLES	CONTINUOUS
SUBSTRATE	GLASS	GLASS	GLASS	ALUMINUM
DEPOSITION	VACUUM	VACUUM	VACUUM	VACUUM
OPERATING MODE	DRO	DRO	NDRO	DRO
ORGANIZATION	WORD SELECT	WORD SELECT	WORD SELECT	WORD SELECT
COMMENTS	USED IN 1107 COMPUTER	*OPERATING SPEED OF WIRED PLANES IS STATED TO BE 5 mc.	MEMORY FOR ADD COMPUTER TESTED FOR AEROSPACE APPLICATION.	IMMEDIATELY AVAILABLE

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Figure 3. Characteristics of available thin film memories and memory planes.

does not use a magnetic anisotropy common to the other magnetic film work mentioned here. It closely resembles an advanced ferrite memory in that domain wall motion is used and the switching constant of 0.6 to 0.7 oersted-microseconds is approximately the same as for ferrites. Fast coincident current switching is obtained by using a high coercive force material (14 oersteds). The core wiring problem is exchanged for a multiple solenoid winding problem although the connection problem is basically the same as for a ferrite memory stack.

The UNIVAC Division has built a 512 word, 32 bit per word feasibility model thin film memory with a read-write cycle time of 250 nanoseconds. This model is, of course, based on much previous work. This feasibility model demonstrated the praticality of a large thin film memory for commercial computer usage. Some of the circuits and techniques developed by this work are discussed later.

UNIVAC has developed several other significant thin film memory systems under sponsorship of a government agency. These include a 10 mc. DRO memory of 1024 words and 24 bits, and a 100 nanosecond search memory of 128 24-bit words.

A recently announced microferrite memory is an extremely interesting extension of ferrite memory elements into the speed and performance range of magnetic film memories. Information available at the time of this writing is somewhat incomplete, but it appears that manufacturing, testing and wiring techniques have been developed that are suitable for economical production. It is almost certainly true that the relative useage of any of the available memory elements will be decided by balancing economic and performance factors.

COMPARISON OF MAGNETIC FILMS TO FERRITE CORES

Anisotropy: Perhaps the most significant difference between magnetic thin films and ferrite cores for example, is that the thin films are made to have a uni-axial magnetic anisotropy [8]. This is just another way of saying that the direction of magnetization will always be parallel to the preferred, or easy axis, unless an external force acts upon it. It is this anisotropy that makes possible a simple nondestructive read-out mode for magnetic films [9]. The anisotropy is usually "built-in" to the films by the presence of an external orienting magnetic field during deposition whether by electroplating or vacuum evaporation or sputtering of the nickel-iron alloy. Several other factors can cause or effect the magnetic anisotropy, strain [10], for example, but these effects are discussed in the references and won't be discussed further. The presence of a preferred or easy axis of magnetization means that the effect of an external field on the magnetization of the film will be dependent upon the angle between the field and the easy axis. This angular dependence provides an extra degree of freedom in the organization of a memory not widely used in ferrite memories [11, 12].

Coherent Rotation: The very fast switching speed of thin films is a result of the simultaneous rotation of the axes of all the electron spins rather than the sequential reversal of the slower domain wall motion switch. The thinness of the films plays an important role in achieving an ultra fast switching time. More complete discussions of the theory and behavior of thin magnetic films may be found in references 8, 11, 13, 14, 15, and 16.

For practical circuits, it is reasonably accurate to say that switching speed is determined only by the rise time of the drive fields. Films have been observed switching in a few nanoseconds or less in special experimental apparatus [17]. Such speeds cannot be practically utilized in any but the smallest memories. Memory systems of several thousand words exhibit so much delay in their drive and sense wiring that their cycle time is determined by physical size and transmission time and not by switching time.

Comparison to Coincident Current Selection: Nondestructive read-out has been achieved with magnetic films in a variety of ways [4, 9, 10]. If we restrict our attention to electrically alterable memories, we can make some interesting comparisons to coincident current selection memories. Assume a 4096 word, 32 bit per word coincident selection memory. This would probably result in 32 planes of 4096 bits (64 × 64). If we assume that the X-Y drivers are arranged in 8 × 8 matrices, we need 32 write drivers, 32 read drivers and 32 bit or inhibit drivers and 32 sense amplifiers. If we now use an NDRO film element in a word organized memory, we might choose 1024 words each of 128 bits. These are, of course, quadruple length but only one set of 32 bits would be gated to the 32 read amplifiers at one time. The other bits on the selected word line would not have their information destroyed and no recirculation path is needed. Thus, a 32 × 32 matrix of drivers with 1024 diodes will provide the main read-write drive current. Only one driver is needed for each line of the 32 × 32 matrix since only one direction of drive current is needed in each word line. This organization requires the same number of drivers, read amplifiers and bit drivers as the coincident selection memory. The film memory would have approximately 800 extra diodes.

All of the film memories reported on to date have used word organization since the requirements for film uniformity are less stringent. Films are made with more than adequate squareness in their easy axis hysteresis loop so that operation is possible in the normal coincident current mode. A slower domain wall motion switch is obtained if the film is used that way so most current work is not going in this direction. Film technology is at or very close to the point where film uniformity is good enough so that coincident current selection with a coherent rotational switching mode may be feasible in the near future.

CHARACTERISTICS OF AN IDEAL MEMORY ELEMENT

The choice of an element for a memory, and the organization thereof, requires sound engineering judgement and a full understanding of the applications and requirements of the memory. For instance, a main store for a large scale commercial computer probably will emphasize large capacity and low cost with fair reliability and speed. A store for a space vehicle will probably emphasize reliability, low power and small physical size. An ideal memory element would fill the requirements for all memories. The thin film, like other memory elements, is not an ideal element, but, in some respects, approaches one. Figure 4 is a condensed chart of some of the characteristics of an ideal element and those of thin films.

Tiny Size: Small size is one of the most important characteristics of an ideal memory element. Lower power and fast access and cycle times are all related to the size of the elements. An ideal element should be as small as can be accommodated by wiring and connection techniques.

Present film memories have elements typically 200 to 1000 to the square inch. Advanced work, however, is trying to increase this density significantly.

Low Power: Low drive power in a memory is extremely important for spacecraft applications. It is also important in other applications as low drive power means less amplification of the sensed output of the element and consequently less delay. Ideally, the drive power would be the same order of magnitude as the output power.

Interrogating currents at present are in the order of 300-800 milliamperes and drive

	HIGHLY DESIRABLE	THIN FILM
PHYSICAL SIZE	AS SMALL AS CAN BE ACCOMODATED	200 – 900 PER SQ. IN.
DRIVE CURRENT DRIVE POWER	COMPARABLE TO OUTPUT POWER	300 – 800 MA DRIVE LINE IMPEDANCE 5 – 30 OHMS
SWITCHING TIME	SMALL COMPARED TO SIGNAL DELAY	NEGLIGIBLE
OUTPUT SIGNAL	MODEST SIGNAL TENS OF MV	1 MV – 100 MV
OUTPUT SIGNAL/NOISE	S/N → ∞	4 – 10
READ OUT	DRO OR NDRO ELECTRICALLY ALTERABLE	BOTH MODES ARE USED IN EXPERIMENTAL AND PILOT PRODUCTION FILM MEMORIES
OPERATING MODE	CAPABLE OF COINCIDENT CURRENT SELECTION	WORD ORGANIZED - COHERENT ROTATION COINCIDENT SELECTION - DOMAIN WALL MOTION
ENVIRONMENT	NOT A LIMITING FACTOR	LARGE MEMORIES DEMONSTRATED -40°C → +80°C, OPERABLE UNDER SHOCK AND VIBRATION
COST	EASILY FABRICATED, COST < $0.01 EACH	SHOWS GREAT PROMISE, COST NOT PROVED IN VOLUME PRODUCTION

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Figure 4. Summary of memory element characteristics.

line impedances are in the 5-30 ohm range. As the size of the film and its drive lines get smaller, the drive current may also become smaller. Interrogating currents may be as small as 50 milliampere in the future.

Switching Time: The switching time of an ideal element should be small compared to transmission and amplification delays. Magnetic film switching time is several nanoseconds or less so that it is negligible in all but the smallest memories.

High Output - Fast Switching Speed: A high output from a memory element allows easy sensing and less amplification of the signal and hence, less delay. An ideal element should have an output in the tens of millivolts. The larger the output, the larger the energy required to switch the element so that outputs in the volt range would be awkward for a large memory.

The outputs of present film memory elements are in the order of 1 to 10 millivolts and of 50 to 10 nsecs. duration. Just as important as a large signal is a large ratio of desired signal to "noise." With careful design a ratio of 10 to 1 has been achieved in large film memories [18].

Simple NDRO and Coincident Current Selection: Simple nondestructive read-out and coincident current selection are very desirable features of a memory element. NDRO eliminates the need for rewriting, resulting in shorter cycle time and less drive power. Coincident current selection reduces the cost and complexity of the drive circuitry. Ideally the same circuits and drivers will be used for reading and writing with the addition of a small bit current to write information.

Theoretically, the threshold characteristics of the magnetic thin film allows both simple NDRO and coincident current selection. Practically, the uniformity of the present day films is such that many of the memories built to date are DRO and word organized. NDRO has been achieved by the BICORE* type of construction used in the UNIVAC ADD Computer [4] and in the cylindrical construction developed by T. R. Long at Bell Labs [9].

Insensitivity to Temperature Variations: Both external conditions and internal power dissipation may cause temperature variations in a memory. It is then important for a memory element to be as temperature insensitive as possible.

The Curie Point Temperature (550°C) of the permalloy film is sufficiently high that the film is practically temperature insensitive. Individual films have been tested from -80°C to 100°C while the complete ADD memory has operated in ambients from -40°C to 80°C [4, 6].

Ease of Fabrication of Element and Memory: In order to make a large capacity memory practical, it is important that the elements can be fabricated and tested in a batch or continuous process. It is further necessary that the drive and sense lines can be prepared without high cost. The ideal memory element will not require any critical alignment to its associated wiring.

The next section will present several techniques, circuit designs and fabrication methods developed in our attempt to solve the practical application problems of a 4096, 50 bit word thin film memory for computer usage.

TECHNIQUES USEFUL FOR A LARGE MAGNETIC FILM MEMORY

Organization: As mentioned previously, UNIVAC has built a 512, 32 bit word thin film memory feasibility model. This is part of a program whose objective is to show that a large, fast film memory can be built that has a competitive advantage over other memory systems. A simple destructive read-out operation is used because component variation and drive current tolerances may be relatively wide. A single polarity word drive pulse provides the read-out signal during its rise time and a digit drive field, of appropriate polarity, overlapping the trailing edge of the word pulse restores the film to its proper information state. For a more complete description of the operating mode, the references should be consulted [13, 16].

Fabrication of the Magnetic Thin Films: Electroplating was chosen as the fabrication method for many reasons. Two of these are: (1) the apparent simplicity and low cost of the basic apparatus, (2) a room environment process should make possible a relatively simple automatic or continuous fabrication method.

The electrolyte is a solution containing nickel and iron sulfates and was approximately 0.8 molar in nickel sulfate. A number of additives were present including boric acid, sodium chloride, sodium laurly sulfate and

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saccharin. Phosphorus was introduced into the final alloy that was electroplated by adding sodium hypophosphite to the solution. A more complete description may be found in the references [19].

The plating cell is a simple rectangular vessel inside of a large coil which provides the orienting magnetic field to determine the anisotropy axis. The plating cell geometry has a pronounced effect on film uniformity. The most favorable plating current density seems to be 6 ma per square centimeter and the plating was done at room temperature in a non-agitated electrolyte. The thickness of the deposited film is easily controlled by the amount of charge transferred in the plating cell.

Present work uses electroplated nickel-iron films on metal substrates instead of the glass substrates used in the feasibility model. This is one of several design improvements that is hoped will decrease the cycle time of a much larger memory to 200 nanoseconds, 50 nanoseconds less than the feasibility model.

Digit Write Circuit: The memory is word organized with three separate transmission lines in the memory stack for the sense circuit, the word drive circuit, and the information write circuit. If 4096 film spots (bit number one of all words for example) were arranged 20 per inch, the bit line would be about 20 feet long (allowing 20% for interplane connections and packing inefficiency). Such a line would have a transmission delay of 50-60 nsec. This is much larger than can be tolerated for a 200 nsec. memory cycle time. One practical solution is to use two to four sections connected in parallel rather than reduce the spot size, decrease the output signal, and increase the packing density by the same factor. Typical films can be written with a bit current of 60 milliamperes from a 0.050 inch wide bit line, so the total current required from the bit driver will be two to four times this current. A single driver transistor can easily supply this current. Figure 5 shows an early circuit that was developed to deliver positive and negative

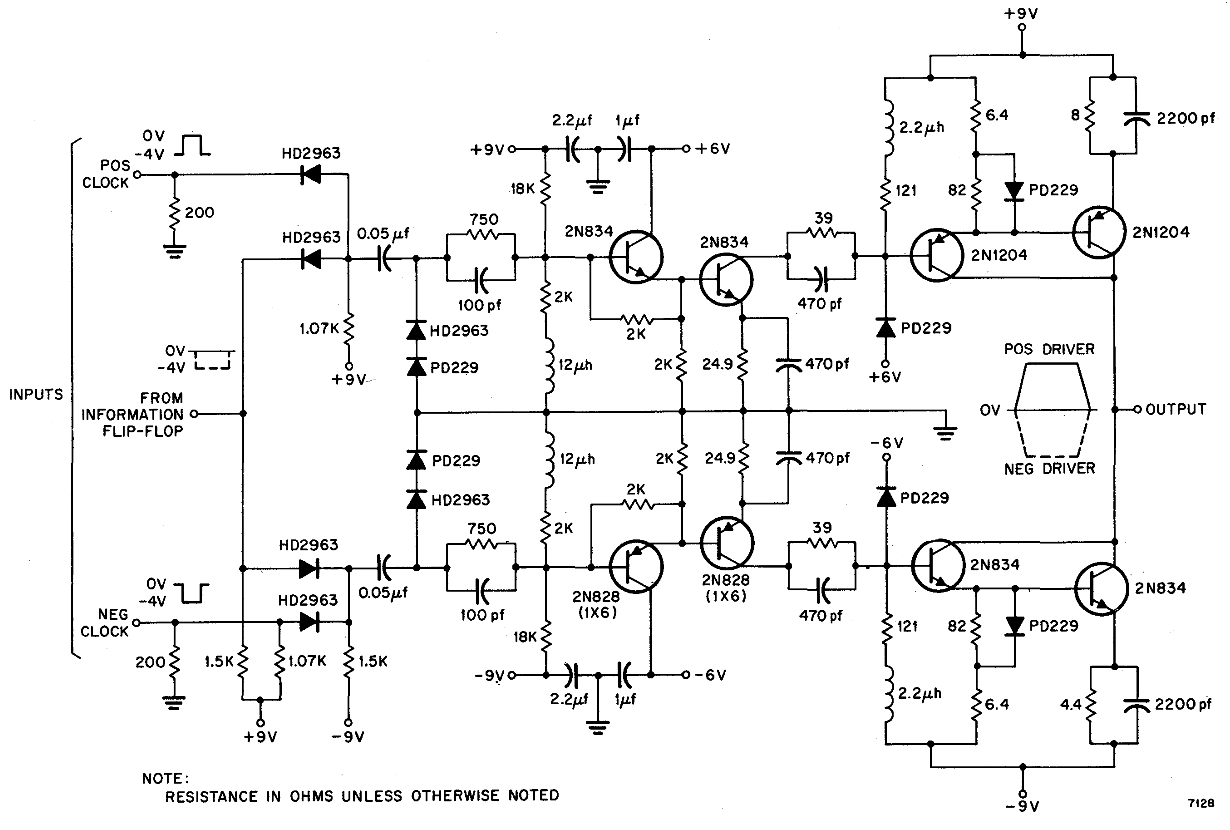


Figure 5. Schematic - digit driver.

pulses of 760 milliamperes with a delay time, rise time and fall time of 10, 15, and 20 nsecs., respectively. For the lower current requirement the paralleled output stages are removed.

Sensing Circuit: Fragmentation of the sense lines, just as that of the digit lines, is used to reduce the delay for the film signals to travel out to the sense amplifier. A means to accomplish the fragmentation of the sense line is shown in Figure 6. Here a fragmentation into eight sections is shown. If the delays and characteristics impedances of the line stubs are essentially the same, and if the load to the system is twice the characteristic impedance of a line stub, there will be no distortions. That is, the output has the same shape as one that has come out of a single line. The delay is, of course, 1/8th that of a signal traveling down a long line. This scheme can be extended to the general case of paralleling N sets of M stubs. The terminating impedance is then M/N times the characteristic impedance of a single stub. If lossless lines could be used, the ratio of output signal power to total available signal power from one line is 1/MN. The output voltage is 1/N times the voltage from a single terminated line.

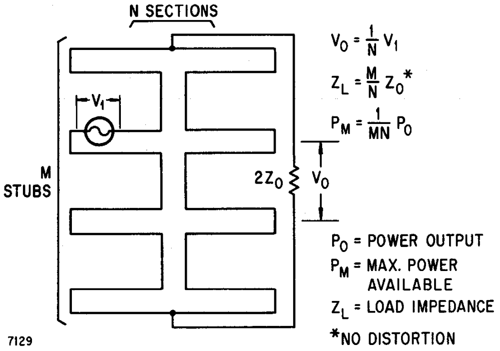


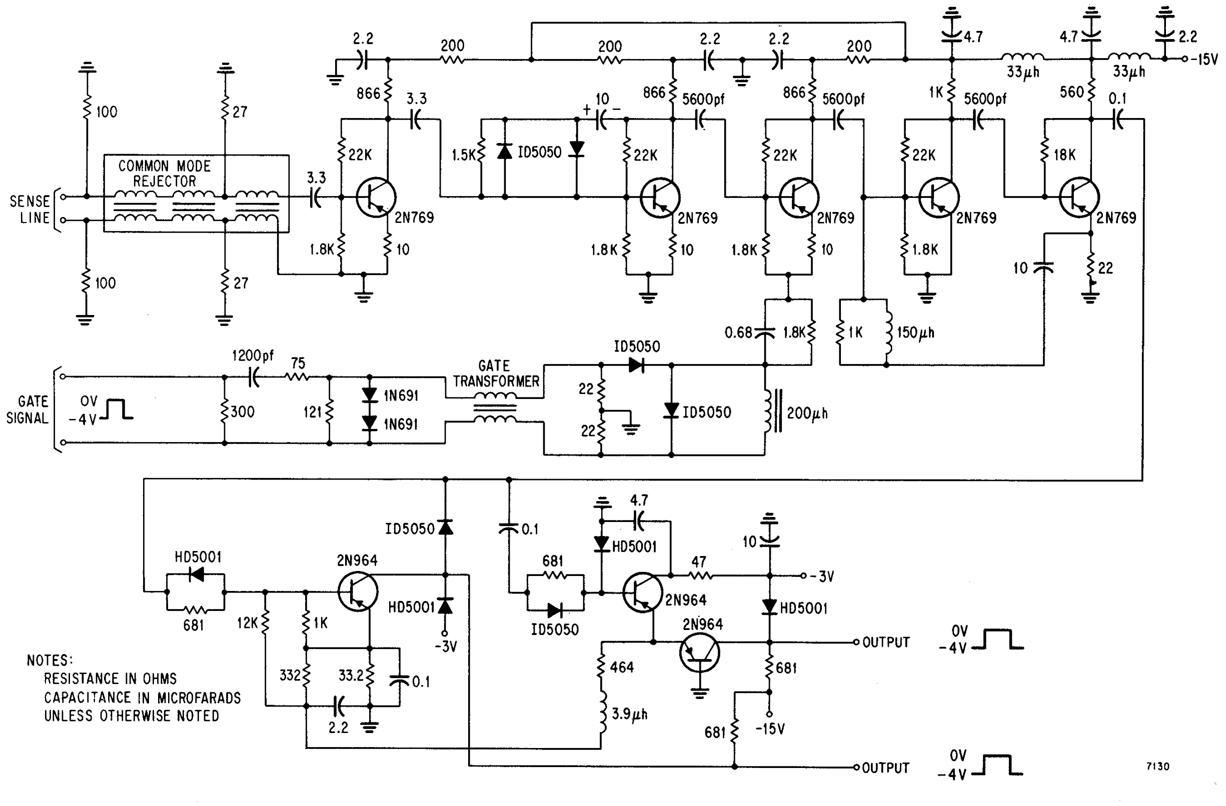
Figure 6. Possible arrangement of sense lines.

The sense amplifier is the most difficult circuit in the film memory. It accounts for a significant portion of the cycle time. The signal out of a film element is high enough so that sensing it is not difficult. However, the common mode noise on the balanced sense line caused by the word current changing and the uncommon mode noise caused by the digit current changing could be over 1000 times and 10 times the signal, respectively. Rejection of the former and rapid recovery from the latter are essential to the operation of the sense amplifier. The conventional approach for rejecting the common mode noise is to carry the signal in two separate channels followed by a difference amplifier. This approach is costly in transistor count and poor in performance. A better approach is used in the circuit shown in Figure 7. In this circuit, a three-core magnetic common mode rejector (CMR) is used. The common mode signals are attenuated by the high impedance; while the film signal, which is differential, is passed by the transmission line and is not attenuated. This amplifier further uses emitter-gating in the third stage to gate out the differential noise caused by the digit drive. The following is the performance of the circuit:

1. Output (5 ns rise time):	Input (15 ns rise time)
Channel A 4V at 12 ma:	0.75 mv min.
Channel B 4V at 12 ma:	-0.75 mv min.
2. Common mode rejection:	60 db min.
3. Gain-gate on/Gain-gate off:	200/1
4. Delay through amplifier:	15 ns
5. Recovery from digit transient of 30 mv (saturation is in the first 2 stages):	50 ns
6. Gate required:	4v, 60 ns wide
7. Gate transient:	0.4v max for 5 ns at output

Typical signals obtained from the 512, 32 bit word memory feasibility model are shown in Figure 8.

Word Lines and Selection Circuits: The word line is next closest to the magnetic film and slit to reduce eddy current damping of the film switching. At the same time the changing field of the digit line can more easily be coupled to the film. Of critical importance to the design of the word lines and their spacing is the amount of drive field that is present at the adjacent, non-selected words. Digit write currents which are not capable of destroying previously stored information by themselves, can cause a loss of information after many thousands of pulses if a transverse field of approximately 5-10% of H_K is present. Since the field generated by



NOTES:
RESISTANCE IN OHMS
CAPACITANCE IN MICROFARADS
UNLESS OTHERWISE NOTED

Figure 7. Schematic - sense amplifier.

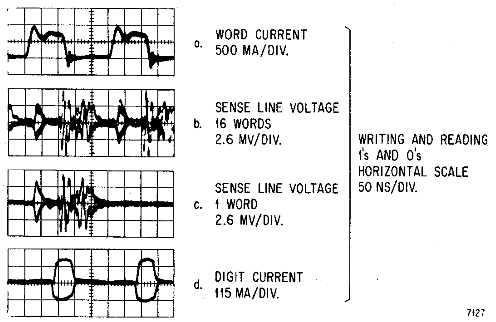


Figure 8. Signals of UNIVAC 512 word thin film memory feasibility model.

the selected word line is usually about twice H_K at the intended film spots, then the spacing between the word line and its return should be about 1/8th to 1/10th of the distance from the edge of the adjacent spot to the edge of the word line to attenuate the word drive field to 2.5-5% of its value.

The choice of the word selection circuit is greatly dependent on the size of the memory. In a small memory (say up to a few hundred words) a straight forward approach of one driver per line with high level matrix decoding may be used. A system like this has the merits of its simplicity and ease of design. However, in a larger system (4096 words), the number of drivers required makes this scheme impractical. A diode matrix scheme may be used. For a 4096 word memory, 4096 diodes, 64 X drivers and 64 Y switches are required. Description of a typical diode matrix may be found in the references [13, 18].

A matrix system has several problems, one of which is the capacitive load on each Y switch. This capacitive load is comprised mostly of the capacity through the digit lines to ground of the 64 word lines connected to each of the Y switches and may be as much as 10,000 picofarads. A circuit has been developed and tested that can charge 10,000 picofarads in 80 nsecs. with peak current of 1.8 amps. The maximum repetition rate is 4 mc. The X driver drives current down the selected word line. Figure 9 shows a circuit that can drive up to one ampere with

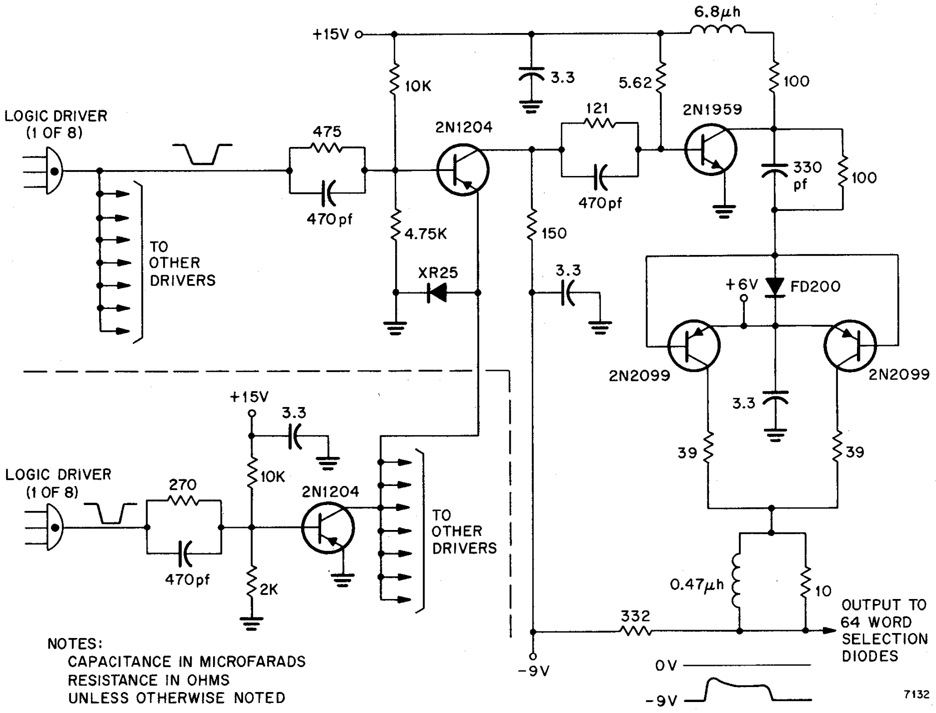


Figure 9. Matrix driver.

rise and fall time of 30 nsec. each. These circuits can select word lines at a rate of 4 megacycles per second.

Figure 10 shows a sketch of the three, closely spaced transmission lines that give access to the film spots. This circuit board was fabricated to avoid the necessity of handling very thin and flimsy sheets of insulating material supporting precision etched circuits. The first layer of wiring is etched and then coated with an insulating epoxy. A sheet of copper is then bonded to the circuit and the second layer etched. The process is repeated for the third layer. One set of index holes in the substantial base serves for registration of all layers. With this technique it has been possible to place the layers of circuits within 1 mil of the previous layer. Registration between layers depends on the original registration of the precision masters and upon the dimensional stability of the base. At no time in the fabrication is it necessary to perform registration of individual circuits to each other.

Figure 11 shows a sketch of the etched circuit low impedance backboard power distribution lines. The 512 word feasibility

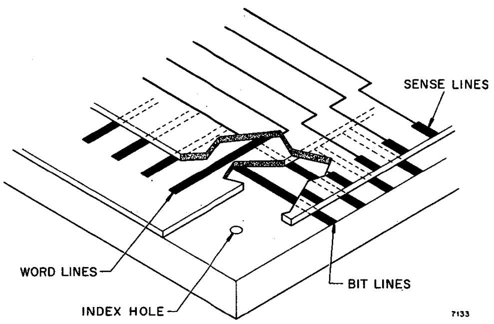


Figure 10. Sketch of closely spaced, three layer strip transmission line.

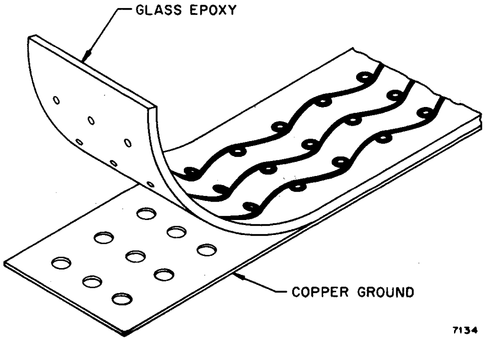


Figure 11. Sketch of etched circuit backboard power distribution.

model uses wire wrap connectors for all of its circuits which are built on conventional cards. The power distribution lines are fabricated from 4 mil double copper clad glass epoxy with a common ground plane and up to eight separate voltage lines. The pins from the connectors go through clearance holes in the ground and the appropriate ones are connected to the voltage lines. After the flexible distribution lines are in place, solder rings were dropped over the pins and a hot air stream used to solder all connections nearly simultaneously. In this case the individual voltage lines have a surge impedance of 5 ohms, although it could be made lower if necessary.

All of the circuits and techniques which have been shown were tested in the feasibility model completed early in 1962. A thin film stack of 512 words and 32 bits was constructed for the feasibility model. Only 16 words were driven and the loading effect on the word selection matrix of the missing words was carefully simulated. All of the drive circuit and logic circuits were spread out in a rack large enough to hold all of the circuits for a complete 4096, 32 bit word memory. Based on the test experience of the feasibility model which operated in a 250 nsec. cycle time, a full 4096, 50 bit word memory with a 200 nsec. cycle time is practical.

CONCLUSIONS

At the present time memories have been built that demonstrate the potential of thin films. In the near future, better solutions to the problems of connections and interconnections to the film elements will make submicrosecond million bit memories practical. These memories are expected to have a competitive advantage over other comparable memories.

Advanced work is leading to greatly reduced size of the thin film elements. Very high packing density (5000-10,000 bits per square inch) and low drive current (less than 50 ma) may be possible. Improved material properties should make coincident current selection with coherent rotational switching possible. With better techniques, high density integrated memory stacks with access lines made on the same substrate with the films seems likely. Microelectronic circuits probably could then be added to or made with the stacks.

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