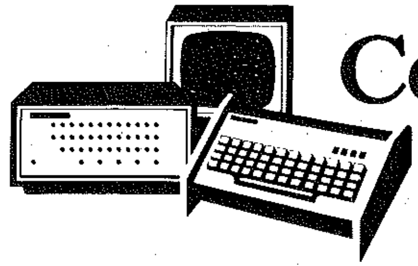


Computer Bits

By Hal Chamberlin

MICROCOMPUTER MEMORY

ALMOST from the start, memory has played a major, if not dominant, role in the practicality and cost of a hobbyist computer system. In the very early days (before 1972), the small "home brew" group of computer hobbyists used any type of memory that was available and relatively low in cost. Telephone relays, magnetic-tape loops, delay lines, salvaged memory drums, and of course core memory stacks were used. However, all of these devices were either extremely slow in speed, or were complex.

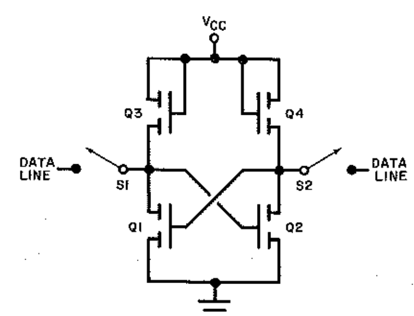
Along about 1972, semiconductor memories became low enough in price to be used by someone brave enough to tackle building a home computer. These memory devices were as easy to use as the rest of the logic within the system, thus adding to their appeal.

So, when the home computer revolution began in 1975 with the introduction of a low-cost microcomputer kit, semiconductor memories were right there along with the microprocessor chips. Even now, the main memory (as distinguished from external mass storage such as a cassette), is the dominant cost and performance factor in a home computer. The speed and sophistication of the MPU mean nothing if the main memory does not have ample capacity. Although some MPU's have more efficient storage of programs, when it comes to raw data storage, all systems are equal.

Types of Memory. Classical memory devices are divided into two distinct groups: random access and nonrandom access. A random access memory requires essentially the same amount of time to read or write a particular memory cell regardless of which cell is addressed, or the order of consecutive addresses. It literally means that a *random* sequence of addresses is handled just as fast as an ordered sequence.

The very earliest memory IC's were long shift registers that were serial access rather than random-access devices. When presented with a random address, a shift-register memory requires a variable access time depending on where the data is within the register. Today's systems use random-access memory exclusively for main memory.

Random-access semiconductor memories can be further broken down into *read-only*, *read-mostly*, and *read/write* classes. A read-only memory (ROM) can only be read. The information in the memory is placed there during manufacture and can never be changed. Read-only memories are typically used for unchanging system programs such as a monitor or BASIC interpreter. The advantage of permanent memory is that loss of operating power does not destroy the memory contents.



Six-transistor static memory.

The read-mostly kind of memory IC normally behaves just like a read-only memory but it is possible, using specialized equipment and a procedure called programming, to change the memory contents. Such memory devices are called Programmable Read-Only Memories or PROM's and the equipment is called a PROM programmer. One type of PROM is manufactured with all memory cells containing "0's". The programming procedure can change selected cells to "1's" to get the desired memory contents. The PROM can be programmed again later to write additional "1's" but once set, a cell can never return to a "0".

Another type of read-mostly memory IC can be *erased* to its all-"0" state and then completely reprogrammed as often as desired. These are called EPROM's for Erasable PROM. The erasure is usually accomplished with intense shortwave ultraviolet light, although a couple of types exist that can be erased with voltage pulses. The EPROM costs more than any other type of memory IC.

A read/write memory, which is usually called just a RAM, can be written into as quickly and easily as it can be read from. Most of the memory in a typical system is of this type because such a memory does not have to be dedicated to any single program or data table as ROM and PROM are. User programs and data are always stored in RAM and frequently many of the system programs such as the assembler and text editor are also stored there. Of course, the very flexibility, and ease of writing, makes RAM contents easily destroyed by errant programs or operating power failures.

Inside RAM. Since plain RAM is the most popular kind of memory, let's take a closer look at RAM operation and terminology. Two basic storage circuits are used in modern RAM's. The first type is a conventional flip-flop (as shown in the diagram) made from MOS transistors *Q1* and *Q2*. Transistors *Q3* and *Q4* function as high-value load resistors and are used because they are physically smaller than an equivalent resistor would be. Switches *S1* and *S2* connect the memory cell to the outside world and provide the read and write data path.

When the cell is unaddressed, both switches are open and the cell is isolated. To read, both switches are closed and the state of the flip-flop can be determined by sensing the voltage level on the data lines. To write, the switches remain closed and other circuitry forces the data lines to voltage levels that will cause the flip-flop to change state.

This type of cell is called *static* because once the flip-flop is set to a particular state, it will remain in that state until instructed to change, or the power supply voltage drops. Switches *S1* and *S2*, are in reality, MOS transistors and so the memory cell in Fig. 1 is a 6-transistor static memory cell.

Another common data storage circuit is just a capacitor and a switch which again is really a transistor. When the cell is unaddressed, the switch is open and the voltage level on the capacitor determines the cell's state. To read the cell, the switch (transistor) is closed thus discharging the capacitor into a sensing circuit connected to the data line. If a surge of current from the discharging capacitor is sensed, then a 1 was stored—no surge represents a 0. The data is then restored to the cell by applying a high voltage to the data line if a 1 had been previously sensed. When writing new data, the initially sensed data is ignored.

This cell is called *dynamic* because the charge will leak away from the capacitors if they are not written or read often enough. At room temperature, the charge remains for a second or so; but at the top end of the rated temperature range, the period may be only a few milliseconds. Actually, in a dynamic memory IC, the capacitor is really just stray capacitance. Thus the entire memory cell consists of just one transistor.

The small size of such memory cells allows as many as 16,384 of them to be placed on one chip, whereas only 4096 of the 6-transistor type are diffused on one chip. Even the lowest cost and most popular dynamic RAM's pack 4096 bits in a chip, whereas static types contain only 1024 cells.

Another advantage of the dynamic cell is that power consumption is very low. Cells just idling don't consume any power. The dynamic RAM consumes power only when being accessed while a static RAM constantly draws current to keep the thousands of internal flip-flops powered. It is not unusual to see a 32k static memory system require over 8 amperes while an equivalent dynamic memory system might require less than one ampere.

As previously mentioned, a dynamic memory system must read or write every cell occasionally to recharge the storage capacitors. Since this does not always happen during normal operation of the system, a separate *refresh* operation is usually performed. Refreshing is quite simple and amounts to nothing more than sequentially reading through a portion of memory using a counter to generate addresses. Due to the internal organization of the memory IC's, only 64 addresses really have to be read to refresh all the cells.

Early memory board designs using dynamic RAM's would periodically stop the MPU while refresh was being performed. Modern designs look at the state of the MPU and during those times when memory access is not required, a refresh cycle is slipped in.

Memory Boards. There are certainly more different kinds of memory boards for hobbyist systems on the market than any other type of board. For Altair (S-100) bus systems, the earliest memory boards contained only 1024 bytes of static RAM. Later, MITS introduced its 4k dynamic memory board using 22-pin 4k RAM's. It was quite power conservative but priced fairly high. Refreshing was done by halting the MPU periodically. This opened the door for competing brands of memory boards which, in the interests of quick development and marketing strategy, used 1k-bit static RAM IC's and had a total capacity of 4k bytes. While they worked well and were low in cost due to intense competition, the much greater power consumption of static RAM's strained the computer's power supply and cooling system. Computer manufacturers responded with massive power supplies to satisfy customers who plugged 32k and more of memory into a system.

Later improvements in printed circuit board fabrication allowed as much as 8k on a board using the same 1k memory components. Finally, the IC manufacturers figured out how to put 4096 bits of static memory onto one chip and also cut the power consumption per bit by a factor of two to four. Thus, 16k static memory boards became available. Although more expensive per bit than the 4k or 8k boards, these larger units are becoming popular.

Finally, memory board designers have found ways to "hide" the refresh cycles of a dynamic memory in the MPU's idle time periods. Also, at the same time that 4k static-memory IC's became available, 16k dynamic RAM's also became available. Using these, it is now possible for 64k bytes to be put on a single board. The 16k IC's are still quite expensive, but an 8k version is being used in very cost-effective memory boards with a capacity of 32k bytes.

However the least expensive memory boards on today's market still use the same 22-pin 4k RAM's that were used in the original MITS 4k board. These have a 16k capacity, utilize hidden refresh, and are $300 to $400.

Memory costs are constantly decreasing. In two years it will be possible to buy a 64k memory board for what a 16k board costs now. Already the computer manufacturers are introducing systems that can address more than 64k of memory to make room for the never-ending memory capacity spiral. ◇