A MINIATURE, LOW COST MAGNETIC TAPE SYSTEM FOR PROGRAMMABLE GAMES

Clark E. Johnson, Jr., President
Micro Communications Corporation
Waltham, Massachusetts 02154

Abstract: As microprocessors become more widely used in consumer products of ever-increasing complexity, there has arisen a need for a low cost magnetic tape peripheral. Such a peripheral is used to store both programs and data. A new, re-entrant tape cartridge about the size of a book of matches, capable of storing in excess of 500,000 bits of data, will be described. Its mating transport is 1" x 3" x 1½" and has only three moving parts. Data encoding schemes requiring minimal electronics and operating over wide tape speed fluctuations will be outlined. While designed as a self-clocking, single-track digital system, the MicroVox Digital Data Storage System can be equipped with a second track for audio effect. This paper describes bulk program tape duplication techniques and unique system configuration to minimize "bootlegging." Finally, it reviews several current applications.

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This paper describes a low-cost, small-size, non-volatile magnetic data storage system designed to be used with microprocessors. The system has already found widespread industrial and commercial applications for program loading, data collecting, RAM back-up, etc.

THE TAPE CARTRIDGE

Figure 1 shows the tape cartridge, which we call a MicroVox Wafer cartridge.

FIGURE 1. Endless-loop magnetic tape wafer cartridge (full size).

The cartridge measures 2.6"x1.5"x0.2". It is re-entrant, that is, the tape is in an endless loop configuration, somewhat similar to the familiar 8-track audio cartridges. The tape is 1.8 mm (.070") wide, less than half the width of a cassette tape and about 25% of the width of an 8-track tape. The tape itself is chromium-dioxide video tape with a coercive force of 530, a remanent magnetization of 1400 gauss and a squareness (the ratio of the remanent magnetization to the saturation magnetization) of 0.85. The tape consists of a 0.83-mil mylar backing with a 0.20-mil magnetic coating. The tape also has a proprietary slippery back coating, which provides a low friction surface so that it can easily wind on and off itself with an ever-changing radius. The advantages of the chromium-dioxide magnetic surface over the more common gamma-ferric oxide is that chromium-dioxide's higher coercive force not only provides a higher data packing density on the tape, but also provides much higher immunity to demagnetization. In addition, its higher remanent magnetization gives a relatively larger output signal.

The Wafer has a non-moving bollard (the spindle around which the tape is wound), wherein 8-tracks have a rotating spindle. The Wafer also has a self-contained pinch wheel, made out of a specifically formulated silicone rubber that resists permanent deformation, thereby permitting it to be left in the drive indefinitely without damage and with assured starting.

Received July 29, 1977

Tape Wafers can hold up to 50 feet of tape, on which approximately 1/2 million bits of data can be stored using the encoding scheme described below.

THE TAPE DRIVE

The drive, Figure 2, consists of a die-cast aluminum frame and a capstan, which is belt driven from the motor. The tape Wafer is seated pos-

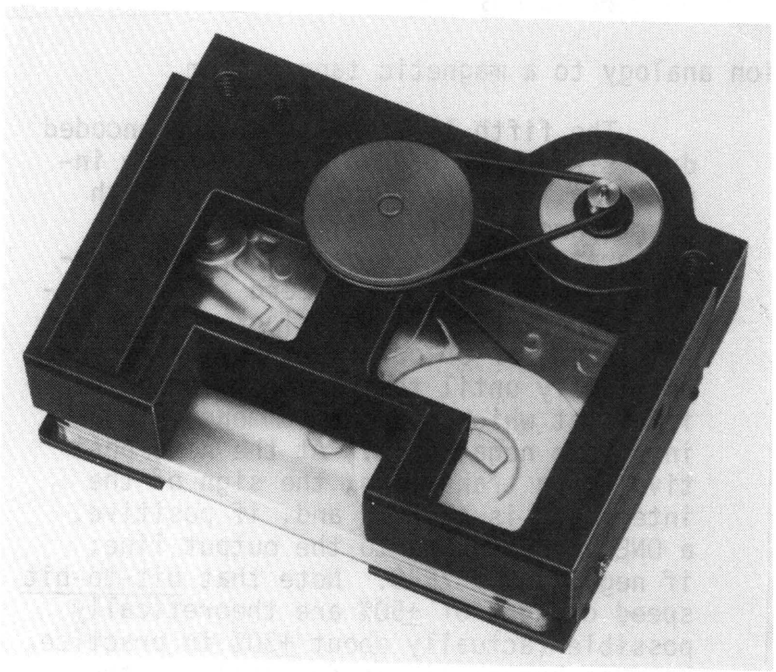


FIGURE 2. Transport to drive tape of Figure 1 (actual size).

itively by two pressure springs mounted in the cover, which serve both to hold the Wafer flat against the rails and to urge it up against the front stops, thereby providing positive, repeatable engagement with the capstan.

The drive accepts either a standard single-channel cassette head for single-track recording or a 2-channel head for two-track recording.

The drive was originally designed to use an "ironless rotor" motor, which has high efficiency (good for battery-powered applications) and extremely low inertia (good for fast stopping and starting, to minimize inter-record gap lengths). This type of motor is very expensive and, hence, not suitable for most consumer applications.

MOTOR-CONTROL CIRCUITRY

While the data encoding scheme described below is extremely speed tolerant, some motor speed control is desirable. Moreover, in audio recording, good speed control is a necessity. Figure 3 shows a special motor-control chip that is ideally suited for controlling small d-c permanent magnet motors. The chip functions by monitoring the motor's back EMF, which is linearly proportional to speed, comparing this voltage to a preset value, and then adjusting the current to the motor so as to minimize the differential.

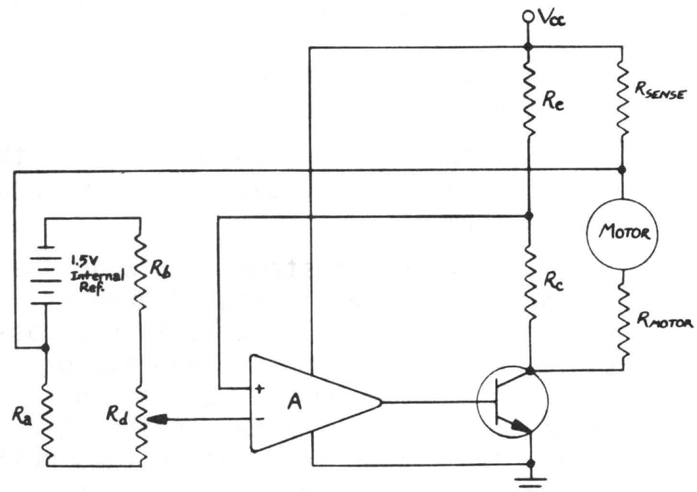


FIGURE 3. Block diagram of back EMF d-c motor chip.

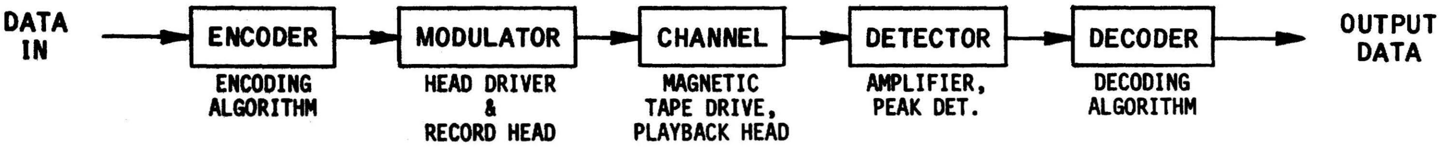
DATA ENCODING

A magnetic tape system can be thought of as a bandwidth-limited communications channel, as is shown in Figure 4. The channel looks like a high-pass filter, since the output voltage on playback is proportional to the time derivative of the write current. Thus, dc cannot be recorded, and the narrower the frequency range to be recorded the easier it is to achieve error-free data recovery.

The elements of the channel are:

1. The encoder, which takes the incoming data stream and converts it to a narrow bandwidth data stream, "matched" to the characteristics of the channel;

2. The modulator, which is simply the head and head driver used to record the data on the tape;



THE ELEMENTS IN A TAPE SYSTEM ANALOG TO A COMMUNICATIONS CHANNEL.

FIGURE 4. A bandwidth-limited communication analogy to a magnetic tape system.

3. The channel, consisting of the tape and playback head;

4. The demodulator, which performs the inverse function of the modulator;

5. The decoder, which converts the recorded data stream back into the input data stream.

In low-cost systems with wide speed variations, we need a high degree of speed insensitivity, and it is not possible, even in the most elaborate of tape systems, to provide the timing mechanically from the tape drive itself. The timing information thus must be recorded on the tape; and, because this is a single-channel system, it must be encoded with the data.

Therefore, we need a narrow bandwidth, self-clocking, speed-insensitive data-encoding technique. Figure 5 shows such a scheme, which is called "ratio recording." The first row is the incoming data. The second row is the data encoded with the clock. Note that the algorithm is a positive-going transition on each bit cell edge (corresponding to the clock). If the negative-going bit edge lies in the first half of the bit cell (normally the 1/3 point) the bit is a ZERO; if in the second half (normally the 2/3 point) the bit is a ONE. The third line shows the signal off the read head. (It is approximately the derivative of the record current.) The next line is the demodulated signal, recovering the encoded data stream.

The fifth line shows how the encoded data stream is decoded back into the input data, even in the presence of both short- and long-term time changes. An integrator (either a capacitor or an up-down counter) is set to zero at each positive-going transition (clock pulse). The capacitor or counter then integrates positively until the negative-going transition, at which time it commences to integrate negatively. At the next positive-going transition, the sign of the integrator is checked and, if positive, a ONE is delivered to the output line; if negative, a ZERO. Note that bit-to-bit speed changes of ±50% are theoretically possible (actually about ±30% in practice because hysteresis is desirable in the integrator output comparator to minimize noise). The speed changes that occur over long time periods are limited only by the gain of the amplifier and the limitations of the integrator.

We pay for this speed insensitivity by having a fundamental frequency of 1.5 times the data rate. (There are effectively three transitions per bit cell.) The frequency range is only 2:1, however. There are other self-clocking encoding schemes that also exhibit only a 2:1 frequency range but whose fundamental frequency is only 0.5 or 1.0 times the data rate. These alternate approaches have the advantage of higher data-storage density (the tape-read head interface limits the number of flux changes per unit tape length) but they are not speed tolerant and may require a preamble to provide read clock synchrony.

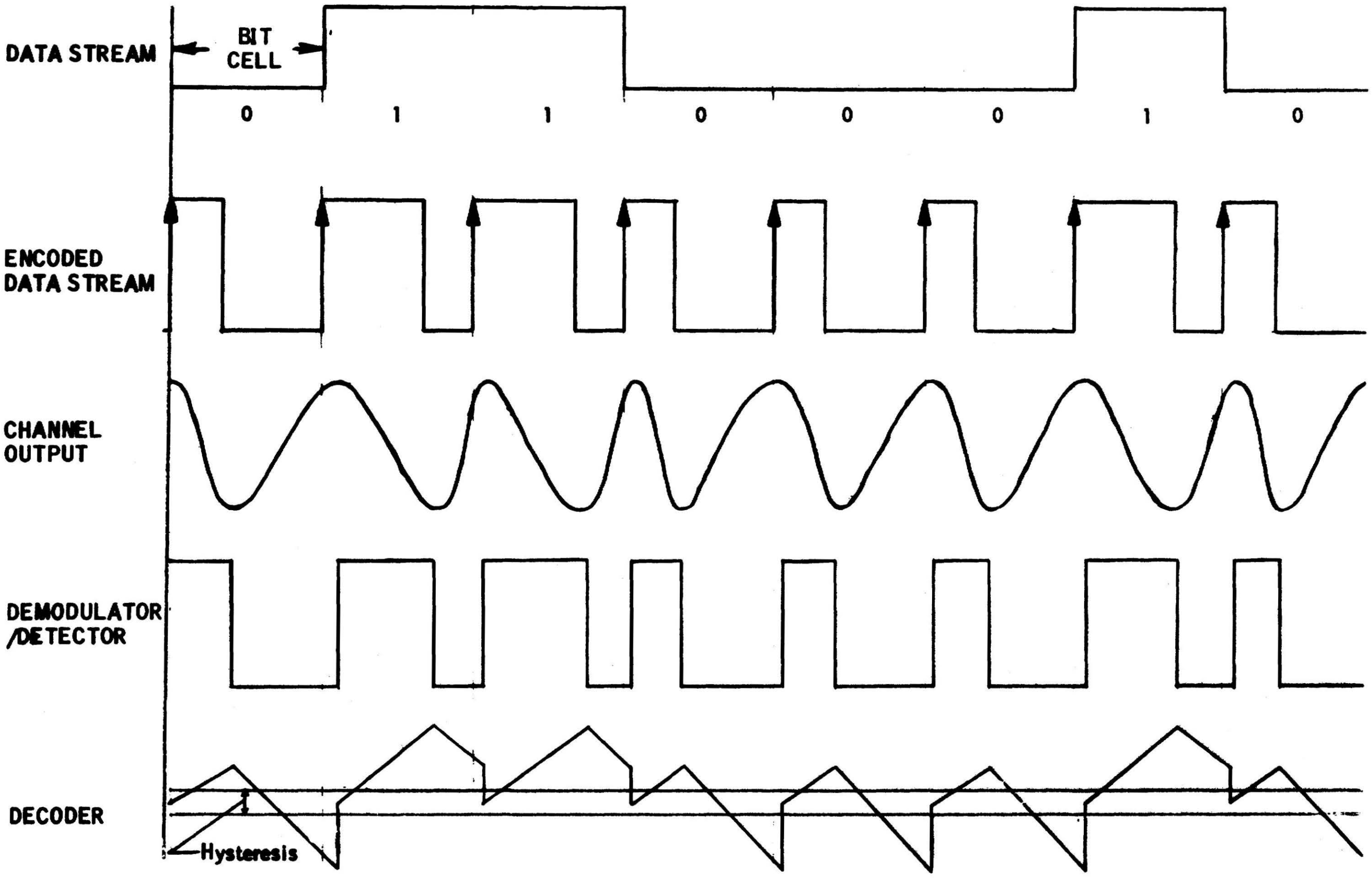


FIGURE 5. A speed-insensitive, data-encoding scheme called ratio recording. The first line is the incoming data; the second is the encoder output; the third is the playback signal; the fourth is the demodulated signal. The bottom line is the data decoded by integrating positively from the clock transition to the data transition and negatively to the next clock transition.

We find that 800 bits per inch is a reliable and compatable density for ratio-recorded data.

GAMES APPLICATIONS

As electronic games become more sophisticated and interactive, they require the storage, both permanently and temporarily, of fairly large amounts of data. A Wafer, however, is relatively large in capacity, compared to the length of a game program; so there can be several programs on one Wafer. Or there can be several program branches in an interactive program, where the next portion of the program to be loaded depends upon the previous results. What are the relative merits of the magnetic tape Wafers compared to ROM? Tape has a much lower cost per bit, because it is replaceable. Tape Wafers are small, easily shipped and readily stored. On the other hand, ROM memory can be addressed directly by the microprocessor, whereas tape requires both a drive and auxiliary electronics plus some auxiliary RAM into which to load the tape data. This makes the initial cost higher for a tape-based system, but the media cost lower. Thus, some juggling of pricing between the "razor" and the "blade" is possible.

BULK DUPLICATION AND PROTECTING PROPRIETARY PROGRAMS

All digital tape Wafers are certified by writing a pattern on them and then reading it back. No errors are permitted. Since the certification program is arbitrary, it could easily be the program itself. Thus, there is no additional cost (except for a set-up charge) for loading a customer's program. Since tape Wafers can be almost any length up to 50', they are tailored to the length of the program. Because the tape is an endless loop, with the end spliced to the beginning, no time-consuming rewinding is required to reload the program.

To many manufacturers, it is highly desirable to protect their proprietary programs. With MicroVox Wafers this can be done in several ways. First of all, one can use an algorithm to convert the program data into a coded program. This requires a decoding algorithm in each playback system, which can be analyzed and duplicated, but with considerable effort. There has been a lot of work done in the past few years on data encryptation for Government security applications. These techniques clearly can be used to help protect games programs.

A second technique, particularly useful when MicroVox Tape Wafers are used, involves a mechanical keying of the Wafer cartridge to the transport. The Wafer, being a patented product, cannot legally be copied by anyone else and, therefore, the incorporation of a mechanical keying system will effectively protect the tape/transport interface. In this way, the games manufacturer can control the tape medium for his own customer base.

C. E. Johnson, Jr.

BIOGRAPHY

Clark E. Johnson, Jr., forty-six and a native of Minneapolis, received his BS in physics in 1950 and MS in EE in 1961, both from the University of Minnesota, the latter under Prof. William Fuller Brown, Jr. From 1950-1959 Mr. Johnson was with the Central Research Laboratories of Minnesota Mining and Manufacturing, working primarily in the area of magnetic recording. His work included fundamental studies of the magnetization process of single-domain particles and led to improved understanding of the magnetic recording process. He co-authored numerous papers with Prof. Brown on shape distribution and magnetization curves of various magnetic powders.

After Mr. Johnson left 3M in 1959, he started several new technology-based companies and is presently the president of Micro Communications Corporation located in Waltham, Massachusetts, which he founded in 1972. Micro manufactures a miniature endless-loop tape cartridge and drive system which is designed for both analog and digital use, for example, microprocessor systems as non-volatile memory.

Mr. Johnson consulted for Graham Magnetics on tape problems and was instrumental in the research program leading to the development of Cobaloy[T]. He is a Senior Member of IEEE, former Chairman of the Boston Chapter of the Magnetics Society (1970-72) and its present Treasurer. He is a member of the American Physical Society, the New York Academy of Sciences, AAAS and ISA. He is listed in Who's Who in the East and American Men of Science. Mr. Johnson holds 13 patents on various magnetic and optical devices and processes. He is presently a member of the Magnetics Society Administrative Committee and is its Finance Committee Chairman.