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DESIGN CRITERIA FOR DIGITAL AUDIO TAPE

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General construction and requirements of all magnetic tape are reviewed. Differences between the recording of analog and digital signals are discussed as they pertain to the magnetic medium. The pecularities of magnetic tape suitable for recording of digital information are examined. Particular emphasis is placed on dropout testing and total tape surface integrity as a function of the interplay of track spacing and recording format.

INTRODUCTION

Digital audio techniques offer the potential for elimination of wow and flutter, tape hiss, modulation noise, print-thru, and noise reduction systems. Significant improvements are to be gained in dynamic range, frequency response, crosstalk and distortion.

The growing interest in digital audio techniques spawns many questions. Currently the unknowns perhaps outweigh the known factors. Technical people try to envision the studio of the future. Will it contain CRT terminals, memory banks and be dominated by a master computer? How does a digital audio recorder differ from present equipment? What new techniques and skills must be acquired? This dissertation addresses itself to magnetic tape and, specifically, to the unique design requirements of digital audio tape.

TAPE IN GENERAL

Magnetic tape is one of those factors in the entire recording process that is usually taken for granted, much as the power cord for the recorder or the cable for the microphone. Tape is expected to perform on demand. Reasonable care is exercised in its initial selection, use and storage--as is the cable from the microphone to the recorder--but tape is also expected to always perform. After all, whoever heard of a technician troubleshooting a tape and replacing components?

Even low grade white box tape is a surprisingly sophisticated product. Precision magnetic tape such as audio mastering, video, instrumentation or computer reflects state of the art technology on a grand scale.

All magnetic tape is comprised of three essential components: magnetic particles or oxide, binder and base film. The base film is the carrier or transporting medium for the oxide. Today all precision tape is produced on polyester base film--in chemical terms, polyethylene terephthalate. Polyester is available from a number of suppliers and under an equal number of trade names: Du Pont (Mylar), Celanese (Celanar), ICE (Melinex) and 3M (Scotchpar). The basic physical strength and environmental stability of magnetic tape is derived from the base film. Film is purchased and coated in widths of up to 48 inches and in lengths on the order of two miles. A ± 5% thickness variation is normally maintained over the width and length of this master roll which is no small accomplishment. Open reel products obtain their nominal thickness description from the base film used--a 1.5 mil thick tape has a base film thickness of about 1.42 mils; 1.0 mil tapes are coated on 0.88 to 0.92 mil base film.

The binder is a complex entity whose prime functions are to hold the oxide firmly and attach the coating to the base film. A binder is more than just a glue, however, for the binder contains lubricants, plasticizers, anti-static agents and dispersants. Binders are the determining factor for such key paramaters as durability, environmental stability of the coating and oxide shed. Two principal forms of binders are used: thermoplastic and thermoset. In general, thermoplastics may be softened by heat and usually are easily attacked by solvents. Thermoset binders are characterized by a curing process. Once curing is complete, a thermoset binder is generally heat and solvent resistant. However, varying degrees of thermoset are possible and a relatively low degree of thermosetting or crosslinking gives properties similar to a thermoplastic. Today most precision tapes are of a thermoset formulation. Balancing all the desirable properties of binders with suitable oxides is a key part in the art and science of producing magnetic tape.

Oxides are the key elements in a magnetic tape. Particles must be uniform in shape, size and magnetic properties. An ideal oxide particle is pencil shaped, is about 5-40 microinches long and has a length-to-width ratio varying from about 4:1 to 10:1. Suitable magnetic oxides are not found free in nature and the magnetic rust--or gamma ferric oxide--must be carefully synthesized by the chemist. End use determines the desired properties of the final oxide particle. Broadly speaking, large particles are used for long wavelength or low frequency signals; small particles for short wavelength or high frequency work. However, particle size is also a factor in tape noise and print-thru. As with binders, the manufacturer must make certain compromises in selecting an oxide particle to provide a suitable finished tape for a particular end use.

Although gamma ferric oxides have by no means reached their final level of development, another form of magnetic particle is with us today. High energy tapes hold forth the promise of improved dynamic range and shorter wavelength (high frequency or greater bit packing density) recording potential. Conventional gamma ferric oxide tapes are characterized by a coercivity of 350 Oersteds or less. High energy tapes run the gamut from [illegible] Oersteds to 1000 Oersteds or more. Coercivity is a measure of the magnetic force required to record or erase a signal on a magnetic particle and is only one of many magnetic particle parameters.

Two types of high energy particles are predominant: chromium dioxide and cobalt-doped gamma ferric oxide. As a rule, record and bias current drive must be increased when using high energy tapes. Full advantage is not achieved unless equalization is optimized. A good many systems still in use today are incapable of using high energy tape without modification to the drive and equalization circuitry and if the tape's coercivity is great enough, problems may be encountered in erasing a high energy tape.

Most precision tapes today incorporate a second, non-magnetic coating on the backside of the tape. A finely textured, highly conductive, carbon based backcoat is used to:

1. Minimize static electricity problems. The conductive surface minimizes the attraction of airborne debris. Hence, fewer dropouts are present.

2. The textured surface provides a controlled coefficient of friction. Tape winding and handling characteristics are enhanced. Improved tape packing results and there is less opportunity for pack slippage or cinching during shipping or environmental changes.

3. Abrasion resistance of the backcoating is superior to that of the polyester base. Fewer wear products are generated and there is less opportunity for damage to the oxide surface from loose debris. This clean running characteristic manifests itself as improved dropout performance.

In essence, precision magnetic tape is a three-layer sandwich consisting of a thin backcoat a relatively thick base film and an oxide/binder coating. There are two broad classifications of magnetic tape: thin coated and thick coated. A thick oxide coat is used for enhanced long wavelength recording. A thin oxide coat favors short wavelength performance. A similar relationship exists in base film also. Thin base tapes generally show improved head-to-tape conformance needed for optimum short wavelength recording. An idea of the relationship existing between these broad classifications may be gathered from Figure 1.

In theory, a superior audio tape should also be good in all applications: video, instrumentation or digital. All tapes require close control of thickness, surface finish, magnetic and electrical properties. However, each broad end use imposes certain critical requirements which are reflected in the finished tape as differing lubricants, mirror finishes, oxide coating thickness, oxide particle dimensions and in test requirements.

As a broad statement, most tape parameters are sample tested for electrical performance. Sampling plans are used to determine how many reels are actually run on a test machine and for what parameters. As little as one reel out of 24 may be tested for long wavelength sensitivity on an inexpensive grade consumer product. On the other hand, every reel of two-inch wide audio mastering tape is full length tested on three channels for output uniformity. Video tape is 100% tested for dropouts.

UNIQUE REQUIREMENTS OF DIGITAL AUDIO TAPE

Digital information is recorded as a series of pulses. The presence or lack of a pulse represents one data bit. Digital recording deals with "yes" or "no"; there is no maybe.

Analog or conventional audio recording deals with sinewaves and combinations of sinewaves. Generally speaking, a 10 microsecond loss of information goes totally unnoticed as the human ear tends to smooth out such a short glitch. An uncompensated 10 microsecond data loss in a digital system can mean the loss of several data bits and a correspondingly noticeable click, pop, change or whatever.

Figure 2 is a stylized model of the head-to-tape interface of an analog system. While it is not entirely technically accurate, it does serve to illustrate.

A signal current fed to the recording head magnetizes the individual oxide particles in accord with the intensity and wavelength of the signal. The longer the wavelength of the signal, the more oxide particles magnetized. The greater the intensity or strength of the signal, the deeper the penetration into the coating and the higher the percentage of particles present are magnetized.

Figure 3 depicts an erased or degaussed tape wherein the oxide particles are randomly polarized. The net magnetic field presented to a reproduce head is zero. Figure 4 serves to show how polarization of the individual oxide particles reflects the recording of a sinewave.

The total number of particles representing a signal or portion of signal would be in the many thousands. However, even with the nine columns of particles shown, the loss of any one column of particles would still allow us to easily reconstruct the original signal, visually or audibly.

A digital signal is a series of pulses, yeses or noes, normally processed with a clock-code indicating when something should be occurring, Figure 5.

Notice that now if one of the columns of particles is missing, there is no way of making an accurate estimate of whether the data bit was yes, no or zero. Minimization of loss of data bits is the crucial key to the design (and use) of digital tape. The use of redundant channels of recorded information, parity codes and recording formats are the equipment designer's means of compensating for the inevitable losses of signals that will occur.

Faithful reproduction of sinewave data using digital techniques is a function of how many times the sinewave is sampled.

The eight samples of Figure 6A would probably not result in as smooth a curve or as faithful a reproduction of the original sinewave as the 16 samples of Figure 6B. Sampling rate and the number of bits recorded in a given length of tape establish the tape designer's requirements for wavelength response. Digital audio systems under evaluation today require the successful capture of wavelength information in the 60 to 100 microinch category. By way of comparison, video and advanced instrumentation recorders operate with the same wavelength signals.

Small oxide particles favor the recording of short wavelengths. If the tape can be driven harder, that is recorded at a very high level, more of the oxide particles are magnetized. There will be less opportunity for a total loss of signal and the signal will be further above the system noise level. A high energy oxide particle appears to be of advantage here. However, the fact that only "yes" or "no" needs to be recorded in a digital format permits ignoring tape recorded distortion. A conventional gamma oxide particle may thus be used and driven to saturation. Short wavelength recording requires intimate head-to-tape conformance and spacing. Spacing losses at these wavelengths have dramatic effect.

Consider the following. A particle of cigarette smoke is on the order of 25 microinches in diameter. When recording a signal of 100 microinch wavelength, a single particle of cigarette smoke has the potential of creating a 13 dB loss.

$$\text{Viz. dB loss} \approx \frac{54D}{\lambda} \approx \frac{54 \times 25}{100} \approx 13 \text{ dB}$$

Surface irregularities of all types can lead to unstable signal performance. Hence, tapes designed for short wavelength recording are characterized by highly calendered, mirror-like finishes. Surface roughness is on the order of four to 10 microinches peak-to-valley. However, these smooth surfaces against a highly polish head or guide have a tendency to wring-in, like precision gage blocks. Consequently, the additives in the binder system must be suitably adjusted to correct this tendency. Static charge build-up only aggravates such a situation so the tape must be made conductive. Finally, to assure the optimum in head-to-tape conformance, a thin oxide coating on a relatively thin base film is used to encourage physical flexibility.

Summarizing thus far, a digital audio tape will generally have these characteristics:

oxide: small particle, either conventional gamma ferric oxide or a high energy type such as cobalt-doped

oxide coating thickness: "thin", about 200 microinches

base film: "thin" polyester, less than one mil thick

backcoat: conductive textured coating, about 50 microinches

surface finish: highly calendered, approximately 10 microinches p-v

The oxide/binder will be a conductive combination with suitable additives for flexibility and lubrication.

Thus far, the design criteria are not too exotic and would describe any number of currently available instrumentation or video products, even a good analog audio product.

DIGITAL AUDIO'S ACHILLES HEEL

The single most critical parameter for digital magnetic tape is dropouts. There are industry standards for video, analog instrumentation and computer dropouts. Recording formats and track spacing are well defined and there is general agreement as to just what constitutes an objectionable defect. PCM or digital instrumentation recording is superceding analog recording as a standard industry technique. Digital audio is in its infancy.

As stated previously, most magnetic tape is tested using a sampling plan. Most tape is not electrically checked. Precision products may be tested for key parameters. Computer tape is tested full length for dropouts as is broadcast video tape. But here standards exist and there is industry agreement as to what constitutes a dropout and how many dropouts of given size are permissible.

Considering digital audio, how many tracks shall be measured? There are systems with nine tracks on 1/4 inch wide tape. Another system uses 36 tracks on the same width tape. Dropouts increase in direct ratio to the number of tracks recorded on a given width tape. At what speed is testing to be done? What format is most suitable, return to bias, return to zero, NRZ or Miller code? A tape with absolutely no errors is an impossibility. What size error can be tolerated? How much time can an error occupy? How deep a loss is permitted and how many such errors can be tolerated? The audio industry is addressing these problems and the tape manufacturer must work with individual equipment producers to develop a suitable level of performance.

PCM techniques have been used on instrumentation recorders for at least ten years. However, the state of the art is now at 32 kilobits per inch with many systems routinely handling 20-30 kBPI. The last two years have witnessed high density pulse recording becoming an industry standard with consequent demands for more precise, error-free tape.

In satisfying the demands of instrumentation PCM recording, an empirical approach was used which stresses surface integrity. This avoided the problem of dealing with specific recording formats. In the case of one-inch wide tape, dropout testing is done at a speed of 120 inches per second using an IRIG standard 28 track head. A one megaHertz sinewave is recorded on every other track across the width of the tape; a total of 14 tracks. A dropout is defined as a 12 dB loss of signal for one microsecond. This is the equivalent of losing one cycle of the one megaHertz signal. An acceptable tape will have 15 or fewer such dropouts in 100 feet of tape on any given track. The average is one error or less per 100 feet of tape per track.

Does the approach work for digital audio? Yes, in fact this level of performance is probably unnecessary and perhaps too costly. Present indications are that a 12 dB loss of signal for 10 microseconds is workable if the total number of such errors can be kept to an average of 10 per 100 feet per track.

And what causes these dropouts? Dropouts may be classified as permanent or temporary. Permanenet dropouts are usually a coating defect: a particle of lint or dust, a scratch in the tape surface, a void in the coating. Temporary dropouts move about and may be removed by wiping or just rerunning the tape. Typical examples include loose dust, edge debris and fingerprints. Indentations in the tape surface caused by writing on an end tab securing the tape will print through many layers of tape to produce dropouts. A crease or wrinkle in the tape, spoking and cinching all contribute to the formation of both permanent and temporary dropouts.

We in the tape manufacturing industry need the inputs from equipment designers as to what their systems can handle electronically. As an industry, specifications need be developed based on current technology. Such specifications should be general to cover as many recording techniques and track configurations as possible.

IN CLOSING

A new era in audio tape sophistication is with us today. Greater precision in manufacture is required and testing requirements become more stringent. Tape manufacturers are and must continue to work hand in hand with the equipment producer. Both in turn must work with the end users to insure the full potential of digital techniques is realized.

CROSS SECTIONS OF MAGNETIC TAPE

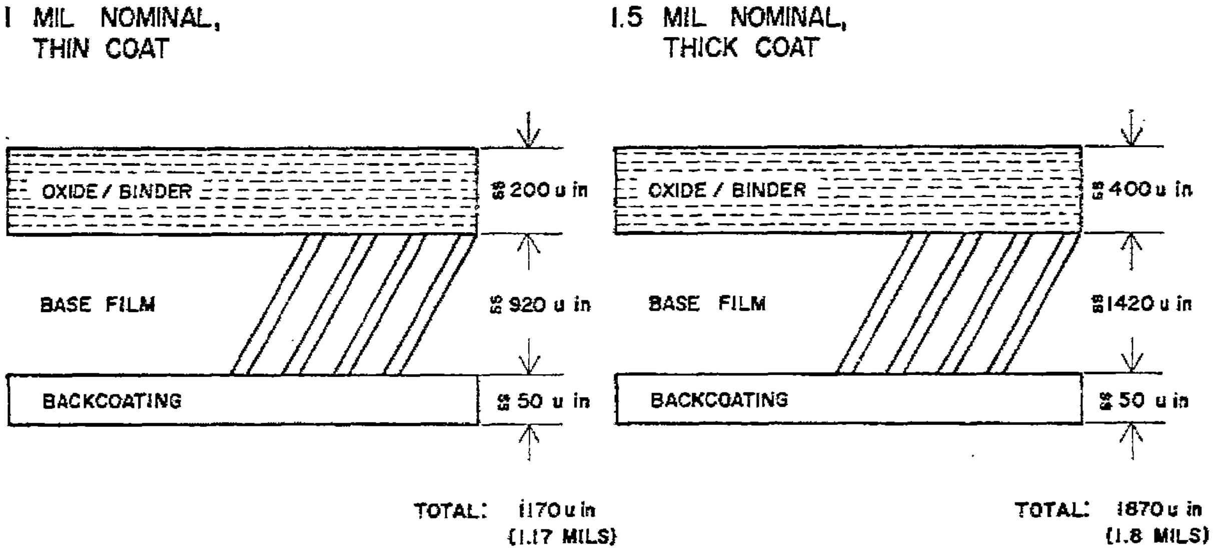


FIG. 1

HEAD TO TAPE INTERFACE

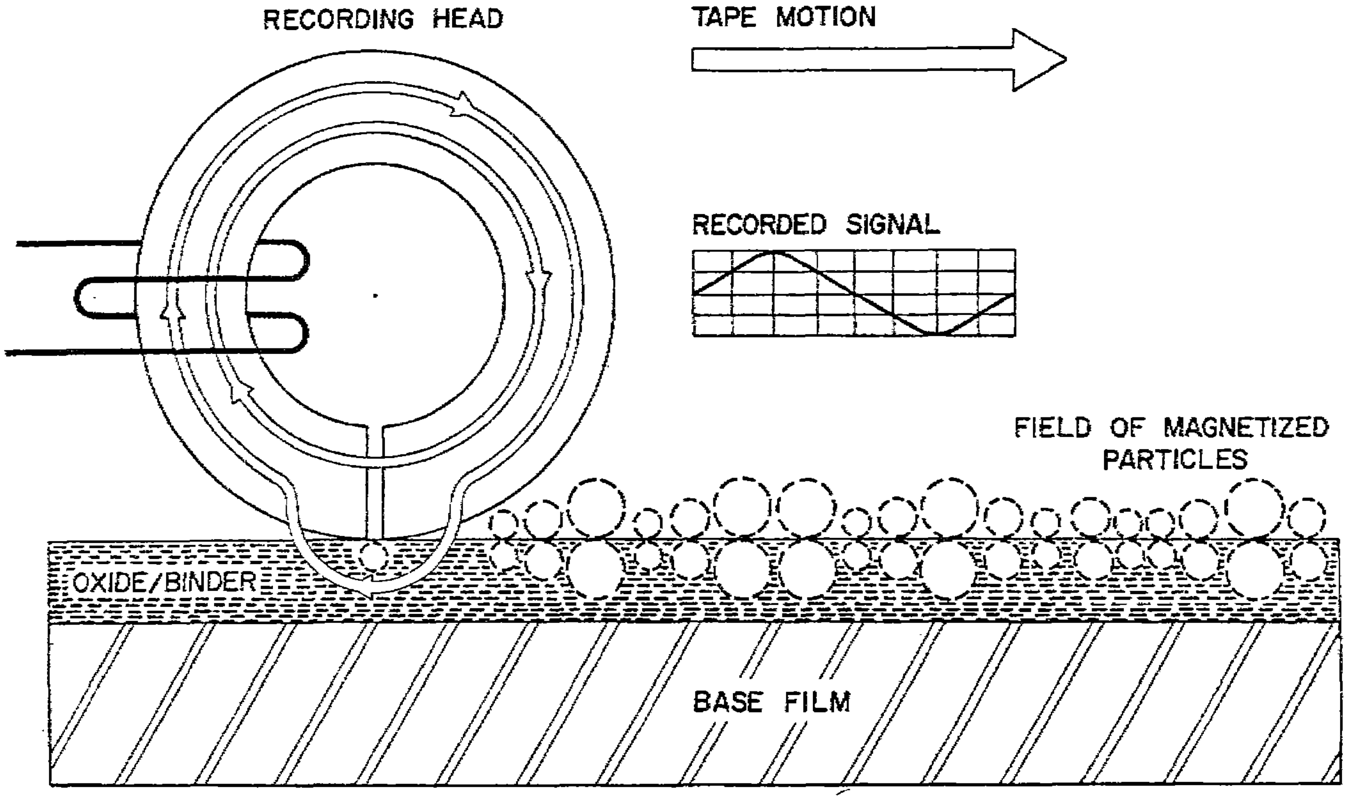
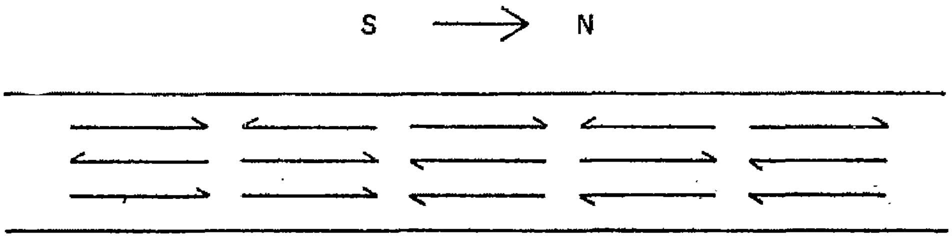


FIG. 2



RANDOMLY MAGNETIZED PARTICLES
OF DEGAUSSED TAPE

FIG. 3

OXIDE PARTICLE POLARIZATION
SINE WAVE SIGNAL

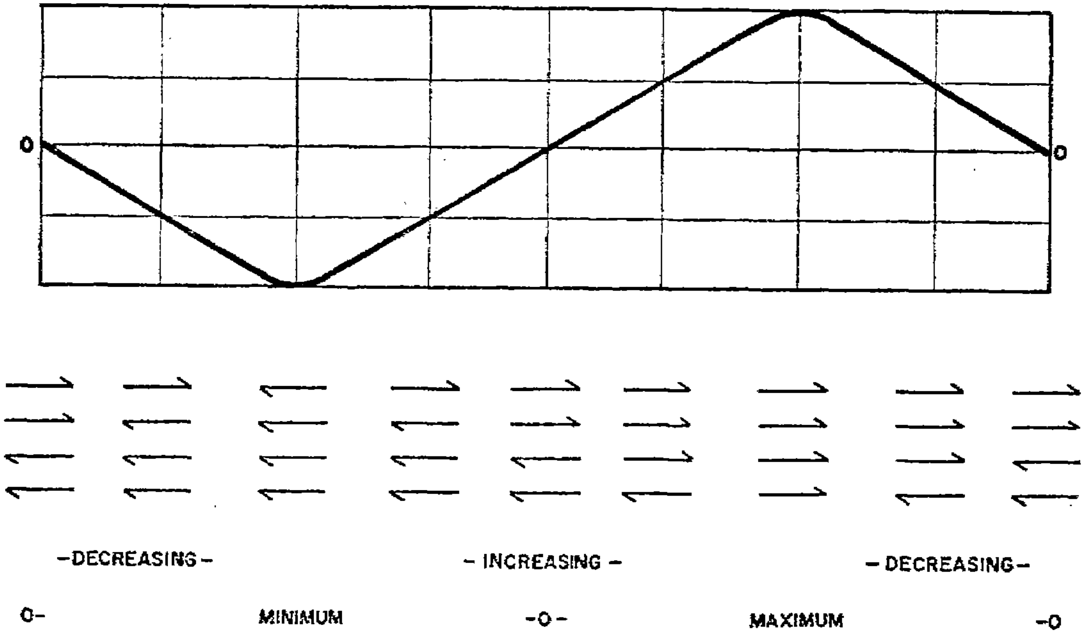


FIG. 4

OXIDE PARTICLE POLARIZATION PULSE CODE SIGNAL

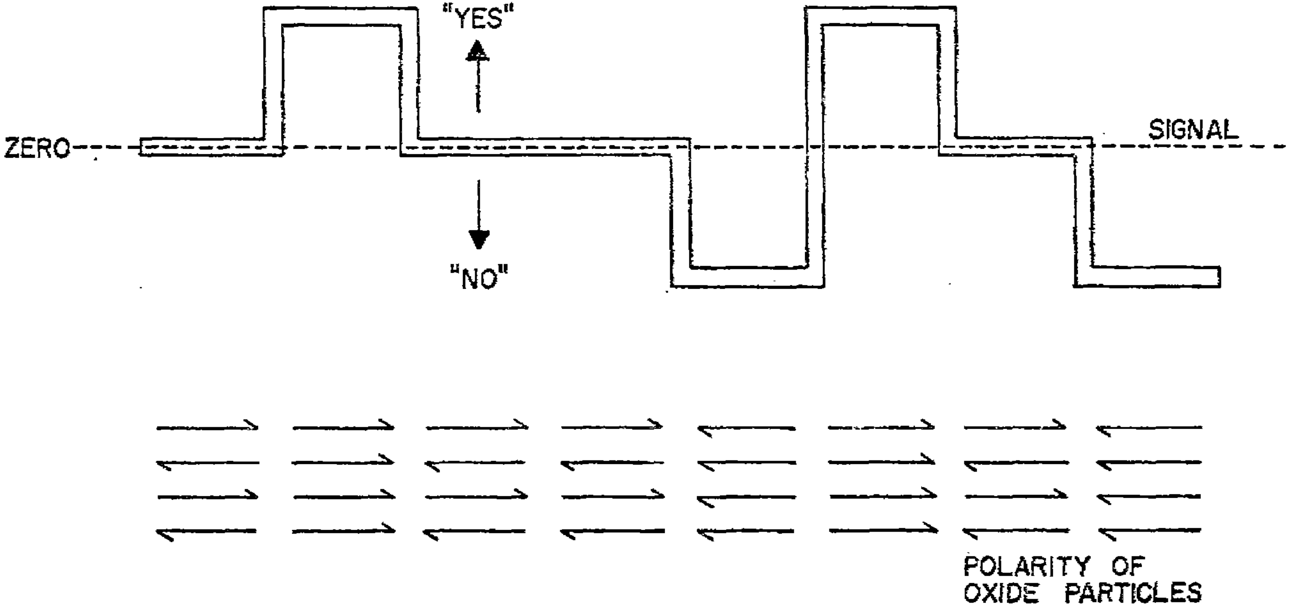


FIG. 5

SAMPLING RATE INFLUENCE

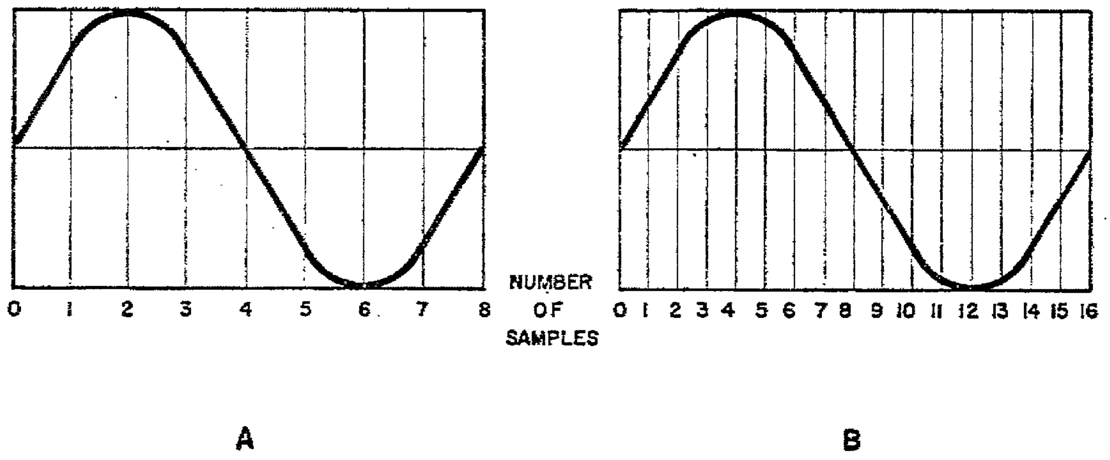


FIG. 6