# A Quasi-Technical Discussion of MAGNETIC RECORDING


Fig. 1. Tape recorder recently developed by Armour Research Foundation. A dual head permits two-direction operation. One-half of tape width is used for each direction.

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***Basic principles involved in the design and operation of present-day wire and tape recording equipment.***

IT HAS been pointed out from time to time that several factors in the design and operation of magnetic recording devices have not been given adequate explanation. An attempt will be made in this discussion to explain those points that appear to have the greatest importance.

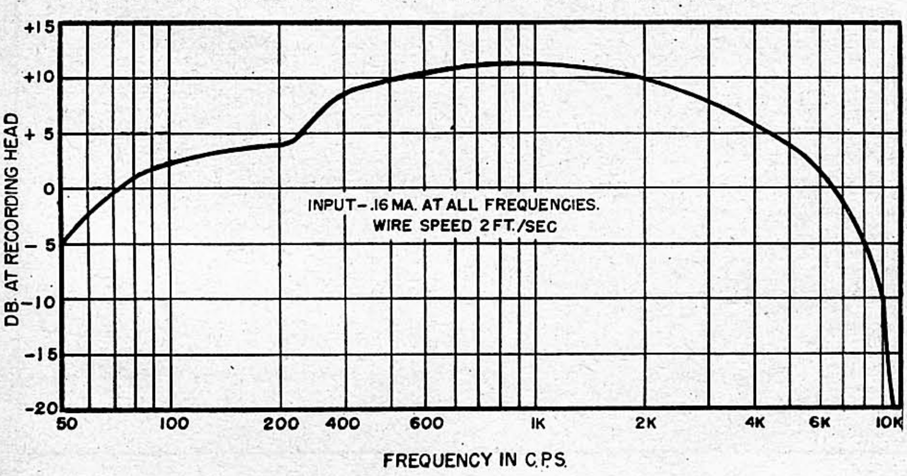
### Magnetic Media

Media suitable for use in magnetic recording may include a variety of physical shapes, but must lie within a comparatively restricted range when consideration is given to magnetic properties. Most common commercial usage is today confined to extremely small diameter (in the order of .004″) wire, and thin tapes (approximately ¼″ width), which are coated with the magnetizable material which has been prepared in powder form. The tape base may be of any material that will satisfactorily meet the requirements of flexibility and economy having, of course, a nonmagnetic characteristic. Plastic and paper-based tapes are commercially available.

Recording magnetically is made possible because of the ability of some ferromagnetic materials to retain a certain amount of the magnetic induction after the applied fields have been removed. This retained induction is termed "remanence." Another important magnetic property is the "residual induction" which is defined as the magnetic induction at which the magnetizing force is zero when the material is in a symmetrically cyclic magnetized condition. As is commonly known, a characteristic relationship between "residual induction" and the "field intensity" which produces it is not of a straight line, or linear nature. While the degree of non-linearity varies depending upon the magnetic characteristics of the medium, it is at once apparent that recording over such a characteristic would result in high distortion content. This undesirable effect may be considerably reduced through the application of a "bias" field which will be considered later.

Wartime wire recorders were designed to operate with a .004″ diameter medium carbon steel wire. While it was a recognized fact that this medium had some rather undesirable limitations, the exigencies of war did not permit further research into the problem at that time. Operation of these devices in tropical climates soon proved the vulnerability of this recording medium to moisture and consequent rust. Wire breakage resulted if the level wind mechanism became out of phase and caused wire overlap. While these recorders were not de-

Fig. 2. Frequency response characteristic of a high impedance (18,500 ohms at 20 kc.) head without equalization. Output from head is approximately 13 millivolts.



signed for fidelity reproduction, the low signal-to-noise ratio and limited frequency response were also substantially attributable to the wire characteristics. Research was accordingly directed toward stainless steel alloys. 18/8 (18% chromium and 8% nickel) stainless steel recording wire was developed as a result of this intensive research. Its qualities as a recording medium consisting of high signal-to-noise ratio and a minimum of cross-talk characteristics between adjacent strands of wire, were immediately recognized. Special processes were developed to insure optimum magnetic characteristics. Coercive forces in the order of 200-300 oersteds and $B_r$'s near 2000 gauss appeared to approximate this ideal, although these values, of course, represent compromises from several standpoints.

Magnetic recording tape is presently being manufactured by the *Minnesota Mining & Manufacturing Company,* the *Indiana Steel Products Company,* and the *Brush Development Company.* Inasmuch as there is a greater cross sectional area presented to the record-playback head with this medium, the speed with which it is driven past the head can be substantially less than with wire. While commercial home entertainment wire recorders all operate at the standard wire speed of 2 feet-per-second, tape recorder speeds have not so far been standardized. Most tape devices, however, operate at either 7½" or 8" per second. At the relative wire and tape speeds in use, frequency response and dynamic range are quite similar when the two media are compared. Naturally, there are some advantages and disadvantages to both systems when specific applications are considered; however, the buyer of a home entertainment recorder must rely upon personal preference when making a choice. A tape recorder employing two-direction operation and recently developed by the *Armour Research Foundation,* is shown in Fig. 1.

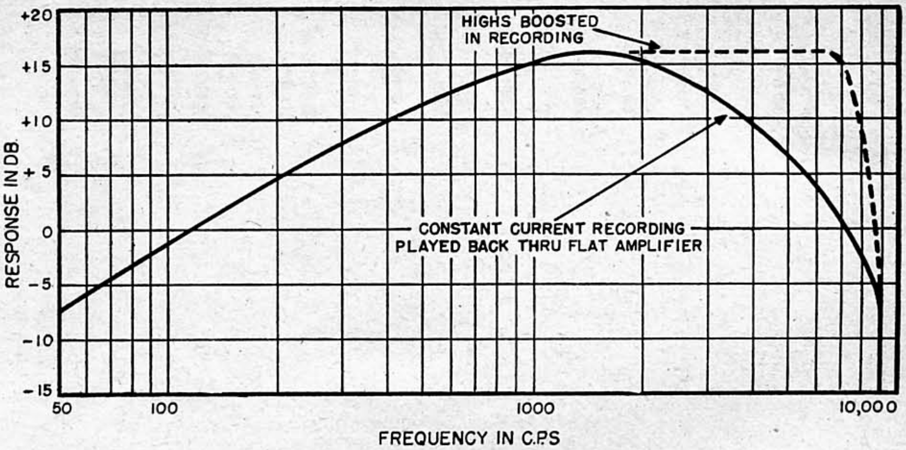



**Fig. 3. Curve shows necessary high frequency pre-emphasis during recording operation. The low frequencies are boosted during playback.**

### High Frequency Bias

Since the days of the original wire recorder, as designed and constructed by *Valdemar Poulsen,* it became apparent that it would be necessary to operate on a linear portion of the characteristic curve in some manner. This may be accomplished through the addition of superimposed alternating or direct fields of proper magnitude. The d.c. bias results in an inherent noise on the medium when the recording is played back. The application of a superimposed field has been termed "bias," notwithstanding the fact that there exists no similarity between this usage and bias as it is commonly understood in the electronics field.

When an alternating field is used for bias, the medium is recorded symmetrically about zero magnetization. Inasmuch as it is necessary to use a field considerably beyond the highest audio frequency recorded, the terminology "supersonic bias" has been applied. [See Bibliography 1, 2, 3, 7.]

This bias is normally at least 5 times the highest recordable audio frequency so that no modulation components will lie within the audio range. The magnitude of the bias field is usually adjusted to a value such that the operating point with zero audio signal will be located at the lower knee on the residual magnetization curve. In general, this can be accomplished with low bias power. However, the optimum value is dependent upon the design of the record head, and wire or tape being used.

Inasmuch as it is highly desirable to use the wire or tape over again for successive recordings, it is necessary to furnish a means to demagnetize or erase the recorded signal. While this may be accomplished by applying a d.c. field, or even a permanent magnet, both systems result in magnetically polarized areas along the medium which will greatly increase the noise level on later recordings. In very much the same way that a magnetized

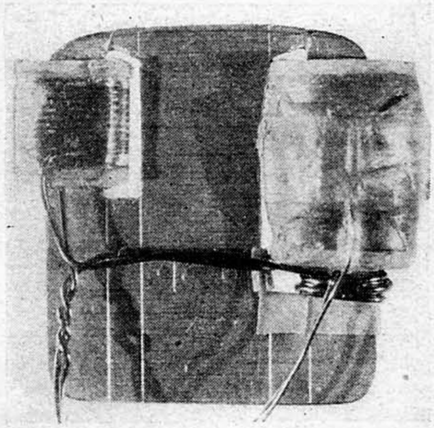


**Fig. 4. One of the first heads designed for stainless steel wire recording.**

watch is made magnetically neutral, the medium may be subjected to a high frequency erasing field before it approaches the record head to receive

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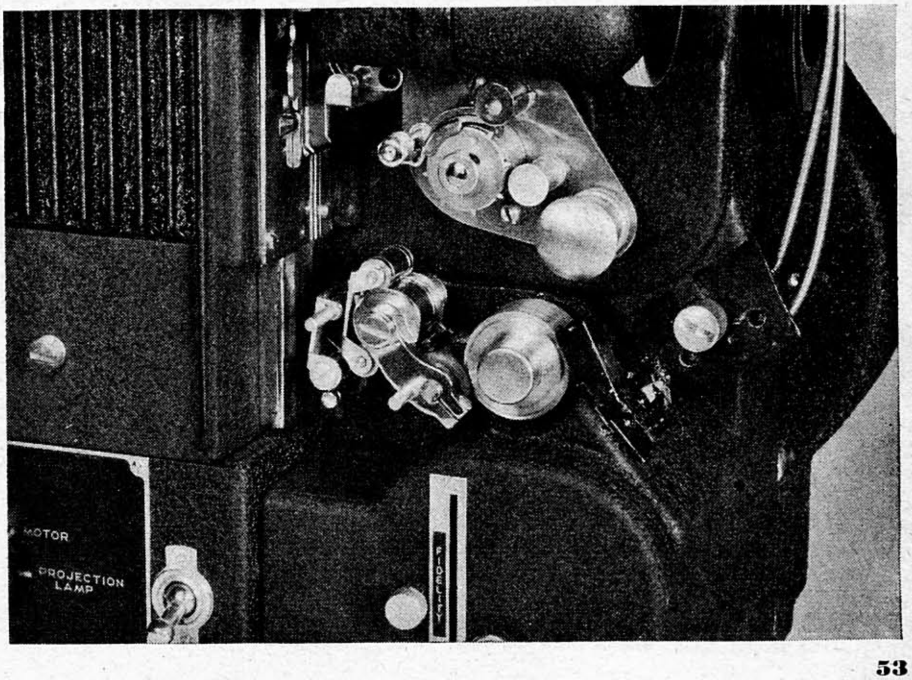
**Fig. 5. Closeup view shows head location on a converted 16 mm. projector. This conversion was made by the Armour Research Foundation.**



## Magnetic Recording

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a new recording. This field may be supplied by the same oscillator that supplies the supersonic bias. The magnitude of the necessary erase energy is dependent upon the head design and the recording medium. It, therefore, follows that if an intensely strong audio signal has driven the medium up to its saturation point, erasing may not be complete if the erase current has been predetermined and set at too low a value.

### Drive Systems

Several different methods may be used to move or drive the magnetic medium. The type of drive system adopted depends upon the purpose for which the recorder is to be used, and the degree of perfection to be expected from the over-all system.

If a recorder is to be designed as an office dictation device in which only speech recording is to be made, a fairly high degree of wire or tape speed variation may be tolerated. This is because flutter or wow, which results from a variation in the speed of the medium, is not easily discernible, and not objectionable when the spoken word is recorded and played back. This is perhaps true for three reasons; first of all, because individuals are accustomed to listening to a variation in the rate or delivery of spoken sentences; second, the average voice range consists of relatively low frequency components, consequently, rate changes are far less pronounced than with higher frequency components; and, third, staccato components of speech are not easily affected by flutter or speed variations.

Musical recording, of course, must take place with a minimum of variation in the speed of the medium. Long sustained musical notes, or instruments in which the trueness of reproduction depends upon harmonic components, are especially vulnerable to the smallest degree of flutter, or wow. Consequently, a drive system that will fulfill the most stringent requirements must be utilized for really flutter-free operation. Such a method is the so-called "capstan drive." This arrangement which was named for its analogous counterpart to the marine application of the capstan, normally requires approximately a half turn wrap of the magnetic medium around the capstan, in which a good frictional contact has been made. The capstan is normally sufficiently weighted with a flywheel so that once the proper operating speed has been attained, inertia effects will insure constant speed. Speed variations of .1 of 1% may be realized through this design.

While the capstan system approaches the ideal from the recording standpoint, it is somewhat expensive, space consuming, and difficult to manufacture on a production basis. A quite satisfactory spool drive may be accomplished through the use of roller devices which have a rubber surface. When intermediate idler mechanisms of this nature are employed, it is important that the surface configuration be as truly circular as is attainable. This type of drive has been adopted by several manufacturers presently producing magnetic recording equipment. It is very satisfactory for most musical recording.

Possibly the simplest type of drive mechanism, and that employed on earlier recorders, is the belt drive. While slippage and belt tension do become a problem when this is employed, they may be minimized through the use of neoprene belts which maintain tension for a long time. Belt drive is currently being used for magnetic recording devices engineered for business dictation uses.

### Heads

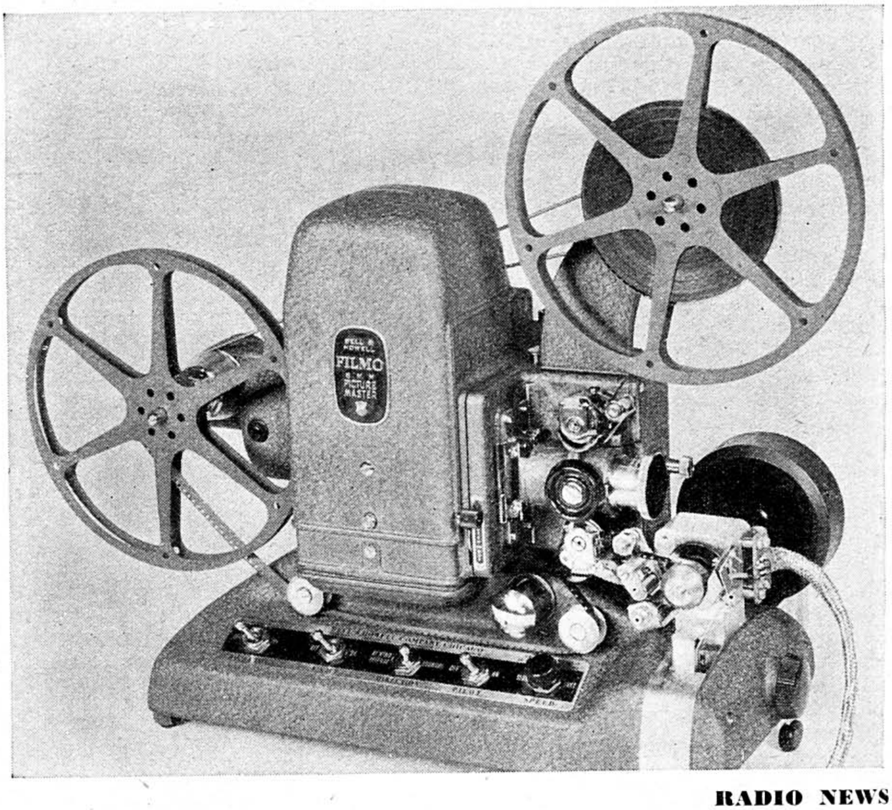
Magnetic heads of the combination record, playback, and erase types have received a great deal of research time. Initially, the erase coil was designed as a separate component from the head proper; however, today, all three functions are combined in one head. Research at the *Armour Research Foundation* has included both open-slot and thread-through heads for wire of various types and designs. A number of heads for tape, both of the high and low impedance types, and heads for motion picture magnetic sound including 35 mm., 16 mm. and 8 mm. equipment have been designed. [See Bibliography 1.]

The first wire heads were designed for use with medium carbon steel wire. These heads were wound on a laminated core and were of the open type (the recording medium did not have to be threaded through the coil area). Because of the magnetic characteristics of medium carbon wire, erasing did not require a strong field. When the stainless steel medium was adopted, head redesign became necessary in order to increase erase efficiency. One of the first heads designed for the stainless steel wire is pictured in Fig. 4. This head was originally designed to erase wire having a coercive force in the vicinity of 200 oersteds. Its core was made of *Allegheny* 4750, an alloy approximately 50-50 nickel-iron, manufactured by the *Allegheny Ludlum Company* of Pittsburgh, Pennsylvania. This head included a recording coil containing 3000 turns of #44 *Formex* wire, an erase coil of 20 turns of #28 *Formex* wire and a coupling coil in series with the erase coil and located adjacent to, but above the recording coil. This latter coil consisted of 4 turns and supplied the supersonic bias component. The recording gap of .002" and the erase gap of .010" were filled with solder after they had been shaped and cut. Constructing a head for either magnetic wire or tape is a precision operation and should be done with great care.

Originally, closed type magnetic heads in which the magnetic medium is passed through the erase or record-playback coils were more highly efficient than the open type. However, recent improvements in open type head design has made possible excellent results equalling closed head performance.

Magnetic heads may be designed to use either high or low impedance windings. While the low impedance

Fig. 6. An 8 mm. projector converted for experimental magnetic sound-on-film recording.



head is somewhat superior from the standpoint of response characteristics, the cost of the coupling transformer precludes its use in low cost equipment. The high impedance head shown in Fig. 4 has a d.c. resistance of 385 ohms and an impedance of 18,500 ohms at 20 kc. Unequalized response for this head is shown in Fig. 2.

### Equalizers

It is apparent from Fig. 2, that in order to make recordings pleasing to the listener, it will be necessary to add some form of frequency equalization into the recording or playback amplifiers, or both.

While logic would indicate the desirability of a perfectly flat frequency response, the optimum recording-playback frequency response curve is affected by several influencing factors including the performance of associated equipment, i.e., microphones, loudspeakers, and individual preference. Another factor of importance must take into consideration whether the recording is made up of entirely music or speech components. We will have to assume, however, that it is desired to achieve a flat response over as great a range as is practicable using available media, heads and standard speeds of operation. [See Bibliography 3, 7.]

In order to approach this problem, it is necessary to know: (1) the approximate level of recording and to have an energy versus frequency curve covering the program; (2) the unequalized response characteristic of the recording medium and heads; (3) information to enable the determination of the overload level; (4) information concerning the noise level over the usable range; and (5) anticipated harmonic distortion and hum to be expected in the amplifiers.

In considering a recording equalizer, it is important to attempt to achieve a maximum signal-to-noise ratio through frequency discrimination so that there is an equal probability of overload at all frequencies. The frequency equalizer for the playback amplifier is normally designed to obtain a flat over-all response after the recording amplifier equalizer has been completed.

For several reasons it has been found expedient to pre-emphasize high frequencies during recording, and post-emphasize lows on playback. Normally, high frequency pre-emphasis is designed to boost frequencies which are above that of maximum response to the level of the frequency of maximum response. This is shown in Fig. 3. The playback amplifier, designed to boost low frequencies, must be carefully designed so as to minimize hum as far as possible. Normally, the low frequency drop off is quite linear, and a low frequency boost of 5 or 6 db. per octave will be satisfactory.

### Signal-To-Noise Ratio and Dynamic Range

Determination of the effective signal-to-noise ratio of a magnetic recorder system depends on several factors. Important among these are the magnetic properties of the medium and its vulnerability to magnetic noise, the speed of the medium, cross-talk or magnetic transfer, mechanical noise resulting from mechanical imperfections in the media, amplifier noise, the effect of stray electrostatic or electromagnetic fields and consideration of the frequency distribution along with considerations relating to the amount of pre- and post-equalization employed.

Dynamic range, which is dependent upon the signal-to-noise ratio, is also a function of the various noise contributions referred to in the previous paragraph and is usually in the order of from 35 to 45 db. for the entire system. This may be raised by careful design.

### Speed vs. Fidelity

The speed at which the recording medium is driven has a very marked effect on high frequency response of a magnetic recording system. The low frequency response, however, is affected only slightly. [See Bibliography 4.]

This high frequency effect is mainly caused by self-demagnetization in the wire or tape and by the relation between wavelength and gap length. Inasmuch as self-demagnetization is not important at the low frequencies, speed reduction does not have much of an effect. As the frequency is increased, self-demagnetization becomes quite evident and increases rapidly with speed reduction after a critical frequency has been reached. High frequency response is also reduced unless the gap length is much less than the audio wavelength.

Through the determination of a constant current frequency response curve at a given wire speed, it is not difficult to obtain curves showing frequency versus speed effects. This may be accomplished by playing back a fixed wavelength at varying speeds, which will render demagnetizing and gap length effects ineffective as they will remain constant. The output voltage will be directly proportional to the speed.

While most commercial home entertainment magnetic recorders will give an essentially flat response from approximately 100 to 4500 cycles, it is possible to design magnetic recording equipment into a really high fidelity recording system. *Armour* has designed a master wire recorder essentially flat in response from 40 to 14,000 c.p.s., and equipment rendering a similar response is available commercially.

### Magnetic Sound for Motion Pictures

In the discussion of magnetic media, heads, etc., this latest application of magnetic sound was intentionally omitted. As a direct outgrowth of magnetic tape recording, the idea of placing a magnetic sound track on the edge of the film was a further step in the utilization of magnetic recording.

Experimental work has so far included the conversion of projectors of 35 mm., 16 mm., and 8 mm. sizes and has proven to be an exceedingly satisfactory means of motion picture recording. Frequency response, essentially flat to 5000 c.p.s., can be easily attained at 24 frame-per-second, 16 mm. sound speed. Response to 3000 c.p.s. can be obtained at conventional 8 mm. speed. [See Bibliography 5, 6.]

Magnetic heads can be either of the high or low impedance type, however, the low are to be preferred so as to minimize hum pickup and decrease head size. The sound track consists of a special iron oxide coating which is applied to the edge of the film. This track is approximately .032" wide and ½ mil thick, placed outside of the sprocket holes.

Some means of film speed stabilization is necessary for satisfactory projector operation with magnetic sound as with optical sound so as to minimize sprocket flutter and wow as far as possible.

Figs. 5 and 6 show head location on converted 16 mm. and 8 mm. projectors, respectively. This is not a conversion that can be accomplished easily in a home shop. Neither the material for coating nor heads are as yet available on the commercial market.

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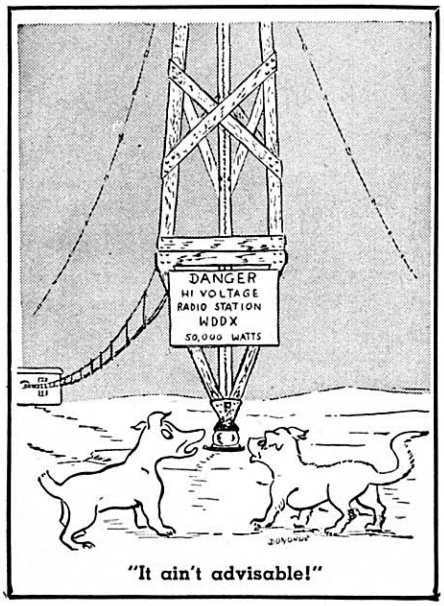


"It ain't advisable!"