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INSTRUMENTATION FOR MAGNETIC RECORDING RESEARCH

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ABSTRACT

An instrument has been designed and constructed for obtaining experimental data needed in the investigation of the performance of magnetic recording-reproducing equipments and processes. The design factors and the circuitry involved are given in detail. Sample data obtained are presented with pertinent discussion of many of the principles of magnetic recording.

PROBLEM STATUS

This is a final report on a small portion of the larger problem; work on the larger problem still continues.

AUTHORIZATION

NRL Problem No. S05-01R

INSTRUMENTATION FOR MAGNETIC RECORDING RESEARCH

INTRODUCTION

In the normal course of collecting research data, it has been found that in a great many instances some method of recording and reproducing that was adaptable to the many and varying Navy problems would facilitate not only the taking of the data but also its later interpretation. But because of the fact that the recording must be done under certain definite conditions and meet special requirements, it has not been utilized to any great extent.

Some of these conditions and requirements are:

1. Data must be taken in the field as well as in the laboratory. Therefore, the recording must be accomplished under conditions such as exist aboard ship, in aircraft, in submarines, and in other types of vehicles.

2. The times required for continuous recording may range from a fractional part of a second to an hour or more.

3. Some applications require high-speed recording and low-speed reproducing, or low-speed recording and high-speed reproducing. The ratio of the recording to reproducing speed or the reproducing to recording speed may be 100 to 1 or greater.

4. The frequencies involved in some applications may be as high as 100,000 cps and may be as low as a fraction of a cycle per second.

5. An analysis of the recorded data is often required. This usually can be accomplished by the use of an endless reproducing track so that the same data can be presented repeatedly to proper measuring or analyzing equipment. These required endless tracks may vary in length from a fractional part of a second to a minute or more.

After a study of the characteristics inherent in the many recording methods - cut disk, embossed disk, embossed film, optical film, magnetic (wire and tape), etc. - was made, only one process, the use of magnetizable media, showed promise in its ability to meet these very special requirements.

The magnetic process is capable of recording under conditions of shock and vibration. Its possible compactness lends itself to portability. By the proper choice of one of the many types of media (coated tapes, metal tapes, wires, coated drums, etc) a wide range of recording times may be made available. The drum-type recording-reproducing equipment is especially suitable for a wide range of operating speeds. For analysis, either the drum-type recorder-reproducer or endless loops of tape may be used.

Therefore, in view of the versatility of a magnetic recording-reproducing system, both as a research tool and as a possible assist to operational functions, investigations were made of the state of the art. It was found that most information about any given recording design problem must be obtained experimentally. Furthermore, because of the large number of variables, it is impractical for a group that is interested in only one particular application to set up experimental equipment to determine the optimum values for the several design parameters. It would seem more practical for one qualified group to set up a flexible test instrument from which design data for any possible application could be obtained.

Since this definite need for design information existed and since most of the problems involved lay outside the field of commercial activity, the Recording Group of the Transducer Branch of the Sound Division proceeded with the design and construction of a suitable experimental test instrument.

This instrument has been designed so that practically all factors of a magnetic recording-reproducing system can be controlled over wide ranges, and so that complete tests can be made on components, such as media and heads, as well as on over-all systems. This testing can also include the use of various types of drives and storage systems such as reels, loops of narrow or wide coated-tape, loops of metal tape, coated drums, etc.

The first section of this report is confined to the specific details of the testing instrument itself. The second section exhibits the various types of data that can be obtained, accompanied by a discussion of those basic principles of magnetic recording needed for a full understanding of the data presented.

DESCRIPTION

A simple magnetic recording-reproducing system must include the following component parts:

1. A recording amplifier with a special driving stage to energize the recording head properly in accordance with some desired frequency characteristic.

2. Proper erase and bias supplies to apply, through suitable heads, magnetic energy to the medium so as to produce the best possible results consistent with the requirements of the particular application.

3. Some type of drive mechanism to transport the magnetic medium at the desired speed, and some type of storage system to hold the unused medium as well as the medium after it has been acted upon by the recording head.

4. A low-noise-level reproducing amplifier including the desired equalization circuits.

A flexible test instrument must have all of the foregoing basic component parts and in addition must provide for adjustment of all variables over wide ranges. Various types of test signals should be available to the input of the recording amplifier and several types of measuring and analyzing equipment should be operable from the output of the reproducing amplifier. The subject instrument of this report was designed to follow these specifications.

All of the necessary components of this instrument have been assembled into a fixed structure consisting of four 6-foot relay racks of standard width as shown in Figure 1. All component parts are functionally placed and their locations are shown in Figure 2.

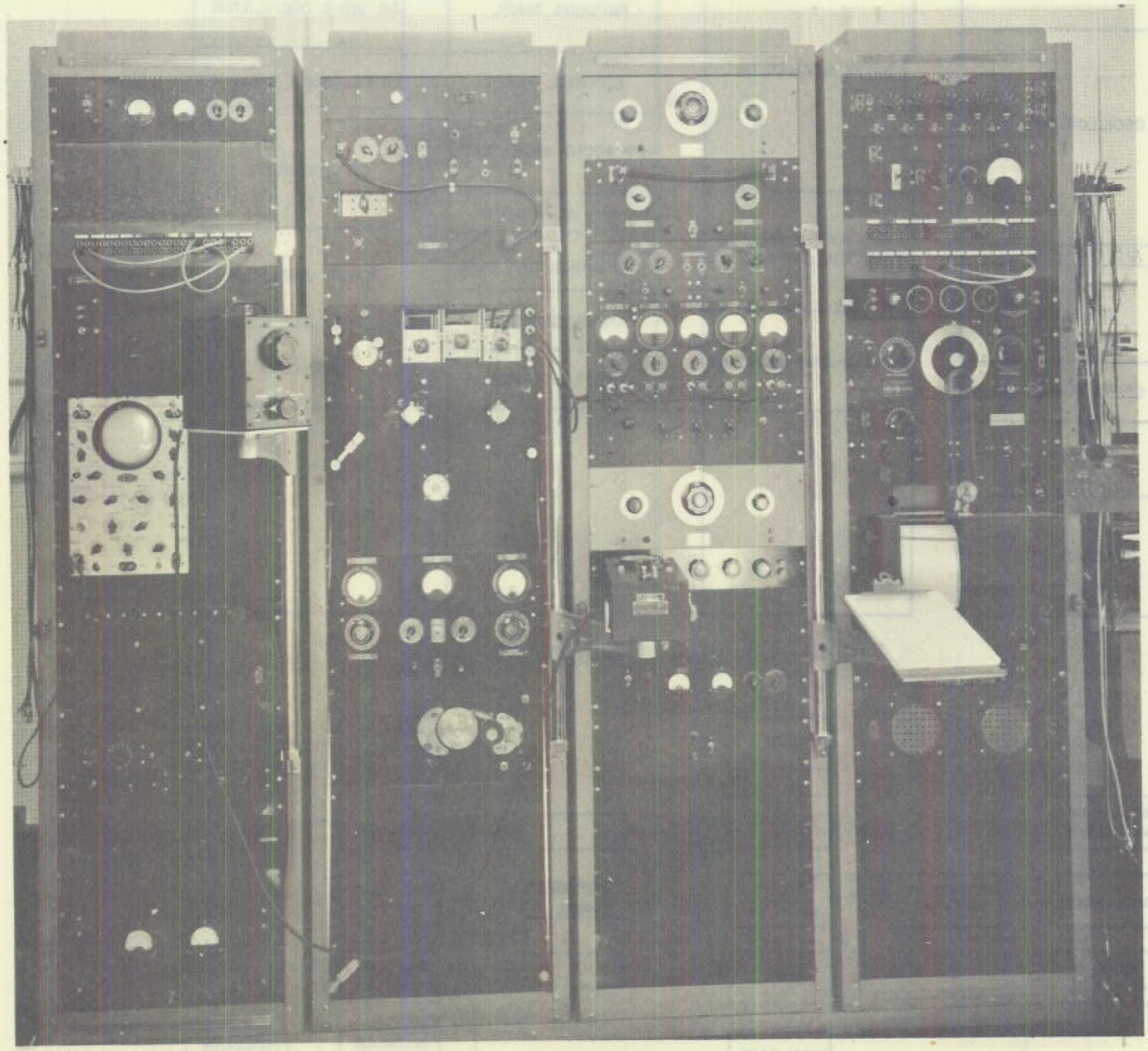


Fig. 1 - The complete magnetic-recording test instrument

In general, signal sources are in the right end rack, recording components are in the right middle rack, drive mechanisms are in the left middle rack, and reproducing and measuring instruments are in the left end rack. Figure 3 shows a simplified block diagram of the over-all system.

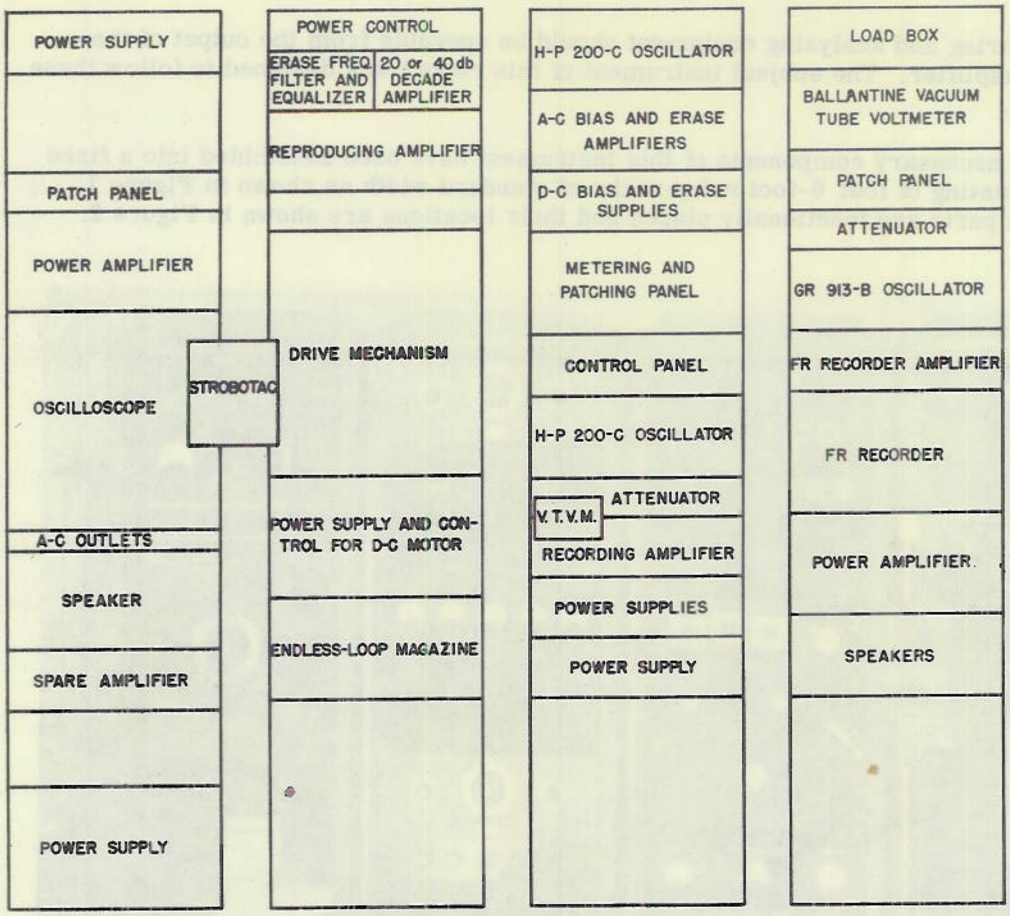


Fig. 2 - Location of components

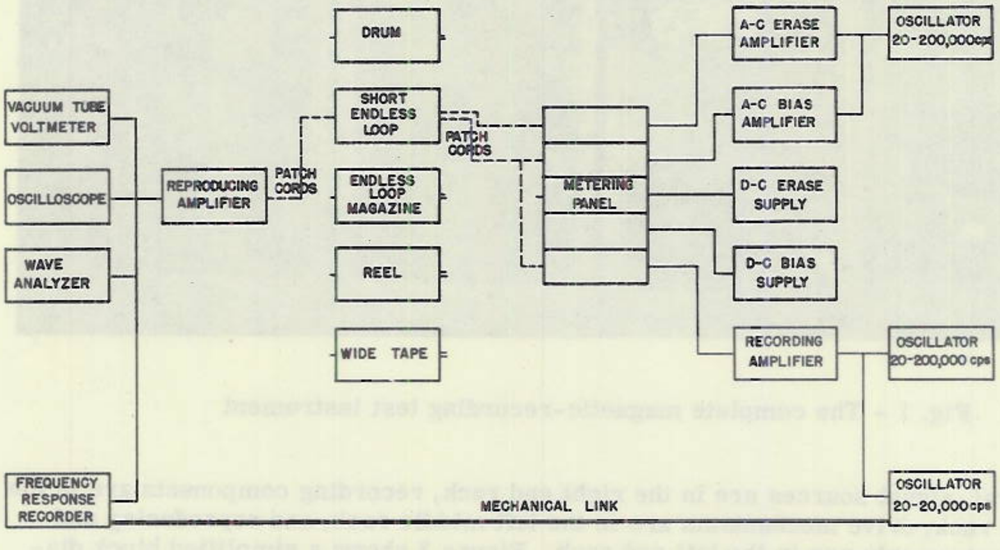


Fig. 3 - Block diagram of magnetic-recording testing instrument

Signal Sources

For supplying sine-wave test signals, two oscillators are available: One, a General Radio 913-B, is usually used for frequencies from 20 to 20,000 cps; the other, a Hewlett-Packard 200-C, is used mainly for frequencies above 20,000 cps. A square-wave generator is also available to supply square waves of from 5 to 100,000 cps. When special complex waves are required, the equipment supplying such signals may be mounted on a rolling table and thus be placed near the recording amplifier input.

The frequency control dial of the 913-B oscillator has a true logarithmic scale from 20 to 20,000 cps. This is conveniently driven mechanically by a graphic level recorder for the production of graphic plots of level versus log frequency in single sweeps through the normal audio-frequency range. The oscillator and recorder combination is shown in Figure 4. The graphic level recorder, made by the Sound Apparatus Company, is called an FR recorder since its main use is in drawing frequency response characteristics of equipment under test. A frequency chart paper for this recorder is available with a logarithmic frequency scale that corresponds with the scale on the oscillator when the oscillator is driven by the recorder through the correct linkage of gears.

In cases where nearly immediate reproduction of the test signal can be made, this frequency chart paper may be used. However, when there is an appreciable time delay between the recording of the signal and its reproduction, another method is more satisfactory.

A recording is made by driving the control dial of the oscillator with the FR recorder through the required frequency range with the insertion of appropriate frequency markers put in either manually by momentarily shorting the oscillator output with a hand key, or automatically by using the contactors on the oscillator dial (see Figure 4). The reproduction of this recording is then made, at any later time, by recording the output with the FR recorder using a plain chart paper having only a vertical scale representing output level. The frequency markers, in the form of a sharp dip in the output level, make it possible to align the recorded curve and trace it, if desired, on frequency chart paper.

One additional feature has been added to the oscillator-recorder combination. In view of the fact that linearity (output versus input) curves are often valuable, a device to record such curves automatically was constructed. Such a device must increase the input to the recording amplifier at a certain uniform rate while the level recorder graphically plots the output of the reproducing amplifier against this

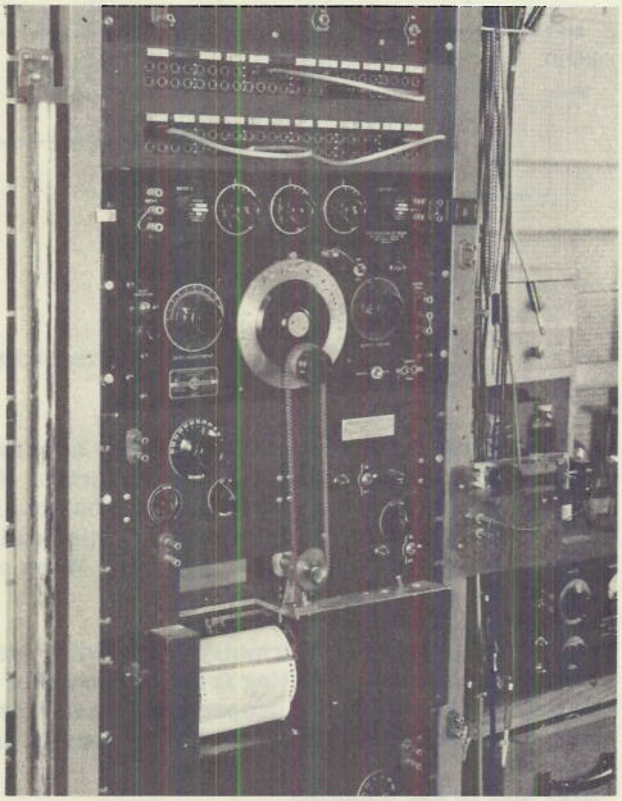


Fig. 4 - Oscillator-recorder combination and associated equipment

increasing input signal. This was accomplished by using a rack and pinion actuated by the recorder paper drive and itself actuating a contact sliding along a linear decibel-potentiometer which controls the input signal. This device can be seen in the photograph, Figure 4, protruding from the right side of the FR recorder.

Recording Amplifier

The recording amplifier is shown in Figure 5. Since the flux across the gap of a magnetic recording head is proportional to the current through the head, it is necessary to drive the recording head from a current source which, for a constant input voltage, varies the recording head current according to some selected frequency characteristic. Since for test purposes it makes comparison of data and components easier, a constant-current characteristic is usually used.

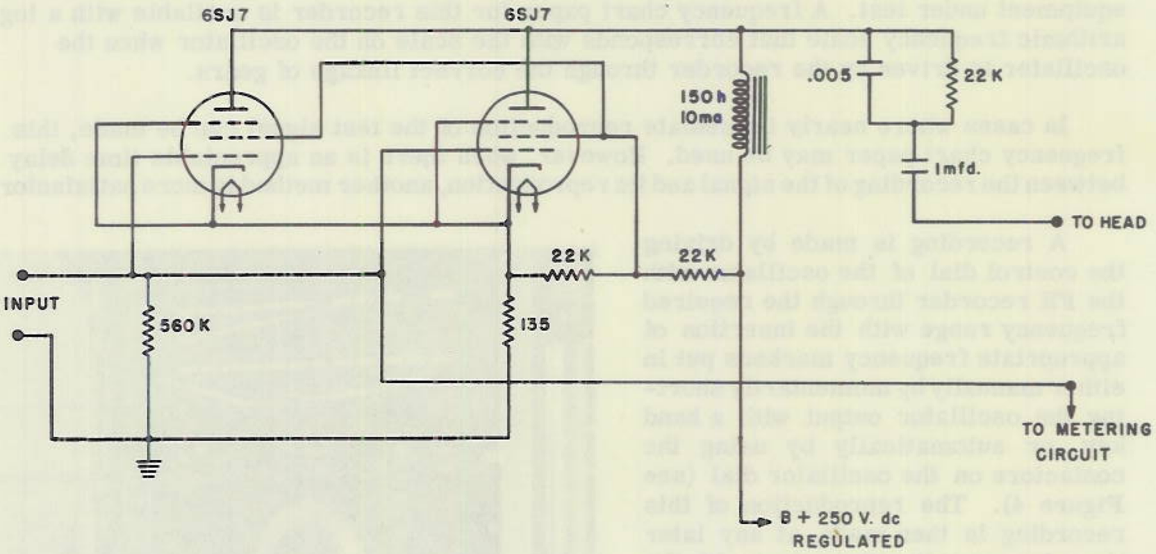


Fig. 5 - Recording amplifier

Two tubes are operated in parallel to provide more than enough current to saturate most media and still maintain low distortion of the recording current. With this particular circuit currents up to 10 ma. can be obtained for head impedance variations from 0 to 20,000 ohms. With the ordinary type head, this means that a constant current can be maintained up to 30,000 or 40,000 cps. When a higher frequency-limit is desired a lower impedance head must be used.

The input voltage normally required to drive this stage is in the order of 1 volt. Provision is made for deviating from the constant current characteristic if desired. This can be done by inserting the proper equalization networks in either the plate or grid circuit. Harmonic distortion of the recording current is less than 0.2 percent.

Bias and Erase Supplies

In order to have a versatile test instrument both ac, up to 200,000 cps., and dc must be available for biasing and for erasing. It is also advisable to have separate bias and erase supplies for absolute control over each.

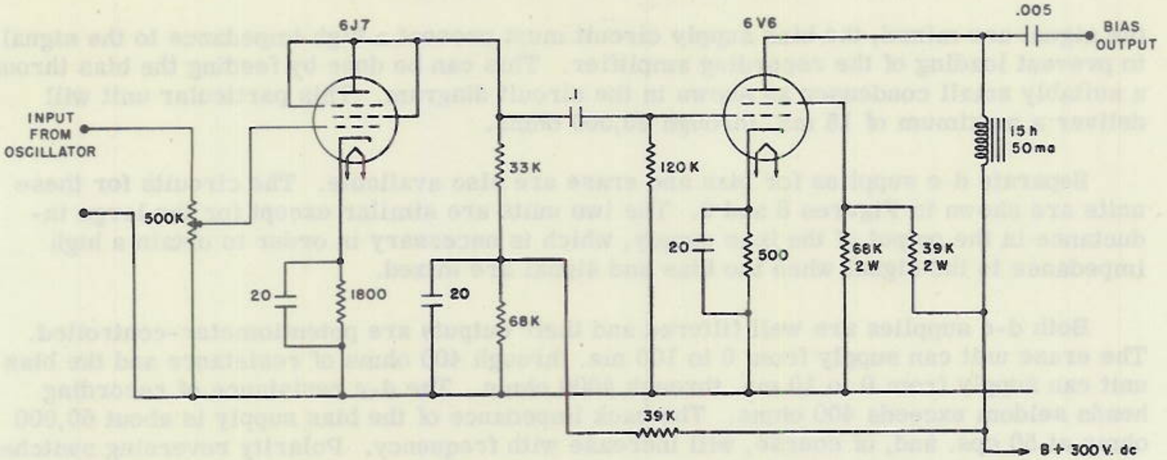


Fig. 6 - A-c bias amplifier

Alternating bias and erase currents are supplied to the heads by two separate power amplifiers which may be driven by standard oscillators. Ordinarily one Hewlett-Packard 200-C oscillator is used to drive both amplifiers but if it is desirable to have different erase and bias frequencies, two oscillators may be used. The schematic circuits of these amplifiers are shown in Figures 6 and 7. They are very similar, the main difference being the type of output tube. Gain controls are used in both amplifiers to control the current supplied to the heads. The erase amplifier will supply up to 50 ma. through an impedance of 10,000 ohms as a direct plate-connected load. For low-impedance heads that require higher currents, transformers are used.

The bias amplifier generally must work into a high-impedance load. Since the bias is usually mixed directly with the signal, and thus must pass through the recording head, the impedance to the higher bias frequencies can become very great. When the bias and

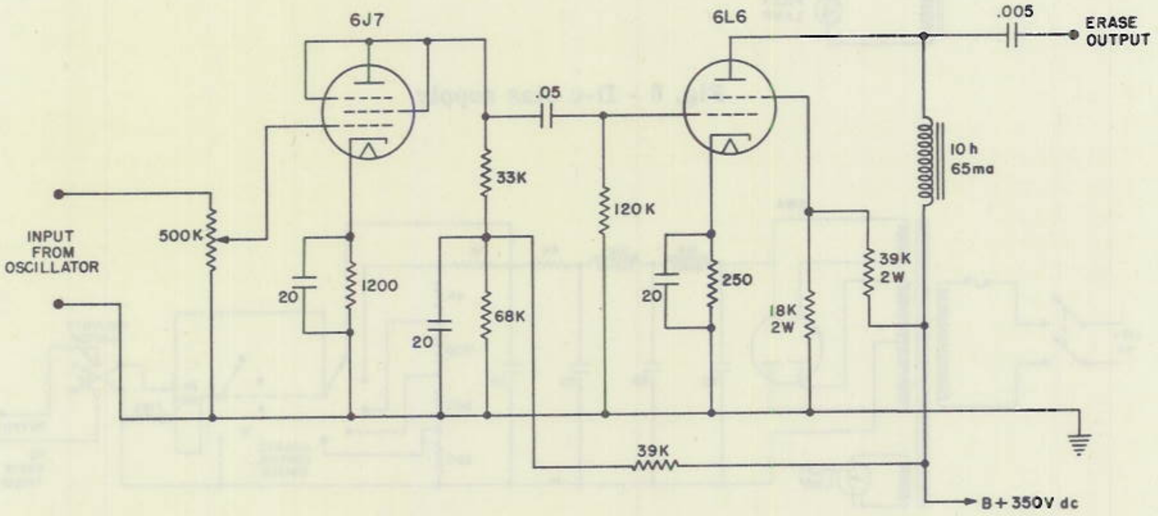


Fig. 7 - A-c erase amplifier

the signal are mixed, the bias supply circuit must present a high impedance to the signal to prevent loading of the recording amplifier. This can be done by feeding the bias through a suitably small condenser as shown in the circuit diagram. This particular unit will deliver a maximum of 15 ma. through 20,000 ohms.

Separate d-c supplies for bias and erase are also available. The circuits for these units are shown in Figures 8 and 9. The two units are similar except for the large inductance in the output of the bias supply, which is necessary in order to obtain a high impedance to the signal when the bias and signal are mixed.

Both d-c supplies are well filtered and their outputs are potentiometer-controlled. The erase unit can supply from 0 to 100 ma. through 400 ohms of resistance and the bias unit can supply from 0 to 10 ma. through 4000 ohms. The d-c resistance of recording heads seldom exceeds 400 ohms. The back impedance of the bias supply is about 60,000 ohms at 50 cps. and, of course, will increase with frequency. Polarity reversing switches are used in both supplies.

Metering Panel

The metering panel is shown in Figure 10. The outputs of the a-c and d-c bias and erase supplies, as well as the test signal from the recording amplifier, are brought to a

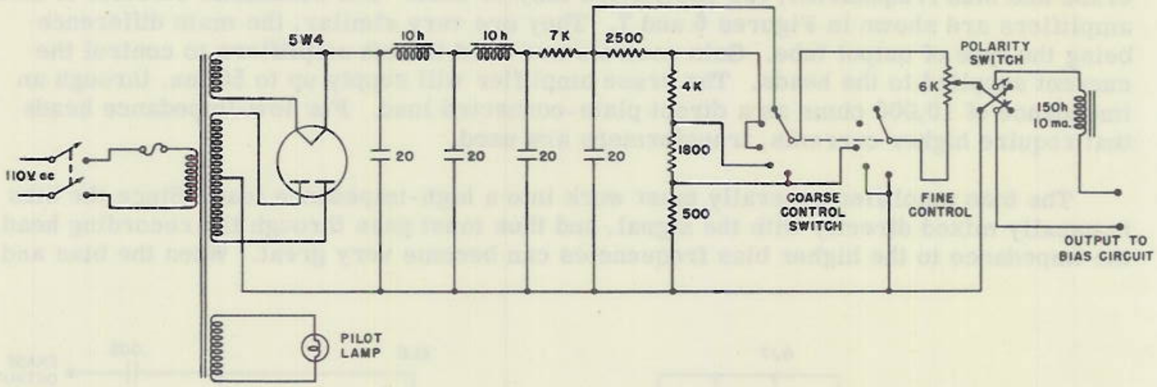


Fig. 8 - D-c bias supply

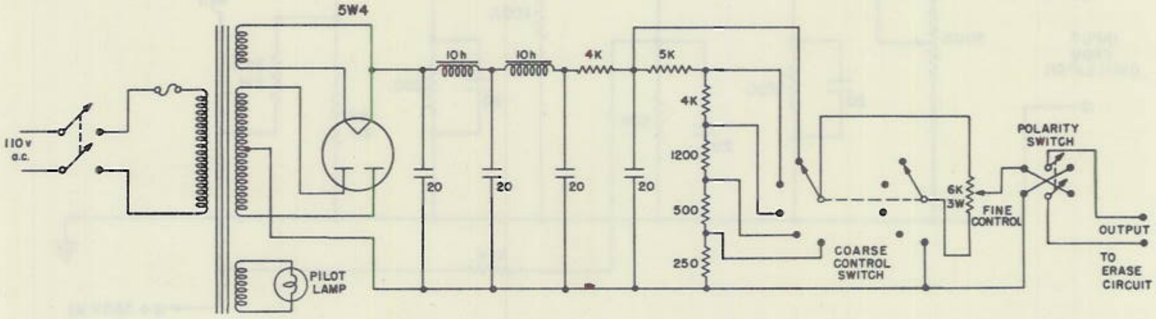


Fig. 9 - D-c erase supply

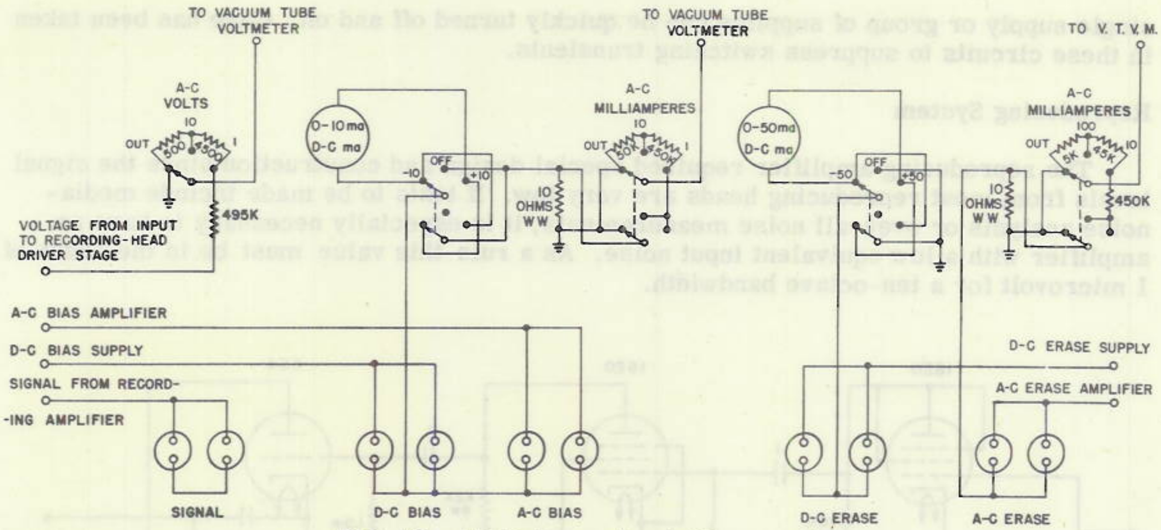


Fig. 10 - Metering and patching panel

metering panel. Each of these five sources is available at the front of the panel through Twinax connectors (Figure 11).

The top contactor of these connectors is tied to the output of the supply indicated, and the lower contactor is connected to the metering circuit. Any recording or erasing head may be connected to any supply by means of patch cords. Patching may also be done between supplies in order to mix them in any manner desired. The low side (the terminal nearest ground potential) of the recording and erase heads is kept above ground and returned to the metering panel through the lower contactor of the Twinax connectors. For a-c metering, a precision 10-ohm resistance is inserted in this return line to ground, and a vacuum-tube voltmeter is used to read the a-c voltage across the resistor. The VTVM may be calibrated to read directly in a-c milliamperes. For d-c measurements, the d-c milliammeter is inserted in the return line.

Directly below the metering panel is a control panel with three lever switches which control relays located in all the bias and erase supplies and in the recording amplifier, so that any

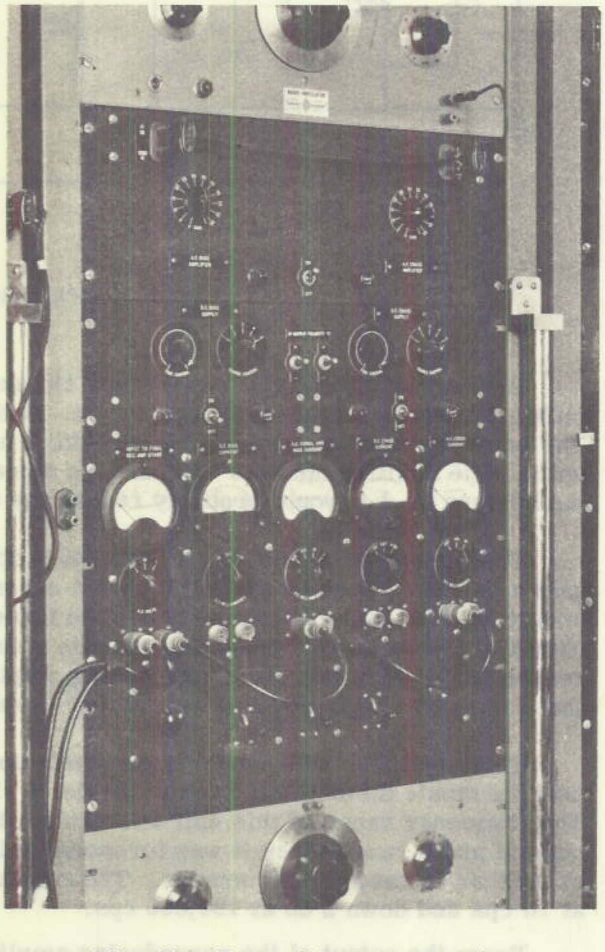


Fig. 11 - Recording components

single supply or group of supplies can be quickly turned off and on. Care has been taken in these circuits to suppress switching transients.

Reproducing System

The reproducing amplifier required special design and construction since the signal levels from most reproducing heads are very low. If tests to be made include media-noise analysis or over-all noise measurements, it is especially necessary to have an amplifier with a low equivalent input noise. As a rule this value must be in the order of 1 microvolt for a ten-octave bandwidth.

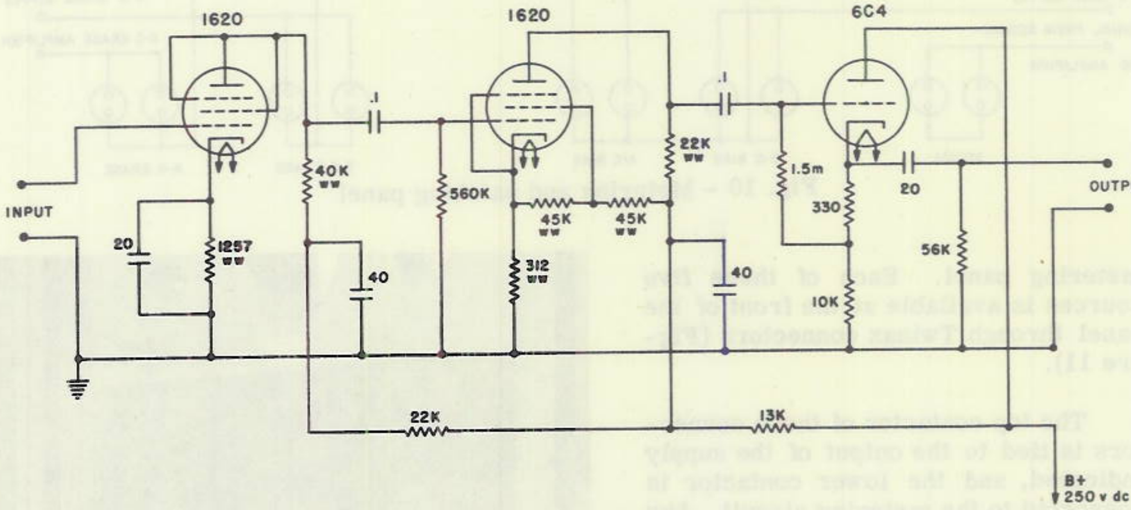


Fig. 12 - Reproducing amplifier

The reproducing amplifier (Figure 12) used in this instrument has two stages of amplification and a cathode-follower output. Both amplifier tubes are double shock-mounted. The equivalent noise input for a bandwidth from 20 to 100,000 cps is approximately 3 microvolts. The limiting noise is 60 cps. hum since the heaters are a-c operated. Operation of the heaters by d-c would probably reduce the over-all noise some 5 to 10 db.

The fixed gain of this amplifier is 46.5 db. It was believed advisable not to use a high-gain amplifier. Such an amplifier is not necessary if a low-noise amplifier is built with enough gain to raise the signal above the noise of any ordinary voltage amplifier used to obtain whatever gain is needed to operate measuring and analyzing instruments. Another reason for using a low-gain reproducing amplifier is the necessity of having an amplifier that can handle high-level as well as low-level input voltages and still have a fixed gain.

This amplifier will handle input levels up to -40 db (re 1 volt) with less than 0.2 percent harmonic distortion. Even at levels of -20 db the distortion is well under 1 percent. The frequency range of this unit was extended beyond both the low and the high end of the normal audio range since it was foreseen that many applications would involve ultrasonic as well as infrasonic frequencies. The response of the amplifier shows it to be down 1 db at 10 cps and down 2 db at 100,000 cps.

From the output of the reproducing amplifier the reproduced signal may be fed into various units. For simultaneous recording and reproducing, a rejection filter for the bias

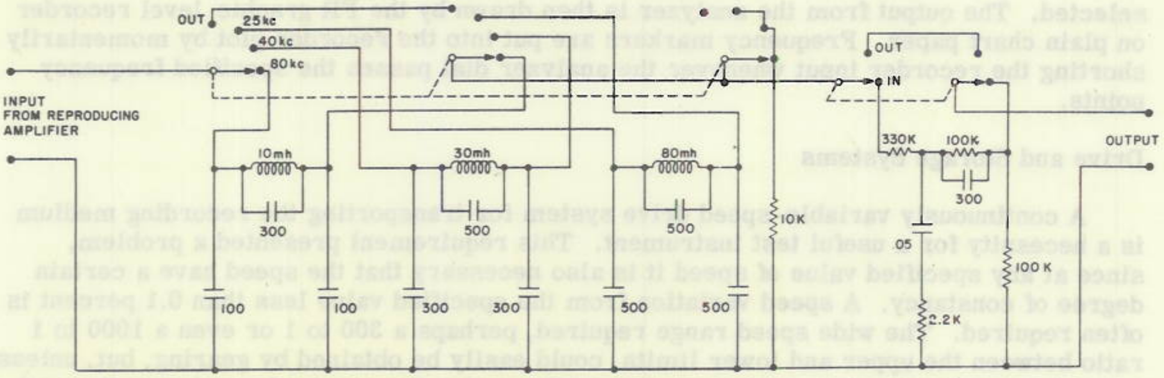


Fig. 13 - Erase-frequency filter and low-frequency equalizer

and erase frequency is usually inserted at this point. Any necessary equalization networks may also be switched in when desired. The circuits now in use are shown in Figure 13. If the signal at this point is at too low a level to operate the measuring or analyzing equipments it is fed through a decade amplifier with two possible gains, 20 db or 40 db. With this arrangement sufficient level is always obtained to operate any instrument such as an oscilloscope, a vacuum-tube voltmeter, a wave analyzer, an intermodulation analyzer, a noise meter, or a graphic level recorder.

One of the most useful pieces of equipment in magnetic-recording measurements is the Sound Apparatus FR graphic level recorder that has been previously mentioned. Since this instrument has no sensitivity control, and also since its input impedance is 10,000 ohms, a special amplifier (Figure 14) was built to precede it. This amplifier has a cathode-follower input (high impedance) and a transformer output especially matched to the input of the FR recorder. It also has two gain controls, one continuously variable, the other variable in 5-db steps. This arrangement is particularly useful since it is possible to set up any db line on the FR recorder chart as the reference level, and then shift the scale in 5 db steps either way from this reference.

For spectral analysis of media noise or of any recorded material, the output from the reproducing system is fed into an Erpi Sound Analyzer which tunes a certain bandwidth as

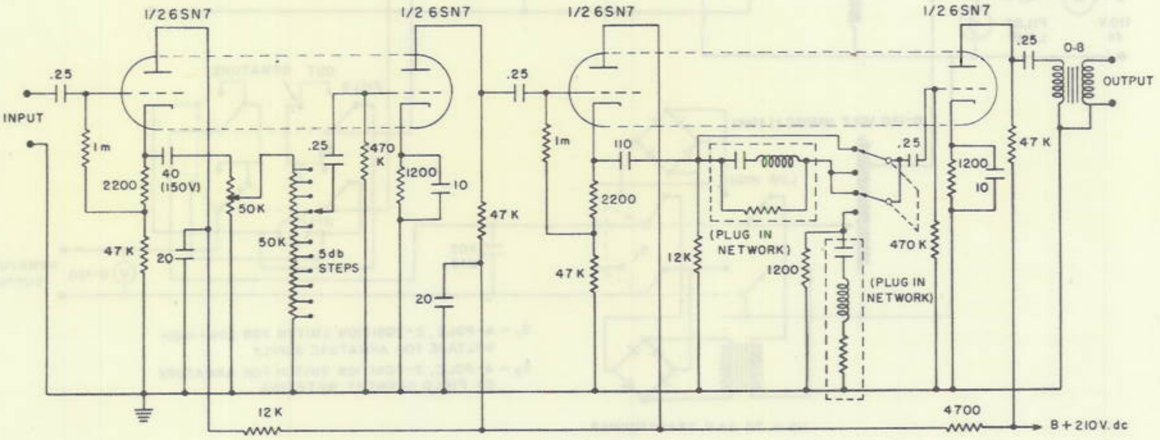


Fig. 14 - FR recorder amplifier

selected. The output from the analyzer is then drawn by the FR graphic level recorder on plain chart paper. Frequency markers are put into the recorder plot by momentarily shorting the recorder input whenever the analyzer dial passes the specified frequency points.

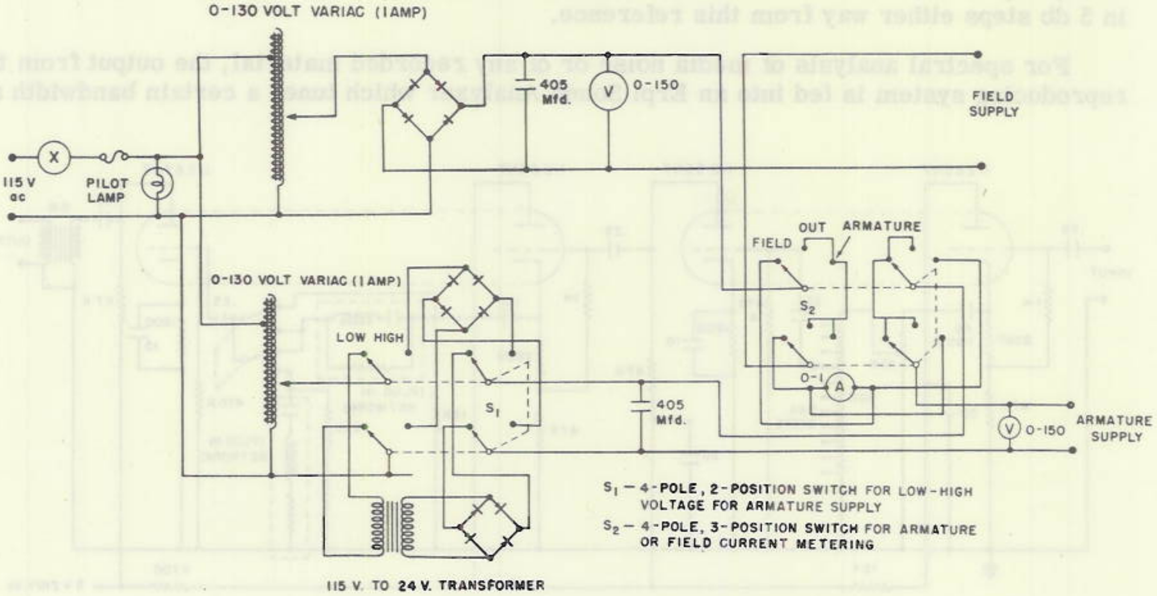
Drive and Storage Systems

A continuously variable-speed drive system for transporting the recording medium is a necessity for a useful test instrument. This requirement presented a problem, since at any specified value of speed it is also necessary that the speed have a certain degree of constancy. A speed variation from the specified value less than 0.1 percent is often required. The wide speed range required, perhaps a 300 to 1 or even a 1000 to 1 ratio between the upper and lower limits, could easily be obtained by gearing, but, unless special precision gears are obtained, they will not give the required constancy of speed. Therefore gears were ruled out and friction drives were used. Friction drives are easy to work with and under proper conditions give a sufficiently constant speed.

After much experimentation, the present setup was developed and it has proved entirely satisfactory for all tests to date. However, a change in the drive system is contemplated. This would consist mainly of making the drive system more compact and installing better speed-change controls.

The drive motor of the present system is a 115-volt d-c compound-wound motor of about 1/6 hp. and a normal speed of 1140 rpm. In order to operate this motor over as wide a speed range as possible, separate d-c supplies for the armature and the field have been furnished. Circuits of these supplies are shown in Figure 15.

The voltage from both supplies is variable from 0 to 130 volts. One of the most important factors in operating a d-c motor of this type as a variable-speed motor is to keep the internal resistance of the supply as low as possible. This is done by using selenium



S_1 — 4-POLE, 2-POSITION SWITCH FOR LOW-HIGH VOLTAGE FOR ARMATURE SUPPLY

S_2 — 4-POLE, 3-POSITION SWITCH FOR ARMATURE OR FIELD CURRENT METERING

Fig. 15 - Armature and field supplies for d-c drive motor

rectifiers driven by a variable transformer. For voltages under 30 volts, the armature supply has a selenium rectifier with fewer plates so that a lower internal resistance is obtained. With this arrangement usable shaft speeds of from 40 rpm to over 2000 rpm may be set up.

The motor shaft is textile-belt-coupled to a jack shaft for a 4-1/2 to 1 speed reduction. This jack shaft has a two-step pulley corresponding to another two-step pulley on the drive shaft that drives the media. The steps of these pulleys have a ratio of 4-1/2 to 1. This means that in relation to the motor shaft speed, the drive shaft speed either is reduced in 20 to 1 ratio or is the same. Therefore the lowest usable drive-shaft speed is about 2 rpm, and the highest is about 2000 rpm. The highest usable speed is limited by the vibration of the whole mechanism, particularly since heavy flywheels are used on both the drive shaft and the motor shaft.

The drive shaft has a tapered end; and three different capstans, 2", 4 ", and 6" in circumference, can be mounted on it. Therefore, actual speeds of the media may be as low as 1/16" per second or as high as 18' per second when driven by the appropriate capstan.

The drive shaft and head mountings can be seen in Figure 16. Three head mounts preceed the capstan, each of which can be moved in any of four degrees of freedom. This can best be understood by studying the photograph (Figure 17) and the drawing (Figure 18). Movement 1 allows for the vertical positioning of the 3 mounts in relation to each other. Movement 2 allows heads of different sizes to be adjusted so that the slot through which the tape or wire must pass is aligned with the slots of the other heads. Movement 3 permits the head to be rotated so that the tape or wire passes tangentially across the head at the gap. Movement 4 permits the gap in the mounted head to be adjusted about 10 degrees each side of a normally perpendicular position. This last adjustment is necessary since the gap of the reproducing head must be perfectly aligned with that of the recording head for accurate measurements of short recorded-wavelength signals.

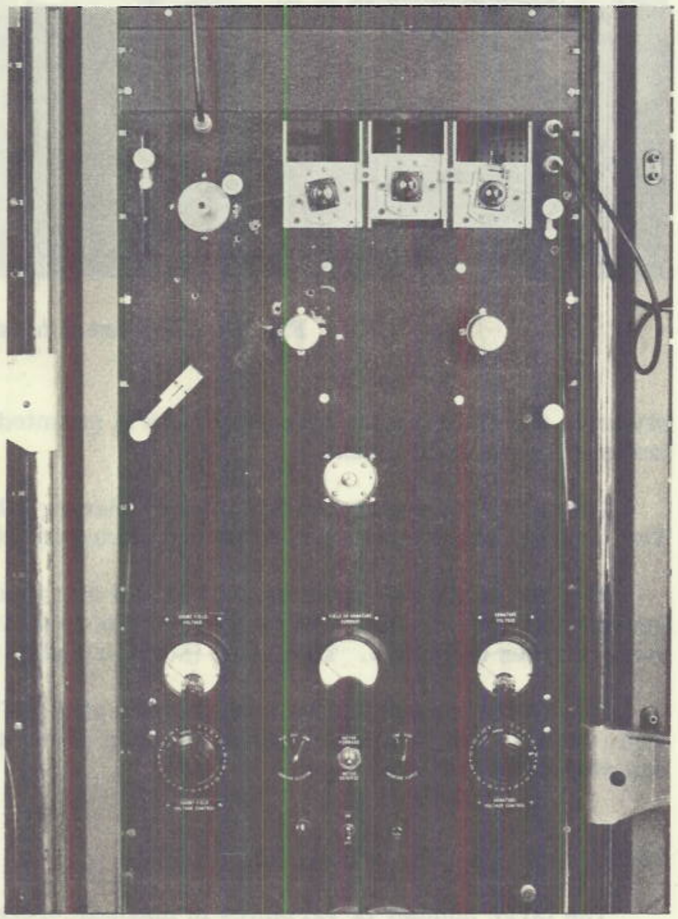


Fig. 16 - Drive mechanism

Heads of various types and designs are easily mounted by using a simple mounting plate that

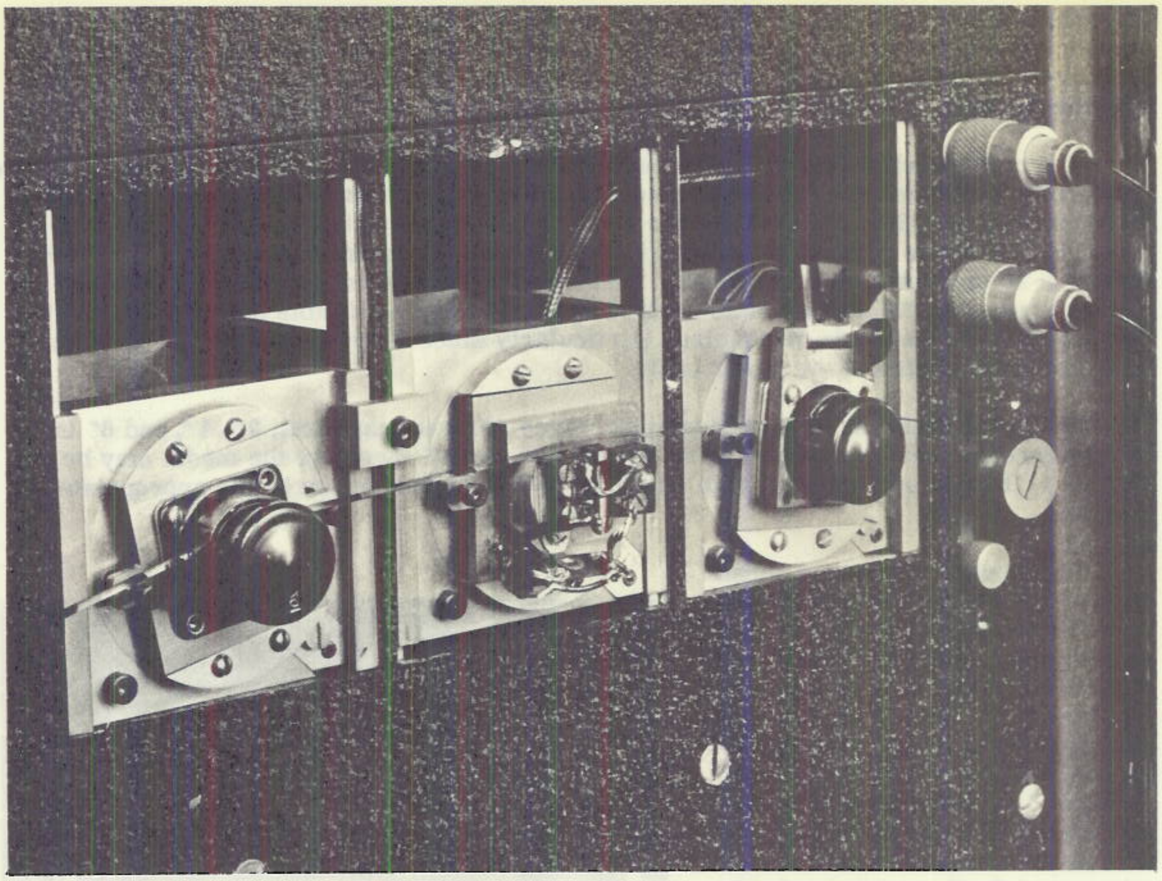


Fig. 17 - Universal head mounts

pivots in the main mount. The head is first mounted on one of these plates, which is then fastened to the main mount.

Loops of various lengths are used by placing idler pulleys at the proper locations. The longest loop commonly used is approximately 14 feet.

The two shafts for mounting standard 8 mm tape reels, 7" in diameter, are located beneath the head mounts. Below these shafts is a single shaft used to mount drums of various types and sizes. This shaft is belt-coupled to the drive system when needed.

The Strobotac that can be seen in several of the figures is used to check approximate shaft speeds. When the speed must be more accurately measured a revolution counter and stopwatch are used.

SAMPLE DATA AND INTERPRETATION

The large number of variables in magnetic-recording systems makes it necessary to select arbitrary values for many of them, if data concerning only one variable is required in a short time. The data obtained in this manner, therefore, cannot be applied

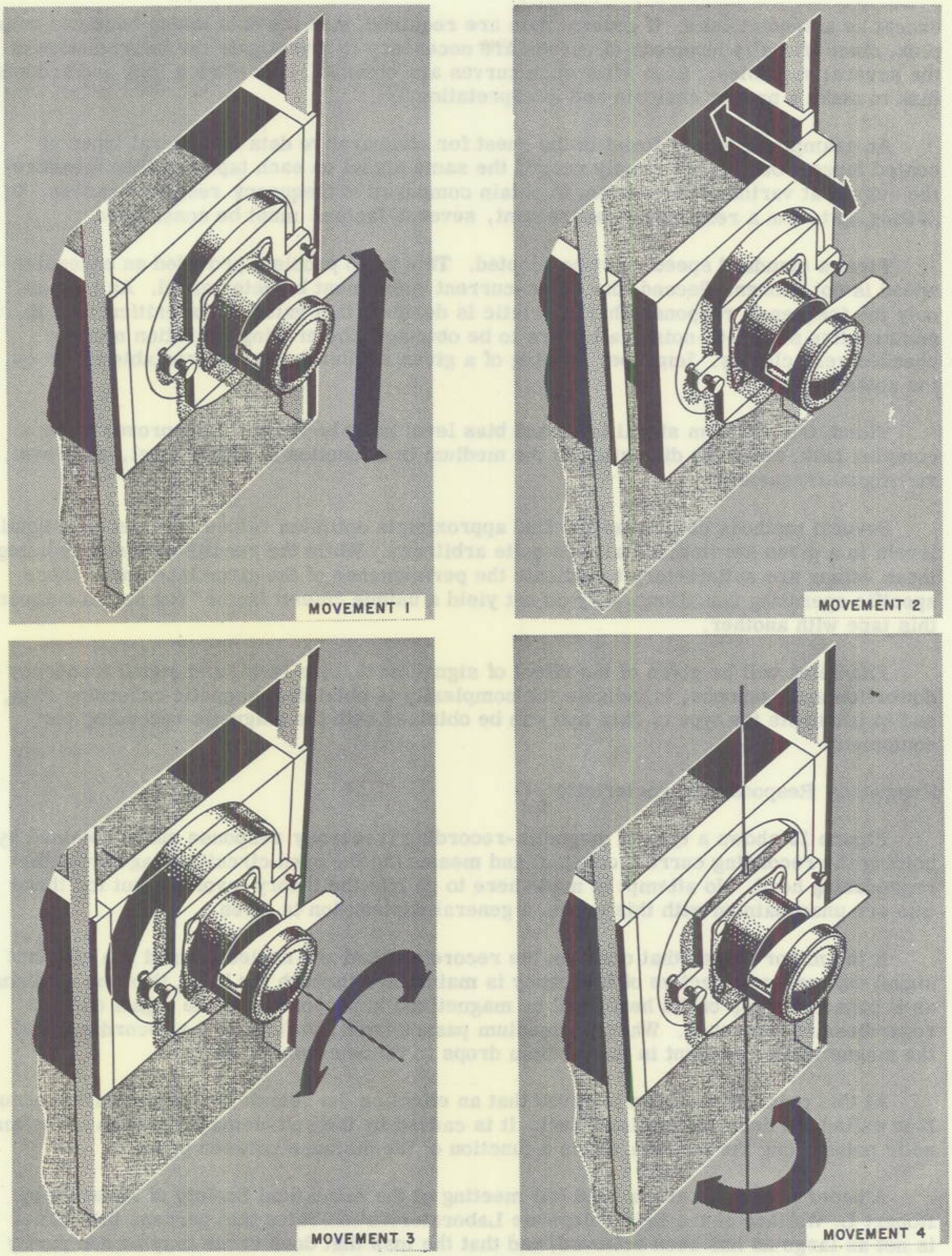


Fig. 18 - Movements of head mounts

except as a special case. If general data are required, then the data taking becomes complex, since literally hundreds of curves are necessary to investigate the interrelation of the several variables. Even after such curves are obtained, it is often a long and arduous task to make a proper analysis and interpretation.

An example of this is found in the quest for comparative data on several types of coated tapes. One cannot simply record the same signal on each tape and then measure the output, at various frequencies, to obtain comparative frequency response curves. In setting up to run a response measurement, several factors must be considered.

First a standard speed must be adopted. This is no problem provided an excessive speed is not chosen. Second, the erase-current value must be determined. As long as only the frequency response characteristic is desired, this value is not critical, but if comparative signal-to-noise ratios are to be obtained, the erasing operation must be checked very closely. Improper erasing of a given medium has an appreciable effect on the noise level.

Third, the optimum signal level and bias level must be found. This proves to be a complex task, since the distortion in the medium is a function of signal level, bias level, and signal frequency.

Several methods can be used to find approximate optimum values for bias and signal levels in a given service, but all are quite arbitrary. While the results obtained by using these values are satisfactory to indicate the performance of the given tape under these specific operating conditions, they do not yield a unique "merit factor" for use in comparing this tape with another.

Examples will be given of the effect of signal level, bias level, and signal frequency on distortion and response, to indicate the complexity of obtaining magnetic-recording data, and to illustrate the type of data that can be obtained with the magnetic-recording test equipment.

Frequency Response Characteristic

Figure 19 shows a typical magnetic-recording frequency response curve obtained by holding the recording current constant and measuring the open-circuit voltage from the reproducing head. No attempt is made here to go into the theory involved, but for those who are unacquainted with this curve, a general explanation is given.

If the minor losses that occur in the recording head are neglected, and if a constant signal current irrespective of frequency is maintained through the head, then the medium, as it passes the gap of the head, will be magnetized in proportion to the signal current regardless of frequency. When the medium passes from the field of the recording head the magnetization present in the medium drops to its remanent value.

At this point, it has been believed that an effect on the remaining magnetization occurs. It is called the demagnetization effect. It is caused by the self-demagnetization of the magnetic poles along the medium and is a function of the distance between poles.

A paper presented at the 1948 fall meeting of the Acoustical Society of America by Robert L. Wallace of the Bell Telephone Laboratories indicates that perhaps this effect is not as large as has been believed, and that the loss that does occur may be due partly to a spacing effect in the reproduction process. That is, even though the medium is in physical contact with the reproducing head, there is a small effective magnetic gap between them.

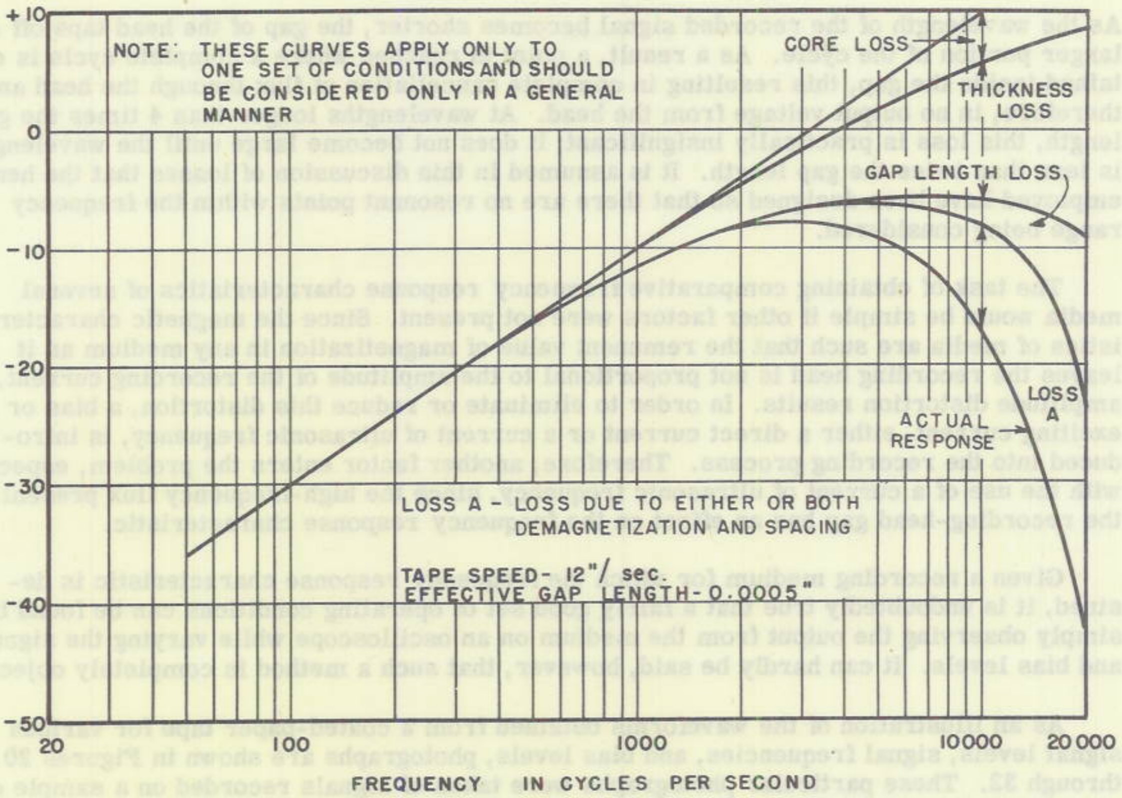


Fig. 19 - Frequency response characteristic and losses of a magnetic-recording system

Other effects to be considered occur in the reproducing process. The voltage from the reproducing head is proportional to the rate of change of flux that cuts the coils of the head. If the medium is uniformly magnetized, the output voltage should rise at the rate of 6 db per octave as shown by the straight line in Figure 19.

Deviation from this 6-db-per-octave rise comes from losses which are a function of either the signal frequency or the wavelength of the recorded signal. The loss due to any frequency effect is usually very small, and in any well-designed and constructed head is not significant below 10,000 cps. This loss is due to the core loss in both the recording and the reproducing heads (Figure 19).

Two losses due to wavelength of the recorded signal are known and have been designated as thickness loss and slit loss (gap-length effect). The thickness loss is a function of the thickness of the magnetizable material of the medium. This loss is often sizeable since the thickness must be in the order of one tenth or less of the recorded wavelength for the loss to be insignificant.

The "gap-length loss" or "slit loss" arises from the fact that the reproducing head actually must tap off a portion of the magnetic field of the medium since there is an actual length to the gap. Even though the state of the art has improved so as to obtain effective gap lengths smaller than 5 ten-thousandths of an inch (1/2 mil), this loss is still an important factor in limiting the frequency range of magnetic-recording systems. Figure 19 indicates this loss.

As the wavelength of the recorded signal becomes shorter, the gap of the head taps off a larger portion of the cycle. As a result, a point is reached where a complete cycle is contained inside the gap, this resulting in complete cancellation of flux through the head and, therefore, in no output voltage from the head. At wavelengths longer than 4 times the gap length, this loss is practically insignificant; it does not become large until the wavelength is less than twice the gap length. It is assumed in this discussion of losses that the heads employed have been designed so that there are no resonant points within the frequency range being considered.

The task of obtaining comparative frequency response characteristics of several media would be simple if other factors were not present. Since the magnetic characteristics of media are such that the remanent value of magnetization in any medium as it leaves the recording head is not proportional to the amplitude of the recording current, amplitude distortion results. In order to eliminate or reduce this distortion, a bias or an exciting current, either a direct current or a current of ultrasonic frequency, is introduced into the recording process. Therefore, another factor enters the problem, especially with the use of a current of ultrasonic frequency, since the high-frequency flux present at the recording-head gap has an effect on the frequency response characteristic.

Given a recording medium for which the frequency response characteristic is desired, it is undoubtedly true that a fairly good set of operating conditions can be found by simply observing the output from the medium on an oscilloscope while varying the signal and bias levels. It can hardly be said, however, that such a method is completely objective.

As an illustration of the waveforms obtained from a coated-paper tape for various signal levels, signal frequencies, and bias levels, photographs are shown in Figures 20 through 32. These particular photographs were taken of signals recorded on a sample of Minnesota Mining and Manufacturing Company paper-base tape (Type 100) at a speed of 1 ft/sec. with standard production Brush Development Company recording-reproducing heads (BK-919) and erase heads (BK-915). For any one level and frequency the gain setting on the oscilloscope was fixed; thus the amplitudes shown in the photographs represent the actual effect of bias on the amplitude of the signal as well as on the waveform.

There are many possible comparisons that can be made from these photographs, but a few general conclusions can readily be drawn. At the lower frequencies more bias is required in order to obtain a less distorted signal. In fact, at 8000 cps the bias seems to have only an amplitude effect and it is shown that a bias level large enough for low distortion at 100 cps reduces the amplitude of the 8000-cps signal considerably.

This effect can be seen to a better advantage in the curves of Figures 33 through 40. These curves are frequency response records for the same tape and operating conditions as for the waveform photographs. In analyzing these curves it must be kept in mind that those representing low values of bias and/or high values of signal do not have much significance since the signal may be decidedly distorted. In general, high values of bias tend to decrease the response at the higher frequencies; and low values of bias give good high-frequency response, but sacrifice linearity.

This effect of the bias on the high-frequency response is mainly due to the spreading of the bias flux at the point on the recording head where the medium leaves the field of the signal flux.

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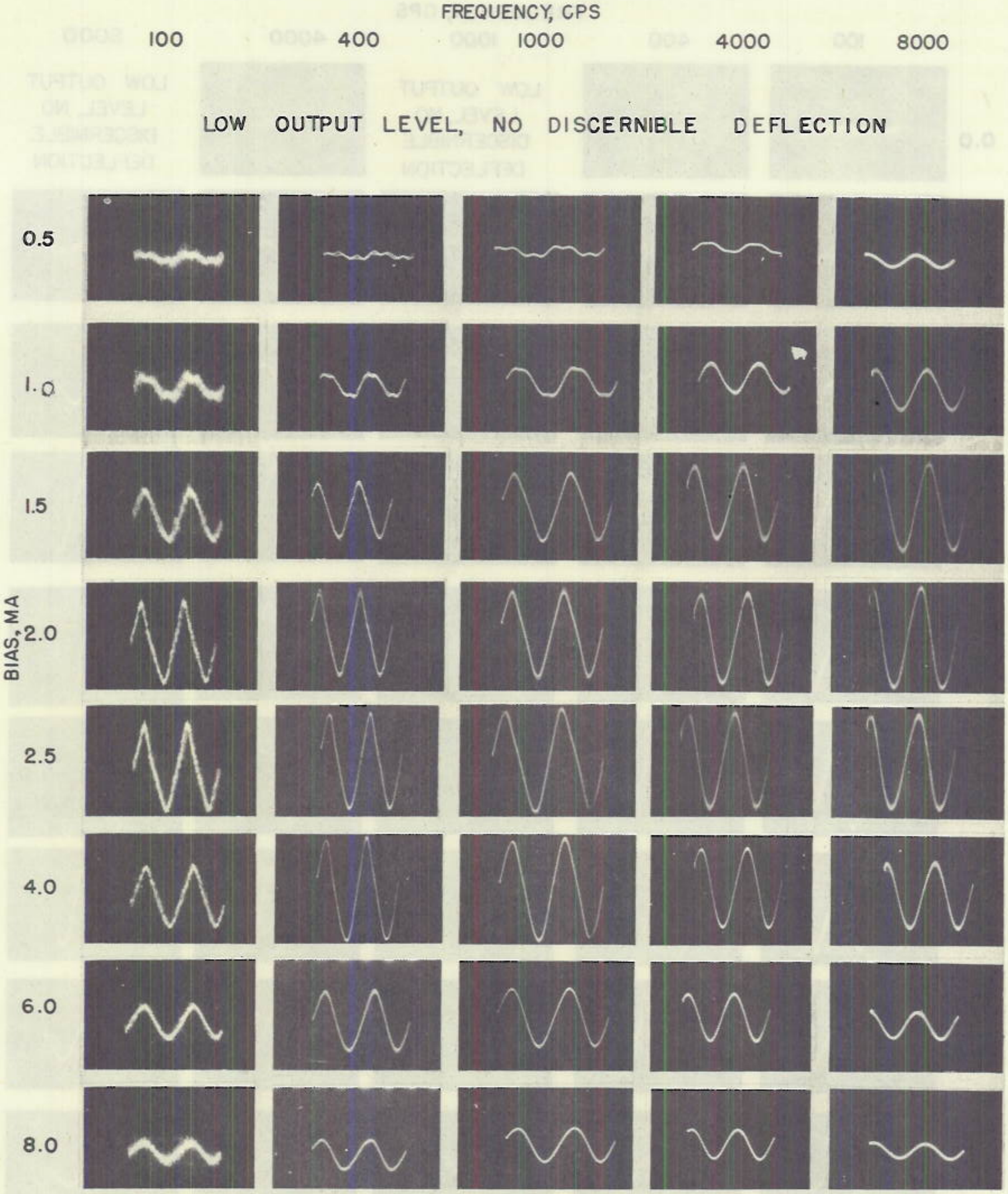


Fig. 20 - Waveforms of the output from one type of coated tape for a recording signal level 20 db below saturation

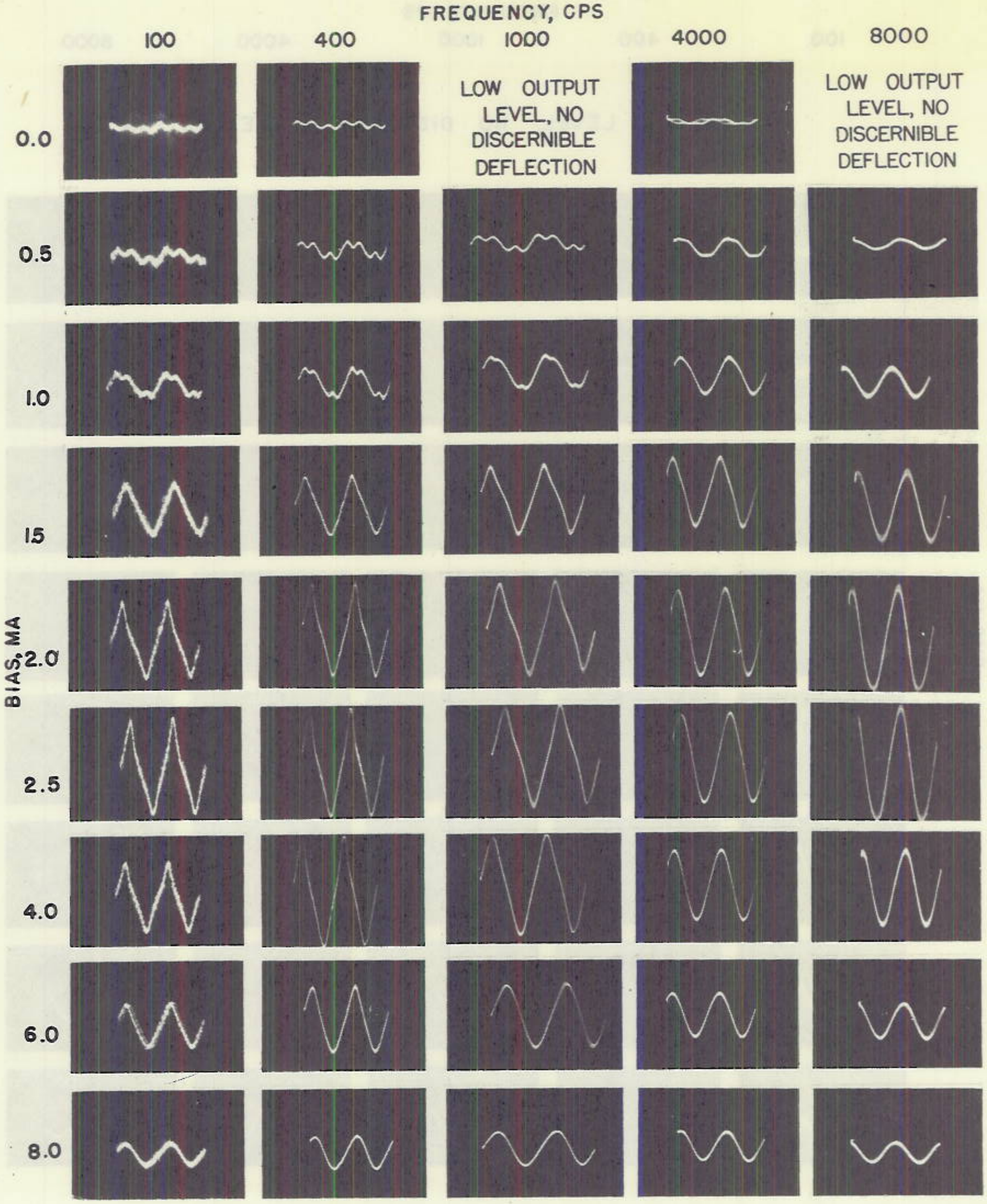


Fig. 21 - Waveforms of the output from one type of coated tape for a recording signal level 15 db below saturation

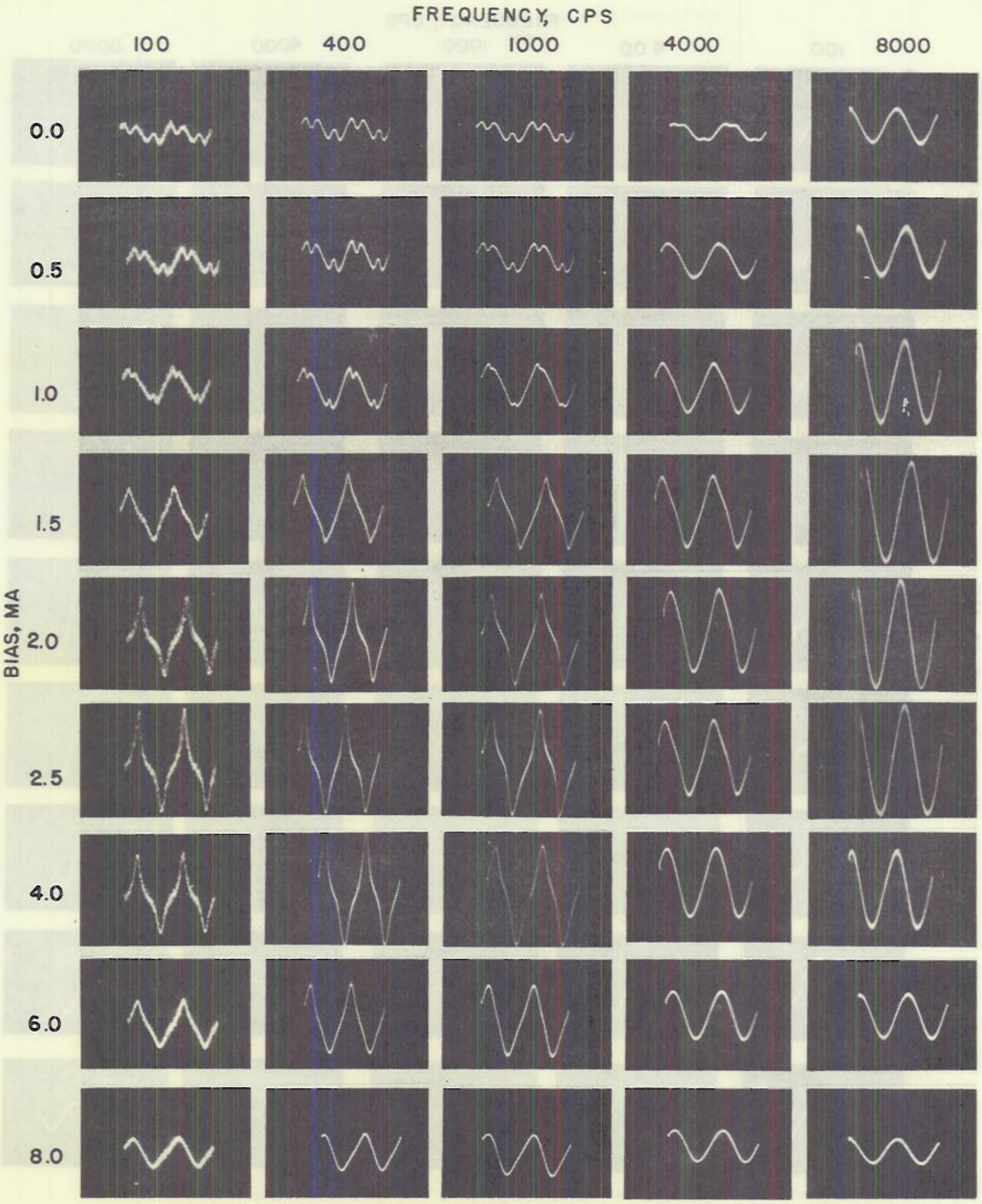


Fig. 22 - Waveforms of the output from one type of coated tape for a recording signal level 10 db below saturation

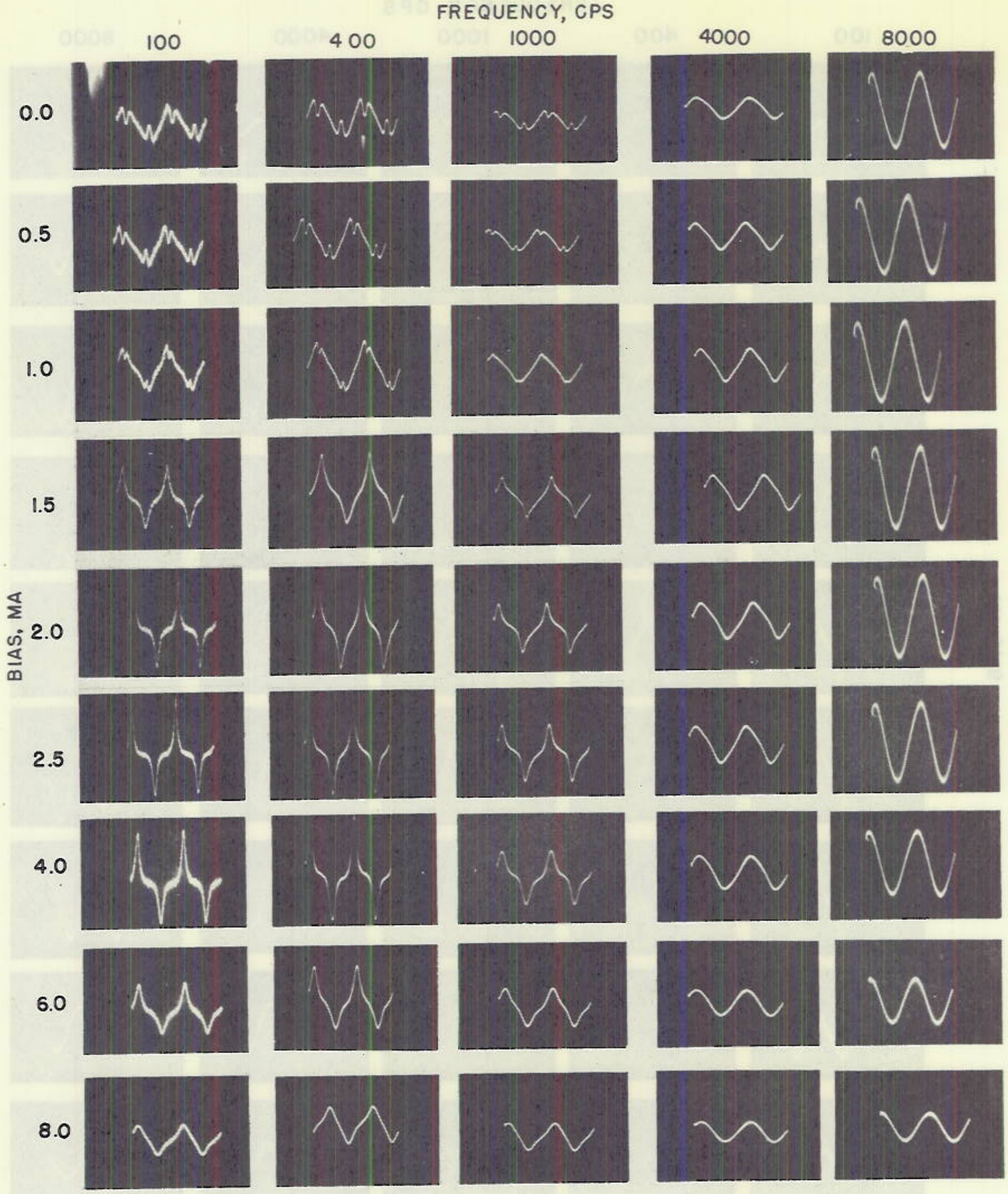


Fig. 23 - Waveforms of the output from one type of coated tape for a recording signal level 5 db below saturation

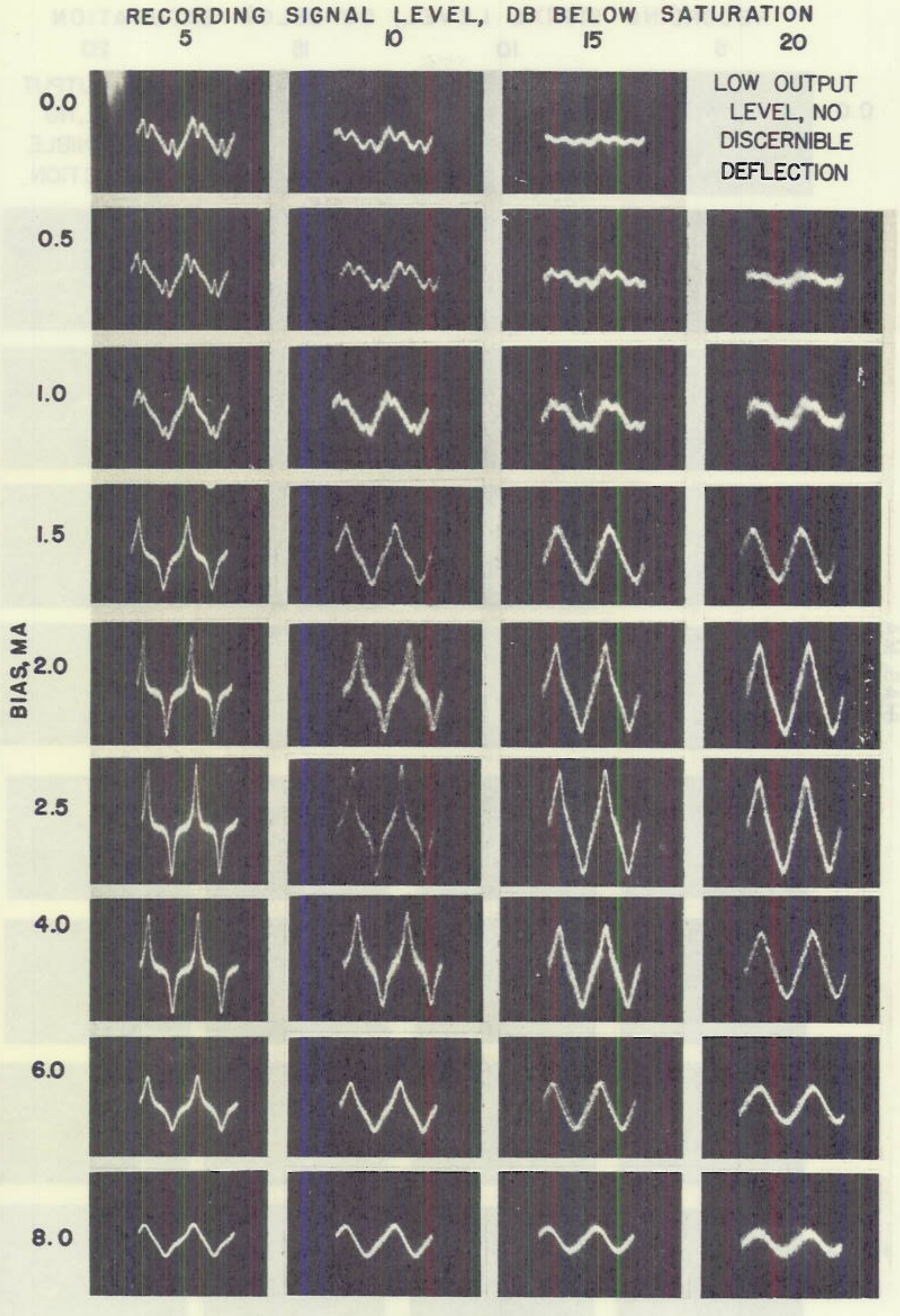


Fig. 24 - Waveforms of the output from one type of coated tape for a recorded frequency of 100 cps

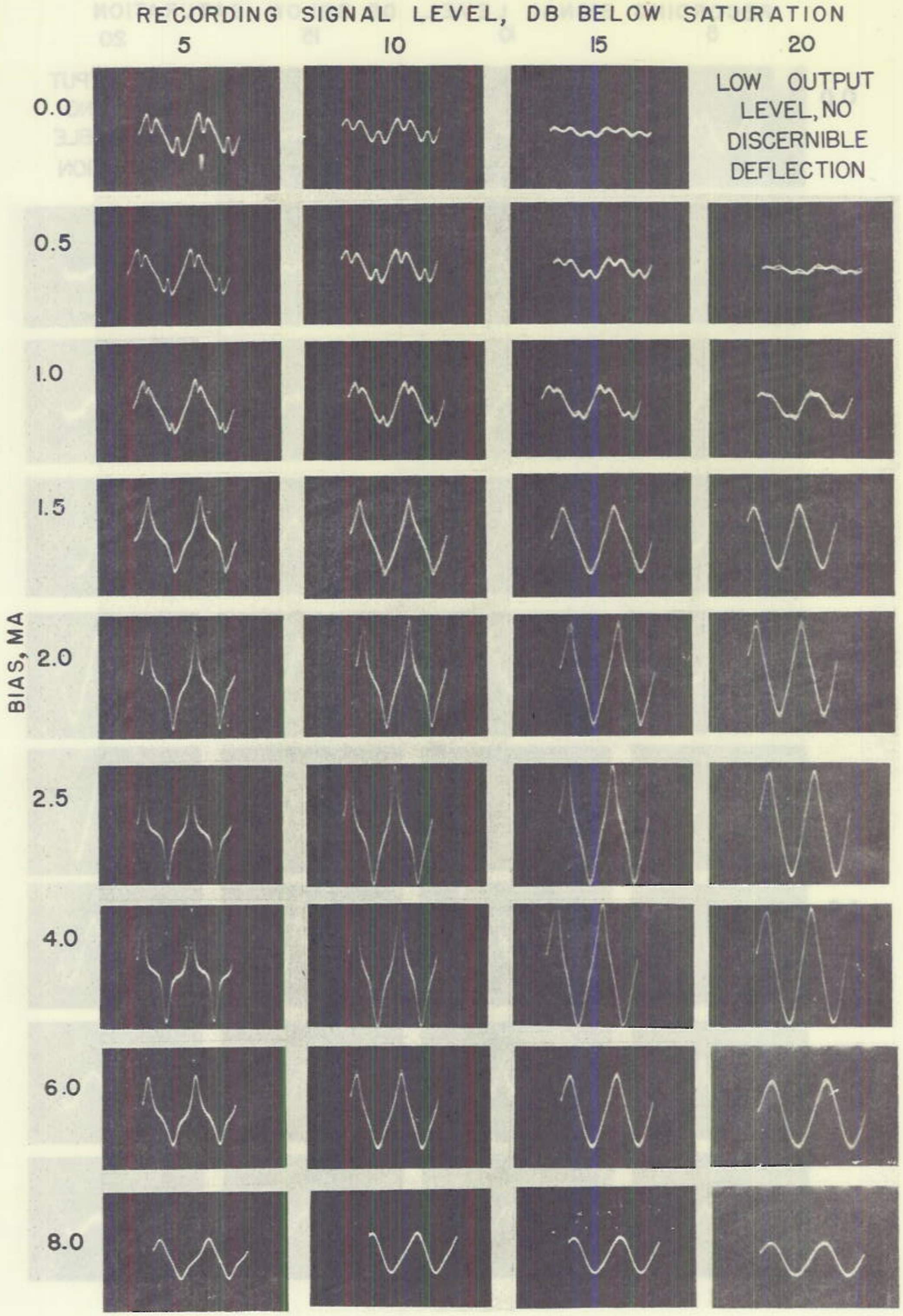


Fig. 25 - Waveforms of the output from one type of coated tape for a recorded frequency of 400 cps

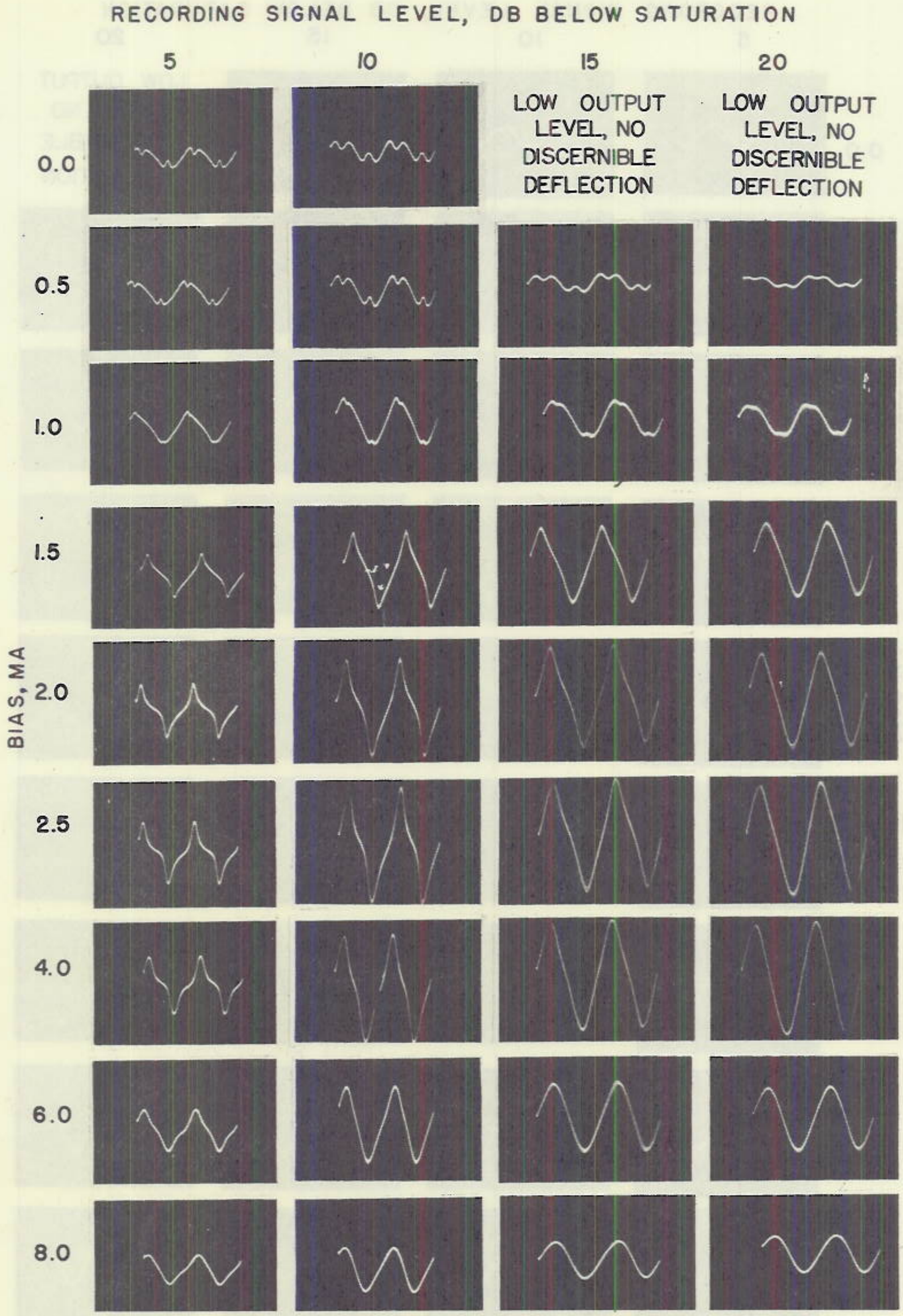


Fig. 26 - Waveforms of the output from one type of coated tape for a recorded frequency of 1000 cps

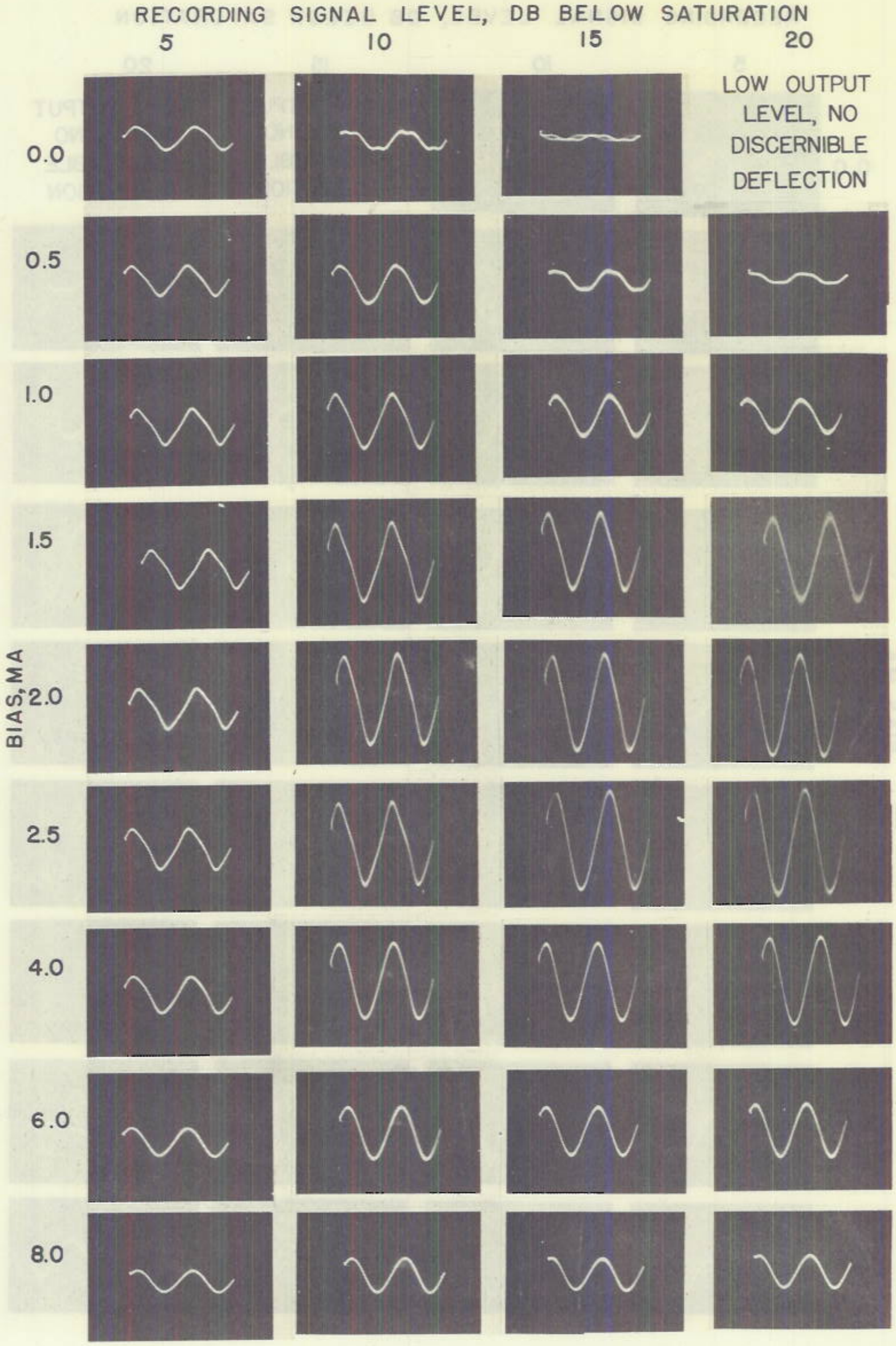


Fig. 27 - Waveforms of the output from one type of coated tape for a recorded frequency of 4000 cps

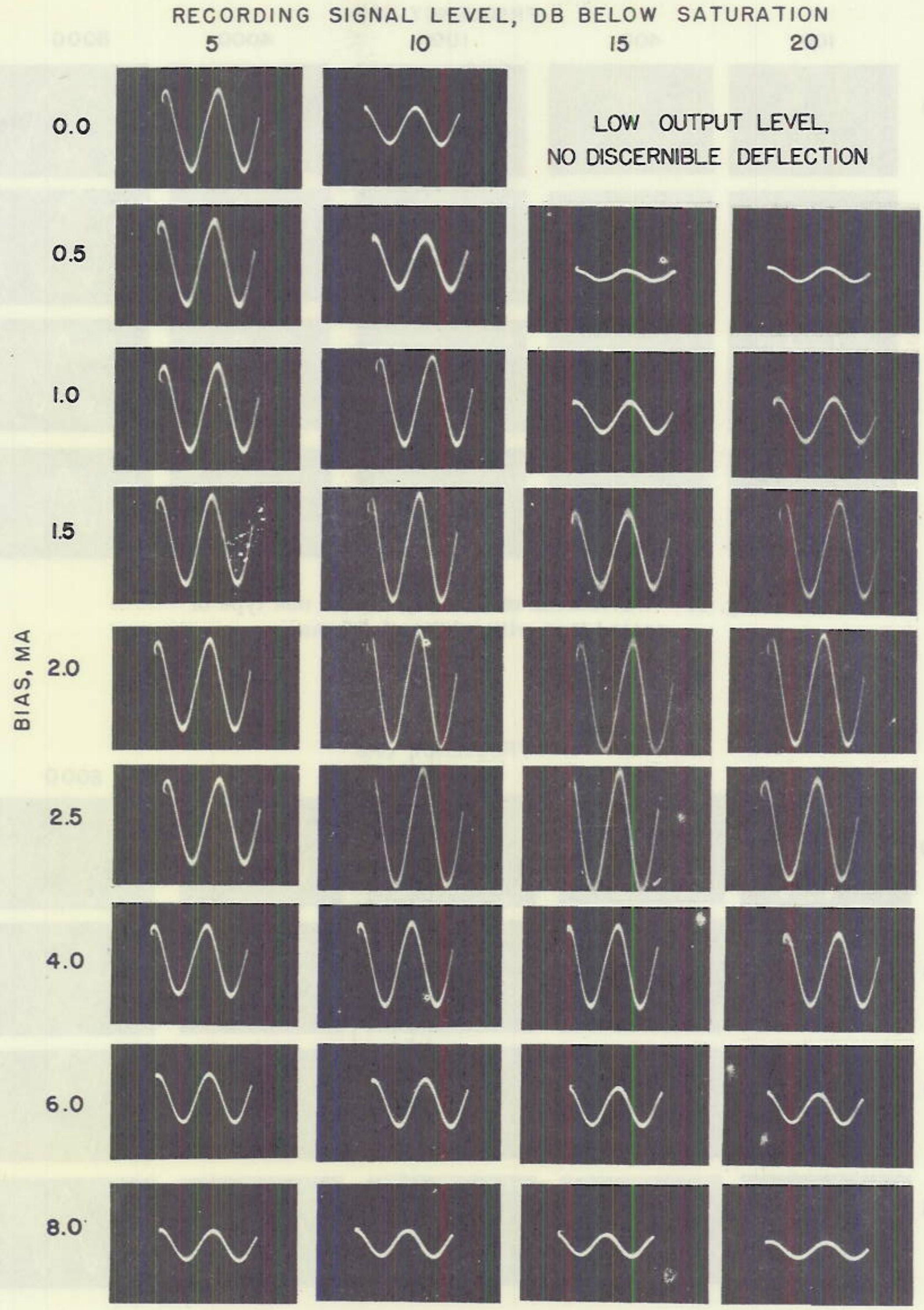


Fig. 28 - Waveforms of the output from one type of coated tape for a recorded frequency of 8000 cps

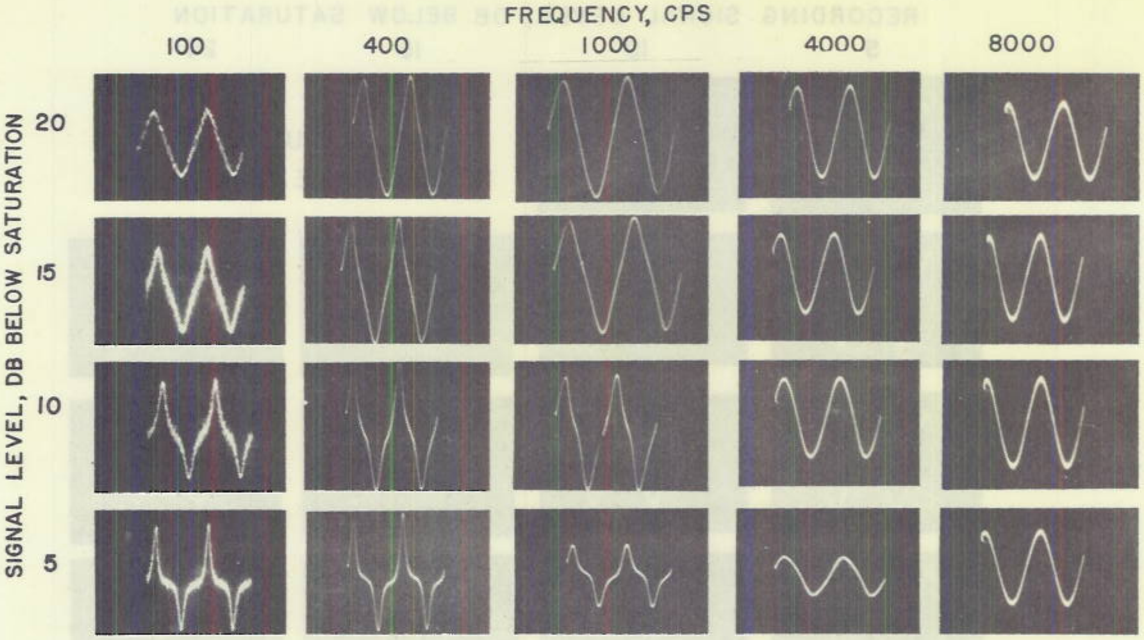


Fig. 29 - Waveforms of the output from one type of coated tape with a bias of 4.0 ma

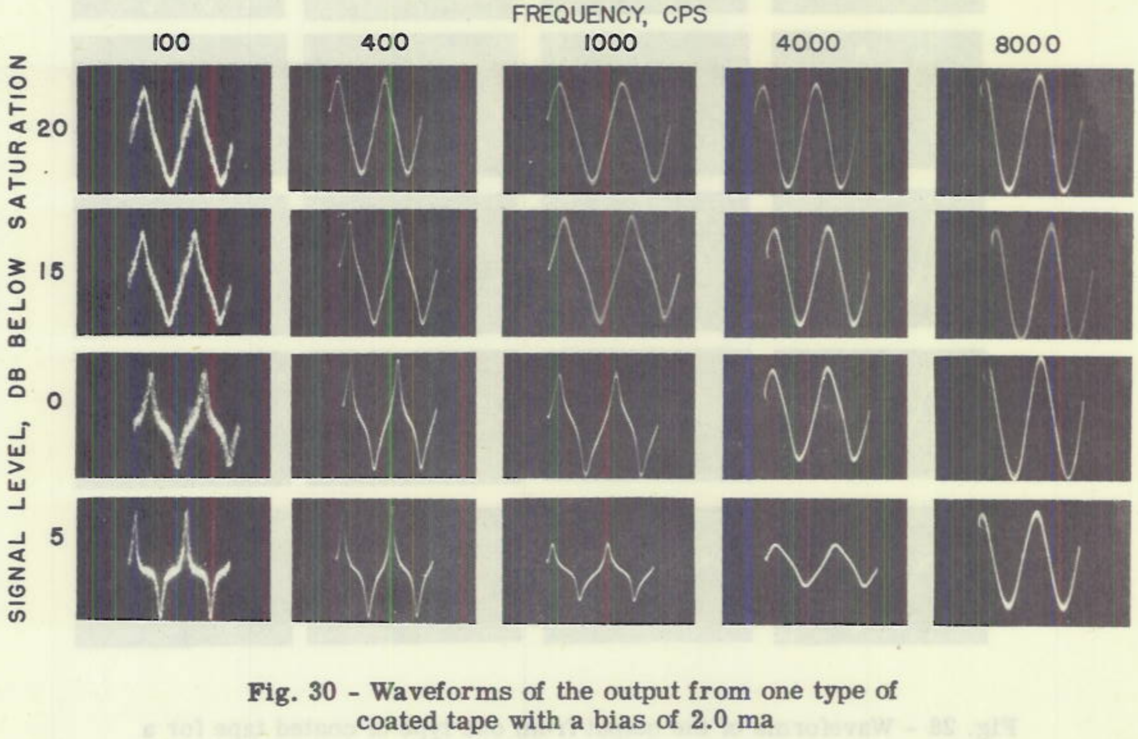


Fig. 30 - Waveforms of the output from one type of coated tape with a bias of 2.0 ma

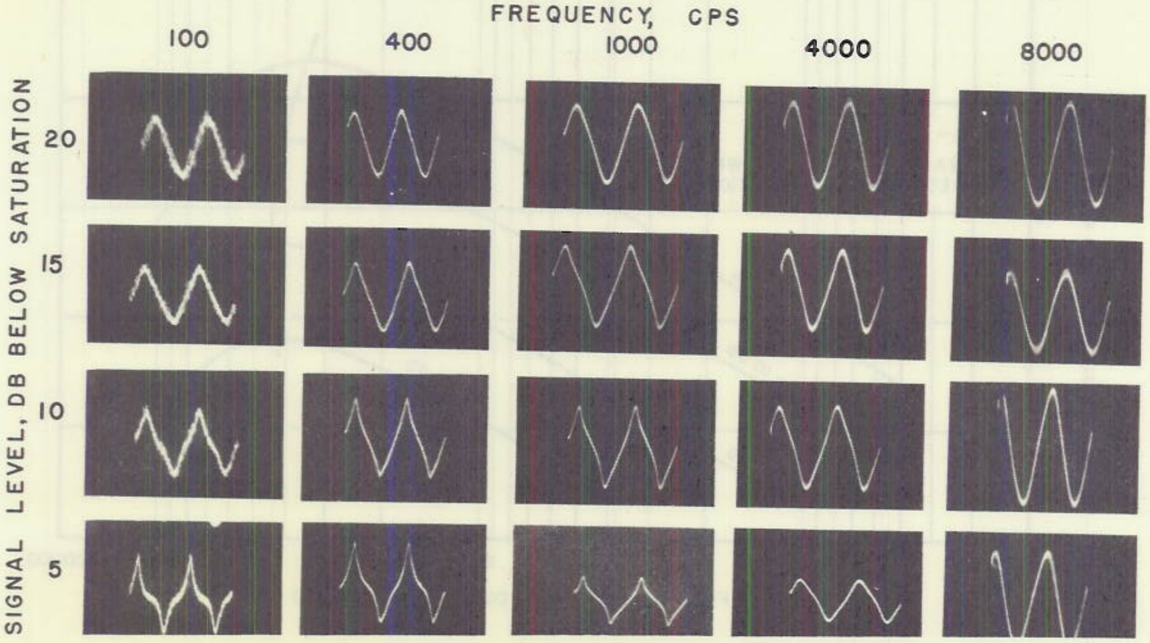


Fig. 31 - Waveforms of the output from one type of coated tape with a bias of 1.5 ma

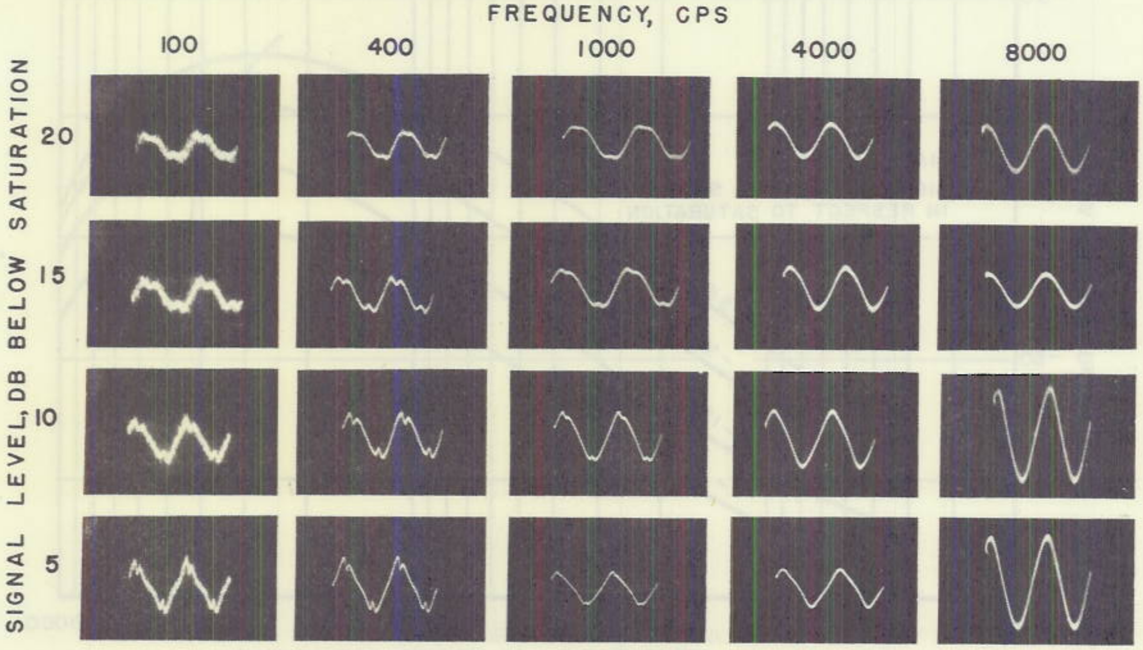


Fig. 32 - Waveforms of the output from one type of coated tape with a bias of 1.0 ma

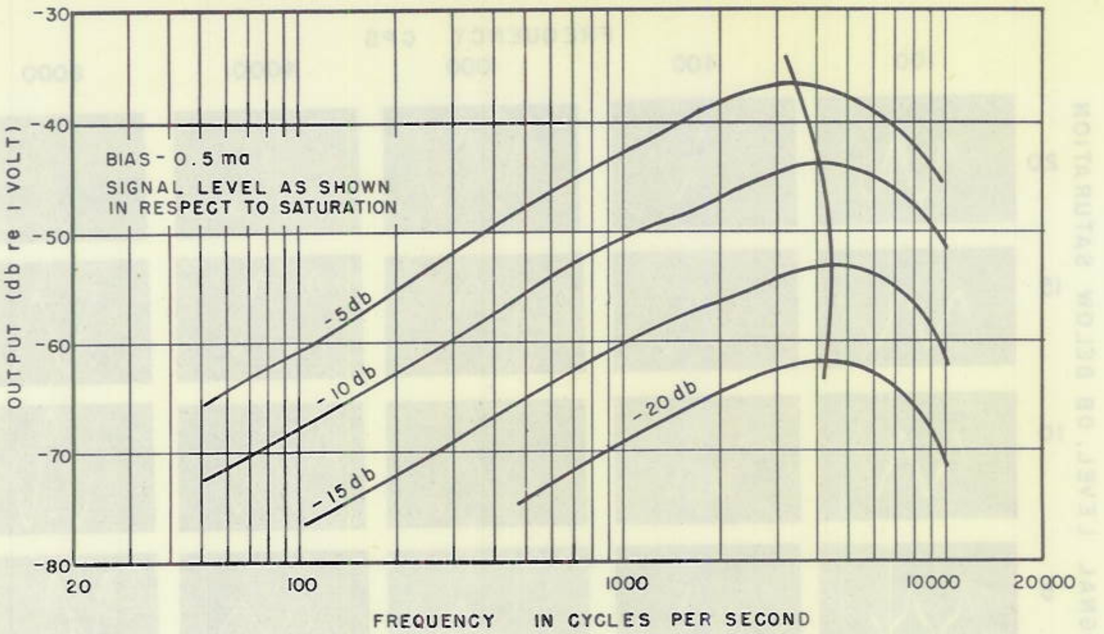


Fig. 33 - Frequency response characteristic of one type of coated tape for various values of recording level, bias - 0.5 ma

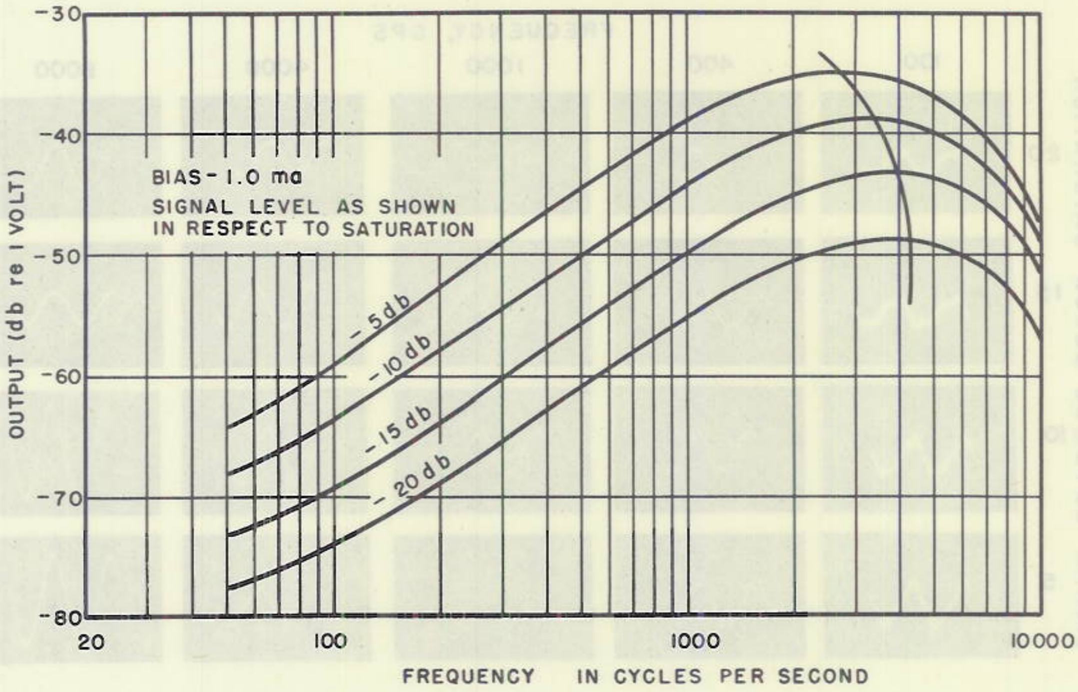


Fig. 34 - Frequency response characteristic of one type of coated tape for various values of recording level, bias - 1.0 ma

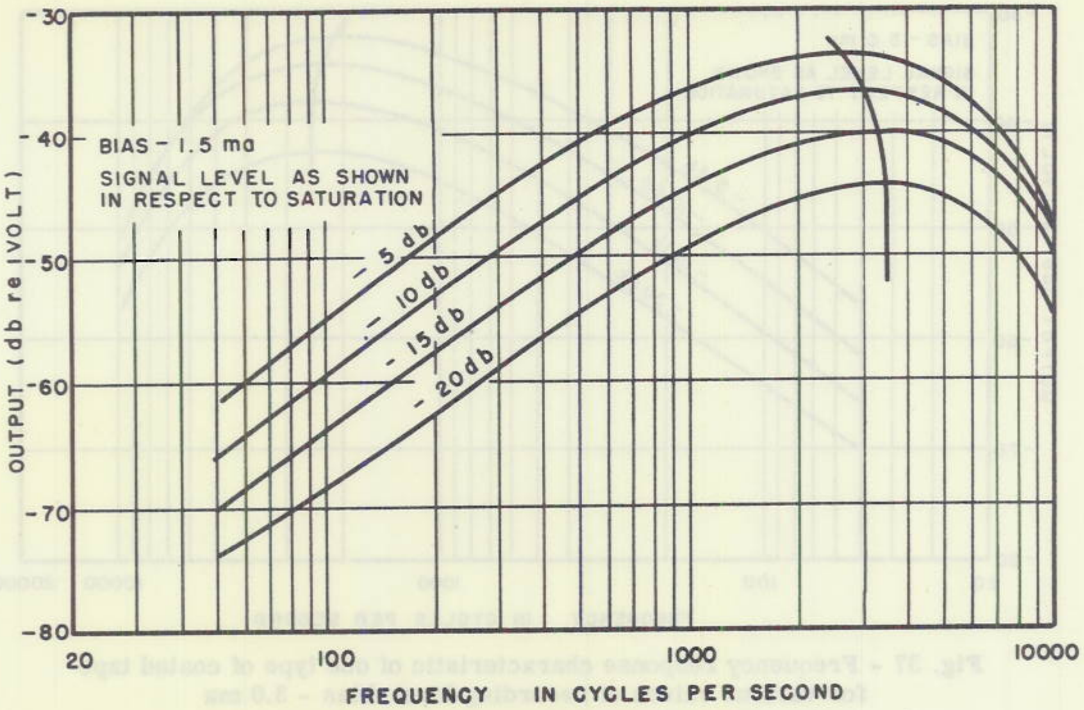


Fig. 35 - Frequency response characteristic of one type of coated tape for various values of recording level, bias - 1.5 ma

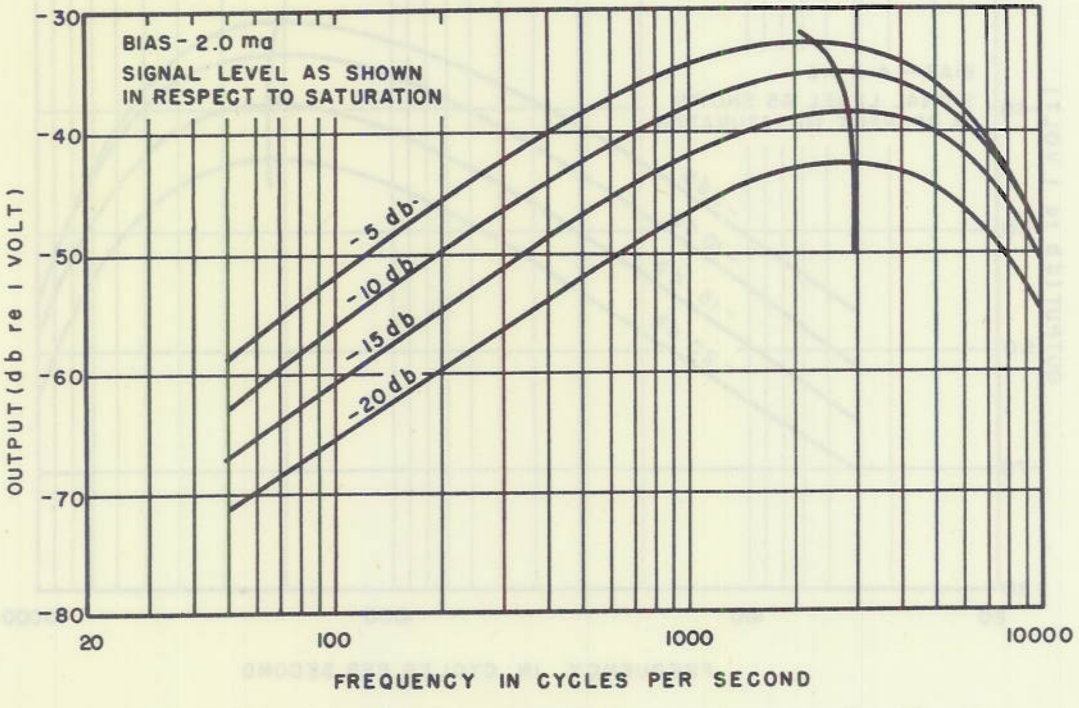


Fig. 36 - Frequency response characteristic of one type of coated tape for various values of recording level, bias - 2.0 ma

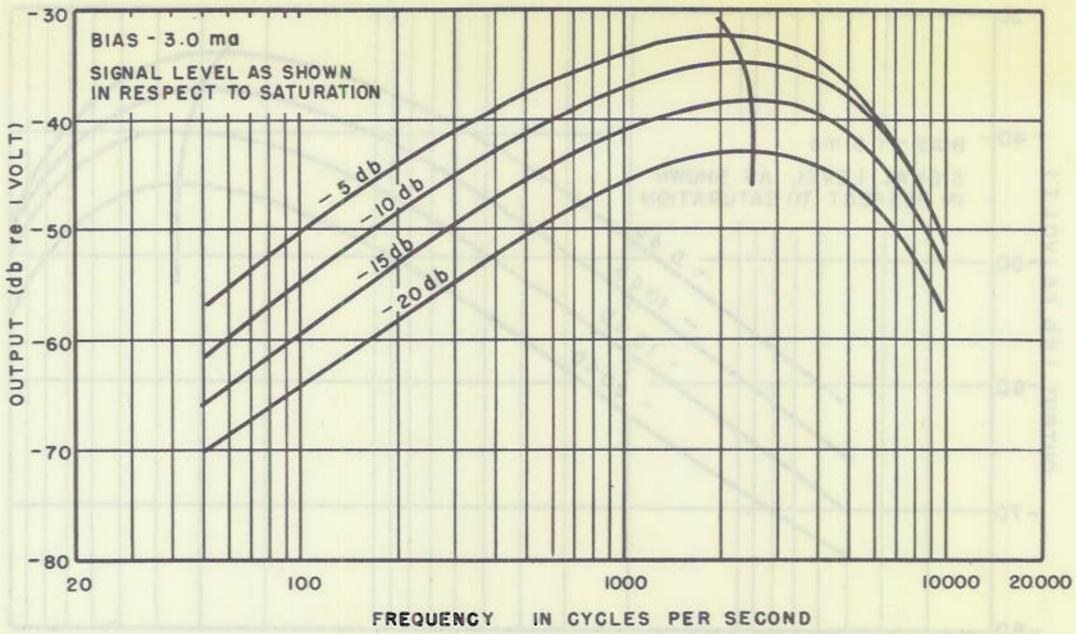


Fig. 37 - Frequency response characteristic of one type of coated tape for various values of recording level, bias - 3.0 ma

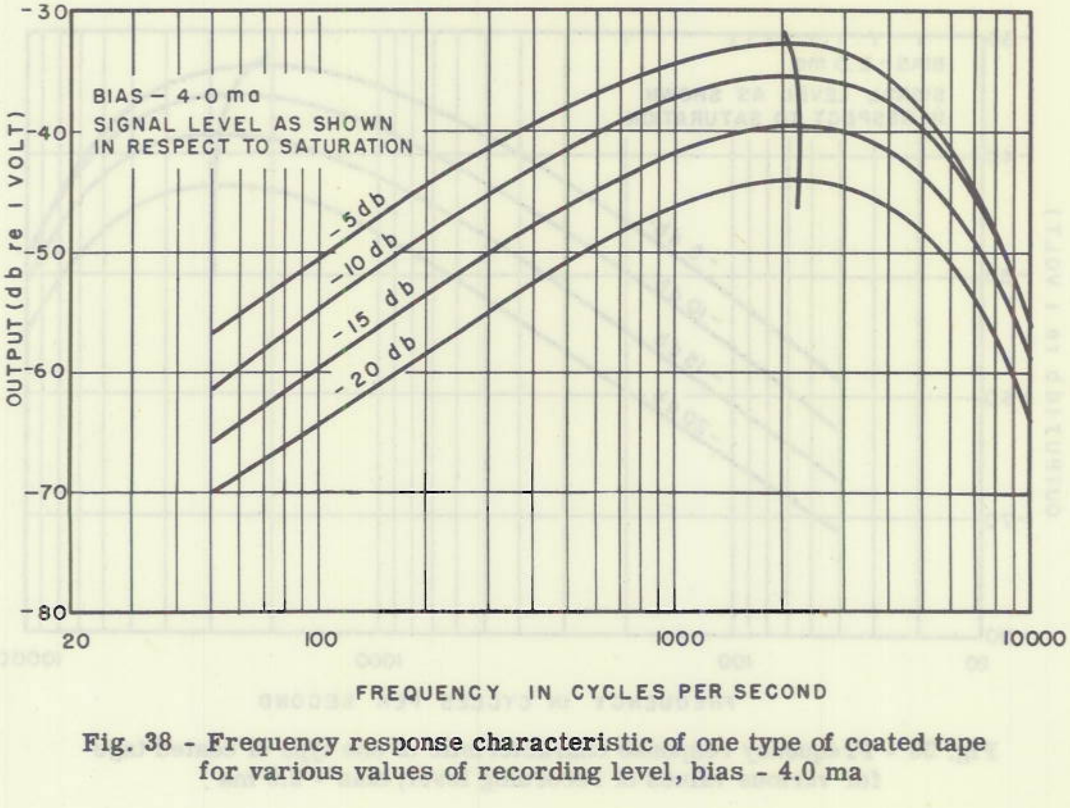


Fig. 38 - Frequency response characteristic of one type of coated tape for various values of recording level, bias - 4.0 ma

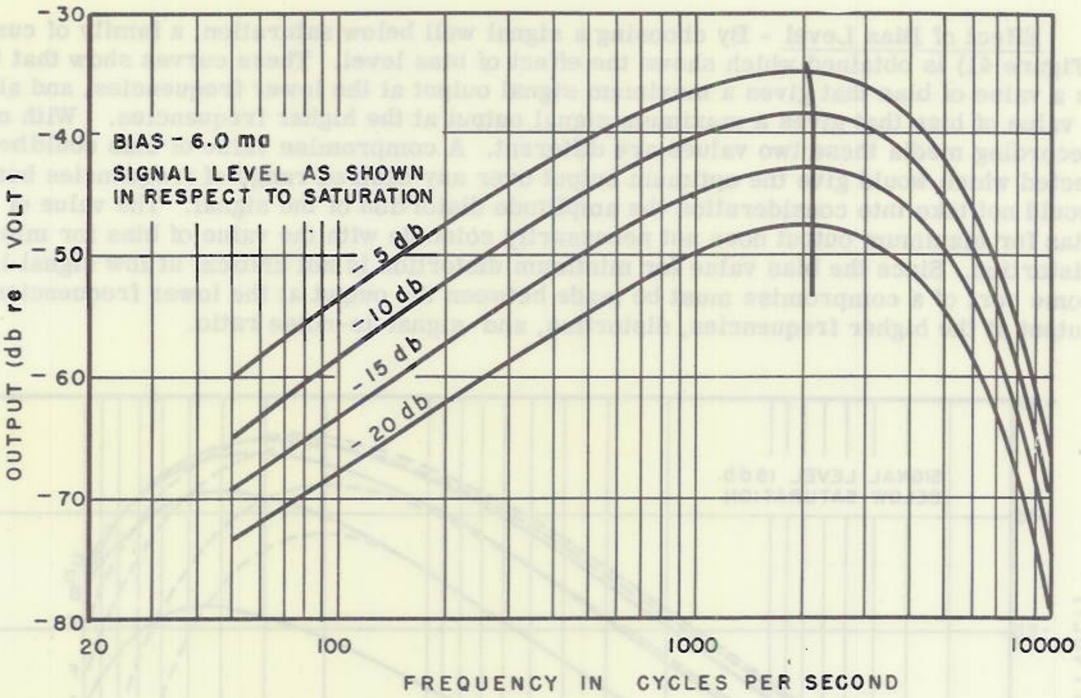


Fig. 39 - Frequency response characteristic of one type of coated tape for various values of recording level, bias - 6.0 ma

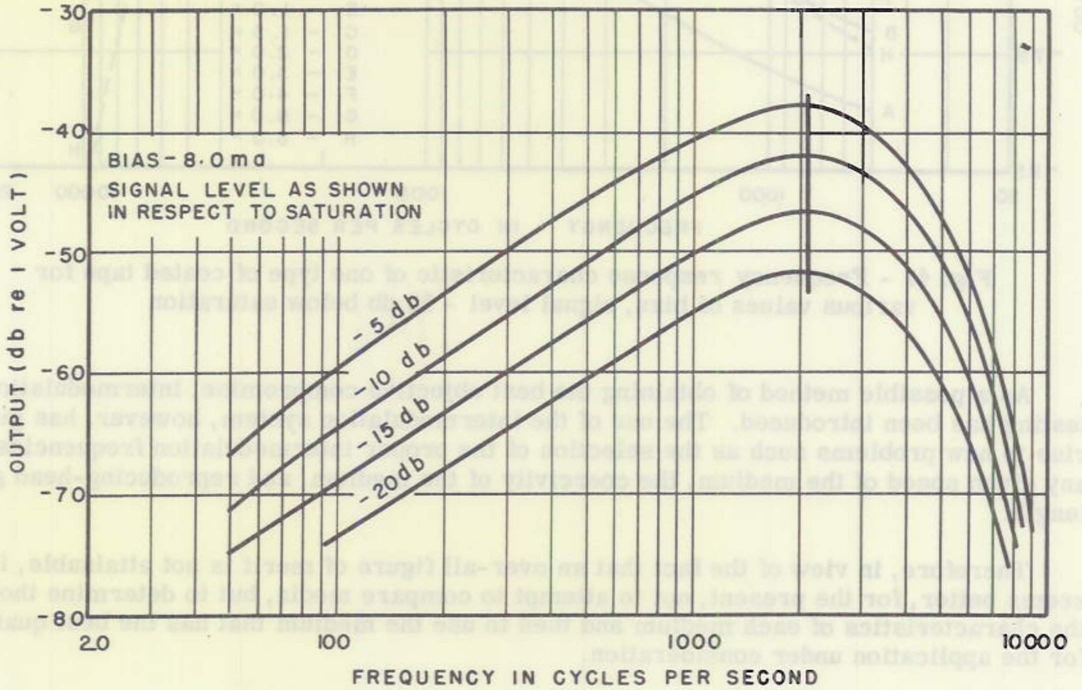


Fig. 40 - Frequency response characteristic of one type of coated tape for various values of recording level, bias - 8.0 ma

Effect of Bias Level - By choosing a signal well below saturation, a family of curves (Figure 41) is obtained which shows the effect of bias level. These curves show that there is a value of bias that gives a maximum signal output at the lower frequencies, and also a value of bias that gives a maximum signal output at the higher frequencies. With most recording media these two values are different. A compromise value of bias could be selected which would give the optimum output over any desired range of frequencies but this would not take into consideration the amplitude distortion of the signal. The value of bias for maximum output does not necessarily coincide with the value of bias for minimum distortion. Since the bias value for minimum distortion is not critical at low signal levels, some sort of a compromise must be made between the output at the lower frequencies, the output at the higher frequencies, distortion, and signal-to-noise ratio.

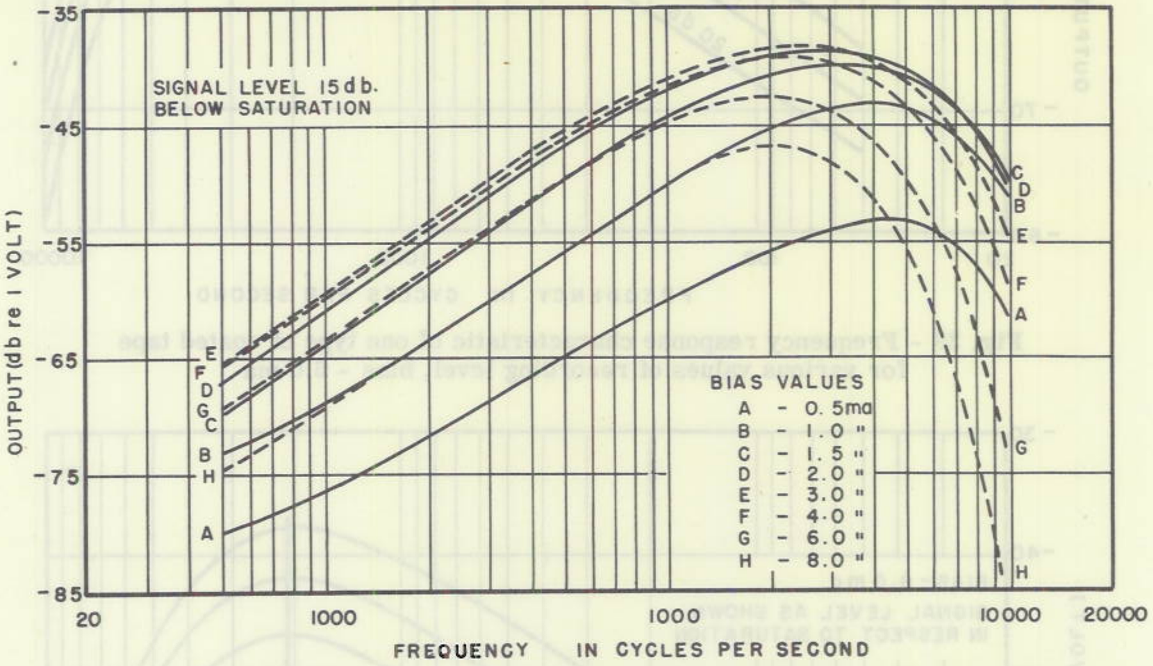


Fig. 41 - Frequency response characteristic of one type of coated tape for various values of bias, signal level - 15 db below saturation

As a possible method of obtaining the best objective compromise, intermodulation testing has been introduced. The use of the intermodulation system, however, has given rise to new problems such as the selection of the proper intermodulation frequencies for any given speed of the medium, the coercivity of the medium, and reproducing-head gap length.

Therefore, in view of the fact that an over-all figure of merit is not attainable, it seems better, for the present, not to attempt to compare media, but to determine thoroughly the characteristics of each medium and then to use the medium that has the best qualities for the application under consideration.

Effect of Speed of the Medium - The frequency response characteristic of any given recording system will change if the speed of the medium is changed. A change in speed means that the wavelength of the recorded signal is longer or shorter as the speed is

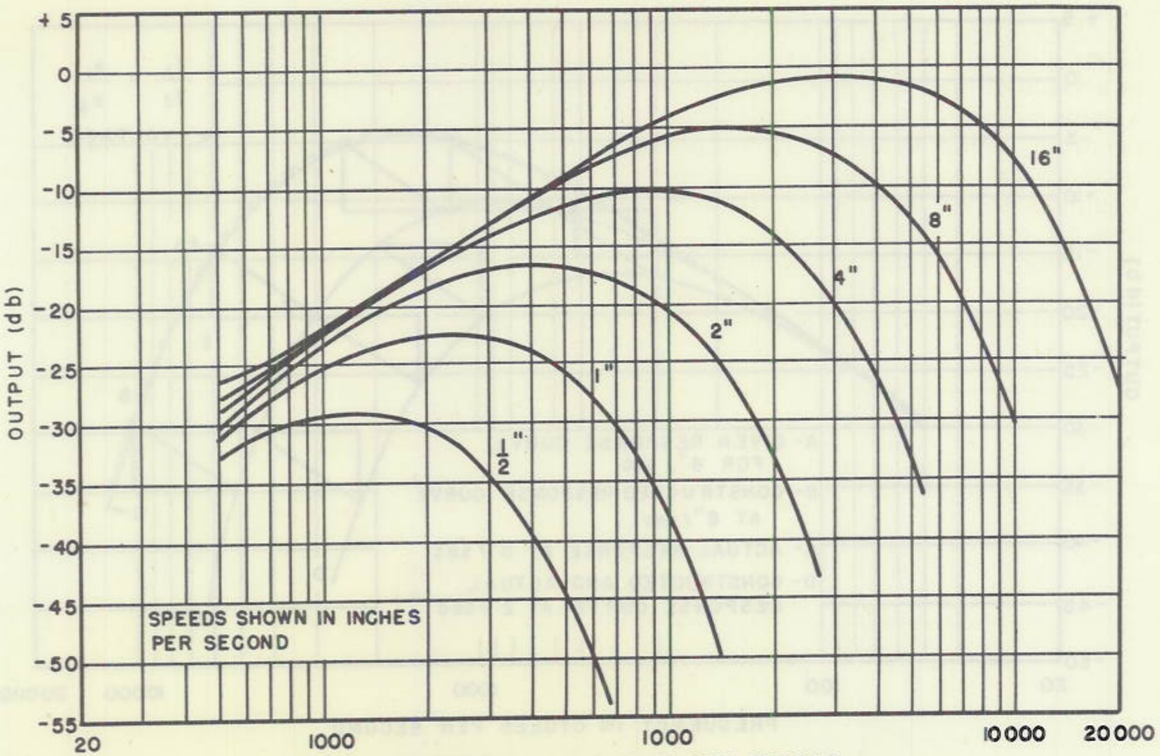


Fig. 42 - Frequency response characteristics of one type of coated tape for various speeds

respectively increased or decreased. Without any of the losses, core loss, thickness loss, gap-length loss, demagnetization and spacing loss, it would be expected that the frequency response characteristic would be the same regardless of speed, since the output of the reproducing head would be directly proportional to frequency. Since these losses are present, the effect of the speed of the medium on the characteristic is considerable.

Figure 42 shows a group of frequency response curves, all taken with the same components and under the same operating conditions except for the variation in speed as noted. It can be seen that for all recorded wavelengths greater than about 20 thousandths of an inch, regardless of speed, the outputs for any selected frequency are equal. For wavelengths shorter than 20 thousandths of an inch, deviation from the 6-db-per-octave rise occurs.

It is possible, given a frequency response curve for one speed, to obtain the approximate responses at other speeds. This method is shown in Figure 43. From any point on the given curve proceed along the abcissa to a frequency which has the same relation to the frequency of the selected point as the assumed speed has to the speed of the given curve.

The point on the new curve then is located at this frequency. The ordinate position of this point is found by moving either upward or downward (depending on whether the assumed speed is greater or smaller than the given speed) to a voltage which has the same relation to the voltage of the original point as the assumed speed has to the given speed. This would actually amount to a 6-db-per-octave rise or fall.

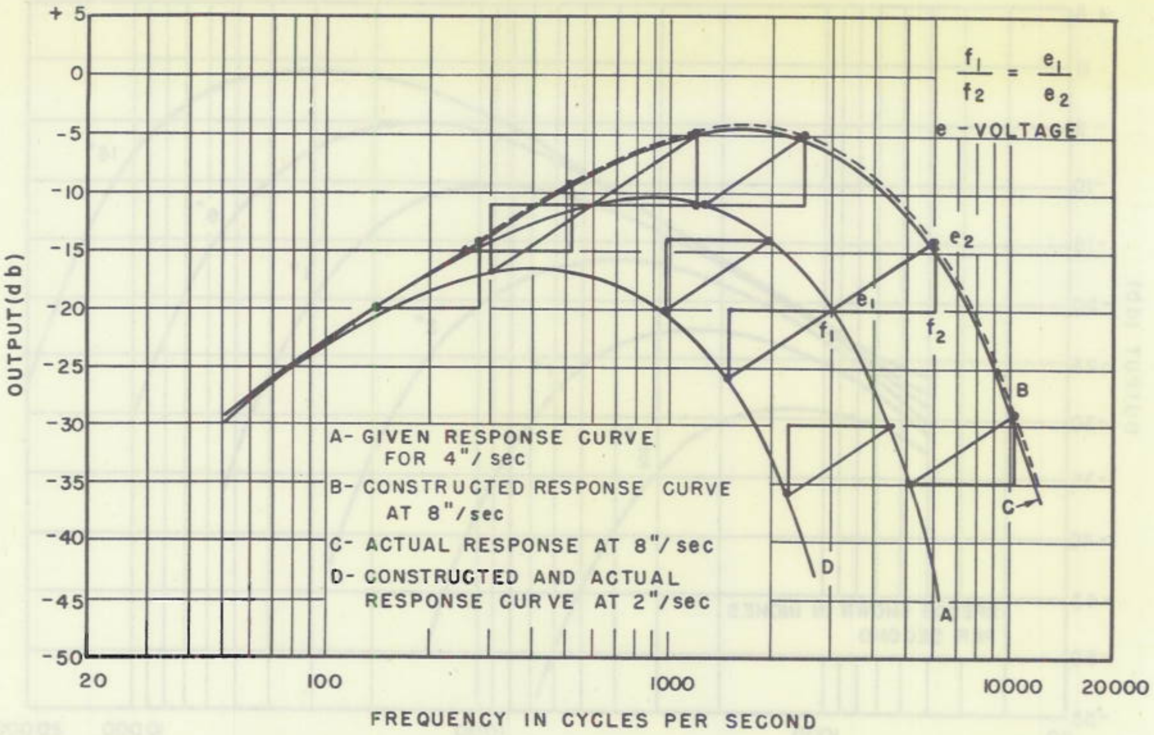


Fig. 43 - Method of obtaining frequency response curves for various tape speeds, given the response at one speed

This method is valid only as long as certain other effects are not present. For normal audio ranges these effects are usually insignificant. For example, at the speeds required to cover the normal audio range, the medium will ride against the head with very little bounce or whipping, but at higher speeds this erratic contact condition causes considerable variation in the output for the shorter wavelengths.

The high-frequency losses of the heads cause the constructed curve for higher speeds to show slightly greater output at the high-frequency end of the range. This effect can also be readily observed in Figure 42 where there is a considerable difference between the shape of the response curves for 16 inches per second and for 1/2 inch per second. This difference should be mainly due to the high-frequency loss.

A head that has a natural resonant frequency within the frequency band of the system will introduce a deviation from the normal response curve. This effect has been and still is being used extensively in commercial recorders to increase the high-frequency output of the head in order to compensate partly for the various losses involved. It is achieved by the use of a condenser in parallel with the head. The capacitance of the condenser determines the resonant frequency of the head-condenser combination. It is sometimes desirable to damp this resonance by means of a parallel resistance. This will usually eliminate any undesirable sharpness in the resonant peak.

Effect of Gap Length in the Reproducing Head - A set of output curves for various values of gap lengths are shown in Figure 44. When the gap length is small in comparison to the wavelength of the recorded signal the output of the reproducing head rises at a rate

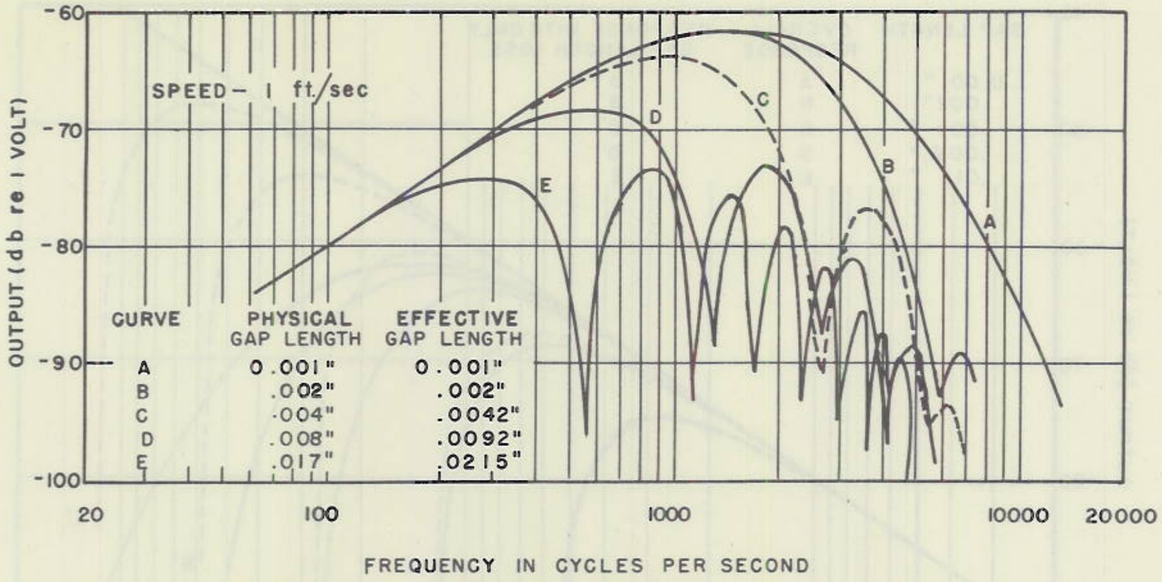


Fig. 44 - Frequency response characteristic for various reproducing-head gap lengths, speed - 1 ft/sec

of 6 db per octave. When the gap becomes longer than about 1/4 of the recorded wavelength, the output is seriously affected. In the set of curves shown, the speed of the tape was 1 ft/sec, or to put it in other units, was 12000 thousandths of an inch per second. This means that the actual recorded wavelength of 12000 cps was 0.001 of an inch; of 1200 cps, 0.010 of an inch; of 800 cps, 0.015 of an inch; of 600 cps, 0.020 of an inch; of 400 cps, 0.030 of an inch, etc.

In the 0.008″-gap-length curve, it can be seen that the output rises at the 6-db-per-octave rate until 300 cps is reached. At this point, where the recorded wavelength is 0.040″, the rate of increase diminishes. At approximately 600 cps, where the gap length is 1/2 the recorded wavelength, the point of maximum output occurs. Then the output falls off rapidly until the null point (where the gap length equals the recorded wavelength) occurs at about 1300 cps.

Simple calculations show that if the gap length were really 0.008″, the null point would occur at 1500 cps. However, the actual effective gap length of a head may be different than the physical spacer that forms the gap. There is the possibility of poor contact of the spacer to the pole pieces and rounded edges of the pole-piece faces.

The 0.008″ curve shows that the effective gap length was .0092″. For gap lengths (as shown in Figure 44) of .017″, .004″, and .002″, effective gap lengths of .0215″, .0042″, and .002″ are computed. This indicates, at least in this instance, that the longer the physical gap, the larger the differential between the effective gap and the physical gap.

From this family of curves it is possible to separate the gap-length loss from all other losses (see Figure 45). Essentially this is done by measuring the response of the over-all system, using such a wide gap length that the entire frequency response curve is restricted to the lower frequencies and correspondingly longer recorded wavelengths. This results in the elimination of the high-frequency and short-wavelength losses.

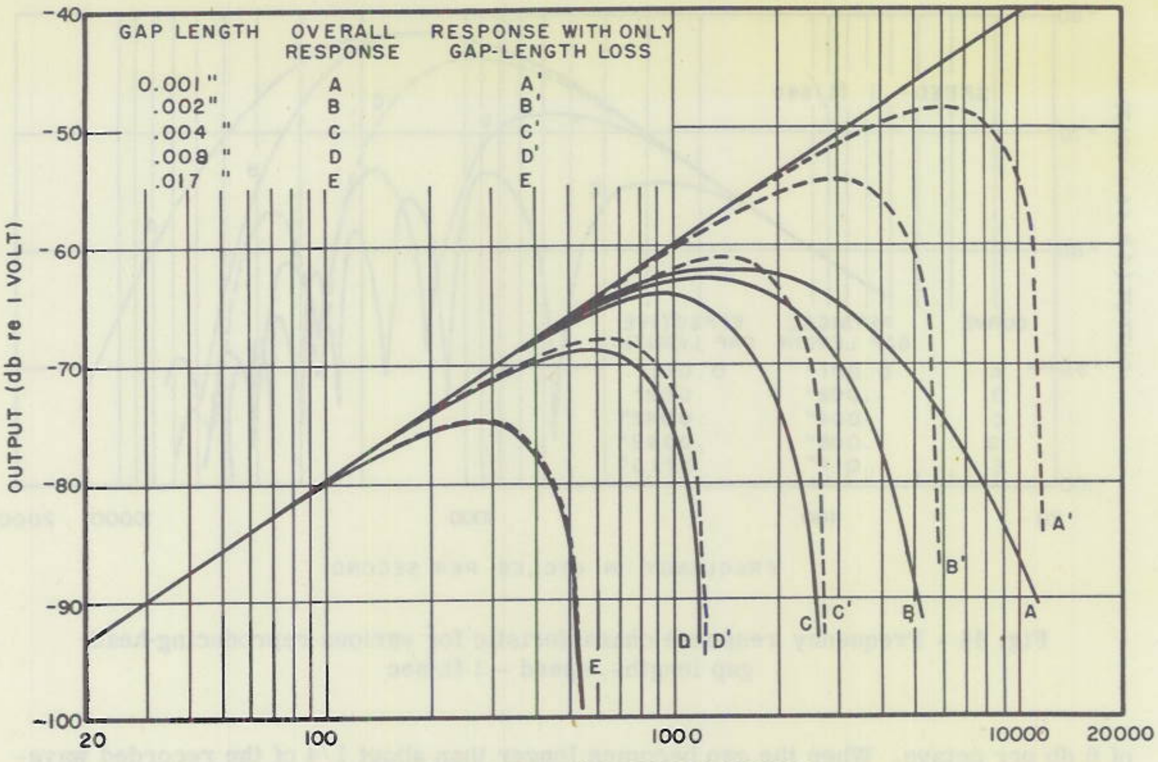


Fig. 45 - Separation of gap-length loss from other losses

The solid curves represent the actual response for the various gap lengths as shown. It should be remembered that all curves were taken at the same speed; thus any selected frequency on all curves has the same wavelength. Therefore the curves for the longer gap lengths, 0.017″ and 0.008″, should contain little or no loss due to demagnetization, thickness, or spacing. The 0.017″ curve, especially, should be free of any loss except the gap-length loss.

In order to check the validity of this conclusion, the theoretically calculated response curves showing only gap-length loss were plotted and are shown by the dotted curves in Figure 45. This shows that the 0.017″ actual response curve does agree with the calculated curve while all other actual response curves differ from the calculated curves. This difference, which becomes larger as the frequency range increases, represents all losses except the gap-length loss.

Effect of Gap Length in the Recording Head - Figure 46 consists of a group of response curves all taken with the same reproducing head, which had a gap length of 0.001 of an inch. Each curve represents a different gap length in the recording head. The speed of the tape in each case was one foot per second. It can be seen that the gap length of the recording head has little effect on the frequency response characteristic of the system. This is due to the fact that as the tape passes over the gap, it is left in the condition that prevails just as it leaves the gap. Essentially, this means that the controlling factor in determining the resolution of the recorded signal is the field pattern of the flux at the point where the tape leaves the field. Thus the gap length affects the frequency response

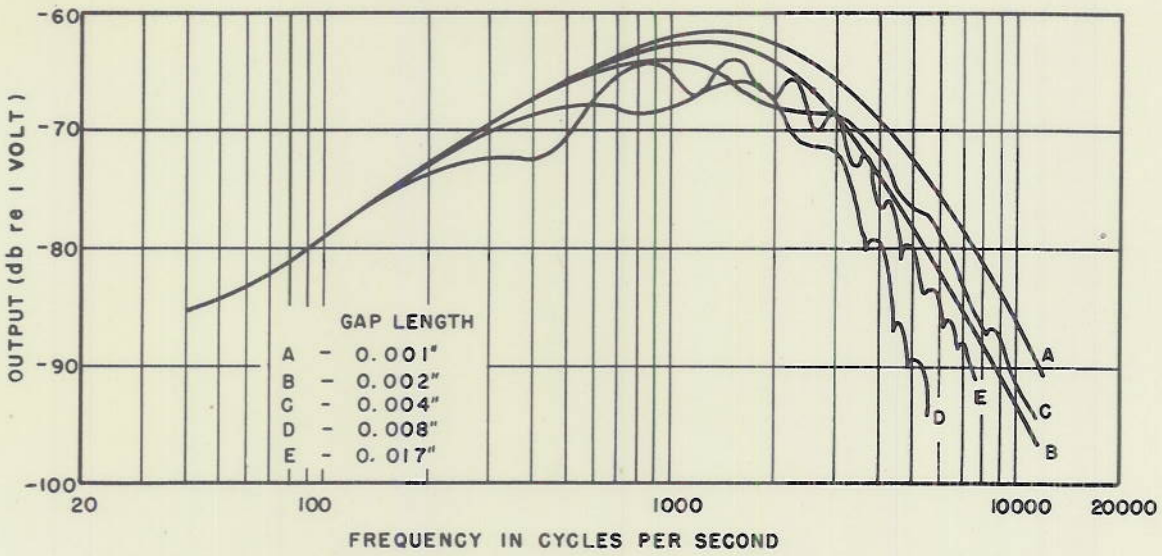


Fig. 46 - Frequency response characteristic for various recording-head gap lengths

characteristic only to the extent to which it affects the field pattern. Usually this effect is insignificant.

The Output-Input Characteristic

As described in the first section of this report, the magnetic-recording testing instrument includes means for energizing a recording head with a linearly increasing signal current and for automatically plotting the output of the reproducing head against this input. With this arrangement, a linear system gives a graphically recorded line making a 45-degree angle to the base line. Both input and output are plotted in decibels to the same scale.

A series of output vs input curves are shown in Figures 47 and 48 for two different types of coated tapes. For any one tape, a series of these curves for various values of bias and for several different frequencies should be plotted. From these curves another curve may be plotted, for each bias value, showing input recording level vs frequency for any given deviation from linearity. That is, on every output-input curve, the input level is found at which there is a certain deviation, say 1 db, from the 45-degree slope. Such input levels for the different frequencies determine to what extent the medium under test can be magnetized without exceeding a certain amount of distortion.

Unfortunately, the output-input curves cannot be taken completely at face value. It is entirely possible that a 45-degree straight line may be accompanied by considerable distortion of the output.

Noise Analysis

Analysis of the noise from an erased magnetic medium as well as analysis of any recorded noise or other signal may be made by using the Erpi Sound Analyzer in conjunction with the FR graphic level recorder. Figure 49 shows one noise-analysis test made on a type of coated-plastic tape.

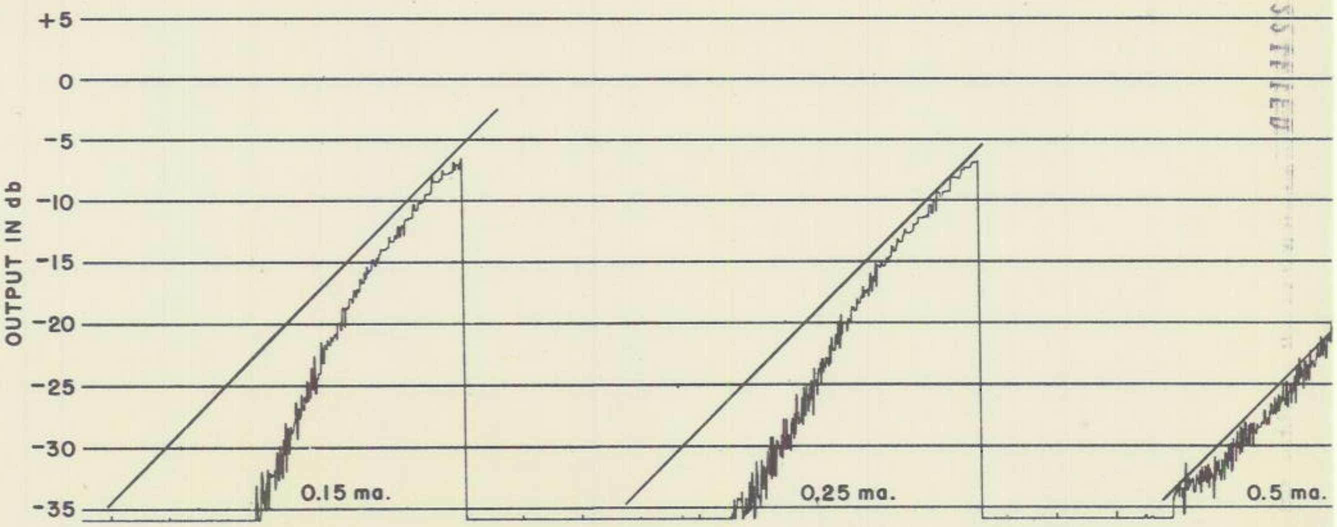


Fig. 47 - Out

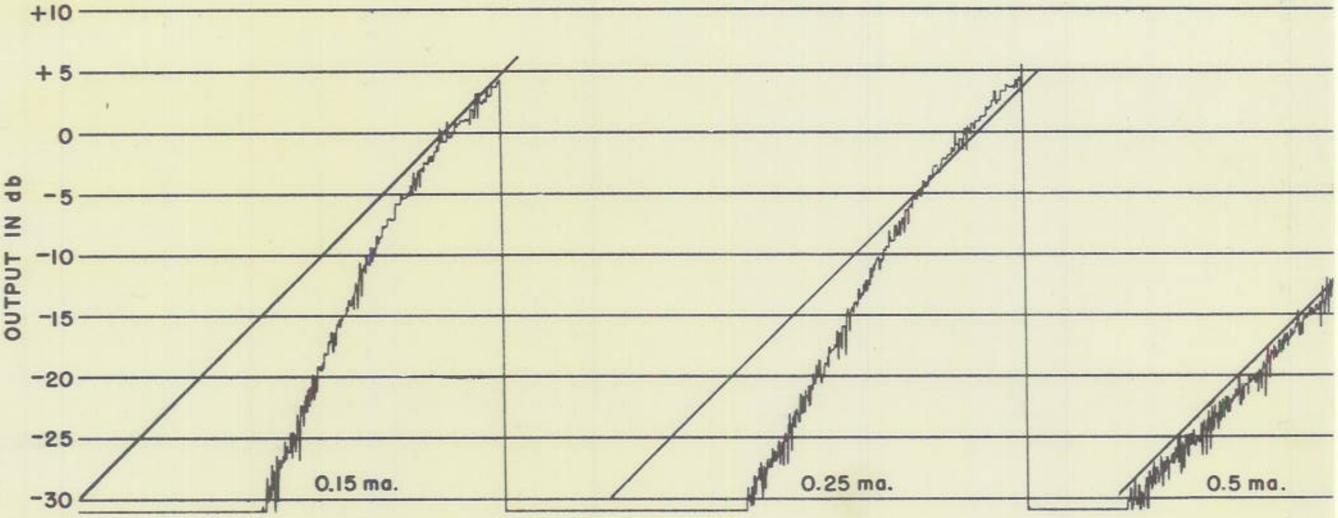
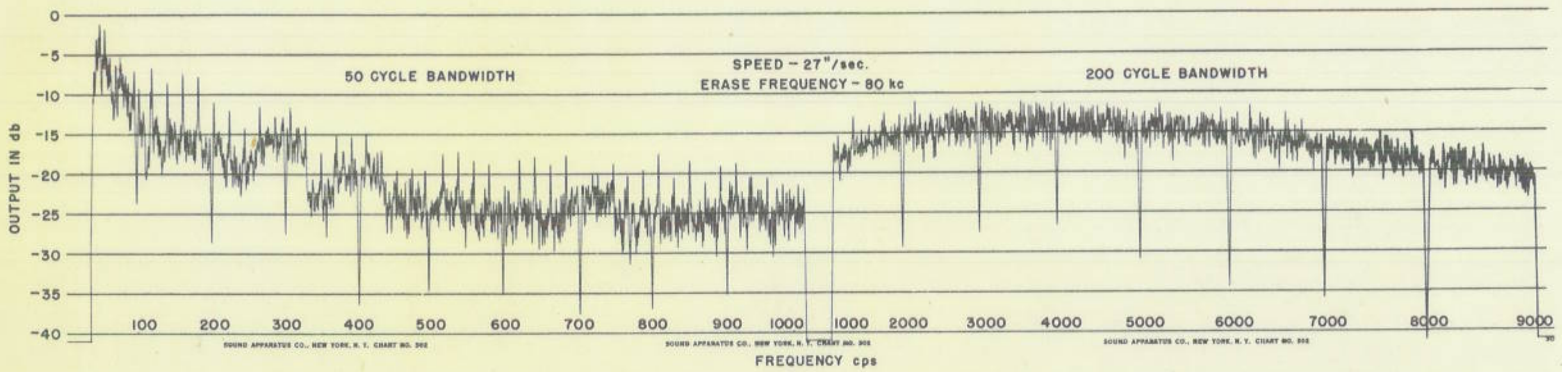
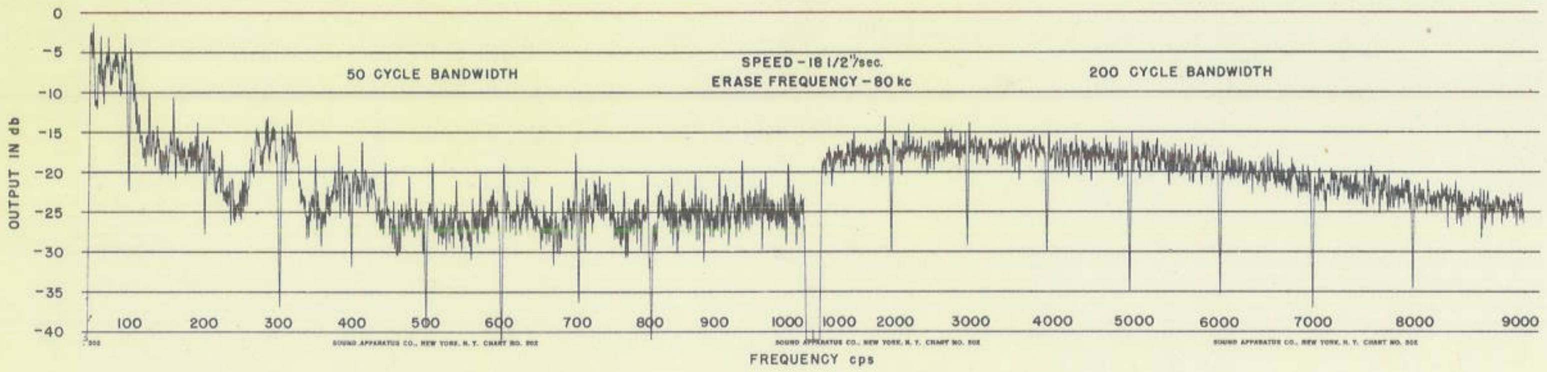


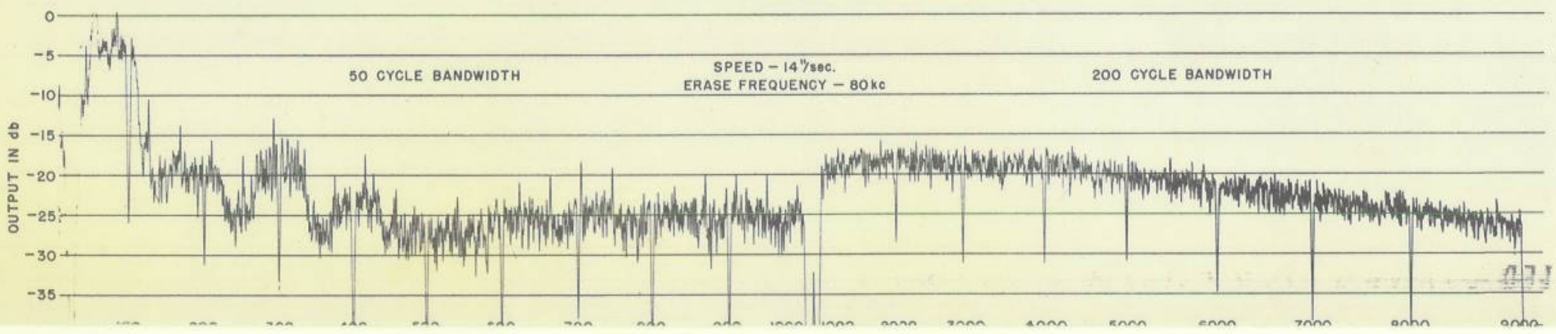
Fig. 48 - Out


OUTPUT IN db
0
-5
-10
-15
-20
-25
-30
-35
-40
50 CYCLE BANDWIDTH
SPEED - 27"/sec.
ERASE FREQUENCY - 80 kc
200 CYCLE BANDWIDTH
100
200
300
400
500
600
700
800
900
1000
1000
2000
3000
4000
5000
6000
7000
8000
9000
SOUND APPARATUS CO., NEW YORK, N. Y. CHART NO. 302
FREQUENCY cps

(a)


OUTPUT IN db
0
-5
-10
-15
-20
-25
-30
-35
-40
50 CYCLE BANDWIDTH
SPEED - 18 1/2"/sec.
ERASE FREQUENCY - 80 kc
200 CYCLE BANDWIDTH
100
200
300
400
500
600
700
800
900
1000
1000
2000
3000
4000
5000
6000
7000
8000
9000
SOUND APPARATUS CO., NEW YORK, N. Y. CHART NO. 302
FREQUENCY cps

(b)


OUTPUT IN db
0
-5
-10
-15
-20
-25
-30
-35
50 CYCLE BANDWIDTH
SPEED - 14"/sec.
ERASE FREQUENCY - 80 kc
200 CYCLE BANDWIDTH
8000
9000

In making such a noise analysis, the noise level of the reproducing amplifier must be at least 10 to 15 db below the noise level of the tape. In the present reproducing amplifier, the ac-operated heaters account for the low-frequency peak shown on the plot of Figure 49. Two sets of analysis plots are made so as to validate the results of the tape analysis. First, the tape is separated from the gap in the reproducing head so that no pick-up from the tape occurs. Next, while the tape is driven at its normal speed, an analysis is made of the output from the reproducing amplifier. Then, with nothing else changed, the tape is allowed to run in contact with the head and another analysis is made. The difference between these two plots shows if the level of the analyzed tape noise is sufficiently above the equipment noise so as to make the analysis valid. Ordinarily a 50-cycle-bandwidth sweep is used in the analysis.

Pulse Recording

With the wider use of computing machines, application of magnetic recording to the recording of pulses has become increasingly important, since it offers means for the storage of numbers and tables, and for dispatching operating orders as well as receiving the results from the computer and holding them until they are transferred to a written record. Pulse recording is also useful for the recording of numerical intelligence. Such applications would include telemetry.

A large quantity of data concerning the processes involved in pulse recording has been obtained by use of the magnetic-recording test instrument, but because of the restricted nature of this data, only a few examples are given.

In most applications of pulse recording it is desirable to record as many pulses as possible on a given length of recording medium and still maintain sufficient resolution so that the output pulses can be distinguished by electronic circuits. If only square waves or successive pulses of like polarity are considered, then any attempt to record more and more pulses per inch of medium will cause the output signal to approach a sine wave having a frequency equal to either the square-wave frequency or the repetition rate of any series of pulses of the same polarity.

Figure 50 shows a few typical photographs of the output from a tape on which square waves were recorded. Actually since the response of the recording system has a 6-db-per-octave rising frequency characteristic, it is essentially a differentiating device. Thus, in an unequalized system, the output from a recorded square wave is a series of "pips," each "pip" occurring whenever the recorded square wave changes polarity. Since these pips can be nicely handled by electronic circuits, there is usually no need to apply equalization in order to obtain in the output the original recorded square waves.

The sharpness of the pips is affected by the recording-reproducing-system losses if they cause the frequency response characteristic to deviate from the 6-db-per-octave rise at frequencies in the region below approximately 10 times the square-wave frequency.

The top photograph of Figure 50 shows the actual recording-current waveform of a 2400-cps square wave. There are 5 columns of photographs, each column representing a different recording speed. The photographs show the output pips as reproduced both at the same speed with which they were recorded and also at a speed one one-hundred-and-twenty-eighth (1/128) of the recording speed.

It may be seen that the sharpness of the pips for any given frequency is a function of the recording speed. This is to be expected since, as has been previously discussed, most losses are due to short recorded wavelengths. If longer wavelengths are obtained by

CONCLUSION

Many types of data* can be obtained from the magnetic-recording testing instrument and the amount of data that can be collected, and effectively used, is practically limited only by the time required for proper interpretation of the results.

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* All of the sample data presented in this report were obtained in work on specific problems.

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