PROCEEDINGS

of the Department of Defense

SYMPOSIUM

on

MAGNETIC RECORDING

Fifth Symposium on Acoustics-in-Air Research and Development

1 MARCH 1954

TABLE OF CONTENTS

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TABLE OF CONTENTS

PREFACE

The Navy Department, Bureau of Ships, has the allocation from the Research and Development Board of the Department of Defense, to provide coordination effort in the area of Acoustics-in-Air Research and Development within the Department of Defense. As part of this coordination effort, four symposiums have been held before the present one, covering a diversity of subjects in this field, with suitable security classification, and with participation by Department of Defense personnel only.

The Magnetic Recording Symposium, the fifth symposium to date, differs from the other four in two major respects. The subject matter has been confined to one major area, magnetic recording, and the majority of papers have been presented on an unclassified basis with participation and attendance by industry and technical organization representatives as well as by Department of Defense personnel. This plan has resulted in the presentation of 18 papers on an unclassified basis with attendance by industry (160 persons, representing 65 organizations), as well as Department of Defense personnel (90 persons, representing 45 organizations).

Welcoming remarks by Chief, Bureau of Ships, Rear Admiral W. D. Leggett, Jr., and by Captain A. B. Jones, former head of Code 565, emphasized the following reasons and purposes of the symposium:

a. Exchange between industry and government groups of up-to-date information in research and development area.

b. Free expression of the position of various technical societies, industry, government groups, and individuals on pre-emphasis and post-equalization systems for recording and playback of magnetic sound. This is intended as an aid to various standardizing groups, and to preparation of government specifications for procurement of magnetic recording equipment, and in which definite specifications must be set forth for required pre-emphasis, post-equalization, and measuring methods.

c. To acquaint industry with the reasons behind some of the more stringent and unusual requirements in militarized recording equipment.

d. As a means of acquainting industry and Department of Defense personnel in this field.

Both Admiral Leggett and Captain Jones emphasized the desire for an informality and comradeship among personnel at this meeting to facilitate the free exchange of technical data in this very active field of research and development. This is also the reason why discussions have been summarized at the end of each paper.

The Bureau of Ships wishes to acknowledge its indebtedness to the session chairmen, to the authors of the various papers, and to the persons and organizations listed below who have helped greatly in obtaining papers and planning the symposium:

Acoustical Society of America (who have helped regularly on Department of Defense Symposiums on Acoustics-in-Air).

Audio Engineering Society (Sponsor of Paper No. 15).

Institute of Radio Engineers (Sponsor of Papers No. 6, No. 8, No. 11, and No. 17. Washington representative on papers committee--Mr. Henry P. Meisinger, U. S. Recording Company).

National Association of Radio and Television Broadcasters (Sponsor of Papers No. 13 and No. 18. Washington representative on papers committee--Mr. A. Prose Walker, Manager of Engineering for NARTB).

Society of Motion Picture and Television Engineers (Sponsor of Papers No. 7 and No. 12. Washington representative on papers committee--Mr. Joseph E. Aiken, Naval Photographic Center.)

Dr. Semi J. Begun, Vice-President of Clevite-Brush Development Company (for his original proposal and enthusiastic support of the Magnetic Recording Symposium.)

Sufficient copies of the present proceedings have been prepared to issue them to government and industry groups who are actively engaged in research and development, manufacturing, or direct application of magnetic recording techniques to Department of Defense problems and applications. Inquiries for copies, with some information on the "need to know", should be directed to: Department of the Navy, Bureau of Ships, Code 362, Washington 25, D.C.

Department of Defense Symposium on Magnetic Recording

Paper 1

FERRITE CORE HEADS FOR MAGNETIC RECORDING

R. J. Youngquist and W. W. Wetzel

Minnesota Mining & Manufacturing Co.
900 Fauquier Avenue
St. Paul 6, Minnesota

9 October 1953

ABSTRACT: Preliminary qualitative experiments indicate that ferrite has considerably greater resistance than mu-metal to the abrasive action of magnetic tape. This may be expected to follow from the relative hardnesses of the materials. It is shown that, through proper design, ferrite core recording heads can be made which are the equivalent in output and frequency response to the mu-metal heads currently in use in the motion picture industry.

Introduction

It is common knowledge that magnetic recording and reproducing heads eventually fail through wear and must be replaced after varying periods of operation.

The useful life of a given head is obviously a function of its design and the conditions under which it is operated. For instance, one parameter of head design which affects its ultimate life is the depth of permeable metal at the gap. A ten mil depth will be abraded to gap destruction somewhat more than twice as quickly as a twenty mil depth. High pressure between the magnetic film track and the head promotes abrasion. Fresh magnetic film has been reported to be more highly effective in producing head wear than film which has been used repeatedly. Wear should also be expected to increase in approximate proportion to the film speed.

Head wear has seldom been reported as a serious problem affecting the operation of magnetic recorders. In the motion picture industry where original takes and dubbing of magnetic sound to optical track have up to now constituted the major use, this wear has been taken for granted. Skilled technicians are employed in the industry as equipment operators. Head wear is readily detected by them and they are competent to make replacements.

Head Life

In the standard operation of 35mm. film, relatively wide magnetic heads and tracks have been employed. It is customary to use heads approximately 200 mils wide in such operations. Between three[1] and five million feet of 35mm. film must usually pass over such a head before replacement becomes necessary. This means the head life is something between 500 and 1000 hours. For narrower tracks of 100 mil width on 16mm. film, the head life appears to be comparable[2] possibly because the tape pressures are made equal to those of 35mm. practice. Del Valle and Farber show approximately 750 hours for the estimated half life of a head under 16mm. operating conditions. This agrees reasonably well with the reported head life for 35mm. operation when a correction is applied for the differences in film speed.

It should be noted that controlled experiments on head wear are not attractive to perform since the times involved in producing observable wear are rather extended. In a normal 40 hour per week laboratory regime from three to six months testing will be required to run a head to the point of destruction. In lieu of results from many controlled experiments, it is necessary to depend upon the experience of the industry which appears to set a figure of about 750 ± 250 hours for the life of a mu-metal head when subjected to a film speed of 90 feet per minute.

While such head life does not impose a limitation on the operation of magnetic recorders in studios, it promises to be somewhat of a costly nuisance in release theaters where magnetic track is used for stereophonic sound. The presently available figures of a 750 hour average life indicates the need for replacement of one of the two heads in a projection booth each nine weeks of operation.

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[1] Kurt Singer and Michael Rettinger, "Correction of Frequency Response Variations Caused by Magnetic Head Wear," Jour. SMPTE 61:1-7 July 1953.

[2] G. A. del Valle and L. W. Ferber, "Notes on Wear of Magnetic Heads," Jour. SMPTE 60:501-506 April 1953.

Abrasive Action of Tapes

The iron oxide commonly used as the magnetically active ingredient in tape and film coatings is a mild abrasive. It is closely related to the material known as crocus (alpha Fe_2O_3) which is used as the final abrasive for glass polishing. Crocus cloth, coated with these same particles of iron oxide, is an article of commerce used for polishing metal.

The magnetic form of red iron oxide (gamma Fe_2O_3) has approximately the same hardness and abrasive action as crocus. On tapes and films, coatings of this oxide act as abrasive or polishing agents which slowly wear through surfaces they contact. The rate of wear of the surface contacted is connected with the relative "hardness" of the surface and the abrasive. Mineralogists use a practical rating called the "Moh" scale of hardness for classifying minerals. One mineral is harder than another under test if it scratches or abrades the test specimen. The Moh scale rates minerals from 1 to 10 in order of increasing hardness. On this scale gamma Fe_2O_3 is rated[3] as having a hardness of 5. A typical head core formed of mu-metal was tested and found to have a hardness of only 3.5 or, in plain words, it could be abraded by the iron oxides in magnetic film.

Two possible approaches leading to the reduction of head wear exist. The first is to produce a film coating formed of magnetically active material softer than the present heads. The second solution is to obtain magnetic core materials which are harder than the oxide. In order that the approach be practical it must sacrifice little or none of the superior magnetic qualities of the gamma ferric oxide now commonly employed. Similarly it would be impractical to adopt abrasion resistant head cores which unduly sacrifice either the excellent frequency response or output of the mu-metal heads.

Our laboratory maintains a project devoted to the evaluation of magnetic powders in a continuing search for materials which might prove superior to gamma ferric oxide as a magnetic recording medium. No soft, adequate substitute for iron oxide has yet been found.

On the other hand, a whole class of hard magnetic core materials called ferrites exists. Many of the ferrites are commonly used as relatively high permeability transformer cores for high frequency applications. Some early experiments[4] showed certain ferrites could replace laminated mu-metal cores for magnetic head construction. Heads made from these ferrites had adequate magnetic permeability and excellent wear resistance. They were inferior to mu-metal heads only in their high frequency response. This deficiency was correctly attributed to a lack of well defined gap edges. This defect has now been overcome as will be seen later.

From the present state of our knowledge it becomes apparent that any immediate solution of the head wear problem must come from the construction of harder heads rather than the production of softer tapes. While it is true that lubricants incorporated in a tape tend to reduce head wear, lubrication is effective by only a factor of two, not ten or one hundred.

Abrasion Resistance of Ferrites

Unfortunately no controlled experiments on the resistance to abrasion of ferrite heads by magnetic film have been made. Only qualitative comparisons exist between the wear resistance of mu-metal and ferrite under the action of 1/4" tape.

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[3] J. D. Dana, "System of Mineralogy," Vol. I, p. 718, 7th Ed. J. Wiley and Sons.
[4] Robert Herr, "Mixed Ferrites for Recording Heads," Electronics 24: 124-125, April 1951.

Ferroxcube No. 101 core forms[5] were used throughout our experiments. This is a compact, fine-grained ferrite having an initial permeability of 1200, a remanent magnetization of 1100 gauss and a coercivity of 0.18 oersteds. Its hardness has been found to be 6.5.

In one abrasion test a toroid of this material 1/2" in diameter and 1/4" thick was weighed. It was then placed in contact with a 4 foot loop of 1/4" recording tape in such a fashion that the tape had a wrap of about 28° about the outer surface of the toroid. The tape tension was 25 grams and its linear speed 24" per second. The loop was replaced with fresh tape twice a day.

After 2000 hours of abrasion under these conditions the weight loss of the toroid was found to be 0.4 milligrams which was approximately the probable error of the weighing. The visible change of the surface of the toroid was a slight polishing of the high areas which contacted the tape. It is our experience that under similar conditions a piece of mu- metal would have shown perceptible wear.

A second qualitative experiment involved about fifty ring type ferrite heads with gaps which were run in contact with essentially fresh tape for a period of 2000 hours at a speed of 18" per second. The wear was inperceptible. Under the same conditions, we should expect loss of 10 mils or more in gap depth of a mu-metal head.

Controlled experiments on the comparative wear of mu-metal and ferrite are being started and some reasonably reliable quantitative comparisons may be expected in the fall of 1954. However, our present qualitative tests indicate ferrites to be many times more resistant to tape wear than mu-metal.

An Experimental Head

Certain questions and misunderstandings have arisen concerning ferrite core heads. Perhaps the most prevalent idea concerns the inability to produce sharp, well defined gap edges. This idea probably arose from the first publication[4] in which a failure to produce sharp gaps was reported. Other questions concern: (1) the effects of the relatively low initial permeability of ferrite compared with mu-metal; and (2) the comparison of output at equivalent inductance.

In order to answer such questions, an experimental ferrite head was constructed which simulated a well known brand of motion picture head. The head width in each case was 0.200 inches. The mu-metal head had a physical gap width of 0.6 mils while that for the ferrite head was 0.5 mils. In each case the inductance was approximately 3 mh.

Figure 1 shows constant current frequency response curves obtained for these heads. The tape speed employed was 7.5" per second. In each case the bias and recording currents were adjusted for optimum output at one percent distortion at low audio frequencies and the results were obtained using the head under test for both recording and reproduction. At low frequencies the output of each head is identical. Peak output for the ferrite is 1 db lower than that of the mu-metal head but at 10 kc the output of the ferrite head is 2.5 db higher. This latter observation is to be expected as the consequence of a slightly smaller physical gap in the ferrite head.

Since these tests show essentially equivalent output and frequency response it is reasonable to conclude that: (a) in spite of the low permeability, it is possible through design to obtain both output and impedance values for ferrite cores which are essentially equal to the values for mu-metal cores heads; and (b)

[5] Manufactured by Ferroxcube Corporation, Saugerties, New York.

half mil gaps in ferrite may be formed sufficiently accurately to approximate the high frequency response of comparable mu-metal heads.

Conclusion

It appears on the basis of incomplete scientific evidence that we are justified in hoping that the new core material offers a large increase in head life without sacrificing quality of the reproduced sound.

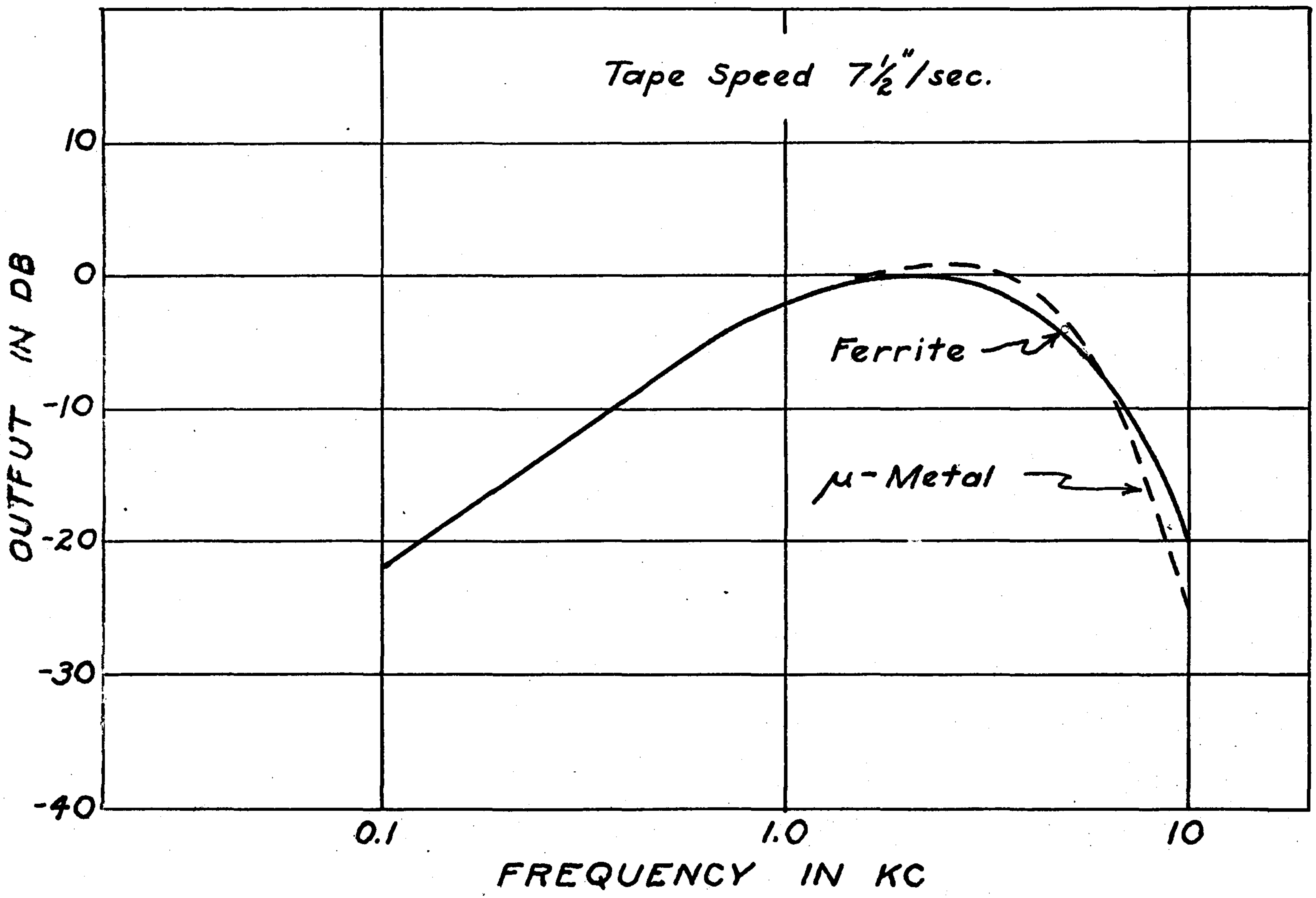

Figure 1. The frequency response and output of a standard mu-metal recording head are compared with the same variables for a ferrite head designed to be its equivalent in performance.

DISCUSSION SUMMARY

Dr. Wetzel advised Mr. Plice of Industrial Research Products that the same head was used for both recording and reproducing. The data for curves was taken with the same head used for both recording and reproducing. Mr. Plice also asked for data on the reversible permeability of the head materials. Dr. Wetzel advised that initial permeability of the materials was approximately 400 (which was comparability to reversible permeability). Dr. Rubens of ERA Division, Remington-Rand, Incorporated, added the comment that the Ferroxcube No. 3 type of ferrite and Ferramic H varies in initial permeability with samples measuring as high as 1500.

Dr. Wetzel replied to Dr. Begun of Clevite-Brush that Minnesota Mining had developed one ferrite head with a gap length of 1/4 mil (.00025 inch) instead of the normal 1/2 mil gap. Its high frequency response was, of course, better than the heads with 1/2 mil gap, but the output signal was much lower. Mr. Bauer of Shure Brothers asked if thinner laminations had been tried to reduce eddy current losses. Dr. Wetzel replied that laminates as thin as .014 inch had been used. There is a practical limit on thinness of laminates. Also, thinner laminates do not reduce hysteresis loss which is the major one in ferrites. In addition, the ratio of laminate thickness to insulation (spacer between laminates) thickness goes down rapidly.

In reply to Mr. Nordyke of IBM, Dr. Wetzel gave ± 1-1/2 db. as the degree of response conformance between heads as now being produced on an experimental basis.

Mr. Schwartz of Devenco asked for information about relative response at frequencies higher than 100 kc. Dr. Wetzel said that response of ferrite heads does not depend on frequency, particularly, even up to one megacycle. For instance, figure 1, showing response at 7-1/2 inches per second, would also apply at 15 inches per second if the frequency scale is doubled.

Mr. Brauer of Bell and Howell was advised that ferrite heads could be made small and in different shapes, that the problem of firing (sintering) could be controlled to end up with the proper shape. However, ferrites are brittle and thin sections are harder to handle and maintain. Minnesota Mining has produced heads only .025 inch thick.

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Department of Defense Symposium on Magnetic Recording

Paper 2

A VACUUM TUBE FOR AN ELECTRON BEAM MAGNETIC REPRODUCING HEAD

Dr. L. E. Loveridge

Research Department
National Union Radio Corporation

14 October 1953

ABSTRACT: The poor low-frequency response of the conventional magnetic reproducing head has been overcome by the use of a special vacuum tube which, when used with a suitable magnetic core structure, responds with uniform sensitivity down to the d-c level. The operation of the tube depends upon the magnetic deflection of the beam between two collectors. The high frequency response is limited by the usual factors such as: gap width, magnetic core losses, and output capacity. The signal output is considerably greater than the output of the conventional head.

Introduction

The purpose of this paper is to describe a special vacuum tube used in a new type of reproducing head for magnetic tape.[1] The head, or pickup, consists of the tube and the associated core structure. Details of the tube, which was developed by the National Union Radio Corporation, will be discussed in this paper. The tube differs somewhat from an earlier type previously described.[2] The core structure, which was developed by Stromberg-Carlson Company, will be discussed in Paper No. 3.

(Figure 1) Functional Schematic of Final Tube Model

Figure 1 shows the principle of operation of the new tube. It is seen that a miniature electron gun, similar to that used in a cathode-ray tube, forms a beam that passes between the two pole pieces. When there is no flux between these faces the beam passes through undeflected to the two plates, or collectors. When the position of the beam is adjusted correctly by a suitable voltage across the electrostatic deflection plates, the beam equally divides between the two plates. Under these conditions the voltage between the two plates, due to the current flowing through suitable load resistors connected to these plates, is zero. The beam path is shown by the dotted lines along the axis of the tube. The repeller, held at cathode potential causes the beam to divide as shown.

A signal in the tape will cause a flux to appear between the pole-piece faces. (Perpendicular to Figure 1). This flux produces a deflection of the beam (in the plane of Figure 1), with a resulting inequality of beam currents to the two collectors. This changing current flowing through suitable load resistors produces an output signal.

(Figure 2) A Comparison of a Conventional Head With The New Pickup Head

Figure 2 shows a sectional view at A of the new type head, along with a similar view at B of a conventional head. The actual shape of the pole pieces and the core, as shown later is somewhat different than that used in the early model shown here.

In the conventional head the output voltage is, of course, proportional to the rate-of-change of flux threading the coil, while in the new design the output voltage is proportional to the flux density in the beam gap. It thus follows that the tube, and also the complete head when used with perpendicular recording and a suitable core, will respond down to the d-c level.

It can be seen that the new head design requires a much larger backgap than does the conventional head. This gap consists of the gaps at the glass bulb and at the position of the electron beam. The former gap could be eliminated but was not thought necessary for the present design. In spite of the large reluctance of the backgap the output voltage, as will be shown later, is much greater than that obtainable with the conventional head.

(Figure 3) Type R2211 Tube

Figure 3 shows a complete tube. This is a standard size miniature tube using a T-5 1/2 bulb and a seven-pin miniature stem. The maximum bulb length is 2-3/8

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[1] The Development was sponsored by the Bureau of Ships, Contract Nos. NObsr-52421 and NObsr-57452.

[2] A. M. Skellett, L. E. Loveridge, J. W. Gratian, "Electron-Beam Magnetic Reproducing Head," Electronics, October 1953.

inches. With the exception of the pole pieces, cathode, and stem leads, all metal parts of the tubes are made on nonmagnetic material. The shape of the tube elements can be seen fairly well, but a better view of some of the elements can be seen in figure 4.

(Figure 4) Cut-Away View of Tube

The tube parts can be recognized most readily by recalling the arrangement in figure 1. Starting from the left end of the tube we have: the cathode, the several elements of the electron gun, the two pole pieces, the electrostatic deflection plates, the collectors, and finally the support mica. Note that the cathode is mounted perpendicular to the axis of the tube in order to save tube length.

(Figure 5) Method of Mounting the Tube for Test

The cover of the shield is removed to show the tube and yoke. Below the tube mount are conventional erase, record, and pickup heads.

Most of the tests at National Union were made with the yoke shown, rather than with the complete head and tape. Tests using the tape were done at Stromberg-Carlson and will be described in Paper No. 3. The advantage of using the yoke is that tests give the characteristics of the tube, after correction for losses in the yoke, independent of the characteristics of tape magnetization.

The yoke consists of a mu-metal core wound with two coils. A signal generator was connected to one coil and a small battery to center the beam was connected to the other coil. This method of beam centering is no longer required with the later model tubes using internal electrostatic deflection plates.

The magnitude of the current through the yoke from the signal generator was adjusted to give an output signal comparable to that obtained when using tape. This output voltage varied from about 0.3 to 1.0 volt depending upon the type of head used.

The noise output voltage under these conditions, when using d-c on the heater, was about one millivolt and was primarily due to the 60-cycle ambient magnetic field penetrating the shield and deflecting the electron beam. More elaborate shielding would have reduced this hum. This residual hum has, so far, prevented measuring the actual tube noise. An additional noise component is introduced when a-c is used on the heater. Shielding has no affect on this component. The signal-to-noise ratio when used with tape is given in Paper No. 3.

(Figure 6) A Typical Schematic for Magnetic Pickup Tube

Figure 6 shows a typical circuit and operating voltages that can be used with the pickup tube shown at the left. This is one form of a difference amplifier and has the desirable features of: (1) a very low gain for signals that are in phase at the two inputs, and (2) changing the push-pull tube output to a single-ended output.

The microammeter is used in adjusting for equal currents through the 100 K load resistors. The effect of using other load resistors will be discussed later in connection with another figure. The circuit shown can be changed into a d-c amplifier, but this will require a higher voltage than the 300 V supply used in the condenser-coupled circuit.

(Figure 7) Output Linearity of Pickup Tube

Figure 7 shows the output voltage as a function of the beam-gap flux density. Note that the curve is quite linear for outputs up to about 10 volts corresponding to flux densities of about 0.7 gauss. This is much greater than output of any conventional head, hence operation in the linear region is assured. Although this curve was taken for the collectors at 400 volts, more recent tubes show essentially the same characteristics when operated at 300 volts. Higher load resistors will increase the output voltage but not appreciably change the dynamic range with respect to flux densities.

(Figure 8) Relative Response Curve of Pickup Tube and Yoke

Figure 8 shows the frequency response of the tube and yoke together. Curve A shows the relative output when used with constant current in the test yoke (see figure 5) previously mentioned. The test was made in such a way as to eliminate the effect of the amplifier input capacity. Essentially the same curve is obtained for load resistors up to one megohm. This shows that the effect of the tube capacity (about 1.0 uuf) is negligible at the frequencies used.

It is thought that the major drop at the higher frequencies is due to eddy current loss in the yoke. The loss in the pole pieces is negligible when compared to the losses in the yoke used. The yoke loss could be made very much less by using thinner material of higher resistance. The mu-metal yoke used was made thick (0.028 in.) for mechanical reasons. Curve B is the result when the response is corrected for eddy current losses. The small drop in response remaining may be due to hysteresis.

(Figure 9) The Effect of Load Resistance on Pickup Tube Sensitivity

Figure 9 shows the effect of variation of load resistance on output voltage. The internal resistance of the tube ia about 2.5 megohms.

A load resistance up to 0.5 megohm can be used with a considerable increase in sensitivity and with about the same signal-to-noise ratio. When these high load resistances are used, however, the supply voltage must be increased to compensate for the increased voltage drop in the load resistor. These high load resistors can be used with an amplifier only if the signal is small enough not to overload the amplifier.

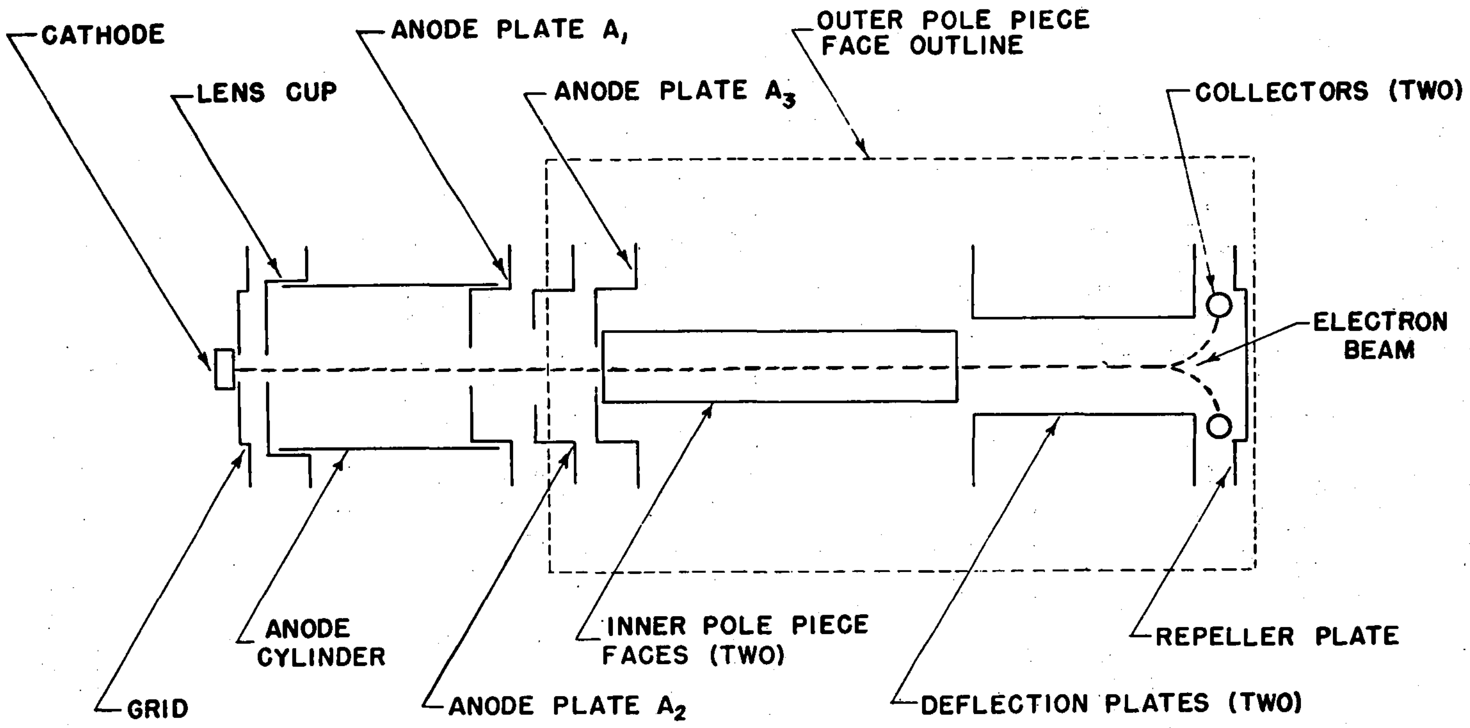
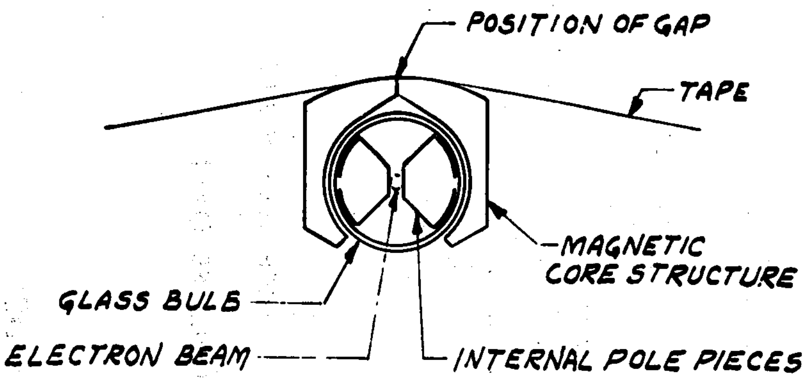
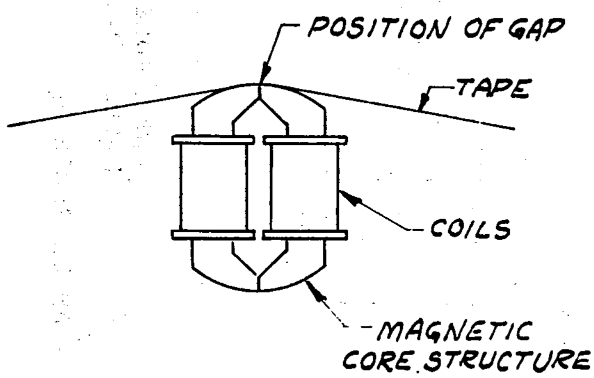


FIG. 1. FUNCTIONAL SCHEMATIC OF FINAL TUBE MODEL



A



B

A. SECTION THROUGH NEW HEAD.
B. OLD HEAD.

FIG. 2. A COMPARISON OF A CONVENTIONAL HEAD WITH THE NEW PICKUP HEAD

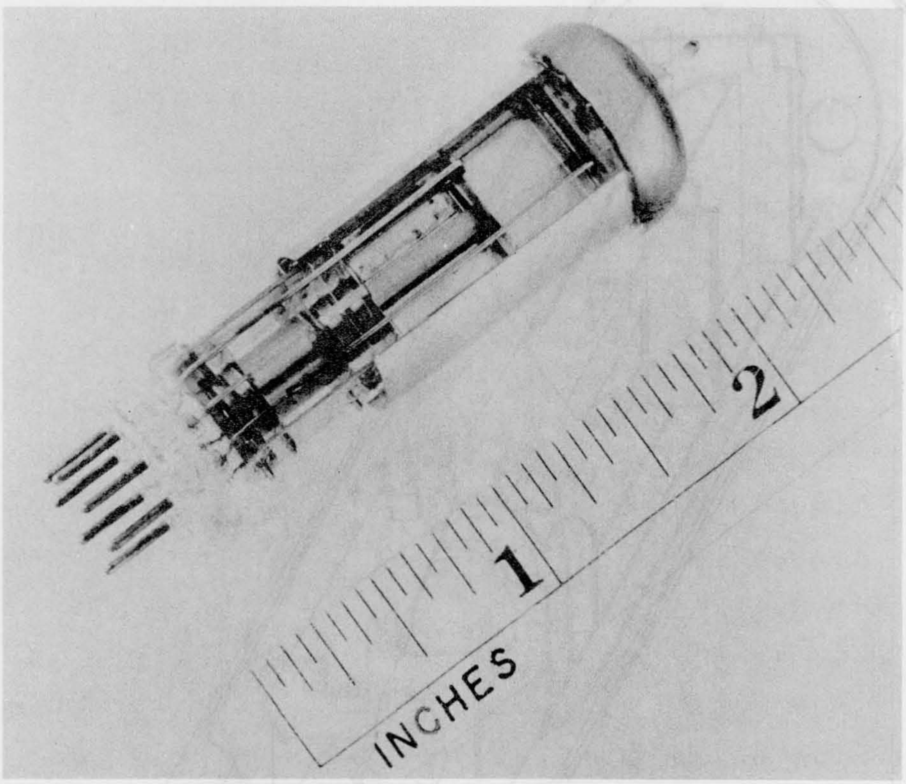


FIG. 3. TYPE R2211 TUBE

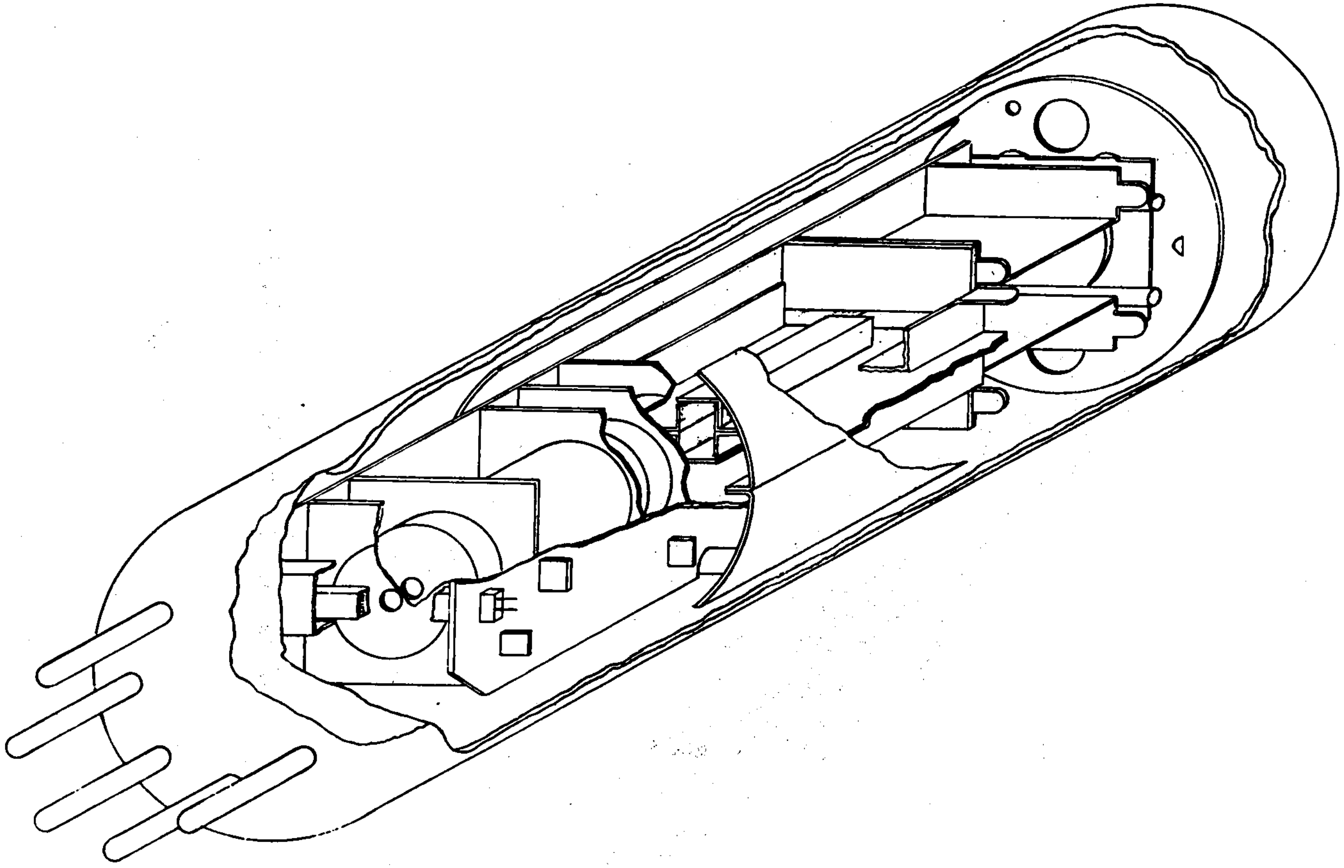


FIG. 4. CUT-AWAY VIEW OF TUBE

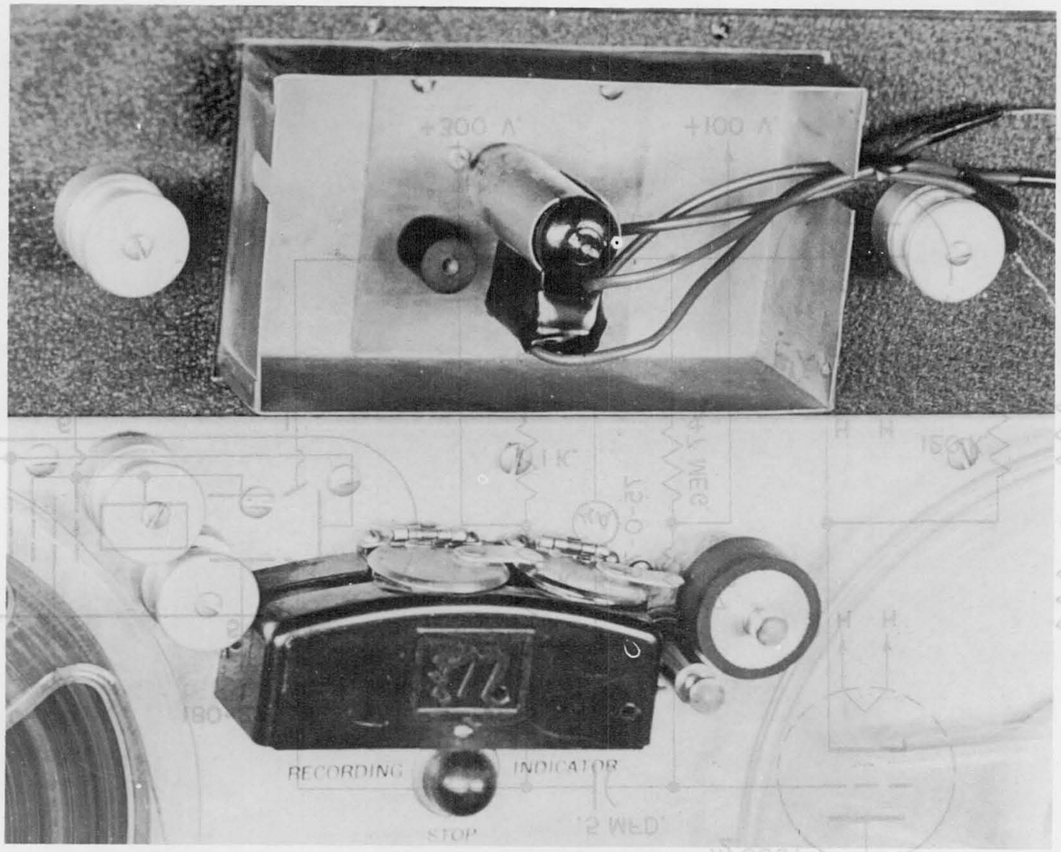


FIG. 5. METHOD OF MOUNTING TUBE FOR TEST

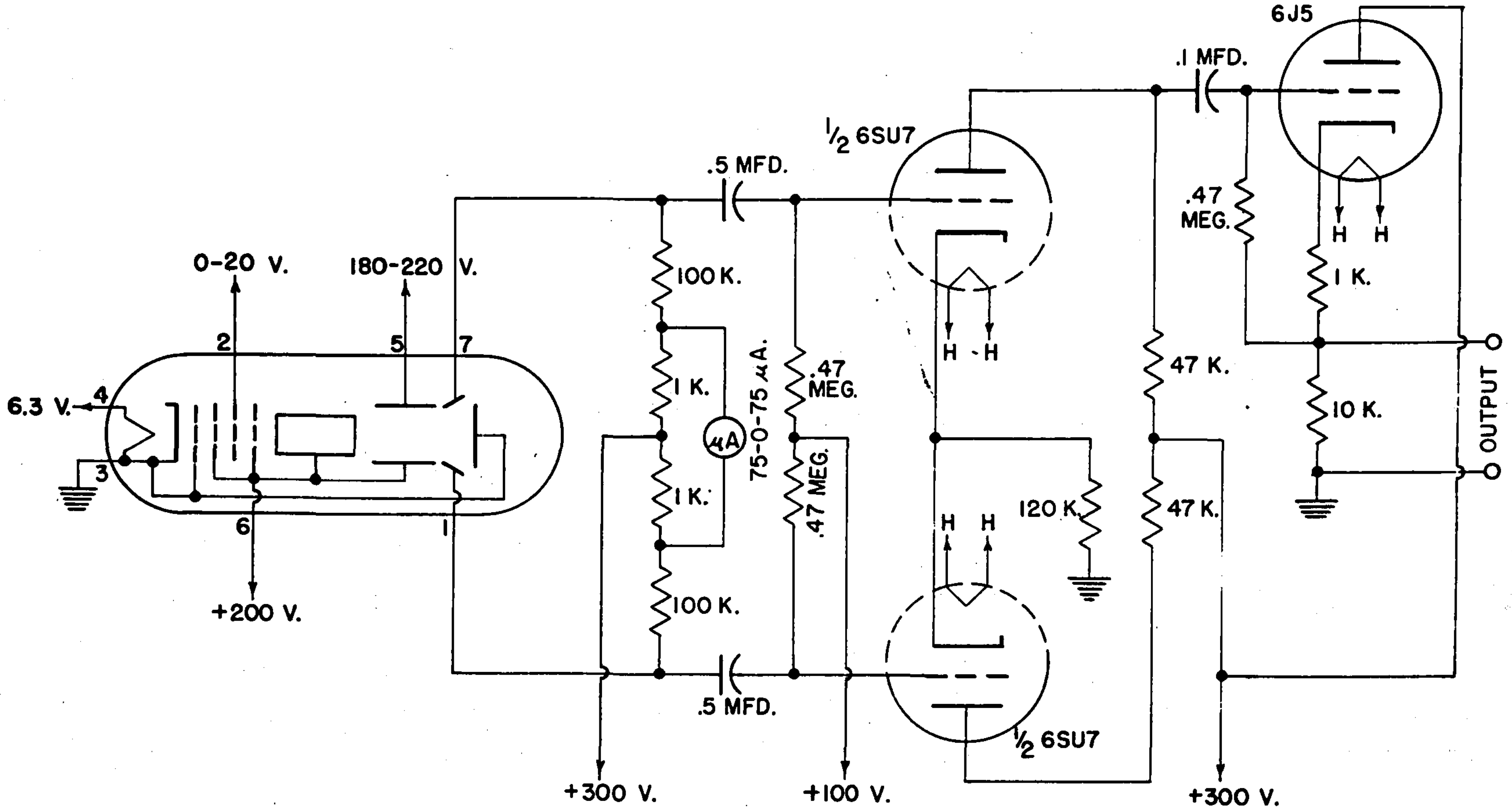


FIG. 6. A TYPICAL SCHEMATIC FOR MAGNETIC PICKUP TUBE

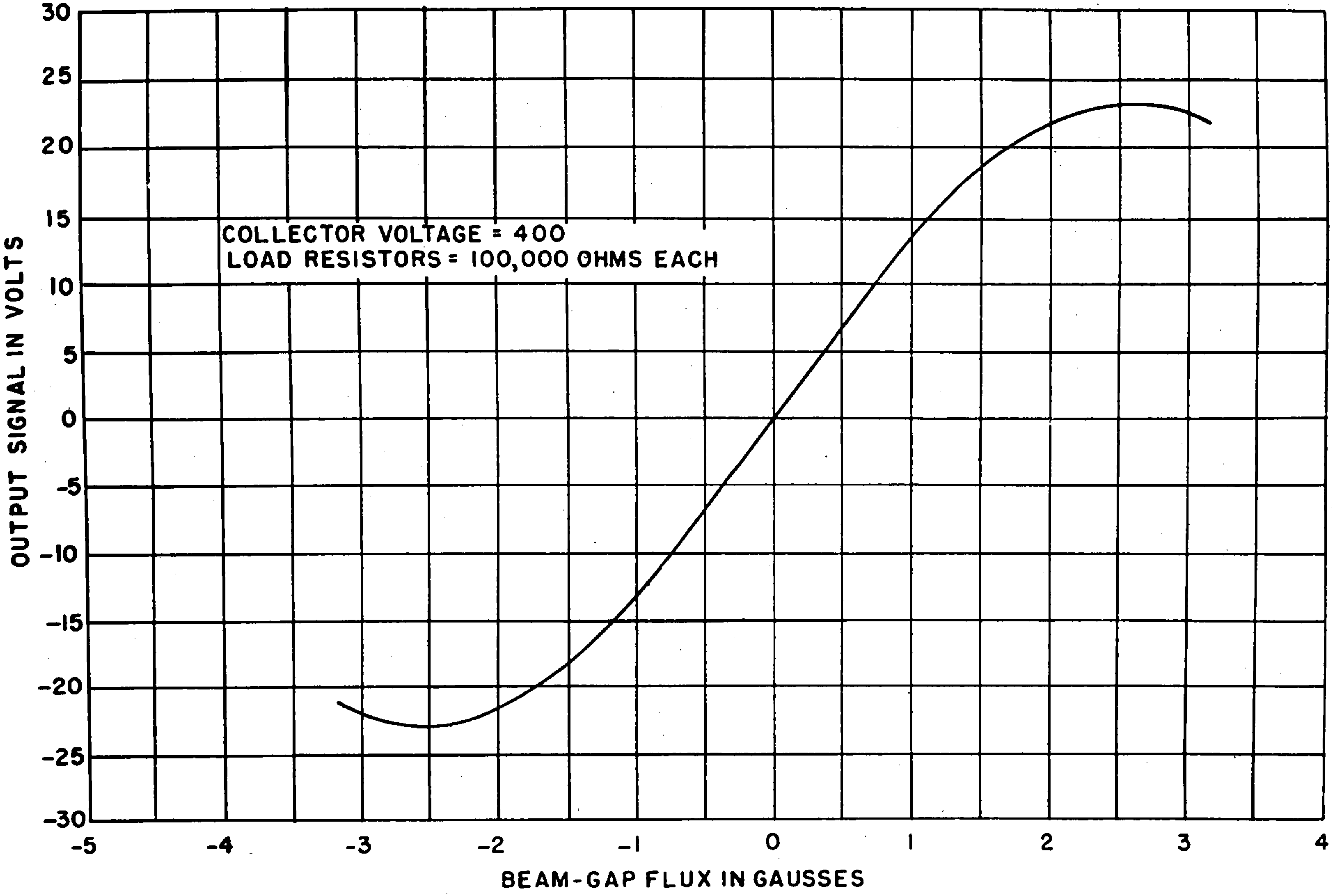


FIG. 7. OUTPUT LINEARITY OF PICKUP TUBE

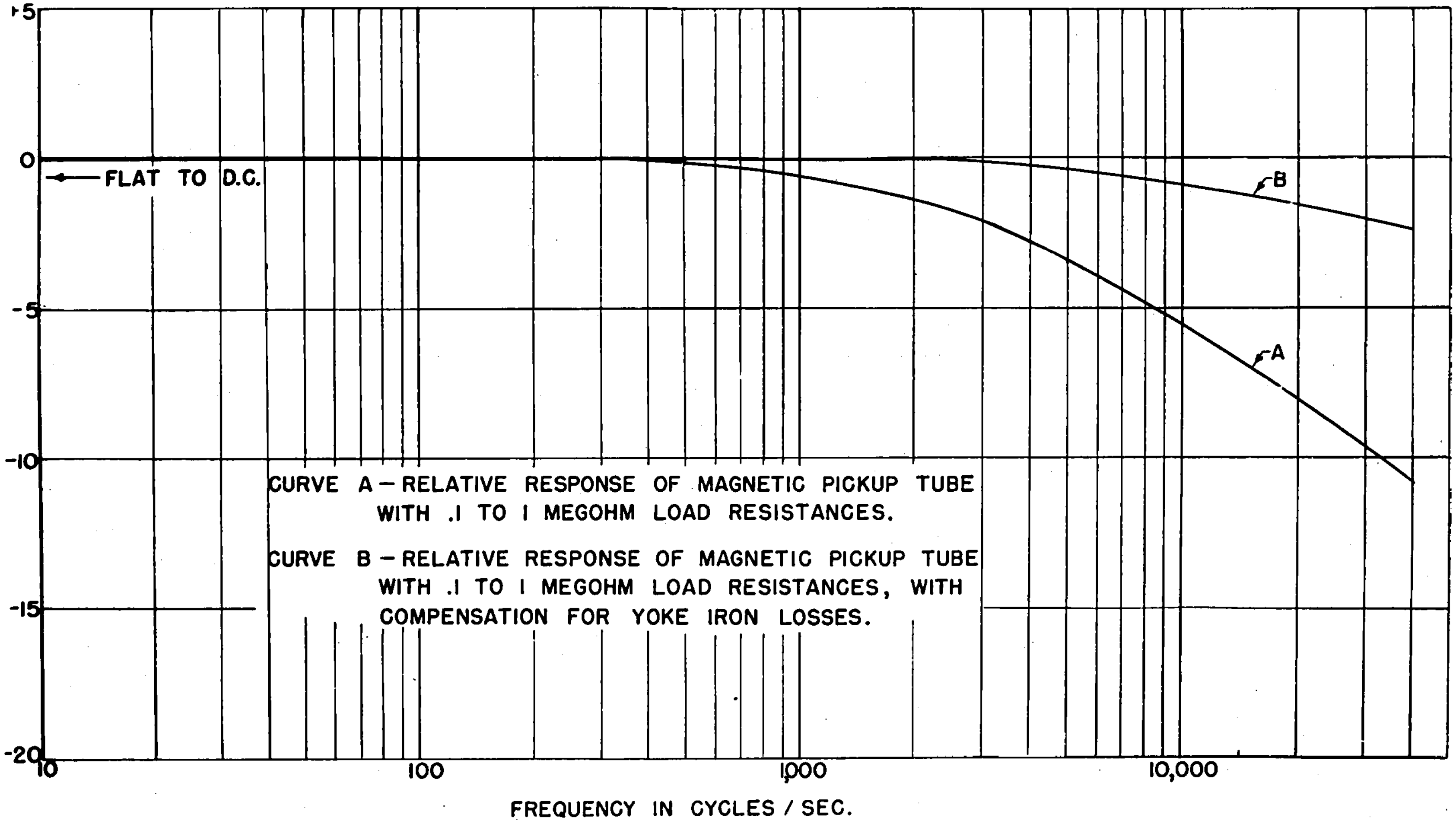


FIG. 8. RELATIVE RESPONSE CURVE OF MAGNETIC PICKUP TUBE

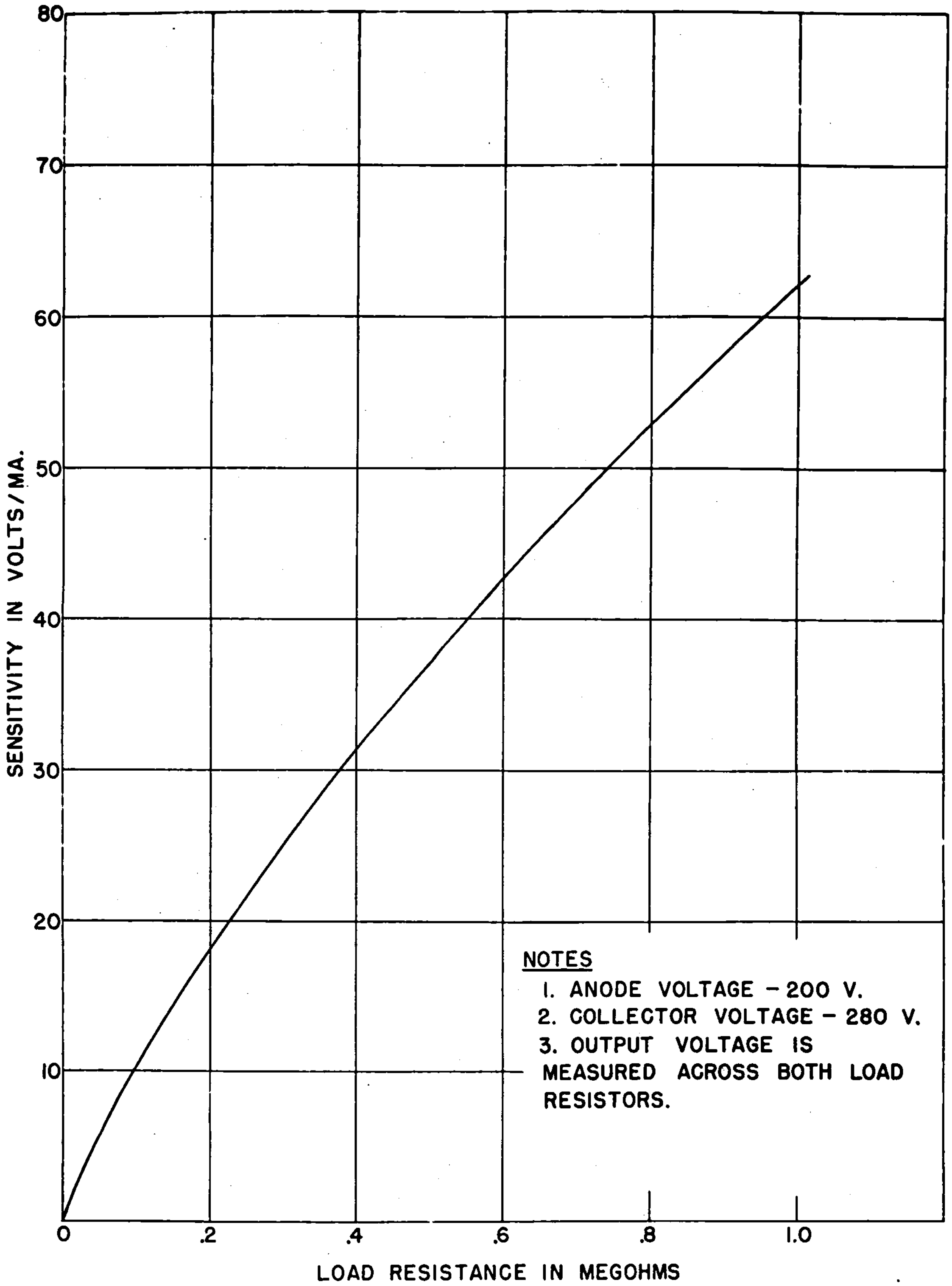


FIG. 9. THE EFFECT OF LOAD RESISTANCE ON PICKUP TUBE SENSITIVITY

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Department of Defense Symposium on Magnetic Recording

Paper 3

CORE STRUCTURES FOR THE ELECTRON-BEAM MAGNETIC REPRODUCING HEAD

J. W. Gratian

Stromberg-Carlson Company

14 October 1953

NOTE: The development work described in this paper was done under a contract sponsored by the Navy Department, Bureau of Ships.

ABSTRACT: As explained in paper 2, the electron beam tube provides an output voltage which is proportional to the flux in the deflecting gap of the tube. The frequency response of the complete pickup, consisting of tube and external core, will be flat over some limited range throughout which the magnitude of the flux directed to the tube is independent of frequency. These limits may be stated most directly in terms of signal wavelength rather than frequency. The data which will be discussed show the manner in which these limits depend upon the physical dimensions and configuration of the external core and the type of recording--i.e., longitudinal or perpendicular.

CORE STRUCTURES FOR THE ELECTRON-BEAM MAGNETIC REPRODUCING HEAD

(Figure 1) Low-Frequency Response of Conventional Pickup.

One of the inherent limitations of longitudinal recording may be appreciated by referring to the response of a conventional ring-type pickup for signals of very long wavelength. For these data, recorded signals having wavelengths between 0.1 inch and 10 inches were reproduced with a ring pickup having a length of 3/8 inch. In the region where the signal wavelength exceeds the length of pickup core by a factor of three or more, the response falls at a rate of 18 db per octave; if an electron-beam tube were substituted for the conventional pickup coil, the slope of the response would be reduced to 12 db per octave but d-c response would still be impossible.

For signals of shorter wavelength, the average response rises at a rate of 6 db per octave; substitution of an electron-beam tube for the coil would result in flat average response throughout this region and up to the high-frequency cutoff. The highest frequency shown here corresponds to a wavelength of approximately 0.1 inch; the useful response range extends two decades beyond this point.

As will be shown later, d-c response can be achieved by using the electron-beam tube in a perpendicular-type recording system. However, the longitudinal pickup is probably of greatest general interest because of its superior high-frequency performance and will be discussed first.

(Figure 2) Cut-away View Showing Magnetic Elements

This cut-away view, with the tip end of the tube and the collector plates removed shows the essential parts of the magnetic circuit. Flux from the tape is directed by the external core to the pole pieces located within the tube and thence to the beam gap where it serves to deflect the electron beam.

A portion of the available signal flux is shunted through the front gap of the external core and wasted. To minimize this effect, the ratio of the reluctance of the path through the beam gap to the reluctance of the front gap is made as small as practicable. An extremely short front-gap length is required to permit resolution of signals having a wavelength of a fraction of a mil. The reluctance of the front gap may be increased, therefore, only by reducing the area of the pole faces. Similarly, the minimum gap lengths which can be tolerated in the useful flux path are limited by the thickness of the tube walls and the space required for passage of the electron-beam; reluctances in this path are reduced to tolerable values through the use of large gap areas.

(Figure 3) Experimental Ring-Type Core Models.

Photographs of two core models which were used in early tests are shown here. Except for the large backgap and omission of the usual pickup coil, the core structure of model A is of conventional form with laminations in a plane perpendicular to the axis of the core. With a front-gap pole-face height of 30 mils, tests showed a drop of 15 db in mid-range sensitivity as the front-gap length was reduced from 5 mils to 0.25 mil.

Model B is a formed-strip type of core with a magnetic structure similar to that previously shown in the cut-away view. The core elements are cast in a thermo-setting resin. In non-laminated models the strip thickness is 14 mils. For model B, each half of the magnetic core consists of a pair of 8 mil thick strip-type laminations concentric with the axis of the core.

Loss in response due to eddy currents at 10 kc is 1.0 db for core A and 1.5 db for core B. This difference is negligible in comparison with other losses which are a function of wavelength when operating at conventional tape speeds. The outstanding advantage of the strip-type core is that it may be easily fabricated in the form of unusually wide structures as needed for use with the electron-beam tube.

(Figure 4) Tape Drive Unit with Electron-Beam Pickup.

A third type of core which will be discussed is the winged model shown here in combination with an electron-beam tube. Construction of this core is similar to that of the previously described close-fitting, laminated, strip-type core except that the outer lamination is formed to a larger radius to provide improved response for signals of long wavelength.

In the tests to be discussed, the tape is erased and constant-current recordings are made using conventional heads. The continuous loop recordings are then reproduced by the electron-beam pickup.

(Figure 5) Wavelength Response Curves for Electron-Beam Tube with Two Different Cores and For Tube Alone.

The response curves shown here are plotted in terms of signal wavelength over a range from .001 inch to seven inches. Curve C shows the response of the tube with no external core and the tape riding on the tube envelope. For curves A and B the tube was fitted with two different close-fitting strip-type cores. Due to the shunting effect of the front gap, the addition of either core reduces tube output for signals of long wavelength. The response range is, of course, greatly extended. With a front-gap pole-face height of 14 mils, as represented by curve B, an appreciable hump in response is observed in the vicinity of two inches signal wavelength. With a pole-face height of 8 mils, as represented by curve A, the response becomes reasonably smooth.

(Figure 6) Wavelength Response Curves for Core Model E Showing Effects of Variation in Shield Dimensions.

These data represent a very brief summary of the effects of shield dimensions and wing width upon the long-wavelength response of the electron-beam tube in combination with winged cores.

Dash-dot curve B shows the response for a core model having a wing width of 1/2 inch. The solid-line curve A, for a wing width of two inches shows an appreciable reduction in the response hump near four inches signal wavelength as well as an increase in output at 10 inches wavelength.

Data for curves A and B were obtained with the pickup unshielded. When using a shield having a length of 10 inches, as represented by curve C, the response at 10 inches wavelength is reduced 2 db and small peaks and dips occur at shorter wavelengths. With a shield length of 4-1/4 inches, as shown by curve D, the loss in response at 10 inches wavelength is approximately 5 db and peaks and dips at shorter wavelengths are excessive.

(Figure 7) Comparison of Electron-Beam and Conventional Pickups.

Curve A shows the overall unequalized response of the electron-beam pickup with a winged core having a length of four inches and a width of one inch. The tape speed was 10 inches per second. If a conventional pickup coil were substituted for the electron-beam tube, the unequalized response would be approximately as shown by curve B. Differentiation of flux in the coil of the conventional pickup produces, in effect, equalization which greatly improves the apparent high-frequency response.

With the addition of equivalent high-frequency equalization, the high-frequency response of the electron-beam pickup is comparable with that of high-quality conventional pickups. As shown by curve C, with a single-section R-C equalizer, the equalized response is flat within ± 3 db from 1 to 10,000 cps. With two sections of R-C equalization, the response is extended to 15,000 cps.

With the conventional pickup, 60 db of low-frequency equalization would be required to obtain response from 1 to 10,000 cps, ± 3 db; since the output of the conventional pickup at 1 cps is only a few microvolts, the desired equalization cannot be applied without excessive loss in signal-to-noise ratio. With the electron-beam pickup, 20 db of high-frequency equalization is required at 10 kc to provide the same response range; with the required equalization, the signal-to-noise ratio exceeds 40 db.

The difference in voltage output scales should be noted. For a conventional high-impedance pickup, the output at the frequency of maximum response is of the order of 10 millivolts; by contrast the electron-beam pickup provides an output of several tenths of a volt over an unequalized range of three decades.

(Figure 8) Comparison of Experimental and Calculated Response of Final Pickup Model.

These curves show the results of an effort to determine the magnitude of the individual losses associated with the overall high-frequency response of a system using the electron-beam pickup. The procedure used is essentially that presented by R.L. Wallace in the October 1951 Bell System Technical Journal.

The heavy line shows the actual measured response. The light-weight lines with points show the deduced individual losses. Of the total loss of approximately 24 db at 10 kc, 12 db is attributed to gap effect, imperfect contact between core and tape and eddy-current loss; the remaining 12 db - the most significant single loss - appears to be caused by the thickness of the tape coating.

These results have been stated rather tentatively because of some doubt concerning certain steps in the procedure. They have been presented here to point out the need for further work along these lines and to suggest that a thinner tape coating may prove advantageous for use with the electron-beam pickup.

(Figure 9) Wavelength Response for Core Model F.

For many applications the extreme long-wavelength response of the winged core is not required. In this case the most practical core for use with the electron-beam tube is a close-fitting strip-type core having an outside diameter of 0.75 inch and a width of 1 inch. The unequalized response for this pickup when used with coated tape operating at a speed of 7.9 inches per second is shown by the solid-line curve.

The dotted-line curve shows equalized response assuming the use of two sections of R-C equalization. The dashed-line curves show the manner in which the low-frequency hump may be reduced by means of an auxiliary Mu-metal plate positioned a small distance above the playback gap. The two dashed curves correspond to two different positions of the plate. The equalized response is flat within ± 1 db from approximately 3 to 7500 cps or within ± 3 db from 2 to 10,000 cps.

It should be noted that, with the new pickup, reducing the tape speed produces no change in output voltage for a signal of given wavelength; only the frequency-response limits shift. For example, the speed may be reduced by a factor of 10 to provide an equalized response range of approximately 0.2 to 1000 cps with no loss in voltage output.

For higher tape speeds, increased eddy-current losses must be considered in determining the upper response limit. At a tape speed of 15 inches per second, the response at 20 kc would be 1.5 db lower than that obtained at 10 kc when using a tape speed of 7.5 inches per second.

(Figure 10) Pulse Response of Longitudinal Type Core.

This figure and the one which will follow show characteristic differences in the pulse response of longitudinal and perpendicular cores when used with the electron-beam tube. In each case a unipolarity, rectangular pulse was recorded and the reproduced output was read, point by point, on a d-c meter as the recorded tape was moved, step by step, over the pickup.

Curves B, C, and D were reproduced using the ring core. For a pulse having a length which is several times the core diameter, as shown by curve B, the reproduced output approaches zero when the pulse is centered over the playback gap and increases as the ends of the pulse approach the gap. Output pulses of reverse polarity occur before the recorded pulse reaches the gap and after it leaves. For a shorter pulse having a length of 0.25 inch, full response is obtained throughout the length of the pulse; even with this relatively short recorded pulse, however, reverse polarity pulses of appreciable magnitude precede and follow the true response.

Curve A for the winged core shows the manner in which larger core dimensions act to improve response at the center of the pulse and to reduce the amplitude of the response peaks which occur near the ends of the recorded pulse.

(Figure 11) Pulse Response of Perpendicular Type Core.

The procedure used in botaining this curve for a perpendicular core was the same as used in obtaining the previous curves for longitudinal cores. The reproduced pulse in this case is a fairly good replica of the recorded pulse. No spikes of reverse polarity occur and full response at the center of the pulse is obtained. The poor degree of resolution near the ends of the pulse is due, of course, to the use of 0.25-inch-wide pole faces in the early tests represented here.

Recent Work.

A large portion of recent work has been concerned with the development of perpendicular core structures, particularly structures which are suitable for use with coated tape. With the most generally useful of these structures, an equalized response range of 0 to 10,000 cps, ± 2 db, has been achieved using a tape speed of three feet per second. Approximately 35 db of high-frequency equalization at 10 kc is required under these conditions. The signal-to-noise ratio is 40 db for a signal level producing three percent third harmonic distortion.

In our most recent work, good progress has been made in the development of a system utilizing both longitudinal and perpendicular recording. The advantage of the system is that d-c response may be realized with no appreciable sacrifice in response for signals of short wavelength.

References:

A. M. Skellett, L. E. Loveridge, and J. W. Gratian, "Electron-Beam Head for Magnetic Tape Playback," Electronics Magazine, Vol. 26, No. 10, pp. 168-171, Oct. 1953.

Material on this development has also been submitted to the Institute of Radio Engineers for publication.

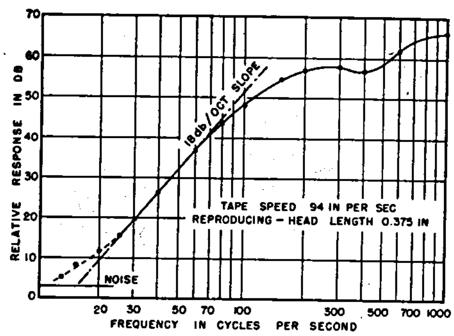

Figure 1. Low-frequency response for a conventional reproducing head.

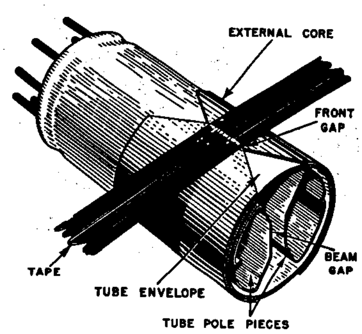

Figure 2. Cut away view showing magnetic elements.

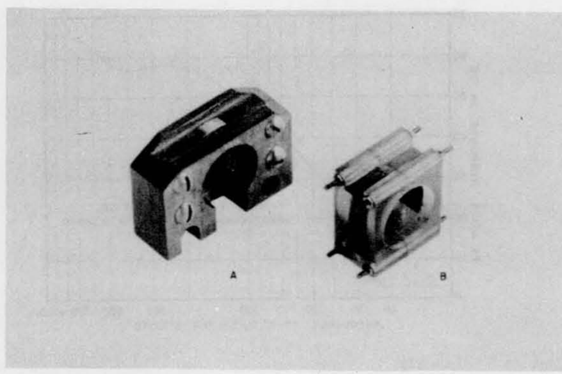

Figure 3. Experimental ring-type core models.

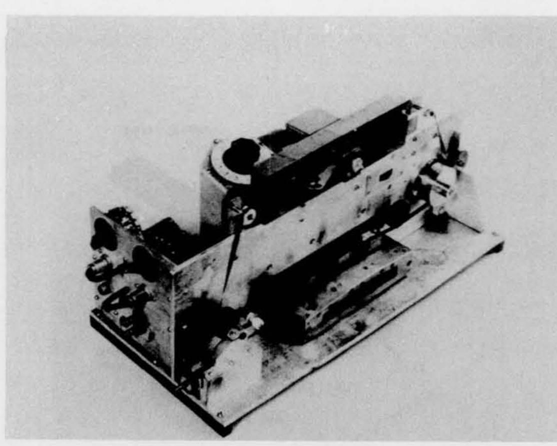

Figure 4. Tape drive unit with electron-beam tube pickup.

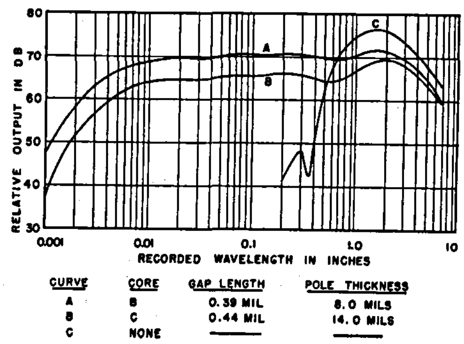

Figure 5. Wavelength response curves for electron-beam tube with two different cores and for tube alone.

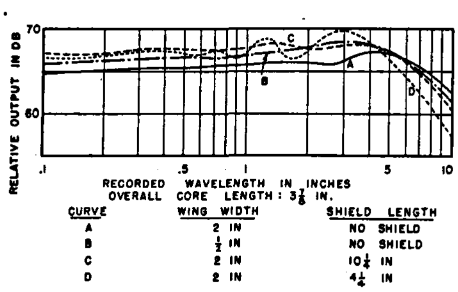

Figure 6. Wavelength response curves for core model E showing effects of variation in shield dimensions.

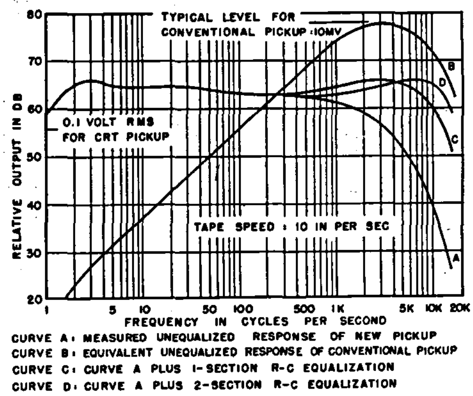

Figure 7. Comparison of electron-beam and conventional pickups.

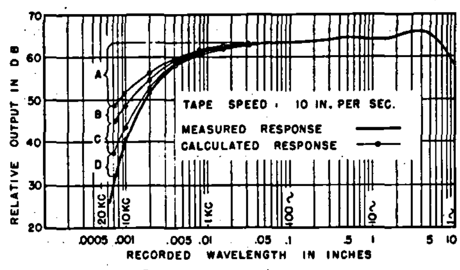

Figure 8. Comparison of experimental and calculated response of final pickup model.

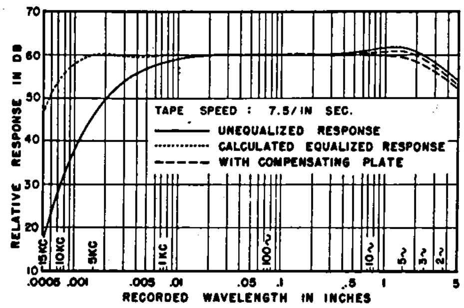

Figure 9. Wavelength response for core model F.

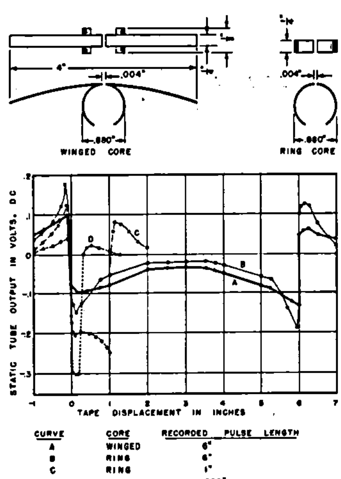

Figure 10. Pulse response of longitudinal type core.

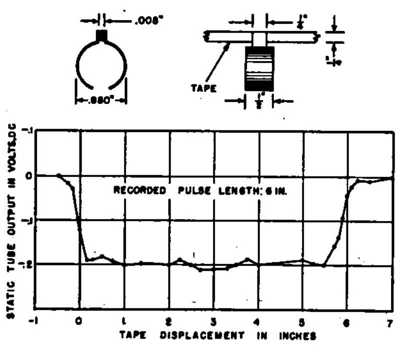

Figure 11. Pulse response of perpendicular type core.

PAPERS No. 2 AND No. 3

DISCUSSION SUMMARY

Mr. W. E. Stewart of Maico Company, Incorporated, asked what the signal-to-noise ratio would be for playback from 7 1/2"/sec. tape with equalization to obtain linear response over the normal frequency band covered by conventional heads and playback systems. Mr. Gratian estimated that system noise would be approximately 40/db. below maximum signal at three percent harmonic distortion for an equalized response as shown on Figure 9 for 7 1/2"/sec. and on Figure 7 for 10"/sec. response. It was also brought out that this noise was not coming from the first tube in the playback amplifier and didn't seem to be tape noise.

Mr. Sibley of Lockheed Aircraft Corporation noted that for reasons pointed out in reference (1)[1] the actual signal-to-noise ratio at various points across the response range may be considerably less than the ratio in relation to a peak recording signal at a specified distortion. In their experience with certain recorders an advertised ratio of 60 db. had turned into an actual ratio of 35db. under operating conditions.

Mr. Sibley also inquired if the use of this new playback system had given any improvement in inherent tape noise, since sensitivity corresponded to flux amplitude instead of rate of change of flux. Mr. Gratian advised that no particular checks had been made of "modulation noise" when using the new pickup but was of the opinion that such noise is primarily a function of the tape and its coating; fluctuations in contact between core and tape also generate modulation noise.

Mr. J. G. Hiemenz of National Security Agency referred to early difficulties with hum pickup from a-c current in the heater. Dr. Loveridge said this condition had been partially corrected but that the amount of pickup varied from tube to tube depending on how the heater wires position themselves in the cathode sleeve and how the field from their current affected the electron beam current. The tube used in obtaining test data cited above was picked at random and still kept a 40 db. signal-to-noise ratio with a-c current on the filament, but all tubes could not be guaranteed to maintain this ratio, especially when using a-c heater current. He noted that a further hum reduction can be obtained by using the push-pull output from the collector plates and electro-statically balancing for minimum hum output instead of equal sensitivity.

When using d-c on the heater the above type of noise is eliminated and the hum reduction is limited apparently by the extent to which ambient fields in the air penetrate right through shielding around the tube and magnetic pickup pole pieces. Due to the tube's sensitivity good magnetic (and electrostatic) shielding is required around the tube and pole pieces. (As shown in the illustration of the bench setup, p. 168 of Electronics—Oct. 1953 article) a rather large triple shield arrangement was used in the experimental setup, but under ordinary use conditions with perhaps one mu-metal shield the actual hum output voltage can be kept down to a few millivolts. This should also be sufficient to prevent the earth's field from changing the operating point with change in position of the tube and pickup polepieces.

In reply to a question from Mr. Nordyke of IBM, Dr. Loveridge advised that the tubes were practically as stable, over a long term, as ordinary vacuum tubes. Changes in cathode emission with use should be same as in a normal tube. Early tubes had difficulty with secondary emission effects, but this difficulty had been largely eliminated.

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[1] Ref: (1) Pages 123-126, etc., of "Magnetic Recording" by S. J. Begun--published by Murray Hill Books, Inc.

A question from Mr. Kornei of Clevite-Brush Development Company brought out that playback tests had been made down to wavelengths of .0005 inch at which point signal level and noise output are about equal.

Mr. Hiemenz of National Security Agency asked if attempts had been made to use metal or ferrite sealed into the glass envelope to reduce the back gap reluctance in the magnetic circuit. This actually had not been tried, said Dr. Loveridge, but had been considered even though it would be a difficult job. It didn't seem important enough to do in view of the present high sensitivity and primary application to audio frequencies. Such a step plus use of ferrite would, of course, improve high frequency response.

Dr. Begun asked that the signal-to-noise ratio of the tube be converted into equivalent ambient magnetic field acting on a quiescent tube. Dr. Loveridge noted that noise had not been measured in exactly that way and that, in his opinion, after shielding against all magnetic disturbances and with d-c heater current the remaining noise output was primarily due to the random distribution of electrons between the two collector plates.

In answer to a question of Mr. Ben Bauer of Shure Brothers, Inc., Mr. Gratian further emphasized the sensitivity of the tube by estimating the output voltage when an unshielded tube is rotated in the earth's field. The authors have since advised that when the tube is rotated 180° in the earth's field (0.3 gauss), unshielded and with no core, the peak output would be about 60 volts if it were not for the fact that this is beyond the dynamic operating range of the tube. This assumes that the position before rotation is such that the maximum component of the earth's field is then perpendicular to the pole piece faces. No figure is available for a tube and core combination. However, it is possible that even then, the sensitivity to the earth's field would still be so great that the tube would be thrown out of its dynamic range. Therefore, if an unshielded head was operating so that maximum output was being obtained from a tape, a 180° rotation of the unit might cause serious distortion or loss of output.

Paper 4

A MAGNETOSTATIC READING HEAD

S. M. Rubens and A. B. Bergh

ERA Division
Remington-Rand, Incorporated

9 October 1953

ABSTRACT: A magnetostatic head and associated circuits comprise a system which permits the reading of magnetic tape records at speeds ranging from zero to 30 inches per second. Signals, recorded at higher speeds, may be conveniently transcribed with this system and a pen recorder at a playback speed of 0.10 inch per second or less.

The operation of the magnetostatic head is effected by energizing a portion of the core with a high frequency, transverse magnetic field which periodically varies the reluctance of the core to pick up flux from the recorded tape without affecting the tape record. The system has a response which is constant to within 1.0 db without equalization for sinusoidal records of 0.10 to 2.0 inch wavelengths. Unequalized signal-to-noise ratios of 37 db have been attained with some heads.

INTRODUCTION

The conventional magnetic reading head responds to the time rate of change of tape signal flux which threads its core, and therefore its output depends on the speed at which the record is read. The magnetostatic reading head, on the other hand, responds directly to the intensity of the flux picked up from the tape record. This device and its associated circuits therefore comprise a system capable of reproducing magnetic records in such a manner that, for a given wavelength, the output is relatively independent of the playback speed over a range of zero to 30 inches per second.

The principle of operation of the device shown in figure 1 is similar to that of the transversely (perpendicularly) magnetized type of flux-gate magnetometer. The reluctance of part of the core of this head is varied by periodically magnetizing it in a direction orthogonal (at right angles) to the path, through the core, of flux "picked-up" from the magnetic tape record. As shown in figure 1, the core of the head is formed of two .014" Mu-metal polepieces, containing the reading gap between them, and a double-layered .002" Mu-metal curved yoke which bridges the polepieces. The yoke is spot-welded to the polepieces before the core is annealed. After annealing the two lamina forming the yoke are electrically insulated from one another along their curved portions. One thousand turns of No. 40 insulated copper wire are more or less uniformly wound along the yoke to provide the output winding. The entire head structure is then cast in an Epoxy type resin which protects and supports it.

As indicated in figure 1, the tabs at the top of each layer of the yoke, are connected to the output of a stabilized 75kc power oscillator. Current flows along one half of the yoke layers and returns along the opposite half. With this arrangement the yoke is periodically magnetized, but the mutual coupling between the conducting yoke and the output winding is low, and the fundamental 75kc signal induced in the output winding is kept small.

In figure 1, section A-A, enlarged, the direction of the flux, in the yoke, is indicated by the arrows. At the instants of peak current from the 75kc oscillator the absolute value of this transverse magnetization is maximum, providing a corresponding minimum value of the effective permeability for the longitudinal flow of flux picked up from the tape. When the transverse magnetization is zero, the longitudinal permeability of the yoke is maximum. Because of this periodic variation of the effective permeability, there is a corresponding variation of the longitudinal flux which induces a 150kc emf. (second harmonic) across the output winding. Other harmonics, especially the fundamental and third, are also present, although the amplitude of these components are independent of the remanent magnetization level of the tape record.

System Arrangement

Figure 2, is a block diagram of the system. The output winding of the magnetostatic reading head is connected to the input of a three-stage amplifier of which the first two stages are tuned to 150kc. This amplifier has a total gain of about 4000 and a bandpass of 30kc. The detector consists of a vacuum-tube phase inverter, a full-wave crystal rectifier, and a low pass (zero to 15kc) filter. The output of the amplifier may be examined directly or the detector output, equalized or not as may be desired, can be observed. A 600 ohm output is also provided from a cathode follower.

Sensitivity and Shielding

In addition to the magnetic field of the tape record the magnetostatic reading head also responds to the earth's magnetic fields, and to stray fields of electrical equipment. To minimize these effects the head is provided with a box-shield constructed of several layers of Mu-metal. The second harmonic output of the head is also dependent on the state of remanence of the core resulting from its past history, and on the incompleteness of shielding against extraneous static fields. A compensating circuit consisting of a frequency doubler, excited by the same oscillator which provides current for the energizing head, and a phase-shifting network is also connected to the input of the tuned amplifier as shown in figure 2. This circuit provides an emf of the appropriate amplitude and phase to compensate for the output of the head resulting from all effects other than the tape magnetization being detected. In normal operation the compensator is so adjusted as to provide at the output of the shielded head a maximum modulation of the second harmonic carrier signal of 5.0 millivolts corresponding to the maximum peak-to-peak recorded sinusoidal signals.

Three factors influence the overall sensitivity of the magnetostatic reading head: The first of these is the relation of the reluctance, of R_g, the reading gap to two reluctance states of the core. These are the states of zero transverse magnetization, R_o, and maximum transverse magnetization, R_1. If the reluctance of the element of magnetic recording medium providing flux to the head is much larger than the combined parallel reluctance of the core and the reading gap, the maximum sensitivity is attained if:

$$(1) \qquad R_g = \sqrt{R_o \; R_1}.$$

If this equation is satisfied, a major portion of the flux picked up from the magnetic record or tape crosses the gap when the yoke is "saturated" (transversely), and when the transverse magnetization is zero, a major portion of the flux picked up from the recording surface threads the yoke.

A second factor influencing the sensitivity of the head is the maximum intensity of the transverse magnetization which controls the value of R_1. As the energizing current is increased, R_1 increases and remains nearly proportional to the transverse magnetic induction until higher currents are reached, when the yoke becomes effectively saturated. With further increase in current, differences in core reluctance $(R_o - R_1)$ tend to increase very slowly. Figure 3 shows a plot of the detector output against the yoke energizing current amplitude. Note that it resembles a normal magnetization curve.

Finally, as shown in figure 4, the sensitivity depends upon the frequency of the energizing current. If complete flux penetration were not prevented by eddy currents, the sensitivity, for a given amplitude of transverse magnetization, should be proportional to the frequency of the current. At lower frequencies this proves to be the case. However, for a given thickness of yoke material, as the frequency is raised, eddy current effects increase in such a way that the sensitivity reaches a maximum and then decreases. This effect is illustrated in figure 4 in which the relative head output level appears vs. energizing current frequency. At each frequency a point on this curve was obtained while operating the head at an energizing current amplitude corresponding to a point above the knee of the sensitivity curve of figure 3. This required considerable retuning and recalibrating of the tuned amplifier and detector of figure 2.

Wavelength (Frequency) Response

In the system described here it was desired that for constant-current sinusoidal recordings the response of the magnetostatic reading head be essentially "flat" to recorded wavelengths over the range 0.0025 to 1.5 inches. This corresponds to a frequency range of 12kc to 20 cps at a 30 inch per second recording speed. Because of its flux reading property, the response of the magnetostatic reading head should be constant over the same frequency range for which the response of a standard dynamic reading head rises at a rate of six db per octave. For the shorter wavelengths (less than 0.010 inch) the magnetostatic reading head response decreases from its constant value for the same reasons that the response of a dynamic reading head departs from its six db per octave rise. The reading gap, head-to-tape spacing, and the "tape-demagnetization" effects which promote attenuation of short-wavelength response are essentially the same for both types of head.

For a reading head constructed as shown in Figure 1 the actual response was not "flat" but possessed strong maxima and minima. Figure 5 is a striking example of this anomalous effect. It was found that if the lengths of the polepieces in contact with the tape exceeded a few thousandths of an inch, and if their contact with the tape was discontinuous at their ends, a reinforcement and cancellation occurred at certain wavelengths producing the anomalous response. As shown in figure 6, this effect is eliminated if the head is constructed in such a way that the polepieces are made to recede from contact with the recorded tape with a spacing that increases linearly with the distance from the gap measured along the tape. The polepieces contact the tape only in the immediate vicinity of the reading gap. The required angle between the tape and the polepieces without sideshields was about 25°. This angle was reduced by the use of Mu-metal side-shields placed on either side of the head and arranged so that they contact the tape, but not the polepieces as shown in figure 6. They serve as magnetic shunts to the head so that the tape to polepiece spacing can be reduced to maintain the correct flux density through the head for a flat response. If two or more of these heads are employed on adjacent tracks, these side-shields plus additional copper shields and the fact that they are energized with high frequency effectively reduces crosstalk between heads. Several heads of this sort, having an overall length of 1.5 inches and a polepiece width of 0.200 inch, were constructed. Figure 7 shows the unequalized wavelength response curves for one such side-shielded head for playback at 30, 15, and 0.10 inch per second from the same original recording. The poorer short-wavelength response at higher speeds may be caused by greater effective head-to-tape spacing at these speeds.

At wavelengths below 0.010 inch compensation for the attenuation has been accomplished by the use of equalization networks. Since the attenuation is a wavelength phenomenon, a separate equalization network must be provided for each playback speed employed. The basic circuit used for equalization and its idealized response curve is shown in figure 8. With this network the response at frequencies higher than those in the desired range is enhanced less and the over-all attenuation is also less than is obtained with the equivalent R-C network. Figure 9 shows the equalized wavelength response curves of the side-shielded head for the 0.1 inch, 15 inches and 30 inches per second playback speeds and for equalization networks of the type shown in figure 8. Notice that the signal-to-noise ratio after equalization is about 20 db. as compared to 32 db before equalization.

Amplitude Response

Since the entire magnetic circuit for the tape signal flux (including the tape itself) contains air gaps, the corresponding hysteresis loop (for this circuit is strongly sheared so that the effective permeability of the magnetic circuit is essentially constant for magnetic fields larger than those encountered in reading magnetic tape. For a given wavelength amplitude, the response of the head is essentially a linear function of the intensity of signal recorded on the tape. Consequently, the amplitude response of the magnetostatic reading head system becomes principally a function of the response of the tape itself to the recording field. Because the magnetostatic reading head responds directly to the pick-up flux intensity, larger distortion of the recorded signal can be tolerated than would be the case in reading the time rate of change of this flux. Figure 10 shows the linear response of the magnetostatic reading head to 0.02 inch wavelength recording over a range of recording levels. The response is linear to within five per cent for recording voltage up to approximately four volts rms.

Output Noise Level

One of the limitations of this head is its relatively high output noise level, seemingly generated in the system itself. The noise has random frequency components covering the entire range of frequencies from nearly zero to above 15/kc. Although some of the noise was found to originate in unstable electronic circuits and pickup from extraneous fields, the limiting noise seems to be that generated in the core of the head itself. It has been found that the noise level varies with the heat treatment of the core which indicates that it may result from magnetomechanical effects. Signal-to-noise ratios equivalent to 37 db have been obtained with well annealed heads operated without equalization.

All test records were made with a modified Ampex Tape recorder, Type 302, on Minnesota Mining Manufacturing Company Telemetering Quality magnetic tape for this work.

The magnetostatic reading head and its associated circuits are being further developed to reduce its size, to improve its performance, and it is hoped, to extend its wavelength response.

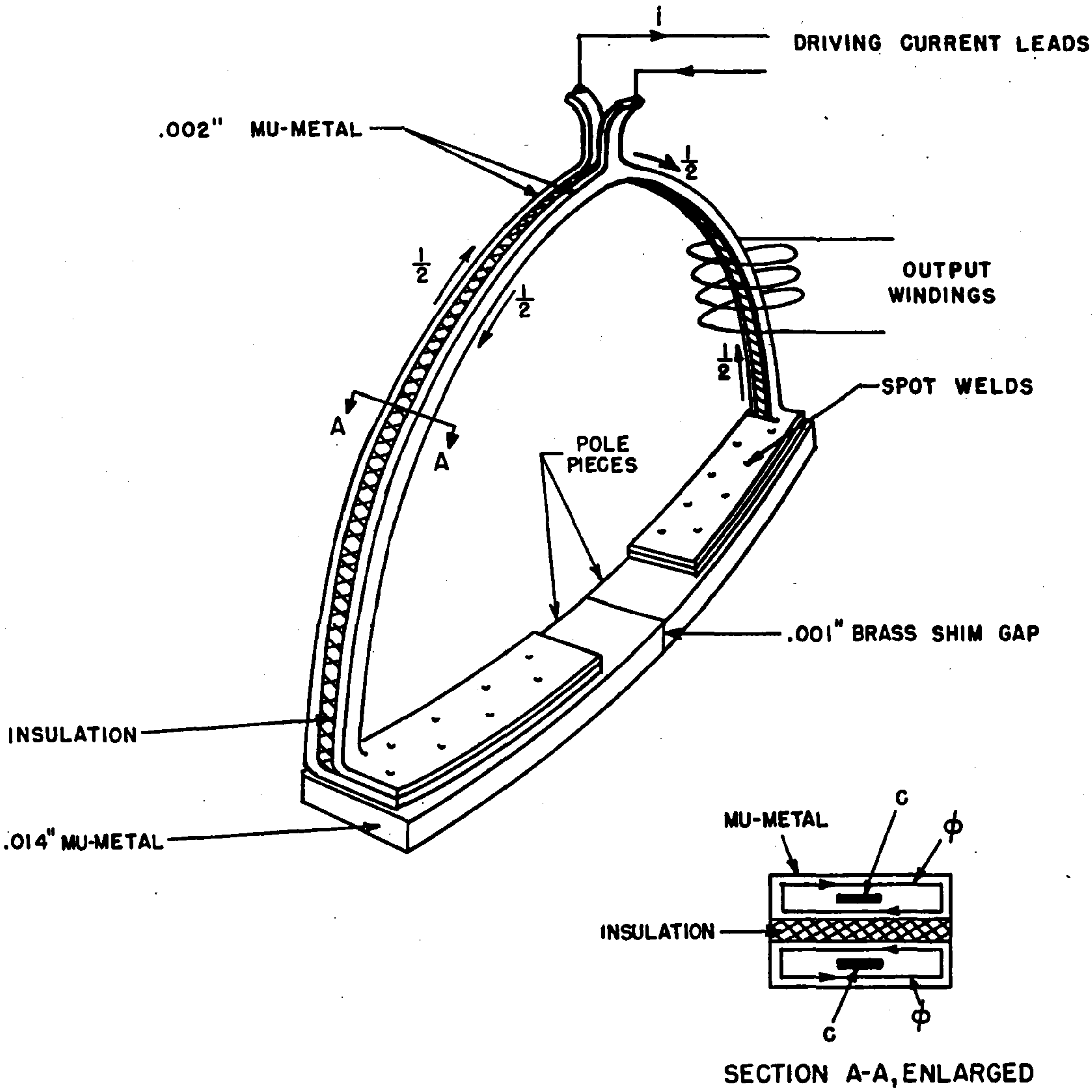


FIGURE I. MAGNETOSTATIC READING HEAD

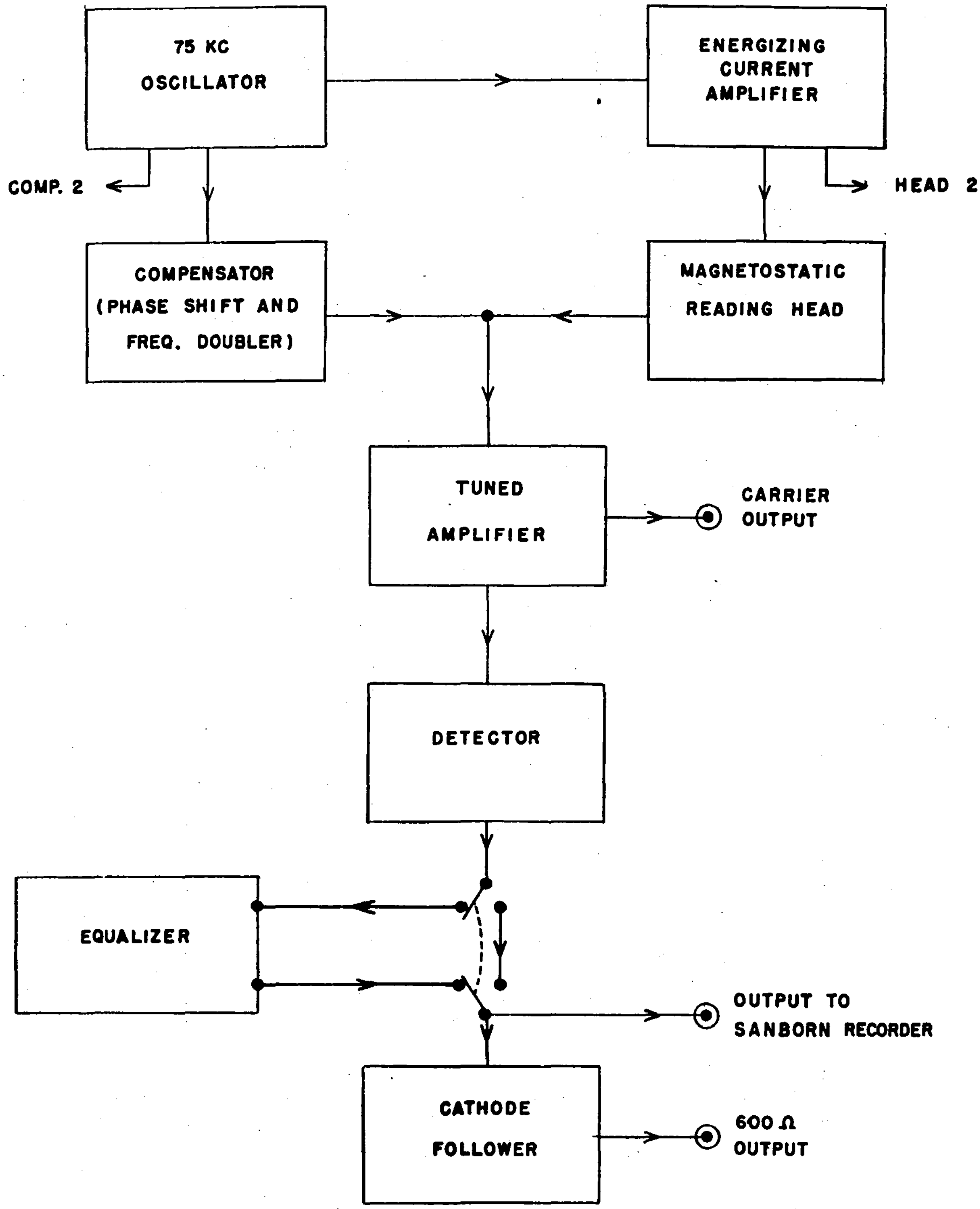


FIGURE 2. BLOCK DIAGRAM OF THE MAGNETOSTATIC READING SYSTEM

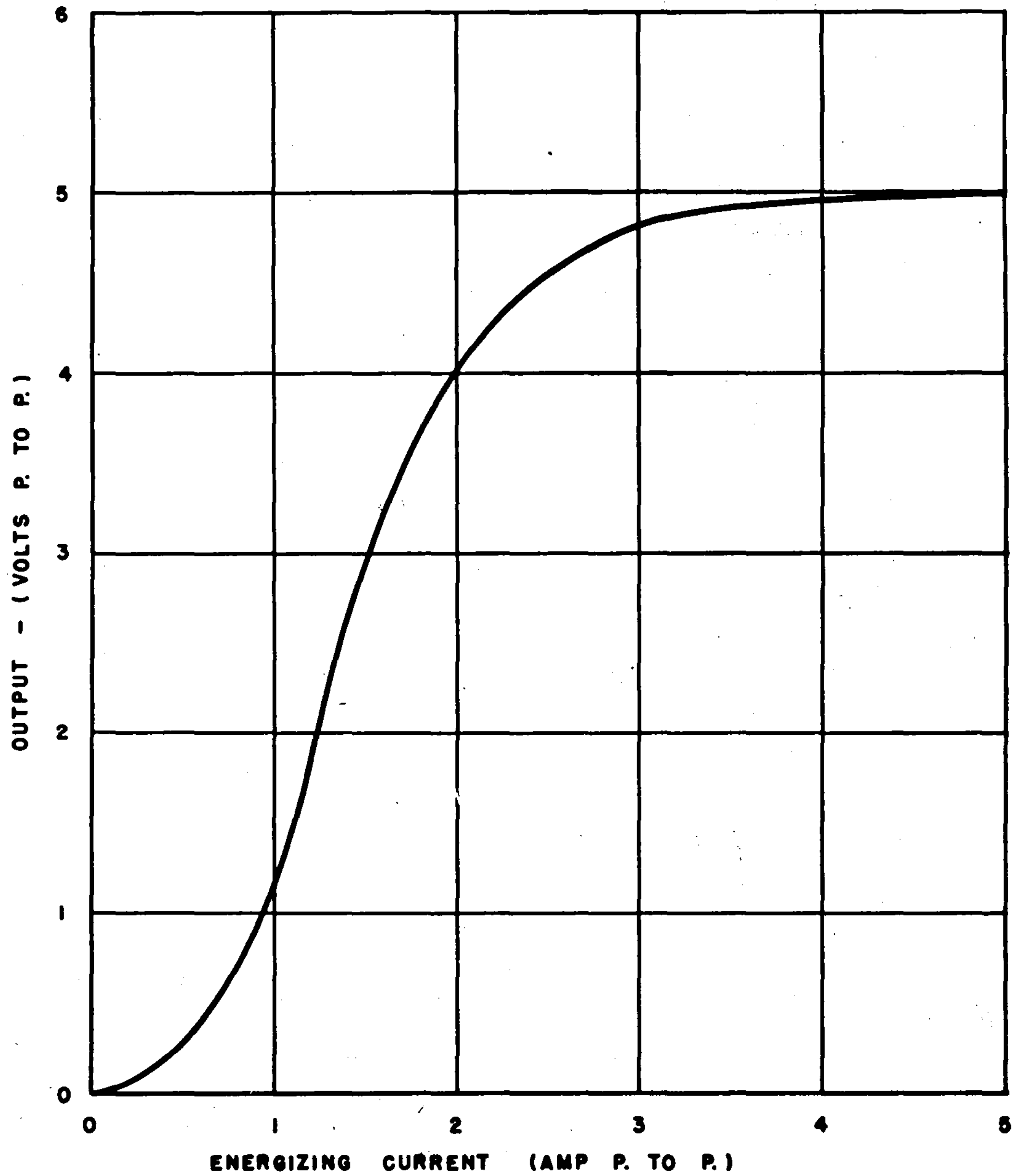


FIGURE 3. SENSITIVITY VS. ENERGIZING CURRENT LEVEL

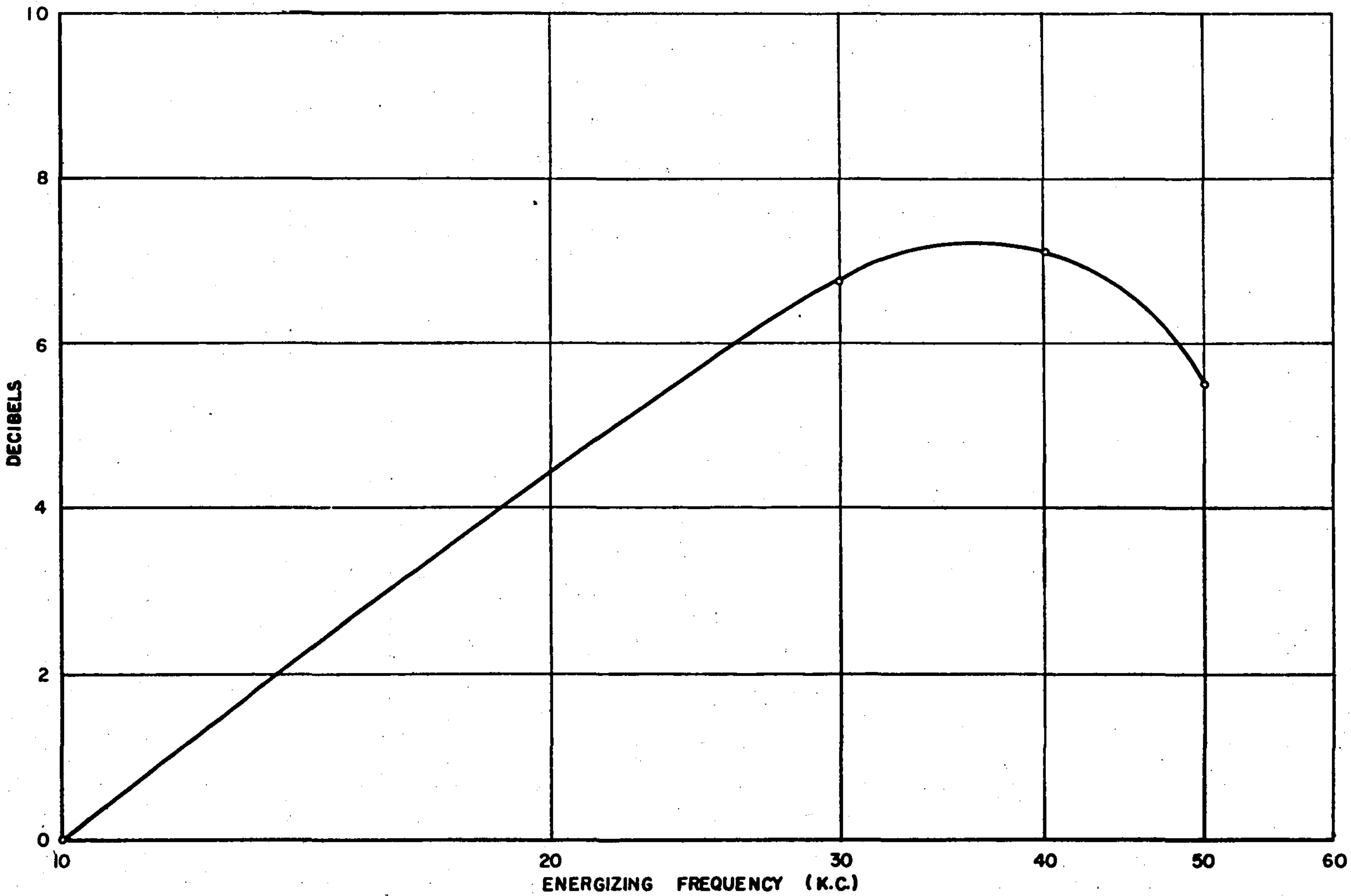


FIGURE 4. SENSITIVITY VS. DRIVING FREQUENCY

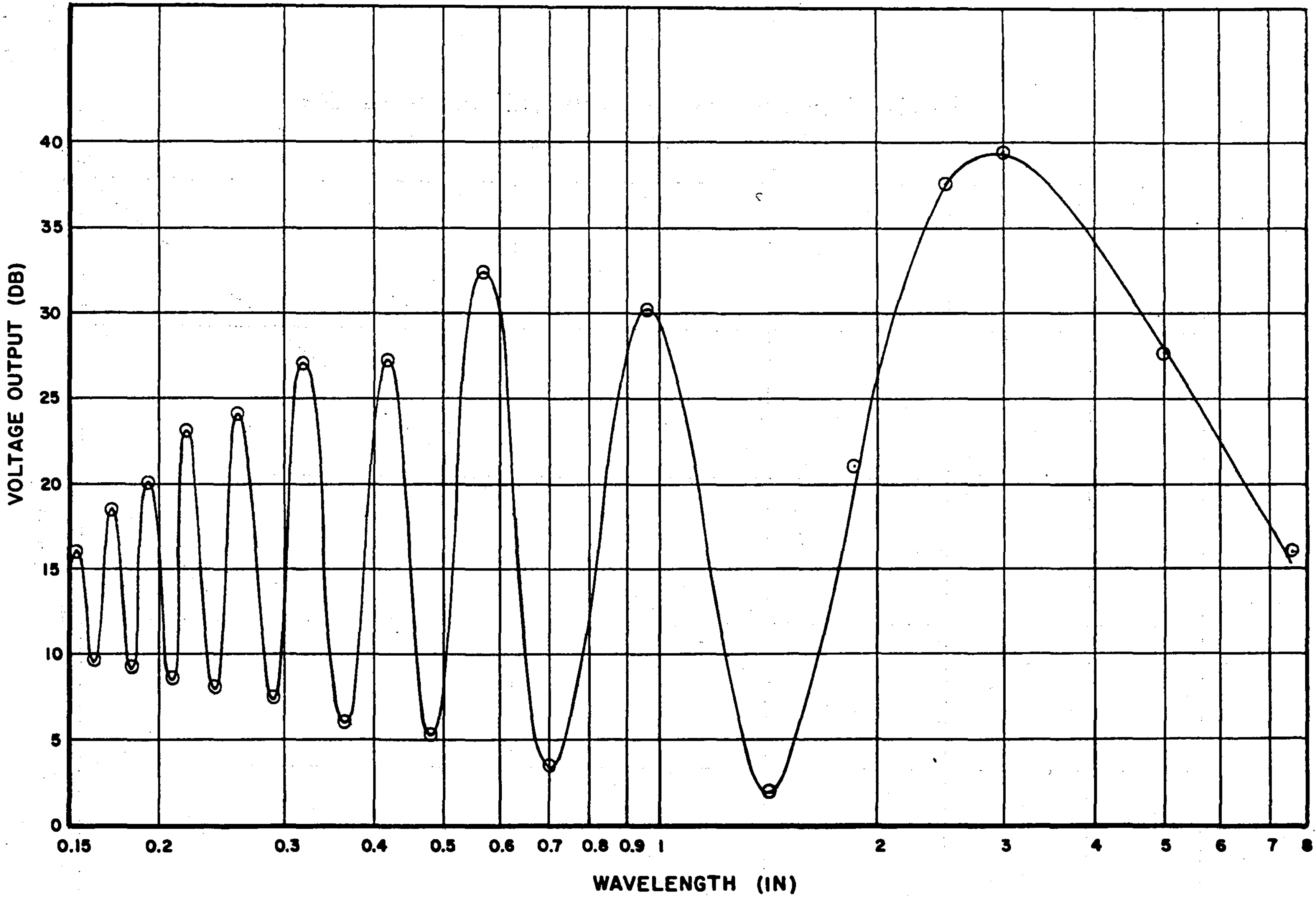


FIGURE 5. ANOMALOUS WAVELENGTH RESPONSE

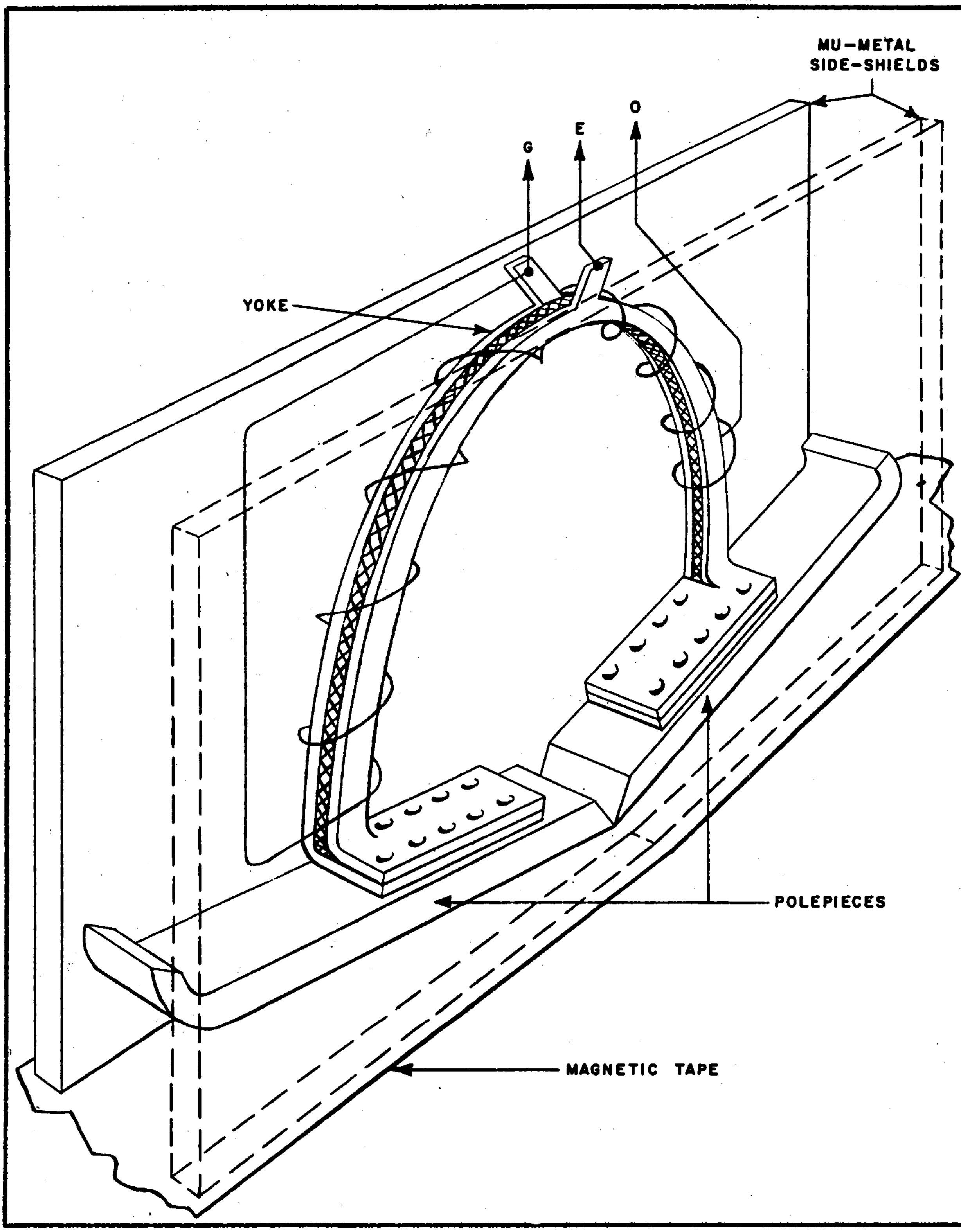


FIGURE 6. MAGNETOSTATIC READING HEAD WITH SIDE SHIELDS

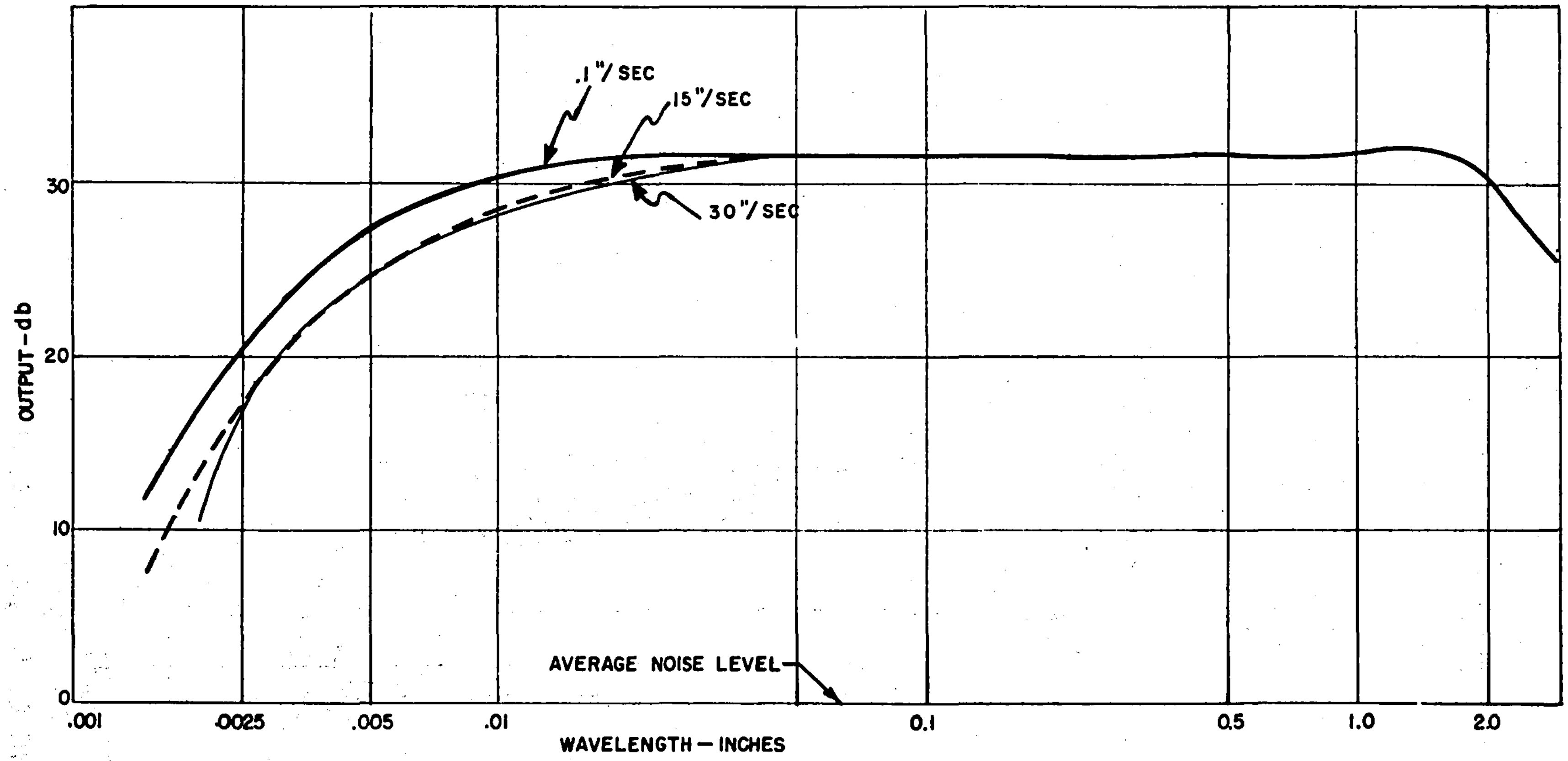
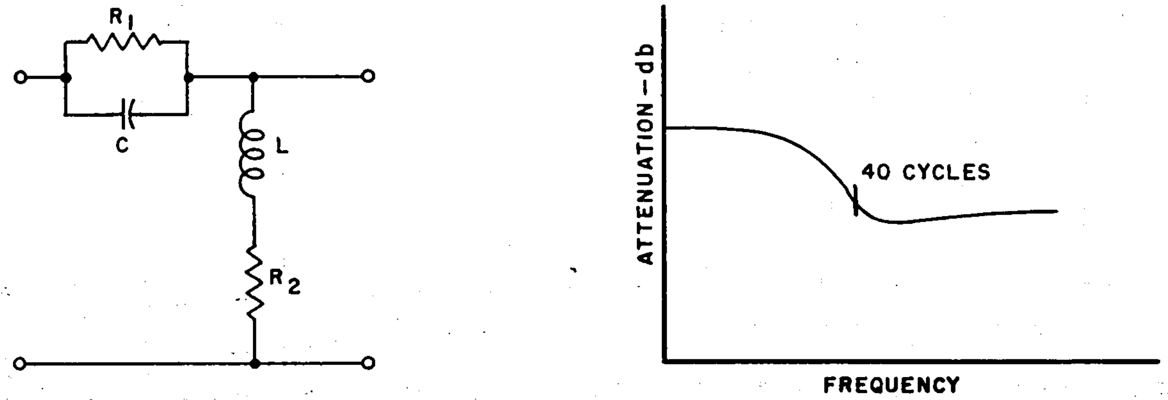


FIGURE 7. WAVELENGTH RESPONSE CURVES - UNEQUALIZED



L-C EQUALIZATION

FIGURE 8. EQUALIZATION CURVE

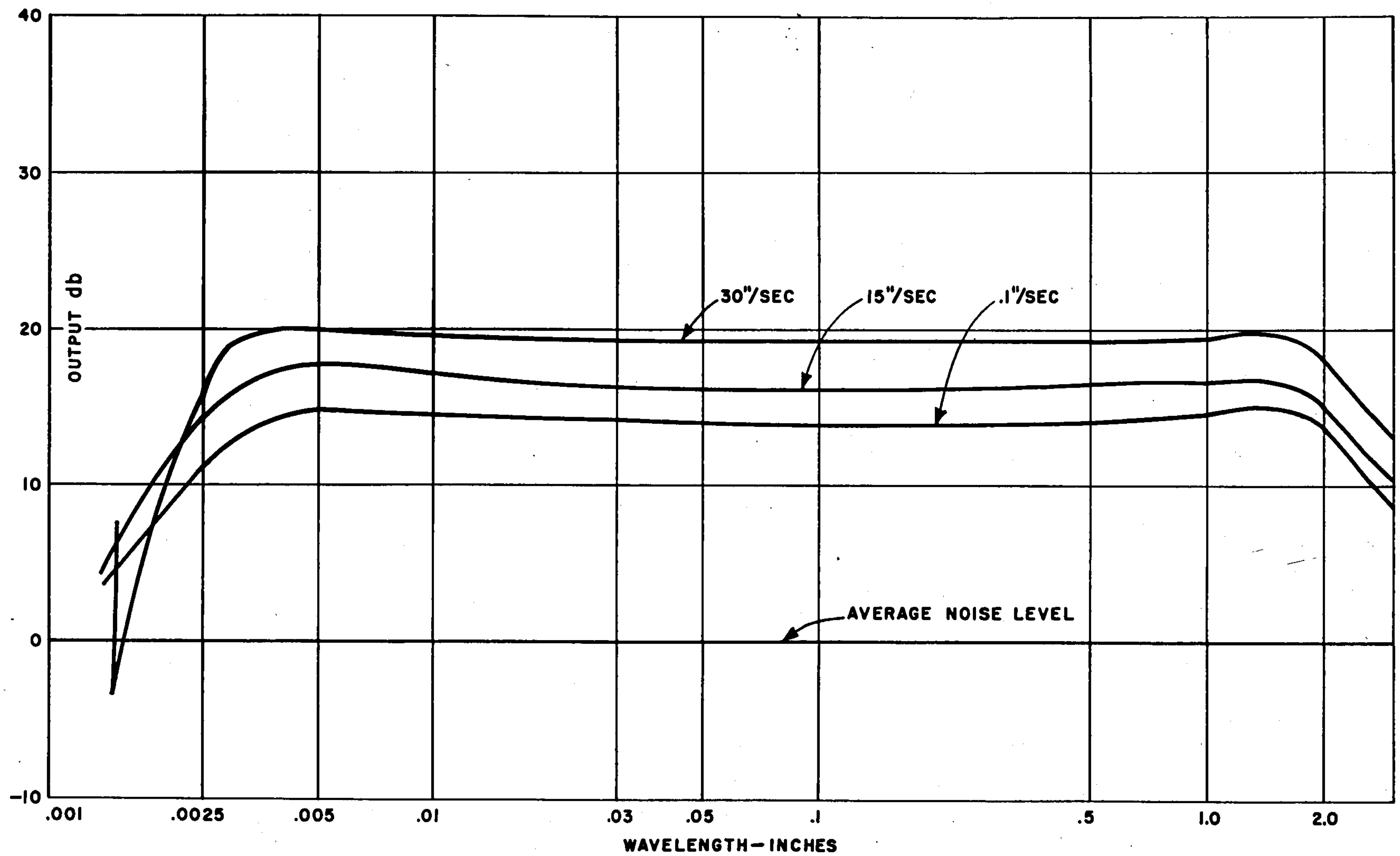


FIGURE 9. WAVELENGTH RESPONSE CURVES - EQUALIZED

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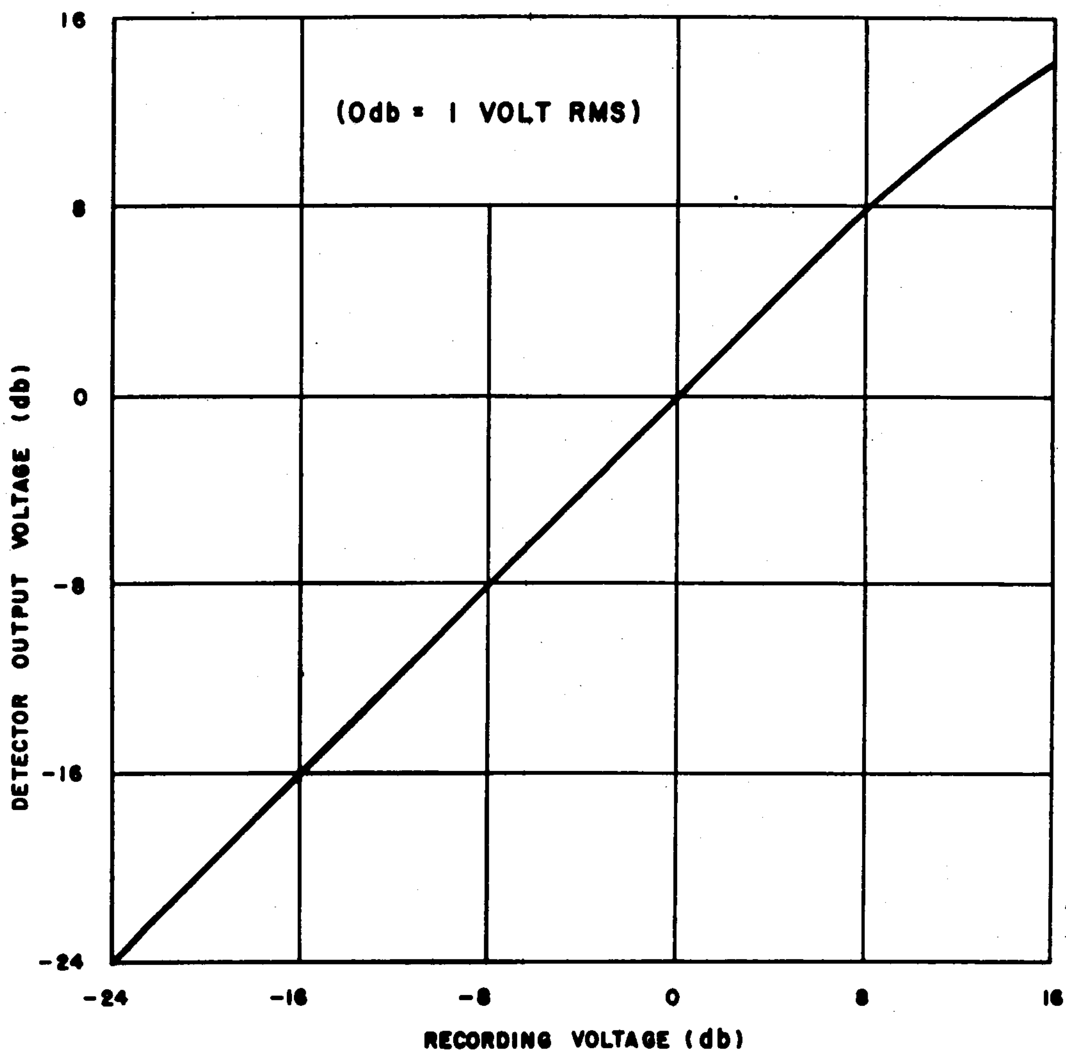

FIGURE 10. RESPONSE LINEARITY

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Paper 5

PERFORMANCE CHARACTERISTICS OF MAGNETOSTATIC REPRODUCING EQUIPMENT

Mr. W. R. Boenning

National Security Agency

9 October 1953

ABSTRACT: A description is presented of an experimental multi-channel reproducing equipment, which is capable of reproducing magnetic tape recordings independently of tape speed. Signals recorded at conventional tape speeds can be reproduced with this equipment at speeds low enough to permit the signals to be displayed graphically by means of a conventional pen oscillograph. The equipment utilizes dual track magnetostatic reproducing heads on a modified commercial tape transport top plate. The circuitry employed with the magnetostatic heads is described as well as a slow speed tape drive modification of the transport system. The performance characteristics of the reproducing system are described and examples of typical magnetic recordings reproduced with the equipment are displayed.

PERFORMANCE CHARACTERISTICS OF A MAGNETOSTATIC REPRODUCING EQUIPMENT

by W. R. Boenning of National Security Agency

Introduction

The magnetostatic reproducing head which Dr. Rubens has described in his previous paper has been incorporated into an experimental reproducing equipment assembly, which was fabricated for the National Security Agency under a contract with Engineering Research Associates. This reproducing equipment has been subjected to a performance evaluation for the last few months. This paper will describe the experimental equipment and discuss some of the performance results which have been obtained from this evaluation.

Description of Equipment

Figure 1 shows the experimental magnetostatic reproducing equipment. The circuitry associated with the magnetostatic head occupies panel space of about 21 inches in the upper portion of the rack along with an auxiliary monitoring oscilloscope. The tape transport system is shown in the center of the rack and is an Ampex Model 302 top plate modified for very slow tape transport at a speed of 1/10 inch a second. This is accomplished with an additional set of speed reduction idlers which may be inserted between the synchronous motor drive and the capstan by means of a mechanical linkage associated with the speed selector switch. The top plate and Ampex head assembly are also modified to accommodate a 1/2 inch tape with two tracks, each 2/10 inch wide. The recording and reproducing electronics associated with the Ampex equipment will provide constant current recording over a range of frequencies from 20 cycles to 50,000 cycles per second, although not all of this range is normally employed. At the left in figure 1 is a Sanborn dual channel pen oscillograph which is used in conjunction with the output derived from the magnetostatic head at the slow speed tape drive.

Figure 2 is a view of the tape transport top plate. The magnetostatic head assembly and its shield housing can be seen at "A" located between the inertia idler and the conventional recording-playback facilities. This location was chosen in order that modifications to the top plate would be simple and yet maintain the conventional dynamic recording and reproducing facilities of the Ampex equipment. The placement of the head assembly at this location necessarily limited the physical size of the core structure to 1.5 inches; thereby restricting the long wavelength response approximately to this length also. Figure 3 is a close-up view of the shield for the reproducing heads. Each of the two head structures is mounted on a movable plate at the top and bottom of the assembly so that angular adjustment of the gaps can be made. Figure 4 shows an individual core structure of the dual track magnetostatic reproducing head assembly. The magnetic tape contacts the polepieces only at the dark region, "B".

In Figure 5 is shown the general block diagram of the equipment. The output from the specially constructed stabilized oscillator is used to drive the power amplifier which provides the current for magnetizing the yoke of the reading head. The oscillator output also is used as the fundamental frequency source for the compensator network consisting of a frequency doubler and a phase shift circuit. The phase and amplitude controlled output of the compensator is connected to the output winding of the reading head in order to provide the background flux, required in the head for adjusting the carrier level and sensitivity. The reading head output is fed into a tuned amplifier which passes only the desired 150 kc modulated signal. The modulated carrier output of the tuned amplifier is monitored at the cathode resistor of the last stage of the amplifier. The modulated carrier output of the tuned amplifier is next demodulated by the detector and the resultant modulation is coupled to the Sanborn output jacks and the output cathode follower directly or through the appropriate equalizer.

Performance Characteristics

In order to operate the magnetostatic reproducing heads, it is necessary to furnish an energizing current to the core structure, to periodically vary the reluctance to the signal flux from the tape. Figure 6 shows the output derived from a constant level recorded signal when the magnitude of the energizing current is varied. This curve resembles closely the normal magnetization characteristics curve for the core material. Since the mode of operation is such that the head cores form a parallel load to the energizing current amplifier, there is no individual control available to more closely match the two output characteristics shown. This is not of particular consequence inasmuch as the actual output level can be adjusted by varying the gain of the individual tuned amplifiers. It is interesting to note that the noise level in the absence of signal follows a curve similar to that of the energizing current characteristic. The operating value of the energizing current for the present heads has been established at a point beyond the knee of the curve to obtain a large output signal and to minimize variations in the output due to amplitude fluctuations from the energizing current amplifier. At an energizing current amplitude of 8 amperes peak-to-peak corresponding to the 120 millivolt value shown on the abscissa of figure 6, a signal-to-noise ratio of approximately 40db has been obtained with nonlinearity within five percent. The noise output in the absence of signal, appears to be random in nature with the exception of 60 cycle ripple and related harmonic components due to stray fields. Since no particular precaution was taken to locate the magnetostatic head assembly with respect to stray transformer and solenoid fields present in the existing rack arrangement, the stray fields contribute quite heavily to the noise output. Therefore, in order not to produce an unfair result, the noise curves shown in figure 6 were obtained with the recording electronics power off but with the power on for the tape drive components.

Reduced Distortion

One of the interesting features of this magnetostatic reproducing equipment is its ability to reproduce higher-than-normal amplitude recordings without the usual marked increase in distortion which accompanies conventional reproduction. This is illustrated in figure 7, which shows the dynamic range characteristics. These curves were obtained at a constant energizing current magnitude corresponding to the 120 millivolt point on the previous curves. A wave length of 0.030 inch, corresponding to a frequency of 1 kc at 30 inches per second was recorded at various input levels and the output level was observed with an rms reading meter. The normal recording level for one percent third harmonic distortion in the conventional dynamic reproducing equipment is represented by the 100 percent value on the abscissa and is well below the value at which a comparable value of distortion with the magnetostatic reproducing head was achieved. The points of three percent nonlinearity (that is, where actual output voltage differs from expected output from a linear system) are denoted for each of the two channels, the nonlinearity representing the departure from a straight line input-output relationship. For playback with a conventional reproducing head corresponding nonlinearity occurs at recording levels approximately 6 db lower than for playback with the magnetostatic head and for the recording bias used in this equipment. Another comparison is the third harmonic distortion at the recording level for three percent nonlinearity as shown on figure 7. This distortion is 3.6% for magnetostatic head playback and 8.2% for conventional head playback. The difference in the form of distortion which occurs with the conventional dynamic head, and with the direct flux measuring magnetostatic head, are illustrated in the wave forms associated with the curves.

Compensation for Stray Fields

It is necessary to provide a compensating signal at twice the energizing current frequency in order to balance out stray constant fields, and to obtain the correct polarity in the output for an alternating flux variation on the tape around a zero magnetization level. Figure 8 shows the output wave form when the compensating frequency amplitude and phase relations are both correctly and incorrectly adjusted with respect to the energizing current level and the flux level from the tape. When carried to the extreme, the incorrect adjustment will lead to an output which is characterized as full wave rectification of the desired output signal.

Wave Length (Frequency) Response

The frequency and wave length response is shown in figure 9. The response, when taken at a tape speed of 30 inches per second, falls off more rapidly in the high frequency or short wave length end than the corresponding wave length output when reproduced at the slow tape speed of 1/10 inch per second. This is due in part to the frequency response afforded by the tuned amplifier and low pass filter of the equipment, and possibly in part to the differences which exist in tape-to-head contact at the active gaps when running at the two different speeds. The response characteristics shown indicate that the output is sufficiently uniform without equalization to be operated over a sine wave response range of 2.0 to .015 inches per cycle before exceeding a tolerance of -3 db. Other experimental heads have shown even wider response range. With equalization, the uniformity of the frequency characteristic can be improved at the expense of reducing the signal-to-noise ratio. An equalized frequency response which is uniform for recorded wave lengths 1.5 to 0.0035 inches per cycle has been obtained with this experimental equipment. Better response has been obtained with other heads.

The system phase response is shown in figure 10. The "record-reproduce" characteristic is shown in the lower curve, and is obtained by measuring the overall phase shift through the recording amplifier and the magnetostatic reproducing equipment. The "reproduce" characteristic was obtained for the magnetostatic reproducing equipment by providing a sinusoidally varying field from a small coil placed at the active gap of the head. The phase shift with the magnetostatic reproducing equipment is negligible for the frequency range covered at the slow tape speed. The departure from linearity at the high end of the frequency range covered is due to the tuned amplifier characteristic and the low pass filter characteristic.

The response of the equipment to recorded sine waves is illustrated in figure 11. These records were obtained utilizing the Sanborn pen oscillograph equipment. It is interesting to note that the noise present in the reproduction of these records was predominantly 60 cycle ripple. Although the presence of 60 cycle ripple at slow oscillograph paper speeds is not particularly objectionable since it merely broadens the trace, it becomes distinctly annoying for higher chart speeds where the frequencies displayed approach the power frequency.

Figure 12 shows the response of the system to recorded square waves. These square waves were recorded by disconnecting the regular recording amplifier and substituting a battery current which was switched on and off. The usual recording bias amplitude was maintained. For repetitive square waves of a wave length corresponding to distances less than the physical length of the head, there is no appreciable reduction in the center of the square wave amplitude. For those square waves exceeding the physical length of the head, however, the total flux available from the record is not linked through the magnetostatic head structure at the center of the square wave and causes a reduction in amplitude.

The response of the head to single, constant amplitude, unidirectional pulses is somewhat different than for a group of repetitive square waves. These are shown in figure 13 for various recorded lengths. The gradual rise in the output level preceding the pulse and the gradual fall in the level after the pulse, is believed to be due to the stray flux from the recorded section of the tape which interlinks the core structure as the pulse approaches the active gap.

One of the important features afforded by the magnetostatic reproducing head is the ability to stack the heads with the active gaps in line for compact multi-track operation. By utilizing copper and Mu-metal shields between the plastic head wafers, the interchannel crosstalk is negligible.

Flutter at low Tape Speeds

A measure of the flutter of the tape transport system was made at the 1/10 inch tape speed by determining the variation in the cycle length from the Sanborn oscillograph record. An rms value of 2.6 percent was calculated from data obtained by recording a 6 kc sine wave. The flutter was originally much greater than this but was materially reduced at the slow speed by substituting guide rollers in place of the usual fixed tape guides in the movable reel idler and tension arms.

Summary

It is believed that the experimental equipment performance has successfully demonstrated the feasibility of employing the magnetostatic reproducing head for long wave length and low frequency reproduction at very slow tape speeds. Since the usual 6 db/octave rise in output with frequency is not present with this type head, the short wavelength response falls off more rapidly than that of the conventional type magnetic head. At the present time, the noise level is relatively high, but the extension of the usable range of recording levels permitted with magnetostatic reproduction offsets this factor to a large degree.

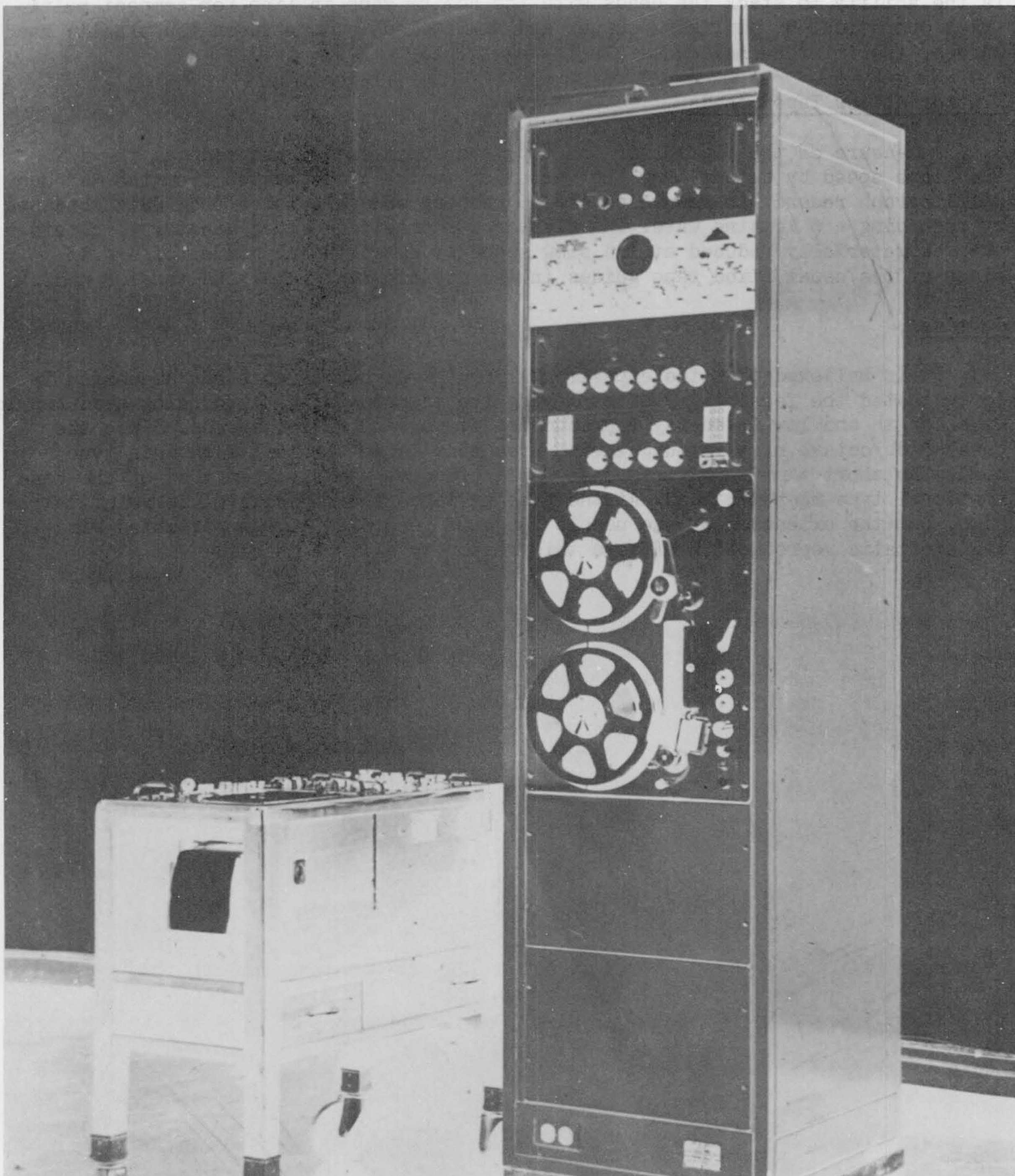


Figure 1. Experimental magnetostatic reproducing equipment.

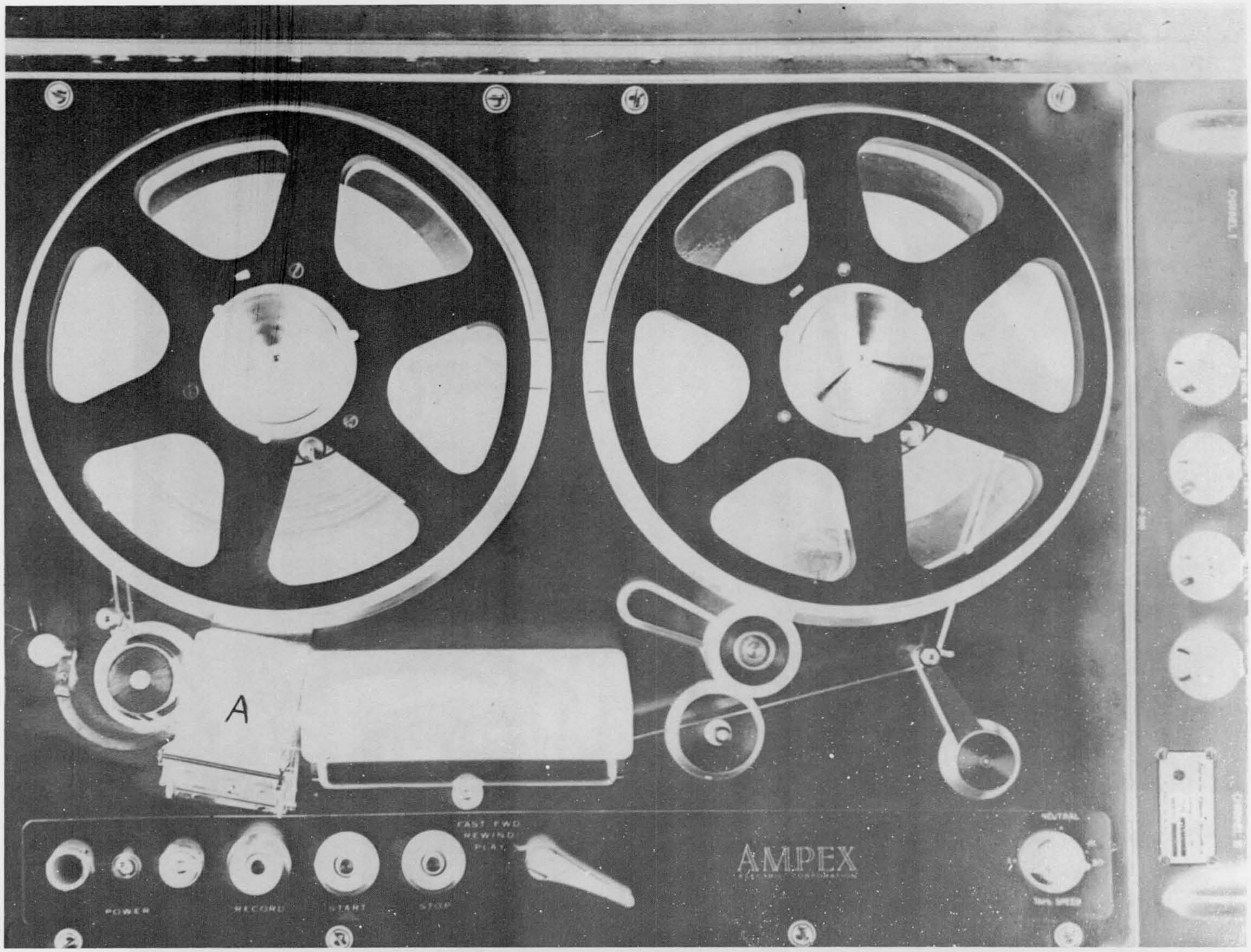


Figure 2. Tape transport top plate. Note magnetostatic head assembly and shield housing at "A."

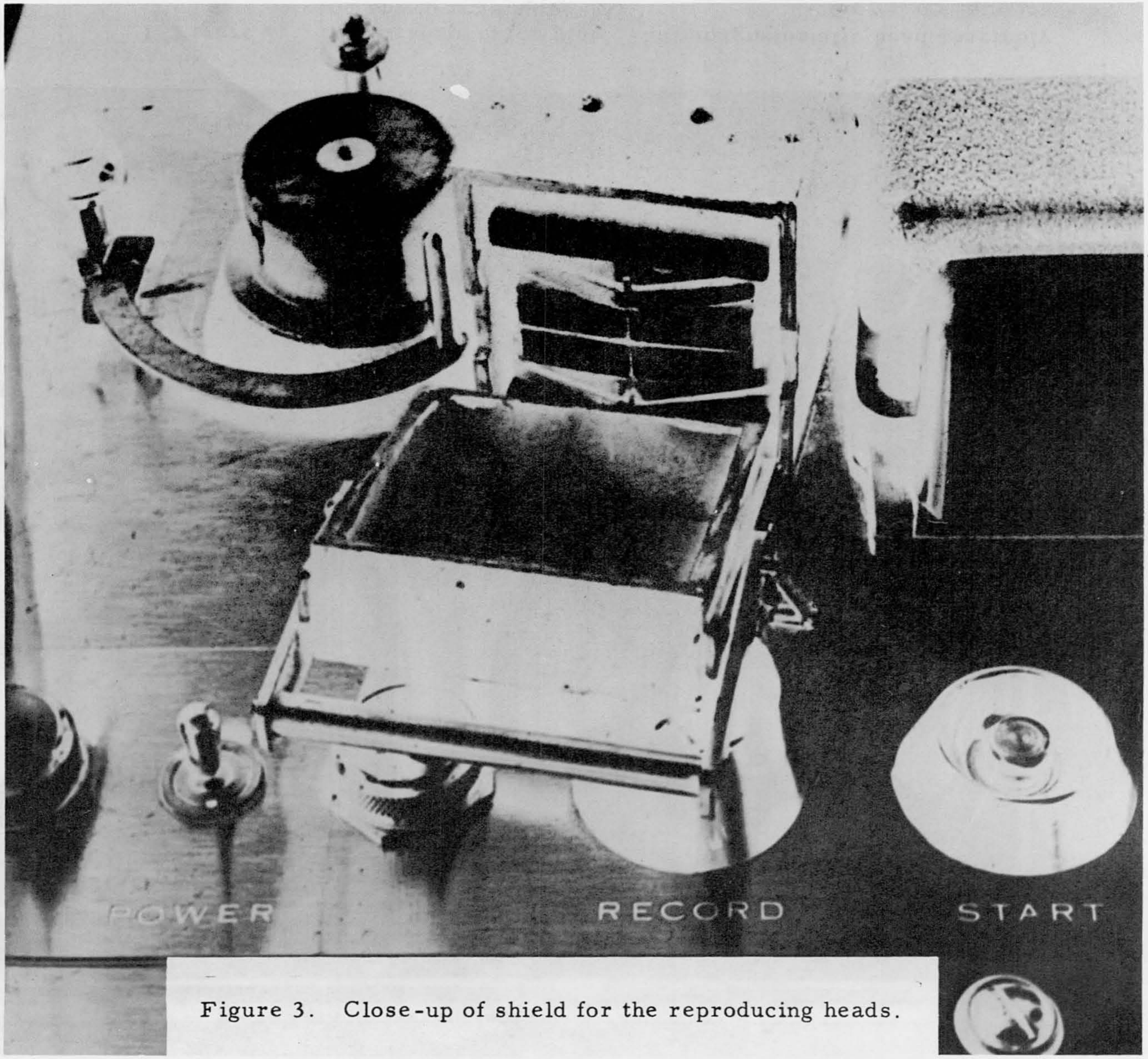


Figure 3. Close-up of shield for the reproducing heads.

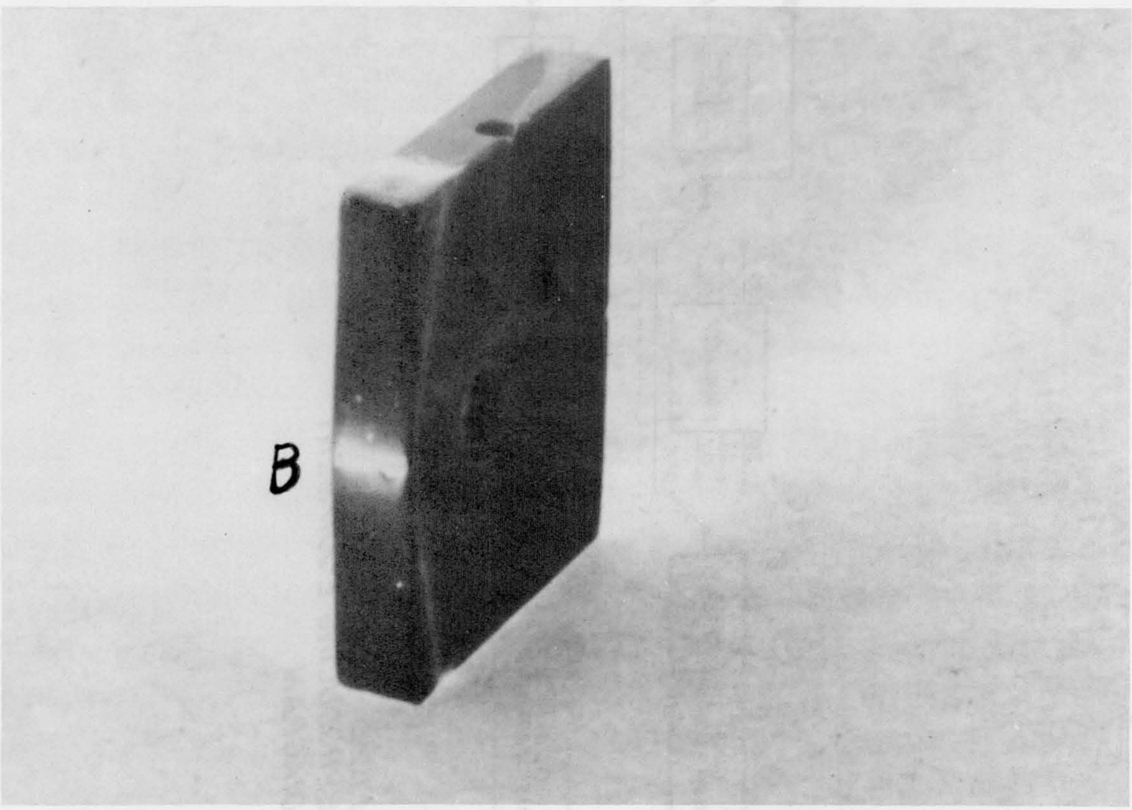


Figure 4. Core structure of the reproducing head assembly. The magnetic head contacts the polepieces at the dark region "B."

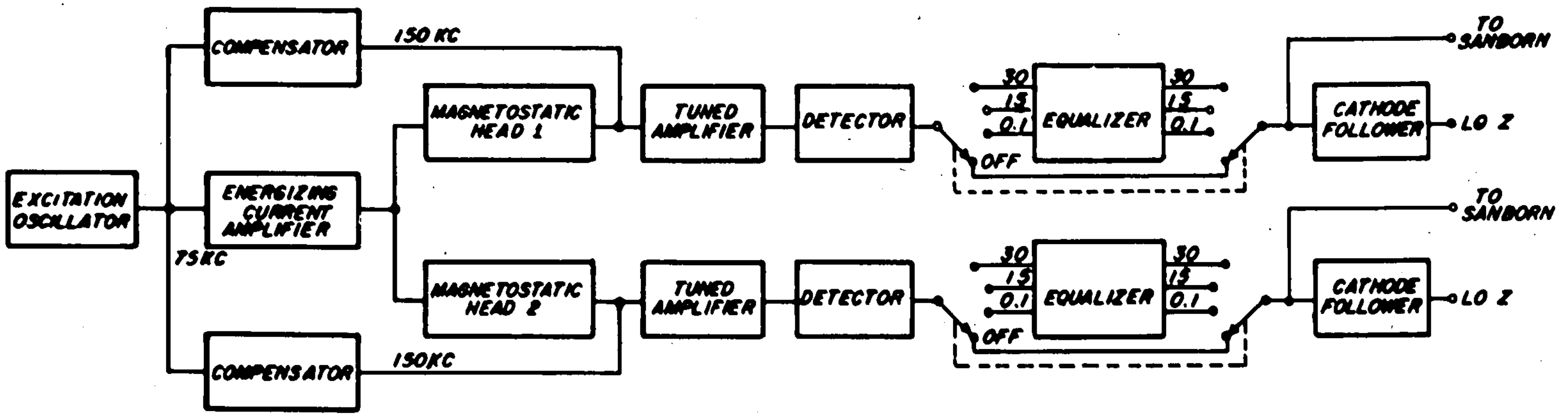


FIG. 5
MAGNETOSTATIC REPRODUCING EQUIPMENT
BLOCK DIAGRAM

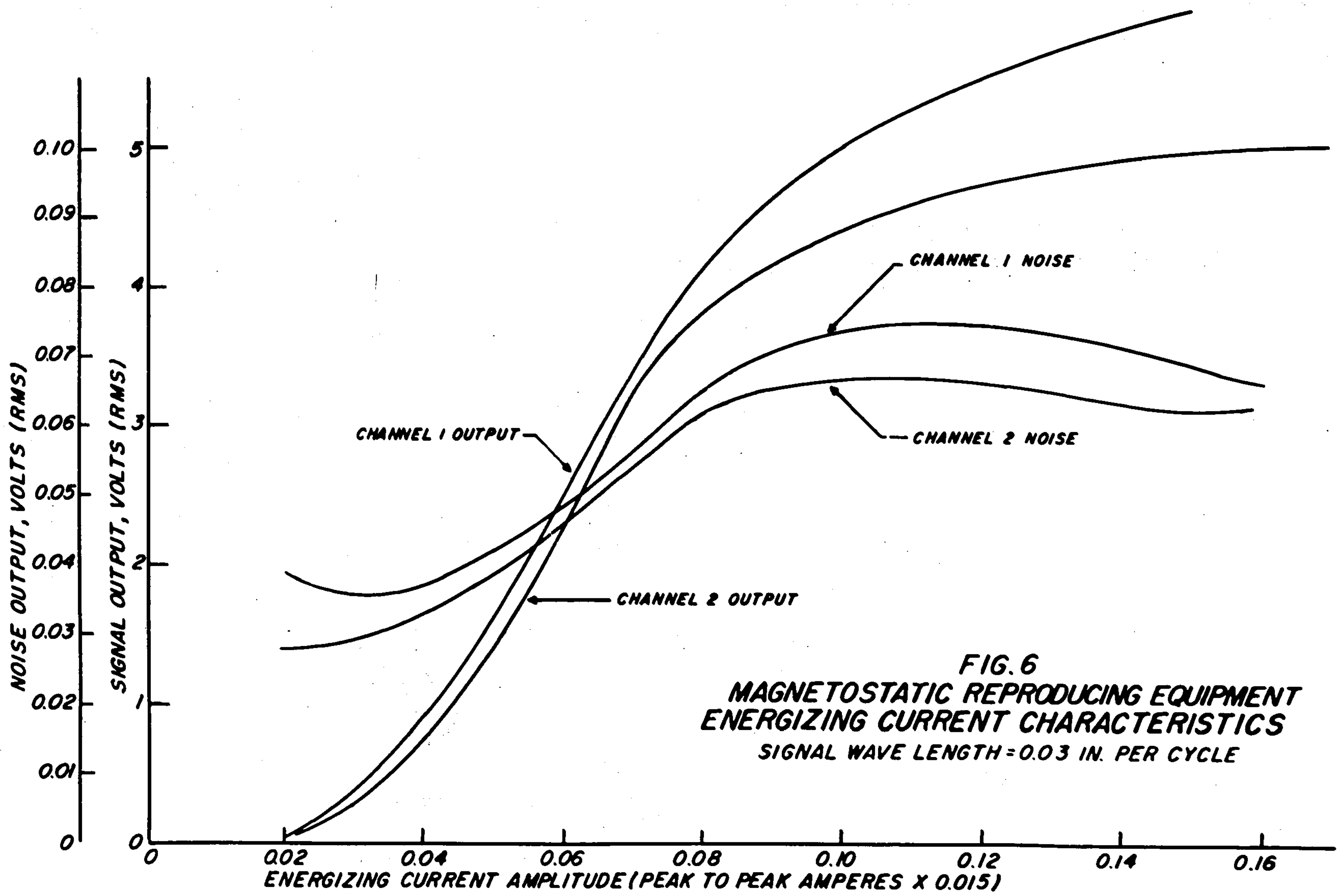


FIG. 6
MAGNETOSTATIC REPRODUCING EQUIPMENT
ENERGIZING CURRENT CHARACTERISTICS
SIGNAL WAVE LENGTH = 0.03 IN. PER CYCLE

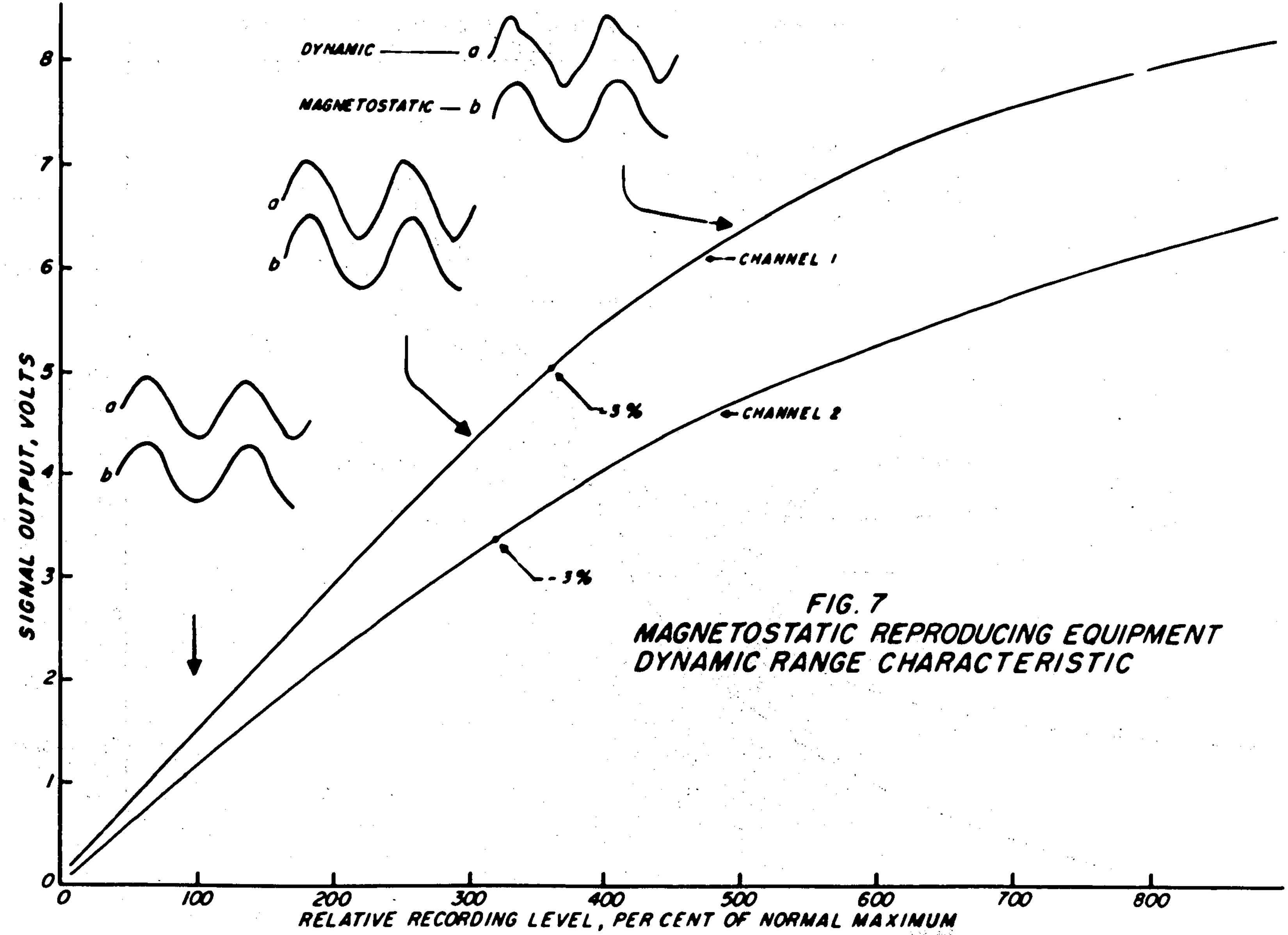


FIG. 7
MAGNETOSTATIC REPRODUCING EQUIPMENT
DYNAMIC RANGE CHARACTERISTIC

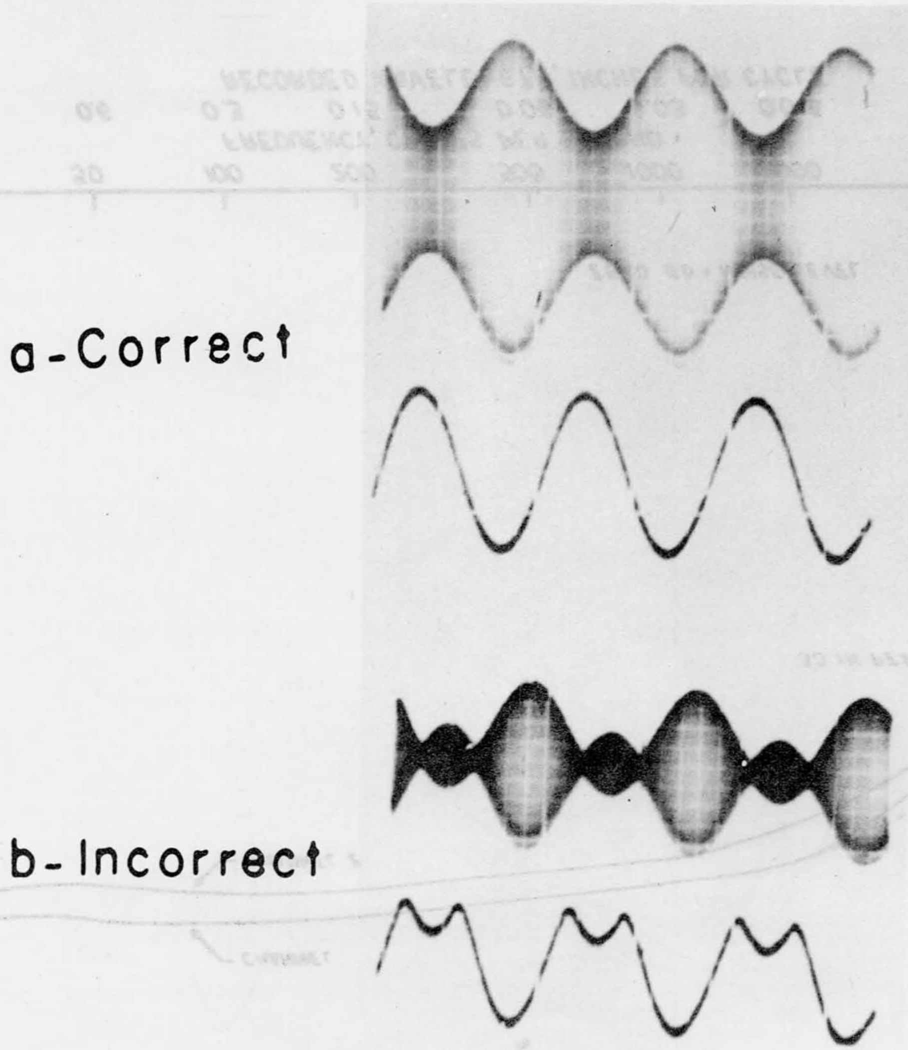
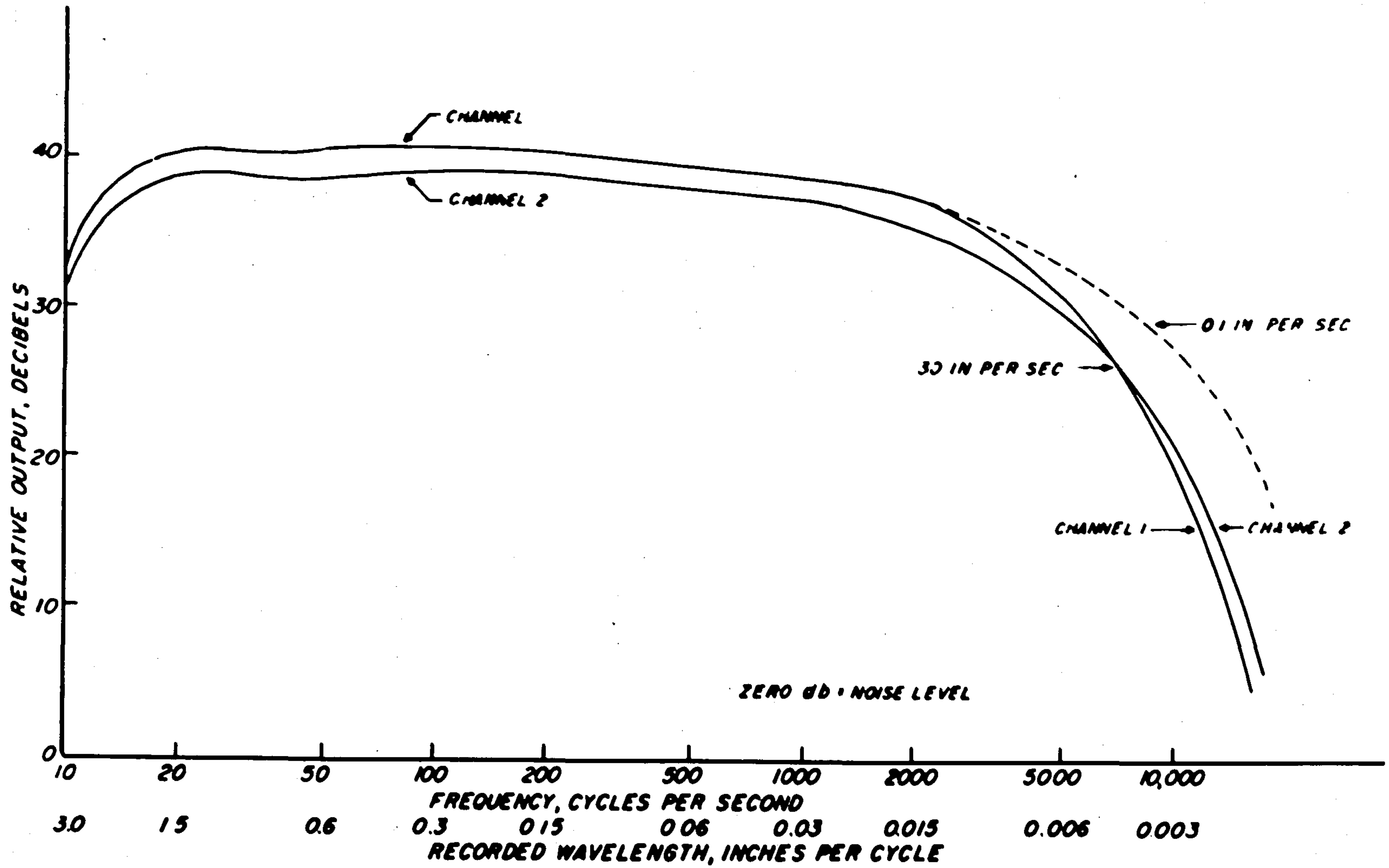


Figure 8 Adjustment of Compensator

FIG. 9
MAGNETOSTATIC REPRODUCING EQUIPMENT
FREQUENCY RESPONSE CHARACTERISTICS
UNEQUALIZED



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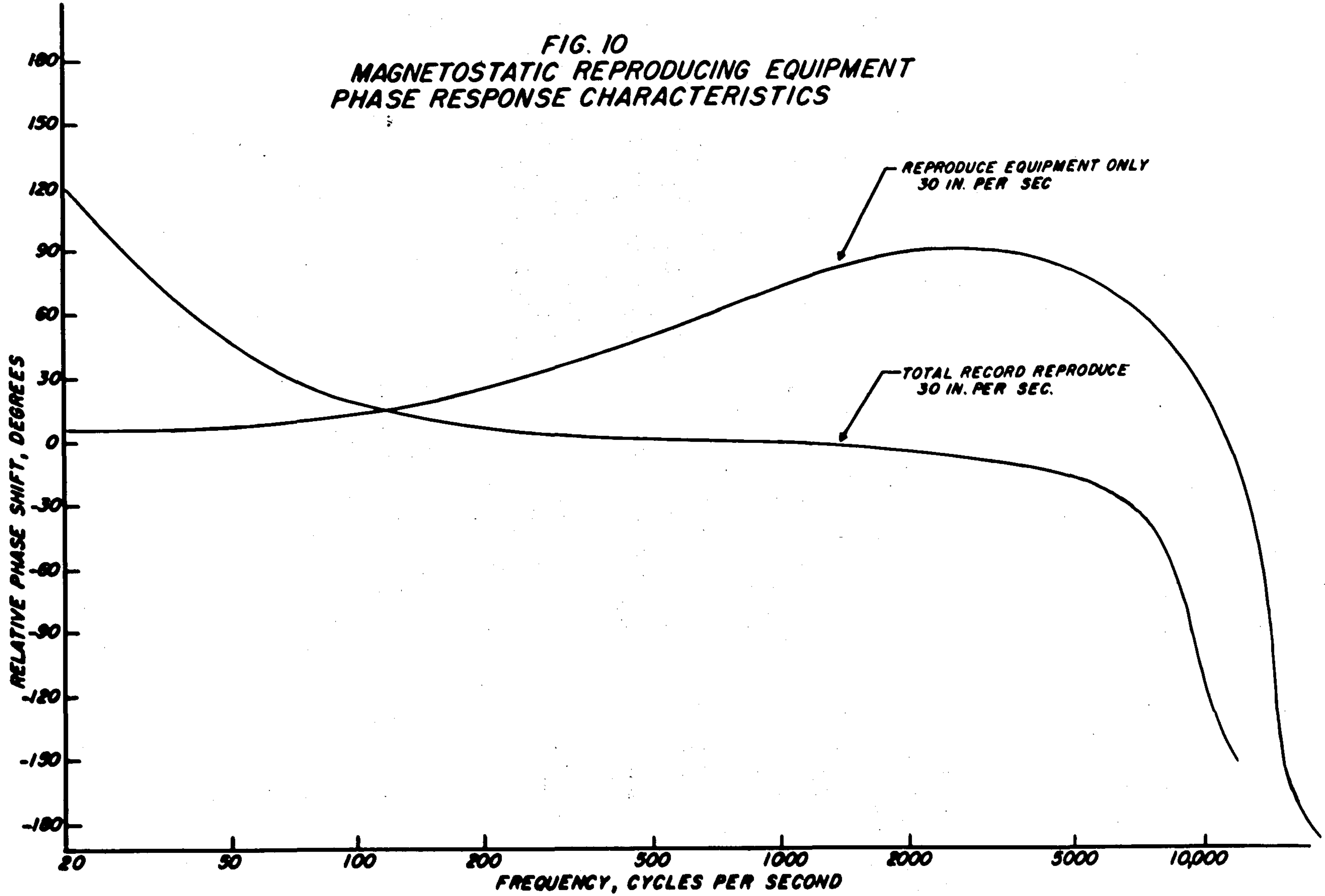
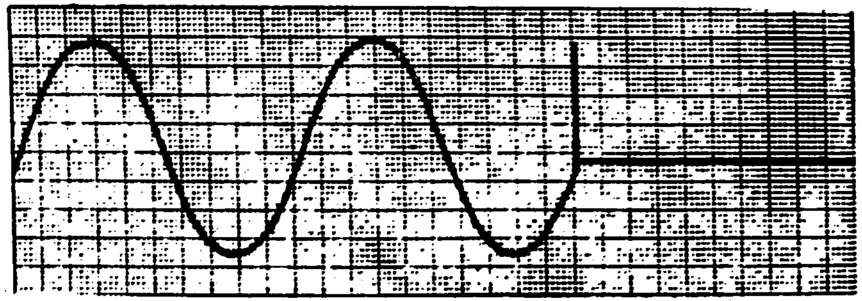
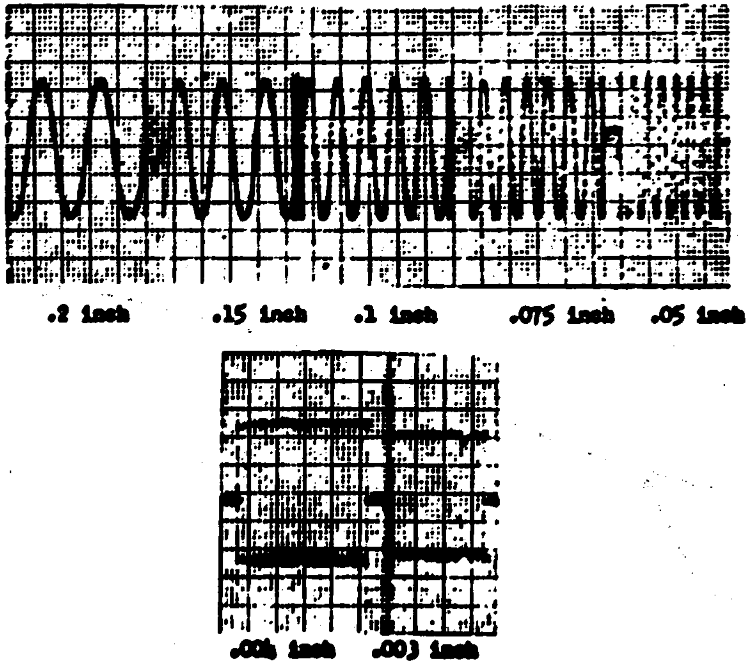


FIG. 10
MAGNETOSTATIC REPRODUCING EQUIPMENT
PHASE RESPONSE CHARACTERISTICS

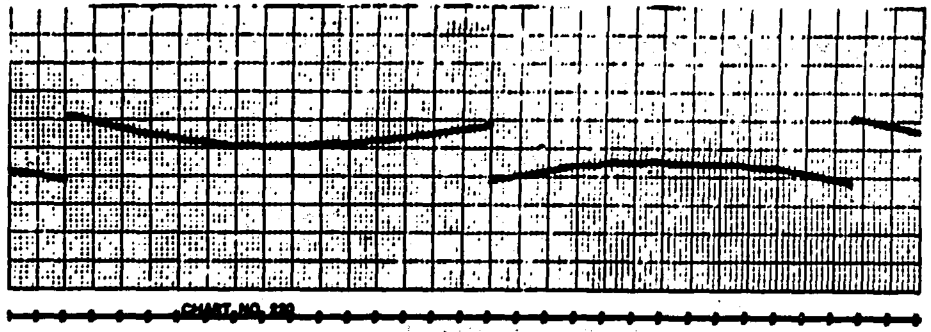


(a) Unequalized Reproduction - 1.0 inch Wavelength

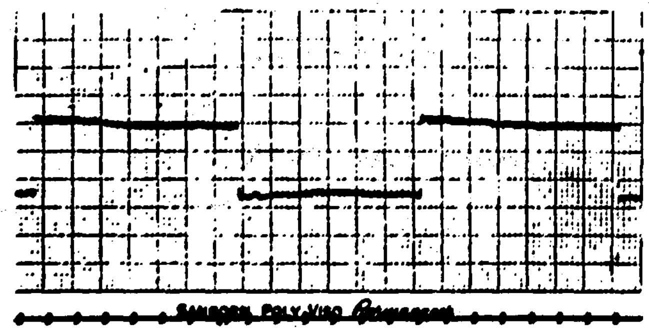


(b) Equalized Reproductions

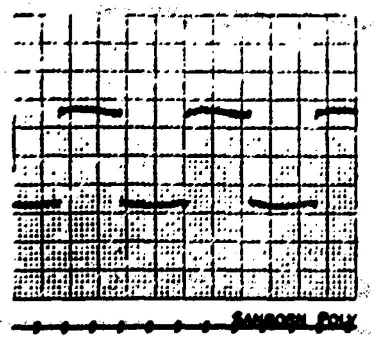
Figure 11. Magnetostatic reading head sine wave reproductions.



3 inch Wavelength



1.5 inch Wavelength



0.5 inch Wavelength

Figure 12. Magnetostatic reading head reproduction of square waves.

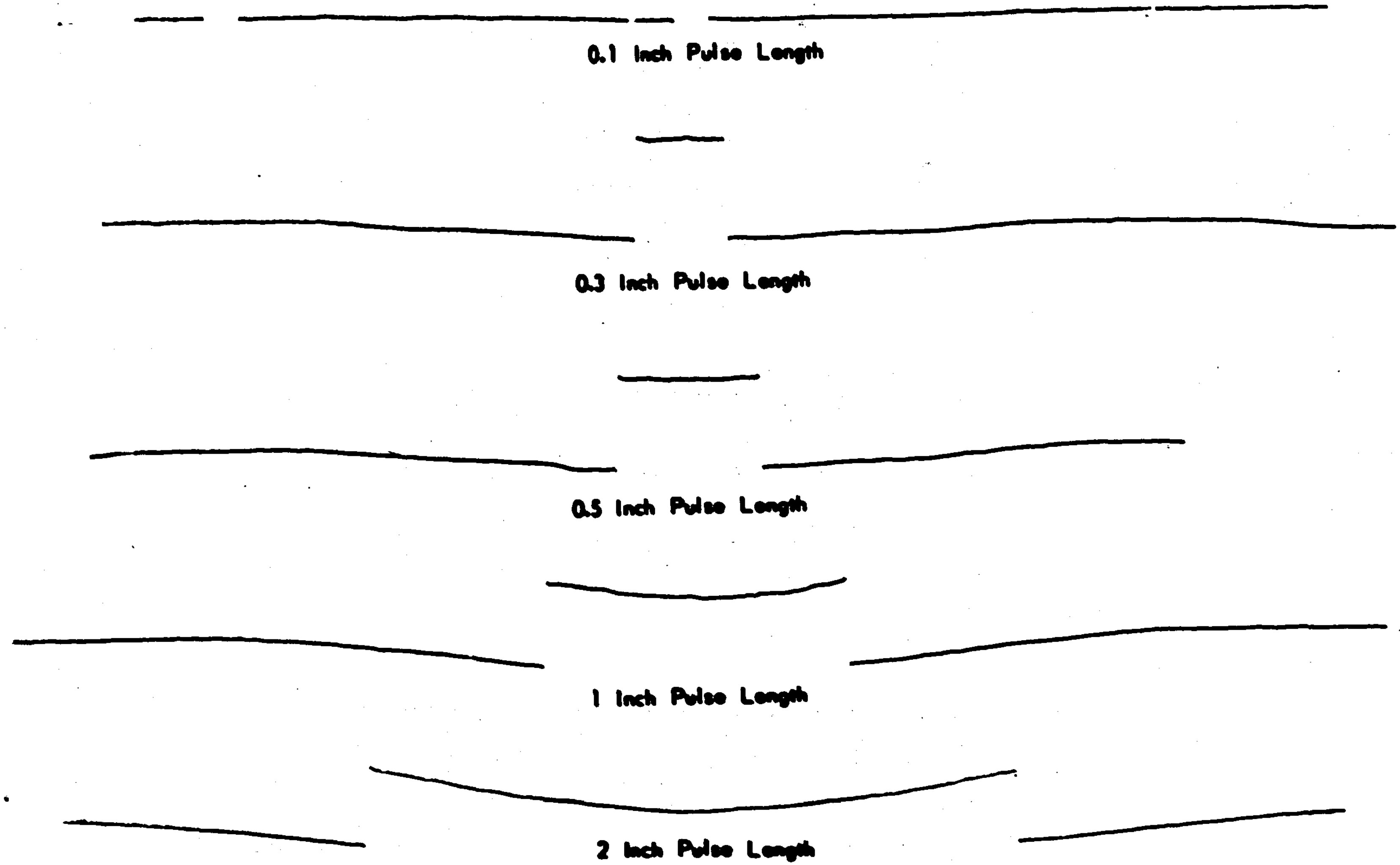


Figure 13. Magnetostatic reproducing equipment single pulse response.

DISCUSSION SUMMARY

Dr. Begun of Clevite-Brush Development Company asked if the noise output from the magnetostriction head was due primarily to Barkhausen jumps and, if so, if any magnetic material was available for the head structure which would reduce the noise output. Dr. Bergh replied that Barkhausen jumps might be suspected since the amount of noise was dependent on the state of stress and anneal of the core. However, the noise frequency components range from zero to high frequencies with very predominant noise at one or two cycles per second, whereas the exciting frequency is 75 kc per second. Dr. Bergh was inclined to think that there is some random relaxation phenomena involved caused by the random shifting of the tips of the butterfly curves which define the effective permeability. No tape was used in these measurements in order to eliminate the extra field pickup. The head was excited by a small winding wrapped directly around the yoke and driven by an oscillator.

When noise measurements are to include tape noise the tape is always in contact with the head, although some work has been done with the tape spaced about .001" away for reading digital records up to 100 digits per inch. This non-contact reproduction worked well but the noise output was just as high. The tape signals from digital records were sufficiently high that the noise output was not a problem.

Mr. Nordyke of IBM asked if mechanical vibrations of the tape affected the head output. Mr. Boenning noted that some rather marked flutter effects had been noted before putting rollers on the reel idler arms. At the slow tape speed used these were caused by friction and jumping of the tape at various fixed points in the tape path. These jumps do not alter the noise output or the amplitude of the signal. The signal wave form and time relations are altered.

Dr. Otto Kornei of Clevite-Brush Development Company asked if any noise could be traced to magnetostriction effects. Dr. Bergh said the heads had not been deliberately squeezed to determine the effect on noise because of the permanent stress that might be left. However, the fact is that the care with which a core is annealed greatly affects the intrinsic noise output. This points toward magneto-mechanical causes for the noise. Noise output has not changed before and after painting heads with rubber, and after casting in resin.

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Paper No. 6

PLAYBACK OF MAGNETIC RECORDINGS THROUGH TRANSISTOR AMPLIFIERS

Mr. C. E. Williams

Armour Research Foundation

9 October 1953

ABSTRACT: Summarizes results of an experimental study to determine the general impedance level of playback heads suitable for use with transistor amplifiers. Shows effect of resistance loading upon output voltage of commercial playback heads; frequency response, voltage gain, input impedance, and power gain of several transistor amplifier circuits. Shows large changes in input impedance at relatively low audio frequencies for some transistor amplifier circuits. Discusses means of obtaining maximum power gain from a single transistor operating from a playback head. Presents graphical results of the actual frequency response of a commercial playback head with transistor amplifier.

Amplifier Operation

Figure 1 shows the equivalent circuits and voltage gain equations for three types of transistor circuits when operating from a zero-impedance generator. The values of alpha, r_b, r_c, and r_e vary with the temperature and d-c operating point of the transistor. Raytheon type CK721 junction transistors were used during most of the experimental work. Their nominal ratings are:

Alpha	.975
r_b (base resistance)	350 ohms
r_c (collector resistance)	0.7 megohms
r_e (emitter resistance)	20 ohms

These values are for a d-c operating point of two milliamperes collector current and minus six volts from collector to emitter.

These equivalent circuits contain no shunt capacitances and thus do not show how the gain and input impedance vary with the frequency. The approximate range of input impedance and voltage gain for CK721 transistors is tabulated below:

Circuit	Input Impedance	Voltage Gain
Grounded-base	50 to 200 ohms	Up to 3000
Grounded-emitter	300 to 1000 ohms	Up to 3000
Grounded-collector	2000 to 100,000 ohms	0.5 to 20

The grounded-emitter circuit was chosen because of its high gain and relatively high input impedance. It has been observed that the voltage gain of a grounded-emitter amplifier decreases rapidly at the higher audio frequencies. The input impedance also decreases as frequency increases. These effects may be predicted from the equivalent circuit of figure 1(a) if a capacitance of several micro-microfarads is connected from the upper end of r_e to the upper end of R_L and the voltage gain equation is derived for this condition.

A CK721 matched in the collector circuit to give maximum power output for a one millivolt input signal gave results as follows:

Frequency	Voltage Gain	Input Impedance
Up to 3,000 cps	1000	580 ohms
5,000 cps	970	400 ohms
8,000 cps	900	330 ohms
10,000 cps	800	300 ohms
20,000 cps	500	220 ohms
50,000 cps	230	200 ohms

It is apparent that the effect of this low input impedance upon a playback head must be determined.

Load Tests on Playback Heads

Figure 2 shows the output voltage of a loaded Magnecord 63 playback head at three different frequencies. The reduction of output voltage as a result of loading is much greater at the higher frequencies. This is to be expected, since the head impedance increases with frequency. This head has approximately 250 turns in its playback winding and its impedance is low enough for use with grounded-emitter amplifiers. The impedances of three commercial heads are plotted as a function of frequency on figure 3. The Shure head has approximately 1500 turns and the Brush head has approximately 1800 turns. It is apparent that these latter two heads would have a greatly reduced high frequency response if operated into a 500 ohm load.

Frequency Response of Transistor Amplifier and Playback Head

The overall frequency response of head and amplifier is given in figure 4. Playback was from a 0.44 ma. constant-current recording made with a Magnecord 63 head. The noise level observed was partly 60-cycle pickup and was 48 db below the maximum signal level. Noise was not bothersome with these transistor circuits. The combined response curve has roughly the same shape as the head-response curve. The maximum power output developed was approximately 2.7 microwatts (.4 volt). This is clearly audible in a set of crystal headphones.

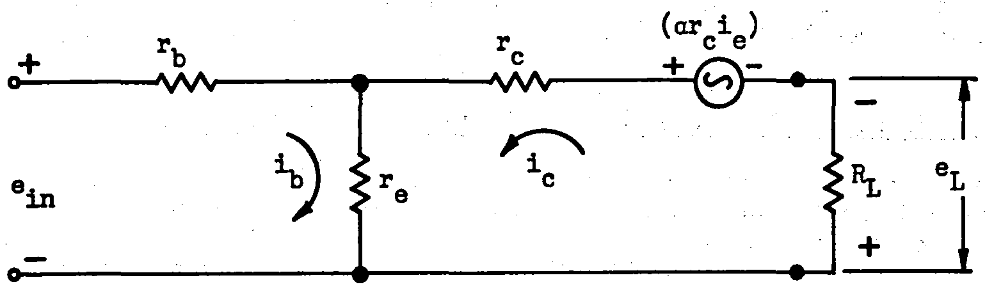
The Raytheon CK721 transistor has a rated power gain of 34 db and a maximum rated collector dissipation of 30 milliwatts. The collector circuit efficiency may be as high as 40 percent in this type of circuit. If the output of the amplifier of figure 4 was properly matched to the input of another grounded-emitter stage with a power gain of 36 db, the total power output would be approximately 10 milliwatts.

A practical transistor playback amplifier would probably use three stages of the type shown in figure 4 to give maximum possible output from a CK721.

SUMMARY OF DISCUSSION

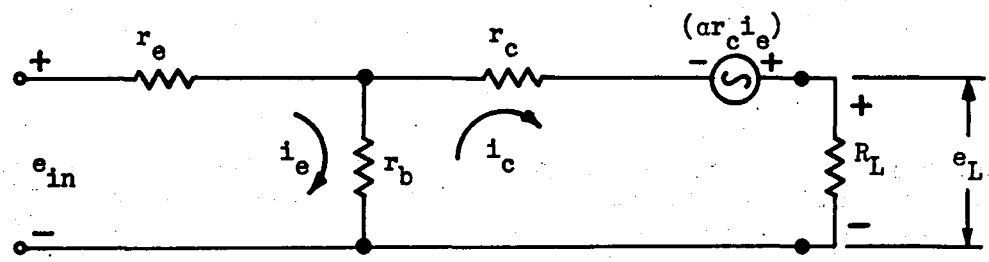
Mr. Camras of Armour Research referred to the capacitive effects which cause reduction of transistor input impedance with rise in input frequency, and asked for a comparison of this effect with the Miller effect in vacuum tube circuits which causes a large increase in apparent shunt capacity at the vacuum tube input. Mr. Williams noted that the capacitive effect in the transistor can be represented in the equivalent circuits (see figure 1) by placing a 10-20 mmf. capacitor, Cc, across V_c. Their combined impedance, Z_c, should be used in place of V_c not only as load for the collector circuit, but also in the expression ($ar_c i_e$) for the equivalent generator. If circuit equations are calculated on this basis they will predict the actual decrease of voltage gain with increase in frequency. This is not concerned with the Miller effect as such, even though the shunt capacity has a double effect in the equations. At higher frequencies, the transient time of holes and electrons in the germanium is sufficiently long to also affect response.

Mr. George Lewin of Signal Corps Pictorial Center noted that the 48 db signal-to-noise ratio at maximum signal was for an unequalized circuit, and asked if data was available for a circuit equalized for flat response. Mr. Williams noted that data of the type shown in figure 4 was all that was taken, since the application was primarily to voice circuits.



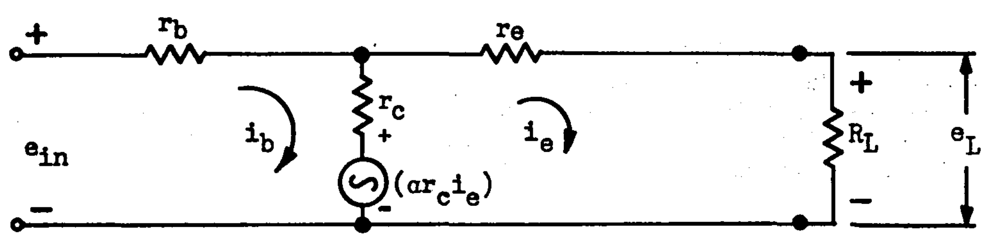
$$e_L = \frac{-e_{in}(r_e - \alpha r_c) R_L}{r_b(r_e + r_c - \alpha r_c) + R_L(r_b + r_e) + r_e r_c}$$

a. Grounded Emitter Circuit



$$e_L = \frac{e_{in}(r_b + \alpha r_c) R_L}{r_e(r_b + r_c + R_L) + r_b(r_c - \alpha r_c + R_L)}$$

b. Grounded Base Circuit



$$e_L = \frac{e_{in} \; r_c \; R_L}{r_b(r_e + R_L + r_c - \alpha r_c) + r_c(r_e + R_L)}$$

c. Grounded Collector Circuit

Figure 1. Transistor amplifier equivalent circuits.

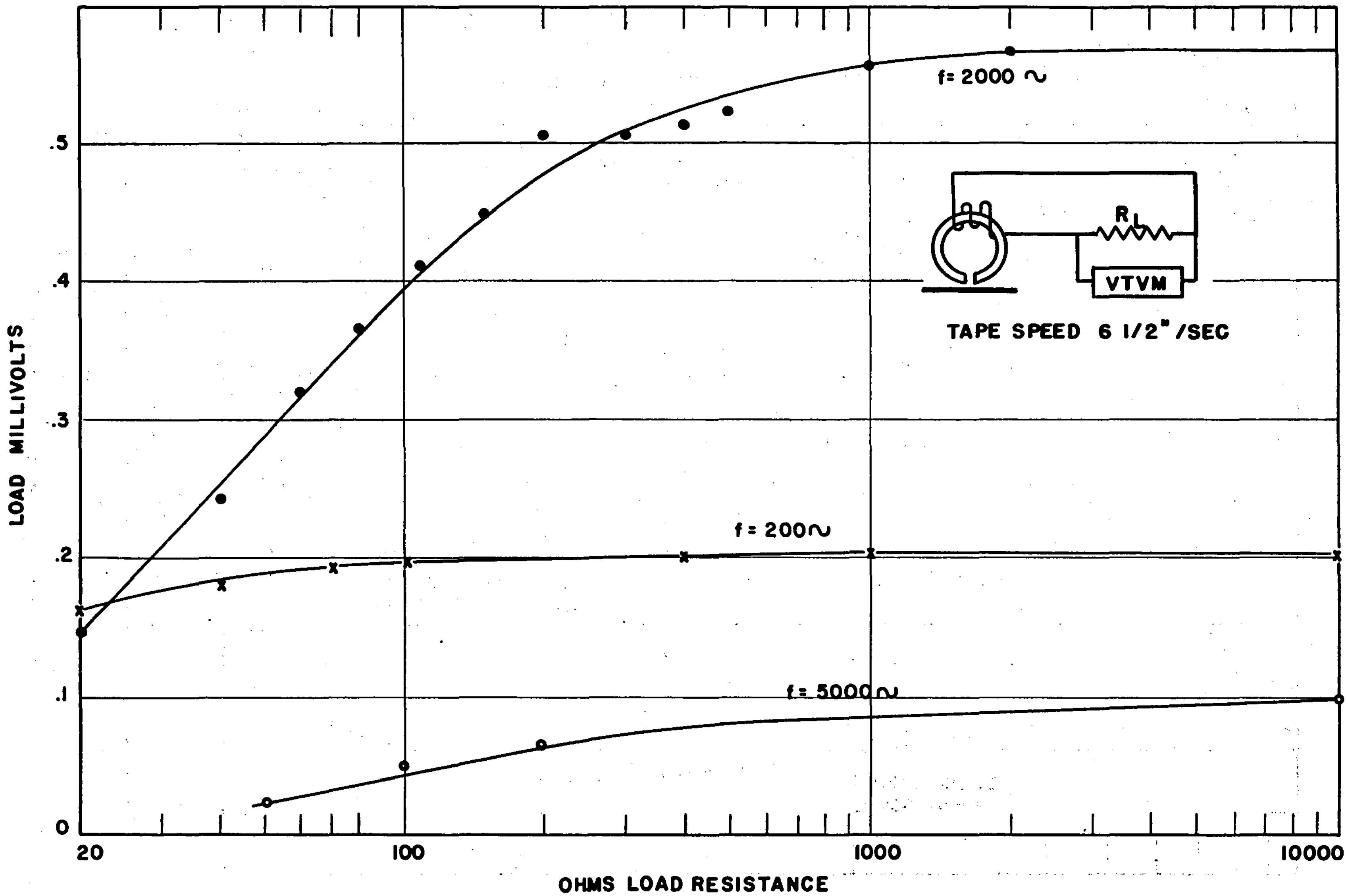


Figure 2. Playback voltage of loaded Magnecord 63 head.

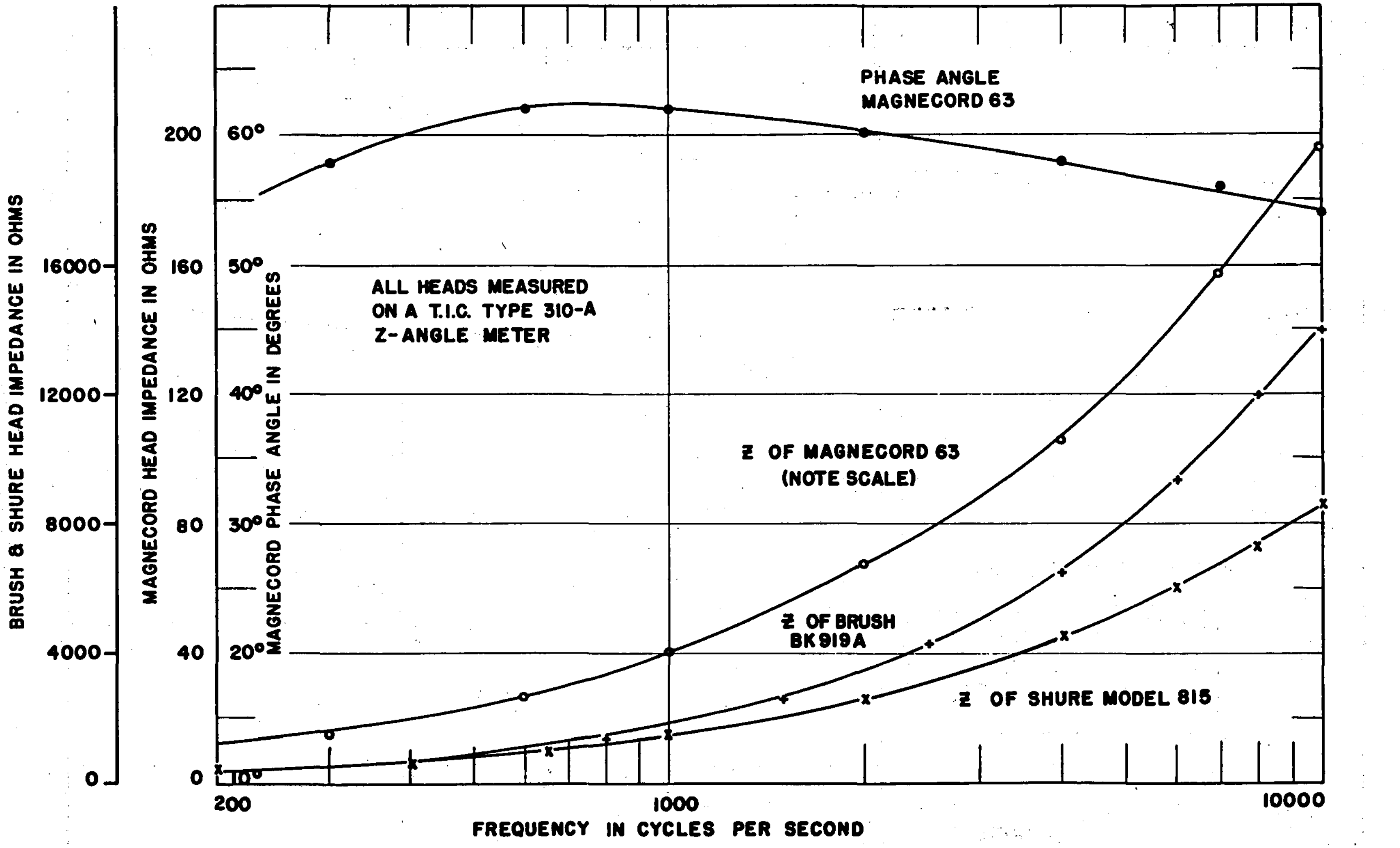


Figure 3. Playback head impedances.

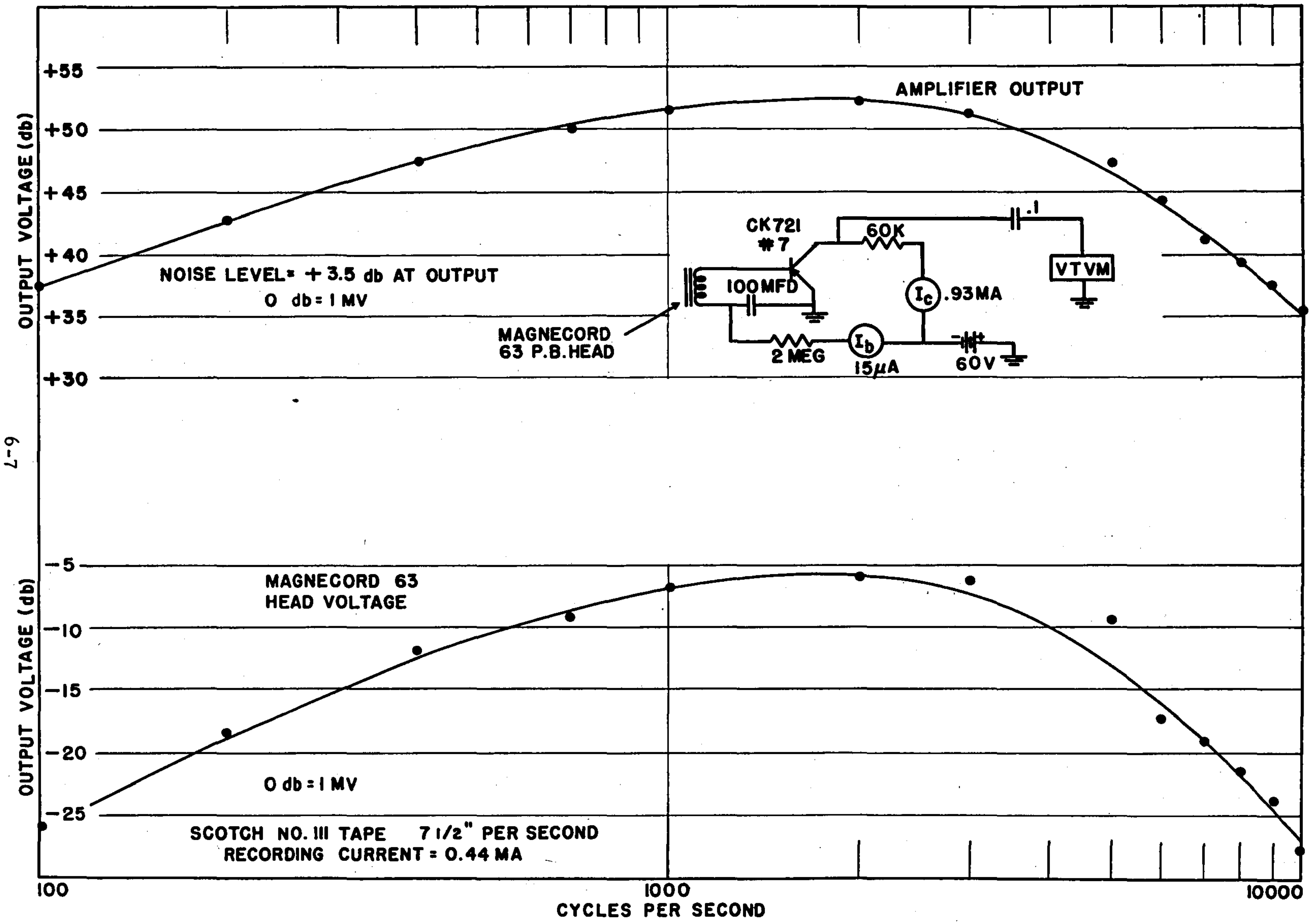


Figure 4. Frequency response of Magnecord 63 head with transistor amplifier when playing back from a constant current recording.

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Department of Defense Symposium on Magnetic Recording

Paper 7

COMPONENTS AND MECHANICAL CONSIDERATIONS FOR MAGNETIC SOUND ON 35 MM FILM

Dr. John G. Frayne

Engineering Manager
Westrex Corporation

9 October 1953

ABSTRACT: This paper outlines the orderly transition from photographic to magnetic sound now occurring in the motion picture industry. Describes development, special techniques, and standards in current use for magnetic adaptation of existing photographic equipment and for new designs. Describes multi-track recorders and re-recorders, including means for reducing "cross-talk" on adjacent sound tracks. Explains current developments for stereophonic sound, including means for multiple duplicates of composite sound and picture release prints for Cinemascope.

It is probably not generally appreciated by engineers outside the motion picture field that sound recording in the motion picture industry had reached a high professional status before magnetic recording began to receive consideration by the radio and television industries. Since 1928 the motion picture industry throughout the world has been equipped with photographic recording equipment, and improvements both in equipment and recording techniques have been made constantly since that time. Not only were the studios equipped with photographic recording facilities, but they had also brought to a high state of development, laboratory, editing, dubbing, and re-recording techniques built around the photographic sound medium. The question, therefore, was why should the motion picture industry change over to the magnetic medium when they seem to have had a highly developed system of recording on film. This situation undoubtedly accounts for the relatively slow adoption of magnetic recording in the motion picture industry as compared to the rapid use of the medium in the broadcast and allied fields. Gradually, however, the benefits accruing from the use of magnetic recording became obvious to the industry--such benefits including lower operating costs, better sound quality, and simplified stage techniques.

Today, near the end of 1953, the motion picture industry is close to being 100 percent equipped with magnetic recording equipment for both production recording on the stage and for other special purposes, such as scoring and re-recording. The fact that the magnetic track was invisible and could not be "read" by the editors was and still is to some extent a stumbling block in the use of magnetic recording for editing and cutting purposes. It was difficult to break down the practices of a life-time for many editors in switching over to the new medium. For this reason, it has been common practice to transfer the accepted "takes" of the original production recordings made on magnetic film to photographic tracks by re-recording or electrical copying. These tracks might take the form of negatives from which prints could be made in a normal fashion, or in some instances they might be direct-positive photographic tracks. The positives made in either manner could then be used for the normal editing, cutting, and re-recording procedures which had been established over a period of years for the photographic medium.

While 1/4-inch tape has become the almost universal medium for magnetic recording in the radio, phonograph, and television industries, it has found relatively little favor in the motion picture industry. The synchronized tape recording machines, which have been described in the literature[1] are in limited use but represent only a negligible share of the film footage used in the motion picture industry. There are several reasons why this situation exists. In the first place, the motion picture industry did not wish to scrap their rather expensive 35 mm photographic film recorders for the newer and untried medium, preferring to have them modified for recording on 35 mm magnetic coated film. In the second place, the problem of synchronizing sprocket-hole sound film in the recorder and sprocket-hole picture film in the camera had been successfully worked out and motor systems had been devised to make this a simple and foolproof operation. As a result, there was considerable skepticism of the feasibility of any attempt to synchronize a tape without sprocket holes but having a superimposed carrier as a means of providing the exact degree of synchronization required. Further, over a period of years the problems of pulling 35 mm sprocket-hole film with a high degree of uniformity of film motion past the line of translation have been largely overcome with a result that by the time magnetic recording made its appearance, professional photographic recorders were available on the market with speed variations well under 0.1 percent[2]. Also, such auxiliary studio devices as film editing machines, rewinds, and

[1] D. G. C. Hare and W. D. Fling, "Picture-Synchronous Magnetic Tape Recording," Jour. SMPTE, 54, 554-566, May 1950.

[2] G. R. Crane and H. A. Manley, "A Simplified All-Purpose Film Recording Machine," Jour. SMPE, 46, 465-474, June 1946.

synchronizers used standard 35 mm type sprockets, and projection rooms used to project the daily sound and picture films were, of course, also equipped with sprocket-type film pulling mechanisms. The conversion or replacement of these equipments by synchronized 1/4-inch tape devices would have meant considerable capital outlay. As a result of all these considerations, the motion picture industry seems to be definitely committed to the use of 35 mm magnetic film or in some cases split film of 17-1/2 mm dimension. Magnetic tape is nominally only 2.2 mils thick and "print through" of the signal occurs between adjacent windings in a reel at a sufficient level to be objectionable in the motion picture technique. This is not a problem with the thicker 35 mm film.

The first usage of magnetic recording in the motion picture studios was largely done on converted photographic recorders, and figure 1 shows a typical photographic recorder thus modified.[3] In this type of recorder, the line of translation for the photographic medium was at the film recording drum. At this point in the film path, the filtering of undesirable speed variations, whether due to gears, sprockets, rollers, etc., was at a maximum and the constancy of speed at a corresponding optimum. It was natural, therefore, to mount the magnetic head so that the line of translation for it would correspond to that for the photographic medium. In figure 2, there is shown a magnetic head mounted in this drum position--the head being mounted inside the film loop formed by the film as it passes around the drum, the magnetic coating being, of course, on the inside of this loop and in direct contact with the magnetic head.

By mounting the head in this position, it was found that the constancy of magnetic film speed was comparable to that of the earlier photographic type of recording, with the single exception that irregularities of motion due to the passage of the film over the magnetic head added considerably to the amount of flutter in the higher flutter rates. Thus, for example, for all flutter rates normally found below the sprocket-hole frequency of 96 cycles, comparable performance was found between the magnetic and photographic methods. At 96 cycles and higher rates, the magnetic film showed a considerably higher degree of flutter disturbance. This was found on examination to be partially due to the polygoning of the film adjacent to the sprocket-hole areas and partly due to the rubbing effect of the film as it passed over the magnetic head. Since the whole area between the sprocket holes of 35 mm film was available for the magnetic sound track, the first of these problems was met by removing the track to a considerable distance from the sprocket holes. Thus, the earlier single track magnetic recorders utilized a film location about 135 mils in from the inside edge of the sprocket holes. This appeared to eliminate the 96-cycle disturbances referred to above. Later, however, when the industry evinced an interest in multiple tracks on 35 mm film, it was found necessary to move the outside tracks closer to the sprocket holes. The compromise[4] finally adopted for three tracks on 35 mm film was as shown in figure 3. This shows that a 50 mil separation was provided between the magnetic tracks and the nearest sprocket holes. Admittedly, this meant some increase in 96-cycle sprocket-hole modulation[5] but at such a level as not to interfere noticeably with the quality of the recording.

In introducing magnetic recording into the motion picture studios, the design engineers were undoubtedly influenced by the already existing photographic recording channels which in turn had proven quite satisfactory to the motion picture industry. Thus, while it was common practice in the 1/4-inch tape equipment industry

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[3] G. R. Crane, J. G. Frayne, and E. W. Templin, "Supplementary Magnetic Facilities for Photographic Sound Systems," Jour. SMPTE, 54, 315-327, March 1950.

[4] G. R. Crane, J. G. Frayne, and E. W. Templin, "Magnetic Recording on Film," Jour. SMPTE, 56, 295-399, March 1951.

[5] L. L. Ryder and Bruce H. Denny, "Magnetic Sound Track Placement," Jour. SMPTE, 58, 119-136, Feb. 1952.

to supply, at least in the initial stages, one instrument embodying all the electronic as well as the mechanical components, this violated a long established practice with the motion picture industry. The studios have always employed separate recorders embodying only the mechanical and optical elements necessary for exposing the photographic film. The mixing unit has always been a separate and usually a highly portable unit and the remainder of the channel equipment, including amplifiers, power supplies, and other accessories, has usually been mounted in separate cabinets, racks, or boxes, and in the case of portable equipment is usually mounted in light-weight trucks. The physical operation of the magnetic recorder from its associated electronic circuits, both recording and monitoring, influenced to some extent the design of the magnetic heads. Thus, while high impedance heads are common practice in 1/4-inch tape recording machines where only short cable runs are necessary from recording and monitor amplifiers, the motion picture industry generally accepts low impedance heads of the order of 2 or 3 mh. This permits operation at a considerable distance over low impedance circuits from the recording equipment and, if necessary, from the monitoring pre-amplifiers. A typical magnetic recording or reproducing head is shown in figure 4, as an exploded view.

Another practice in which the motion picture magnetic film recording differs from tape recording is the almost complete absence of electronic erase heads from the recording machines. This is largely due to the fear of the motion picture industry that such an erase head might well result in the accidental erasure of material which had been obtained at a very great cost, and could only be replaced in many instances with the expenditure of an equal amount of money. This led to the development of bulk-erasure equipment and although commercial bulk erasers were made available, most of the motion picture studios have seen fit to develop their own particular way of accomplishing this result. A typical magnetic bulk eraser is shown in figure 5. This is one of the simpler non-automatic types and requires manual movement of the film through the erasing field--the film passing through a total of three times with the roll being rotated 20° before each pass. In general, it has been found that such a type of eraser is very satisfactory and seems to result in less noise than is found with the use of electronic type erasing.

The modification of existing photographic recording equipment to provide magnetic recording facilities was followed by the development of magnetic recording systems. The principal components of a typical system are shown in figure 6. They consist of a recorder, a two-channel mixer, and a power supply. The recorder is provided with high-quality film-monitoring facilities which can also be used for reproduction from magnetic sound track using either the monitoring or the recording magnetic head.

Figure 7 is a view of the magnetic recorder with front cover and the cover plate over the magnetic head assembly removed. Simplicity of operation and flexibility to meet various studios' operating procedures have been given special attention. A signal light indicates the proper film threading loop for optimum filtering of the film drive. A selector dial automatically sets the drive conditions and circuit connections for recording, reproducing from either magnetic head, or high-speed rewind. Either film reel can be operated in either direction to accommodate a studio's practice with reference to the direction in which they wind their film. Shock rollers absorb the initial increase in film tension at start to insure a minimum of film wear.

Another interesting medium employed in the studios is the combination of photographic and magnetic recording on a single film. This has not attained universal acceptance but is employed in a few of the Hollywood studios. In this case the magnetic coating appears in the form of a stripe placed on the film base, the film itself being coated with a standard photographic emulsion. A recorder equipped to provide simultaneous photographic and magnetic recording is shown in figure 8. The purpose of this type of recording is to provide a photographic track which may be used for the inspection of the daily prints and for editing and cutting purposes. In this case, normal studio practices for photographic editing, cutting, etc., are employed. Since the photographic and magnetic modulations are colinear, the film may be cut straight across and spliced together and maintain proper synchronization with the picture film. The magnetic track on such a film is normally employed only for re-recording or dubbing purposes since it is generally accepted that the quality of recording from a magnetic track is superior to that of a photographic track. If this type of equipment had been made available in the early stages of conversion from photographic to magnetic recording, this technique might have become more widely adopted. However, since magnetic editing and cutting from so-called Magnastripe[6] film is becoming quite popular in the studios, the future of this type of recording is decidedly limited. The same might be said for the practice discussed above of transferring from magnetic to photographic recording for editing purposes. With the conversion of magnetic editing machines and the introduction of new editing machines,[7] such as shown in figure 9, the editing of magnetic films has been made quite simple; hence, in the not too distant future the use of the photographic medium in the motion picture studios for all production and studio operations will undoubtedly become less in evidence and the whole field will be taken over by the magnetic medium.

The use of multiple tracks posed the problem of minimizing cross-talk between adjacent tracks. Cross-talk even in minute quantities becomes a very important matter especially when separate intelligences are recorded on each of the individual tracks. For example, triple-track film might have a dialogue sequence on track number 1 and a music sequence on track number 2. At some time during the production of the motion picture, it might prove desirable to erase the dialogue on track number 1 and replace it with a somewhat different version, or even with a different language. For these reasons, it is quite obvious that cross-talk of the original dialogue into the music track would be very undesirable. It was found that most of this cross-talk occurred at lower frequencies or longer wave-lengths, due apparently to the spreading of the magnetic fields of the longer magnets at the lower frequencies. A very ingenious device shown in figure 10 illustrates how this problem of cross-talk was overcome. This involved the use of what has come to be known as decouplers[8] which are mounted between the individual sections of the multiple track-head. These strips of mu-metal are deliberately placed so as to introduce an out-of-phase signal from one head into the other and of sufficient value to cancel out the induced cross-talk signal. It has been found that with the use of these decouplers, the cross-talk can be reduced effectively to a value approximating 60 db below that of the fully modulated signal. This reduction is a function of frequency as shown in figure 11, curve 1, but when the ear weighting characteristic is superimposed on the cross-talk curve, effective cross-talk reduction is found over the entire useful audio spectrum, as shown in curve 2.

The use of the multiple tracks on 35 mm film necessitated a modification of the film drive mechanism outlined previously in this paper. It was no longer possible to mount a multiple track head at the recording drum. As a result, the double flywheel type of drive such as shown in figure 12 was developed for this type of operation. The basic elements of the Davis Drive[9] almost universally used in sprocket-type film pulling mechanisms was retained in this newer double flywheel type of mechanism. In this case the magnetic heads, both recording and monitoring,

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[6] Edward Schmidt, "Commercial Experience with Magna-Stripe," Jour. SMPTE, 60, 463-469, April 1953, Part 2.

[7] G. R. Crane, Fred Hauser, and H. A. Manley, "Westrex Film Editer," Jour. SMPTE, 61, 316-323, Sept. 1953.

[8] C. C. Davis, J. G. Frayne, and E. W. Templin, "Multi-channel Magnetic Recording," Jour. SMPTE, 58, 105-118, February 1952.

[9] C. C. Davis, "An Improved Film-Drive Filter Mechanism," Jour. SMPE, 46, 454-464, June 1946.

are mounted on a plate between the two drums. It was found that when the moment of inertia of the two drums and their associated flywheels equals that of the single drum and flywheel, equally good flutter performance is obtained with this type of drive. In fact, the double flywheel type of drive showed an improvement over the single flywheel in that the polygoning was considerably reduced due to the much lesser curvature of the film as it passed over the magnetic heads. In the type of machine shown in figure 12, the film wrap around each magnetic head is of the order of 30°, thus providing a large area of contact with the permalloy core. This in turn reduces wear and increases the useful life of such a head. With this arrangement the performance on all three tracks is identical and when the decouplers referred to above are installed in such a recording head, a signal-to-noise ratio in excess of 60 db is obtainable.

This multiple-track recorder was originally designed for scoring and dubbing work in the motion picture studios before the recent revived interest in stereophonic recording.[8] With the introduction of Cinerama a little over a year ago, which has seven stereophonic sound tracks on a standard 35 mm film, the industry became quite conscious of the entertainment value of stereophonic sound. The triple-track recorder described above was obviously made to order for this type of recording and when Twentieth Century-Fox decided to add stereophonic sound to their proposed Cinemascope pictorial presentation, this machine was immediately used for the stereophonic production scoring and dubbing recording operations. However, in its original form it was not suitable for portable type of operation so that a new or rather a modified single channel portable recorder was developed to provide stereophonic recording. Such a portable recorder is shown in figure 13. This recorder incorporates, in addition to the film pulling mechanism and the magnetic sound heads, the necessary electronic items for its operation. These include a bias oscillator which furnishes bias current for the three tracks and three monitor amplifiers as well as the various operating controls. This recorder when associated with the mixer shown in figure 14 provides the necessary electronic items for a complete production stereophonic channel.[10] The power supplies required for such a channel are housed in a separate container. For stereophonic recording, the cross-talk reduction of 60 db previously mentioned is not necessary in view of the natural cross-talk between the microphone pickups on the stage. With the elimination of the decouplers, cross-talk reduction of the order of 40 db is possible and this seems to be quite satisfactory for stereophonic recording.

With recording machines of this type and re-recording machines of the earlier type described above, the motion picture studios were in a position to do production stereophonic recording and carry on the re-recording operations in the same medium.

In order to get the stereophonic sound into the theatre, the first attempt made during the early part of 1953 was to supply a separate 35 mm magnetic film on which were recorded three 200-mil magnetic tracks. This film was projected over a separate sound dummy, such as shown in figure 13, located in the projection booth, provision being made for interlocking this machine with one of the projectors for ordinary flat pictures or with both projectors for 3-D pictures. This was accomplished by mounting two-pole Selsyn motors tied in together electrically, each unit being driven through a reduction belt from the driving motor on each mechanism. This arrangement worked reasonably satisfactorily and many pictures were projected throughout the country during the year using this arrangement.

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[8] C. C. Davis, J. G. Frayne, and E. W. Templin, "Multi-channel Magnetic Recording," Jour. SMPTE, 58, 105-118, February 1952.

[10] J. G. Frayne and E. W. Templin, "Stereophonic and Reproducing Equipment," Jour. SMPTE, 61, 395-407, Sept. 1953, Part 2.

The economic difficulties as well as the technical problems of supplying two or three films to theatres in order to put on a complete show led to the development of single film methods which embody many of the entertainment features of these pictures. Thus, during 1953, the Cinemascope process was brought to complete development and introduced into the theatres. In this process there are several innovations. For the first time in the history of motion pictures a single film carries both the picture and the associated stereophonic sound tracks. These sound tracks are provided by striping certain areas, otherwise unused, of the picture film with narrow magnetic coatings. Four such coatings in all are supplied--two being outside the sprocket holes and two inside and adjacent to them. A diagram of the Cinemascope film showing the location and dimensions of the magnetic stripes and of the recorded track areas is shown in figure 15. The three 50-mil tracks provide the stereophonic signals to the three speakers behind the screen. The narrow track which is 29 mils wide provides a signal for auditorium speakers as well as a control signal for cutting these speakers in and out. Another item of novelty in this film is a new sprocket-hole design. The standard sprocket hole has been abandoned in favor of a narrower one in order to provide more room for the sound tracks. The old sprocket hole which was 0.110-inch wide has been reduced to 0.078-inch wide, the height being reduced at the same time from 0.078-inch to 0.073-inch. The change of sprocket hole means, of course, a change of all existing sprockets in theatre reproducing equipment.

In order to be able to run this Cinemascope film in the motion picture theatres throughout the world, it was decided to design a new sound head specifically for playing these tracks. Since this new sound head is located on top of the projector housing, it has been denoted variously as a penthouse, button-on or sandwich head. A typical one is shown in figure 16. This means that the practice, which has been adopted since the introduction of sound pictures, of advancing the sound track start mark ahead of the picture by 20 frames to permit scanning the sound track in a special head located beneath the projector has had to be abandoned. For the Cinemascope film the start mark has been retarded by 28 frames. An item of interest about this new Cinemascope sound head is that the sprocket is film-driven rather than being used as a means of pulling the film through the machine.[11] The film is pulled by the upper sprocket in the picture projector and the sprocket in the penthouse head is simply used as a means of maintaining a loop of a certain length. Otherwise, the film drive in this penthouse head is quite similar to that used in the recorders and re-recorders described previously in this paper.

In reproducing the four Cinemascope sound tracks in the theatre, four preamplifiers are used. These are usually mounted in a box on the front wall of the projection booth. The frequency response of these amplifiers is shown in figure 17. This characteristic incorporates the customary 6 db per octave magnetic reproducing characteristic in addition to low and high-frequency post-emphasis. The latter amounts to about 6 db at 50 cycles and 4 db at 8 kc--these values corresponding to recorded complementary pre-emphasis at the same points in the frequency spectrum. The resulting overall frequency response is essentially flat from 50 cycles to 8 kc with a loss of about 3 db at 10 kc.

The loudspeakers used behind the screen are the standard two-way theatre horn systems with the dividing network cross-over frequency located at 500 cycles. A photograph of a typical three-horn installation is shown in figure 18. The low frequency units used in these speakers are usually standard 16-inch paper cones driven by permanent-magnet-actuated drivers and are mounted in a combination horn baffle. The high frequency units are mounted above the low frequency units and to insure proper distribution of the more directive high frequencies, either multi-cellular-type horns or acoustic lenses are employed. In order to provide good coverage in

[11] C. C. Davis and H. A. Manley, "An Auxiliary Multi-track Magnetic Sound Reproducer," Jour. SMPTE, ...

the theatre, especially those having balconies, more than one high frequency unit may be used in order to direct the sound uniformly throughout the auditorium. The loudspeakers are usually placed at the center and at the right and left of the screen--the centerline of the side speakers being located at a distance from the outer edge of the screen which is equal to one-third the screen width. This has been found to give good distribution when employed with screens up to 65 feet wide, such as employed for Cinemascope projection in large theatres. It is characteristic of most commercial high frequency units that there is considerable fall-off in high frequency response above 8 kc. At the present time, no attempt is made to equalize electrically for this fall-off in response. In fact, it is generally necessary to provide some high frequency roll-off to secure satisfactory reproduction of dialogue in many auditoriums. In other words, the motion picture industry has not succeeded to date in putting what might be called high-fidelity sound into theatres even with magnetically recorded tracks and with stereophonic sound. The situation, however, is considerably improved over single photographic track systems where a very rapid attenuation of the high-frequency response above 7500 cycles has been standard practice.

The advent of magnetic tracks in theatres has created the problem of how to make many duplicates from a master recording. So long as the photographic medium was employed, the prints were made from a photographic sound negative--the printing process being usually carried on simultaneously with that of printing the picture. Since no acceptable method has been developed for making contact magnetic prints, electrical copying of such prints is necessary at the present time. In order to accomplish this, a single multi-track reproducer using a four-track magnetic master film is used to feed signals to a bank of multi-track magnetic recording machines. A photograph of a typical installation is shown in figure 19. This shows one reproducer and four recorders. In order to accelerate production this group of machines may be operated above the normal motion picture film speed of 90 feet per minute and speeds up to 180 feet per minute are permissible. With increased speed and the use of a number of recorders, the magnetic transfer process can be highly accelerated.

The story on Cinemascope tracks would not be complete without a brief mention of the method of applying the magnetic material to the Cinemascope picture prints. In this case the finished photographic print is run through what is known as a striping machine, a view of which is shown in figure 20. A solution carrying the finely ground magnetic oxide is fed from a hopper through four nozzles which lay down the four tracks previously discussed. Since these tracks are in the liquid state, the film must be passed through a dry box similar to that used in film developing machines before the material can be used in the printing machines described above. A variation from this type of coating machine is one in which very thin strips of previously coated base are laminated onto the picture film. The latter method has not attained practical acceptance yet in the industry and as far as is known, the only system currently employed in commercial practice is that similar to the one provided by the machine shown in the last figure.

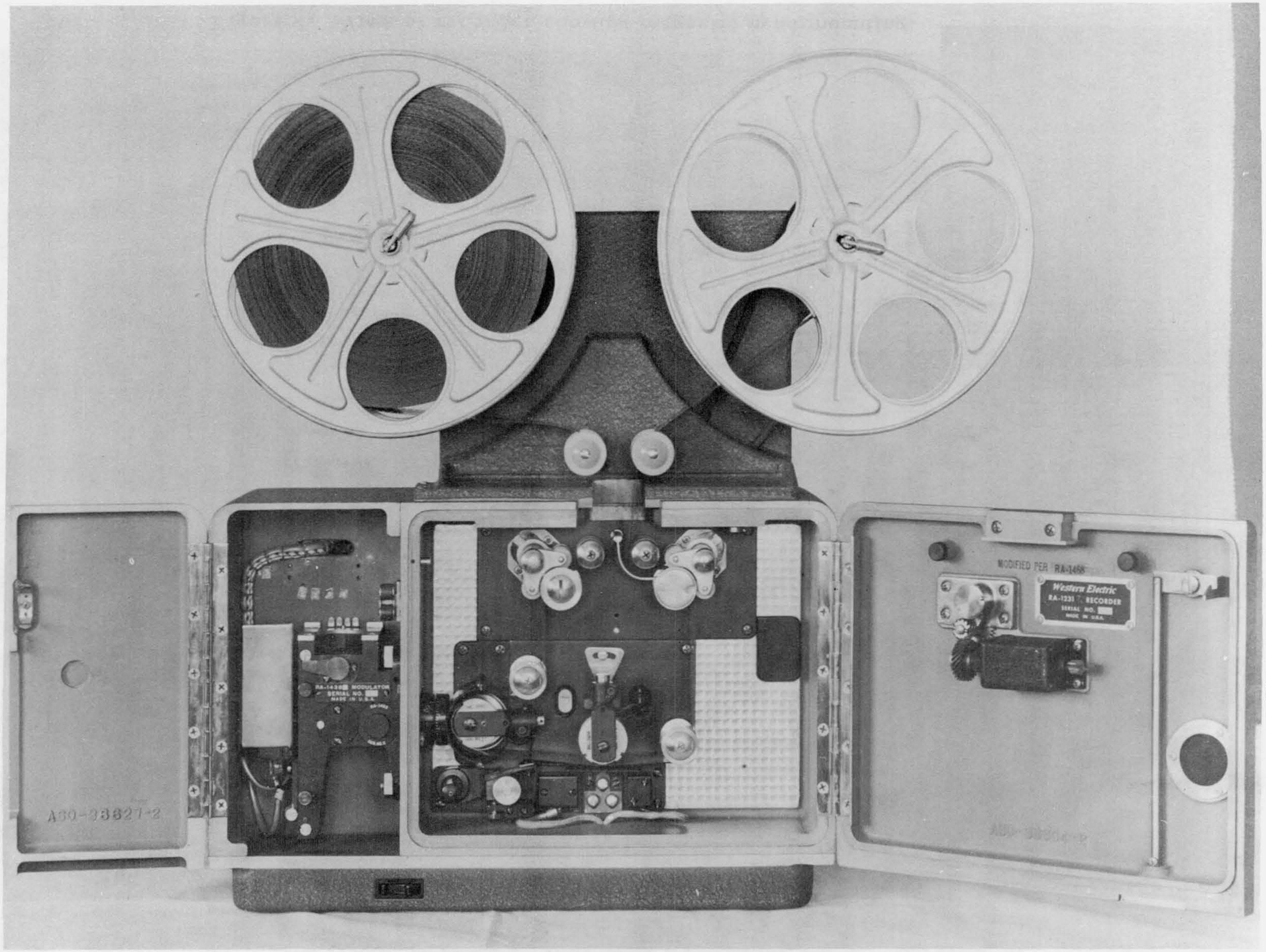

Figure 1. Photographic recorder modified for magnetic recording.

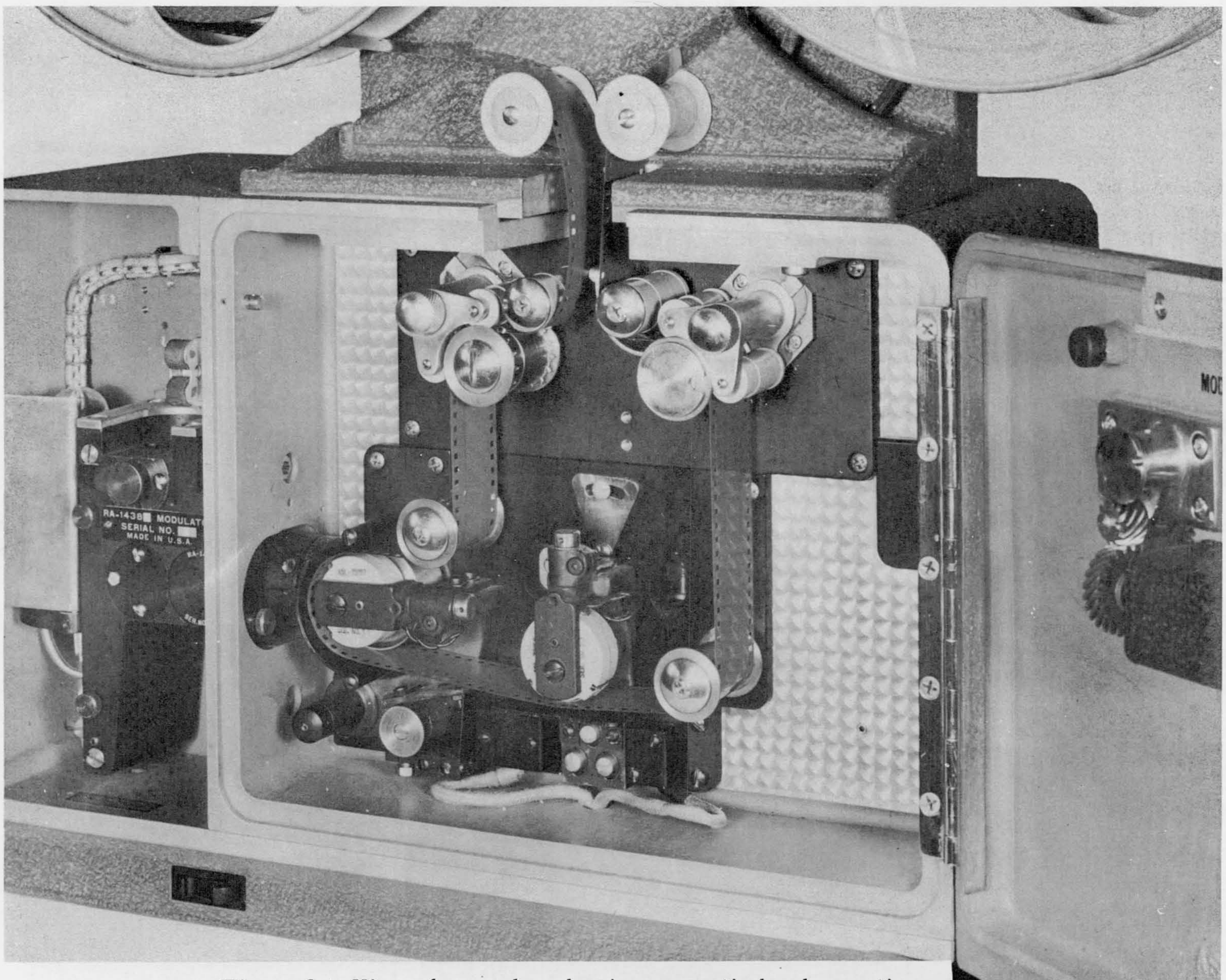

Figure 2. View of recorder showing magnetic head mounting.

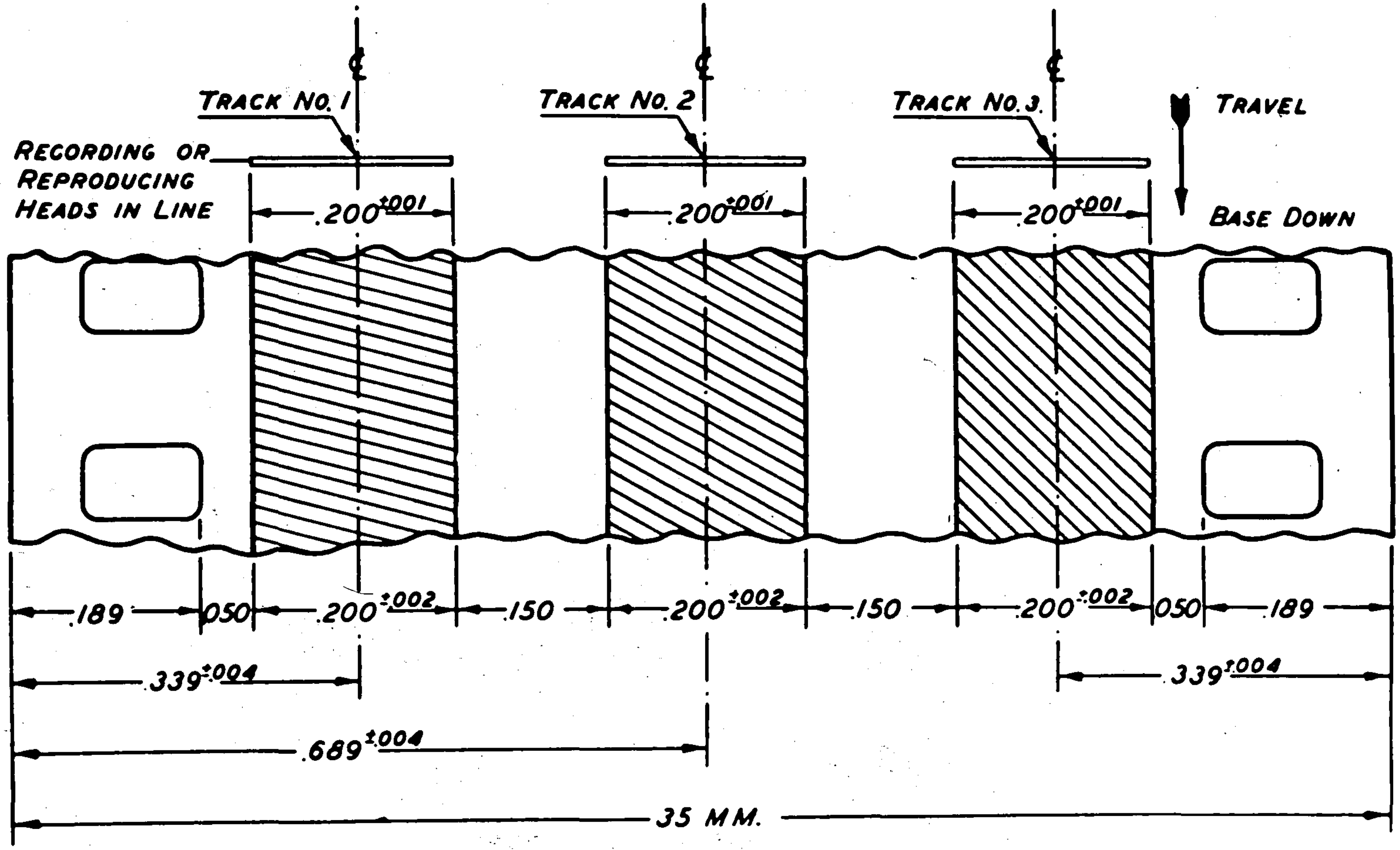

Figure 3. Magnetic film-track standards.

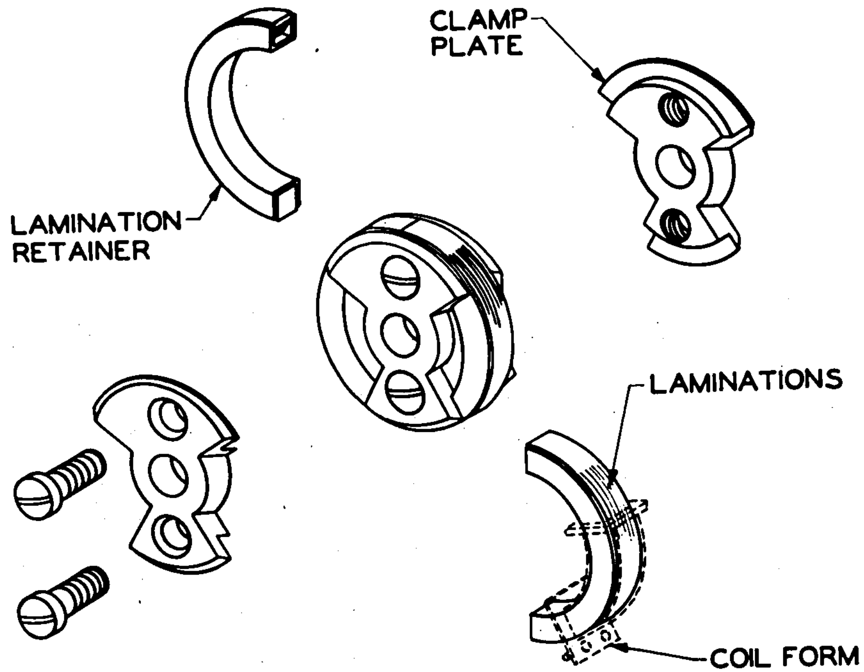

Figure 4. Exploded view of typical magnetic head.

Figure 5. Typical bulk eraser.

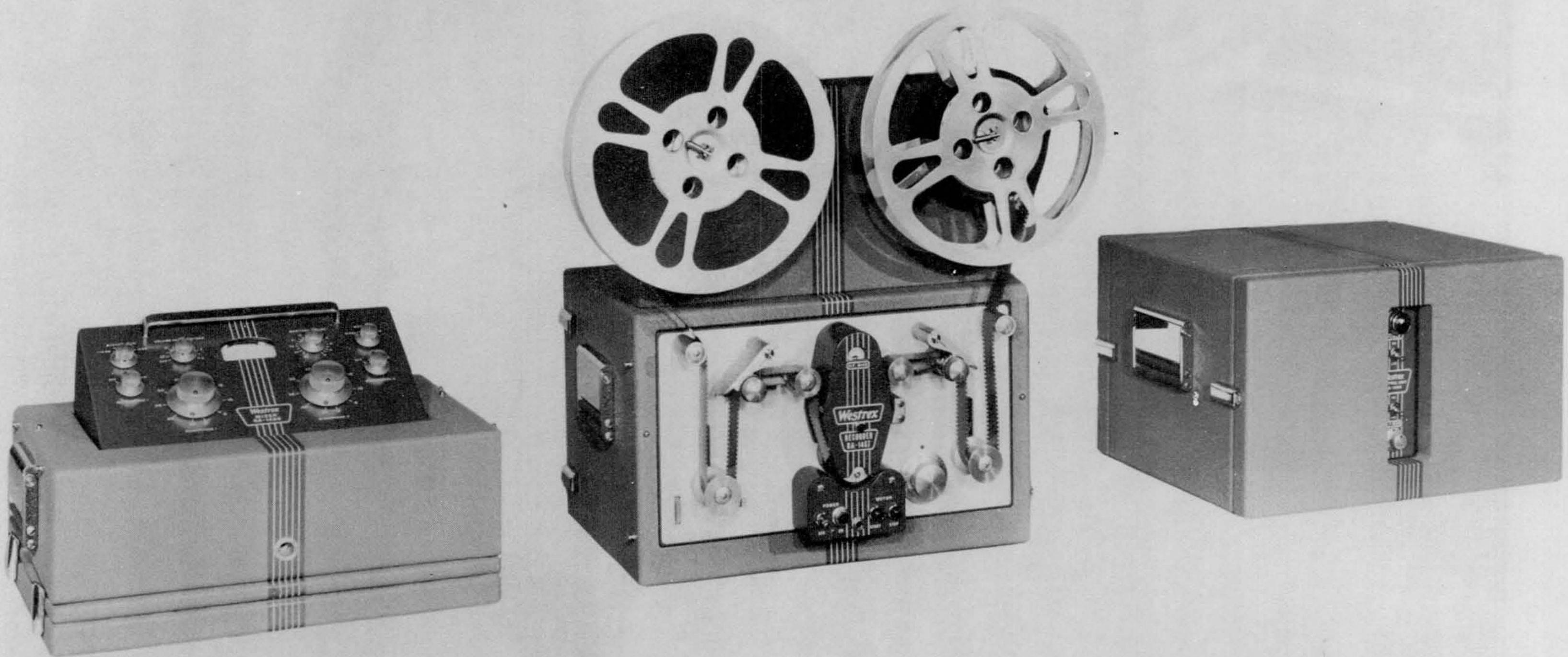

Figure 6. Typical magnetic recording system.

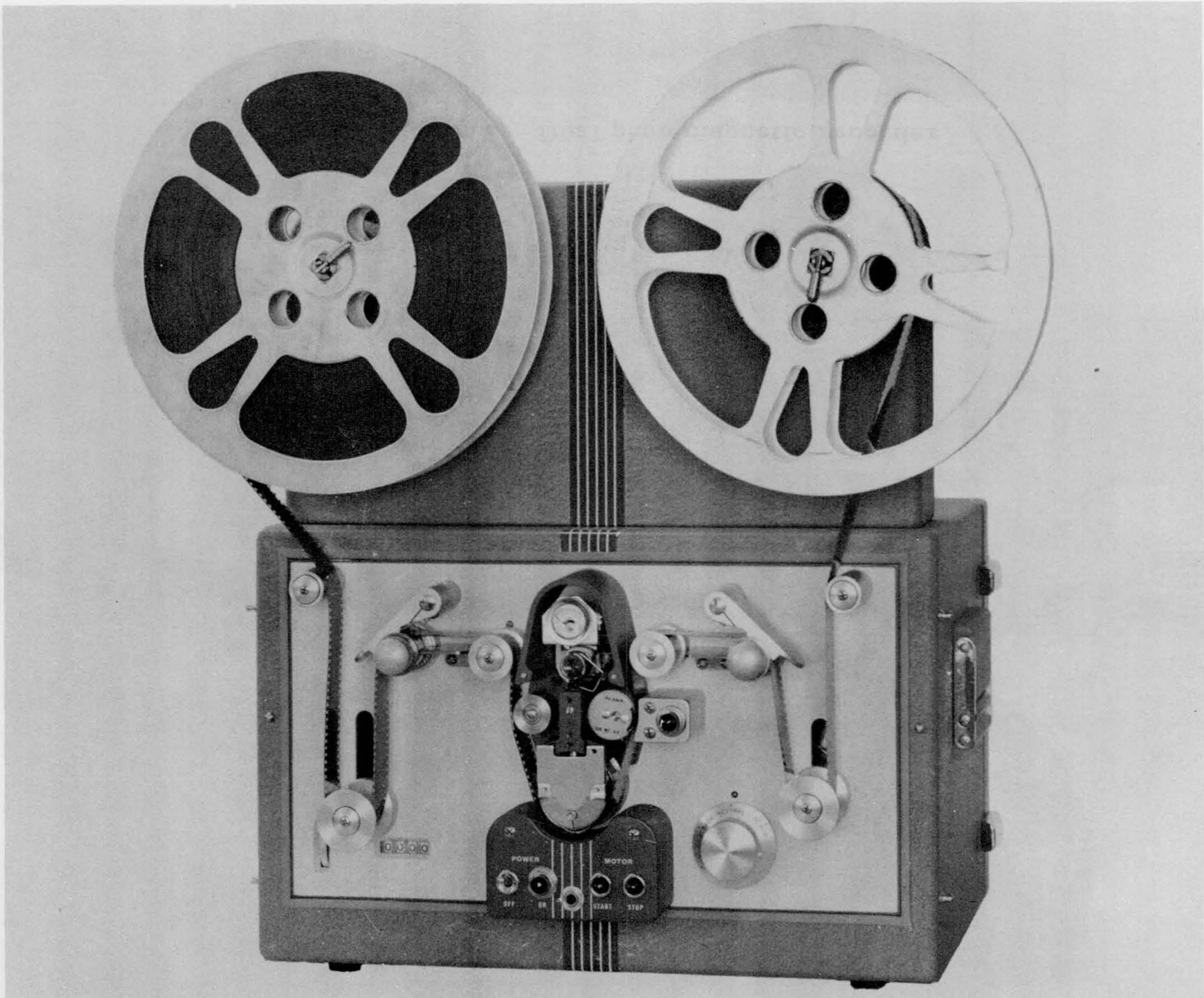

Figure 7. Magnetic recorder with front cover and cover plate removed.

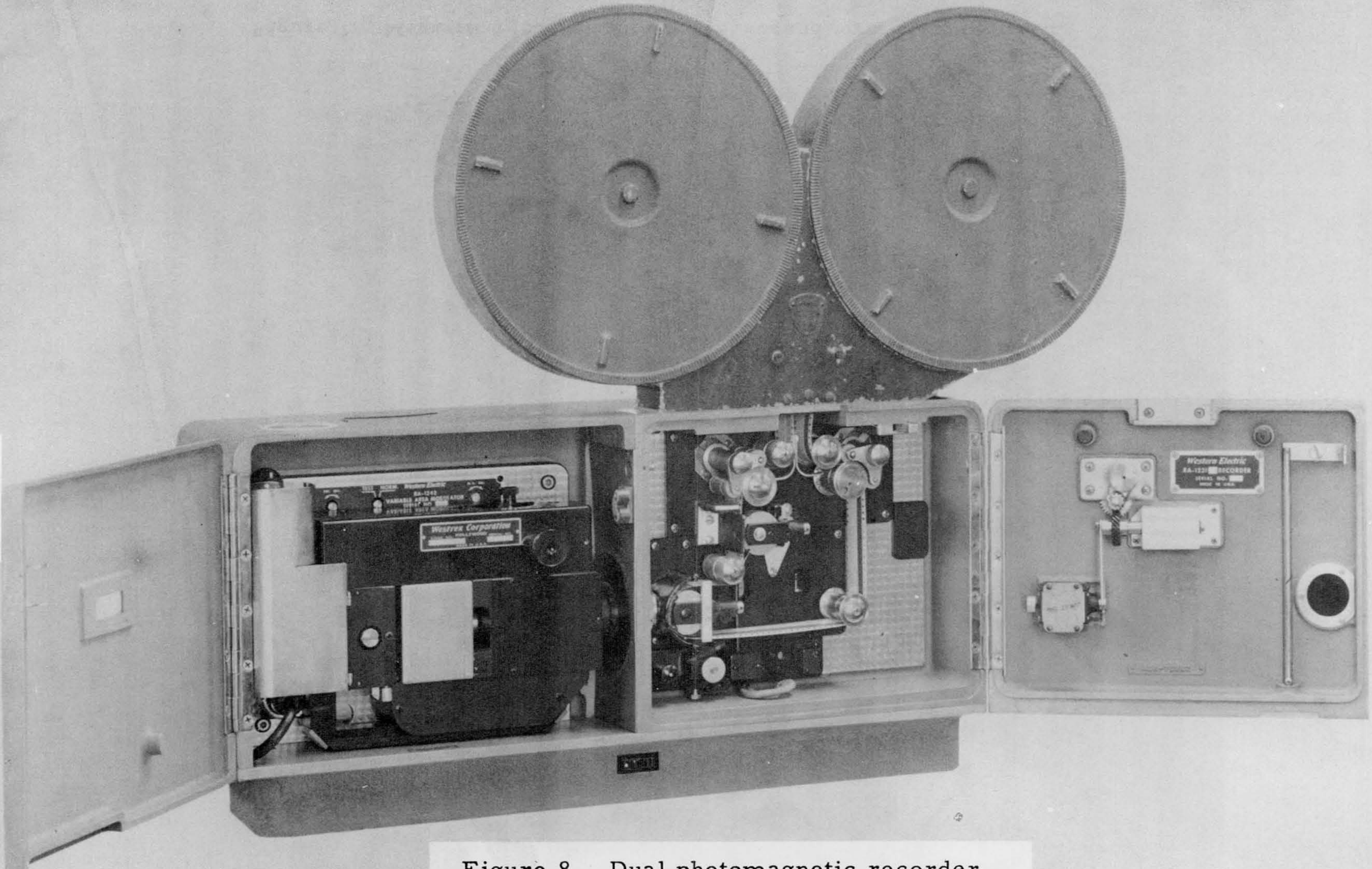

Figure 8. Dual photomagnetic recorder.

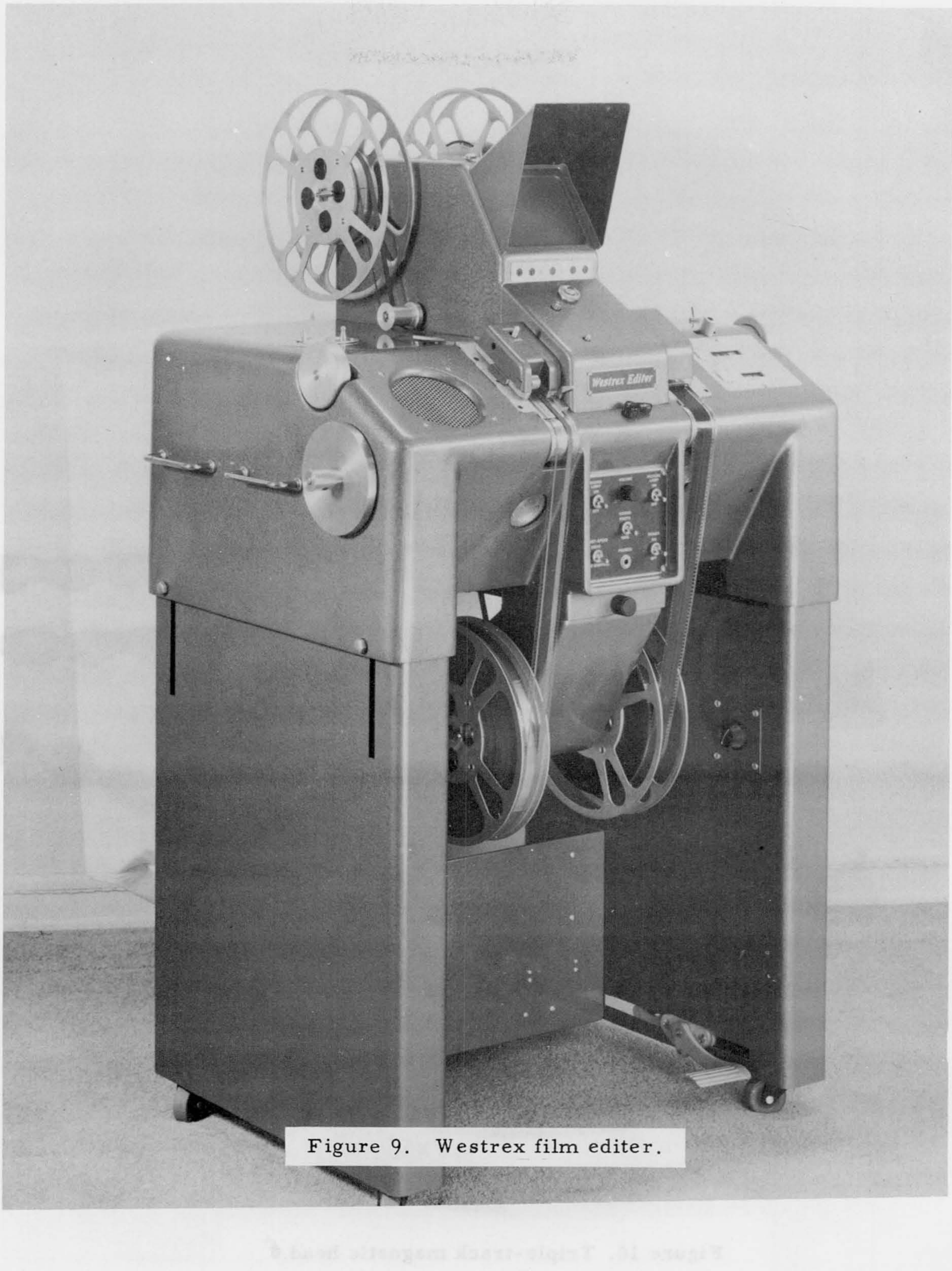

Figure 9. Westrex film editer.

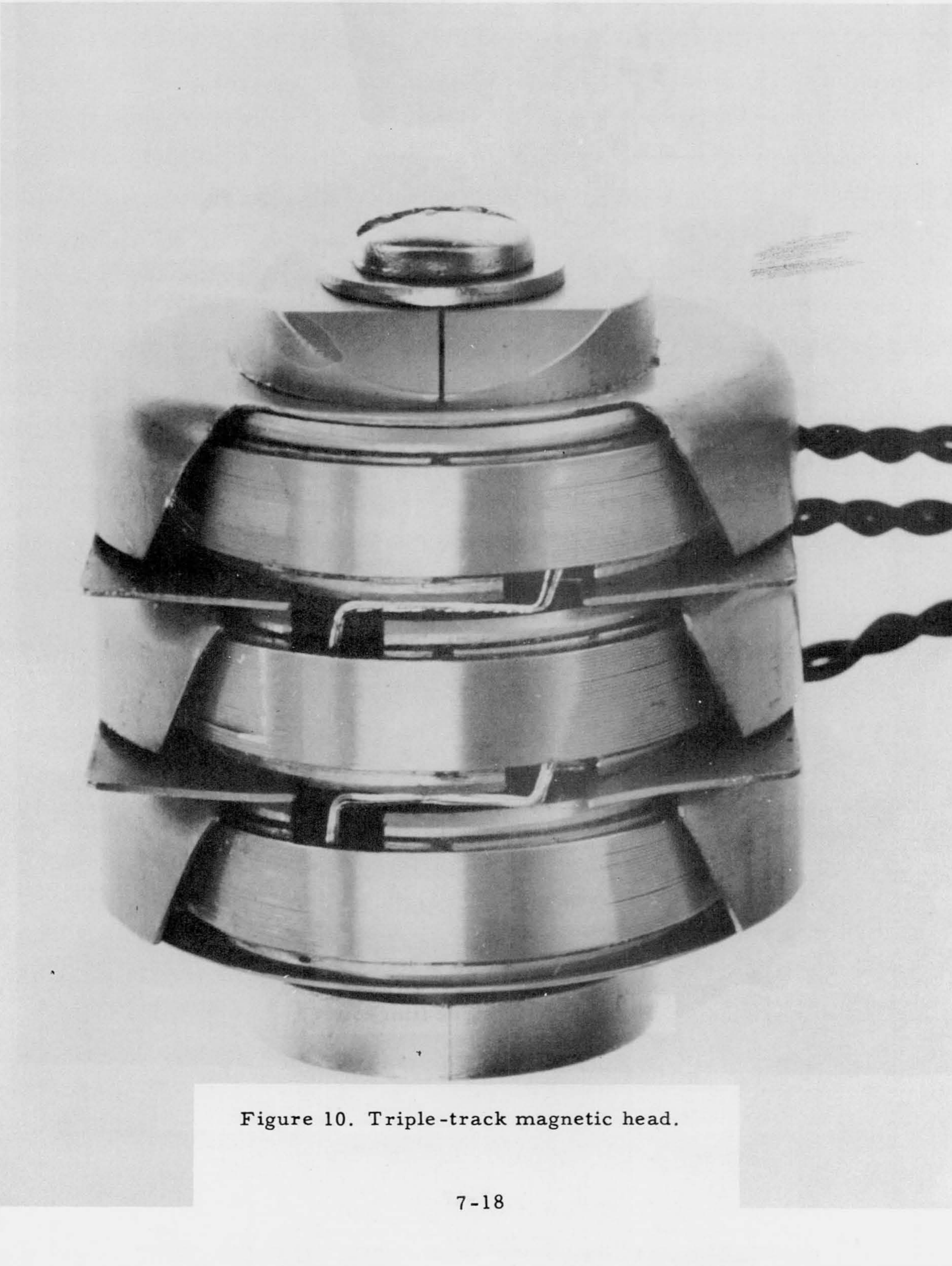

Figure 10. Triple-track magnetic head.

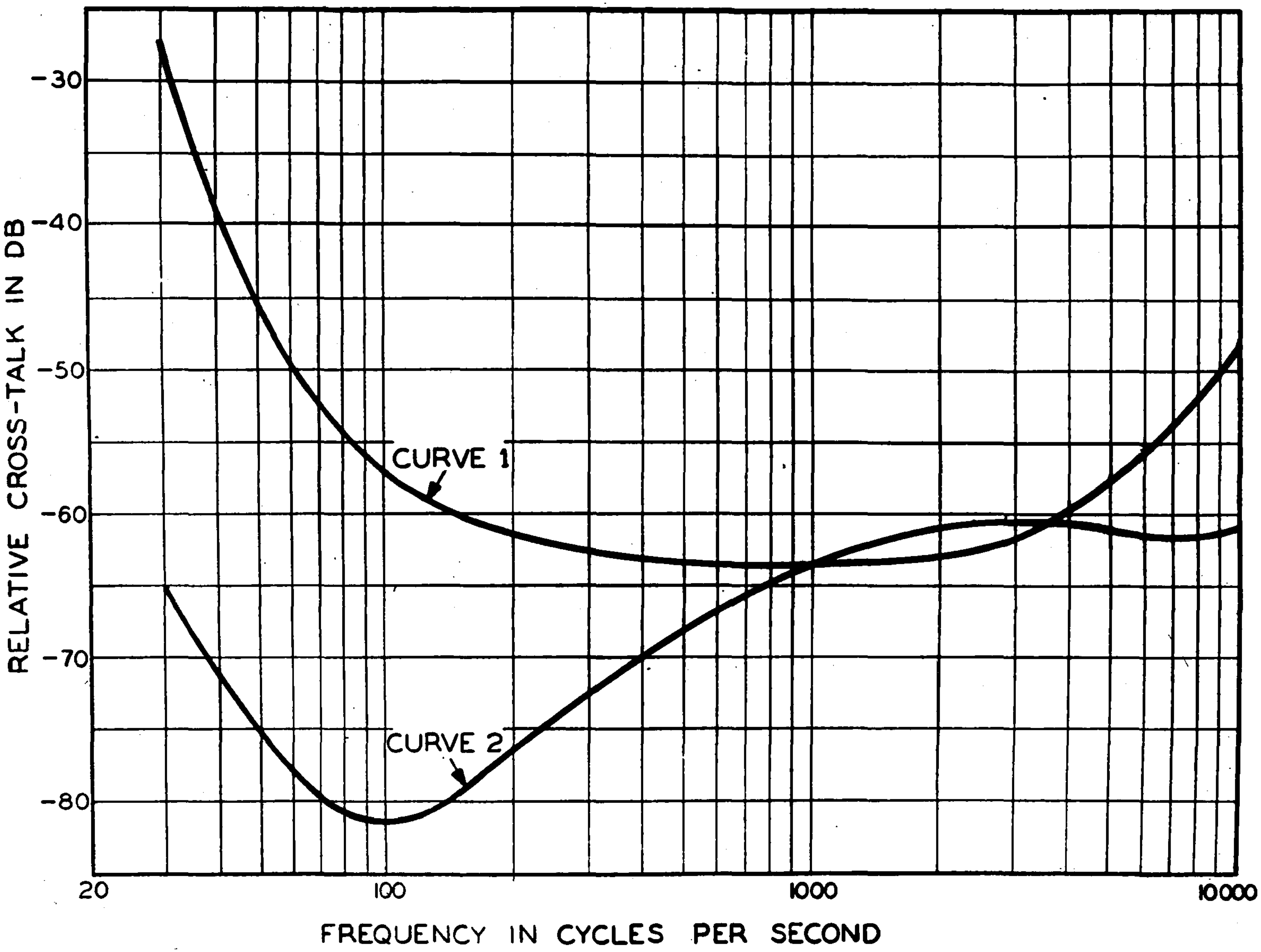

Figure 11. Crosstalk as a function of frequency.

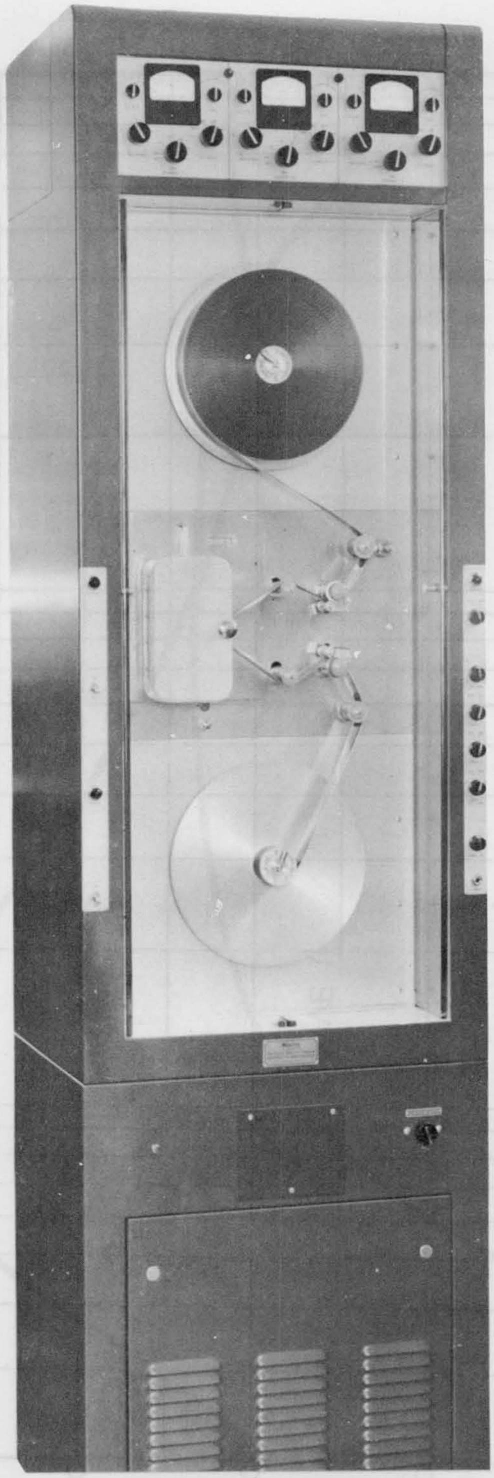

Figure 12. Triple-track recorder.

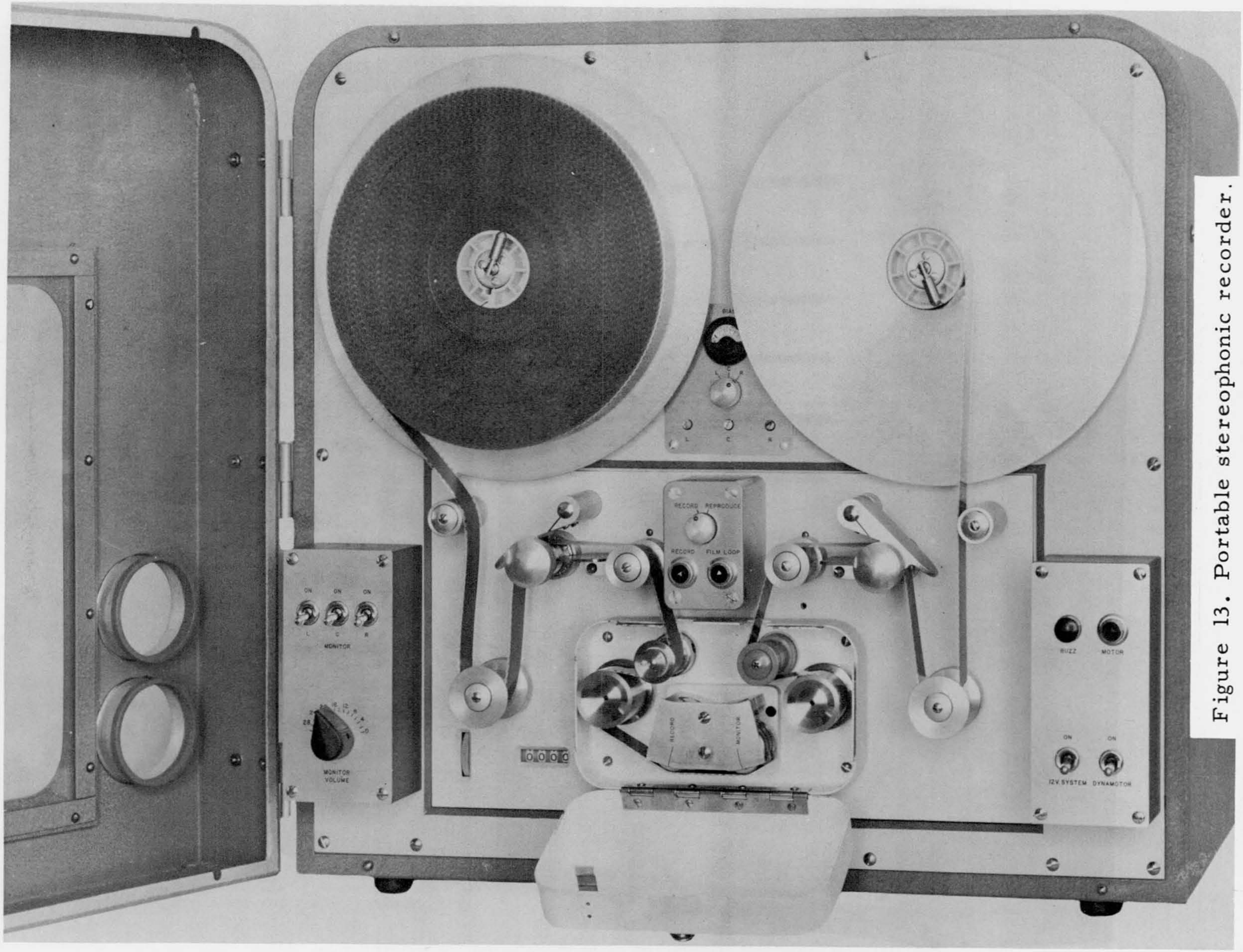

Figure 13. Portable stereophonic recorder.

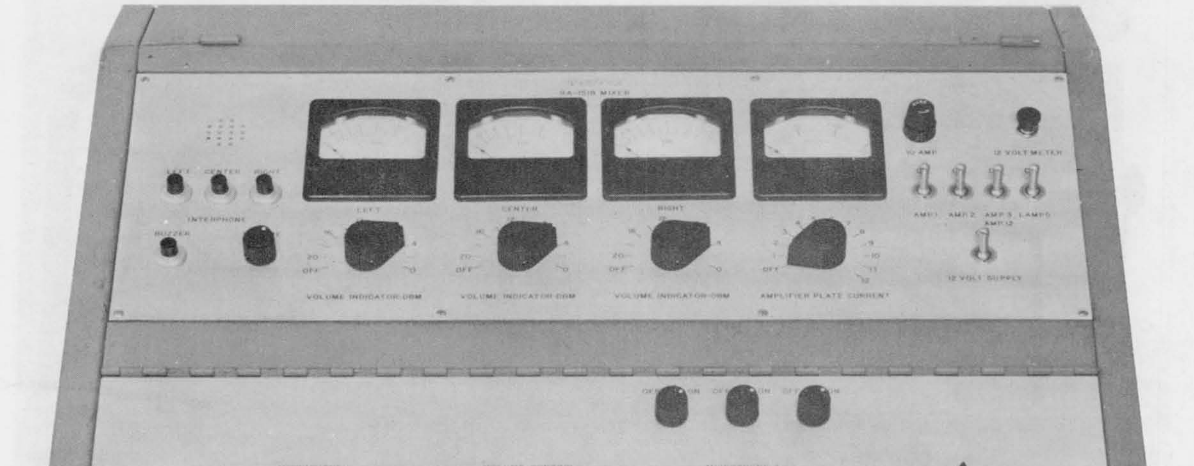

Figure 14. Stereophonic mixer.

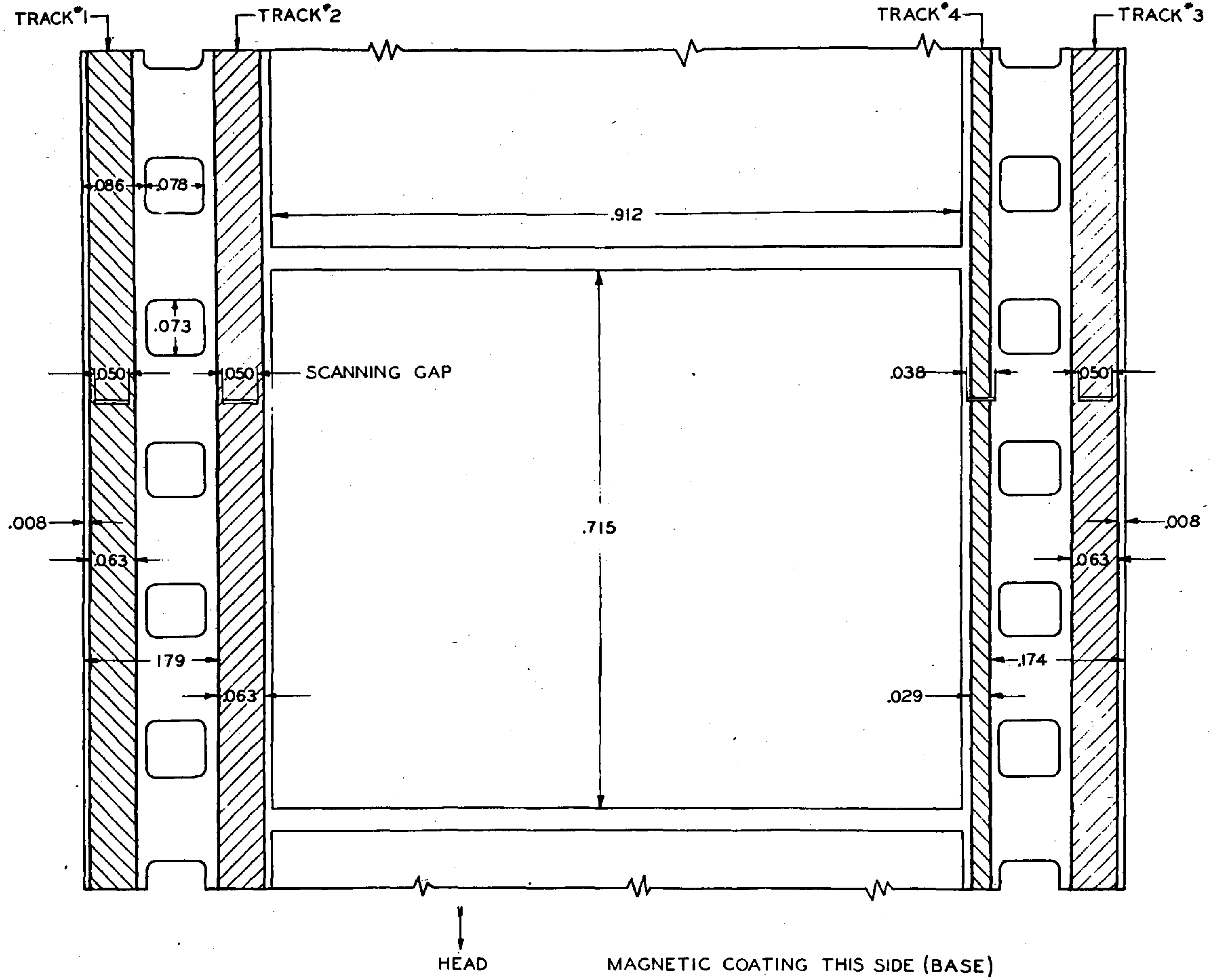

Figure 15. Proposed standard for Cinemascope sound track.

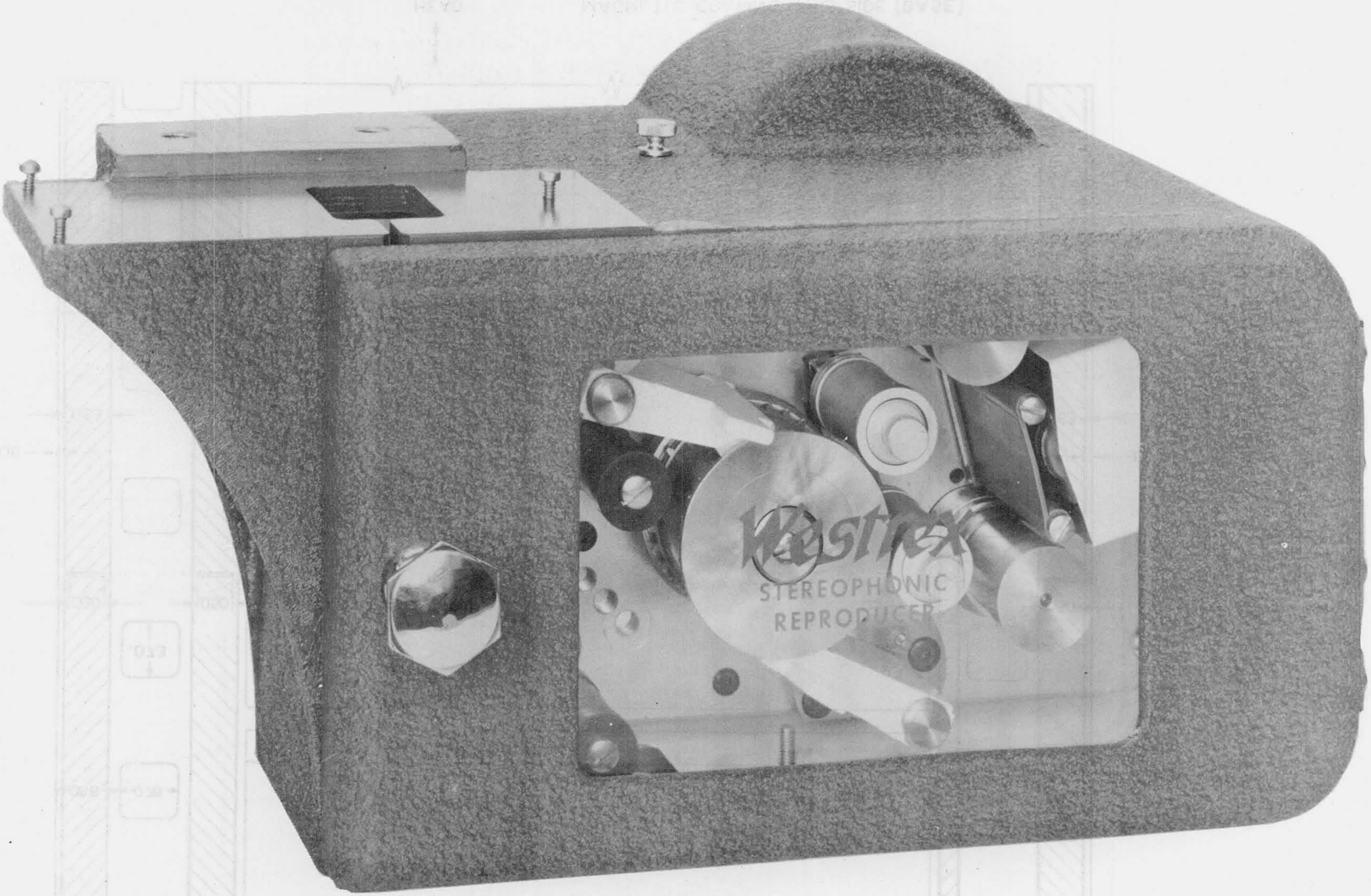

Figure 16. Theatre reproducer for Cinemascope film.

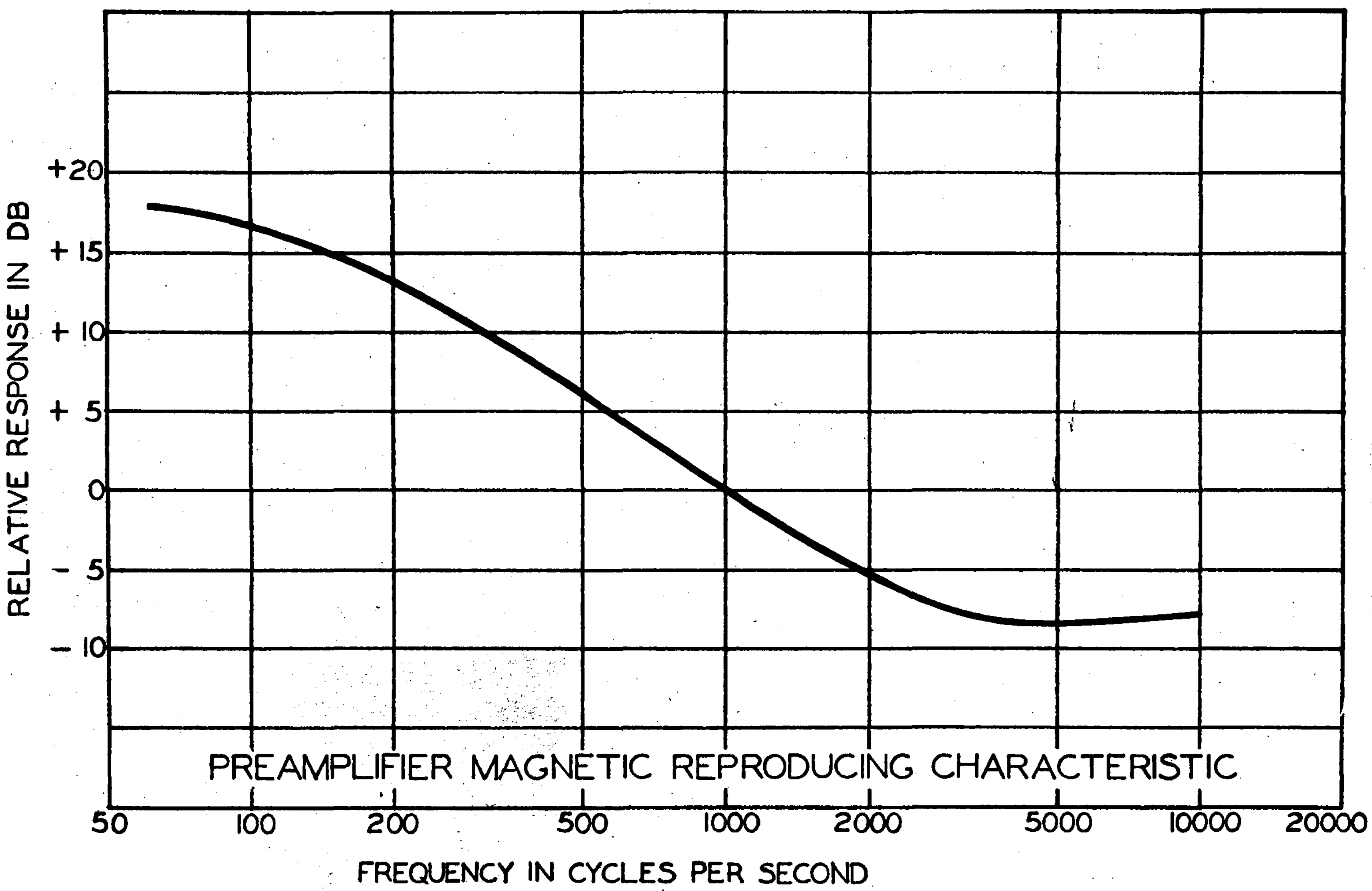

Figure 17. Pre-amplifier magnetic reproducing characteristic for Cinemascope sound track.

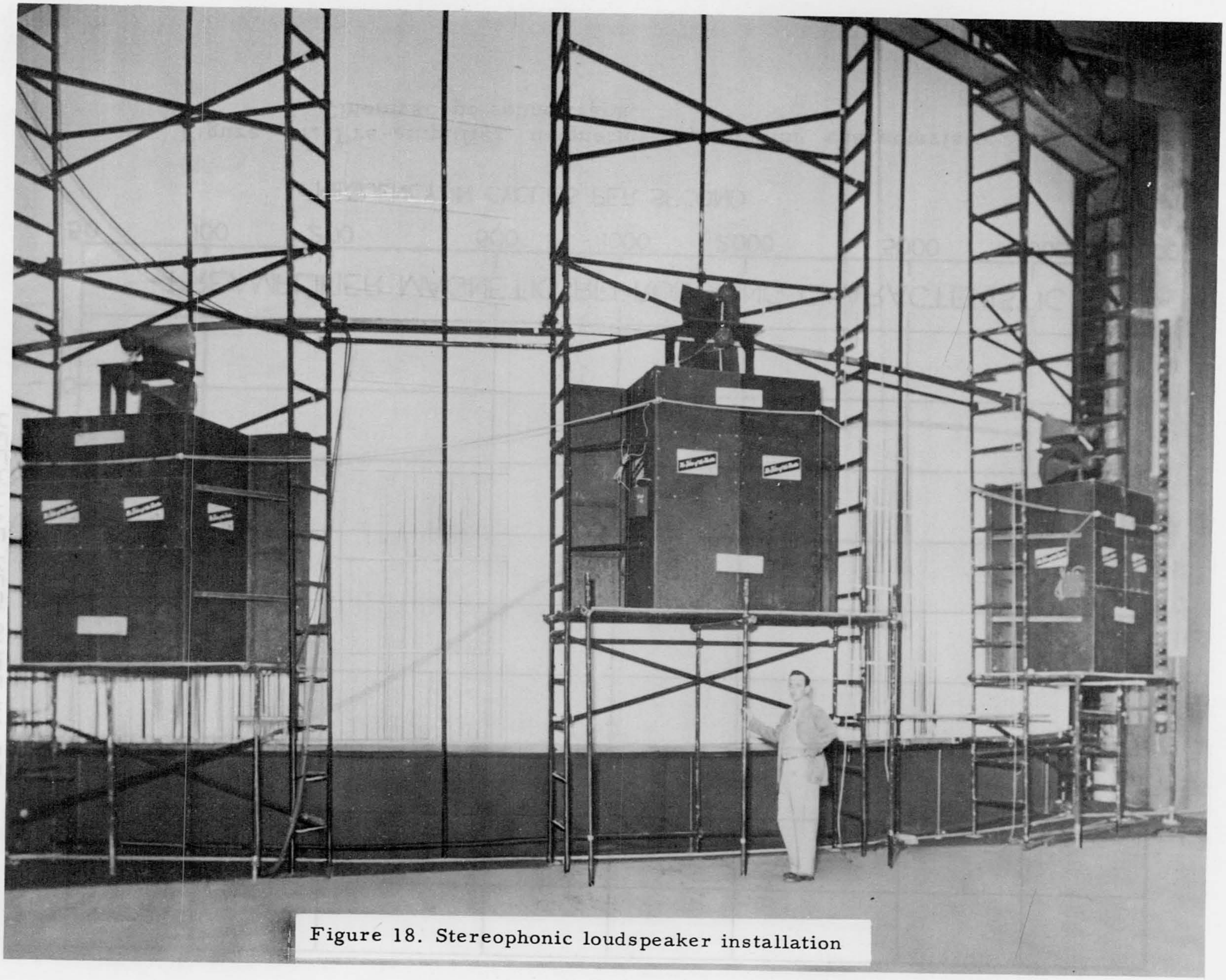

Figure 18. Stereophonic loudspeaker installation

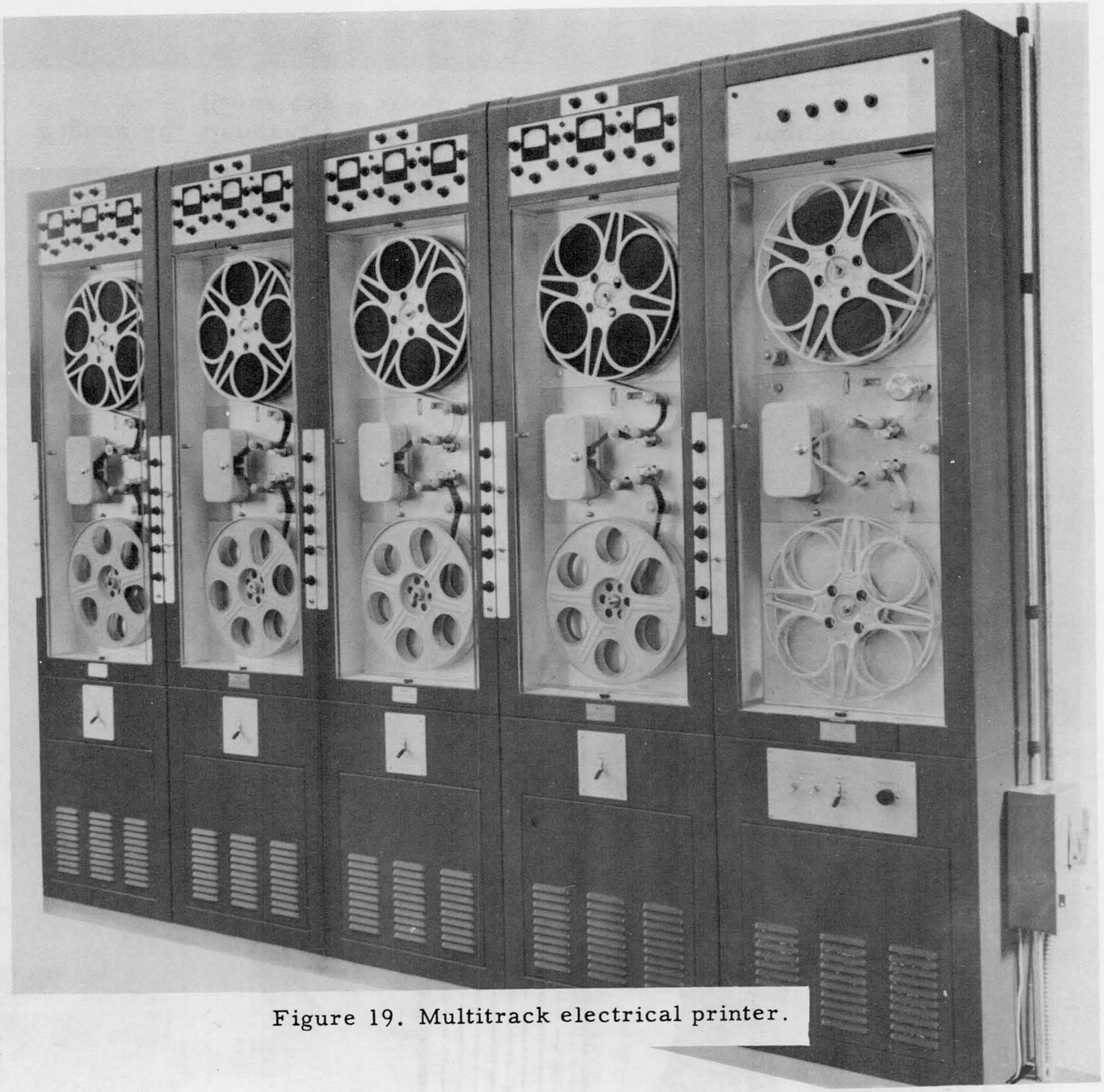

Figure 19. Multitrack electrical printer.

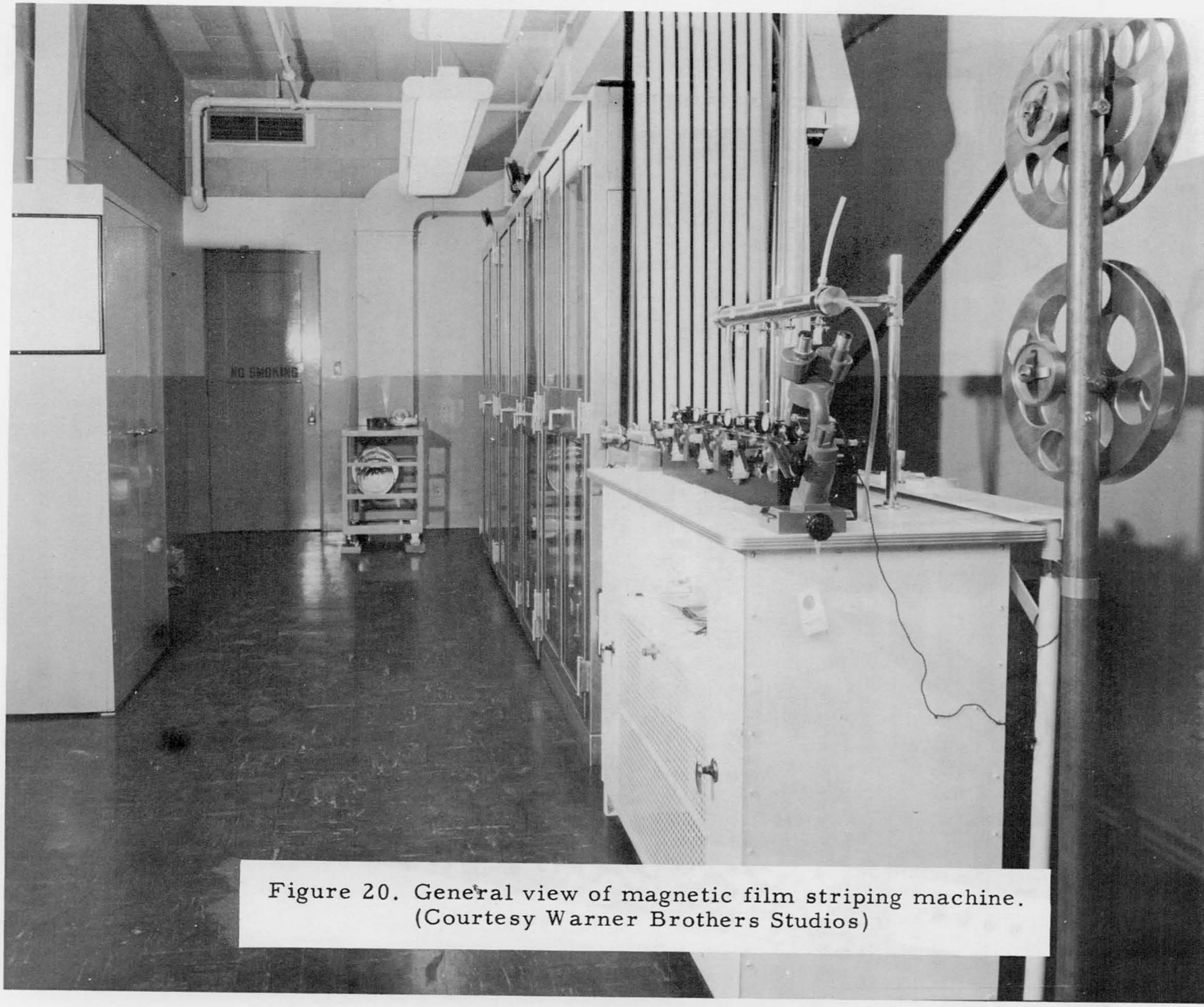

Figure 20. General view of magnetic film striping machine.
(Courtesy Warner Brothers Studios)

PAPER No. 7

DISCUSSION SUMMARY

(This includes answers supplied later by Dr. Frayne)

Mr. Witt of International Business Machines, referring to the narrow tracks on Cinemascope film, asked for a comparison of the signal-to-noise ratio on the .029-inch track with .038-inch head as compared to the ratio on the .063-inch tracks scanned by .050-inch heads. Dr. Frayne has advised that the change in the signal-to-noise ratio is proportional to the ratio of the widths of the two tracks, or about 4 db. Mr. Witt also noted that the .063-inch widths for magnetic coating and the .050-inch playback scanning width allowed .013-inch for errors in tracking due to inaccuracies in film slitting, edge guiding, and shrinkage. He asked if this was sufficient safety factor to prevent the edge of the tracks from weaving inside the end of the playback scanning slits. Dr. Frayne has noted that any irregularities in the coating on the narrow track probably do affect the overall signal-to-noise ratio. However, since signal-to-hum ratio on magnetic tracks is the usual dominating factor he believes that hum is a limiting factor on any of the four tracks. He did not believe the trouble mentioned has been found in properly lined-up heads and also mentioned that only a 50 mil width is scanned of the 60 mil coating. This gives a little more tolerance.

Mr. George Lewin, Signal Corps Pictorial Center, felt that in the New York area, at least, the use especially by independent producers and television outlets, of quarter-inch tape with synchronous control was more widespread than generally realized. The Signal Corps uses both the high frequency (14 kc) type of control track and the 60 or 120 cycle low frequency type of control track, and felt that both systems were fairly successful and reliable. Dr. Frayne clarified his point to say that he did not imply that synchronized tape is not being used, but that there is comparatively little use of it in the motion picture industry as a whole.

Mr. Ben Bauer of Shure Brothers, Incorporated, asked about the problem of headwear and the extent of improvement being made by the use of ferrite heads. Dr. Frayne advised that until recently there had been no real experience with long life tests of magnetic film on heads in theatres. There is several years of experience with magnetic wear on magnetic heads in studio recording equipment where the magnetic heads are well maintained and cleaned and the film is kept in good condition. Under these conditions, useful head life has corresponded to running lengths of film up to five million feet. After this point, there is a noticeable dropoff in high frequency response. This can be partially corrected by adjusting the bias current in the recording system.[12] There is very much interest in the work that Dr. Wetzel of Minnesota Mining is doing on the development of ferrite heads. Dr. Frayne feels that a long wearing material of this type is the only answer to commercial use of magnetic recording in theatres where films are run daily on an almost continuous basis.

Dr. Begun of Clevite-Brush Company felt that the present Cinemascope multiple track arrangement required a very high degree of control and accuracy not only to maintain heads in proper contact and azimuth but to prevent undesirable phase changes in the relation of sound output from the various channels.

Dr. Frayne noted the activity of the Clevite-Brush Company in production of magnetic heads and assumed that Dr. Begun would be well versed in this problem. He said there is no question but that a very accurate degree of alignment is required

[12] Singer and Rettinger, "Correction of Frequency-Response Variations Caused by Magnetic Head Wear," Jour. SMPTE, 61, July, 1953.

when one has to scan tracks that are located all the way across 35 mm. film. The azimuth alignment on each particular track presents no serious problem due to the extremely narrow widths of track employed. However, in the case of stereophonic reproduction, the misalignment caused by the advance or retardation of any one gap relative to another should probably not exceed one-half a wave-length of the shortest wave-length being reproduced. Thus, for reproduction of 9,000 cycles, which has a two mil wave-length on 35 mm. film, a misalignment tolerance could not be greater than one mil or we might get cancellation from the same modulation on two adjacent tracks. In lining up the heads, every attempt is made to get uniform contact on all four tracks. This is difficult due to the fact that it is almost impossible to keep 35 mm. film perfectly flat. This problem was the one that had the greatest influence in deciding to mount the sound head on top of the projector so that the magnetic film could be scanned before the film had been subjected to the intense heat of the arc as it passed through the projection machine. It is a well-known fact that film is much flatter before it enters the arc than after it leaves. However, even with this arrangement, it was necessary to increase the tension in the film path to scanning point to about 500 grams to get satisfactory contact. Another important factor is the angle of wrap which the film makes around the magnetic heads. If this is too great, excessive polygonning results. If it is too small, poor contact results. A maximum wrap of about 20° seems to be indicated.

Mr. Marvin Camras of Armour Research noted the contrast between film recording response requirements of the order of 7500 cycles at 18 inches per second and the efforts of some in tape recording at getting 18,000 cycle response at 7 1/2 inches per second. He also noted the concern of some film processing laboratories that their processing solutions, especially those for color film, may be spoiled if film with magnetic sound tracks is passed through the solutions. Dr. Frayne noted that in the Cinemascope process the picture is printed first, and the magnetic striping is done last, so there is no question of the photographic film solutions being spoiled in any way by the presence of the iron oxide.

Paper 8

BASIC MECHANICAL CONSIDERATIONS FOR TAPE TRANSPORT SYSTEMS

Mr. O. C. Bixler

Director of Engineering
Magnecord, Incorporated

9 October 1953

ABSTRACT: It is believed that technical papers have generally overlooked the vital importance of the design considerations concerning the mechanical components of magnetic recording systems. This paper describes the intricacies of the design problems covering all the mechanical components necessary for uniformly controlling the translation of magnetic tape past the erase, recording, and reproducing points. Details are also discussed concerning the electrical and mechanical control systems necessary to allow flexible and precise operation and remote control of the tape handling mechanism. The tape is followed from the pay-off reel entirely through its path until it is once more wound up on a take-up reel. Both design and practical considerations of each component element which handles the tape are discussed.

General Design Objectives

The object of this paper is to discuss all the component elements in the tape path which contribute to the tape handling and to the characteristics of the recording which are dependent, to a great extent, upon the mechanical tape transport unit.

The objective of the design of a mechanical tape transport is to provide means of storage for magnetic recording tape both before and after recording and to translate the tape uniformly at a controlled and even speed past a point where the tape may be erased, recorded, or reproduced. An additional design objective is to provide such flexibility of mechanical design as to allow fully automatic control when desired, and to incorporate safety features and means for remote control. The result of the mechanical design should yield safe mechanical and environmental conditions for the magnetic recording medium.

General Mechanical Configurations

One of the usual tape transport configurations is shown in figure 1 as a bare panel view, and in figure 2 as a completed unit. The tape pays off from one reel, passes over a non-rotating alignment guide, which is combined with a spring loaded compliance arm, then passes over a tape stabilizer roller before being fed to the head assembly where the erasing, recording, and reproducing are done; following the head assembly, the tape is pulled and its motion metered by passing between the capstan driven at a constant speed and a pressure roller with a rubber rim; following the capstan tape puller, the tape is fed over another non-rotating tape guide combined with a compliance arm and fed to the take-up reel.

In some tape machines, the capstan is placed at the input to the head assembly. Either arrangement may be used except that it is believed some inherent advantages accrue in having the capstan beyond the head assembly as follows:

(1) Should the tape break beyond the capstan or should the tape take-up reeling mechanism fail, the recording may be safely made even though the tape piles up on the floor. A floor pile up of tape may be readily cleared by reeling the tape up carefully without disturbing the pile. (2) A faster start is possible with a tape puller. The pressure roller may be engaged with the continuously moving capstan, thereby bringing the tape from standstill up to its normal speed in less than a tenth of a second.

The compliance arm following the tape puller is used to take up the momentary starting slack until the take-up reeling mechanism has a chance to get started. Some machines use a transient surge of power in order to overcome the reel starting inertia and to prevent throwing a tape loop during the starting period.

Tape Storage Mechanisms

The most usually used form of tape storage is that of a simple reel. Other means of storing tapes are: (a) By passing the tape over a number of spools which may be distributed about a panel. (b) By feeding the tape into a tape tank just wide enough to receive the tape and within which tank the tape makes a number of folds back and forth upon itself. The tape is usually fed from the top and pulled out from either the side or bottom of the tank. (c) Spiral endless loop device where each layer of tape slides on the adjacent layer.

These devices are utilized in endless loop service wherein it is not required to store the length of tape required in the usual recording operations. Their application is limited to tape lengths of several hundred feet.

Tape Reeling Mechanisms

The storage of tape on reels is the usual mode of operation in most recorders. Nationally, we have standardized upon 7", 10-1/2", and 14" diameter spools. It is to be noted that the position of the drive slots in the reels have been the subject of tacit national standardization in order to obtain reels which are interchangeable between tape machines. The most common tape width is, of course, 1/4" at the present time.

In the usual design of tape handling mechanisms a spindle is provided with a fixed flange onto which the tape reel can be slipped. The reel spindle is usually mounted on some sort of bearing assembly behind the front panel of the recorder and may be attached directly to a torque motor shaft to save the cost of extra bearings. The spindle shaft is controlled in one of several ways in order to put either back or forward tension upon the tape for pay-off and take-up reels respectively. This holds the tape taut with from two to eight ounce tape tension so that it does not flop loosely over the recording heads.

There are three basic reeling control means in use at the present time: (1) Friction disc clutches which are adjustable in order to control the spindle drag and consequently the tape back tension. The usual felt-to-brass clutch is designed from the formula $T = FN \frac{(r1 + r2)}{2} \mu$

where T = torque

F = axial force

N = number of clutch surfaces

μ = coefficient of friction = .3 for felt against brass

r1 and r2 = the inner and outer clutch radii

(2) Torque motors, figure 3, operating at full voltage during high-speed reeling and at reduced voltage during normal forward operation of the machine in order to provide both back torque and forward take-up torque; motor braking for the pay-off reel may also be applied by means of energizing with d-c.the windings of an a-c motor; (3) By means of servo controls operating through servo motors or magnetic clutches. These latter are the more elaborate and costly systems, and operate through sensing tape tension and correcting the reel torque accordingly. These schemes have been used to obtain essentially constant tape tension.

It is to be noted that in the first two of the three control modes mentioned above, constant torque rather than constant tape tension is obtained. It should also be noted that the true design objective is to obtain constant tape tension over the magnetic record/reproduce heads, and thus maintain a minimum disturbance to the capstan pull so that minimum flutter or wow result. The tape tension force F is related to the torque, of course, by the simple formula:

$$F = \frac{\text{Torque}}{\text{Radius of tape pay-off}}$$

Since the torque is essentially constant with either torque motors or any other good constant torque device, it will be seen that the tape back tension varies as the ratio of the outer reel to the tape hub diameter. The tape back tension desired is usually in the neighborhood of two to eight ounces and the tape take-up tension about six to 20 ounces. Typical torque motor curves are shown in figure 4.

In most commercial tape reels today, an effort has been made to minimize this diameter variation. Maximum to minimum tape pay-off ratios are now usually held to approximately two to three, although a few years back this ratio was as high as five (figure 5). To date, no really satisfactory simple automatic mechanical device has been devised to compensate for this diameter change. In the motion picture industry, where large diameter ratios and heavier, wider "tape" are used, tape follower arms have been installed which continuously measure the diameter of the reel and adjust the reel torque accordingly to obtain essentially constant tape tension. When 1/4" wide tape is used, mechanical clearances are such that this device is tricky to use. The fragile nature of the 1/4" wide tape only .002 thick also militates generally against the use of the mechanical follower arm. Devices depending on the weight of the tape to determine tape tension have also been used, but for only vertical operation of the machine.

High quality professional machines may use any of the three reeling control methods listed above, but it is felt that the simplest and most dependable method of reel control is through a torque motor.

When a motor is used, the torque characteristics through every degree of rotation of the motor are important since it is desired to maintain constant tape tension independent of the angular position of the reel. Some problems have been encountered in this respect since it has been found that motors may be built for "constant" running torque, but that during slow speed operation (15 to 60 RPM) within one revolution the torque may vary as much as 25 percent in extreme cases. In one investigation of a quantity of torque motors, it was found that variations in the air gap and in the electrical properties of the rotor caused motor torque variations within one revolution as shown in figure 6, Curve A. In a cooperative program with a motor manufacturer, this torque variation was reduced to that shown in figure 6, Curve B. The effect of the high torque variation was to insert a flutter rate, which is to say, a tape speed variation rate in the order of one or two cycles per second. Reduction of the torque variation was sufficient to improve recorder performance appreciably and to allow other tape handling elements to further improve the constancy of tape speed.

Tape Stabilization and Motion Filtering

The tape stabilizers located on either side of the head assembly form a portion of the filter system which prevents any reeling or reel mechanism irregularities from affecting the smoothness and straightness of tape travel over the heads in order to hold flutter and signal drop-outs to a minimum while maintaining adequate tape wrap around the head gap magnetic structure to obtain good low frequency response. These stabilizers take the form of flywheel loaded pulleys over which the tape passes. The tape wrap around these pulleys must be made sufficient so that, with the tape to pulley surface coefficient of friction, no slippage can occur in normal operation. Further, one of these inertia or flywheel loaded pulleys (preferably the one following the heads) is utilized as the main tape drive element and is therefore designated as the capstan which is motor driven either directly or through some speed reducing means. Both the stabilizer roller and the drive-motor-stabilizer assembly require close tolerance precision honed-oilite (± .00015 dia. tolerance) or precision ball bearings. It becomes of importance to remove heavy flywheels during shipping in order to avoid Brinelling of the bearing races or bending of the flywheel shafts, which could cause flutter later.

Typical tolerances on a capstan with a nominal diameter of .2367" moving at 600 rpm to achieve 7-1/2" per second tape motion are as follows: diameter tolerance ± .0002; run-out tolerance ± .00005. Such accuracies assure 7-1/2" per second tape speed flutter below 0.15 percent and tape timing with an accuracy of ± 3 seconds in one-half hour of recording. The other flywheel loaded pulley is driven by the tape itself.

If a-c torque reeling motors are used, it is the usual thing to expect a certain amount of 60 cycle and 120 cycle hum to appear in the tape tension. The stretch or compliance of the tape between the tape reel and the spring loaded compliance arm acts with the tape stabilizer inertias to absorb this 60 cycle and 120 cycle variation in tape tension, and to completely eliminate this effect from reaching the head recording area.

Examining the tape, the tape compliance arm, and both stabilizers as a filter, it may be said that we have a low pass filter. It is desirable to push the filter cut off down to as low a frequency as is practicable, considering the physical size of the flywheel used in the stabilizer. This is desirably below one cycle and in practice can be easily held to about 1/4 to 1/2 cps. An illustrative calculation follows:

Considering the pay-off reeling mechanism, both stabilizers and the first compliance arm for a practical case, we then have:

$$F_R = \frac{1}{2\pi\sqrt{IC}} \quad \text{and} \quad C = \frac{\phi}{F}$$

where

F_R = low pass filter resonance (near cut off) frequency in c.p.s.

I_1 = tape driven stabilizer rotary inertia

$= \frac{wt}{2}(R^2 + r^2)$

$= 2.47 \times 10^{-4}$ slug ft^2

I_2 = motor driven stabilizer inertia

$= 2.25 \times 10^{-3}$ slug ft^2

C = equivalent arm compliance

ϕ = arm deflection in radians = .75 radians

F = arm deflection torque = $\frac{1}{192}$ lb ft

Then for the tape driven stabilizer:

$C = .75 \times 192 = 144$ radians per lb ft

$$F_{R1} = \frac{1}{2\pi\sqrt{.000247 \times 144}} = 0.85 \text{ cps}$$

This cut-off frequency filters out the 60 cps and 120 cps flutter components. The tape couples the motor drive stabilizer to the driven stabilizer so that even lower frequencies are filtered out by the combination of both stabilizers:

$$F_R\,(1+2) = \frac{1}{2\pi\sqrt{(.000247 + .00225) \times 144}}$$

$$F_R\,(1+2) = 0.267 \text{ cps}$$

This last value is very satisfactory. The actual mechanical arrangement and simplified electrical analogue is shown in figure 7.

Present day professional tape recorders are capable of maintaining flutter between 0.05 and 0.3 percent. The weather may actually enter into the flutter performance of the tape recorder, since stickiness of the tape affects its travel over the heads and other elements in the tape path. Tape is both thermoplastic and humidity plastic. Sticky tape may cause chatter, which is to say variable speed or flutter.

Tape Drives

Over the years that recordings have been made on a moving medium, various driving methods have been used. The modern tape recorder draws from all previous experience and knowledge and has used many various drives and speed reducers. Since for speeds below 600 rpm, overly large motors are necessary, it is desirable to have the drive motor running at 600 rpm or some speed in excess of 600 rpm. A speed reducing scheme is then normally used in order to obtain adequate capstan torque and the low speed from a small drive motor. Standard motor speeds used have been 600, 900, 1200, 1800, and 3600 rpm. General practice has established about five pounds available capstan pull to do a satisfactory tape driving job. The actual average pull on the tape is much less than this, about six to eight ounces.

For a professional or industrial type recorder, it is usual to select a synchronous drive motor in order to minimize actual tape speed errors. Since tape has no sprocket holes to eliminate slippage, the design philosophy is to make all other parts of the drive mechanism as accurate as possible, thus making the major speed error that of the actual physical tape slippage itself. In the smaller fractional horsepower ratings a straight synchronous motor is not too efficient insofar as physical size, starting torque, and running torque are concerned. Therefore, the trend has been toward the use of hysteresis synchronous motors in designing these mechanisms. Hysteresis synchronous motors have the drawback of running hottest when lightly loaded, thus making heat dissipation a problem.

Speed reduction methods that have been used are: (See figure 8.) (a) Gear reductions with their usual complications of gear tooth modulation and worm irregularity modulation. These effects can be minimized in design by the use of helical gears and by using multiple thread worms. Gears and worms are difficult to handle, insofar as flutter elimination is concerned, because they generate low frequency flutter which most easily passes through the low pass filters discussed previously under Tape Stabilization and Motion Filtering.

(b) Puck speed reducing systems, where a rubber rimmed puck reduces the speed between the motor shaft and a driven hub, which in turn directly drives the capstan and reduces the motor speed in the ratio of approximately the drive motor shaft diameter to the drive hub diameter. This puck reduction in speed must be corrected for an error which is the result of the difference of indentations in the rubber puck by the drive motor shaft, and the larger driven hub shaft. The puck is maintained at the normal puck optimum wedge angle of 114°. This angle is that which is subtended by the driven hub and motor shaft with the puck hub considered as the apex of the angle. Absolute looseness of the puck support is essential in order to assure self-centering action with its resultant uniform drive. Some recorders use two parallel pucks in order to assure uniformity of drive. A special form of puck may be used which is essentially a rim drive. The puck effect is obtained by putting a rubber rim around the driven hub and resting the drive motor shaft against this rim. An alternate system is to place a small rubber drive tire around the motor shaft, which in turn rests against a solid driven wheel. This latter configuration is not as satisfactory as the others because the speed error is greater in this case due to the rubber indentation in the small motor roller causing a greater error than a similar size indentation in a larger driven hub.

(c) A toothed compliance belt, which is an efficient and accurate speed reducing means, but which produces flutter within itself at both the belt rotation rate and the belt tooth rate. It is then necessary to utilize a mechanical filtering system beyond the driven hub to eliminate these two flutter rates. This system is somewhat more complex and more difficult of deriving satisfactory results than those previously mentioned.

(d) An endless woven flat belt; due to the compliance of such a belt, this method is ideal insofar as eliminating flutter components which might come from the motor. However, because of the vagaries of woven materials and because of belt slippage, the belt drive average speed control is not as precise as some of those previously mentioned. In the usual professional machine wherein high accuracy of tape timing is desired, it is then necessary to evolve a more complicated drive speed control system wherein servo elements are used to control or meter the tape. This is usually handled through recording of a standard control frequency on the tape so that when it is played back, the reproducer can be controlled to play with exactly the original timing. This standard recorded control signal has taken the form of superimposed 60 cycle modulation, a high frequency carrier 60 cycle modulated, and printed patterns on the reverse side of the tape from the oxide surface.

(e) A direct drive system wherein the tape is driven directly by an accurately ground area located on a shaft extension of the motor. This is perhaps the simplest accurate drive system possible, but requires careful design in order to reduce the flutter effects caused by shaft run out, bearing and housings tolerances, and vibration due to being directly coupled to the motor. This design is capable of good results if as low a speed motor as is practicable is used to prevent reducing the tape drive diameter of the capstan to too small a physical size. Experience has shown that diameters below approximately 0.2 inch should not be used. Too small a drive diameter is not only physically weak and subject to bending to cause flutter, but should any oxide deposits from the tape build up on the capstan, their effect in speed deviation (once per capstan revolution) is greatly exaggerated.

Tape Guidance

Proper tape guidance first assures uniform wind on both take-up and rewind reels, Secondly, it assures the tape of a uniformly straight linear motion with no snaking or side to side motion over the heads. Since 1/4" tape is normally held to slitting width tolerances of +0 -.002 inches, it is seen that the slot or guides which control the tape movement from side to side may be fairly accurate. Too much control, that is to say, too tight a pressure on either side of the tape will result in tape buckling so that an added means of flutter could be induced on a machine or poor tape contact with the heads might be obtained.

It is usual to establish the compliance arm tape guides to control reel winding and in addition to use some means in the head area to achieve control over the tape movement from side to side. Tape slither or skating from side to side causes the tape transverse axis to no longer be parallel to the longitudinal axis through the head area (to which the head gaps are aligned at 90° during the so-called azimuth alignment). This, of course, results in momentary head to tape misalignment so that high frequencies are not reproduced at normal amplitudes. In some cases where tape is not properly controlled, the high frequency output near the upper limit of the tape recorder may vary as much as 20 or 30 db. This amplitude variation should be held to one or two db at the most. Surface and contour squareness of recording heads, pulleys, guides, etc., are critical in order to minimize tape skating.

Control Features and Miscellaneous

The control features of a recorder are aimed at making all conditions of tape travel as automatic as possible so that they are completely controlled by the transport with a minimum of control effort expenditure by the operator. Thus, after loading the machine with tape, the operations of normal forward, high speed forward, and high speed rewind, should be available to the operator at the touch of a button. This requires mechanical linkages, relays, solenoids, etc., in order to provide for fail-safe operation and safe handling of the tape under all conditions without tape breakage.

Some means of keeping the tape under constant tension between the reels must be built into the machine not only in normal and high speed operations, but under braking conditions from high speed to stop as well. This requires that torque differences for all conditions of operation be established between the take-up and pay-off reels and particularly during the stopping conditions from high speed operation. This latter problem may be solved either by dynamic braking or mechanical braking of the pay-off reel at a slightly higher rate than the take-up reel.

The mechanical braking can be achieved by making use of the differential braking of a band brake. One end of the band is fixed while the other end is moved by either a mechanical or electrical device to apply braking. A fail-safe method is to operate the brake with a spring arrangement and to release it with a solenoid. This provides safe braking of the machine should the power fail, as well as providing for normal operation (figure 3.). A 180° band, felt lined, 1/2-inch wide brake of 2-3/4 inch diameter can provide a direction differential of 4 inch oz. with 7 inch oz. and 11 inch oz. total braking torque in the two directions of rotation respectively.

Another essential control feature of a tape transport is to lift the tape clear of the heads during high speed forward or rewind operation in order to save wear on the heads and tape. This may be accomplished by either solenoid or mechanical linkage operation interlocked with the forward and high speed control functions. There are two design possibilities; one is to lift the tape from the heads, during high speed operation; the other is to physically wrap the tape around the heads during normal operation and to allow it to fall away during high speed conditions. Either function is quite satisfactory.

When full solenoid control is designed into a tape transport, it is relatively easy to provide for remote control with remote lights indicating the operating state of the mechanism. Since a large amount of tape can be spoiled because of tape breakage during high speed operation and because a remote operator usually does not have direct view of the reels during normal operation, it is standard to install a "tape break" switch in conjunction with one of the moving compliance arms in order to bring machine rapidly to a stop should the tape break. With a tape puller capstan the tape break switch is installed between the pay-off reel and the capstan; this insures continuity of program should the tape fail beyond the capstan.

Mechanical and electrical interlock functions must be provided to assure operational safety so that an operator will be forced to go through the "stop" condition from "high speed" conditions. This is necessary since if the tape is moving fast when the pressure roller grips the tape against the positive metering capstan, the tape is usually broken.

An important feature which is too often not considered is the desirability of building into a precision tape mechanism adequate cooling. A blower will dissipate to the surrounding atmosphere the heat of the torque motor, drive motors, and other electrical elements. Over an extended operating time, the operating temperatures of the front panel and tape handling parts may come excessively close to the nominal 105°F upper tape limit which is set to minimize the tape stickiness unless cooling provision is included.

Conclusion

The overall design of a tape transport for a professional tape recording system is very complex, full of many compromises and special problems, involving not only design, but the physics of machine shop practice in order to turn out a device which may be manufactured readily with uniformly good operating characteristics.

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DISCUSSION

Mr. Robert W. Nichols of Boeing Airplane Company, Seattle 14, Washington, stated that their company had noticed that certain types of professional machines with clutch slipping arrangements for tape braking had more difficulty in maintaining uniform head contact for tapes of different stiffness than some machines with other methods of braking. In playing back a 10,000 cycle signal they had noticed a 2-3 db variation in amplitude which they had been able to reduce to 1/2-1 db by making their own feed reels of rather heavy design. They also noticed that the amplitude seemed to vary at a sine wave rate. Also, by choosing a more flexible tape they were able to eliminate this trouble. Mr. Nichols asked if any studies had been made to relate basic design of machines to choice of tapes.

Mr. Bixler noted that the section of his paper on torque motors and drive systems (which was shortened during his talk to save time) dealt with the steps taken in recent designs to reduce non-uniformity of braking throughout a revolution of the feed reel. He also noted that modern professional recorders usually have a compliant member between the feed reel and tape heads to reduce the effect on recording of variations in tension as the tape comes off the feed reel. Earlier designs of the band brake clutch on Magnecorders had certain limitations to the physical design of the clutch but present designs are aimed at producing uniform torque with resultant uniform tape tension.

Mr. George Lewin, Signal Corps Pictorial Center, Long Island City, New York, asked if wear on the heads during speed rewind was as serious a problem as recorder engineers had first thought, since he had heard it stated that during high speed tape travel a layer of air builds up between the tape and the heads and this prevents the excessive head wear.

Mr. Bixler advised that in every case he had known so far where the operator didn't lift the tape from the heads during rewind the machine came in for head servicing and replacement more often than on machines where tape was lifted during rewind. He doubted that the protective air film theroy would apply in this particular case.

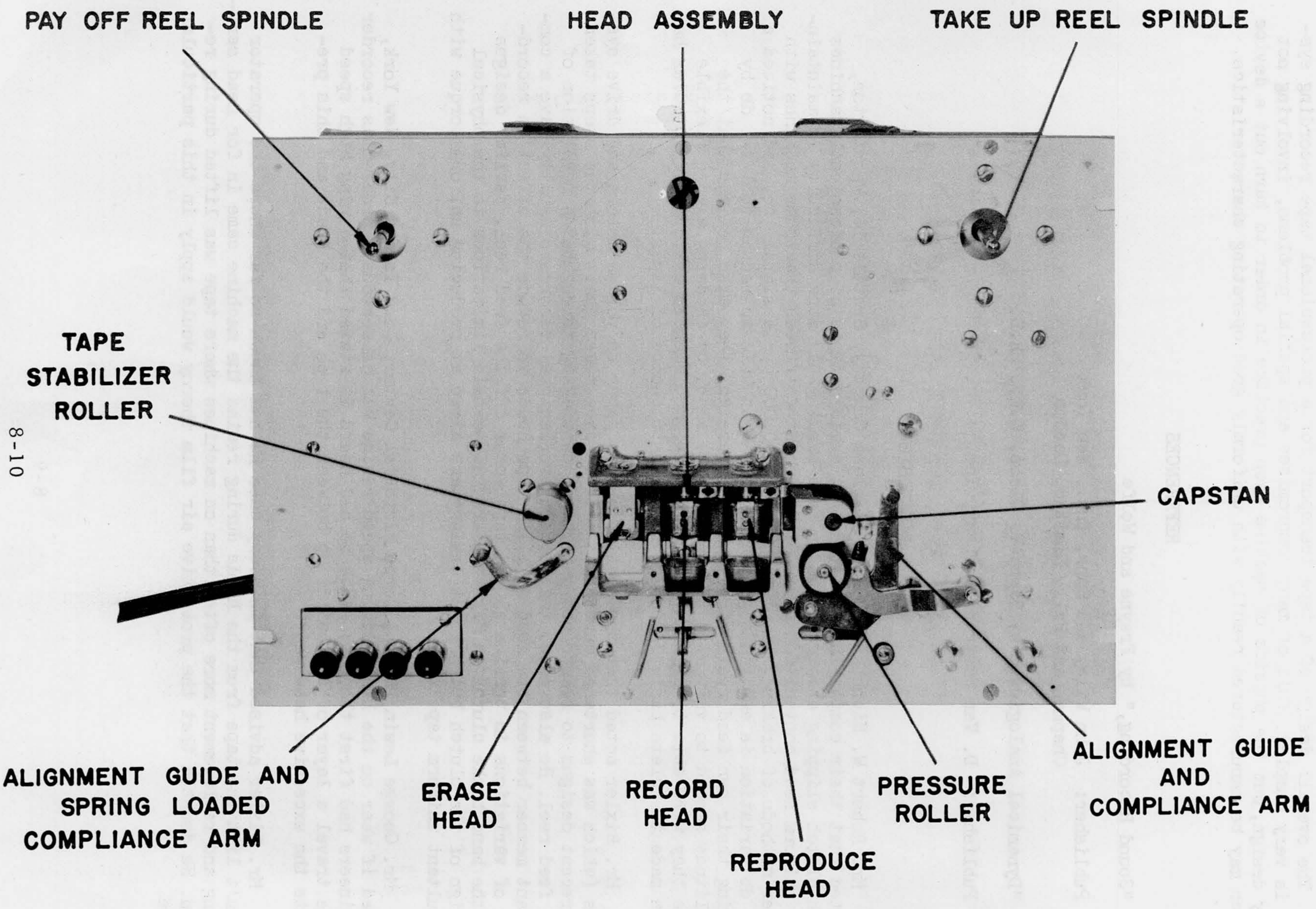

Figure 1. Tape transport bare panel view.

Figure 2. Tape transport completed--panel view.

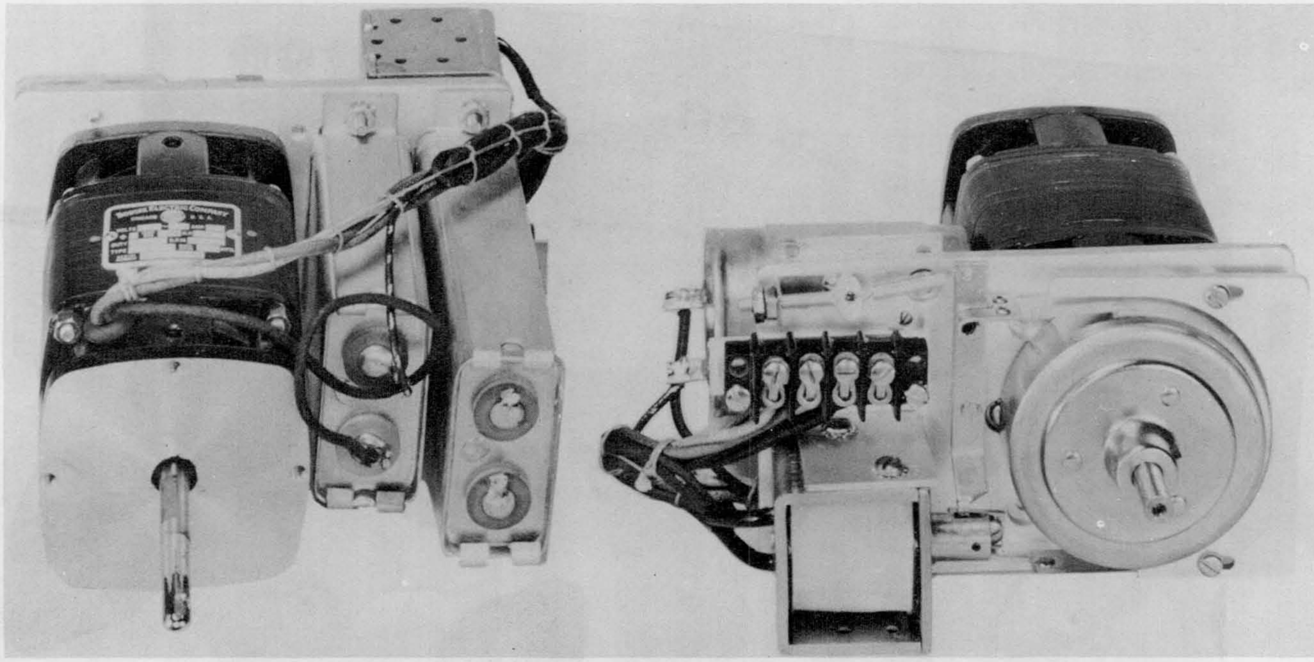

Figure 3. Bi-directional torque motors with condensers and band brake assemblies.

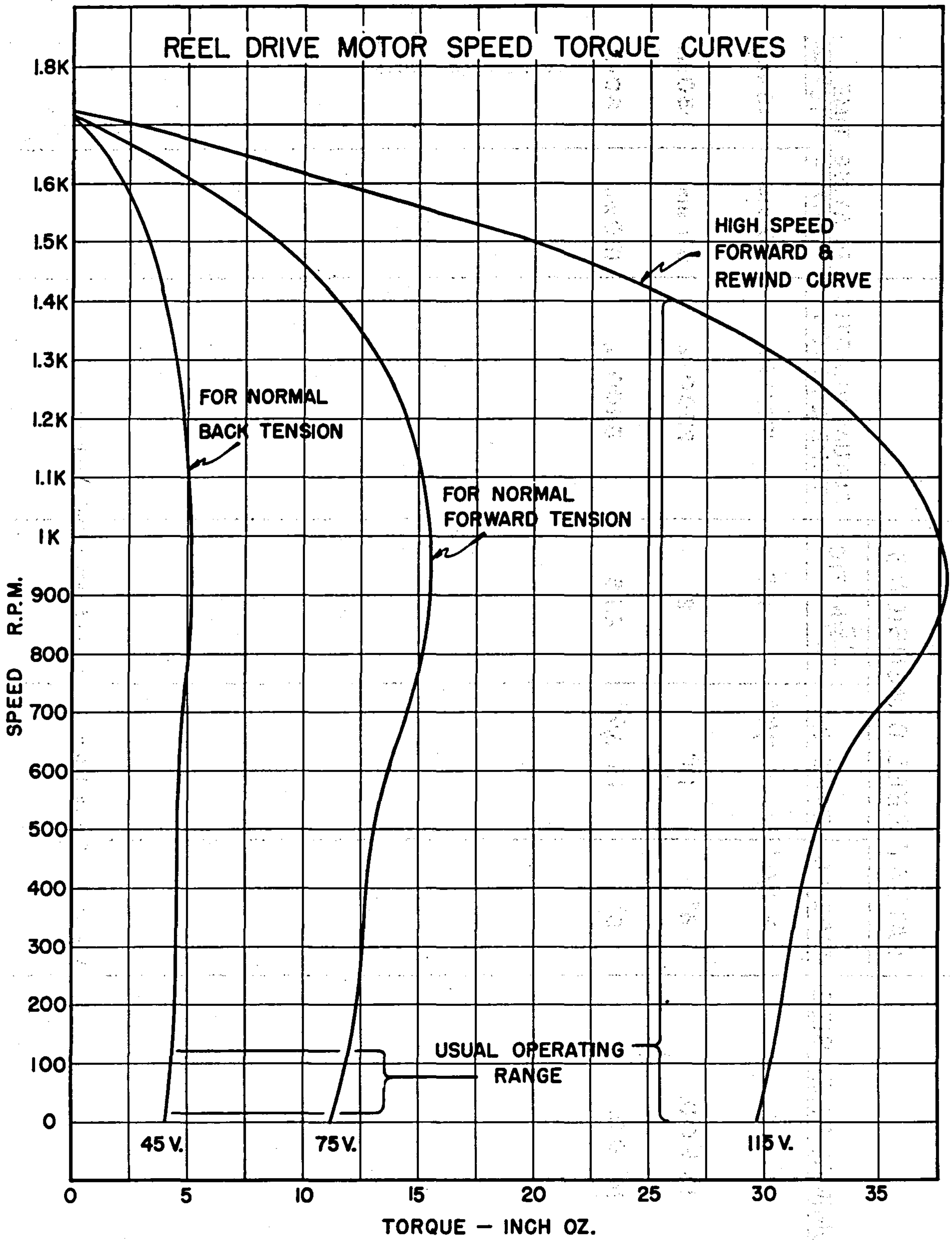

Figure 4. Typical motor-speed-torque curves.

NOMINAL REEL SIZE	LATEST REEL DIMENSIONS			ACTUAL PLASTIC TAPE LENGTH	PLAYING TIME	
	TAPE I.D.	TAPE O.D.	O.D./I.D. RATIO		7.5"/SEC.	15"/SEC.
7" O.D.	2 3/4"	6 7/8"	2.5	1250 FT.	30 MIN.	15 MIN.
10 1/2" O.D.	5"	10"	2	2500 FT.	60 MIN.	30 MIN.
14" O.D.	5"	13 3/4"	2.75	5400 FT.	120 MIN.	60 MIN.

Figure 5. Present day reel pay-off ratios and playing time.

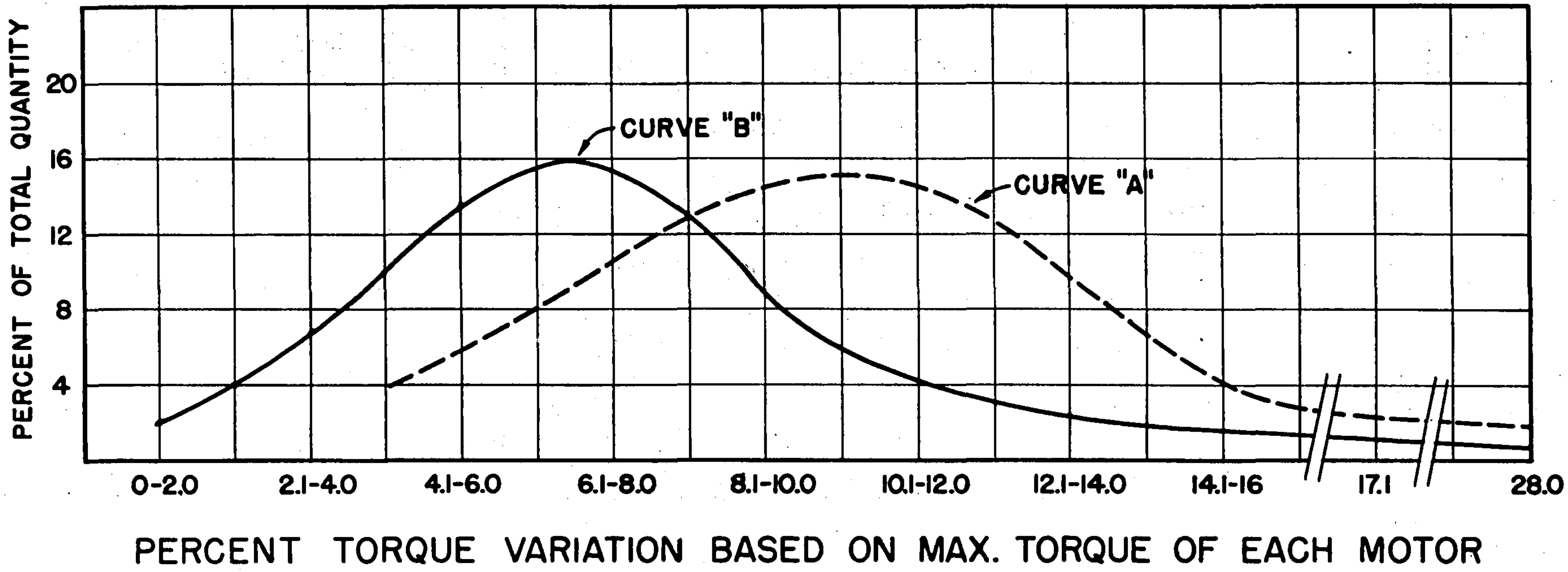

Figure 6. Torque motor torque variation within one revolution (A) and after (B) quality improvement.

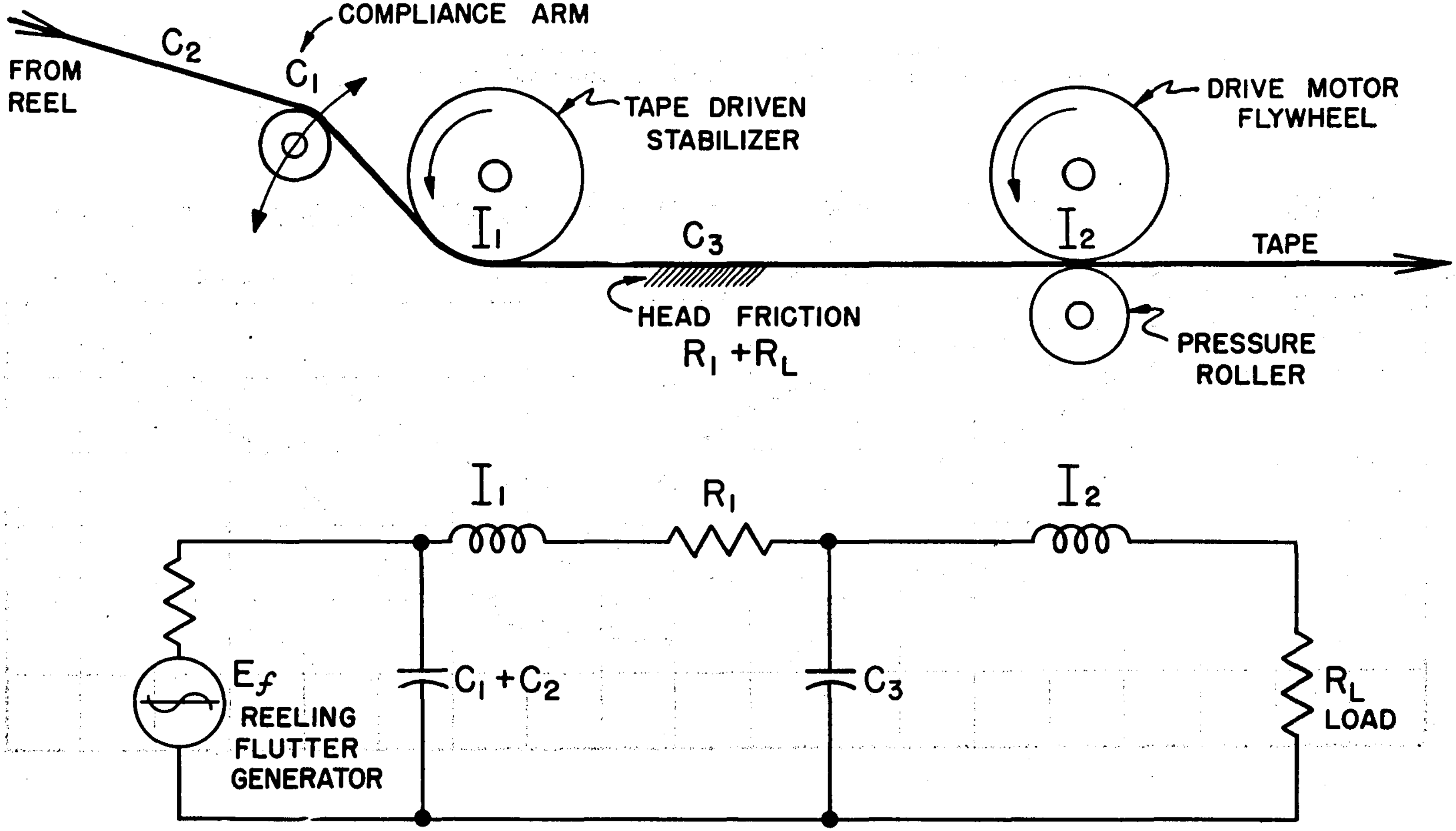

Figure 7. Tape transport simplified mechanical electrical analoque schematic. Hi-frequency flutter source at heads neglected.

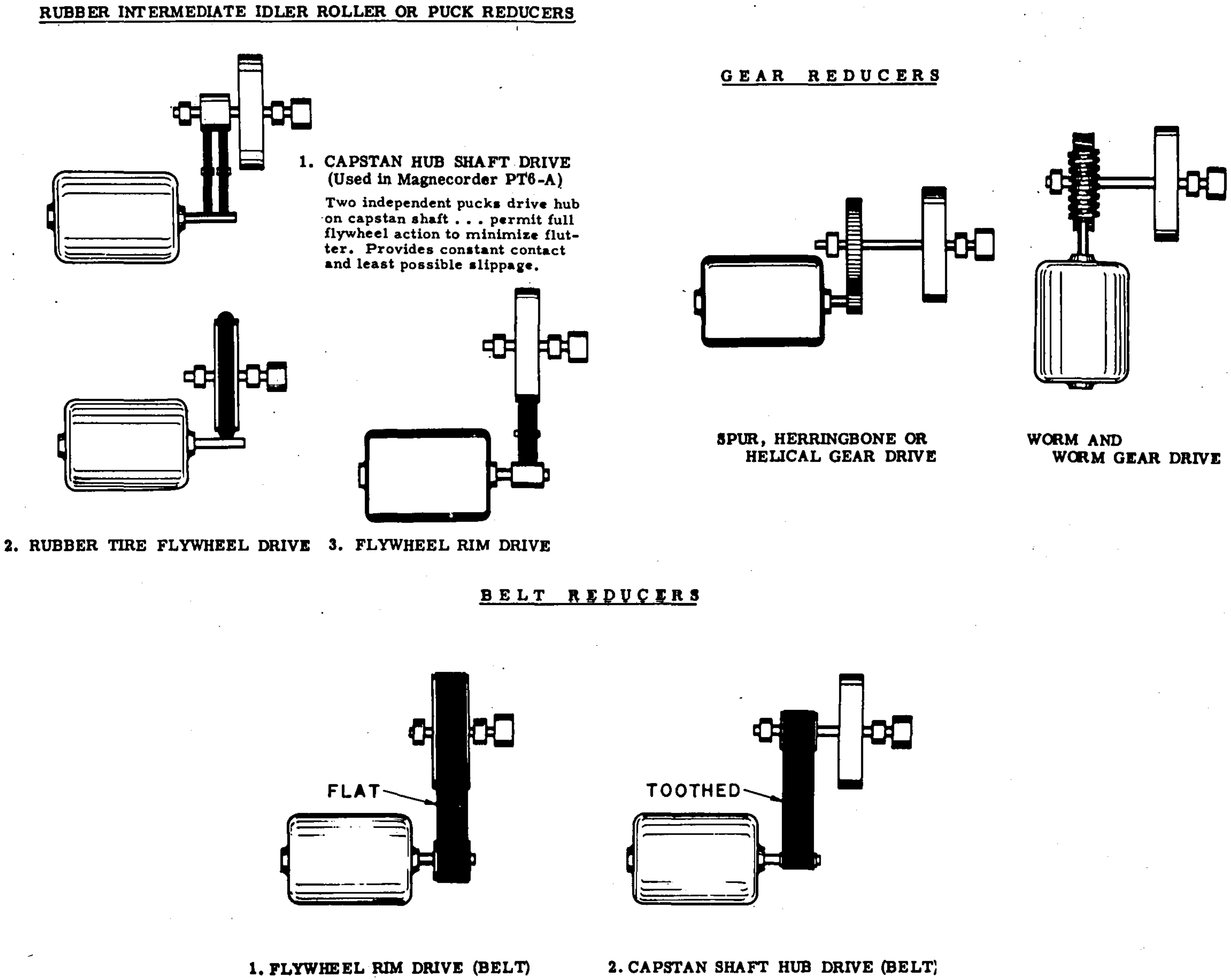

Figure 8. Speed reducer systems.

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Paper 9

MECHANICAL FACTORS GOVERNING TAPE COATINGS, BACKINGS, AND REEL DESIGN

Mr. J. E. Johnston

Sales Development Engineer
Electrical and Sound Recording Tape Division
Minnesota Mining and Manufacturing Company

9 October 1953

ABSTRACT: A discussion of the factors involved in recording machine performance with respect to wow, flutter, speed, constancy, and amplitude uniformity. Also included is a discussion of various tape backings and their respective performance from magnetic and physical standpoints.

Introduction

This talk was originally limited to reels and their designs, and the influences of the reel on the tape in the transport mechanism, however the Navy has requested that we also include a discussion of the properties of the various backings that have been evaluated over a period of years; so very quickly we'll consider the reel portion of this paper and get on to the backing discussion which seems to envoke more interest.

Tape Warping Affects Output Uniformity

One of the most important factors in magnetic tape recording and reproduction is that of the output uniformity. Among those things which can affect changes in uniformity, a principle cause is the physical distortion of the tape. Tape which has been unevenly wound on a reel and then stored for a long period of time--especially under humid conditions or varying conditions in humidity, will very often show severe output variations on both AM and FM recording systems. Although the susceptibility of the backing to distortion is important, and discussed later, important improvements have been made in reel designs--both the seven inch RTMA reel and the 10-1/2 NARTB reel--to improve tape handling, winding, and uniform speed characteristics.

Improvements in Reels

Figure 1 shows the principal dimensions for the earlier RTMA seven-inch reel. The hub diameter is 1-3/4 inches and the distance between the flanges is.33 inches.

A bad feature of this earlier reel was the wide slots at the hub to accommodate drive pins, these slots in the early reel causing very severe deformations in the tape extending outwards from these slots a considerable distance from the hub. In later models of this particular reel the slot openings were reduced at the hub to reduce this problem.

However, the new 2-1/4 inch hub reel has been substantially changed, reducing this deformation to a minimum.

Figure 2 illustrates the new 2-1/4 inch reel. The chief change has been, of course, from 1-3/4 to 2-1/4 inches on the inner hub. Also the distance between the flanges has been changed to .336 inches at the periphery of the reel and reduced to .306 inches at the hub. This particular change in this tape reel has helped considerably in improving the winding characteristics of the tape and reducing the number of loops thrown during high speed rewind. The change to this 2-1/4 inch hub was decided after a long series of tests of speed constancy using magnetic recording machines in all price classes and after a considerable field experience with an interim professional reel which had a 2-3/4 inch hub.

Effect on Tape Speed of Diameter Variations

Graph I illustrates variations in speed throughout length of the tape as the diameters of the supply reel and the take-up reel change as the tape is played from beginning to end. Two curves are shown on this graph as boundaries for the cross-hatched area. Curve A is the portion of greatest deviation from the mean speed and Curve B of least deviation. In this particular graph running speeds of 7-1/2 inches per second were used. However, tests were also made at 15 inches / sec. speeds, all reference data was corrected back to zero reference (7-1/2 inches). Also, in the data, the mean speed of machines were corrected to 7-1/2 inches/sec. where necessary.

The shaded area represents differences obtained from various machines and various conditions of operation, tests being made at relative humidity conditions from 20 - 80 percent. On some machines, variations in excess of three percent occurred toward the end of the reel, whereas on higher priced machines the maximum variation was less than 3/4%. It was found that the lower diameter of the take-up reel hub does not seem to affect the speed deviation nearly as much as does lower diameter of the supply reel hub as evidenced by the difference in curve shape at the end of the graph.

At the 2-1/4 inch value, most of the error occurring on the 1-3/4 inch reel is corrected, and since the other considerations influencing reel design can be satisfied with a seven-inch outside diameter, this hub dimention was adopted on the basis of this curve.

Interim Federal Specification W-T-61A requires the seven inch reel to maintain 0.2 of an inch "e" dimension. This "e" dimension being defined as the difference in the outside radius diameter of the reel and the radius of the tape at outside layer. The difference between these two radii for adequate safety in handling should be .2 of an inch. Graph 2 shows that the lines drawn for the "e" radial clearance for the three hub diameters are 1-3/4 inches, 2-1/4 inches and 2-3/4 inches. Early magnetic recording tape thickness nominally was running at .0022 inches. If the tape had remained at the .0022 inch thickness, it can be seen the change to the 2-1/4 hub would not have been possible. However, by oxide improvements, it has been possible to reduce the coating thickness on a tape while maintaining the same magnetic output level. Present day tape has an overall thickness of about 2 mils, permitting adequate clearance.

Improved Threading Slot

Another advantage results from a change in the hub design. Rather than having a standard threading slot, this new reel has a "V" slot threading device which not only simplifies threading, but considerable reduces tape distortion caused by gap pressure at that point.

Figure 3 illustrates the current 10-1/2-inch reel. The distance between flanges in this particular case is .345 inches.

Figure 4 illustrates the new plastic NARTB reel of the same design as Figure 1, the major change being the reduction of distance between the flanges to a value of 2.70 inches. This reel as designed, is of glass-filled plastic and with the changes the winding characteristics has vastly improved.

Figure 5 illustrates a supplemental 10-1/2 inch reel just developed. This reel has a small center hole, corresponding to the seven-inch reel and contains other drive holes to adapt it to the recording machines of various manufacture.

Figure 6 pictures the two new reels for comparison.

Magnetic Recording Tape Backings

Because of the nature of many military applications of magnetic recording tape it is necessary to use a tape backing which has the greatest amount of stability and uniformity. Ideally, of course, the backing would have a high strength without stretch in thin films with a very low coefficient of humidity expansion, be stable over a wide temperature range, have a perfectly smooth surface, and cost very little.

No available backing meets all these requirements. Comparing backings of the four main classes, paper, plastic, metal and laminates, we have qualitatively rated them on the magnetic factors, physical factors, and cost factors on Table I. Not considered here are physical properties which concern manufacturing problems--that of coating, anchorage, etc., but rather on performance characteristics.

Based on these factors and the manufacturing considerations, the best backing types available are the plastic materials. The laminates have been evaluated chiefly on thicker films (.002 inch to .005 inch) rather than on the standard (.0015 inch) backings.

Table 2 considers the particular plastic films which are available today, cellulose acetates, polyester which is under the trade name "Mylar", ethyl cellulose and tensilized polyvinyl chloride, more commonly known as Luvitherm. They are rated quantitatively and qualitatively under the several factors shown.

The tensile strength of practically all of these films are adequate in view of the tape handling mechanisms that exist today. The outstanding characteristic of the polyester films and the Luvitherm type are their low coefficient of humidity expansion. The Luvitherm, however, is limited by upper operating temperature, undergoing deterioration at something just above 150 degrees Fahrenheit.

An outstanding property of acetate, accounting for its wide use today, is its excellent surface and thickness uniformity. The polyesters as yet suffer in both thickness uniformity and surface uniformity.

Table 3 shows the representative stress characteristic of the various .0015 inch films. Polyester exhibits a very excellent recovery, showing no dead stretch up to five pounds per 1/4 inch. Ethocel breaks at something less than five pounds; polyvinyl chloride shows 27 percent and acetate 23 percent residual elongation at five pounds stress. This stress value is very high and is only used to bring out the differences that exist in the films. At the normal operating tensions the residual elongation of all of these films is essentially zero. These values change slightly at very high humidity conditions.

Effect of Backing on Output Uniformity

Figure 7 illustrates the output uniformity characteristics of magnetic recording tape with the three most common backings. All coatings were made under the same conditions of manufacture. In obtaining this data the recorder has been biased to emphasize the differences in surface uniformity of the backing. The distance for a large chart division is 2 db, and the polyester shows a considerably greater variation in its output uniformity than does the acetate (no. 111A) with the paper backing the poorest of the three.

Polyester films are improving each month and it is hoped that sometime in the near future it will be possible to obtain this backing having uniformity characteristics of acetate, or perhaps even better. In most of the applications where this very high degree of stability is desired, the consumers also require an instrumentation quality tape. This uniformity improvement will be necessary before large use of the polyester films can take place.

Special Features

These backings can be processed where desired for special applications. They can be metallized on the backing side or the oxide side; they can be treated with various surface lubricants to change their coefficient of friction; etc., all on special order for individual applications. Of all the many backings which have been evaluated considering all aspects, especially cost and performance, cellulose acetate today still provides the best all-purpose economical tape.

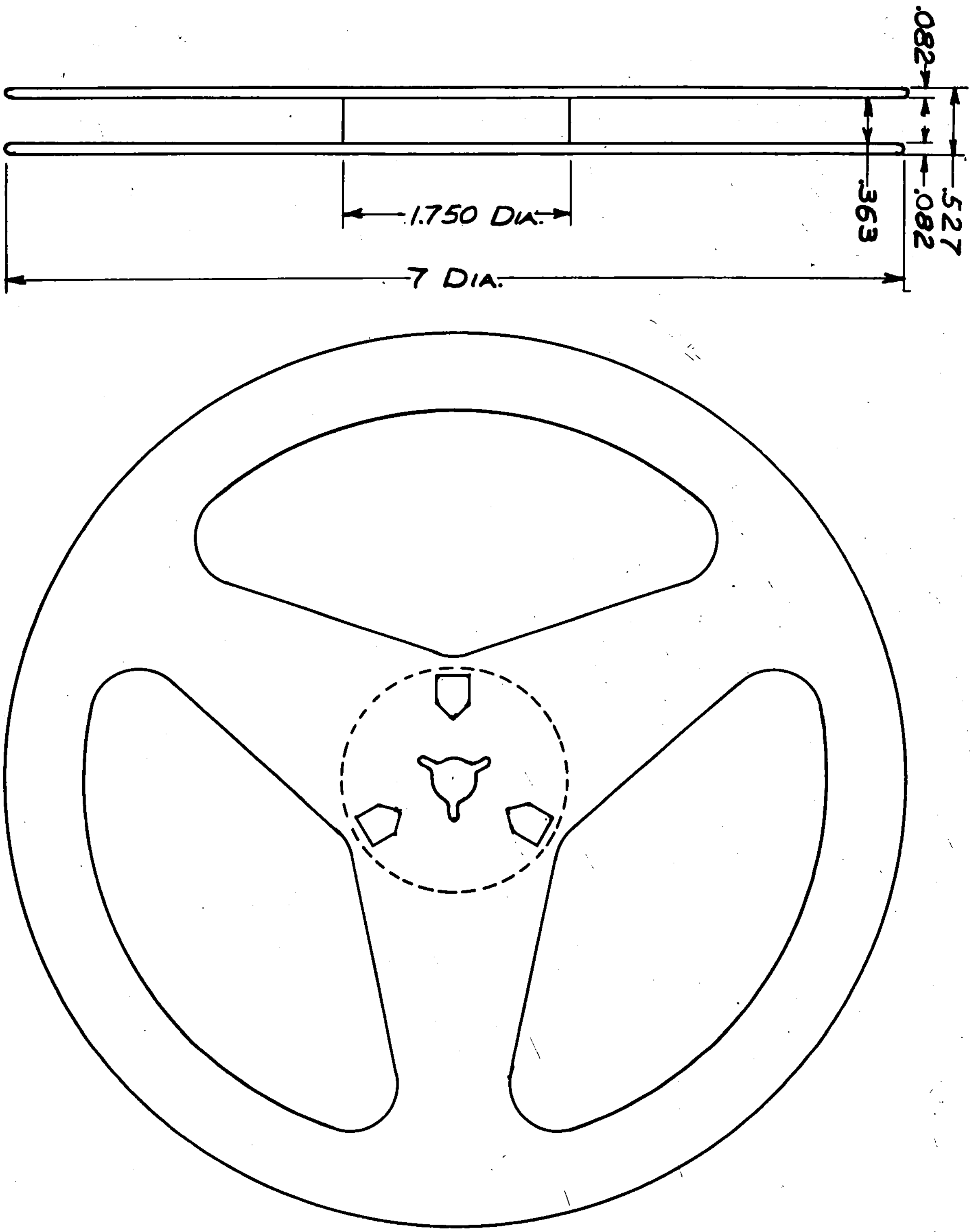


Figure 1. Principal dimensions for earlier RTMA 7-inch reel.

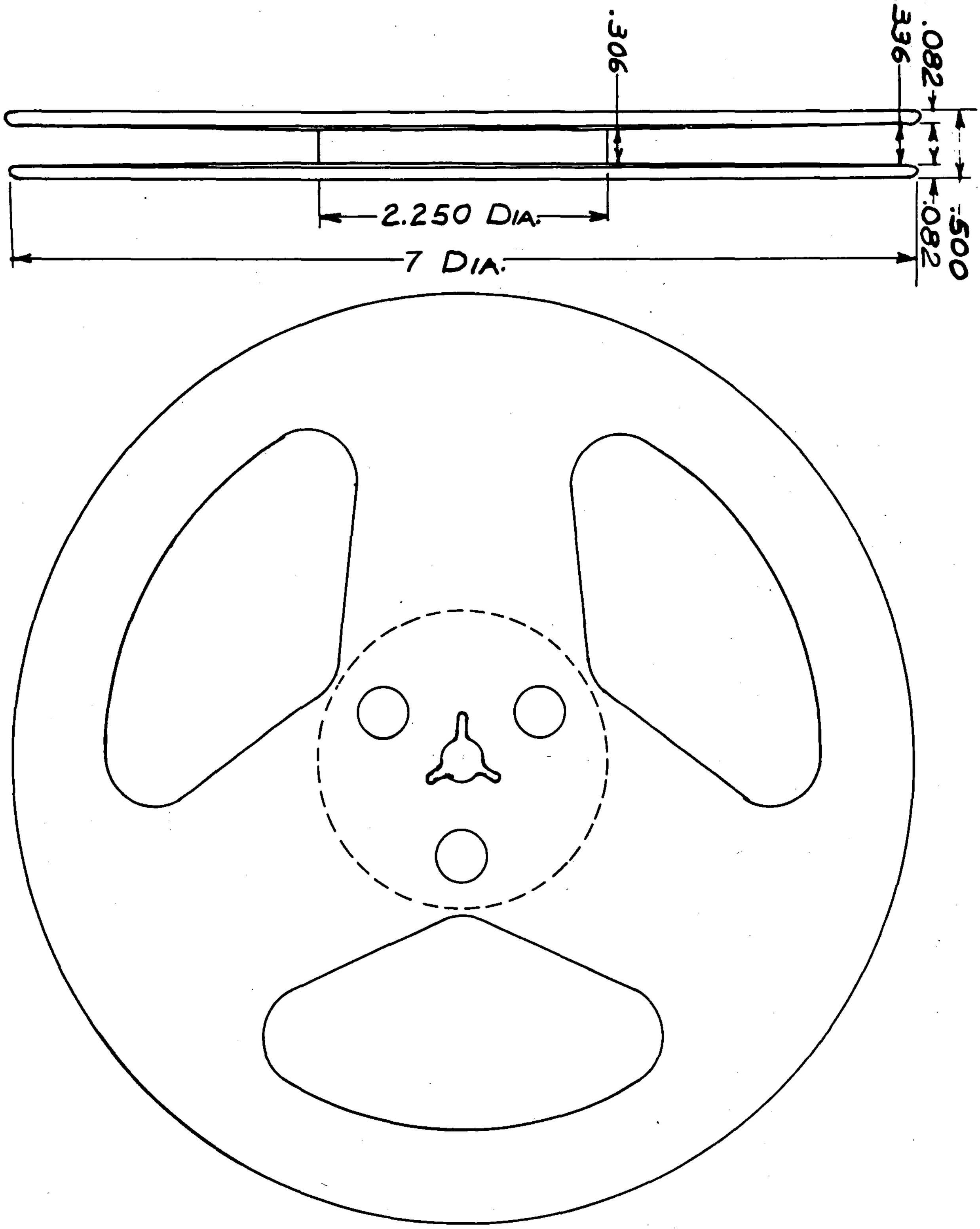
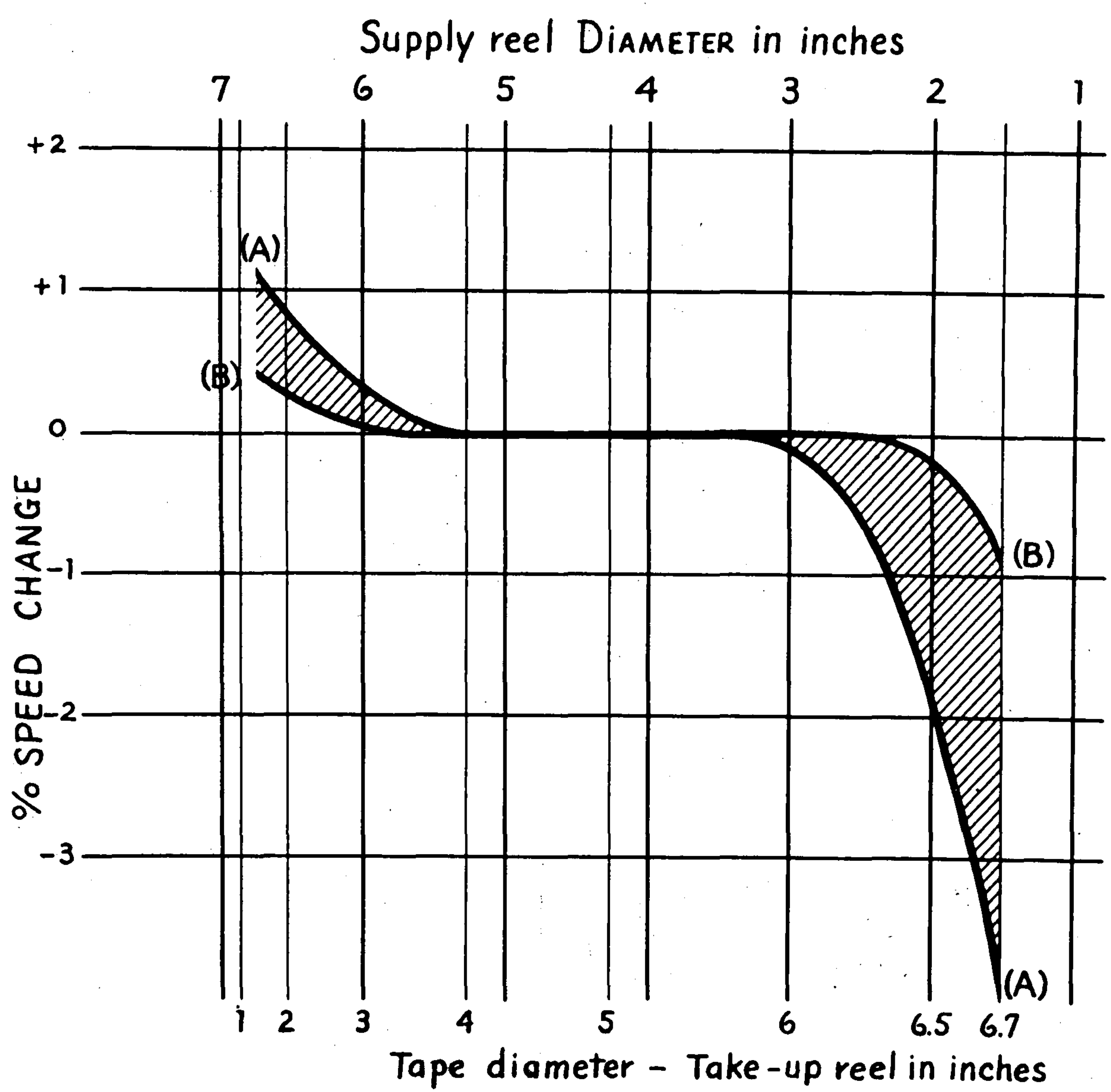
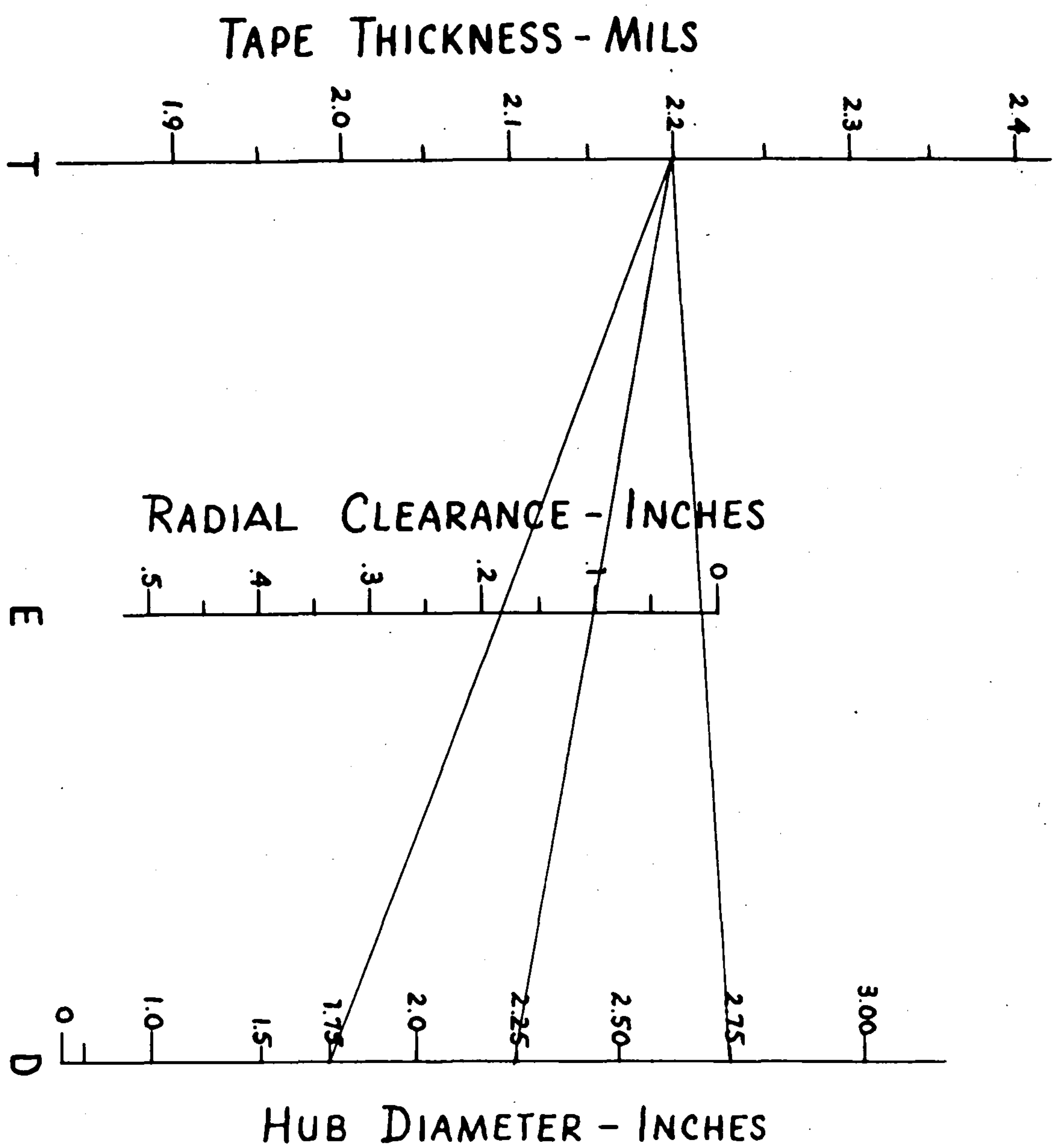


Figure 2. New 2-1/4 inch reel.



Graph 1. Variations in speed as reel diameters change.



Graph 2. "e" dimensions for 1-3/4, 2-1/4, and 2-3/4 inch hubs.

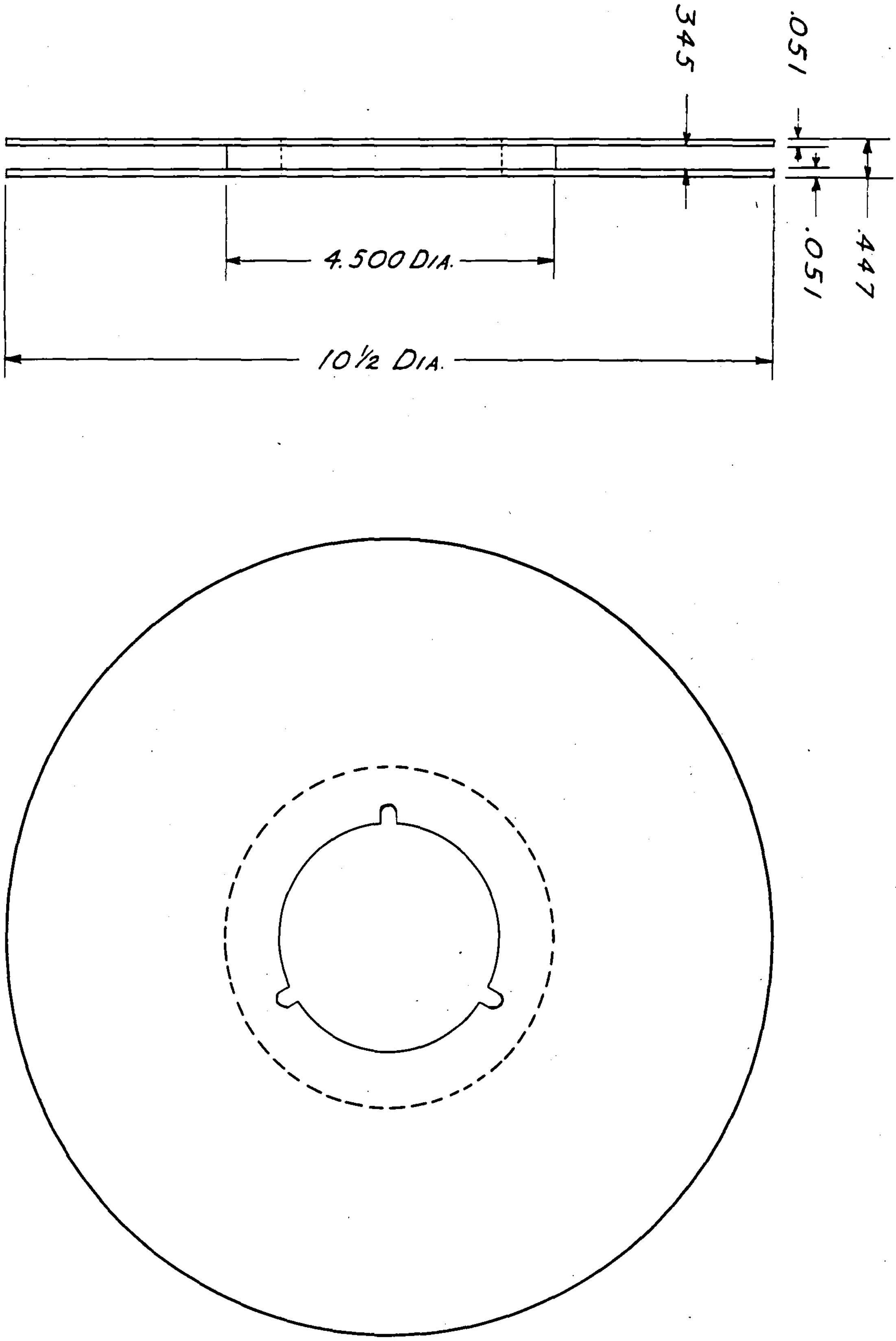


Figure 3. New 10-1/2 inch reel.

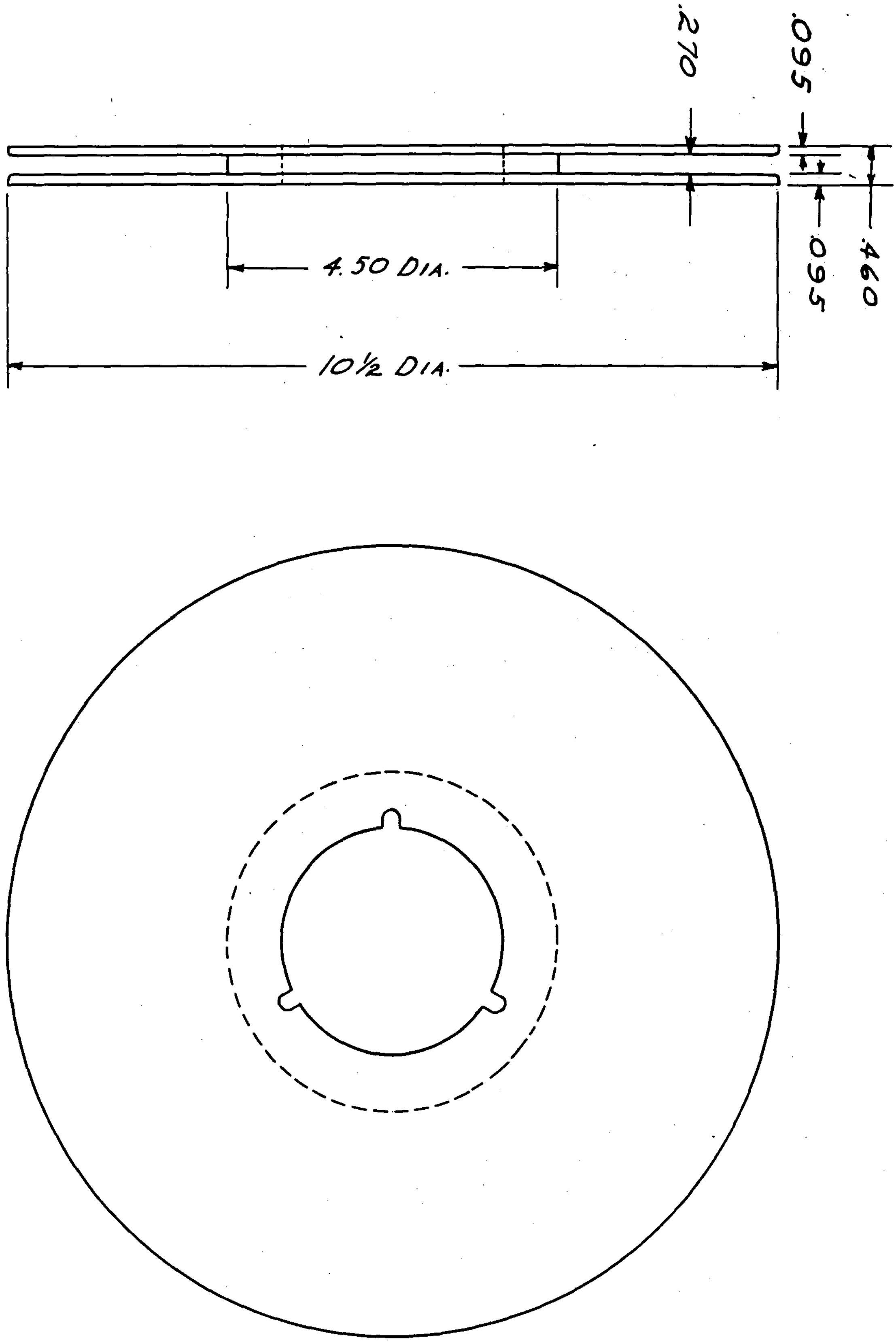


Figure 4. New NARTB plastic reel.

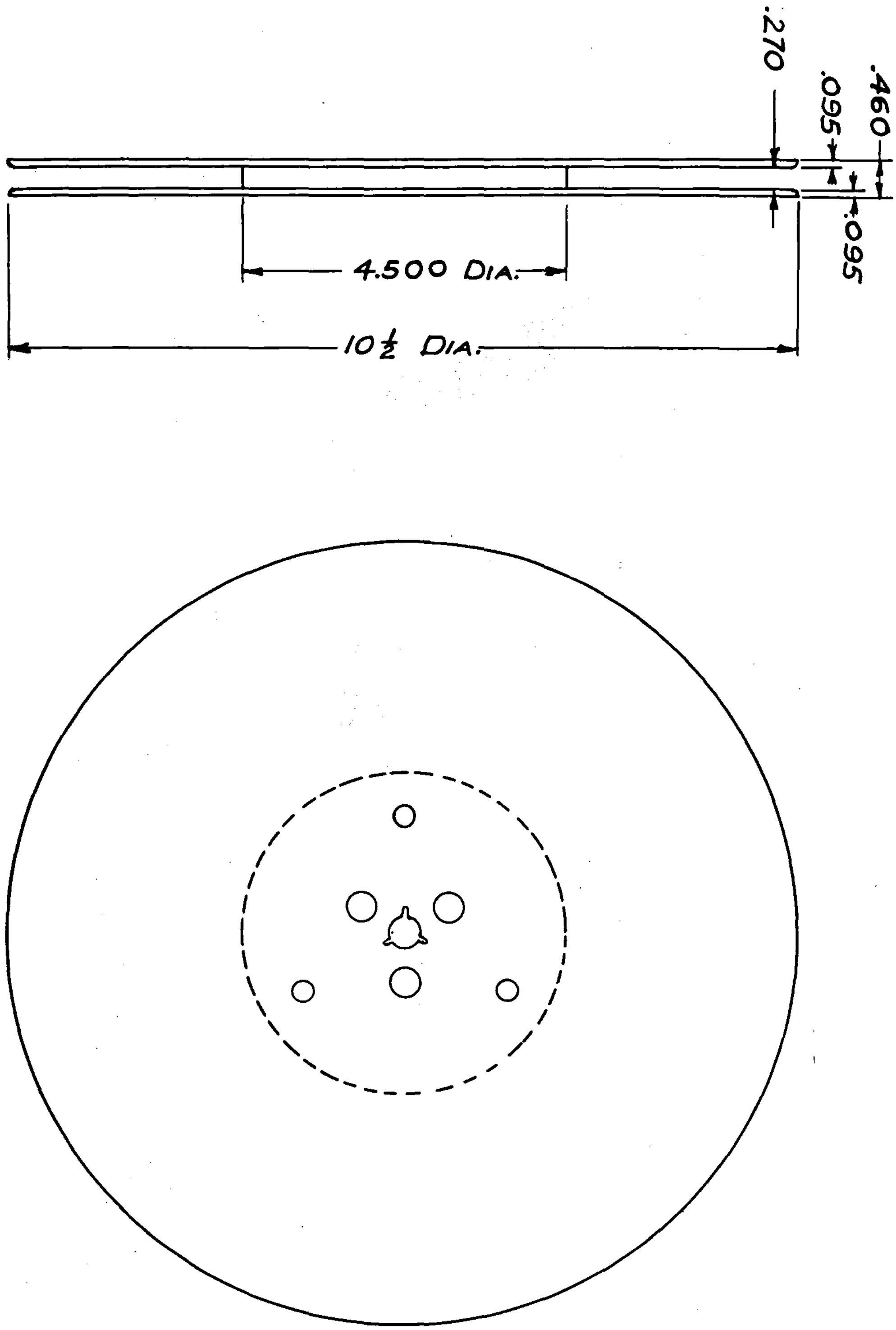


Figure 5. Newly developed supplemental 10-1/2 inch reel.

Figure 6. Comparison of the two new reels.

Table 1.

COMPARISON OF BACKING TYPES FOR Magnetic Recording Tapes

	MAGNETIC	PHYSICAL	COST
PAPER	POOR	GOOD	LOW
PLASTIC	GOOD	FAIR-GOOD	MEDIUM
METAL	GOOD	EXCELLENT	HIGH
LAMINATES	FAIR	GOOD	HIGH

Table 2.
9-14

PHYSICAL PROPERTIES OF COMMERCIAL PLASTIC BACKINGS (.0015" films)

	ACETATE	POLYESTER	ETHOCEL	VINYLS
Tensile (lbs.)	5.5	9	6	8.5
Relative Humidity expansion coef.	60	5	11	7
Maximum operating Temperature	200° F (+)	200° F (+)	200° F (+)	150° F *
Thickness Uniformity	±.00003	±.0001	±.00005	±.00012
Surface Uniformity	EXCELLENT	POOR	VERY GOOD	POOR

* Deteriorates

COMPARATIVE HYSTERESIS LOOPS
for Various Plastic Backings

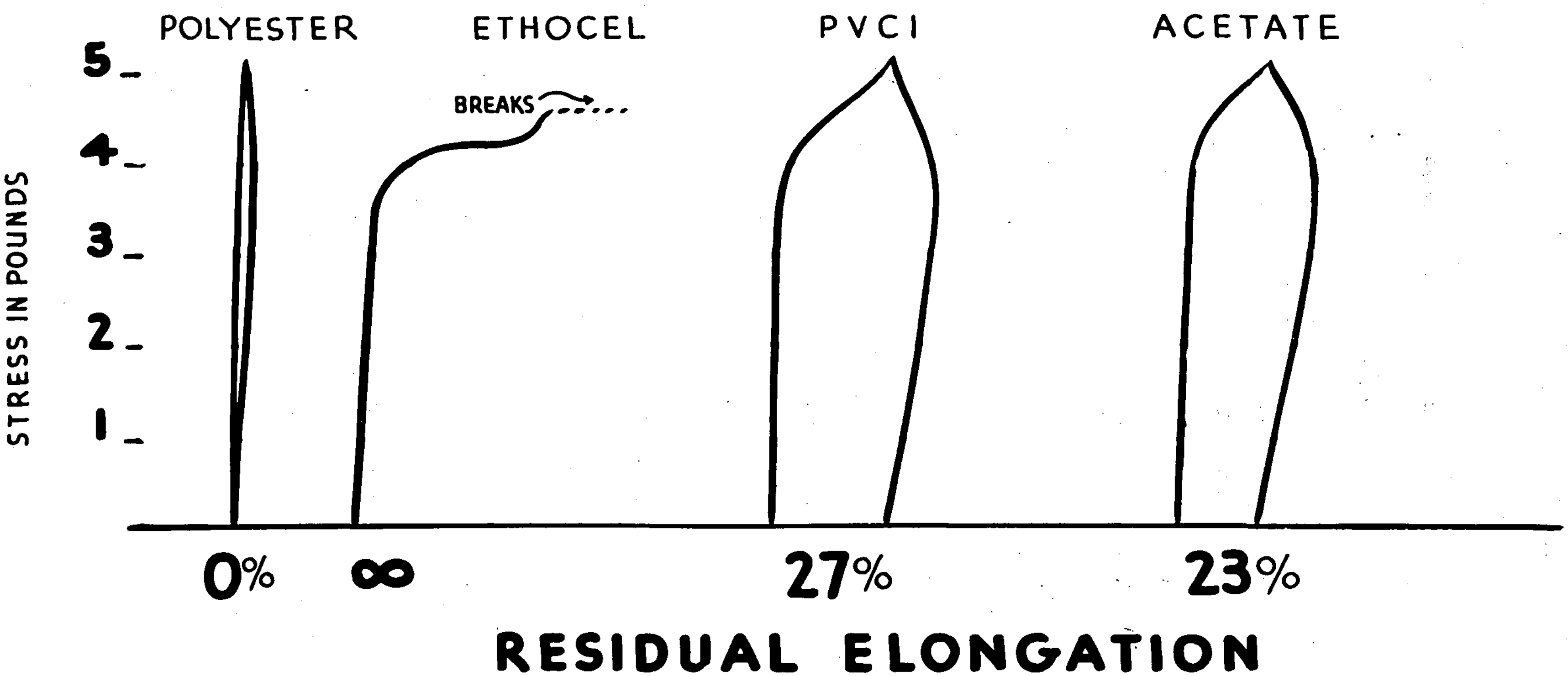
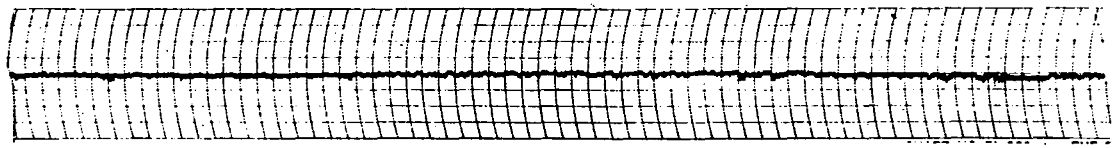
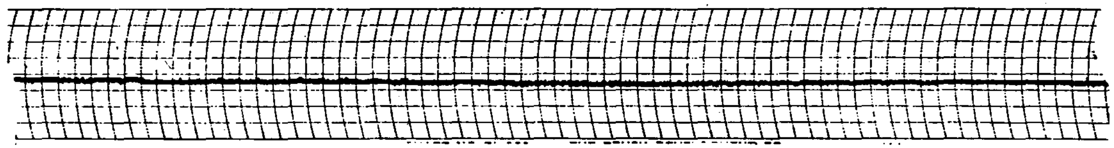


Table 3.

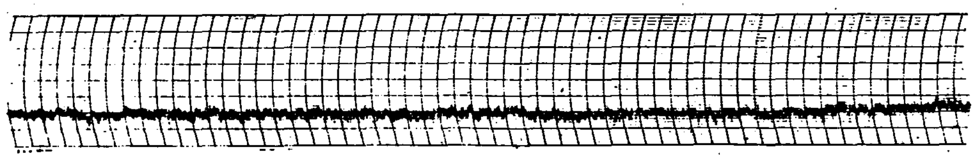
OUTPUT UNIFORMITY OF VARIOUS BACKINGS...



POLYESTER



ACETATE



PAPER

Figure 7.

DISCUSSION SUMMARY

In reply to Mr. Sibley of Lockheed, Mr. Johnson advised that data for Figure 6 was taken using a 200 cps signal for deep penetration of the tape coating, and with the recorder overbiased. The bias may not have significance in the test.

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Department of Defense Symposium on Magnetic Recording

Paper 10

MAGNETIC RECORDERS FOR DATA RECORDING UNDER ADVERSE ENVIRONMENTS

Mr. G. L. Davies

President of The Davies Laboratories

9 October 1953

ABSTRACT: Describes types of magnetic recording equipment specifically developed for multi-channel recording of data information such as vibration, displacement, pressure, temperature, etc. Equipment has been designed to operate over wide ranges of temperatures, pressures, humidities, accelerations, and vibrations as experienced in aircraft, vehicles, and other adverse environments.

Original Requirements

The work that we are discussing today was started as a result of Air Force requirements (Contract No. AF33(038)-11380) for the recording and analysis of vibration in aircraft. The frequencies concerned were somewhat lower than those usually encountered in sound recording, as the minimum frequency required was three cycles per second. The linearity requirements were very high in that accuracy of output voltage versus input voltage was desired to the order of two percent. The environmental conditions were severe, being the standard military specifications for equipment which is to be used in an airplane: vibration, humidity, temperature, and last but not least--24 volt d-c operation.

In this case also, extreme stress was laid upon small size. This is common to most aircraft installations, but the aim of this particular equipment was use in small aircraft, notably small fighter planes beginning with the F-86. Thirteen data channels were required, and the frequency response and linearity requirements dictated a frequency modulated carrier system. In such a system, flutter and wow rears its ugly head in a far more nasty form than it usually does in audio work, inasmuch as the first result of it is a spurious noise output, as a result of spurious modulation on the carrier introduced by the irregularities of tape motion.

Tape Drive

This dictates the best possible tape drive that can be engineered. However, an early investigation of tape drives indicated that, especially with 24 volt d-c operation, an attempt to develop an extremely smooth and constant speed drive might well require a B-36 rather than an F-86 to carry the equipment. Consequently, a scheme for compensation of at least the first order effects of flutter and wow was devised. Tests made with it indicated that this would be sufficient, at least for this particular application, to enable a very small and very simple tape drive mechanism to be used, and thereby achieve the necessary small size and weight together with the 24 volt d-c operation.

Speed Vs. Temperature

Actual capstan drive was accomplished by means of a governor controlled 24 volt d-c motor geared to a capstan. The average speed uniformity of the drive has been entirely satisfactory, inasmuch as a control tone recorded on the tape from a crystal oscillator has been used for servo control on playback to obtain the original recording speed instead of trying to play back at a constant speed. The capstan drive motor holds speed within about plus or minus two percent for voltage variations from 22 to 28 volts, and within possibly another two or three percent over the extremes of temperature from about -30^{0} to $+ 70^{0}$ Centigrade. Actually, other difficulties prevented using the recorder at temperatures below -30^{0} Centigrade; therefore, an electric blanket was used to limit the temperature drop. The actual specification, I believe, is -55^{0} or -65^{0}, and the electric blanket was used to keep the actual recorder temperature up to approximately -20^{0} or -30^{0} Centigrade.

A 24 volt motor incorporating a gear reduction box was also used for the take-up reel, and a relatively simple brake on the supply reel maintained a reasonable tape tension. With this type of mechanism, rms flutter and wow is in the order of one or two percent. The combination of servo control of playback speed plus compensation for the first order effects of flutter and wow resulted in a system which gave approximately a 40 db signal-to-noise ratio, a value approximating that obtainable with laboratory type mechanism without compensation. Reproduction of recorded frequencies to an average accuracy of about half a percent of playback speed in relation to recording speed--linearity of approximately two percent, and distortion of the same order of magnitude were also achieved. This is done in an enclosure approximately 20 inches long, 11 inches deep, and 12 inches high, weighing 55 pounds, and completely self-contained except for a remote control box.

Final Recorder

Figure 1 shows this recorder with its control box and connecting cable. The tape reels were special. The Recorder was designed on an aluminum casting, a second casting being used to carry the vibration isolation mountings. The recording oscillators were subminiaturized to a certain degree and plugged into the bottom of the recorder. A calibrating arrangement was incorporated, so that, when the switch is thrown to calibrate, the meter indicating the calibration signal level may be zeroed by means of a knob on the control box. Pushing the record button then records the calibrating signal on all channels simultaneously.

An automatic timer was incorporated so that a pilot without additional assistance could take data with the recorder. The recording push button starts the tape drive mechanism (the electronic gear has to be turned on first and warmed up somewhat) and an automatic timer in the recorder operated the tape for a predetermined time variable between one and one-half and four seconds, adjustable within the recorder. If the recording button is held down for five seconds and then released the total recording time will be that five seconds plus the automatic pre-set time in the recorder. If the button is just punched momentarily, then the pre-set time governs.

Figure 2 shows a closer view of the front of the recorder, with cover removed from the tape transport mechanism. I might mention in passing that the head for this recorder was not available at the time the work was undertaken and the then Brush Development Company designed the head for us.

The principal problem in the head design was alignment of gaps. Since we planned to use a compensation scheme, we specified that the 14 gaps in the head be aligned with an accuracy of $\pm$ .0001", and Brush has, I think, quite satisfactorily met the requirement with the design of this head.

Figure 3 shows the top view of the recorder. The large tubes are mostly Amperite voltage regulators to hold the heaters at a reasonably constant potential with variations in supply voltage. Relays are shown at the top. The tubes at the bottom are for control circuits and plate supply voltage regulation.

Figure 4 shows the bottom with the 13 FM recording oscillators plugged in. The one at the lower left corner without any handle on it is the crystal controlled reference generator which puts the so-called reference signal on one channel of the tape tracks.

Figure 5 is the remote control box with the calibrate-record switch, the recording push button, signal lights, etc. The meter indicates tape remaining on the reel.

Figure 6 is a close-up of the FM recording oscillator. One can estimate the size by the octal plug at the bottom and the standard potentiometers at the top. The ends of the subminiature tubes are visible.

Figure 7 gives a quick idea of the type of recording oscillator operation, the solid line indicating operation at one signal voltage, and the dotted line at another. This is not a positive biased multi-vibrator as is commonly used for this application, but a variation of a phantastron oscillator. The advantage of this technique is that over the major portion of the cycle there is a relatively long slope which is linear and is inversely proportional to the modulating voltage. Now, if the flyback time on the cycle can be held to a very small value, the period of the overall wave will be inversely proportional to the modulating voltage, and therefore the frequency will be directly proportional to it. This gives a frequency modulation linear with voltage without dependence upon tube characteristics, at least for first order effects. The reduction of flyback time has finally been carried to a fairly satisfactory point. In oscillators running at 25 kilocycles, the flyback time is of the order of a quarter of a microsecond, so it is a very minor part of the total cycle; the long slope, or trace time as we call it, is the major governing feature controlling frequency.

Playback System

Figure 8 is a block diagram of the playback system showing the tie-in between the so-called reference or compensation channel and the signal channels. The reference signal is recovered from its particular head, which is the lower one shown here, and passed through a limiting amplifier and discriminator of the same type as used for the signal channel, then passed, in this original equipment, through a low pass filter and a phase inverter to derive an error signal which represents in voltage the tape flutter and wow. Since that voltage is present in the outputs of all signal channels it is necessary only to add the phase inverted error signal to the signal channel by means of an adder, and thereby eliminate the spurious noise in the signal channel produced by tape flutter and wow. A second output from this reference channel is carried to the servo speed control. This compensation method requires rather careful matching between the two different channels, particularly in connection with the low pass filters. However, it has been possible to match filters within a few degrees as to phase characteristics up to and through cutoff. A more recent development has made it possible to incorporate the error signal into the signal channel prior to filtering, which then eliminates the necessity for close phase match of filters. The equality and matching between the limiting amplifiers and the discriminators is easily set up by proper calibration equipment in the playback unit.

Figure 9 shows the equipment furnished to Wright Field for both playback and automatic Fourier analysis of the vibration data. The equipment includes 13 signal channels plus the compensation channel, thus providing for simultaneous playback from all tape tracks. The tape transport mechanism is centered in the left-hand rack, and below it is the box for the loop of tape which is formed from one piece of data. The panels above the transport are adjustment and calibration panels, plus the servo speed control panels. Immediately below the recorders in the center and right-hand racks are the selective amplifiers of the dual-channel harmonic analyzer. The motor-driven oscillator of the analyzer is at top right. The recorders are modified Brown potentiometer recorders for making the report of amplitude versus frequency to show the components of the vibration information. In actual use, a piece of tape comprising a certain amount of vibration information, perhaps two to five seconds long, is formed into a loop and put into the machine. When the machine is then started, the analyzer analyzes the first two channels on the tape, then retraces and selects the next two channels and runs an analysis of those, and continues until it has analyzed all 12 vibration channels. The thirteenth data channel is the tachometer channel to check on the basic forcing source of the vibrations. This playback and analysis equipment has been in operation for well over 2000 hours, and is operating regularly eight hours per day.

Playback speed Control

Figure 10 shows a block diagram of the servo speed control. The limiting amplifier is common to Figure 8, and in this case not the linear signal channel discriminator but a high sensitivity tuned circuit discriminator is used to get large servo loop gain without excessive amplification. An oscillator is controlled in frequency by the d-c from the discriminator, a limiter being used to bring the tape speed up to a point where the signal will be on the operating portion of the discriminator. The oscillator, incidentally, has exactly the same circuit configuration as the recording oscillators. Finally, a power amplifier and synchronous motor drive the capstan. This arrangement has demonstrated that it will reduce departures from nominal recording speed by a factor of approximately 10. In other words, if the recording speed is within five percent of its nominal value, then the playback speed will be within one-half percent of the correct value, which was the design requirement. Of course, if the recording variation is less than five percent the accuracy is somewhat better.

Signal Analysis

Figure 11 is a block diagram of the wave analyzer, a standard analyzer of the General Radio type except that extremely narrow filters were necessary and a tuning fork operating at 3,000 cps, was resorted to as a filter. The Q's of these forks are at least 6,000, so that it is possible to obtain a filter bandwidth of about one-half cycle at 3,000 cps, which was the top limit for forks then available. The variable oscillator runs from 3,000 to 5,000 cps and the input signal can range from three to 2,000 cps. The tuning fork itself is a rather inflexible device, of course, and it was desirable, because of the tape recording technique, to have some control of bandwidth. Therefore, a feedback bandwidth control was devised and incorporated so that with the tuning fork a bandwidth range of approximately one-half cycle to eight or 10 cycles could be obtained. Later on, an ordinary electrical tuned circuit with a toroidal coil was added to increase the possible bandwidth to 50 cps. Between the fork and the coil the total range of the bandwidth is from one-half to 50 cycles per second. The output is rectified and fed into a standard Brown potentiometer recorder--standard, that is, except for a logarithmic slide wire to obtain reasonably constant percentage accuracy over the entire range.

Recent Developments

Recent developments have included increasing the upper frequency limit for recorded data to 5,000 cycles per second (it was 2,000 in the Air Force equipment), and reducing the lower frequency limit to d-c, which required some complication of the recording oscillator. It is no longer a two tube affair for a d-c to a 5 kc range, but still in a fairly small package. At the present time designs are underway for a recorder--again for airborne use--which will carry standard 10-1/2 inch reels. The reels on the recorder shown here were five inches in diameter and provided from three to four minutes of recording time at 30 inches per second or about six minutes at 15 inches per second. There is a need for a recorder with longer recording time and that is being designed at the present time. Also recent developments have added a certain amount of shock resistance to the recorder. The original design was specified only to withstand aircraft vibration in accordance with a standard Air Force specification, plus constant downward acceleration of 7 g. The redesigned units have provided entirely satisfactory recording while undergoing 10 g shocks with a duration of about 0.1 second. In these tests the vibration isolation mount was <u>not</u> used.

DISCUSSION SUMMARY

Mr. Camras of Armour Research asked about cost of the recorders described. Mr. Davies estimated the Model 501 at $6300.00 with 13 channels and response from one to 2,000 cycle response. The later design with eight channels responding from zero to 5,000 cycles is in the neighborhood of $5,000.00. It is very difficult to come up with a "standard" recorder because of the many variations desired by different users.

Dr. DeVaud of Raytheon asked how many tracks per inch can be accommodated. Mr. Davies replied that the Brush Development Company head they used would accommodate eight per inch, but he understood a more recent version will accommodate 14-15 per inch by an interleaving arrangement. Dr. DeVaud was also advised that the start-stop time is very fast, so that not more than five to six inches of tape are lost between stopping on one recording and starting on the next one.

In reply to Mr. Berkshire of Texas Instrument Division, Mr. Davies spoke of a program currently under way for using each track on the tape to accommodate six separate data channels. Each track will accommodate standard telemetering frequencies from 2.3 to 10.5 kc. with standard deviation of $\pm$ 7-1/2 percent. In addition, a 14-1/2 kc crystal controlled signal will be recorded on each tape track to act as a compensation signal. Standard telemetering discriminators will be used in playback. With this arrangement a 14-track recorder will handle 84 data channels. The system for which it is being built contemplates the use of 252 data channels with associated recording oscillators, all contained in one airplane.

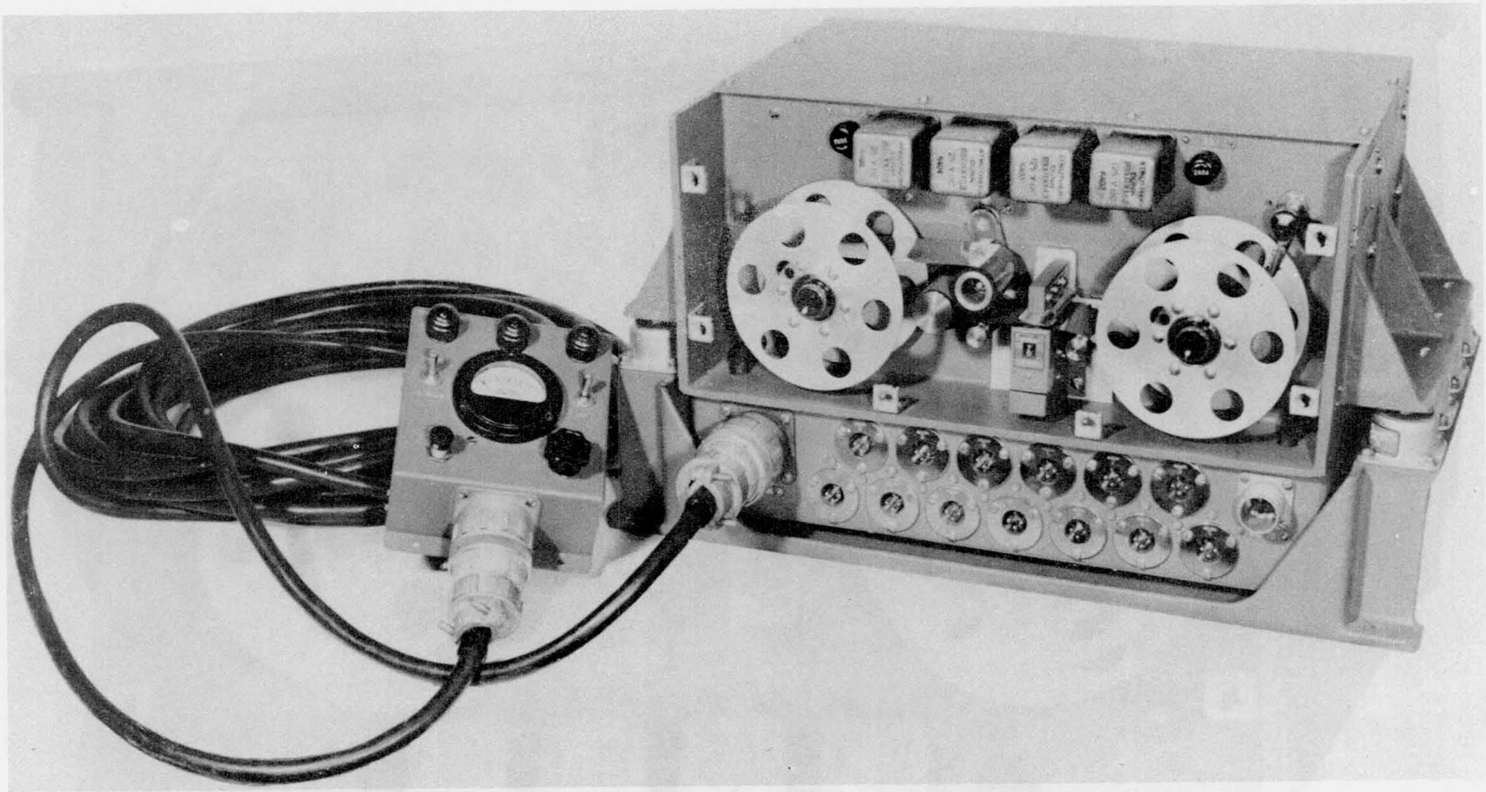

Figure 1. Compact recorder with control box.

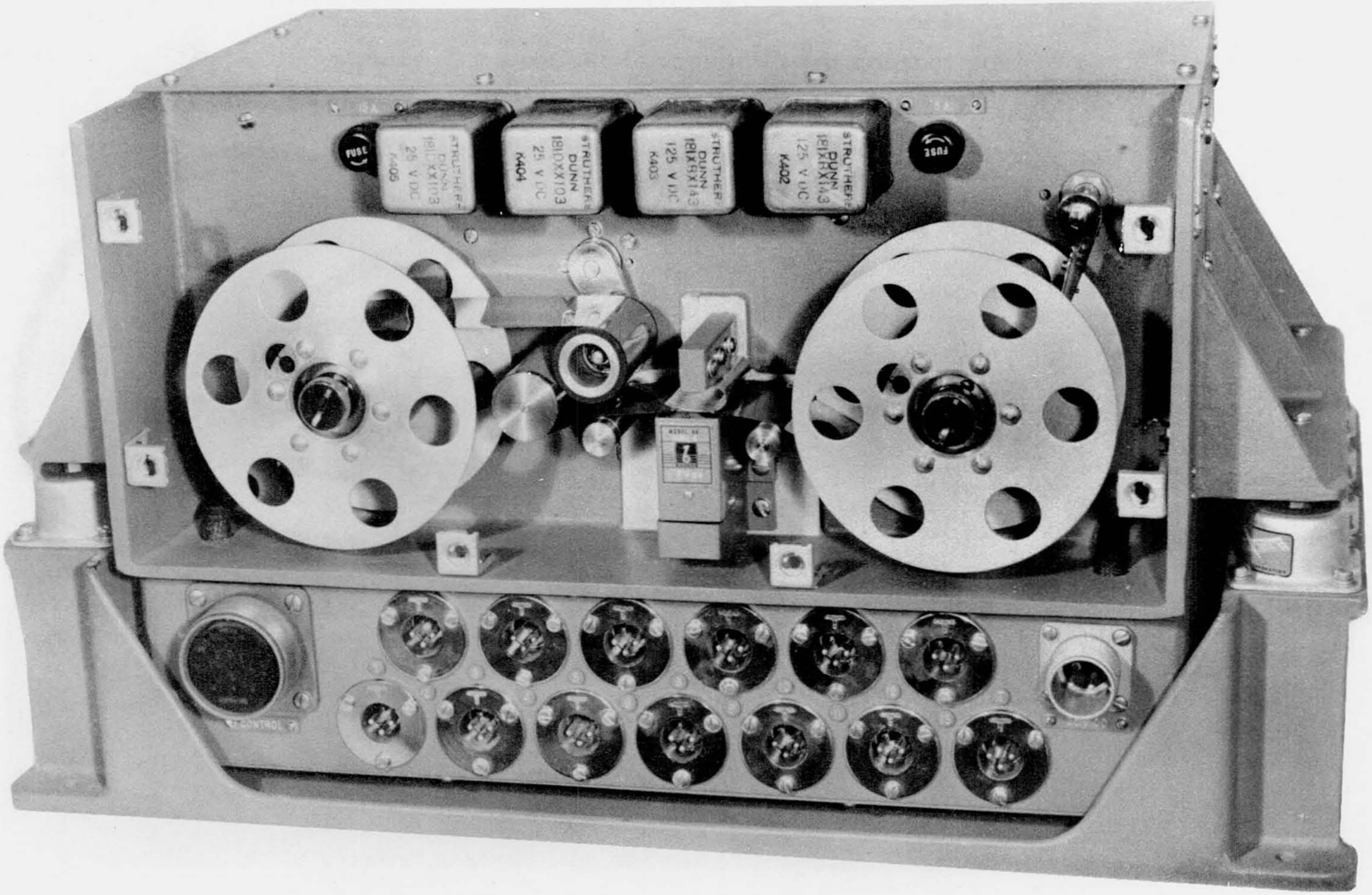

Figure 2. Front view of recorder with tape transport mechanism cover removed.

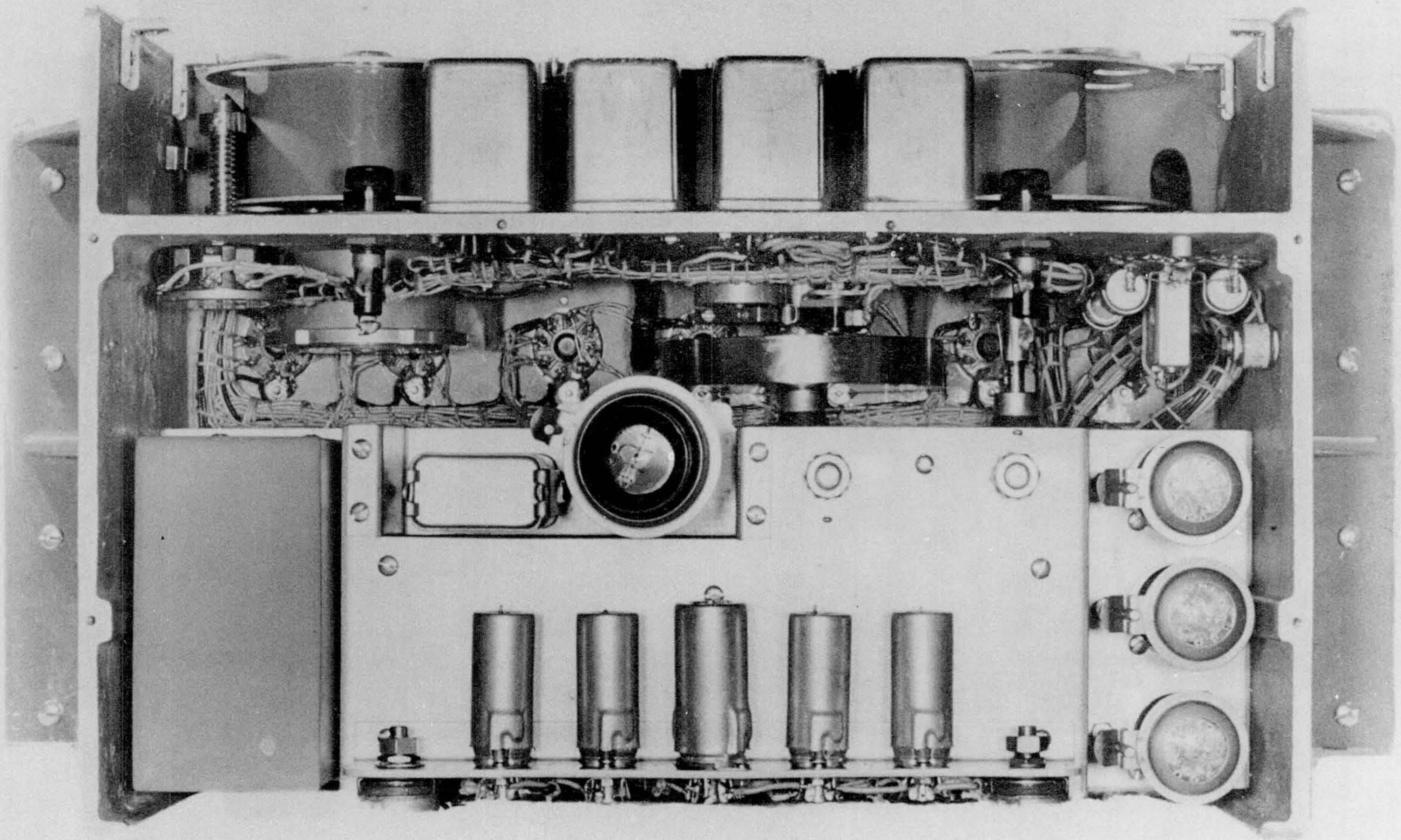

Figure 3. Top view of recorder.

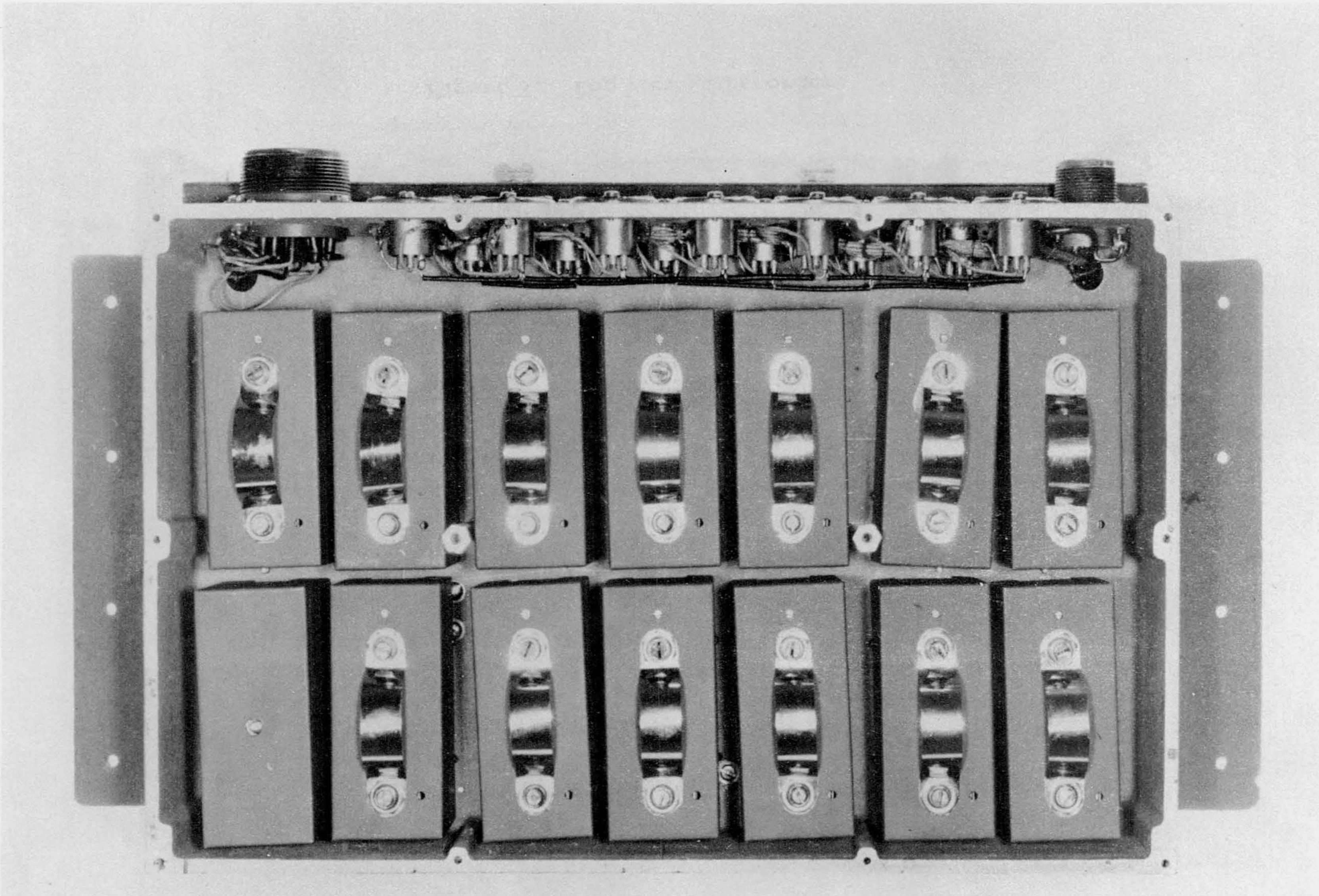

Figure 4. Bottom view of recorder with the 13 FM recording oscillators in place.

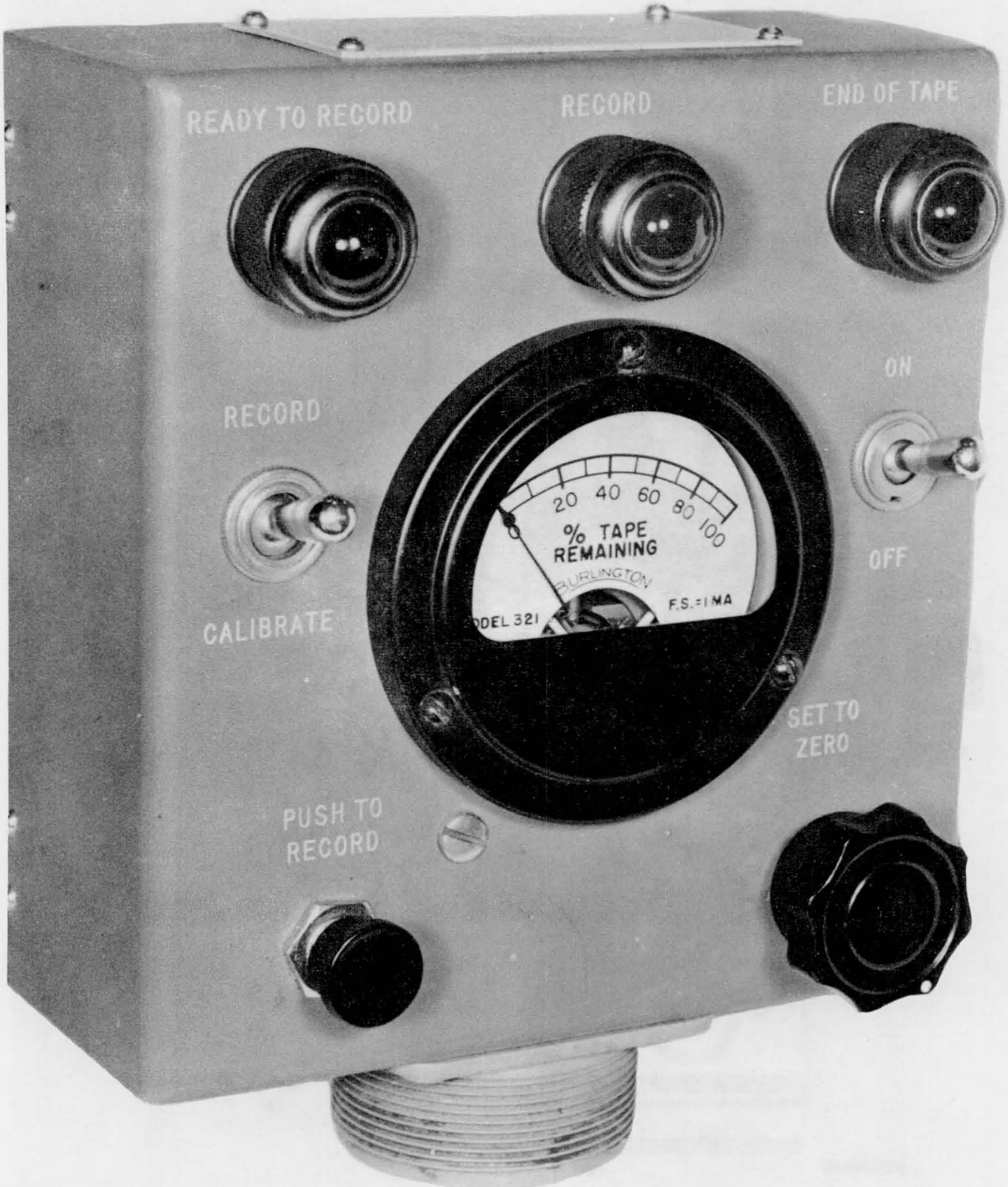

Figure 5. Remote control box.

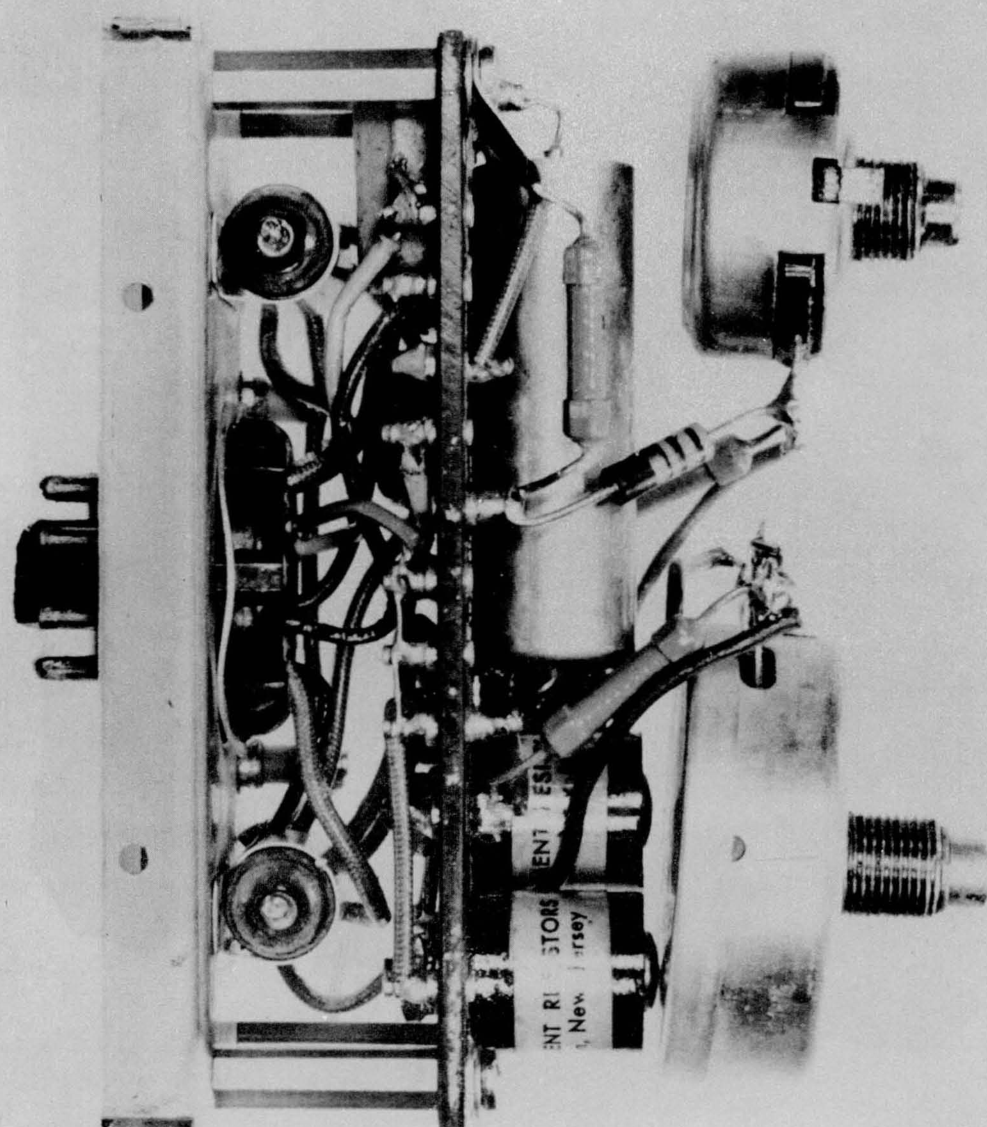

Figure 6. Close-up of FM recording oscillator.

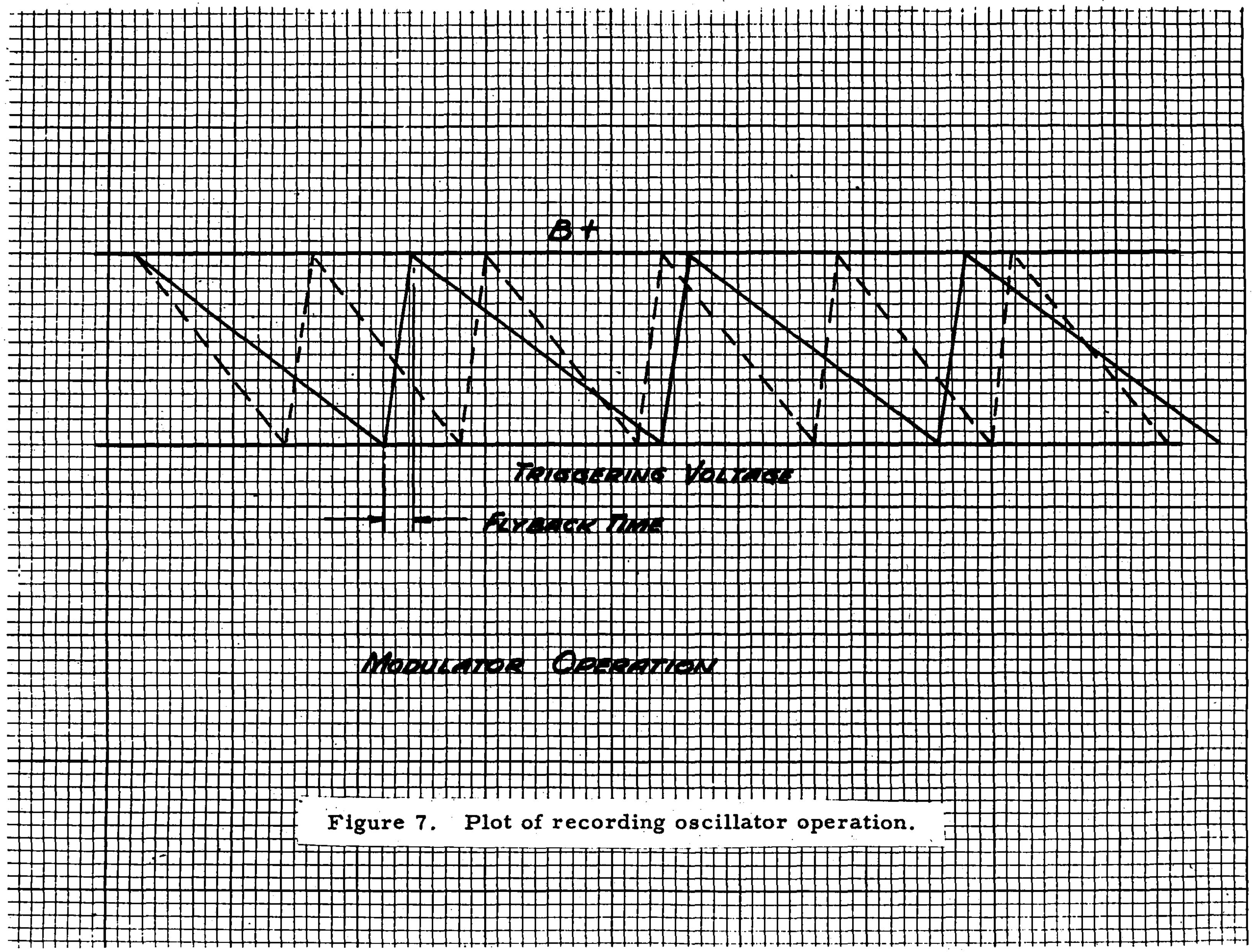

Figure 7. Plot of recording oscillator operation.

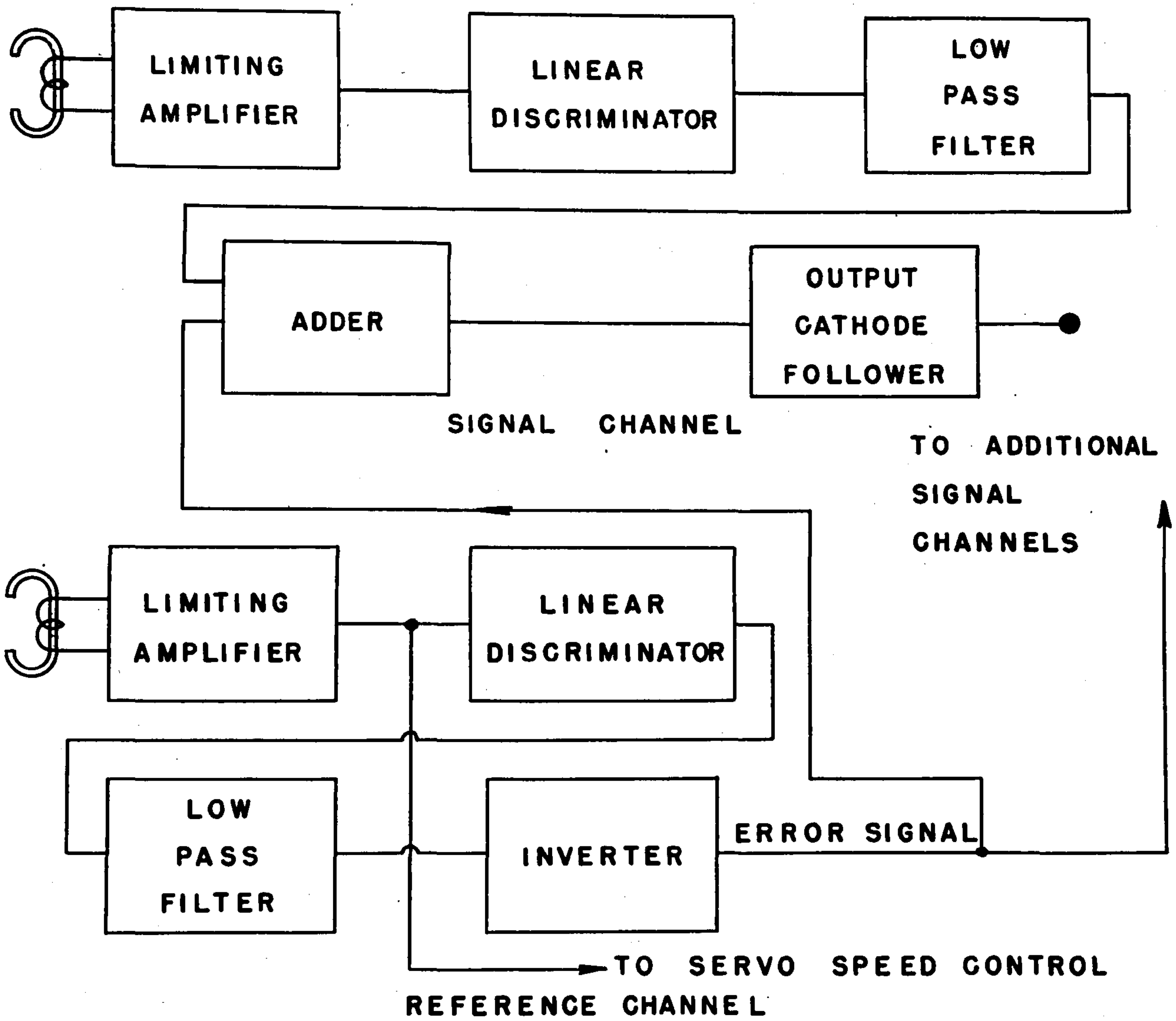

Figure 8. Block diagram of the playback system.

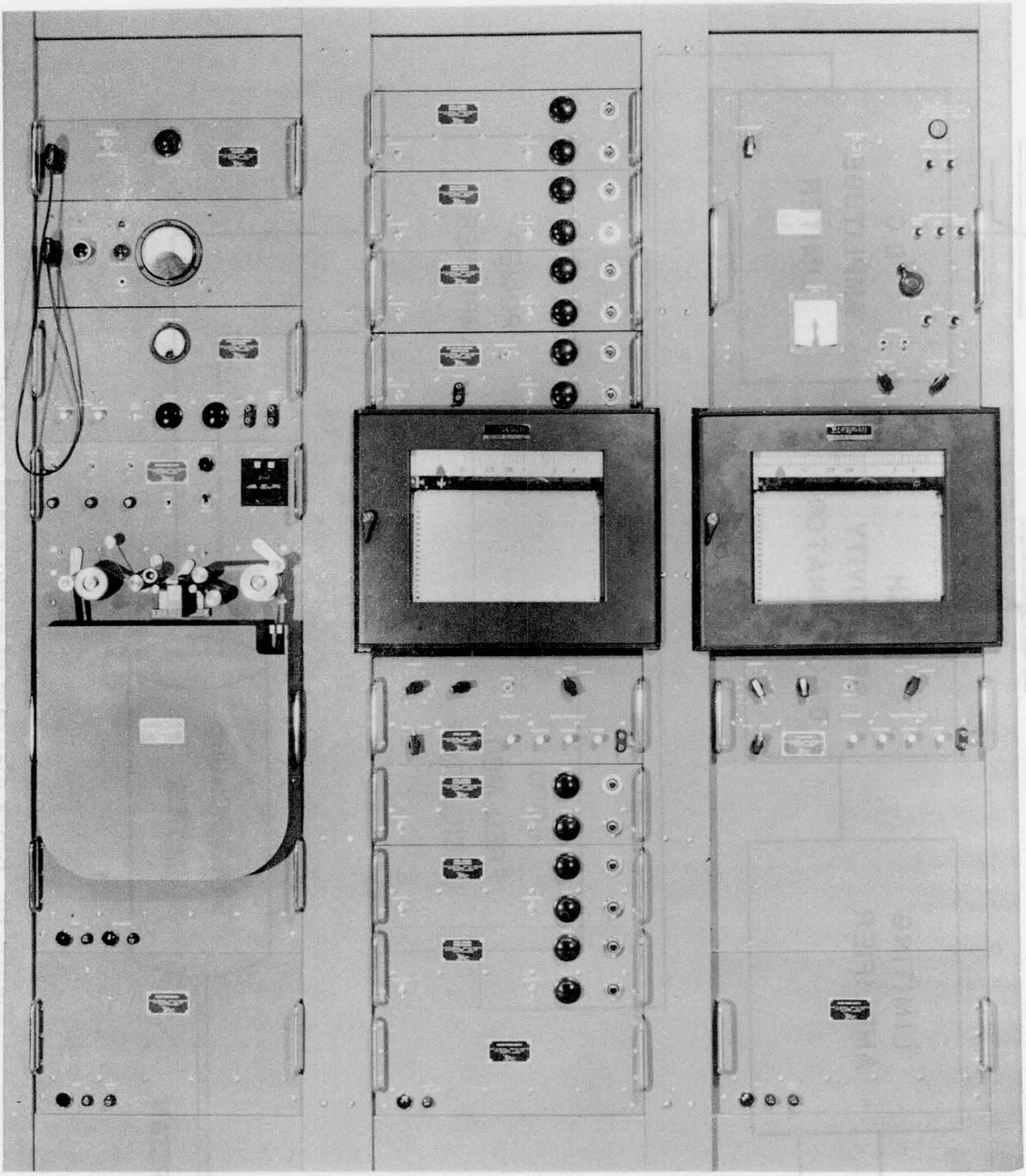

Figure 9. Equipment used for playback and Fourier analysis.

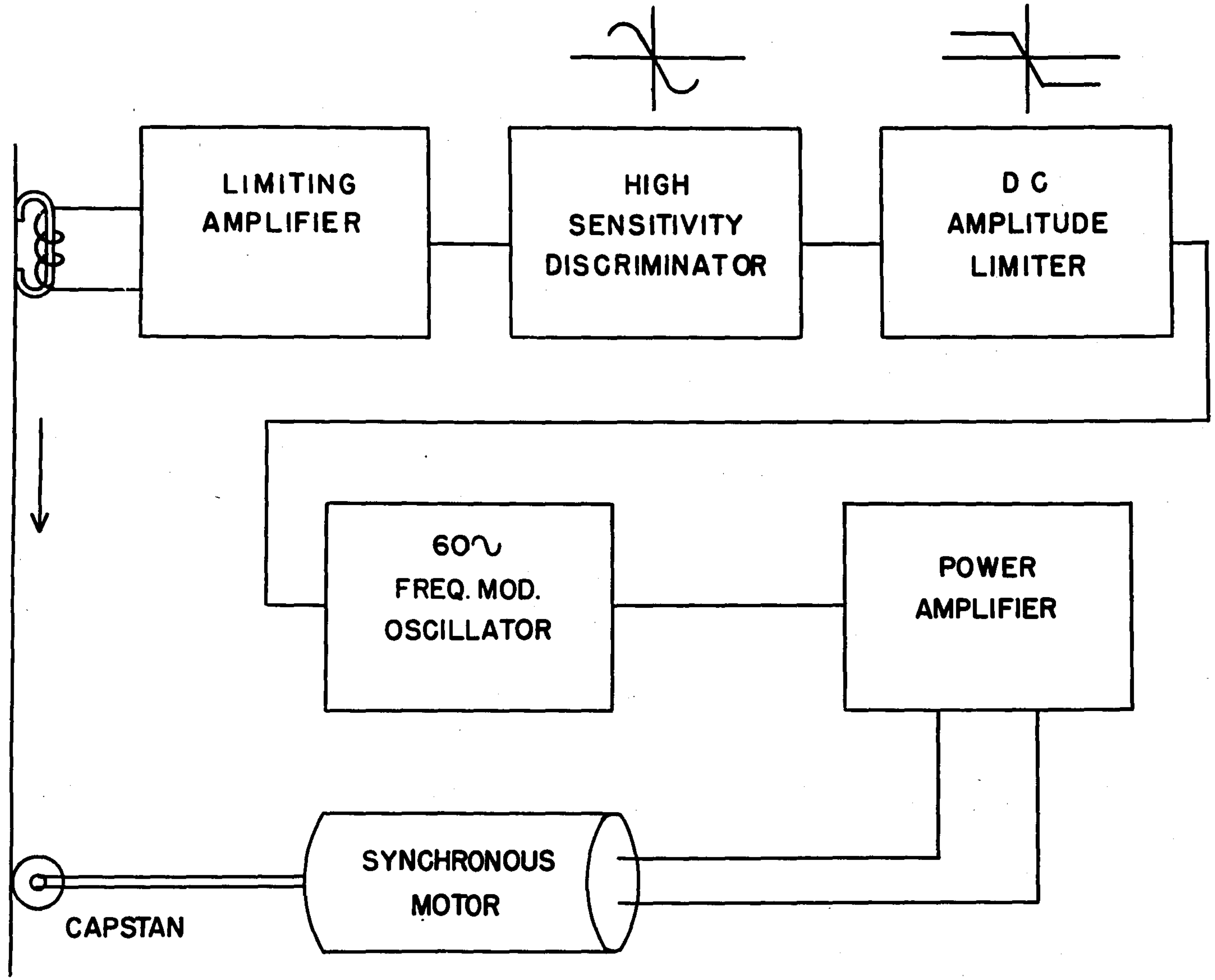

Figure 10. Block diagram of servo speed control.

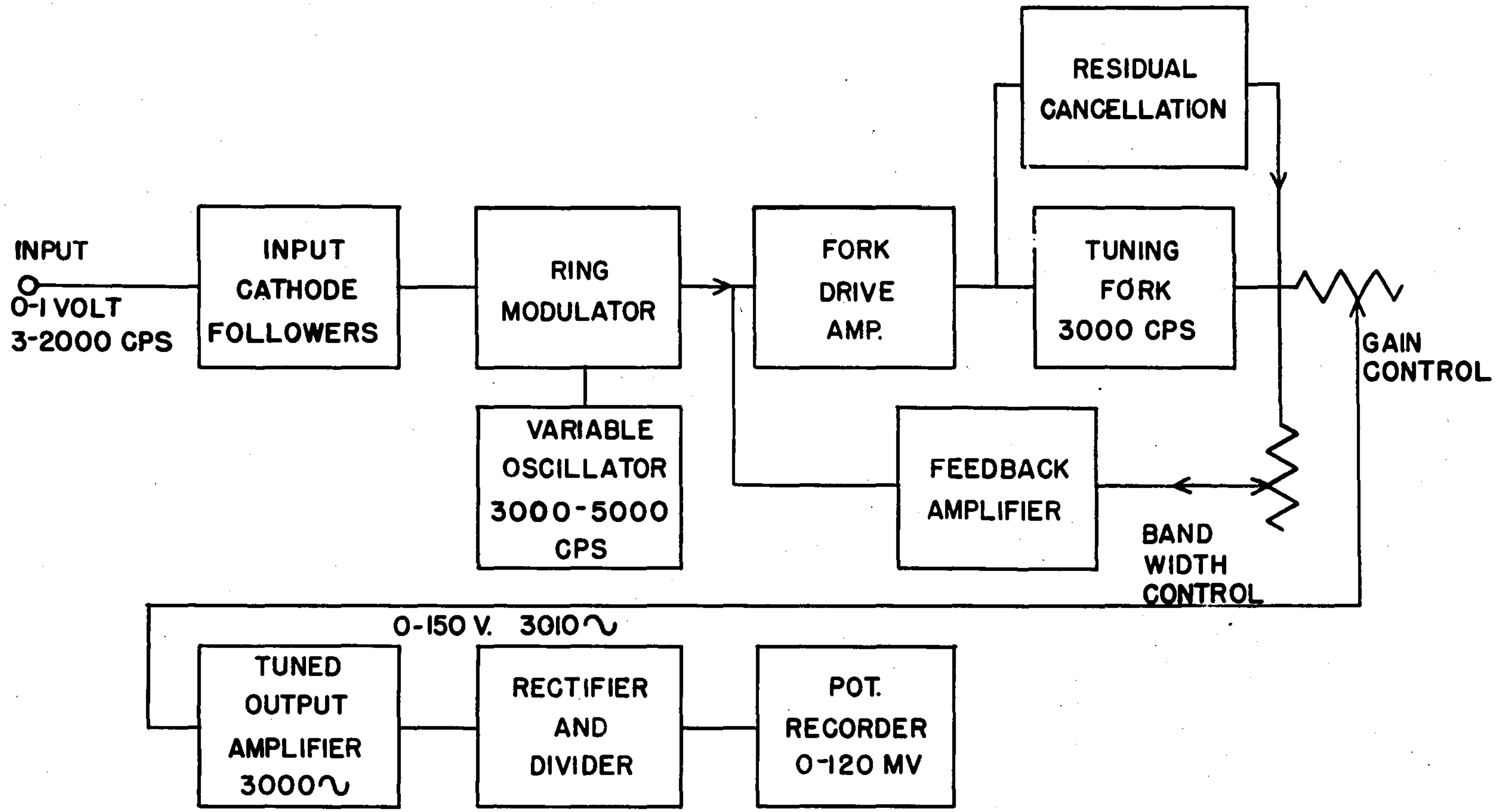

Figure 11. Block diagram of wave analyzer.

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Paper 11

IMPROVED PERFORMANCE OF MAGNETIC RECORDING SYSTEM FOR PRECISION DATA

Mr. Walter T. Selsted
Chief Engineer
Ampex Electric Corporation

9 October 1953

ABSTRACT: A recent paper, "A Magnetic Recording System for Percision Data," presented by Myron J. Stolaroff before the Institute of Radio Engineers, New York City, March 1953, has described a new FM carrier recording system making possible accurate recording of transient information with response to d-c. This paper describes recent improvements which provide stable d-c performance while still maintaining the simplicity of construction and compactness of a-c circuits. Also, improvements in low frequency response uniformity and overall linearity result in an extremely accurate recording system for wide scale applications, simplifying modifications for operations at various speeds.

Introduction

The equipment I am going to describe was designed a number of years ago at the request of a group of oil research people and by the Atomic Energy Commission. It was specifically designed for recording low frequency transients, such as occur in geophysical research work and atomic explosions, and was used for making short term records of frequencies from five to 300 cycles. However, as time went on it became apparent that it was desirable to make this equipment useful for long term recording of information signals extending from zero to several thousand cycles, and to overcome the shortcomings of our original design. The most troublesome shortcoming was that of long term d-c drift. As all of you who have worked with d-c amplifiers realize, rectifying d-c drift in hot, compact equipment is not easy.

Present System

Figure 1 shows redesigned equipment which has these limitations largely removed. This is a fourteen channel fm carrier type magnetic recorder known as the Model 306 System. The left hand rack contains the transport, the magnetic drive power amplifiers, and power supplies. The electronics are in the rack at the right, the upper third containing the recording amplifiers, and the lower two-thirds of the rack the playback amplifiers.

Figures 2 and 3 show the chassis type construction that we use for the record and playback amplifiers. Figure 2 shows two record amplifiers on such a strip. Each amplifier requires a ballast tube and three miniature tubes to constitute one record amplifier; the duplicate of it is for channel two on the right. Figure 3 shows a single playback amplifier but of similar construction. Since it requires more vacuum tubes only one amplifier was mounted per strip chassis.

Figure 4 is the circuit for the recording amplifier. The input signal on the left is coupled directly to the first grid in the d-c amplifier which is a compensated type in that the plate load resistor is the other half of the first dual triode tube, V201. The purpose of this is to improve d-c stability by standard compensation techniques. The effects of filament drift and tube ageing are largely overcome in this fashion since common variations in the two halves of the tube tend to cancel the effect of one another in the circuit. The output of the V201 d-c amplifier is coupled directly to the multivibrator which is the V202. It is a standard frequency modulated multivibrator which generates the carrier for this system. The third tube, V203, is strictly a head impedance matching amplifier to isolate the multivibrator from the head circuit and to supply sufficient power to saturate the tape in recording.

Circuit Improvements in Recording Amplifier

Several circuit changes have been made in the record channel amplifier circuit in order to correct difficulties in the earlier models. Switching the record amplifier on and off at the beginning and end of a record cycle in now accomplished by controlling the B supply voltage to the last stage, V203, instead of turning the entire B supply off to the complete record amplifier. This reduces the thermal changes which occur due to changes in plate dissipation in the previous two stages, and reduces temperature drifts quite considerably during the initial few seconds of the recording cycle. Filament circuitry has also been improved. In both this present equipment and the original equipment ballast tubes were used in series with two of the heaters in order to reduce modulator drift with changes in line voltage. However, as shown in figure 5, this alone was not sufficient. Curve A of figure 5 shows the effect of filament voltage change, as caused by line voltage change, in causing drift of the base frequency of the modulated multivibrator. As you see, drift in percent varies almost linearly with change in filament voltage.

The addition of ballast tubes in series with two of the tube heaters gives us Curve B which is much improved but not good enough. As you notice the change with ballast tubes goes through a nul in the center and then gets progressively worse again. We have found that the only way to economically overcome this--both space wise and dollar wise--is to use a line voltage regulator in addition to the ballast tubes. In that case, the drift due to filament temperature changes falls within the shaded area labelled C.

Figure 6 shows the amount of drift caused by power supply and filament variations combined in the Curve labelled A. Again, with a ballast tube alone we were getting drifts in the order of 1-1/2 to 2 percent. Use of a line voltage regulator to overcome B supply drifts as well, caused the overall drift to fall within the shaded area, B.

Aging of tubes is another important cause of drift in equipment of this type. Tubes pulled directly from their cartons and placed in service exhibit far worse drift characteristics than those which have been aged a number of hours. We found that a minimum aging of two hours under a normal filament voltage, normal operating conditions, improved drift from them by a fraction of approximately 50 percent which is quite significant.

Figure 7 shows the overall drift versus warmup time in minutes during warmup of the modulator and its associated power supply. The obvious cause of drift during this period is thermal stabilization with tubes themselves contributing about 90 percent of the drift. After a warmup period of approximately thirty minutes the overall drift does not exceed one percent at 100 percent modulation of the carrier. If the recording equipment is left on for an hour, then is put on standby, stabilization within one percent drift is reached in five seconds which is the time for transport to get up to normal speed.

Circuit Improvements in Playback Amplifier

Figure 8 shows the circuitry of the demodulator wherein most of the circuitry deficiencies of our earlier design were corrected. Remembering that the original equipment was designed for a specific purpose and in a very great hurry, many of the little refinements which reduced d-c drift were not considered at that time. The frequency response at the input stage, V310, has been improved for several reasons, but not primarily to correct d-c drifts. The principal reasons were: extending its useful range to permit various tape speeds to be used without having to change the demodulator circuitry each time a change in speed is made. Stage one can now handle carrier inputs that extend from a thousand cycles to 50 kilocycles without any changes. Stage two was altered in the same way, being very similar to stage one in function. In stage three, besides low frequency and high frequency response improvements, the limiting voltage was stabilized by reducing the bias source impedance for the diodes which are the limiters. This stabilization is important in that it prevents a change in level from the input from causing a change in the resultant square wave voltage level. Some of the change in level was due to the fact that the bias supply of the last limiting diodes was higher than might have been desired, so diode bias is now derived from the cathode drop in the cathode load resistance in this final stage. Note that bias for the first stage, second stage, and third stage diodes are taken at different points along the cathode resistor string. This turned out to be a very stable arrangement and as a result the variations in pulse level at the grid of the phase inverter, V310, are much smaller than previously with a much more uniform pulse level than before. Therefore, changes in level of signal from the tape do not give appreciable d-c drift.

In stage four, V310, there were a couple of components which suffered seriously from temperature variation and temperature drift. These were removed and the circuit redesigned so that these effects were negligible. The primary way in which this was done was to move the differentiating circuit for the cycle counter type of discriminator to a point after the phase inverter, whereas formerly it had been before the inverter. This results in several improvements; the principal one being that changes in gain of the phase inverter due to temperature changes do not change the a-c gain appreciably but only the change in the d-c level. The d-c level change does not affect the output since the differentiation occurs just before the diodes which are the discriminator. Also, in the original equipment a shelf occurred in the low frequency portion of the spectrum, due to differentiations which were occurring in the phase inverter circuitry. Since the phase inverter is now a straight pulse amplifier rather than a d-c amplifier as well that particular defect is gone. The frequency response at very low frequencies in now uniform. Formerly, it dropped about five percent.

In stage five, the diode rectifier, V313, and cycle counter, V314, certain constants were rechosen so that the carrier frequency of 50 kilocycles or higher could be handled without change of components as well as carrier frequencies as low as a thousand cycles which occur at very low tape speeds. The circuity could now be used with tape speeds as low as one inch per second giving a carrier of 1,000 cycles per second, and up to 60 inches tape speed which corresponds to a carrier frequency of approximately 54 kilocycles, This allows the manufacturing of one type of device which is very useful over a very wide range of frequencies.

Stage six, V314, has now a compensated cathode follower. It is compensated for d-c drift in a similar manner to that which was used in the d-c amplifier of the recorder section (see V201 in figure 4) in that the plate voltage is supplied through another triode in the same envelope rather than through a plate resistor or directly from the B plus supply. Same plan is used in the output stage. This arrangement again reduces the effect of changes in the filament voltage and tube aging.

Early customers wanted a 600 ohm output impedance and in the attempt to obtain this considerably higher currents were required from the cathode follower than might be desirable from the standpoint of considerations of grid current and heater current changes. Therefore, in the present equipment, we have changed the output load impedance which the customer should use to load the amplifier in order that the drift due to temperature changes in the cathode follower as well as due to grid current drawn on the grid of the output cathode follower could be greatly reduced.

The filter between V314 and V315 is the carrier rejection filter. Its output impedance approaches a half megohm so grid current in the final stage, V315, is a possibility with attendant grid voltage which would of course produce a very serious source of drift. However, since the triode section which serves as load is in the cathode circuit rather than in the plate circuit of the final stage compensation is thereby achieved for possible grid current flow.

Figure 9 shows the overall drift of the demodulator after the changes were made and, as you see, stability approaching three-quarters of one percent was obtained within an hour after turning the equipment on. Prior to that time it's somewhat higher as the graph shows. Again, the remaining drifts are due to such things as diode characteristics changing due to temperature, tube and resistance components changing due to change in temperature. We have decided that improving it beyond this point is economically impractical at this time considering that a large number of elements would have to be controlled in production in order to improve it sufficiently.

Power Supply Circuitry

Figure 10 shows the type of power supply now being used. It's the same as has always been used except for a couple of interesting things which has been discovered about its performance. As you see, it's primarily a regulated positive supply with 250 volts d-c, positive 75 volts, and positive 150 volts. The latter two voltages are derived from the use of a pair of VR75 tubes and a voltage regulating circuit. Insofar as stability is concerned, the 250 volts supply is by far the most important to the circuitry which is used in the record amplifier. The most serious source of drift of this voltage were changes in the filament voltage to the 6AC7 tube, V903. This had the same effect on d-c drift of the 250 volt supply as changes in filament voltage in the record amplifier and modulator. Therefore, either a regulator had to be build into the power supply for that filament or an external regulated line source is desirable. Actually, in most laboratory conditions, the line voltage stability is fair but if it is not a source of regulated power is available and greatly improves the d-c drift. Aging of new tubes had similar effects here as it did in the record amplifier, and demodulator, and a two-hour aging period for new tubes greatly improves the stability of the power supply as well.

Occasionally a tube of the VR75 type will have some peculiar characteristics and it may jump up or down a few millivolts just at will. The only cure that has been found for this is to replace the tube. Changes in them do not seem to be appreciable once a good VR75 has been found. About 90 percent are good VR type tubes and about 10 percent of them seem to be bad.

Improved Frequency Response

Figure 11 shows the overall frequency response prior to the improvements described above. The only change in frequency response as a result of these improvements has been that the small shelf, far left on the upper curve, is no longer there and the response is now flat out to zero at the same level as it is at the 500 cycle point. Variations from this will amount to something on the order of a tenth to a quarter of a decibel in the worst cases. This apparently is due to other factors in the filter rather than in the basic circuitry.

The response at the high frequency end is within a decibel or less up to 5,000 cycles in this particular circuit, at a tape speed of 30 in./sec., and drops off very rapidly for higher frequencies. Response at various tape speeds is of the same order as shown except with changes of range in accordance with the tape speed used.

Figure 12 shows the transient response of the overall equipment for an input square wave of 50 cycles into the modulator, recording on tape, subsequent playback and demodulation. Note the overshoot of about five percent which occurs as a result of ringing in the LC circuit in the carrier rejection filter. If this is a serious objection the frequency response can be modified somewhat at the high frequency end by critically damping the circuit with a consequent reduction of this ringing effect. As a result the leading and trailing edges of the square wave are rounded over and the overshoot is not there.

Signal-To-Noise Ratio

The signal-to-noise ratio of 40-50 db on this equipment has not been improved since this ratio is primarily limited by the speed stability of the transport. For those who need a better or higher ratio than 40-50 db this can be accomplished by either using a more precise tape transport which we also manufacture, or by narrowing the bandwidth of the recording and playback amplifier system. The primary causes of frequency flutter are tape squeak, scrape, and other noises causing speed variations. In the type of transport which we normally supply most of these effects are in the region between 1,000 and 3,000 cycles, so for recordings that only need a bandwidth of 500 cycles, for example, a 500 cycle low pass filter will greatly improve signal-to-noise ratio. In fact, with a bandwidth of zero to 300 cycles a ratio of 53 to 54 db is not uncommon.

Overall Response Stability

For recording a bandwidth of zero to 5,000 cycles a 30 inch tape speed is necessary using a carrier frequency of approximately 27 kilocycles. Harmonic distortion runs less than two percent. At maximum recording level the a-c linearity is two percent or better; the d-c linearity, measured as the error in voltage output versus voltage input at any particular level, does not exceed three percent. This is better than saying three percent of full-scale as the maximum error. Using a line voltage regulator for both record and playback, the error in d-c stability in a recording made over a 15 minute period, after a 30 minute warmup, will not exceed three percent of full-scale. After a 60 minute warmup the error will not exceed 1-1/2 percent of full-scale. This holds for normal changes in ambient temperature of the order of two degrees during the recording period. A-c stability, that is the variation in overall a-c gain, is less than one percent maximum signal over any 15 minute period under the same conditions as mentioned above.

For an average production machine recording over a period between five and 10 minutes, a typical performance is an average error of less than one percent due to changes in ambient temperature, line voltage changes to the regulator, and other variations which might enter due to temperature, humidity, and other factors. This one percent overall accuracy is nearly half the expected error in the average source of input signal. We have found that transducers of the type that are used on aircraft and other types of input generators usually have an error which is in excess of one percent and therefore, the limiting factor, we feel, is not going to be the recording equipment for this type of measurement.

DISCUSSION PERIOD SUMMARY

In answer to a question from Mr. Boenning from National Security Agency, Mr. Selsted advised that the Sorensen electronic regulator was used for stabilizing line voltage rather than the magnetic type regulator, such as the Sola, because the magnetic type regulators are sensitive to changes in frequency and will not perform properly if frequency departs too far from the design center. Since the magnetic recording equipment is often used in the field where supply may be from a motor generator where the frequency as well as the voltage is subject to severe variations the electronic type voltage regulator was chosen as being the most satisfactory.

F. B. Langley

Mr. Smith of National Advisory Committee for Aeronautics requested information on the carrier frequency used and the percentage of deviation for full-scale modulation.

Mr. Selsted noted that for a zero to 5 kc bandwidth the carrier center frequency is 27 kilocycles at a tape speed of 30 inches per second and that the deviation is plus or minus 40 percent of that carrier frequency for maximum modulation output. The standard input for 100 percent modulation is one volt rms.

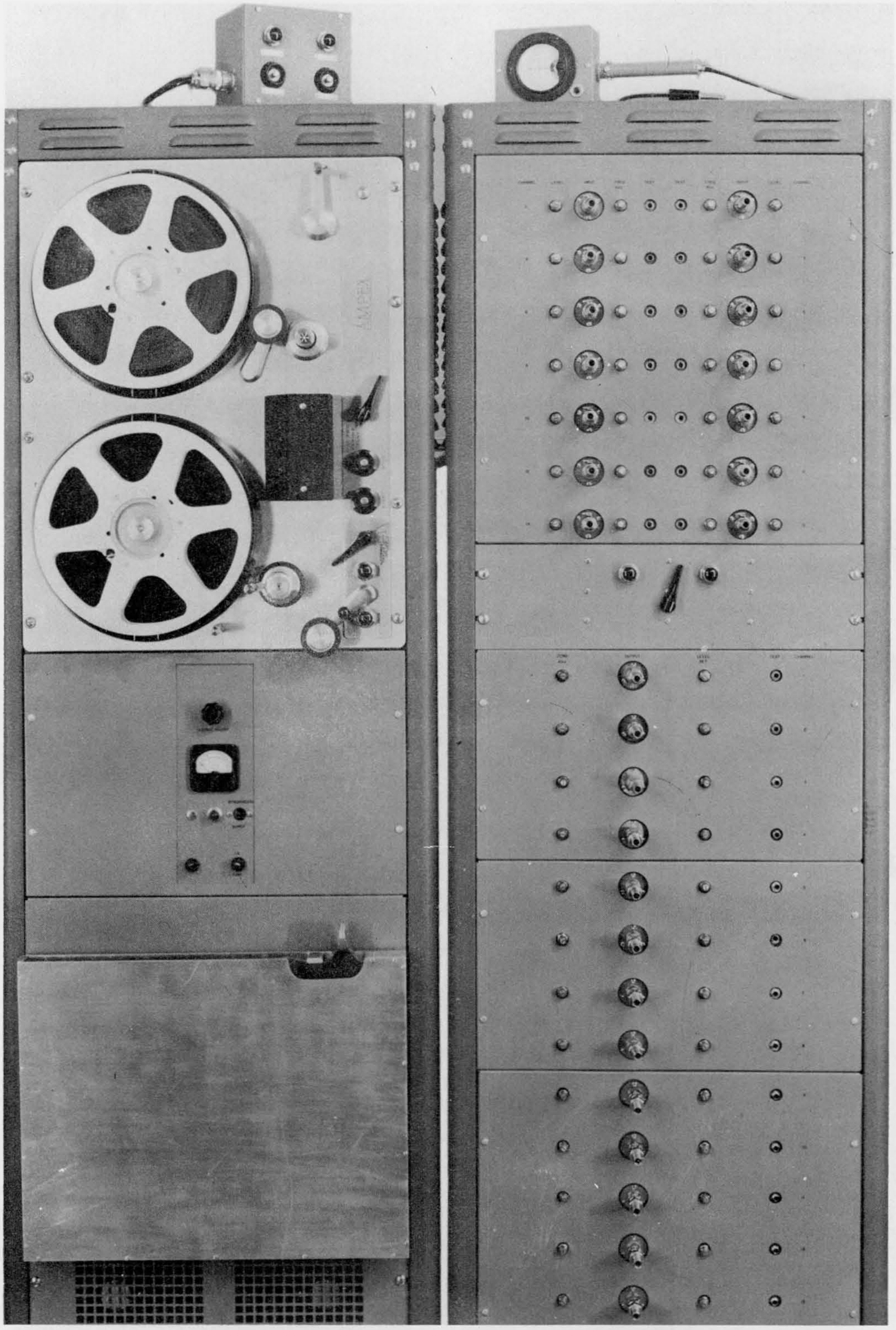

Figure 1. Fourteen channel FM carrier type magnetic recorder.

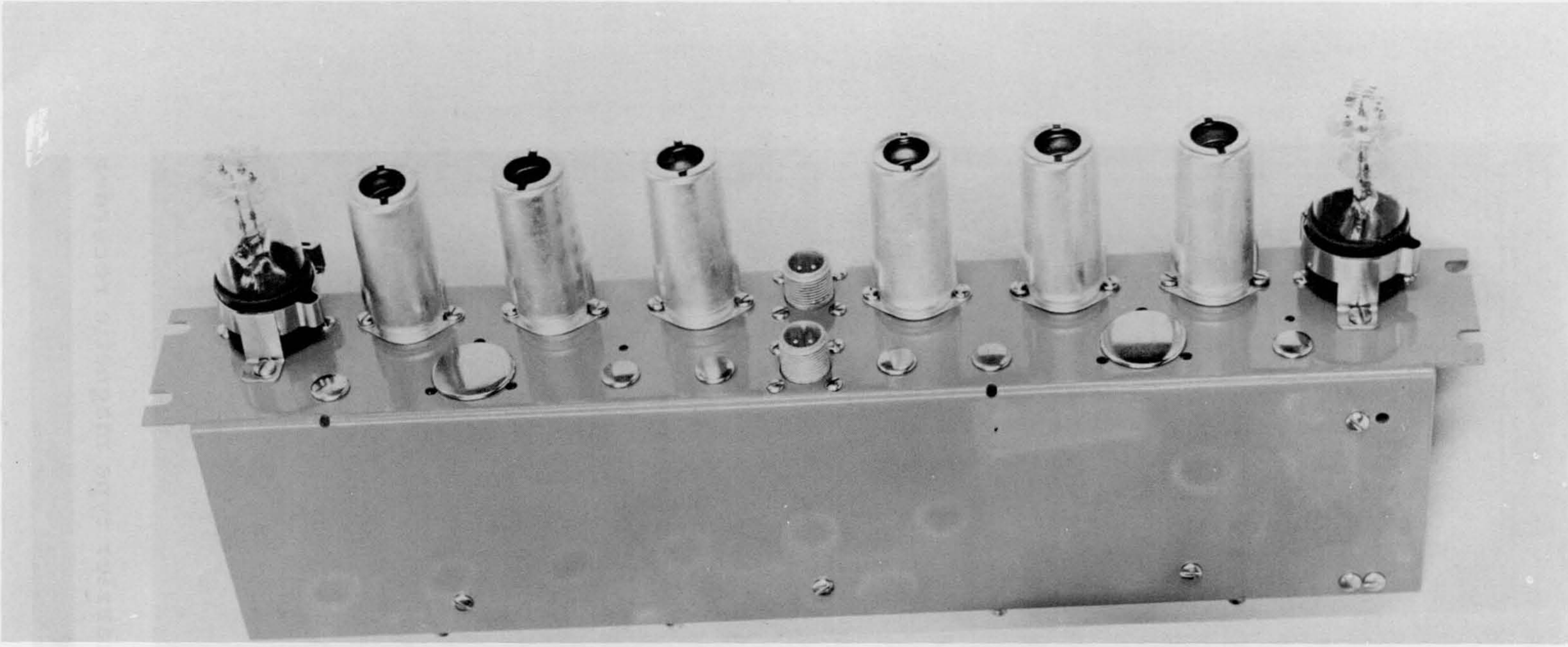

Figure 2. Chassis construction for two record amplifiers on one strip.

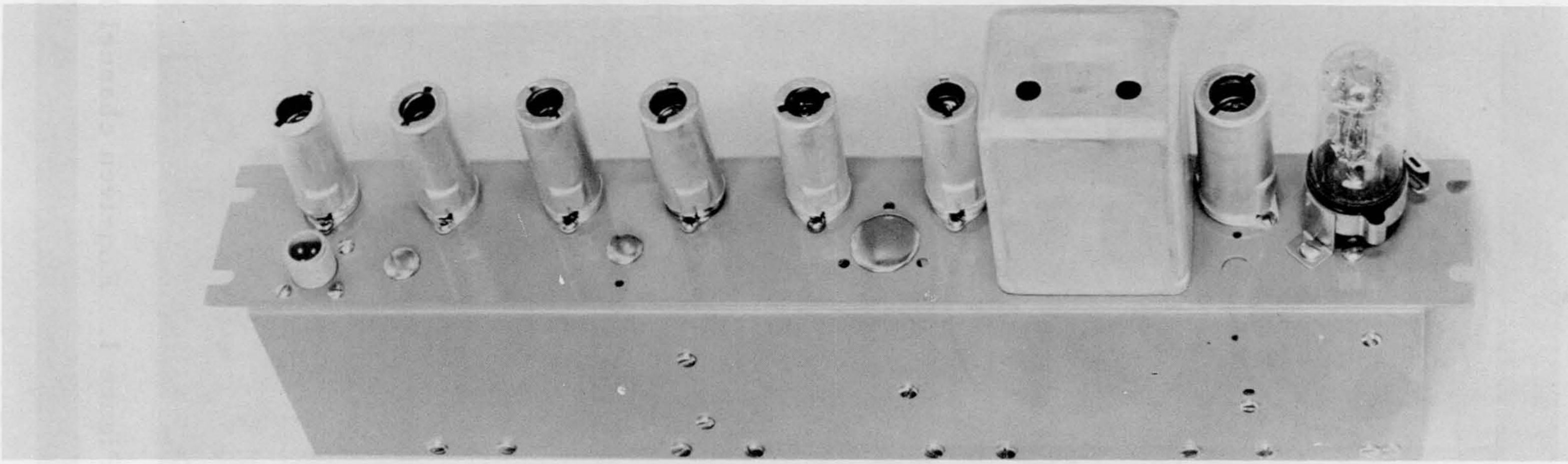

Figure 3. A single playback amplifier of similar construction.

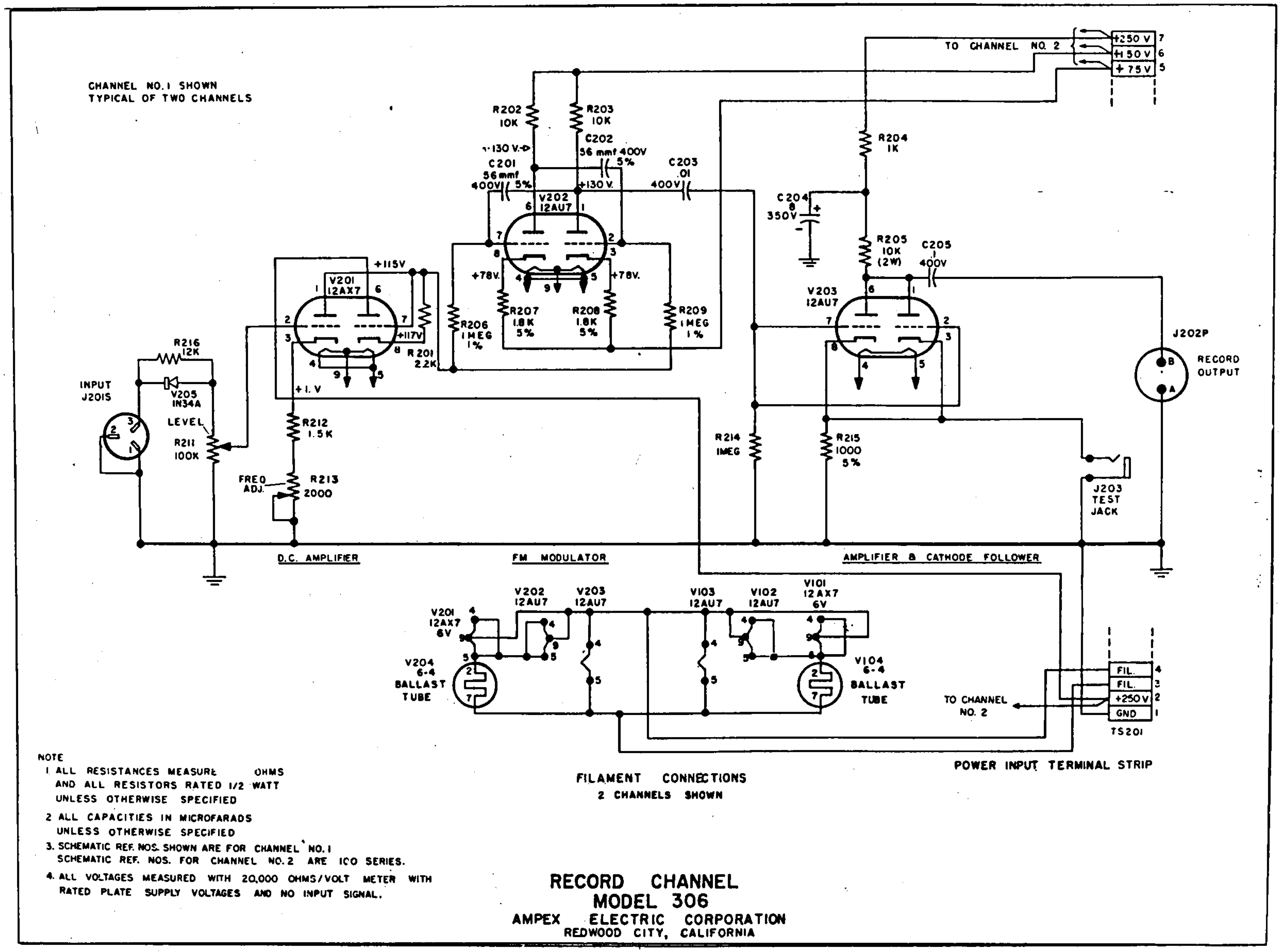

Figure 4. Circuit diagram for recording amplifier.

Figure 5. Modulator drift versus line voltage with respect to heaters only.

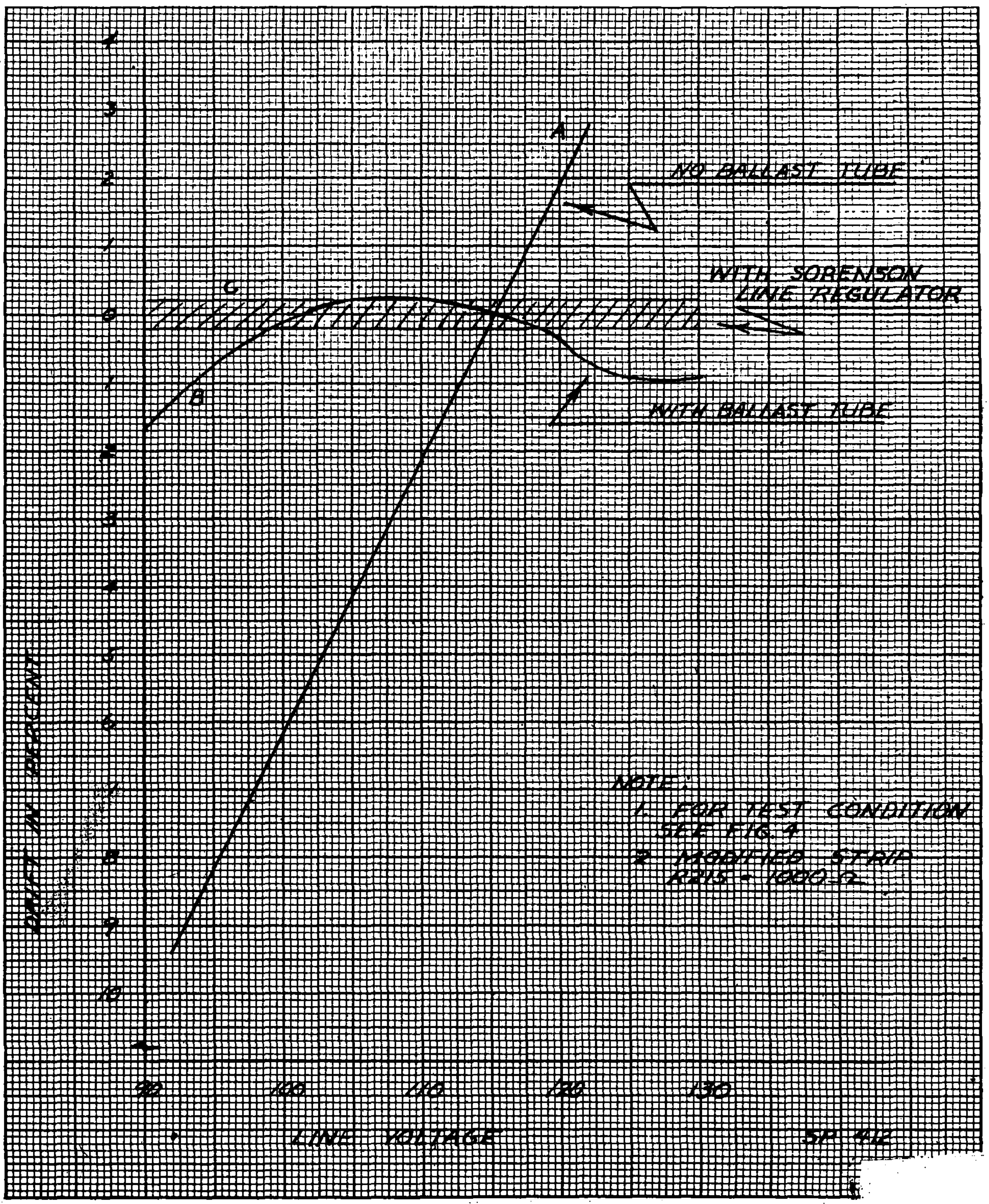

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Figure 6. Drift of modulator and power supply for line voltage change.

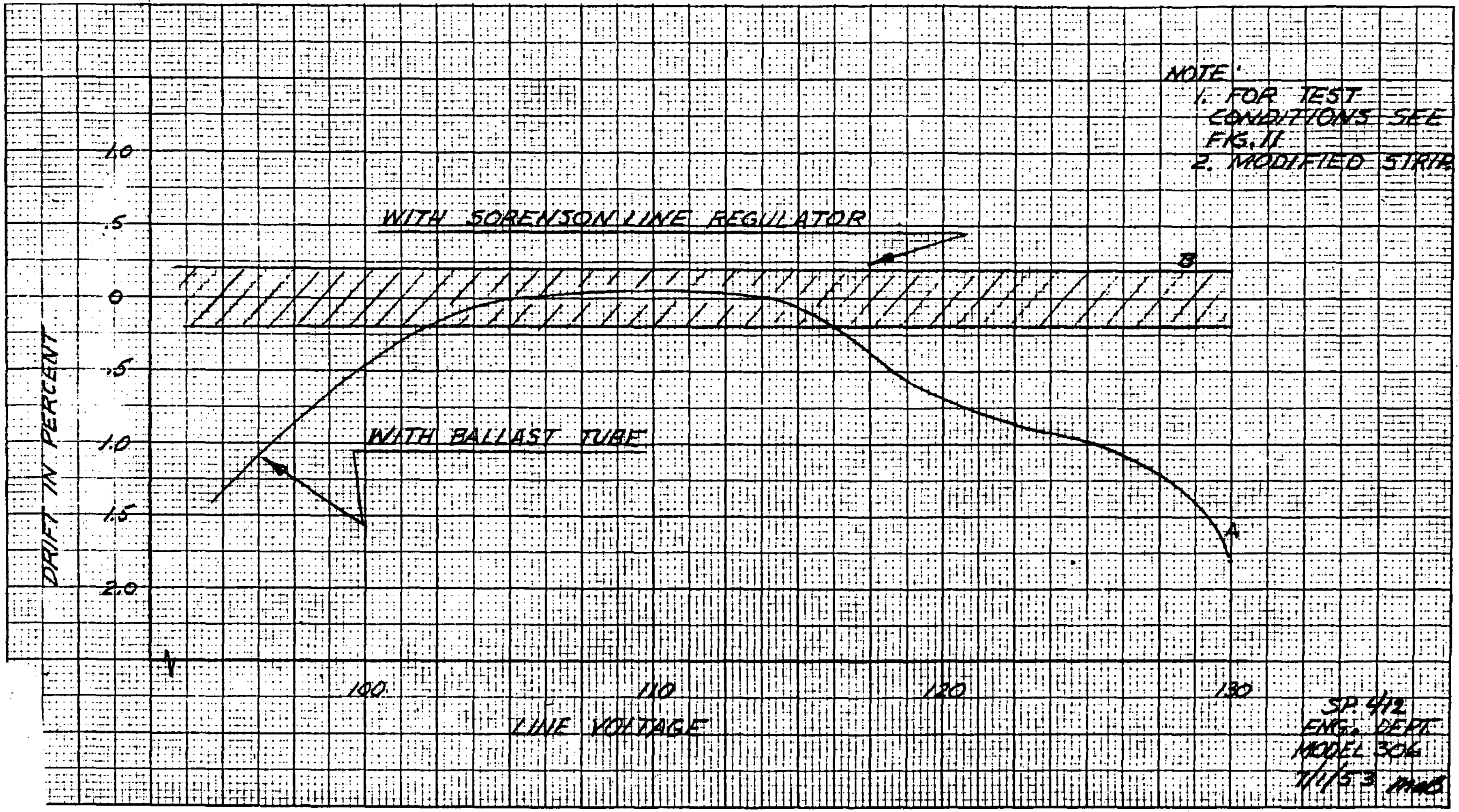
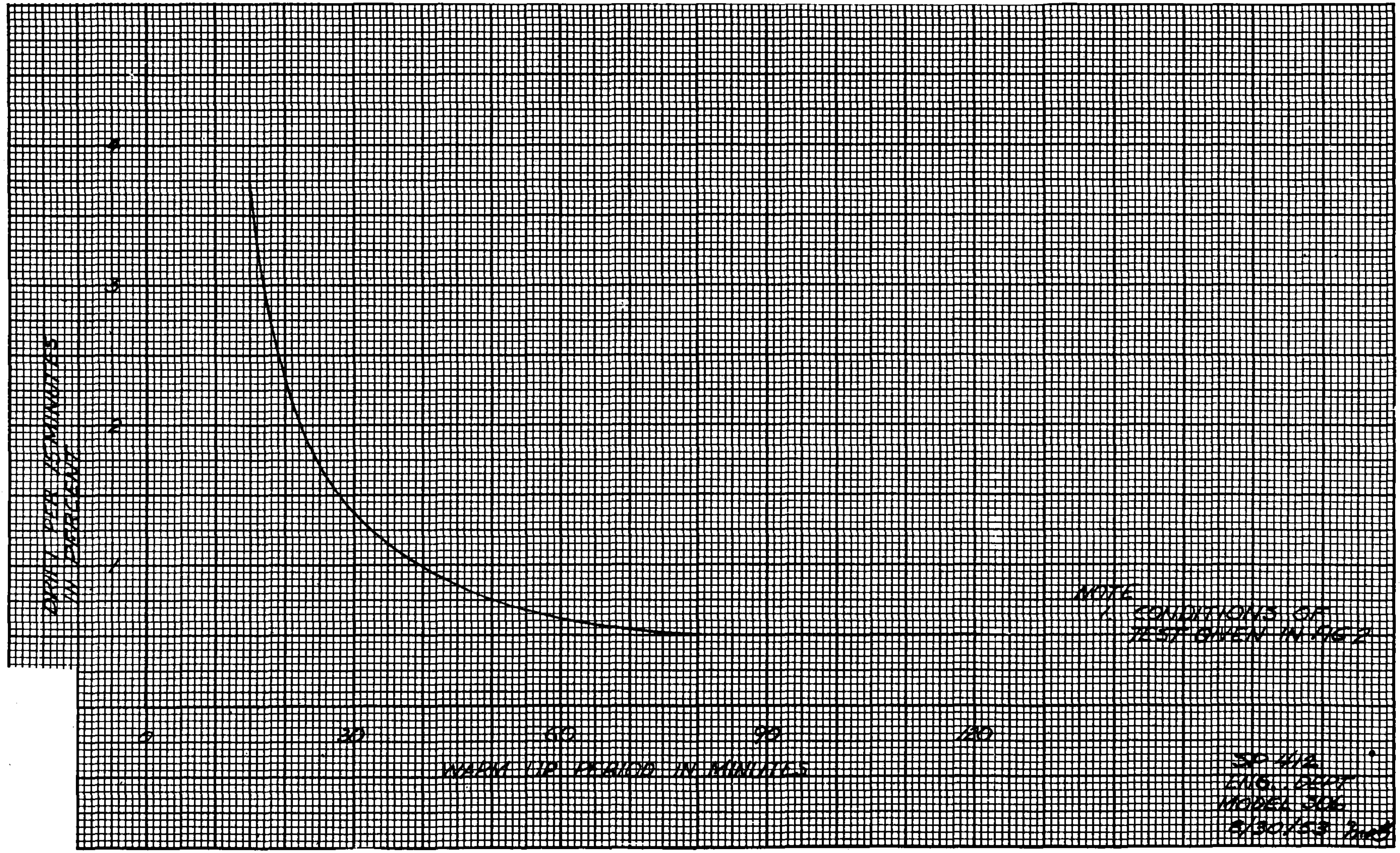
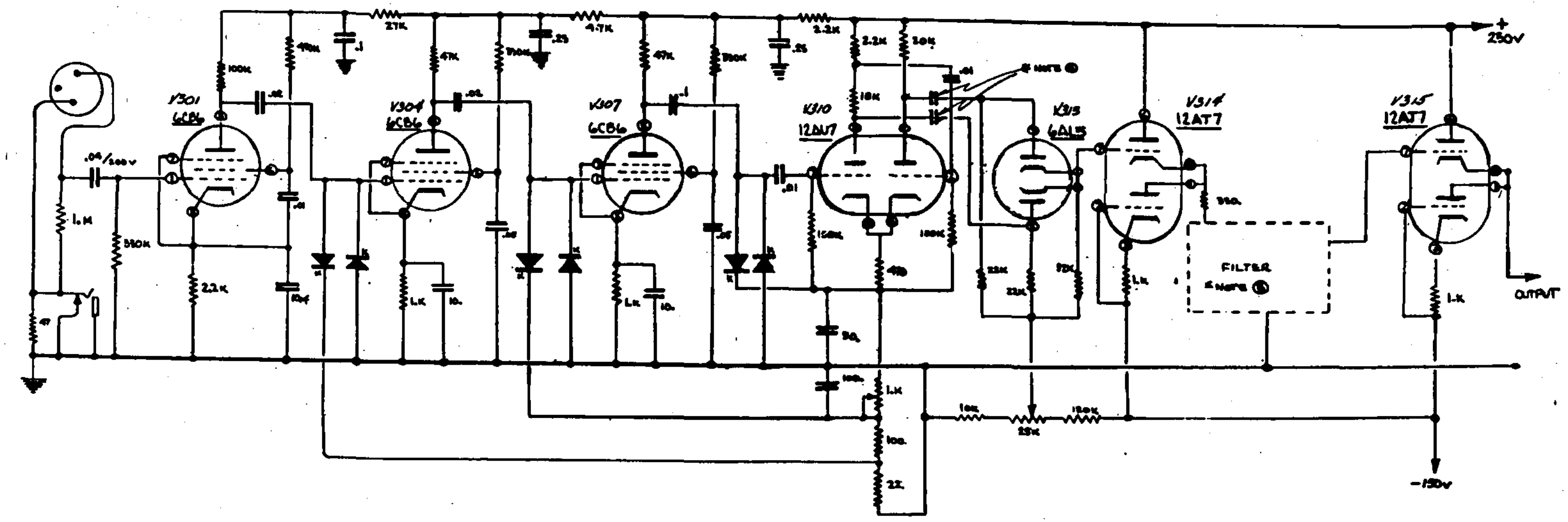
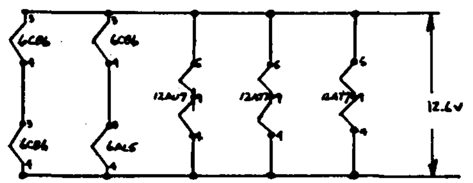


Figure 7. Predicted maximum modulator drift.





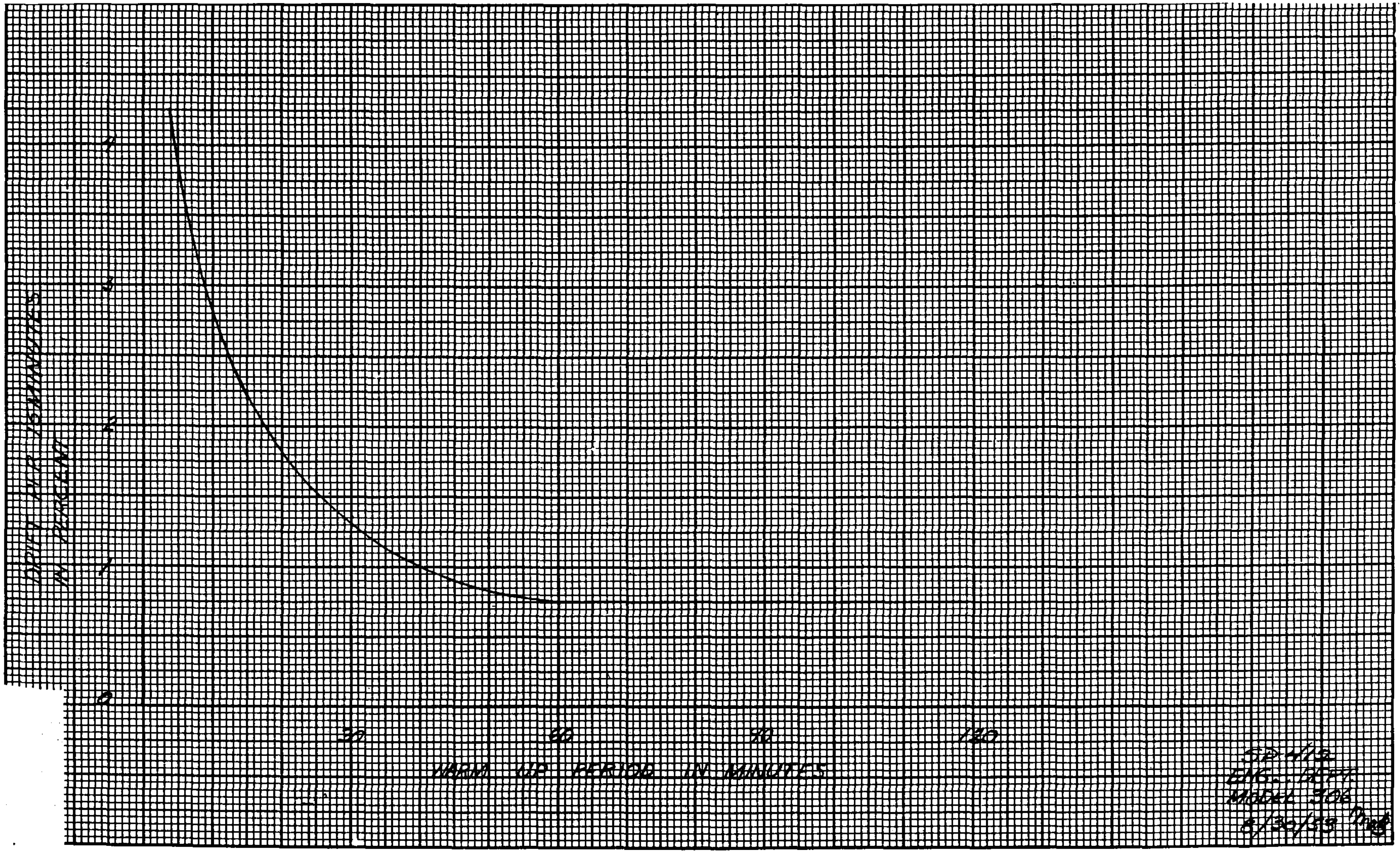
CARRIER	NOTE (A)	NOTE (B)
54KC	20μμf each	10KC cutoff
27KC	47μμf "	5KC "
13.5KC	100μμf "	2.5KC "
6.75KC	200μμf "	1.0KC "

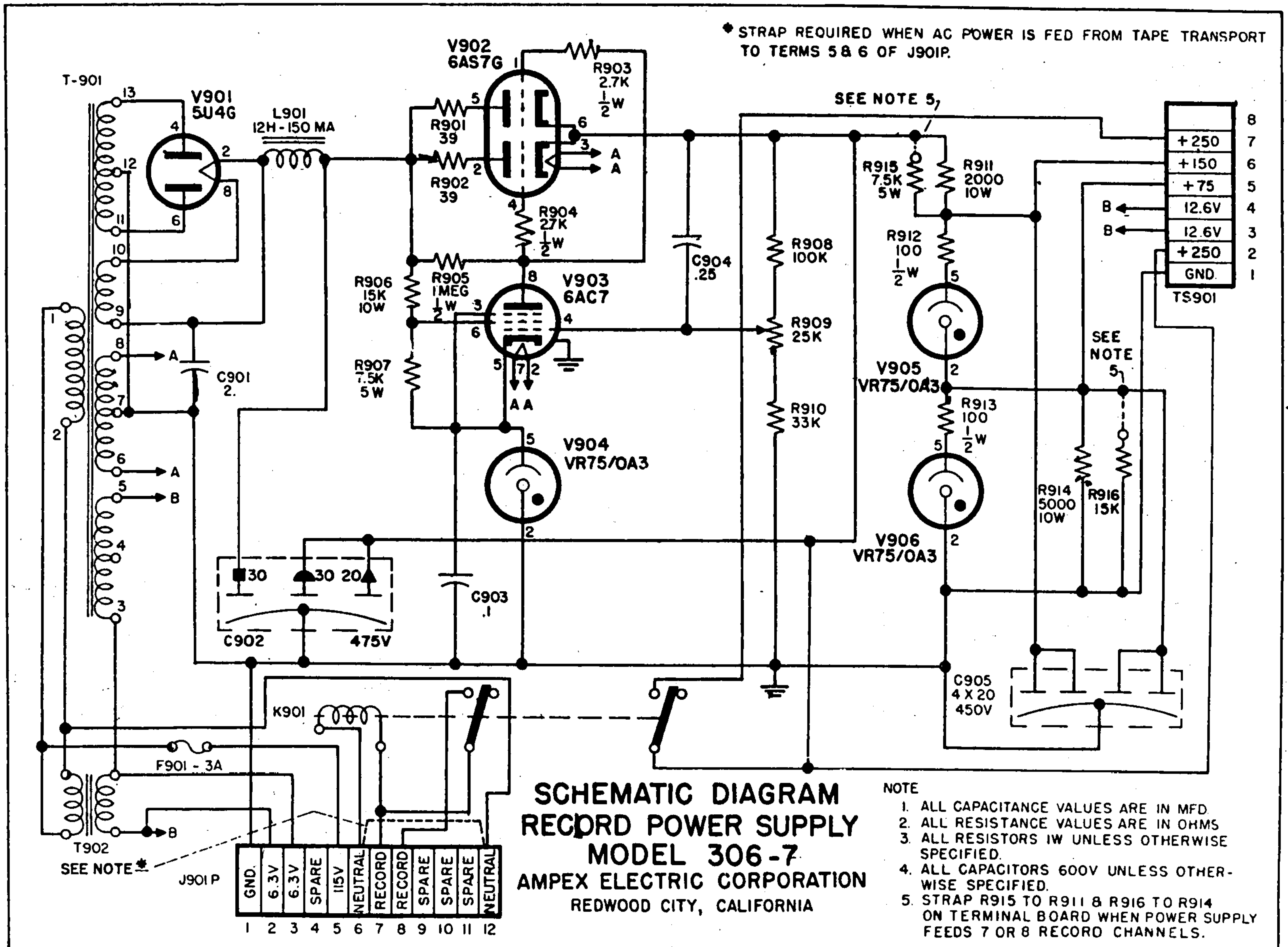


306 DEMODULATOR STRIP
WITH SUGGESTED MODIFICATIONS
AS OF 8-10-58
W.J.P.

Figure 8. Circuit diagram of improved demodulator.

Figure 9. Predicted demodulation drift derived from observed maxima of four typical modified units.





SCHEMATIC DIAGRAM
RECORD POWER SUPPLY
MODEL 306-7
AMPEX ELECTRIC CORPORATION
REDWOOD CITY, CALIFORNIA

NOTE
1. ALL CAPACITANCE VALUES ARE IN MFD.
2. ALL RESISTANCE VALUES ARE IN OHMS
3. ALL RESISTORS 1W UNLESS OTHERWISE SPECIFIED.
4. ALL CAPACITORS 600V UNLESS OTHERWISE SPECIFIED.
5. STRAP R915 TO R911 & R916 TO R914 ON TERMINAL BOARD WHEN POWER SUPPLY FEEDS 7 OR 8 RECORD CHANNELS.

Figure 10.

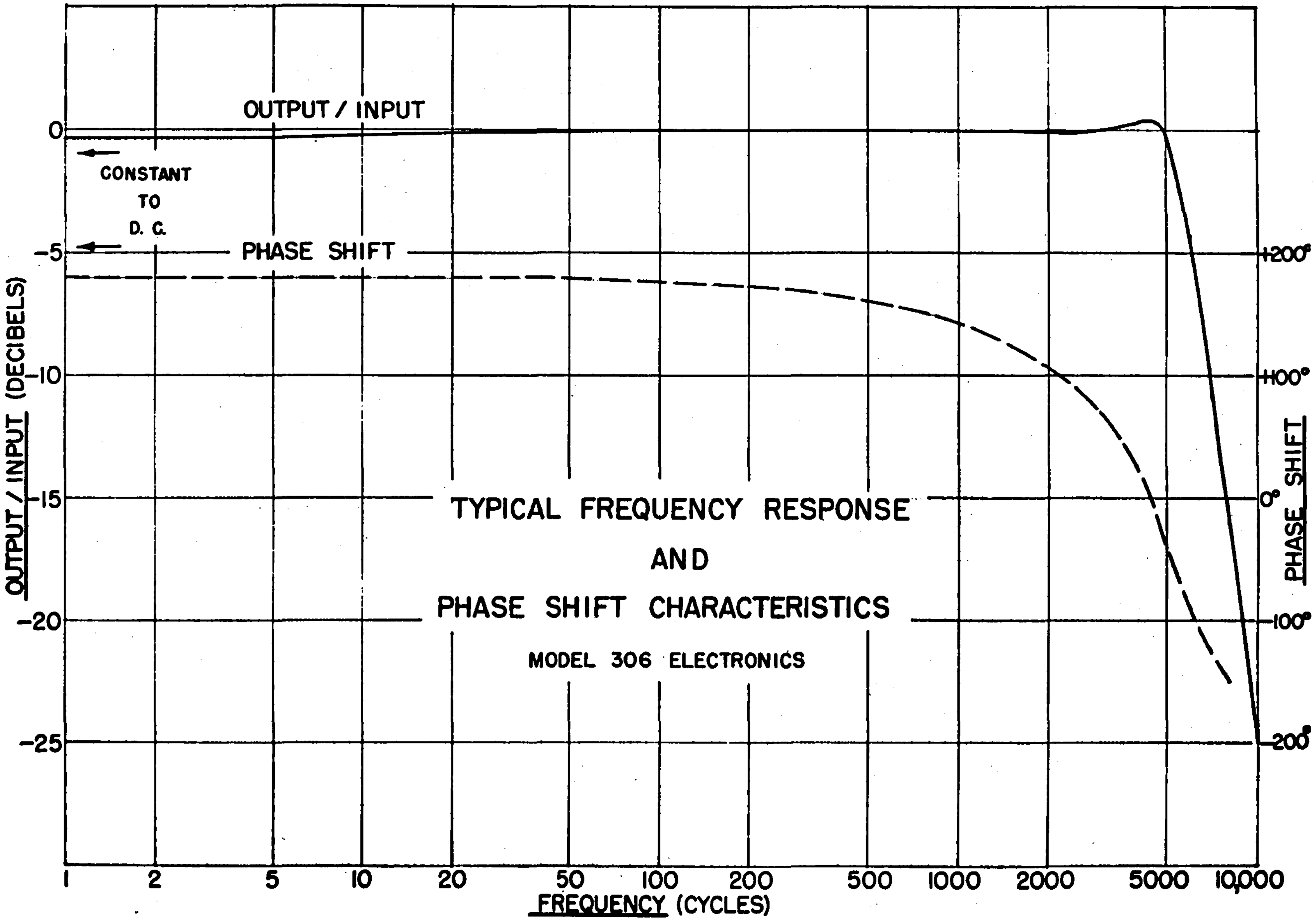

OUTPUT / INPUT
CONSTANT
TO
D. C.
PHASE SHIFT
TYPICAL FREQUENCY RESPONSE
AND
PHASE SHIFT CHARACTERISTICS
MODEL 306 ELECTRONICS
0
-5
-10
-15
-20
-25
OUTPUT / INPUT (DECIBELS)
+200°
+100°
0°
-100°
-200°
PHASE SHIFT
1
2
5
10
20
50
100
200
500
1000
2000
5000
10,000
FREQUENCY (CYCLES)

Figure 11.

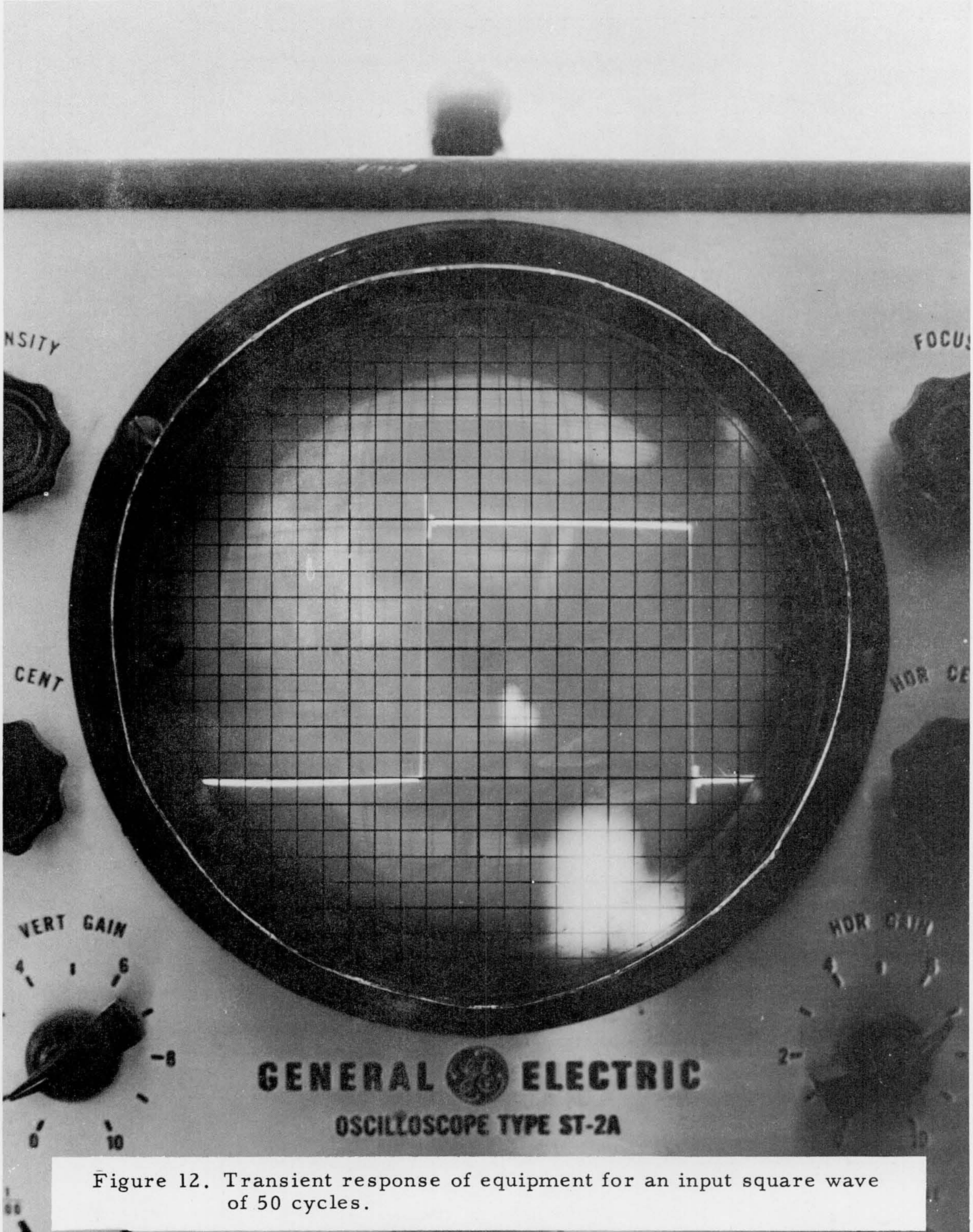


Figure 12. Transient response of equipment for an input square wave of 50 cycles.

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Department of Defense Symposium on Magnetic Recording

Paper 12

PRESENT STATUS OF A 16 MM STANDARDIZED REPRODUCTION CHARACTERISTIC

E. W. D'Arcy

DeVry Corporation
Chicago, Illinois

9 October 1953

Dr. John Frayne's paper yesterday certainly attested to the wide-spread use in the motion picture industry of magnetic sound. It certainly must afford Dr. Begun, Marvin Cameras, Dr. Wetzel, and Dr. Schmidt a large amount of personal gratification in noting the progress of their pioneering work during the past few years. In observing this progress through the media of our Society's journal and committee actions, a few pertinent facts emerge defining differences in our use of magnetic as compared to the tape equipments now so widely popularized. Let us define one of the most important of these basic differences as component versus system sound quality control.

Now motion picture sound quality is determined in the final essence by the establishment of standardized reproduction and listening conditions. The review room, so-called, is the final arbiter as to whether a picture is acceptable as to sound quality. A second difference which I should like to emphasize is that the motion picture sound track finally released may be, due to the complexity of film production, of the third and fourth generation, due to rerecording.

The laws of Darwin hold here very stringently, and any component in the link must be of the highest quality in order to stand up under this rigorous quality control need. Now you can see why some of our members look with disrespect on what they call the "dictating machine" theory about recording. Interchangeability of film between equipment is therefore not the only consideration involved in standardization. If you can, however, establish a standard reproduction condition review room, you can then leave the individual steps of component control up to the individual film producers.

The preceding I thought essential to lay the groundwork for what is being done in the moving of magnetic sound into a system suitable for motion picture theatrical use. As the matter now stands, with respect to the review room for magnetic sound, the research council of the twelve leading film producers are presently conducting listening tests in Hollywood. This is aimed towards establishing a standard review room condition for magnetic sound similar to that presently existing for photographic sound. As an addenda to that, there is a desire on their part to extend the frequency range appreciably above what has presently existed for a photographic sound.

With reference to 16mm, my subcommittee had to deal with the relatively simple component theory of establishing a reproduction characteristic for magnetic sound, in which case all that is involved is the determination of a reproduction frequency characteristic when utilizing a standard magnetic sound multiple frequency test film. Inferentially, this means the establishment of a record characteristic; however, establishment of a record characteristic alone would not suffice since the characteristics of the recording head and of the film would enter into the consideration.

Figure 1:

The whole matter really centers around this rather basic slide. If you turn the figure upside down, you can see the amount of equalization that would be required to make the system flat. That is a rather simple statement. How you spread that equalization between the post and the pre-equalization phases of the thing is what has aroused so much interesting comment from members of my subcommittee and has been responsible, I might say, for a great deal of interest.

Figure 2:

Now, this you might say, is the dictating machine concept again. I am not speaking disrespectfully of the Navy in this case, but it is a tape machine and this is the post-equalization required.

Figure 3:

Supplementry to this would be this, which would be pre-equalization required. Now, let us see where we differ with the tape theory with regard to film.

Figure 4:

This is the post equalization characteristic of the RCA 400 16mm. magnetic recorder projector. Now, as you can see, the top end is quite different to what we had before in your tape machine, and this immediately indicates that there is a lack in the pre-equalization in the high frequency end as compared to the tape machine.

Figure 5:

This again is a recording characteristic. As you can see from this it is quite different from the one you saw previously. There is, as a matter of interest, a feeling in the motion picture industry, which was expressed during this last committee, that you cannot go above 12 db in equalization at 800 cycles. We could not get committee approval of anything in excess of this. None of the people would approve such an excessive compensation, and the same feeling would prevail with regard to the low frequency end of the spectrum; there is a feeling that you could not exceed 6 db at 50 cycles, 3 db at 100 cycles. There seems to be the feeling that, that is the maximum amount of recording equalization that can be used considing the program material and the stowage capabilities of magnetic film.

Figure 6:

This is the overall characteristic of the RCA 400 magnetic projector utilizing experimental test film of the Society.

Figure 7:

This is a frequency characteristic that we are using at the present time in the experimental JAN magnetic equipment, the pre-amplifier post-equalization curve. Now, these two things may make a pattern. I have them identified so that I can go back and pick them up there rather rapidly to define the problem.

Figure 8:

This too, is the pre-equalization characteristic required in that division of equalization. As you can see here at the top end, at 8000 cycles or 7000 cycles, we have some 12-1/2 db which at the present time is the maximum that can be practically used.

Figure 9:

This is the overall end result of the two previous equalization phases.

Figure 10:

This is the post-equalization characteristic that the people that produced this experimental test film decided would be essential to reproduce the film flat.

Figure 11:

This is their record characteristic. You can see that the lower end is not so far off from the 6 db that I stated. You can see that they cheated a little bit, up around 8-1/2 or 9 db, and at the end, within the limit of 12 db. Now most of these systems that we are talking about now in terms of frequency range, are 8000 cycles high. There is no thinking at the moment of extending our 16mm. range out beyond that. Practically enters here and one thing is to be able to reproduce it. You certainly could in a dictating machine operation where you reproduce on the same equipment that you record on, but this is the case where the equipment is going to be used throughout the field, and you have to record on the equipment, or in the studio. We expect 8000 cycles at the end of the operation, with different film recorded in different studies, and that is quite a different thing.

Now actually another thing has emerged. We spoke a moment ago of film calibration, and that is a part of the subject of my talk. At this time there is no calibration technique with which we could get agreement as an absolute method. The wide gap method we started on rather optimistically as a committee action this last year in the thought that it would be a satisfactory method for calibrating film. There immediately arose a dispute between the "short gap proponents" and their "long gap adversaries", and it turns out that these differences have not been reconciled as yet, and we are still looking for a method in which there can be complete agreement, and which is basically sound. At this time it seems to me that we are quite a way from it. I certainly hope to get some information myself this afternoon. This part of the paper is pretty well taken care of by that very simple statement. If anyone has an idea how to calibrate film as to level or frequency, I am certainly very much interested in it as a committee action. We need such a method very badly.

Now, in regard to measurement techniques, I think that too will be the subject of papers this afternoon. There has been no get-together on an approved method of measuring magnetic track. As a matter of fact, we don't even have a piece of magnetic level film, on which we can agree. So at the moment, it arises that in order to make the magnetic test film, we have this one film. We are making ten more, and those films are being calibrated by watching the current in the magnetic head very closely, and that is considered as the calibration of the film. That seems kind of black, but that also is the way the Research Council on the coast is doing it at this time. I really wanted to stress the fact that this business of measurement has not been reduced as yet to an exact science in regard to magnetic.

DISCUSSION SUMMARY

Mr. M. A. Kerr, Bureau of Ships, spoke of the hope that a common meeting ground could be found between pre-emphasis, post-equalization, biasing systems, and head characteristics used for tape recording at 7 1/2 inches per second and 16mm. film recording since the linear speeds are within four percent of each other. Also, this would open up the possibility of using a 16mm. projector either for simple recording ("dictating machine" type) from a single microphone through its own amplifier or for more elaborate and complicated recording by considering the projector to be a film transport, only, and connecting the record and erase heads to an external recording amplifier and mixer system which would also be the same unit normally used for recording to a transport mechanism for 7-1/2 inches per second tape.

This concept also offers the possibility of allowing most projectors to be "playback only" and yet be available as recorders through externally connected facilities.

Mr. Kerr also raised the question as to whether the same review room conditions established for 35mm. film sound listening were the proper ones to use for 16mm. magnetic sound listening since 16mm. films, in general, are used under much less perfect acoustic conditions, much higher noise levels, much different reverberation conditions.

Mr. D'Arcy agreed and noted that some thought was being given to these differences. It is his understanding that in some review rooms when mixing is done for 16mm. film recording the level of the review room speaker system is lowered about 6 db as compared to 35mm. level. This causes the mixers to reduce the dynamic range of their sound mixing with resultant improvement in reception when the release prints are shown under field conditions.

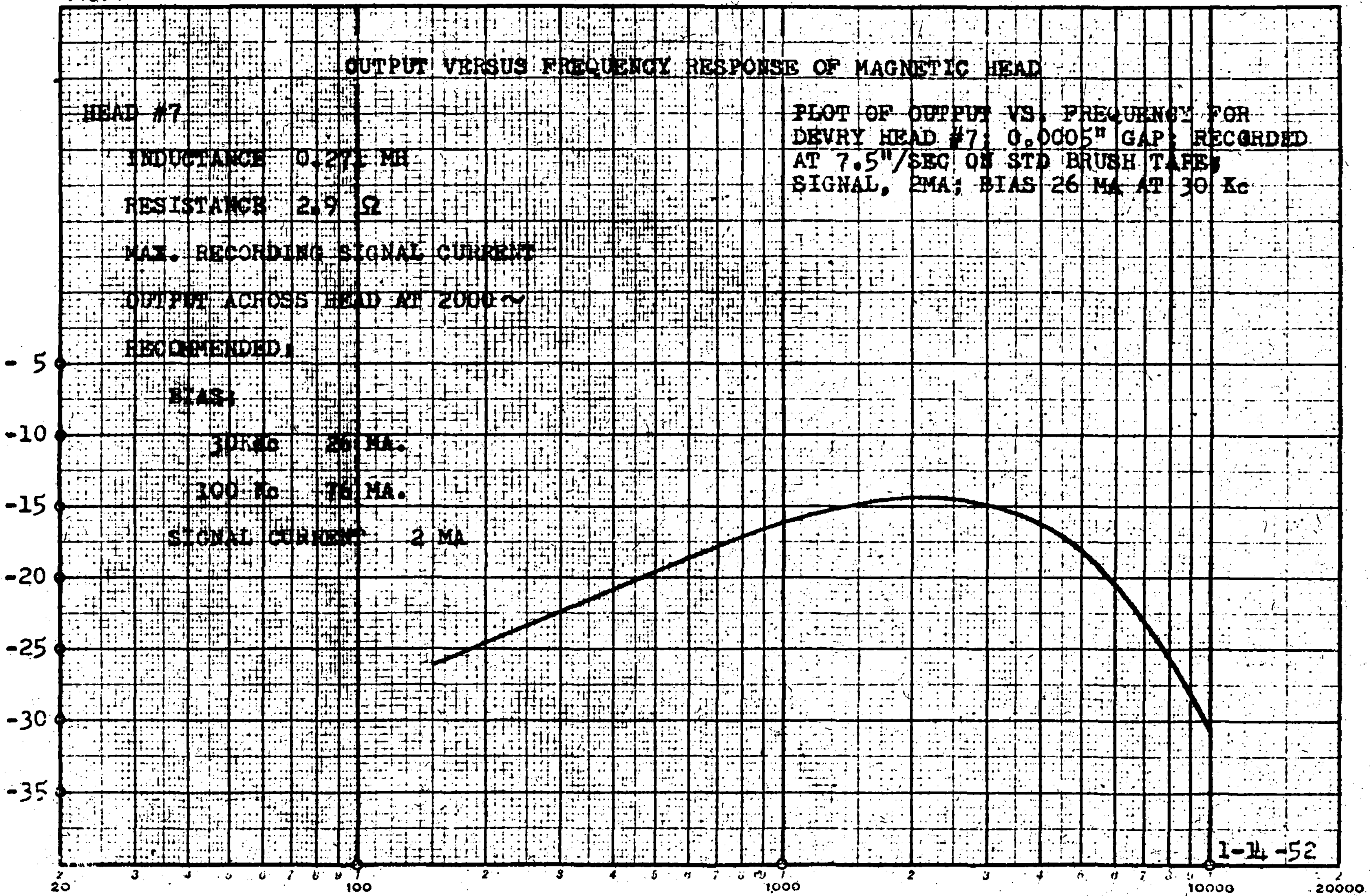
Mr. Aiken of Naval Photographic Center noted Mr. D'Arcy's presentation of the need for standards in 16mm. recording in order to permit good reproduction on one manufacturer's equipment of film recorded on another manufacturer's equipment. He asked Mr. Selsted of Ampex or someone from the 1/4 inch tape branch of the industry as to what extent standardized record-reproduce characteristics have been attempted between manufacturers of 1/4 inch tape recording equipment.

Mr. Selsted said that a more complete answer would be provided in Paper No. 17 to be presented that afternoon, but that the NARTB had established a standard reproduce characteristic which, when used with an "ideal" head, gives a flat frequency response. A standard tape is made by adjusting recording equalization until the flat overall response is obtained when played back with the standard reproduce characteristic. The CCIR (International) and NARTB (National) standardizing groups are in very close agreement as to how to establish this reproduce system with the ideal head. In the use of 35mm. magnetic film Ampex finds that they can apply the same techniques and equalization used successfully at equivalent (15 inch/sec.) tape speeds and obtain essentially identical performance characteristics. Ampex has found that the wide-gap and short-gap methods of calibrating a magnetic recording are in agreement when checked against each other.

Mr. Camras of Armour Research referred to the strong feeling of some members of SMPTE committee on magnetic sound that high frequency pre-emphasis should not exceed 12 db at 8,000 cycles as illustrating the need for a standardized reproduce characteristic with no specifications on the recording characteristic required to get the proper reproduction.

Mr. Stewart of Maico Company pointed out the effect of program content on determining pre-equalization and the inability to disregard this factor in any attempts at standardization.

FIG. I

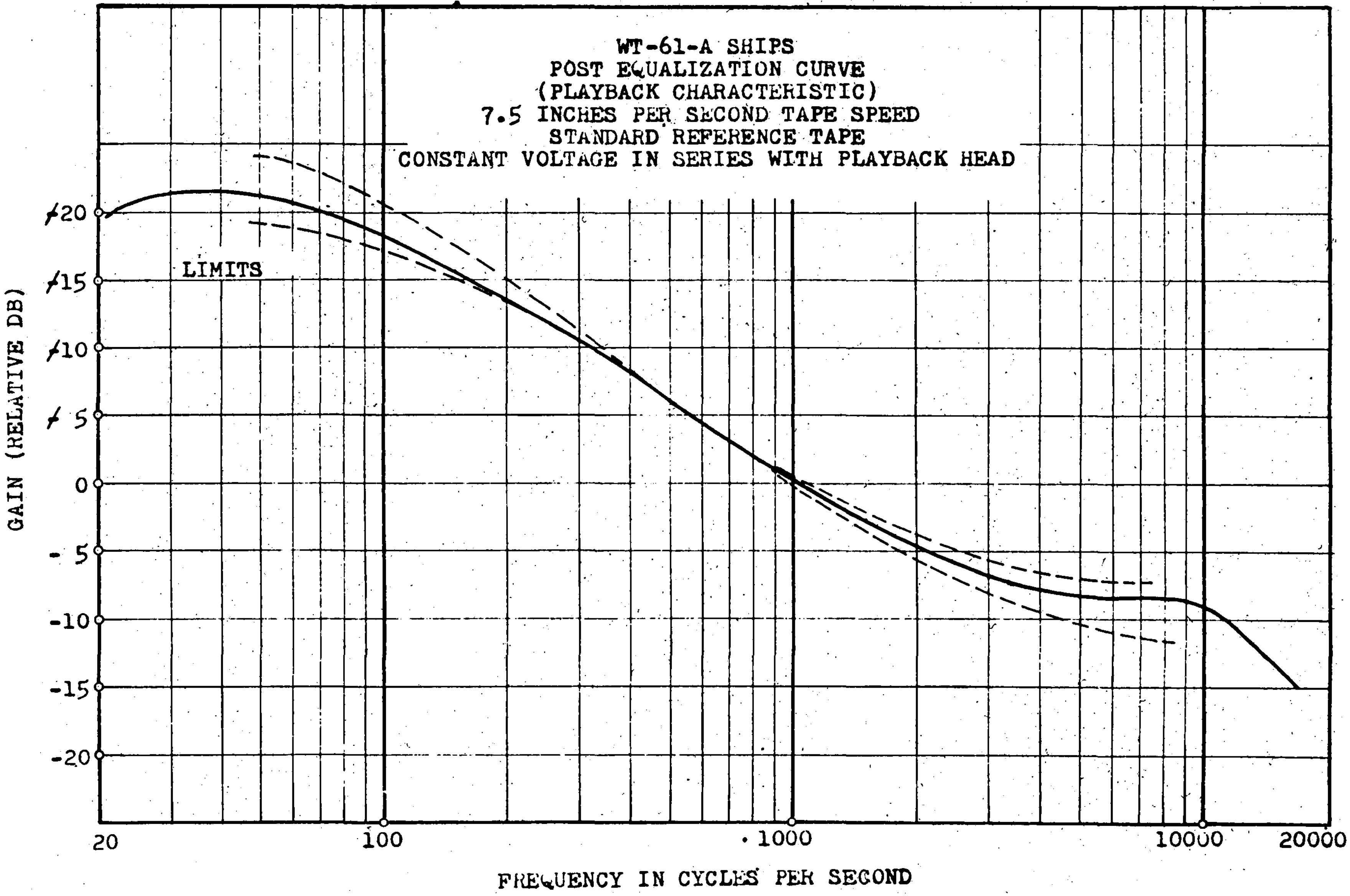


FREQUENCY IN CYCLES PER SECOND

ENGINEERING DEPT
DEVRY CORPORATION

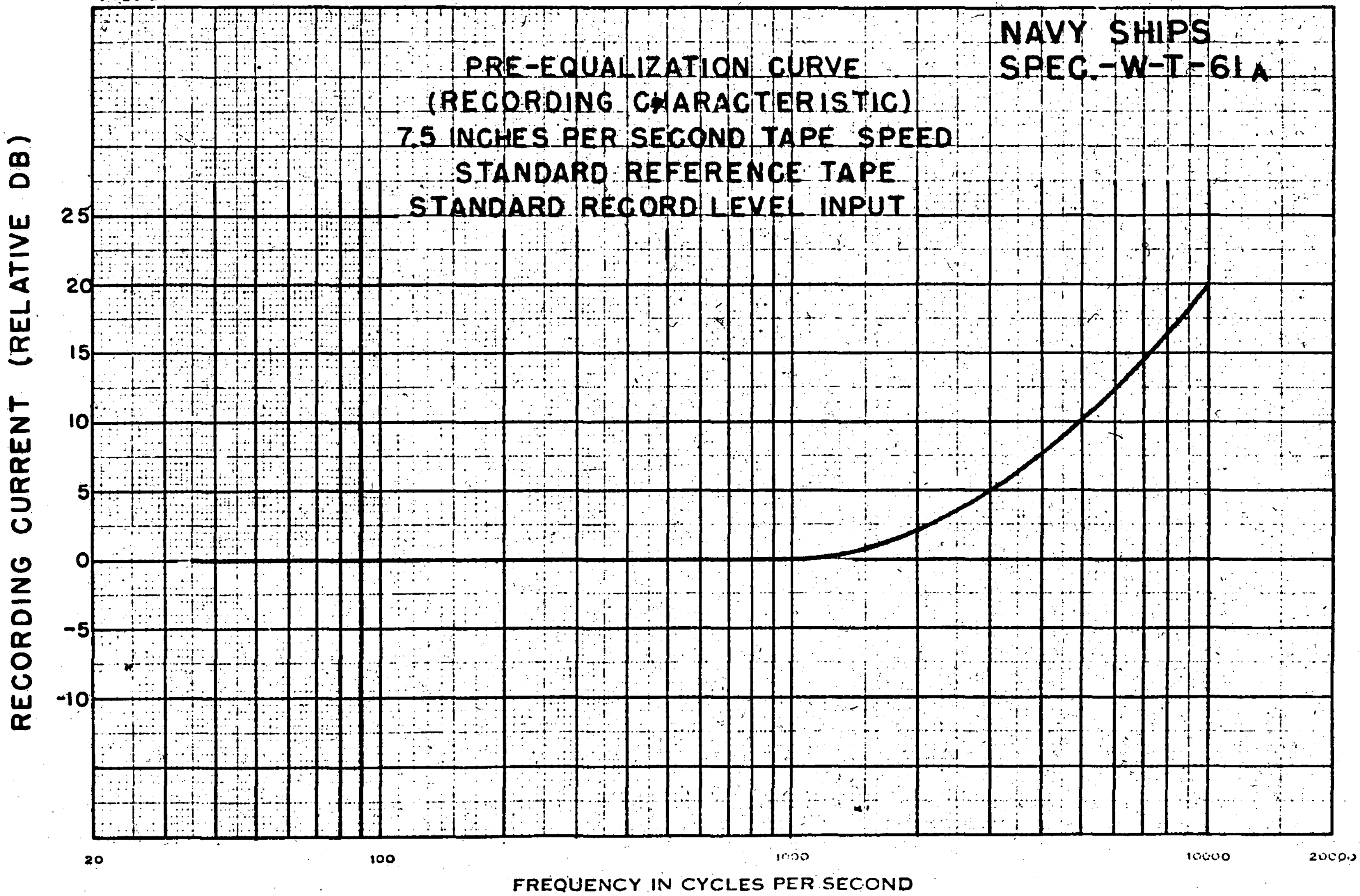
12-6

FIG. 2



WT-61-A SHIPS
POST EQUALIZATION CURVE
(PLAYBACK CHARACTERISTIC)
7.5 INCHES PER SECOND TAPE SPEED
STANDARD REFERENCE TAPE
CONSTANT VOLTAGE IN SERIES WITH PLAYBACK HEAD
LIMITS
GAIN (RELATIVE DB)
+20
+15
+10
+5
0
-5
-10
-15
-20
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

FIG. 3



PRE-EQUALIZATION CURVE
(RECORDING CHARACTERISTIC)
7.5 INCHES PER SECOND TAPE SPEED
STANDARD REFERENCE TAPE
STANDARD RECORD LEVEL INPUT
NAVY SHIPS
SPEC.-W-T-61A
RECORDING CURRENT (RELATIVE DB)
25
20
15
10
5
0
-5
-10
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

REPRODUCE CHARACTERISTIC RCA "400" 16 MM MAGNETIC RECORDER-PROJECTOR MI 35001

FIG. 4

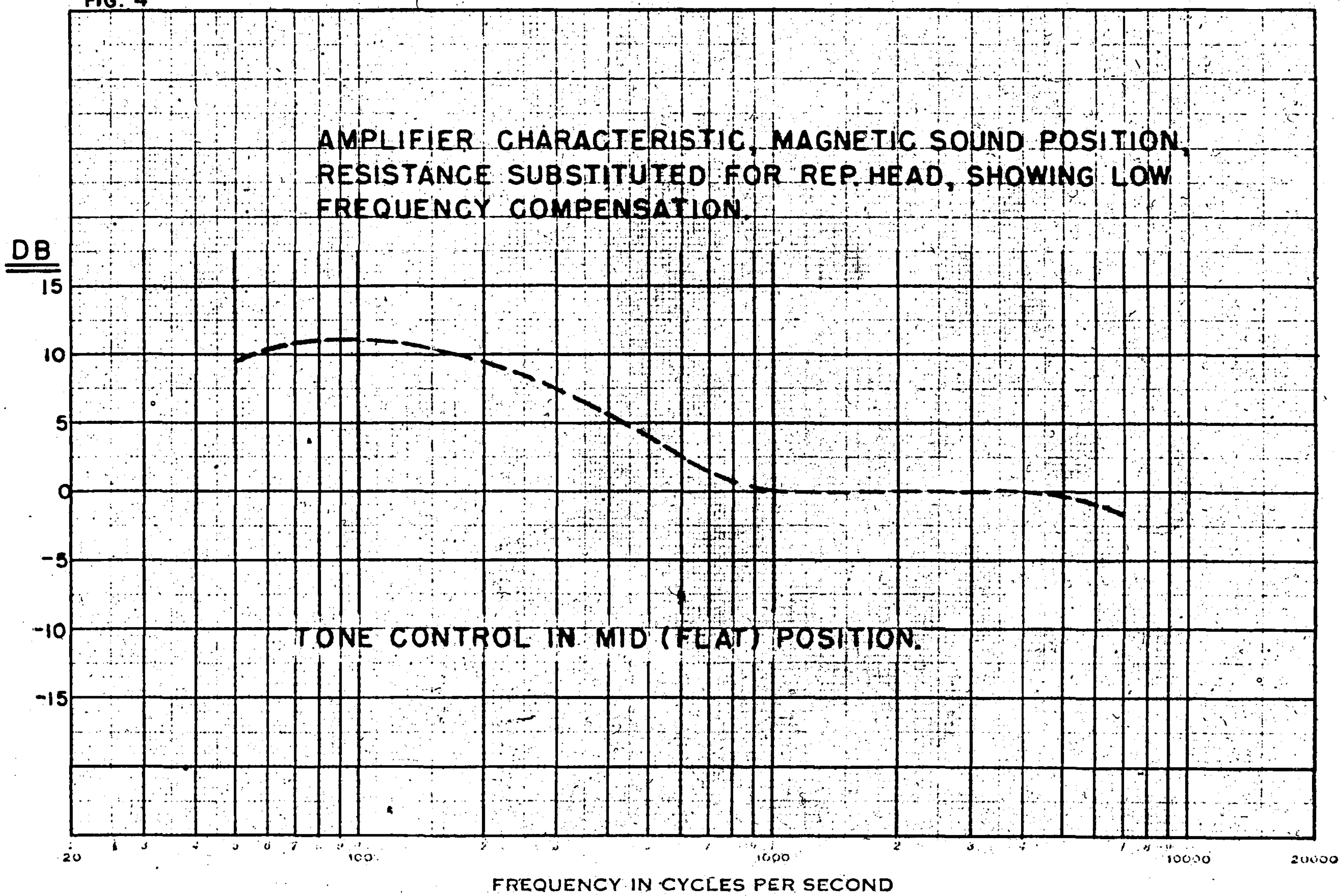
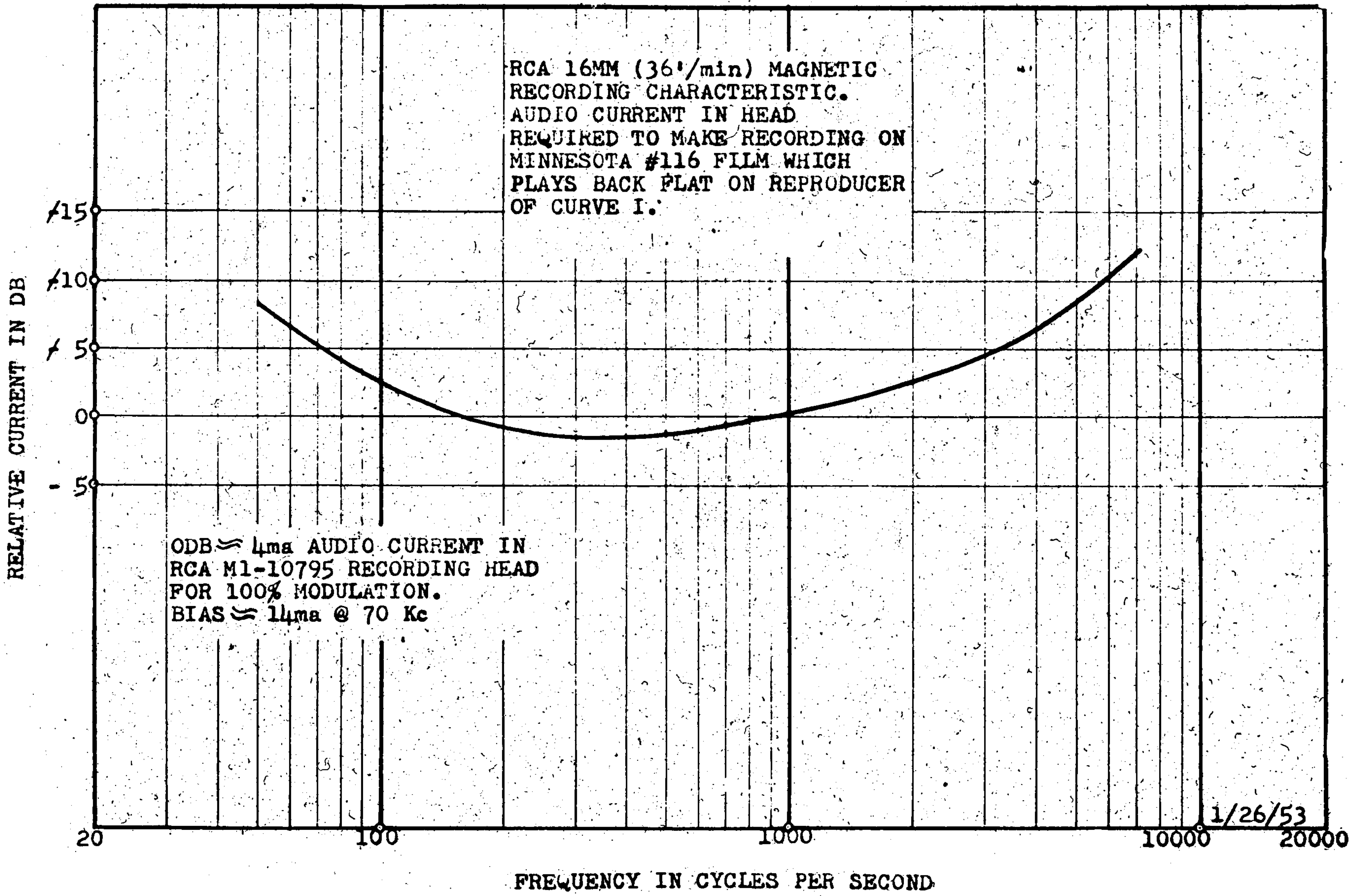


FIG. 5



12-10

A1253251_0472

FIG. 6

REPRODUCE CHARACTERISTIC RCA "400" 16 MM MAGNETIC RECORDER-PROJECTOR MI 35001

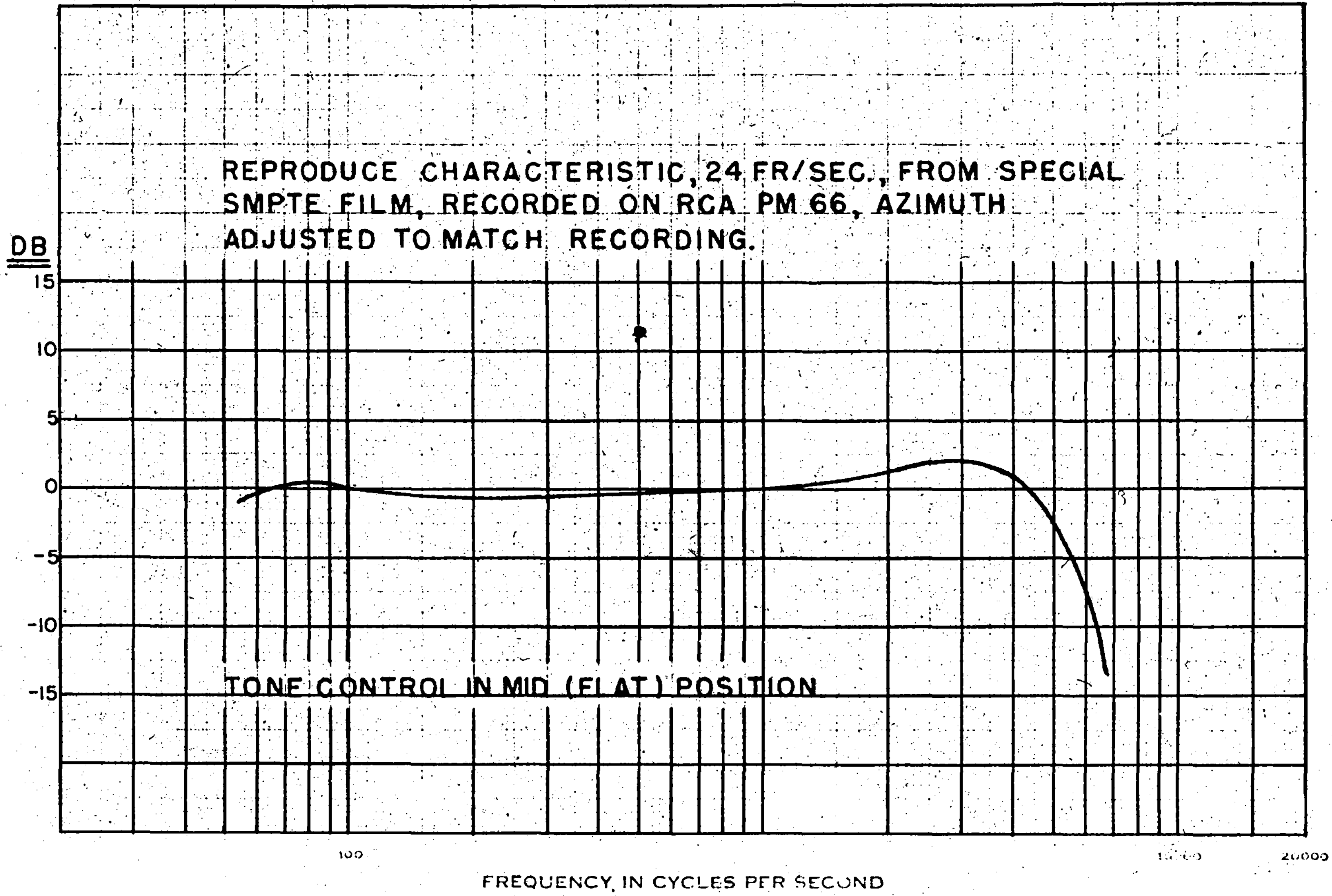
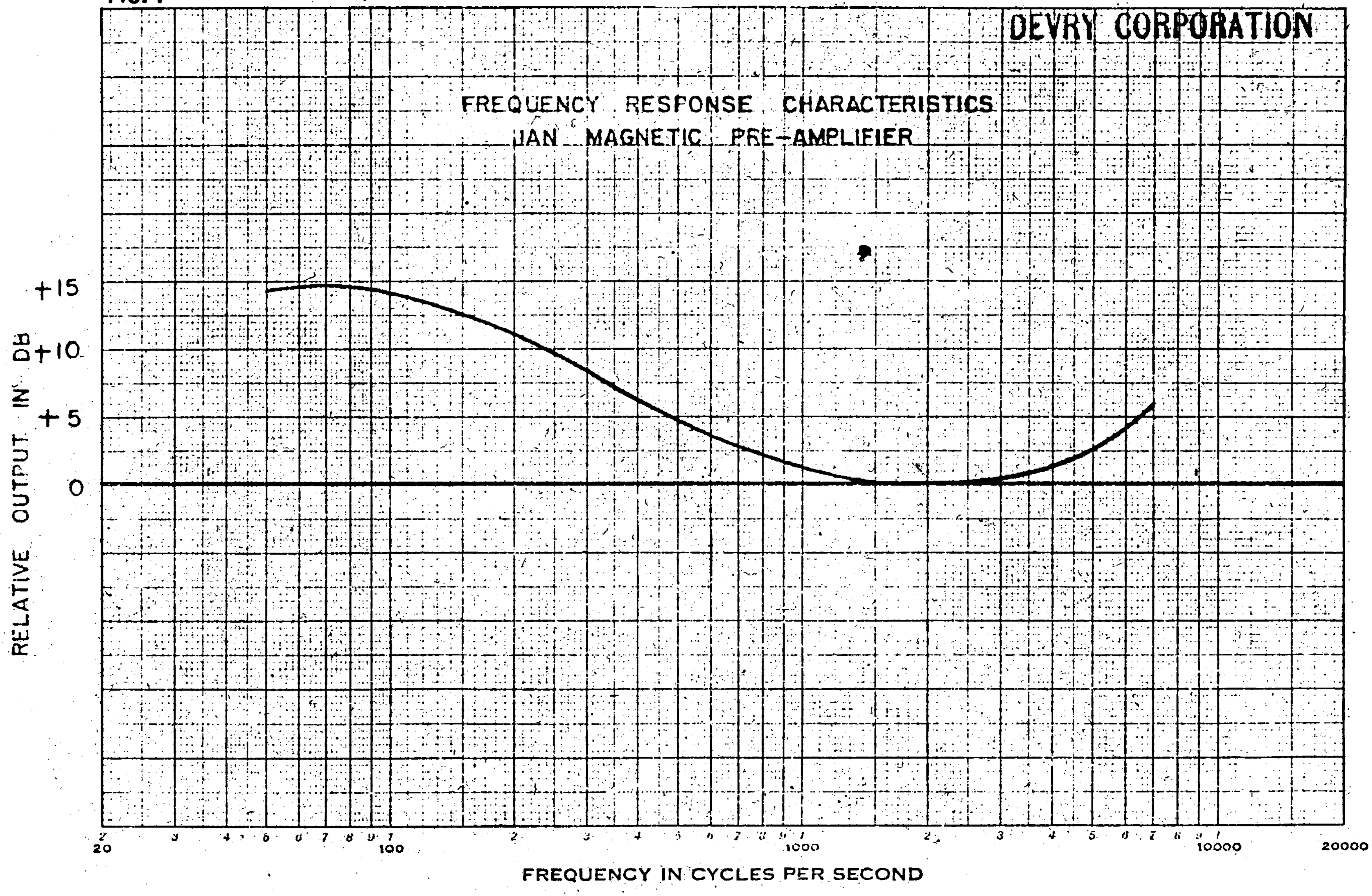


FIG. 7



12-12

A1253251_0474

FIG. 8

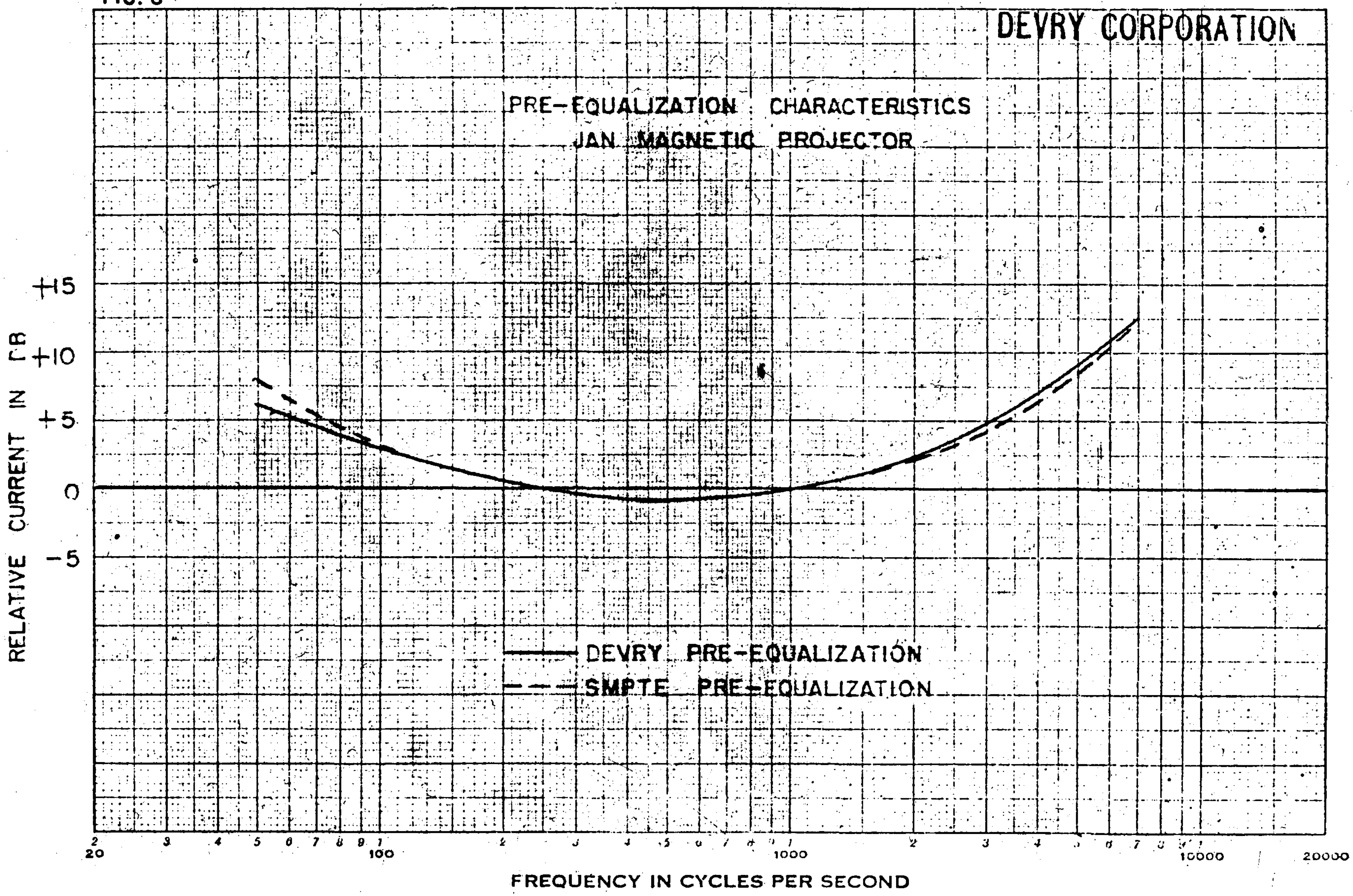

DEVRY CORPORATION
PRE-EQUALIZATION CHARACTERISTICS
JAN MAGNETIC PROJECTOR
RELATIVE CURRENT IN DB
+15
+10
+5
0
-5
DEVRY PRE-EQUALIZATION
SMPTE PRE-EQUALIZATION
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

FIG. 9

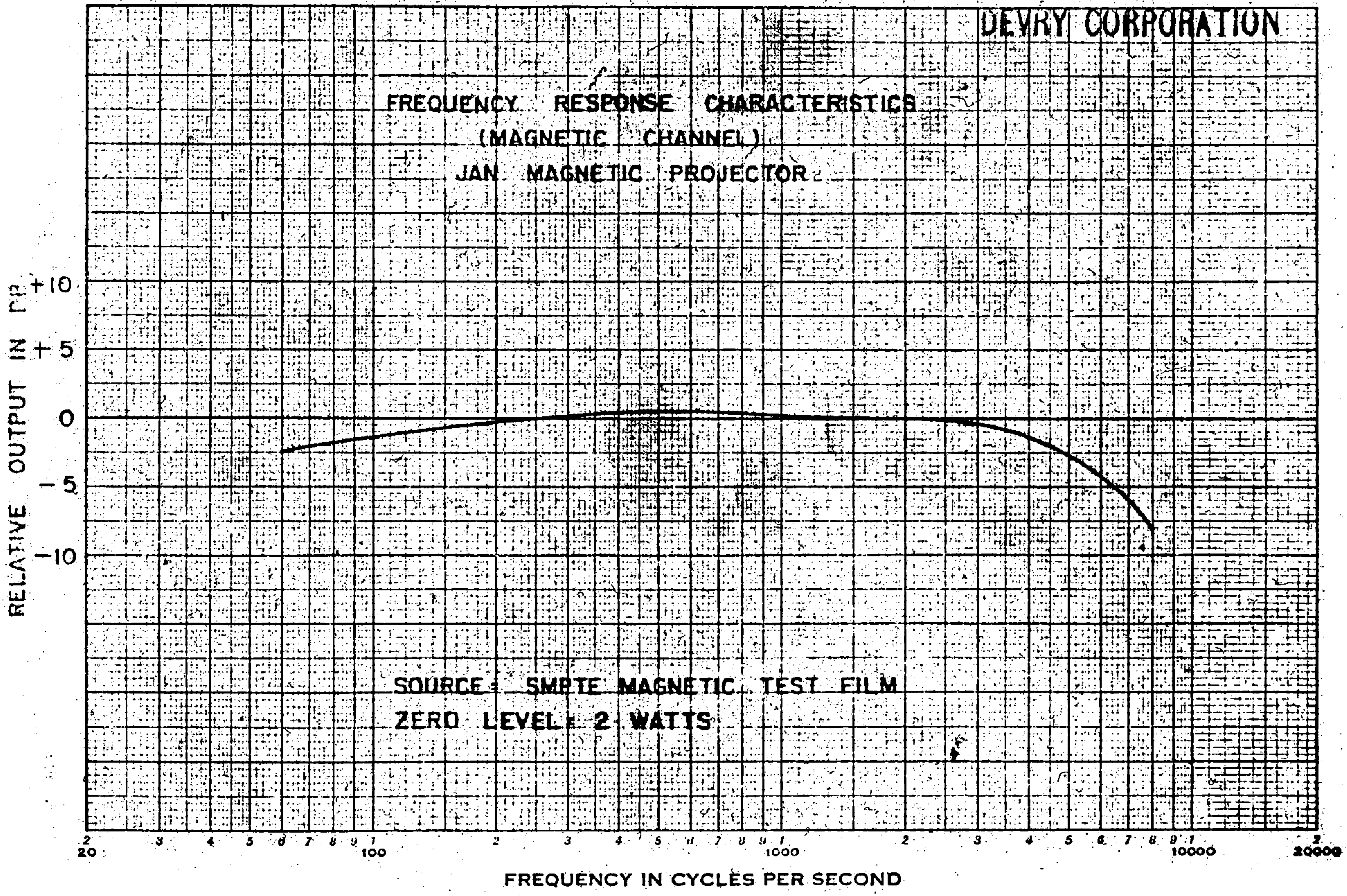

DEVRY CORPORATION
FREQUENCY RESPONSE CHARACTERISTICS
(MAGNETIC CHANNEL)
JAN MAGNETIC PROJECTOR
SOURCE: SMPTE MAGNETIC TEST FILM
ZERO LEVEL: 2 WATTS
RELATIVE OUTPUT IN DB
+10
+5
0
-5
-10
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

FIG. 10

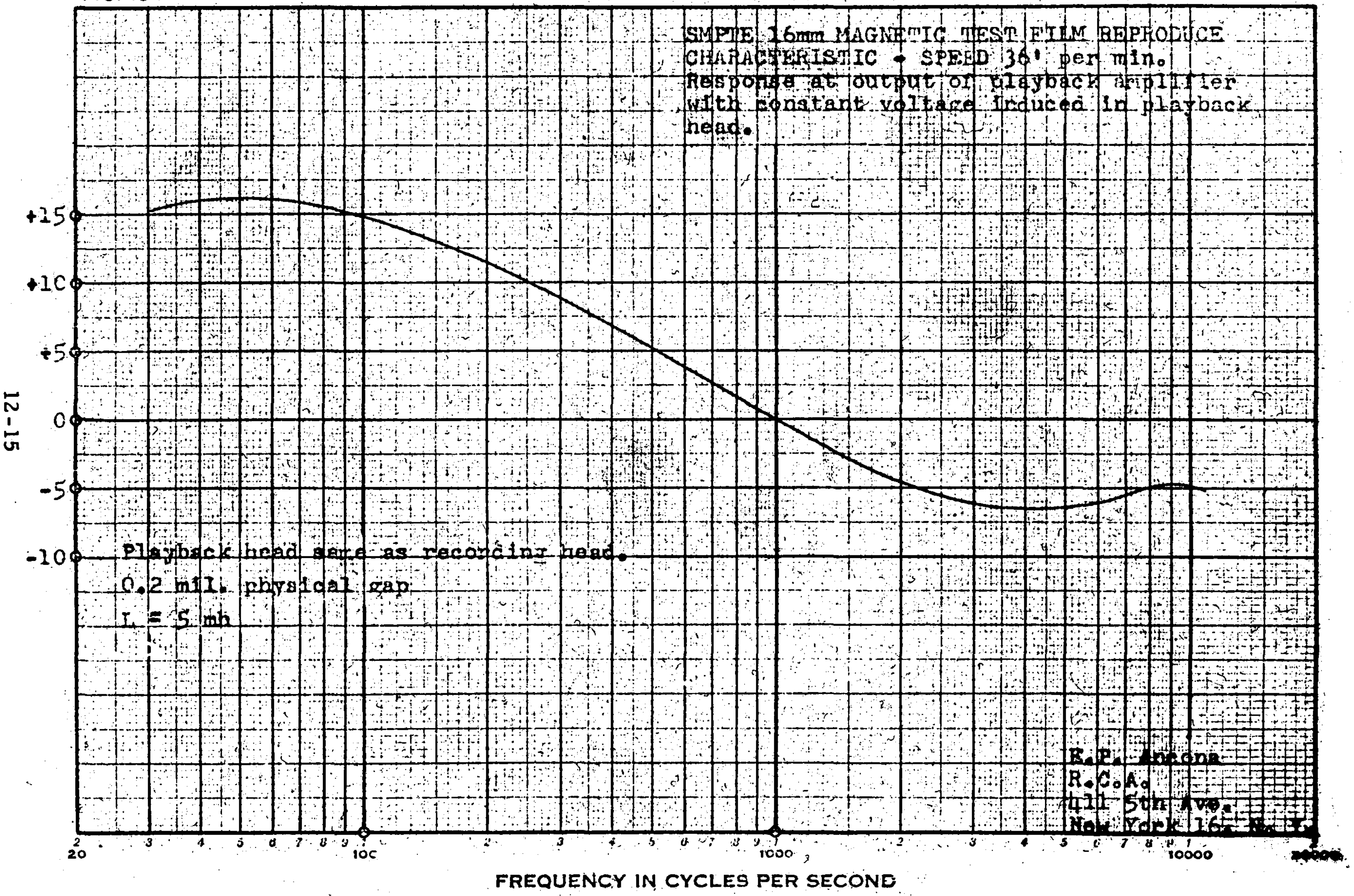
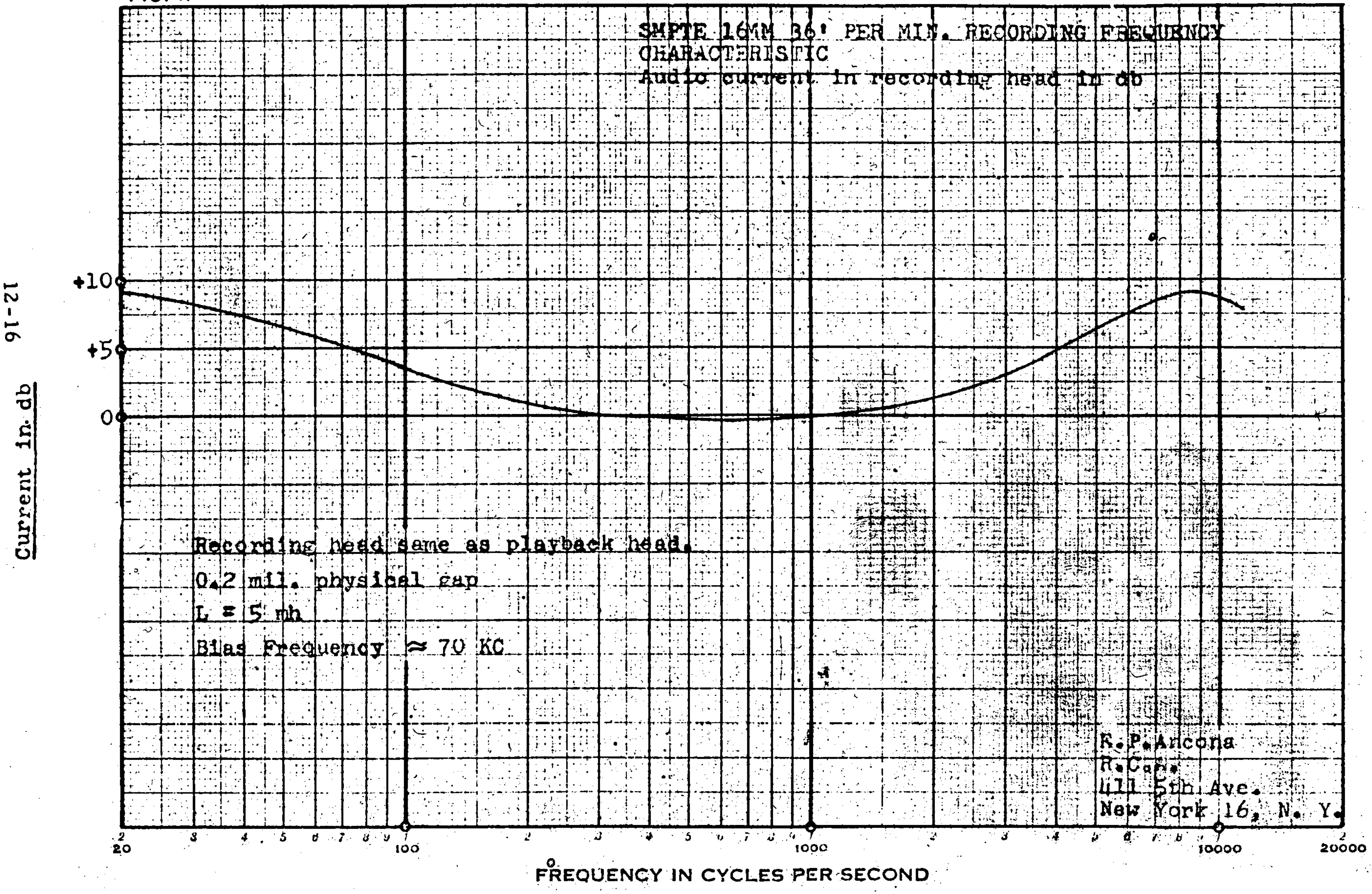

SMPTE 16mm MAGNETIC TEST FILM REPRODUCE CHARACTERISTIC - SPEED 36' per min.
Response at output of playback amplifier with constant voltage induced in playback head.
+15
+10
+5
0
-5
-10
Playback head same as recording head.
0.2 mil. physical gap
L = 5 mh
E.P. Ancona
R.C.A.
411 5th Ave.
New York 16, N.Y.
20
100
1000
10000
FREQUENCY IN CYCLES PER SECOND

FIG. II



12-16

A1253251_0478

Paper 13

MAGNETIC TAPE TESTING ON A COMPARISON BASIS

Walter H. Erikson

Radio Corporation of America
RCA Victor Division
Engineering Products Department
Optics, Sound, and Special Engineering Section
Camden, New Jersey

9 October 1953

ABSTRACT: A method of evaluating samples of magnetic recording tape for high quality sound recording applications is described. The method is based on the belief that neither a tape recorder nor a reference tape is consistently reliable enough to permit the measurement of small differences in tape characteristics from day to day over a period of several months. The method consists of the comparison of the relative performance characteristics of several samples of tape on a commercial tape recorder within a period of a few hours using one sample as a temporary reference standard.

A method of measuring modulation noise with an intermodulation distortion analyzer is discussed and it is shown that this method correlates fairly well with listening tests.

A typical set of test data in tabular form compares the frequency response, recording sensitivity, output versus distortion, and modulation noise of 21 samples from three manufacturers, using maximum sensitivity bias current for each sample. Another table shows the corresponding data for a constant high value of bias current for all samples which minimizes the differences in recording sensitivity and frequency response that are apparent for tapes from the three manufacturers when operated at maximum sensitivity bias.

INTRODUCTION

This paper gives the results of a portion of our magnetic recording tape evaluation program. This tape evaluation is primarily concerned with high quality sound recording applications such as broadcast audio tape recorder design, master tapes for phonograph records and broadcast network recording. The subject matter of the present paper is limited to a discussion of the basic philosophy of our tape evaluation program as applied to sound recording applications and a typical set of tape test data. The 21-tape samples from three manufacturers represented in this paper were manufactured approximately two years ago. These old tape samples were deliberately selected to illustrate the basic philosophy presented in this paper in preference to current production since the three major brands of tape at that time had widely different magnetic characteristics. One of the objectives of these investigations was to show that tapes with widely different magnetic characteristics can be made to produce very similar performance characteristics under certain operating conditions. The performance data presented here are not representative of current production as the three major tape brands do not now have the widely different magnetic characteristics shown in this paper.

Objectives of Tape Evaluation Program

The information obtained during the course of this tape evaluation program is expected to be of practical value to those making high quality tape recordings and to those responsible for the design of high quality tape recording equipment. There is no intention here to make absolute measurements of the fundamental properties of magnetic tapes on a laboratory recorder as has been common practice. Rather it is intended that the measurements be made strictly on a tape comparison basis using commonly used high quality commercial tape recorders and restricting the upper and lower limits of operating conditions to a practical range. Following is a list of the primary objectives of this program:

(a) Development of tape testing techniques which provide a significant evaluation of the important performance characteristics.

(b) To determine the extreme limits of the variations in performance characteristics to be expected in a large number of tapes from any one manufacturer and from two or three sources.

(c) To determine if there is one particular brand of tape that is so outstandingly superior in performance characteristics that it should be used exclusively.

(d) To determine if there is a particular tape recorder operating condition which will minimize the differences in two or three brands of tape so that all tapes from these sources may be freely interspliced without serious differences in frequency response or playback output level.

(e) Obtain very comprehensive performance characteristic data on a few representative samples from two or three manufacturers.

(f) Obtain information that may be useful for the development of a standard reference frequency response tape.

Tape Characteristics Under Consideration

In this paper we are considering only the following tape characteristics which are believed to be essential for acceptance testing of tape for high quality sound recording applications:

(a) Relative high frequency response from one to 15 kc at 15 ips (inches per second) tape speed.

(b) Relative recording sensitivity or playback output level for a given audio current in the recording head.

(c) Relative playback output level for the three percent harmonic distortion point at 400 cps and 15 ips tape speed.

(d) The modulation noise.

(e) Relative bias current for maximum recording sensitivity at 400 cps and 15 ips tape speed.

The first four characteristics listed are measured at two or three practical values of bias current, one of which is the bias for maximum recording sensitivity. The measurements reported here employ only the first 100 or 200 feet of a roll of tape to minimize the time required to evaluate each sample since several dozen samples will be involved eventually. We now have about 100 samples. It is recognized that there are significant variations in tape characteristics throughout the length of a roll of tape and at a later date we expect to evaluate the variations in all of the important performance characteristics throughout the entire length of a few representative rolls of tape.

Basic Philosophy on Tape Evaluation

It appears that most organizations that are evaluating magnetic recording tape employ what they consider to be a standard reference recorder and make what amounts to absolute measurements on each sample of tape under consideration. The reference recorder is apparently considered to be sufficiently reliable as a measuring tool so that the measurements are a true indication of the tape characteristics. It has been our experience that no tape recording system is consistently reliable enough to evaluate small differences in tape performance characteristics from day to day over a period of several months. Also we cannot yet trust any arbitrary reference frequency response tape or any other technique of which we know to calibrate a recorder each day, therefore we have decided to base the information for this report, on the results obtained by comparing a group of tape samples on a commercial tape recorder within a short period of time, usually within three to four hours. The results are considered valid only if consistent differences between samples are obtained for repeated measurements. This technique minimizes the possibility of experimental errors due to a sudden change or a slow drift in some characteristic of the recorder which is not revealed by routine checking of the recorder. The data for Table I were obtained by running the 21 tape samples through the recorder in three series of runs. During the first run, data for frequency response, recording sensitivity, and bias requirements were obtained. Data for the playback output level for three percent distortion were obtained during the second run and the modulation noise data during the third run.

Test Methods used for Tape Evaluation

Frequency Response--A tape sample with the best relative high-frequency response in a group of tapes is selected as a temporary reference tape. Using this reference tape, operated at maximum low-frequency recording sensitivity bias, the high-frequency equalizer controls are adjusted to produce the flattest possible frequency response (usually within 0.1 db) from one to 15 kc at 15 ips tape speed, with measurements at one, five, 10 and 15 kc. It has been found that these four test frequencies provide an adequately significant evaluation of the relative frequency response of any tape sample. Since the recorder being used has considerable high-frequency pre-emphasis in recording, it is necessary to determine that the tape is not operating in a sufficiently non-linear region to affect the frequency response. The technique used here is to select a recording level such that the relative frequency response obtained is the same as that obtained at a recording level 5 db higher or lower. The other tape samples are measured with the same frequency response equalization that is used for the reference tape. Regardless of whether a particular tape sample is being measured at maximum sensitivity bias or at some other bias setting, the frequency response obtained with the reference tap at maximum sensitivity bias is still used as a frequency response reference. Thus, in the three tables in this paper in which frequency response data are tabulated, the reference is always the frequency response obtained with Brand B Sample No. 1, the frequency response reference tape for this paper, at maximum sensitivity bias. For optimum high-frequency response, it has been found that the tape samples with the least compliance and with a tendency to cup or curl, require higher tape tension over the heads than other tapes that are more flexible and are flat. Also, it has been found that various samples require different azimuth alignment adjustment between the recording and playback gaps for optimum high-frequency response. This is probably because the tapes are not cut straight. The recorded tracks on such tapes could be expected to be on a very large radius circle in spite of the tendency for high tape tension to straighten the tape, therefore, parallel record and playback gaps would not produce optimum high-frequency response. We have found this to be a very common characteristic of tapes, in that if they are not cut straight they will curve one way or the other on playback, making as much as several db difference in output at wave lengths as long as .001". This is an important point to remember in the choosing of tape for azimuth alignment purposes. For these tests the tape tension was adjusted to be high enough for all samples and was not varied, but the azimuth was adjusted for each sample.

Relative Recording Sensitivity--Using the reference tape, Brand B Sample No. 1, with maximum sensitivity bias, the gain controls in the recording and playback amplifiers were adjusted for an overall record-playback insertion loss of 0 db at 1 kc. Thus, by maintaining a standard input signal level of .10 db and measuring the playback output signal level for each tape sample, a comparison of relative recording sensitivities is obtained. The test signal frequency is 1 kc at 15 ips tape speed and these data are obtained during the measurement of relative frequency response.

Output Level For Three Percent Harmonic Distortion--The playback amplifier gain control was adjusted so that the distortion measurements would not be limited by distortion in the output stage of the playback amplifier. The distortion meter was the high-pass filter type which measures total harmonic distortion and noise. By means of a wave analyzer it was determined that in all cases the measured distortion was predominantly third harmonic. The test signal frequency was 400 cps at 15 ips tape speed. This is about the highest low frequency that can be used. The recording signal level was adjusted until the playback output signal had three percent total harmonic distortion and the relative output level was then measured. In the tabulation of these data the tape sample producing the greatest output, 20 dbm, Brand C Sample No. 2 at maximum sensitivity bias, was used as the reference. There is no particular significance in the 20 dbm level, it is simply a convenient reference level.

Maximum Sensitivity Bias--For this test the actual bias current in the recording head was not measured, but instead, a voltage was measured which is directly proportional to the bias current in the recording head. It is this voltage reading that is tabulated here but it does accurately represent the relative bias current in the recording head. The test signal was 400 cps at a recording level on the tape well below the one percent third harmonic distortion point. The test routine was to try to determine directly the relative bias current which produced the maximum recording sensitivity. Since the curve of output vs. bias usually has an appreciable flat top, it has been proposed that the maximum sensitivity bias be determined as the average of the two bias values which reduce the output 1 db below the maximum. We believe that it is more satisfactory to determine the bias for maximum sensitivity directly if reasonable care is taken in making the measurements. The following measuring technique was used in determining the bias current for maximum recording sensitivity. Using a fixed input signal level, the playback output level is observed on a VU meter or a vacuum tube voltmeter, while adjusting the bias current control for a maximum output level indication. When a bias control setting is found which seems to produce the maximum output level, the bias current meter indication is read and tabulated. This routine is repeated several times until a definite trend in the tabulation of the bias current values is noted. A typical sequence of bias current meter readings might be as follows: 41, 42, 40, 41, 41. In this example we believe that it is safe to say that the maximum sensitivity bias is 41 with an accuracy of better than two percent. This technique is especially useful where the output level from the tape varies in a random fashion so that it is very difficult to decide at what bias current control setting the output is 1 db down from the maximum. There is no doubt about the maximum output point for a fluctuating output tape, it simply requires more time for a reading as compared with a constant output tape.

Modulation Noise--Modulation noise is not ordinarily included in magnetic recording specifications. However, we believe that modulation noise is important and that unusually high modulation noise is a sufficient reason to reject an otherwise excellent roll of tape. There is no established method of measuring modulation noise, but we have been using a method which seems to correlate fairly well with listening tests and is an extremely easy measurement to make. Measurements are made on an Altec Lansing Intermodulation Distortion Analyzer which is actually an amplitude modulation meter for a carrier frequency range of two to 20 kc. The test signal consists of 2 kc recorded at any level within the working range at 15 ips tape speed. Ideally, the frequency should be a little lower but none of the commonly available analyzers can use a lower frequency. The meter readings are tabulated as percent intermodulation modulation noise. There is no intermodulation distortion involved since only one signal frequency is used, but the designation percent intermodulation modulation noise is used here to indicate that an intermodulation analyzer is employed for the measurement. It was found that the meter readings increase severalfold momentarily at random intervals. These momentary increases are attributed to the so-called "drop-outs" or "magnetic holes" in the tape. While listening to the modulation noise under the 2 kc signal and watching the meter, it became apparent that these drop-outs usually do not result in any audible modulation of the signal. As an example, if the average meter reading was about 0.3 percent, the audible modulation noise would be judged to be about 50 db below the signal, and drop-outs of as much as 3 db as viewed on an oscilloscope would not produce any audible effect. The audible modulation noise continues at a constant level throughout all such drop-outs. It is actually impossible to detect drop-outs of as much as 3 db by listening to the reproduction of a 2000-cycle recorded signal. Thus the drop-outs are ignored in reading the intermodulation analyzer meter. An attempt is made to obtain a meter reading which corresponds to the audible aspects of the amplitude variations by taking the minimum meter reading obtained during a one or two second interval. Sometimes a group of drop-outs occurs at a repetition rate of several times a second which produces a steady meter indication for a couple of seconds which is a few times the minimum reading but there is no change in the audible modulation noise. The meter movement in the Altec Lansing Intermodulation Analyzer has a very short period which appears to be an advantage for this application as it makes it possible to obtain significant modulation noise readings in spite of drop-outs. An intermodulation analyzer with a sluggish meter movement is not recommended for modulation noise measurements. Although it will be found that the intermodulation modulation noise readings increase as the signal frequency is increased above 2 kc, this technique does not appear to provide a significant measurement of audible modulation noise for test signal frequencies above 2 kc, one reason is that the predominant modulation noise we hear is for high frequencies 2-3 kc, on either side of the signal frequency while most modulation analyzers do not measure modulation rates above 500 cycles.

Tabulation of Performance Data in Table I

The data for Table I were taken with the high frequency bias current adjusted for maximum recording sensitivity, and with Brand B, Sample No. 1, as a reference tape. Thus, the reference tape has 0 db output at all four test frequencies, while all samples have 0 db output at 1 kc. The output-vs-input column, third from the right, shows the relative recording sensitivity at 1 kc. The record-playback channel was adjusted for 0 db insertion loss with the reference tape, Brand B No. 1. The playback amplifier output level in dbm was measured for each sample using a signal level of 10 dbm on the input of the recording amplifier. Brand C No. 2 produced the largest playback output for three percent harmonic distortion and the playback amplifier gain control was adjusted to produce an output level of 20 dbm under these conditions. All of the data on output for three percent distortion tabulated in Tables I, II and III were obtained with the same playback amplifier gain. The percent IM Modulation Noise readings, right hand column, were obtained on the Altec Lansing Intermodulation Analyzer. The tabulations represent minimum meter indications that were maintained for at least one second, many times during a period of 15 to 60 seconds. As was mentioned before, all of the data tabulated in this report were obtained on only the first 100 or 200 feet on a roll of tape. At the end of each of the three manufacturer type listings, are tabulated the maximum and minimum values of each factor for the manufacturer type group. At the bottom of Table I, the maximum and minimum values for all 21 samples for the operating condition of Table I are tabulated.

The usual policy in reporting the results of investigations of this type seems to be to tabulate the actual meter readings obtained in the laboratory. In these reports we have decided to use purely arbitrary scales whenever possible to minimize the amount of mental arithmetic required on the part of the reader in analyzing the data. The reference levels for the numerical values of the five tape characteristics reported here have been deliberately selected to be in different nonoverlapping regions as much as possible. Thus, modulation noise is in the range of 0.2 to 0.65, recording sensitivity 4.8 to 10, output for three percent distortion 16.8 to 20, bias 28 to 60, and frequency response -8.3 to 1.4. Maximum recording sensitivity among all samples was arbitrarily made 10, maximum output for three percent distortion made 20, and the frequency response reference the customary 0 db. The modulation noise data are absolute measurements and cannot be placed on an arbitrary scale. There did not appear to be any good reason to change the scale for the relative bias current. It is hoped that all this will facilitate comparison of the data in the various tables.

Comments on the Data in Table I

The bias current requirement varies from 28 to 48 for Brand C Sample No. 1. This wide range means that either the bias current must be changed for some of the manufacturer type groups, or a compromise bias current must be found which will permit all tapes to be used with a fixed value of bias. Tables II and III show the results of attempts to arrive at such a bias current setting. These statements are based on the philosophy that the bias current must never be less than that required for maximum recording sensitivity at a low frequency. It has been found that, almost invariably, the use of considerably less than maximum sensitivity bias current results in excessive modulation noise, output level fluctuations and nonlinear distortion. Relative bias current of about twice that for maximum sensitivity is being used successfully in some magnetic recording systems. Thus, for the present we shall consider only the relative bias current range from maximum sensitivity bias to two or three times the maximum sensitivity bias.

The Brand B samples have definitely higher recording sensitivity and high-frequency response than the other samples. Tables II and III show the results of attempts to find a bias current setting that would minimize the differences in recording sensitivity and high-frequency response among all samples.

The Brand B samples are definitely superior in all performance characteristics except output level for three percent distortion. The recording sensitivity is remarkably constant within ±0.3 db and the high frequency response at 15 kc varies ±1.2 db. These samples are especially superior with respect to modulation noise. It is interesting that the Brand B samples with the lowest bias current requirement have the best high-frequency response, while the Brand B samples with the highest bias current requirement have the poorest high-frequency response among the Brand B samples. One possible explanation of this apparent correlation is that the samples with the lowest bias current requirement have the smoothest coating surfaces which results in more intimate contact between tape and heads. A minor defect of some of the Brand B samples is the periodic variation of about ±0.2 db in output level. This characteristic of Brand B is a nuisance in measurements of this type but is considered to be of no consequence in sound recording. A possible disadvantage of Brand B Tapes is that a fixed bias current setting, which results in the superior performance of Brand B is completely unsatisfactory for the other two manufacturer types listed in this paper.

Even if one varies the bias current and the recording level to accommodate the variations in bias requirements and recording sensitivity of these 21 samples, there is still a ±2.8 db variation in high-frequency response at 15 kc. It is interesting that the two Brand A samples, with maximum and minimum high-frequency response both came from the same day's production. The Brand C samples are definitely superior with respect to output level for three percent distortion, generally being 1 to 2 db better than the other tapes.

Tabulation of Performance Data in Table II

For the data in Table II, the measurements on the Brand B samples were repeated with a bias current of 42 which would be satisfactory for practically all of the other samples. All of the operating conditions, except bias current, are the same as in Table I, so that direct comparison can be made in all cases. It is apparent that the Brand B samples at this bias current still have higher recording sensitivity and relative high-frequency response than the samples in the other manufacturer type groups. It will be noticed that the variations in recording sensitivity and high-frequency response are greater than at the lower bias currents.

Tabulation of Performance Data in Table III

Since a bias current of 42 was not sufficient to reduce the recording sensitivity and high-frequency response of the Brand B samples to be comparable with the other samples, it was decided to try a bias current of 60 which is approximately double that for maximum sensitivity with Brand B. All of the measurements in Table I were repeated with this bias current of 60 with all of the operating conditions except bias current, the same as in Tables I and II.

Comments on the Data in Table III

It appears that a bias current of 60 is a reasonably good compromise to minimize the differences in these 21 samples. The variation in recording sensitivity is reduced from ±2.6 db for maximum sensitivity bias to ±1.1 db. This would allow intersplicing of different brands of tapes in many applications. If about 10 percent of the samples are eliminated, this variation is reduced to ±0.8 db. The variation in relative high-frequency response at 15 kc is ±2.8 db, the same as for maximum sensitivity bias. If 20 percent of the samples are eliminated, the variation in high-frequency response at 15 kc is ±1.7 db at the bias current of 60. With respect to modulation noise, the higher bias current results in a slight increase for Brand A samples, considerable increase for Brand B, and considerable decrease for Brand C samples.

It is interesting to note the changes within a manufacturer type group in going to the higher bias current. The Brand B samples have considerably poorer performance characteristics except for the output level at three percent distortion, which is 0.3 to 0.9 db better. The variation in recording sensitivity increased from ±0.3 db to ±0.85 db. The variation in high-frequency response at 15 kc increased from ±1.2 db to ±2.65 db. The other manufacturer type groups generally show less variations in going to the higher bias current. It is apparent that any superiority that Brand B may have can only be obtained by operating at maximum sensitivity bias, in which case the other manufacturer types cannot be used unless the bias current is readjusted.

At this high bias current of 60, none of the manufacturer type groups is definitely superior in performance characteristics. The Brand B samples are still superior with respect to modulation noise as was the case for maximum sensitivity bias. The Brand C samples are still superior with respect to output level for three percent distortion, generally being 1 to 2 db better than the other tapes.

Comments on Tables I and III

In view of the fact that the Brand B samples represent many different production batches, it seems safe to say that Brand B provides superior performance with respect to modulation noise and absolute high-frequency response and uniformity of recording sensitivity and relative high-frequency response from roll to roll. This superior performance is obtained only at maximum sensitivity bias which means that if the superior performance of Brand B is to be realized in a commercial recording establishment, Brand B must be used exclusively, or at least certain recorders reserved for the exclusive use of Brand B.

A curious effect relating to the frequency response characteristics of magnetic recording systems was discovered during the course of these investigations. By comparing the response at 5 kc relative to 1 kc in Tables I and III, it will be found that for each of the 21 samples the relative output at 5 kc relative to 1 kc actually increases for bias currents greater than maximum sensitivity bias. If this system was adjusted to have an absolutely flat frequency response using maximum sensitivity bias, it was found that the frequency response curve had a hump of around 0.5 to 1.5 db at approximately 5 kc at 15 ips tape speed when the bias current was increased by a factor of 1.5 to 2. This effect was verified by very careful measurements on two of the samples and is definitely not a result of experimental errors. By using tape speeds of 7.5 and 15 ips, it was determined that this is a wave-length and not a frequency effect.

At the time that the measurements were made we could find no theoretical explanation of this effect. At a later date other activities revealed the source of this tendency to hump at 5 kc. It has been found that magnetic recording system operating at zero bias has a frequency response with a deep notch at a wavelength which is a function of the gap dimension of the recording head. As the bias current in the recording head is increased the depth of the notch decreases. It appears that the notch is not completely eliminated until the bias current is increased to about two times the maximum sensitivity bias. Thus if a magnetic recording system operating at maximum sensitivity bias is equalized to have an absolutely flat frequency response, increasing the bias current by a factor of 1.5 or 2 will result in a hump of about 1 db in the frequency response at the frequency corresponding to the wavelength of the notch obtained without bias.

Conclusions

In reviewing the conclusions listed below it should be kept in mind that the tape test data apply only to these tape samples which were manufactured about two years ago. The test data on specific tape characteristics definitely do not apply to current production.

(a) Comparison tests on 21 tapes from three manufacturers show a disturbingly wide range of tape characteristic variations. Maximum sensitivity bias current requirement varies 1.7:1. Recording sensitivity varies over a range of about 5 db. Relative high frequency response at 15 kc and 15 ips tape speed varies $\pm$2.8 db.

(b) It has been found that a certain high value of bias current permits all 21 tape samples to be used at a fixed value of bias current with variations in performance characteristics that are probably tolerable. Recording sensitivity varies over a range of about 2 db. Relative high frequency response at 15 kc and 15 ips tape speed varies $\pm$2.8 db.

(c) Brand B tape at maximum sensitivity bias provides definitely superior performance. Recording sensitivity varies over a range of only 0.6 db. Relative high frequency response at 15 kc and 15 ips tape speed varies only $\pm$1.2 db. To obtain this superior performance maximum sensitivity bias must be used which is completely unsatisfactory for the other brands of tape listed in this paper.

(d) A method of measuring modulation noise in magnetic recording is described which seems to correlate fairly well with listening tests.

(e) It has been discovered that a magnetic recording system which is equalized to have a flat frequency response at maximum sensitivity bias will have a hump of about 1 db at 5 kc and 15 ips tape speed when the bias current is increased by a factor of 1.5 or 2.

DISCUSSION SUMMARY

Mr. Witt of International Business Machines asked if RCA tests had included effects of age on tape characteristics--sensitivity in particular. Mr. Erikson replied that such tests were planned eventually but no data was now available.

Mr. Lewin of Signal Corps Pictorial Center asked for more details as to why the playback head azimuth alignment had to be changed for maximum high frequency response from different tapes. Mr. Erikson explained that, since the record and playback heads were at different points along the tape path, a tape that has curvature along its edge will require realignment of the playback head in order for the slit to remain perpendicular to the tape edge at a later point along the curved tape travel.

Mr. Carson of Naval Research Laboratory added a comment that in his own experience some tapes required realignment of playback azimuth for maximum highs, and that it seemed to be caused by the manner in which the tape positioned itself between the drive capstan and pressure roller.

Mr. Selsted of Ampex asked if RCA tests had indicated the possible sources of modulation noise. Mr. Erikson advised that for lower modulation frequencies it appeared to be caused by lack of uniform contact between the tape coating and the head; perhaps caused by dirt, unevenly dispersed coating. At higher test frequencies there is a frequency flutter (not amplitude modulation). This is caused by the mechanical relation between the tape and the recorder.

Mr. Lewin noted that no data was shown for tape noise in the absence of any recorded signal. Mr. Erikson replied that this type of measurement had been discussed and rejected because of the inability to positively separate it from noise caused by the playback equipment. Mr. Lewin mentioned Signal Corps Pictorial Center experience with amplitude fluctuations, and that on some tapes these appeared to occur at a regular cyclic rate. Mr. Erikson replied that dropouts as high as

3 db had been noted in the RCA tests, but were usually of the order of a few tenths db and were inaudible even with a steady state sine wave signal, because of their short duration.

Mr. Sibley of Lockheed asked if noise output had been made after saturating a tape with d-c, since such noise seemed to bear a direct relation to modulation noise. Mr. Erikson replied that about three methods of noise measurement had been compared and had found good correlation between the different noise measurements. The method he described in Paper #13 was used because of its use of a standard intermodulation test equipment and because no modifications were required in the tape recorder.

TABLE 1.--Comparative tape Characteristics using maximum sensitivity bias

Mfr. Type	Sample No.	Relative Bias Current	High-Frequency Response Relative to 1 kc in db			dbm Output for 10 dbm Input at 1 kc	dbm Output for three percent Distortion	Percent IM Mod. Noise
			5 kc	10 kc	15 kc			
Brand A	1	41	-0.7	-0.8	-1.2	5.8	17.4	0.36
Brand A	2	42	-0.7	-1.0	-1.4	6.2	17.9	0.36
Brand A	3	42	-1.2	-1.8	-2.7	5.2	17.2	0.5
Brand A	4	41	-0.1	-0.2	-0.3	6.0	17.5	0.36
Brand A	5	43	-0.4	-1.0	-1.9	5.1	16.9	0.45
Brand A	6	44	-1.0	-1.8	-3.2	4.8	16.8	0.45
Brand A	7	42	-0.9	-1.7	-2.6	4.8	16.9	0.46
Brand A	8	42	-0.4	-0.7	-1.4	5.1	16.9	0.45
Brand A	9	43	-1.0	-1.5	-2.5	5.4	17.4	0.5
Brand A	Max.	44	-0.1	-0.2	-0.3	6.2	17.9	0.5
Brand A	Min.	41	-1.0	-1.8	-3.2	4.8	16.8	0.36
Brand B	1	28	0	0	0	10.0	17.6	0.2
Brand B	2	32	+0.1	-0.3	-0.9	9.6	18.0	0.25
Brand B	3	30	-0.2	-0.5	-0.8	9.4	17.3	0.25
Brand B	4	32	-0.8	-1.4	-2.0	9.7	18.1	0.2
Brand B	5	31	-0.8	-1.2	-1.6	9.5	17.5	0.2
Brand B	6	30	-0.9	-1.6	-2.1	9.5	17.1	0.3
Brand B	7	29	+0.1	+0.2	+0.3	9.7	16.9	0.2
Brand B	Max.	32	+0.1	+0.2	+0.3	10.0	18.1	0.3
Brand B	Min.	28	-0.9	-1.6	-2.1	9.4	16.9	0.2
Brand C	1	48	-1.4	-3.5	-5.3	6.3	19.5	0.55
Brand C	2	47	-0.6	-1.6	-2.7	6.7	20.0	0.5
Brand C	3	45	-1.3	-3.4	-4.8	6.3	19.6	0.65
Brand C	4	42	-0.9	-2.4	-3.3	5.8	18.1	0.45
Brand C	5	42	-0.9	-2.0	-3.0	6.1	18.6	0.55
Brand C	Max.	48	-0.4	-1.6	-2.7	6.7	20.0	0.65
Brand C	Min.	42	-1.4	-3.5	-5.3	5.8	18.1	0.45
Max. all samples		48	+0.1	+0.2	+0.3	10.0	20.0	0.65
Min. all samples		28	-1.4	-3.5	-5.3	4.8	16.8	0.2

TABLE II.--Comparative brand B tape characteristics using bias current of 42

Mfr. Type	Sample No.	Relative Bias Current	High-Frequency Response Relative to 1 kc in db			dbm Output for 10 dbm Input at 1 kc	dbm Output for three percent Distortion
			5 kc	10 kc	15 kc		
Brand B	1	42	+0.9	-0.5	-1.7	7.8	18.3
Brand B	2	42	+0.3	-1.1	-2.3	8.4	18.4
Brand B	3	42	+0.3	-1.3	-2.7	7.9	17.9
Brand B	4	42	-0.5	-2.4	-3.9	8.6	18.4
Brand B	5	42	-0.3	-2.0	-3.5	8.2	18.1
Brand B	6	42	-0.5	-2.4	-4.0	8.1	17.7
Brand B	7	42	+0.7	-0.2	-1.0	7.5	17.6
Brand B	Max.		+0.7	-0.2	-1.0	8.6	18.4
Brand B	Min.		-0.5	-2.4	-4.0	7.5	17.6

TABLE III.--Comparative tape characteristics using constant high current bias

Mfr. Type	Sample No.	Relative Bias Current	High-Frequency Response Relative to 1 kc in db			dbm Output for 10 dbm Input at 1 kc	dbm Output for three percent Distortion	Percent IM Mod. Noise
			5 kc	10 kc	15 kc			
Brand A	1	60	0	-2.4	-4.2	4.2	17.5	0.32
Brand A	2	60	+0.3	-1.7	-3.7	4.7	18.0	0.33
Brand A	3	60	0	-2.8	-5.1	4.1	17.4	0.4
Brand A	4	60	+0.9	-0.9	-2.7	4.2	17.5	0.36
Brand A	5	60	+0.4	-2.3	-4.2	3.9	17.0	0.45
Brand A	6	60	0	-2.9	-5.1	3.8	16.8	0.45
Brand A	7	60	+0.1	-2.7	-5.1	4.0	16.9	0.43
Brand A	8	60	+0.7	-1.5	-3.7	4.1	17.0	0.45
Brand A	9	60	+0.3	-2.1	-4.6	4.6	17.6	0.45
Brand A	Max.		+0.9	-0.9	-2.7	4.7	18.0	0.45
Brand A	Min.		0	-2.9	-5.1	3.8	16.8	0.32
Brand B	1	60	+1.2	-1.2	-3.9	4.3	18.5	0.25
Brand B	2	60	+0.9	-2.1	-5.6	5.1	18.7	0.35
Brand B	3	60	+0.5	-2.5	-5.8	4.6	18.0	0.35
Brand B	4	60	-0.5	-4.5	-8.3	5.5	18.7	0.3
Brand B	5	60	+0.1	-3.5	-7.1	4.8	18.0	0.3
Brand B	6	60	-0.2	-3.9	-7.5	4.6	17.4	0.3
Brand B	7	60	+1.4	-0.7	-3.0	3.8	17.7	0.25
Brand B	Max.		+1.4	-0.7	-3.0	5.5	18.7	0.35
Brand B	Min.		-0.5	-4.5	-8.3	3.8	17.4	0.25
Brand C	1	60	-0.7	-4.0	-6.7	5.4	19.4	0.45
Brand C	2	60	-0.4	-2.9	-5.2	6.0	19.9	0.4
Brand C	3	60	-1.0	-4.2	-6.8	5.2	19.6	0.45
Brand C	4	60	-0.2	-3.1	-5.3	4.1	18.0	0.35
Brand C	5	60	-0.1	-3.1	-5.3	4.6	18.3	0.35
Brand C	Max.		-0.5	-2.9	-5.2	6.0	19.9	0.45
Brand C	Min.		-1.0	-4.2	-6.8	4.1	18.0	0.35
Max. all samples			+0.9	-0.9	-2.7	6.0	19.9	0.6
Min. all samples			-0.5	-4.5	-8.3	3.8	16.8	0.25

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Paper 14

CHARACTERISTICS OF RECENT COMMERCIAL 1/4-INCH MAGNETIC TAPES--EFFECTS OF TRENDS ON NAVY TAPE STANDARDIZATION

F. A. Comerci, S. Wilpon, and R. Schwartz

Material Laboratory
New York Naval Shipyard

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ABSTRACT: A comparison of magnetic characteristics of the most recent available commercial 1/4-inch magnetic recording tapes will be presented. Some of the characteristics to be compared are: output and distortion versus bias level and frequency, signal-to-d-c noise ratio, ease of erasure, and layer-to-layer signal transfer. Trends in characteristics varying from the norm will be discussed with regard to their effect on the Navy Tape Standardization Program.

Background

It seems that a number of people here do not know that the Bureau of Ships and the Navy Department in general has a specification for magnetic recording tape. This has been developed by the Department of the Navy, Bureau of Ships, and was published or issued March 28, 1952. It is called the Interim Federal Specification, "Tape Recording, Magnetic Coated, and Reels, Recording Tape, 1/4 Inch," and the number of it is W-T-61A.

With this specification for the evaluation of magnetic tape there is a standard reference tape and the specification refers to a referenced recorder. The referenced recorder was selected to eliminate any problems in the amplifiers so that the referenced recorder would be able to handle all size reels encountered.

The actual evaluation of the magnetic recording tape is done on the basis of a comparison with this standard reference tape. The standard reference tape was selected some two years ago, and the Material Laboratory has been doing evaluation of 1/4 inch magnetic recording tape for at least that period of time, if not longer.

Recently, a survey of the characteristics of four of the most recent productions of 1/4 inch plastic magnetic recording tapes was performed at the Material Laboratory to determine whether any improvements in tape would warrant revision of the Interim Federal Specification W-T-61a.

Results

Three samples, representing the current production of general type brown oxide magnetic tape from the three major tape manufacturers and one sample of a special high output tape recently introduced on the market were compared through measurements outlined in the tape specification at a tape speed of 7-1/2 inches per second. The results of these comparisons indicate that differences in the performance of the three general type brown oxide tapes were not great and that they essentially met requirements of the specification. The high output tape, although presenting between four and 6 db higher output than the general type tape, possessed no particular advantage with respect to signal to d-c noise ratio and suffered from greater "print through" or layer to layer signal transfer. The results are shown in the following figures:

In figures 1 through 5 the variation in output level and total harmonic distortion with changes in high frequency bias current are presented for two different audio levels and three different frequencies.

In figure 1 under conditions of standard record level and 1000 cps the curves of output level for the three general type tapes are essentially similar. The curve of output level for the high output tape is also similar but shows approximately 6 db greater output. On this figure the specified limits for sensitivity are indicated, showing that the three general type tapes meet specified requirements for sensitivity. The distortion characteristics of the four tapes are similar and meet the specified requirements of a maximum distortion of 2 percent. As a point of interest, some tapes show a more constant output over the bias range of $\pm$ 10 percent. Since in service use it might be expected that the bias current may vary over this range, this particular characteristic is desired in a tape for general use. That tape, in which a large change in output level occurs with bias current, is particularly advantageous for use as a standard reference tape where a determination of peak output point is sought.

In figure 2, under conditions of standard record level and 200 cps, the curves of distortion and output, with the exception of the higher output for the high output tape, are again essentially similar.

In figure 3, under conditions of standard record level and 5000 cps, the variation in output of the four tapes are amplified. The absence of distortion curves on this figure is due to the inability of the tape system to resolve the predominant third harmonic distortion component at the speed of 7-1/2 inches per second.

In figure 4 one of the three general type tapes fails to meet the maximum distortion requirement of 4 percent over the bias current range of ± 10 percent operating bias by as much as 1/2 percent at 0.26 relative bias current, the -10 percent point.

In figure 5 the variations in the curves shown are similar to those in figure 4. Recent experience indicates that an additional requirement should be inserted in the specification to cover low frequency sensitivity and distortion since they are affected by coating thickness.

Curves of output level and distortion vs input levels for operating bias current and 1000 cps are shown in figure 6. All four tapes meet the maximum distortion requirements of four percent at maximum record level and two percent at standard record level.

In figure 7 the frequency response curves of the four tapes are shown to differ by not more than 6-1/2 db at 10000 cps nor 2 db at 5000 cps. All the tapes meet specified requirements for high frequency output at 5000 cps. The variations in high frequency response for the four tapes are not considered appreciable for the type of usage envisioned by the Federal Services.

Frequency Response Variations

The variations in frequency response are due to the fact that the operating bias current was not an optimum for each tape, but a compromise between optimum bias for all tapes. By selecting proper currents the frequency response curves for the four tapes were made to coincide. This is indicated for the high output tape in figure 8.

Signal-To-Noise Ratios

Overall and high frequency noise measurements for the four tapes were primarily an indication of amplifier noise and would have no meaning with respect to comparison of noise produced by these tapes. All tapes surpassed the specified requirements of 60 and 65 db for signal to overall and high frequency noise ratios, respectively.

The signal to d-c noise for the four tapes met the minimum requirement of 50 db. Comparative measurements are:

Tape No.	Signal to d-c Noise Ratio (db)
1	65
2	58
3	65
4	67

General Conclusions

Essentially there is no difference between the high output tape and two of the general type tapes. One of the general type tapes could be improved but there is not enough difference to warrant changing the specification to force such an improvement until it can be shown that the presently specified minimum value of 50 db, results in a perceptible modulation noise.

The ratio between signal and layer to layer signal transfer or "print through" for the high output tape measured about 8 db less than the three general type tapes evidently due to its greater sensitivity for low magnetizing fields. This seems to be the only property of this tape which is a disadvantage. All of the general type tapes just met the specified minimum requirement of 50 db.

The high output tape was erased more easily. All four tapes met the specified minimum requirement of 50 db erasure. The general type tapes were erased to the extent of 61 db whereas the high output tape was erased to the extent of 71 db. It is noted that the advantages of the high output tape are not accompanied by higher signal to tape noise ratios and in addition present a problem in layer to layer signal transfer. It is not compatible with the general type tapes now approved for Federal use, and its higher output alone does not justify an additional specification to cover its procurement and the problems associated with the stocking of two different types of tape. However, the high output tape does represent a step of progress in the magnetic recording field and further development in this direction should be encouraged.

Effect on Tape Specification

In conclusion it can be said that Federal Specification W-T-61a which represents requirements of a 1/4 inch magnetic recording tape for general use by the Federal Services can be essentially met by three current producers of magnetic tape. One manufacturer does not comply with requirement of distortion for the minimum operating bias. It is considered that a change in magnetic qualities can, and in the interest of standardization should, be accomplished in order to correct this deviation. Thus the specification in its present form permits the purchase of tape from two of the major producers of magnetic tape and provides for standardization of an important item in the tape recording system.

DISCUSSION SUMMARY

In reply to Mr. Smith of National Advisory Committee for Aeronautics, Mr. Wilpon noted that the specification covered tape intended primarily for audio frequency recording, but that many features of specification W-T-61A were applicable for obtaining tape suitable for FM. carrier type and other types of data recording. The specification does have some requirements to reduce "drop-outs" which Mr. Smith noted caused considerable trouble in data recording.

Mr. Comerci of Navy Material Laboratory added that the tape specification requirement for uniformity of output at test frequencies of 1000 and 5000 cycles does show up the increase in "drop-outs" at higher frequencies. This requirement was in the specification primarily to determine the manufacturer's ability to make a tape with a smooth coating. He felt that with care in selecting the tape desired, the smaller quantities required for telemetering work could be selected from the stocks for general audio work.

Mr. Roberts of Dictaphone asked if the d-c noise measurements were broad band type or were plotted against frequency. Mr. Wilpon said broadband measurements were made of noise and then referred to the 1000 cycle maximum signal level for signal-to-noise ratios. Mr. Roberts advised that work at Dictaphone had included analysis against frequency of the tape noise after d-c saturation. Maximums do occur, especially at very low tape speeds with very narrow heads. These noise spectrums are of great value in determining choice of post-equalization.

Mr. Johnston of Minnesota Mining asked if the tape noise was the real limiting factor in field use on the "VRT" type recorders which the Navy has. Mr. Comerci answered that, while it was true that signal-to-noise ratios were as low as 35-40 db on some Navy "VRT" type recorders, this noise was predominantly 60 or 120 cycle hum which was not usually heard in the acoustic output whereas tape noise was predominantly hiss noise which could be heard. Therefore, the Navy felt that the 50 db signal-to-noise limit was needed and represented the level below which noise would not be heard.

Mr. Witt of International Business Machines pointed out that the type of noise which gave difficulty in instrumentation applications--for instance, high frequency "spikes"--was not the type of primary difficulty in audio work. Also, he didn't notice any considerations of physical wear properties of the tape. Mr. Comerci advised that, while Paper No. 14 did not cover such points, there was a group of physical measurements and requirements in the specification which include effect of tension, shock tensile strength, layer-to-layer adhesion, coefficient of friction, oxide peel-off under high tension, and others.

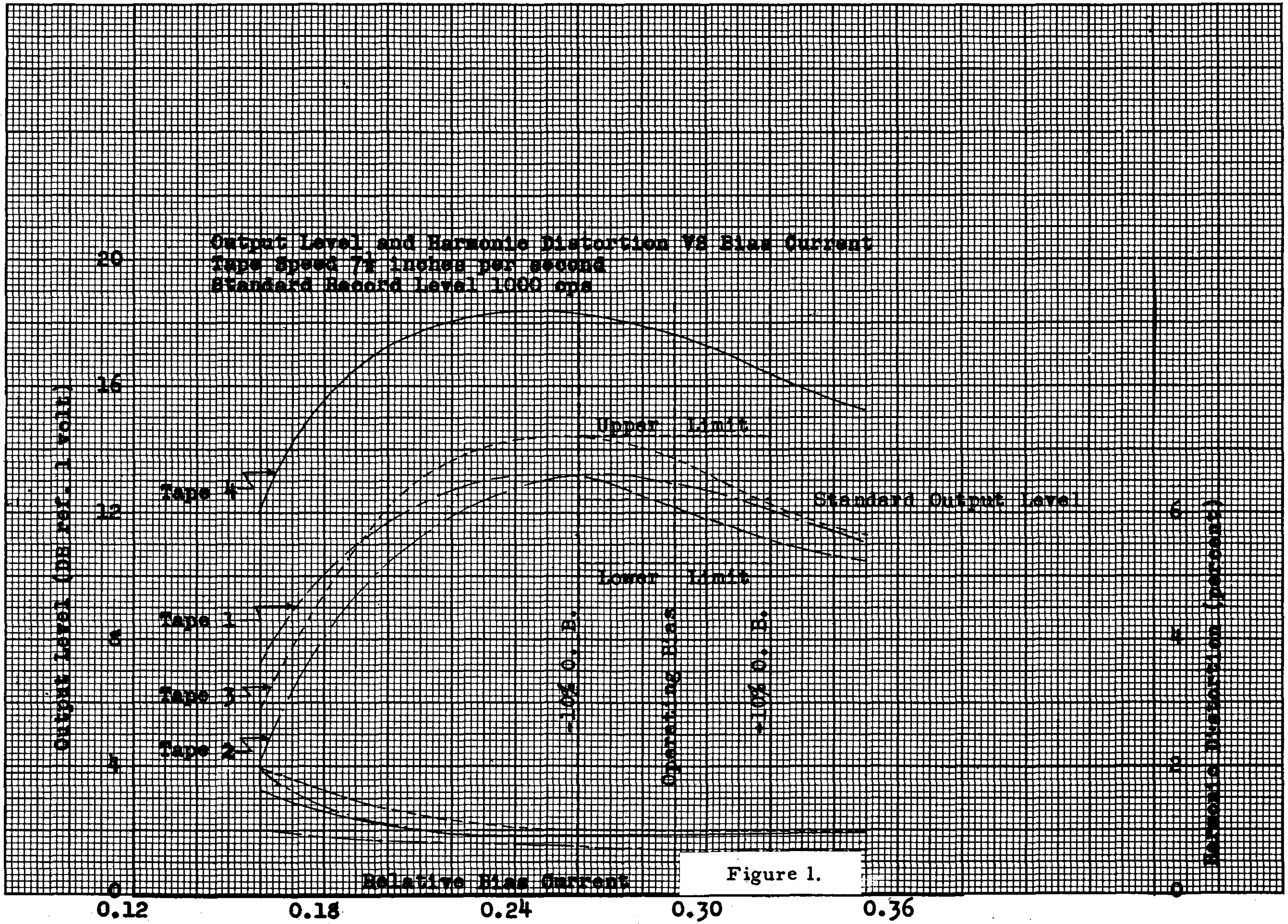
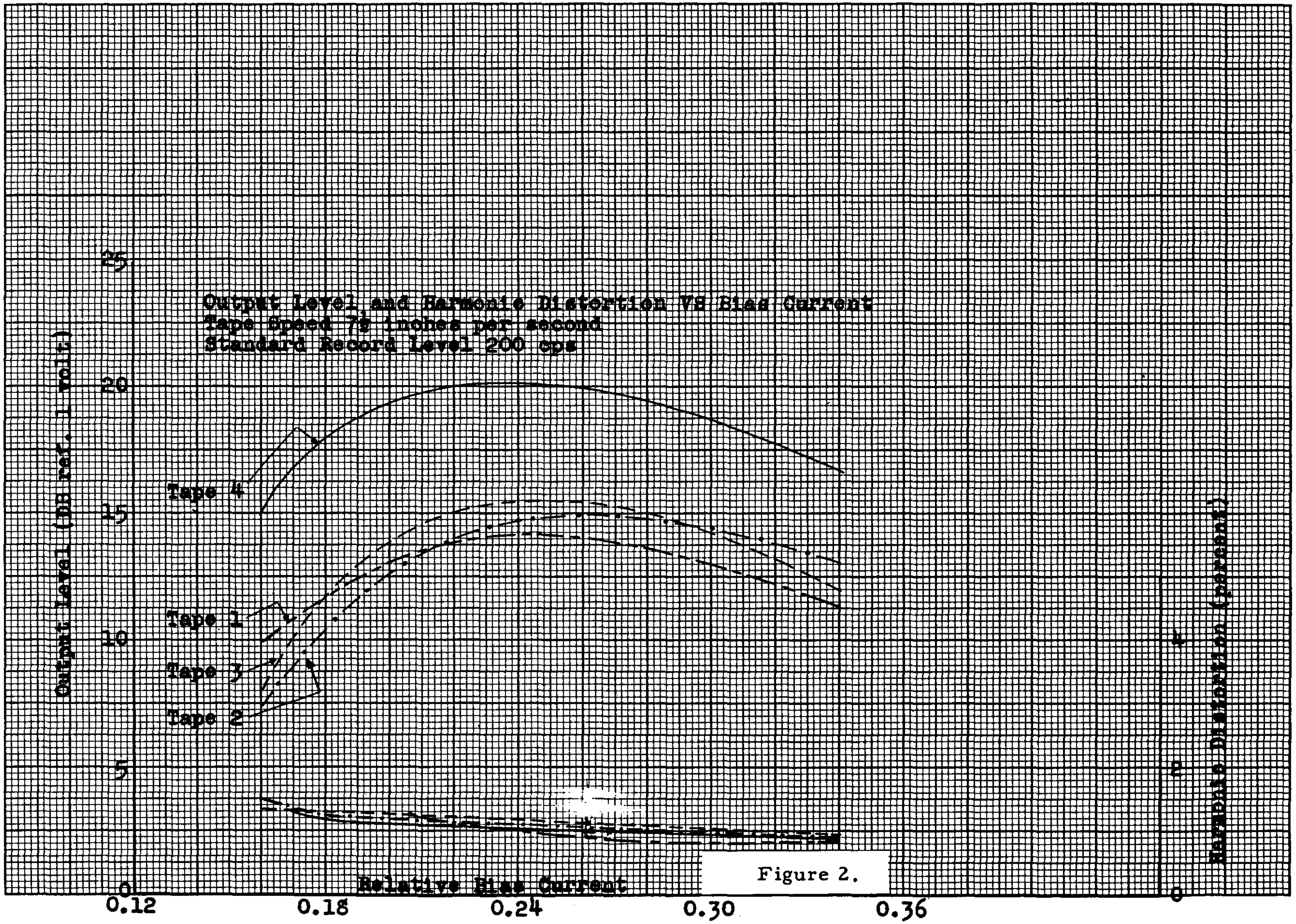

Output Level and Harmonic Distortion VS Bias Current
Tape Speed 7½ inches per second
Standard Record Level 1000 cps
Output Level (DB ref. .1 volt)
20
16
12
8
4
0
Upper Limit
Standard Output Level
Lower Limit
Tape 4
Tape 1
Tape 3
Tape 2
-10% O. B.
Operating Bias
+10% O. B.
Harmonic Distortion (percent)
6
4
2
0
Relative Bias Current
0.12
0.18
0.24
0.30
0.36

Figure 1.



Output Level and Harmonic Distortion VS Bias Current
Tape Speed 7½ inches per second
Standard Record Level 200 cps
Output Level (DB ref. 1 volt)
Harmonic Distortion (percent)
Relative Bias Current
Tape 4
Tape 1
Tape 3
Tape 2
0
5
10
15
20
25
0.12
0.18
0.24
0.30
0.36
2
4

Figure 2.

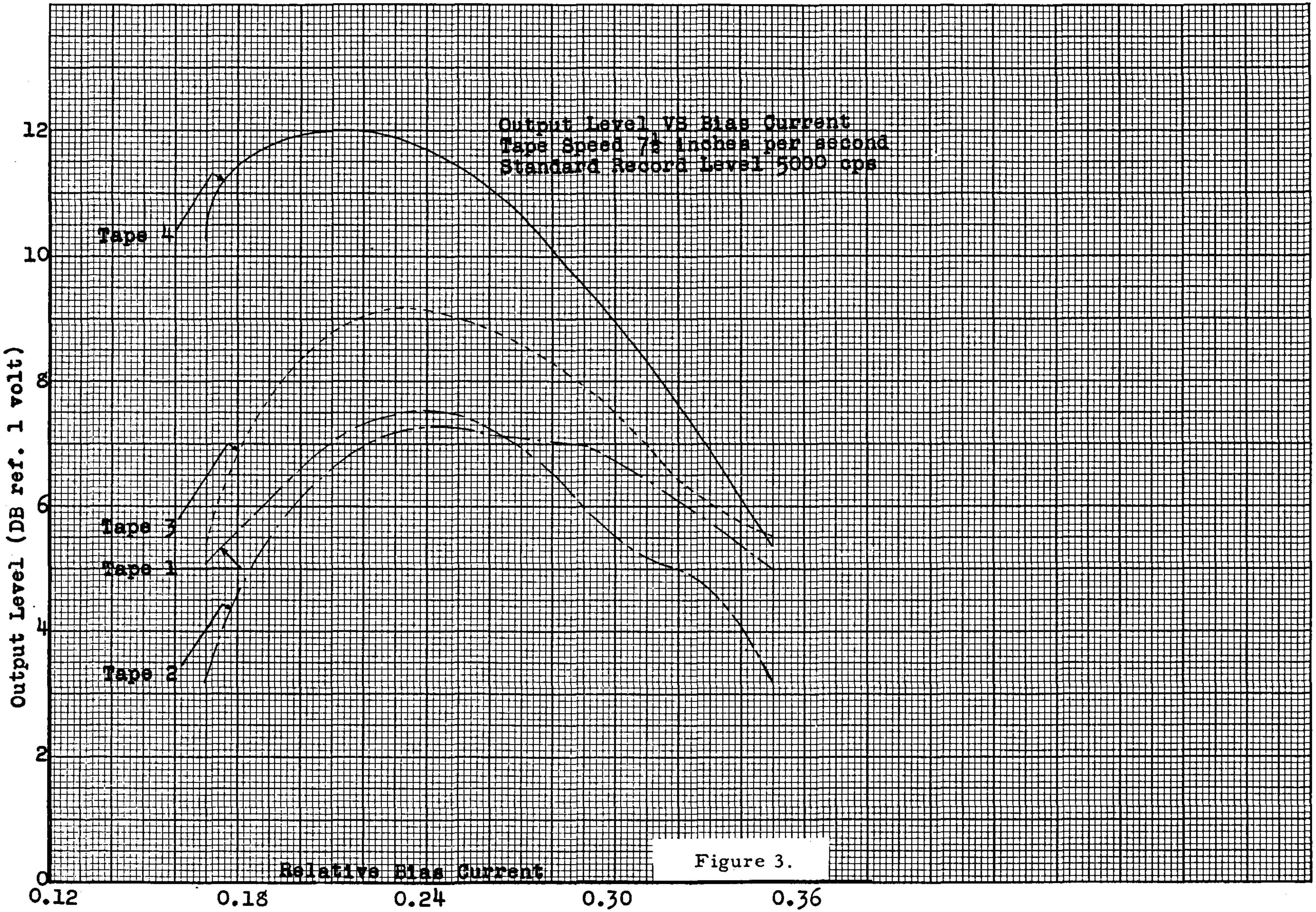


Figure 3.

14-8

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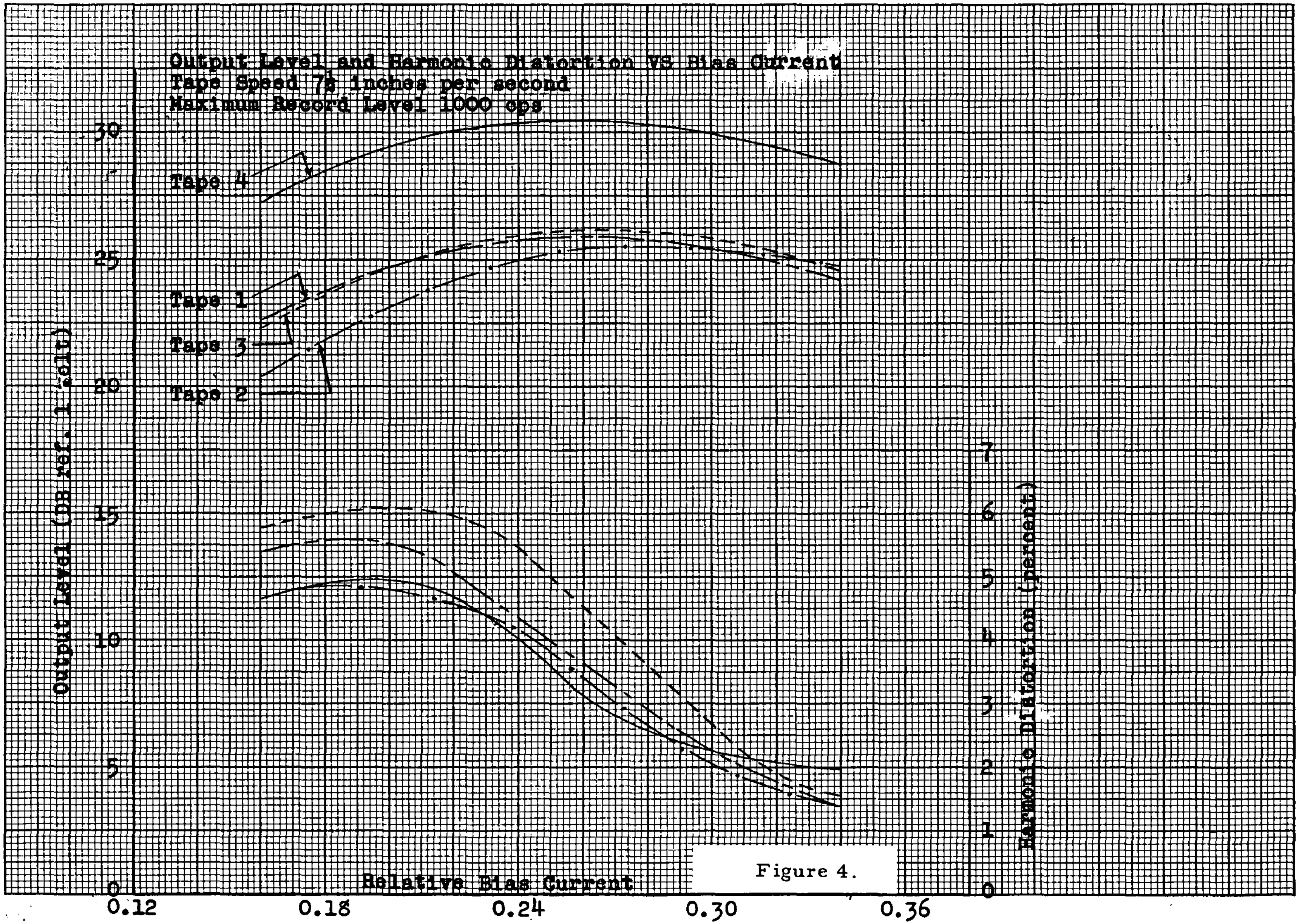

Figure 4.

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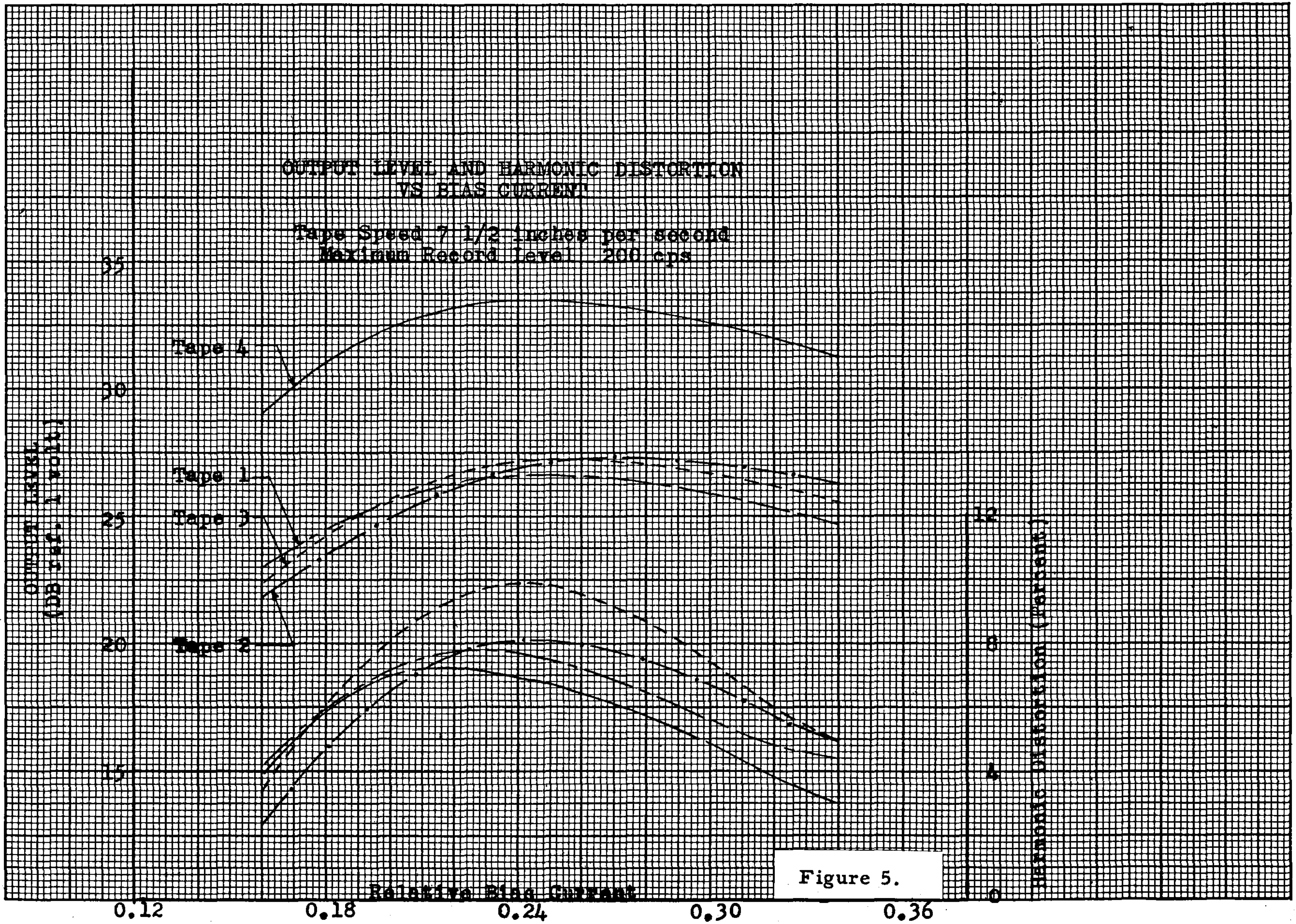
OUTPUT LEVEL AND HARMONIC DISTORTION
VS BIAS CURRENT
Tape Speed 7 1/2 inches per second
Maximum Record Level 200 cps
OUTPUT LEVEL
(DB ref. 1 volt)
35
30
25
20
15
Tape 4
Tape 1
Tape 3
Tape 2
Harmonic Distortion (Percent)
12
8
4
0
Relative Bias Current
0.12
0.18
0.24
0.30
0.36

Figure 5.

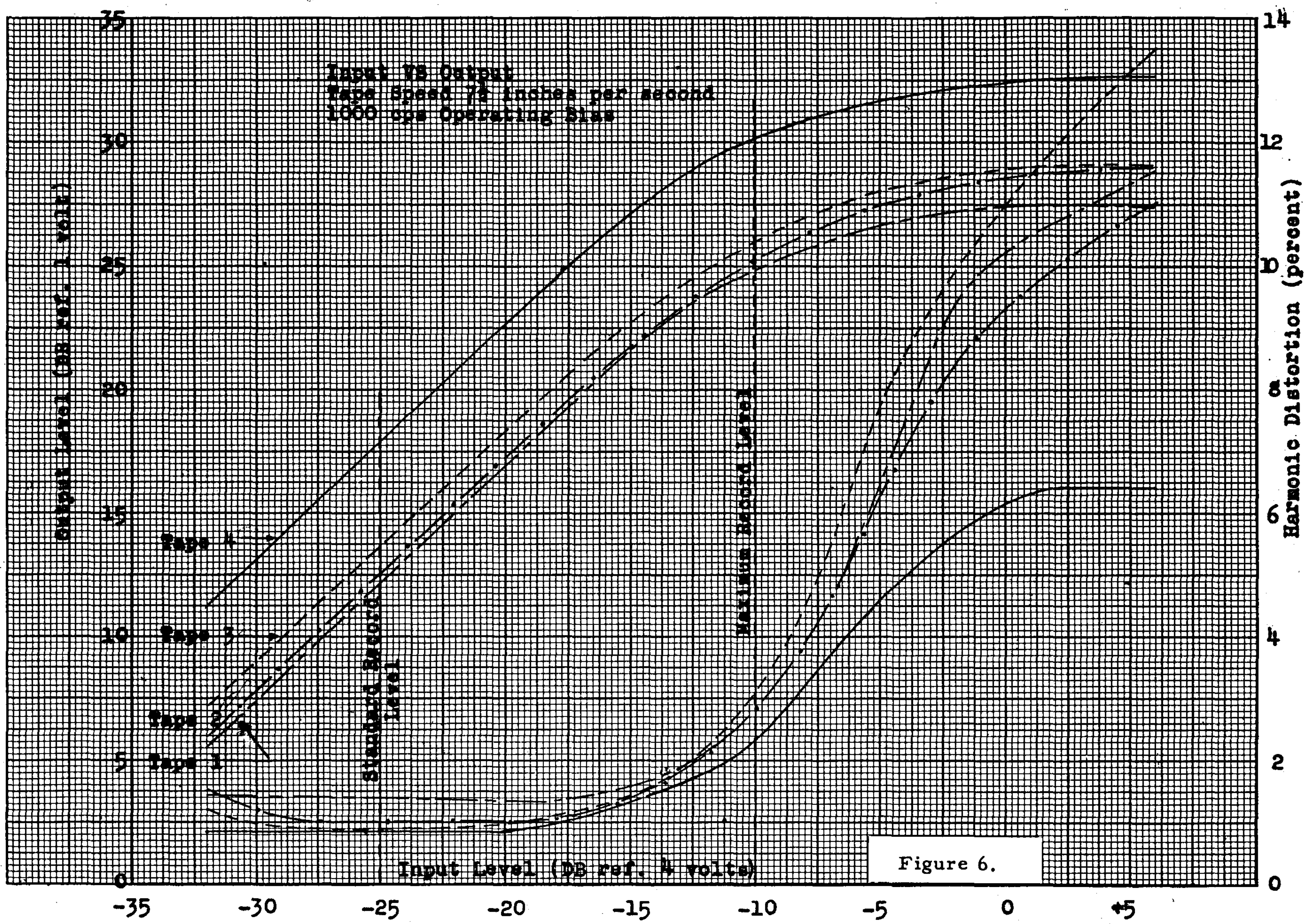
Input VS Output
Tape Speed 7½ inches per second
1000 cps Operating Bias
Output Level (DB ref. 1 volt)
Harmonic Distortion (percent)
Input Level (DB ref. 4 volts)
Tape 4
Tape 3
Tape 2
Tape 1
Standard Record Level
Maximum Record Level
35
30
25
20
15
10
5
0
14
12
10
8
6
4
2
0
-35
-30
-25
-20
-15
-10
-5
0
+5

Figure 6.

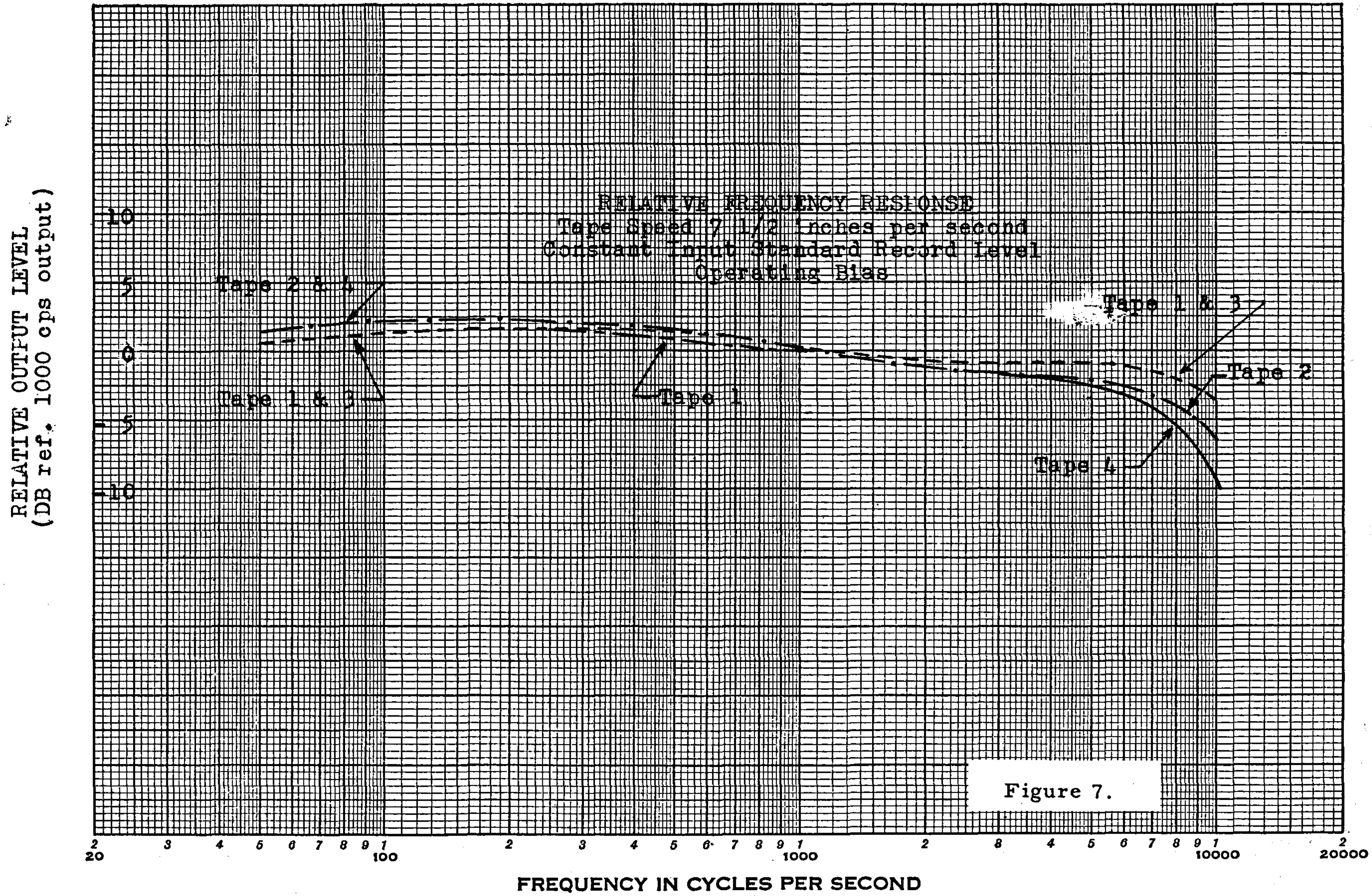
RELATIVE FREQUENCY RESPONSE
Tape Speed 7 1/2 inches per second
Constant Input Standard Record Level
Operating Bias
Tape 2 & 4
Tape 1 & 3
Tape 1
Tape 1 & 3
Tape 2
Tape 4
10
5
0
-5
-10
RELATIVE OUTPUT LEVEL
(DB ref. 1000 cps output)
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure 7.

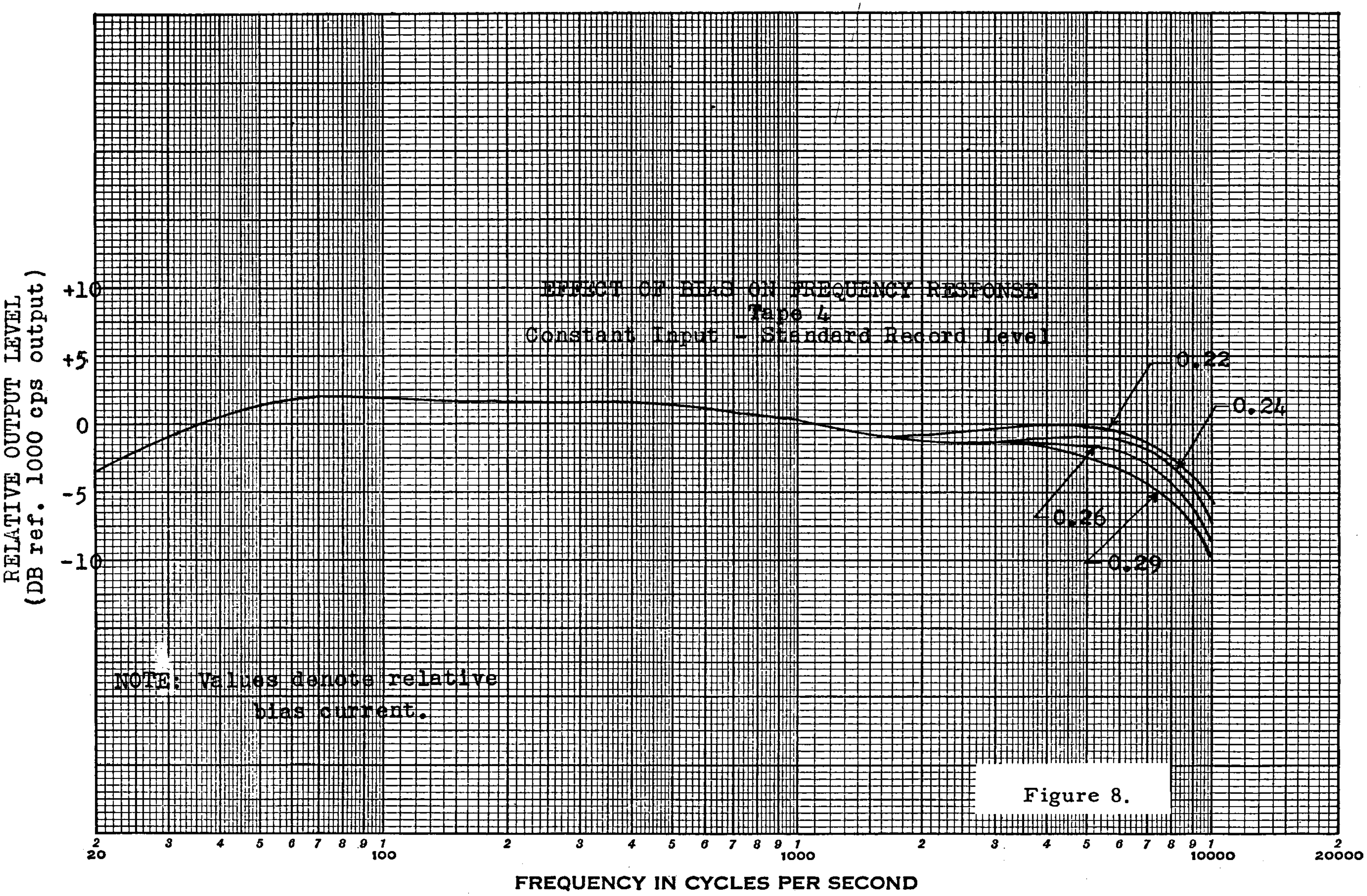
EFFECT OF BIAS ON FREQUENCY RESPONSE
Tape 4
Constant Input - Standard Record Level
RELATIVE OUTPUT LEVEL
(DB ref. 1000 cps output)
+10
+5
0
-5
-10
0.22
0.24
0.26
0.29
NOTE: Values denote relative
bias current.
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure 8.

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Paper 15

SOME NOTES ON PROBLEMS ENCOUNTERED IN THE USE OF THE STANDARD REFERENCE TAPE

Mr. Frank Radocy

Director of Quality Control
Audio Devices, Incorporated

9 October 1953

ABSTRACT: The paper includes:

(1) A description of the "Reference Tape" method as used in the Interim Federal Specification W-T-61a(Navy Ships) dated 28 March 1952.

(2) Observations on the changes in performance characteristics of the Standard Reference Tape resulting from physical changes due to repeated playings.

(3) Variations in the Standard Reference Tape performance resulting from replacement of magnetic record and reproduce heads.

Reference Tape Method

For those who are not acquainted with the Reference Tape method of standardization, the high points will be outlined briefly.

(a) A Reference Recorder is selected which has certain minimum features, including specified limits on record and playback characteristics, flutter and wow limitations, minimum bias frequency, etc.

(b) The next step involves the selection of a magnetic tape, which, when used in conjunction with the Reference Recorder, gives the desired performance. This tape is called the "Primary Standard Reference Tape." The actual performance of this tape is secondary, since it is to be used only as a "Reference;" therefore, the prime consideration in selecting the "Primary Standard" is its stability.

(c) "Standard Reference Tapes" (which have been calibrated against the "Primary Standard") can be used to adjust Reference Recorders for frequency response, operating bias current, maximum record level, and standard output level.

(d) Standard Reference Tapes may be obtained from the Material Laboratory, Bureau of Ships, Department of the Navy, and are used in conjunction with Interim Federal Specification W-T-61a.

Problems in Use

The first problem concerns the changes in characteristics of a Standard Reference Tape due to frequent use.

The particular "Standard Reference Tape" concerned was used as a production standard, against which daily samples of magnetic tape were checked. Within a week's time, it was obvious that a change was taking place. The high frequency response of production samples appeared to be getting poorer and a shift in peak bias seemed to be taking place.

A thorough investigation revealed that some of the characteristics of the "Standard Reference Tape" had changed. Visual examination of the tape showed that the coated surface had become highly burnished. Micrometer measurement of the tape revealed a 10 percent reduction in the coating thickness, as compared to the original measurement.

As a result of these physical changes, the performance characteristics were affected. Figure 1 is a graphic comparison of the bias, output and distortion characteristics of the "Standard Reference Tape" before any change occurred, with the same tape after much use. The data for these curves was taken on our No. 1 Reference Recorder at a speed of 7 1/2 inches/sec, a frequency of 1 kc and a standard output level determined by the new tape. The output figures are arbitrary.

The uppermost section of figure 1 compares the bias--vs--output curves of both tapes. Notice that the curve of the worn tape has become sharper with an increase of approximately 1 db in maximum output and a nine percent reduction in Peak Bias. Also note the slight increase in the distortion of the worn tape, in the lower section of figure 1. This increase in distortion is not a serious change; however, it confirms the fact that a reduction of coating thickness has occurred.

Figure 2 is a set of frequency response curves, also taken on our No. 1 Reference Recorder at a speed of 7-1/2 inches/sec. The standard output level was determined for each tape so that a true comparison is shown. The procedure for determining the standard output level also involves the simultaneous determination of operating bias current so that the peak bias shift demonstrated by figure 1 has been accounted for.

The worn tape shows an increase in output of 3 db at 7.5 kc, at 5 kc the increase is 2 db, and at 1 kc the increase is approximately 1 db. This is considerable increase in response and can cause much confusion unless the user is aware of the changes taking place. Whether this particular tape is the exception has not been determined; however, it serves its purpose in revealing the changes that will occur with all tapes to some degree.

The best precaution to be taken, to avoid being misled by the changes described, is to obtain two "Standard Reference Tapes" or to divide one tape into two sections, using one as a daily reference control and cross-checking weekly or monthly against the other.

Some other measures to minimize the wear and tear on a magnetic tape should also be practiced:

(a) The "hold back" and "take up" tensions should be kept at a minimum, especially in hot, humid weather.

(b) Avoid using small reels on machines designed only for large reels.

(c) Use the largest hub diameter practicable for your operation.

(d) Avoid machines with excessively hot erase heads.

(e) Try to keep your tapes at constant temperature and humidity to minimize compression and distortion during storage.

The second point to be discussed concerns the performance of the Reference Recorders. It is not expected that all recorders will have identical performance characteristics, but it has been generally assumed that the relative differences in the performance characteristics of two tapes would not be disturbed by a change of recording machines, so long as the machines conformed to the Reference Recorder specification in Federal (Interim) Specification W-T-61A. Unfortunately, this assumption now seems incorrect.

Figure 3 is an illustration of the output--vs--distortion characteristics of two tapes run on each of two separate recorders. In each case, the operating bias current was set at peak bias. The upper section of figure 3 shows the curves taken on our No. 1 Reference Recorder. A "Standard Reference Tape" and a production tape appear to be within .5 db of each other. However, the curves (lower section of figure 3) of the same tapes taken from our No. 2 Reference Recorder show the production tape to have 3.5 db higher output at three percent distortion, than the "Standard Reference Tape".

Figure 4 is the bias--vs--output characteristics of the same tapes used for figure 3, on the same recorders. Again these figures were taken at a speed of 7-1/2 inches/sec, 1 kc and at the Standard Output Level determined by the "New Standard Reference Tape".

In accordance with Federal (Interim) Specification W-T-61a, the Operating Bias Current is 110 percent of the peak bias current of the "New Standard Reference Tape". Applying this adjustment of bias current to the No. 1 Reference Recorder (upper section of figure 4), we find our Operating Bias Current to be 7 ma. This is about eight percent less current than needed to reach the peak bias of the production tape. In the lower section of figure 4, however, the same adjustment results in an Operating Bias Current of 26.5 ma which is six percent beyond the peak bias of the production tape. Obviously, the Operating Bias Current on these two recorders bear a different relationship to the peak of the production tape.

Figure 5 demonstrates the differences in relative frequency response on both recorders. The operating conditions remain the same as in figure 4. The output of the New Standard Reference Tape is adjusted to show a flat response to 7.5 kc. The output from the production tape is drawn in relation to the adjusted output of the "Standard Reference Tape". At 7.5 kc on the No. 1 Recorder, the production tape produces .5 db more output than the Standard Tape. On the No. 2 Recorder at the 7.5 kc output point, the production tape shows 1 db lower. This relative difference of 1.5 db in 7.5 kc output on the production tape can be attributed to the Bias irregularities described by figure 4.

It is easy to foresee the difficulties involved in trying to correlate performance characteristics through the use of a "Standard Reference Tape," if the parties concerned have recorders that vary in characteristics as much as those in figures 3, 4, and 5.

It would appear that the use of a "Standard Reference Tape" does not, in itself, provide a reliable standard of tape performance, probably due to an unforeseen reaction between tape and recorder characteristics. It seems necessary, therefore, to provide a better definition of the test recorder than is presently provided.

DISCUSSION SUMMARY

Mr. Zenner of Armour Research reviewed an experience in production testing of magnetic recording heads with a tape loop drive as compared with tests in the final recorder assembly with a long frequency response tape on reels. The loop test gave better high frequency response because the head surfaces were not truly flat along the playback slit. The multiple passes of the loop tape gave it time to conform to the head curvature better than the single pass of the tape on reels. Mr. Radocy replied that the machines used in tape tests at Audio Devices had been in use over a year and that the heads should be worn down to proper shape by now.

Mr. Sessions of Naval Electronics Laboratory noted the large difference in bias current (see figure 4) in the heads of the two reference recorders, and noted that measure of bias current does not necessarily indicate what the head is delivering to the tape. This would seem to indicate the need for a standard head as well as a standard tape. Mr. Radocy agreed and felt that the Federal (Interim) Specification, W-T-61A, (prepared by Department of the Navy, Bureau of Ships) should specify the type of head as well as the machine characteristics for tape testing.

Mr. Comerci of the Navy Material Testing Laboratory reviewed a premise on which the standard reference tape is based: that a given magnetic head would act on different pieces of tape in the same way. This theory was tested with three "Standard Reference Tapes" and three different types of tape recorders before distribution was started of the "Standard Reference Tape". This comparison showed that maximum sensitivity bias currents were within a two percent tolerance and maximum record levels were within a 0.3 db. tolerance. He called attention (see figures 1 and 4) to the sharper peak in the output-vs-bias curve for the "Standard Reference Tape" as compared to some production tapes. This characteristic for the "Standard Reference Tape" was chosen deliberately in order to locate more accurately the correct bias for maximum output. In the experience of the Material Laboratory, on some brands of tape where the output changes more gradually with change in bias current, the tolerance for correct bias current must be as high as six to eight percent. He also noted that the Material Laboratory recommends that each user get two reference tapes so that one may be kept in reserve and used only occasionally for checking characteristics of the other which is used for production testing.

Mr. Johnston of Minnesota Mining reviewed their experience with certain tape samples in which the high frequency output would change by as much as 3 db when the tape was reversed, end to end, before running over the playback head. Other tape samples showed no change when reversed.

Mr. D'Arcy of DeVry spoke of the advice he had received that the magnetic track on test films for 16 mm. should be burnished with a sapphire block before recording and playback in order to get more uniform results. Mr. Radocy agreed that this would improve uniformity of high frequency response but sometimes causes squeal (flutter at a very high frequency rate) and other difficulties in use.

Mr. Comerci advised that specification, W-T-61A, specifies that at least 5500 feet of tape shall have passed over the heads of a test recorder before measurements are taken. Also, before the "Standard Reference Tapes" are shipped they have been passed over normal heads at normal tension at least five times and also undergo a certain amount of humidity conditioning. This does reduce spacing loss, number of dropouts and obtains more uniform output from the tape.

Data for Figure 1

Worn Standard Reference Tape			New Standard Reference Tape		
Bias	Output	Dist.	Bias	Output	Dist.
4 ma	58.0 db	1.20 percent	4 ma	56.2 db	1.10 percent
5	59.7	1.05	5	58.2	.90
6	59.9	.85	6	58.9	.70
7	59.5	.75	7	58.8	.60
8	59.0	.65	8	58.5	.50
9	58.5	.60	9	58.1	.50
10	58.1	.60	10	57.8	.50
11	57.6	.60	11	57.4	.50
12	57.1	.60	12	57.0	.50
Peak Bias			Peak Bias		
5.8 ma	60.0 db	.90 percent	6.4 ma	59.0 db	.65 percent

(Output figures are arbitrary)

Legend--No. 1 Reference Recorder
Freq--1 kc
Speed--7-1/2 inches/sec
Level--Standard Output Level determined by "New Standard Reference Tape".

Data for Figure 2

Freq.	New Standard Reference Tape	Worn Standard Reference Tape
100	-1.0 db	-0.2 db
500	-0.6	+0.4
1 kc	0.0	+0.9
2 kc	+0.8	+2.1
3 kc	+1.0	+2.6
4 kc	+0.8	+2.7
5 kc	+0.5	+2.6
6 kc	0.0	+2.4

Freq.	New Standard Reference Tape	Worn Standard Reference Tape
7 kc	-0.5	+2.1
7.5 kc	-1.0	+2.0

(Output figures are arbitrary)

Legend--No. 1 Reference Recorder
Speed 7-1/2 inches/sec
Level--Standard Output Level determined by each "Standard Reference Tape".

Data for Figure 3

Recorder No. 1

Dist.	Production Tape	New Standard Reference Tape
1.0 percent	58.0 db	58.5 db
1.5	62.0	62.5
2.0	64.5	65.0
2.5	66.5	67.0
3.0	68.0	68.5

Recorder No. 2

Dist.	Production Tape	New Standard Reference Tape
1.0 percent	62.0 db	58.5 db
1.5	66.0	62.5
2.0	68.5	65.0
2.5	70.5	67.0
3.0	72.0	68.5

(Output figures are arbitrary)

Legend--Speed 7-1/2 inches/sec
Freq--1 kc
Bias--Peak Bias on each tape.

Data for Figure 4

New Standard Reference Tape		No. 1 Recorder Production Tape	
Bias	Output	Bias	Output
4 ma	56.2 db	4 ma	56.8 db
5	58.2	5	58.4
6	58.9	6	59.0
7	58.8	7	59.2
8	58.5	8	59.1
9	58.1	9	59.0
10	57.8	10	58.7

New Standard Reference Tape		Production Tape	
Bias	Output	Bias	Output
11	57.4	11	58.4
12	57.0	12	58.0
Peak Bias		Peak Bias	
6.4 ma	59.0 db	7.6 ma	59.2 db

No. 2 Recorder

New Standard Reference Tape		Production Tape	
Bias	Output	Bias	Output
20 ma	58.0 db	20 ma	58.2 db
25	58.9	25	59.1
30	57.5	30	58.1
35	56.0	35	56.8
40	54.4	40	55.4
Peak Bias		Peak Bias	
24 ma	59.0 db	25 ma	59.1 db

(Output figures are arbitrary)

Legend--Speed 7-1/2 inches/sec
Freq--1 kc
Level--Standard Output Level determined by "New Standard Reference Tape".

Data for Figure 5

	New Standard Reference Tape		Recorder No. 1 Production Tape	
Freq.	Actual Output	Converted Output	Actual Output	Converted Output
100	-1.0 db	0 db	-0.8 db	+0.2 db
500	-0.6	0	-0.4	+0.2
1 kc	0.0	0	+0.2	+0.2
2 kc	+0.8	0	+1.0	+0.2
3 kc	+1.0	0	+1.2	+0.2
4 kc	+0.8	0	+1.1	+0.3
5 kc	+0.5	0	+0.8	+0.3
6 kc	0.0	0	+0.4	+0.4
7 kc	-0.5	0	-0.1	+0.4
7.5 kc	-1.0	0	-0.5	+0.5

Recorder No. 2

	New Standard Reference Tape		Production Tape	
Freq.	Actual Output	Converted Output	Actual Output	Converted Output
100	-1.5 db	0 db	-1.3 db	+0.2 db
500	-0.5	0	-0.3	+0.2
1 kc	0.0	0	+0.2	+0.2
2 kc	+1.0	0	+1.1	+0.1
3 kc	+1.0	0	+0.9	-0.1
4 kc	+1.0	0	+0.7	-0.3
5 kc	+0.5	0	0.0	-0.5
6 kc	0.0	0	-0.7	-0.7
7 kc	-1.0	0	-1.9	-0.9
7.5 kc	-2.0	0	-3.0	-1.0

Legend--Speed 7-1/2 inches/sec
Level--Standard Output Level determined by "New Standard Reference Tape".

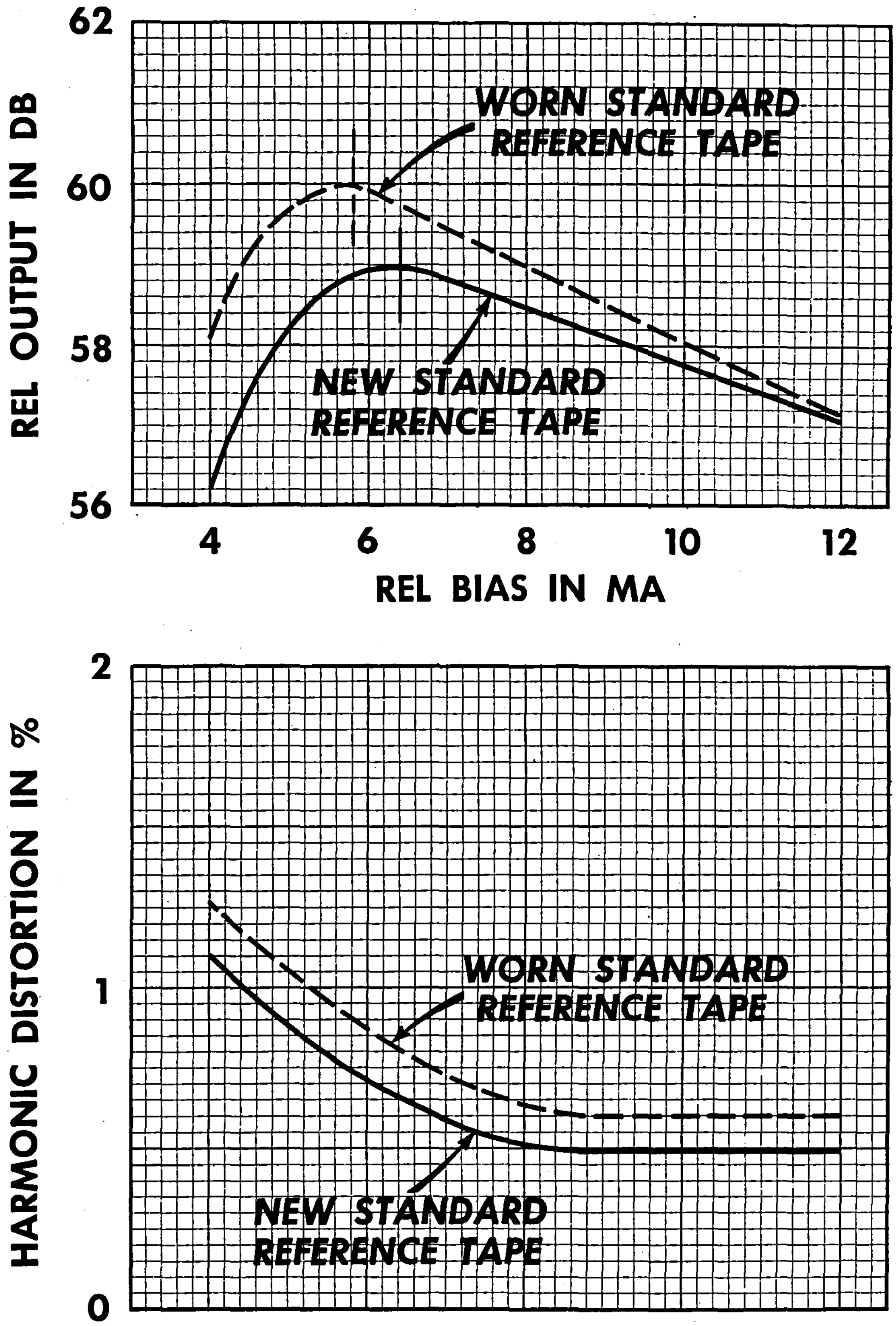
62
60
58
56
REL OUTPUT IN DB
WORN STANDARD
REFERENCE TAPE
NEW STANDARD
REFERENCE TAPE
4
6
8
10
12
REL BIAS IN MA
2
1
0
HARMONIC DISTORTION IN %
WORN STANDARD
REFERENCE TAPE
NEW STANDARD
REFERENCE TAPE

FIG 1

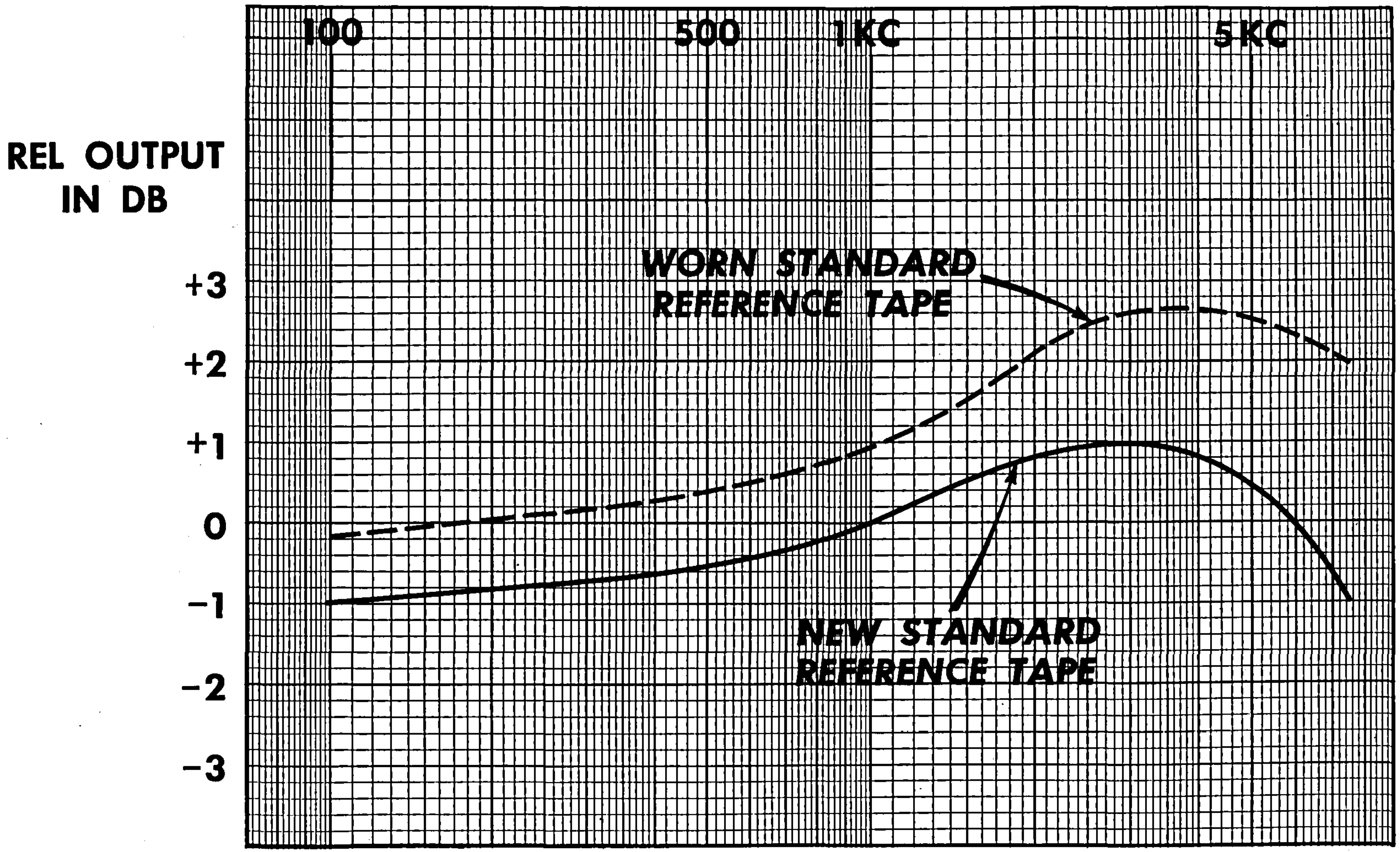

FIG 2

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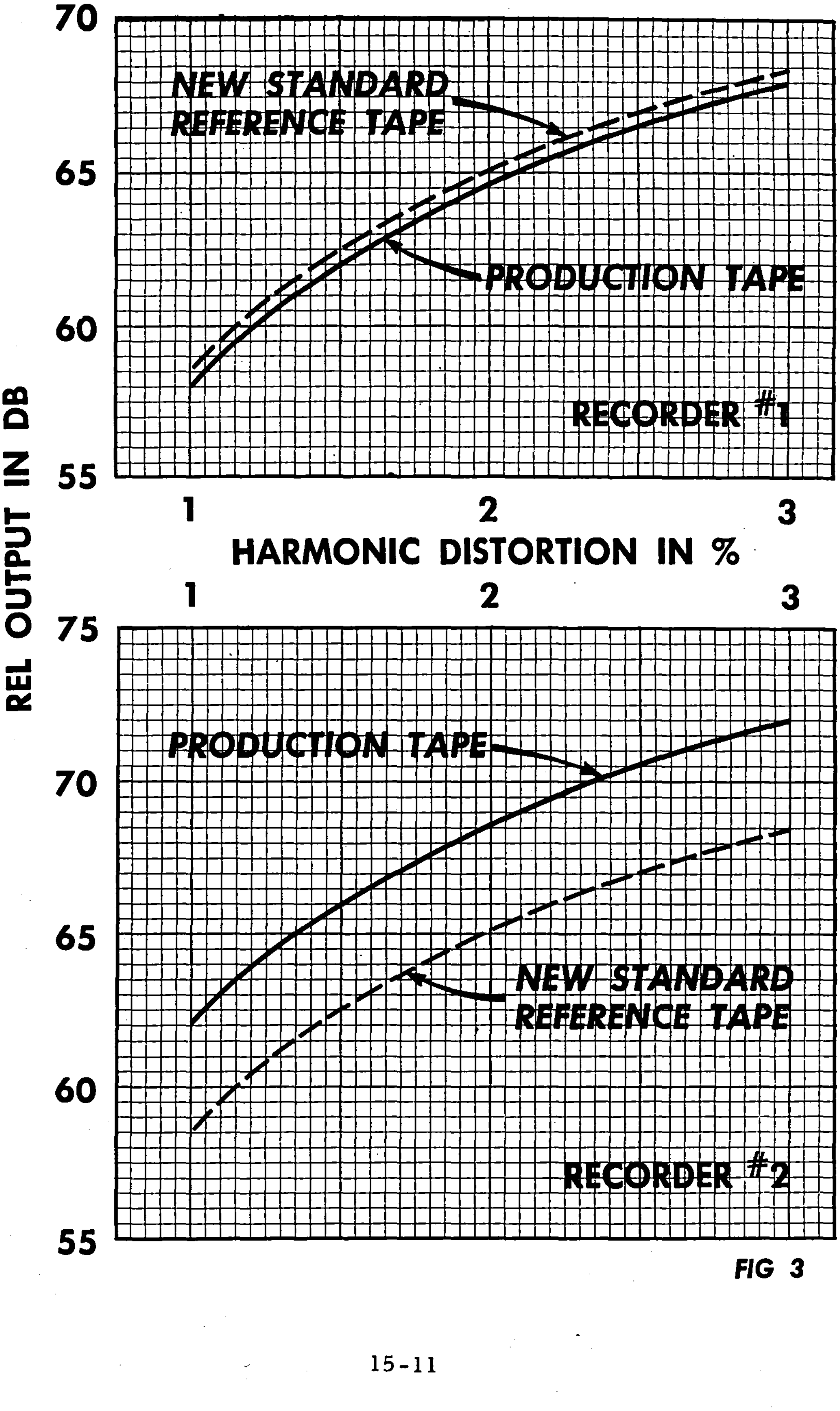

70
65
60
55
NEW STANDARD
REFERENCE TAPE
PRODUCTION TAPE
RECORDER #1
1
2
3
HARMONIC DISTORTION IN %
1
2
3
REL OUTPUT IN DB
75
70
65
60
55
PRODUCTION TAPE
NEW STANDARD
REFERENCE TAPE
RECORDER #2

FIG 3

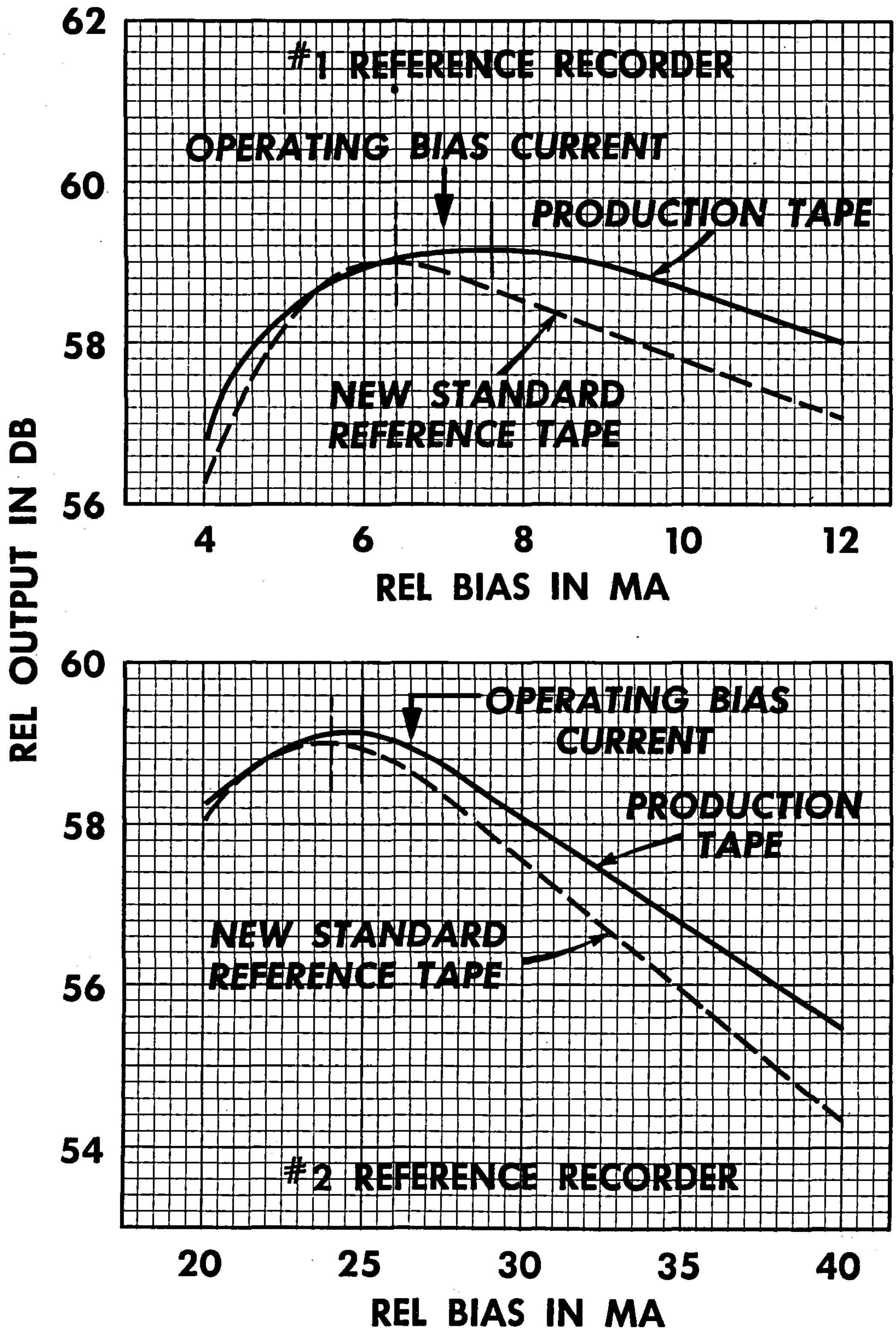
#1 REFERENCE RECORDER
OPERATING BIAS CURRENT
PRODUCTION TAPE
NEW STANDARD REFERENCE TAPE
REL OUTPUT IN DB
62
60
58
56
4
6
8
10
12
REL BIAS IN MA
60
58
56
54
OPERATING BIAS CURRENT
PRODUCTION TAPE
NEW STANDARD REFERENCE TAPE
#2 REFERENCE RECORDER
20
25
30
35
40
REL BIAS IN MA

FIG 4

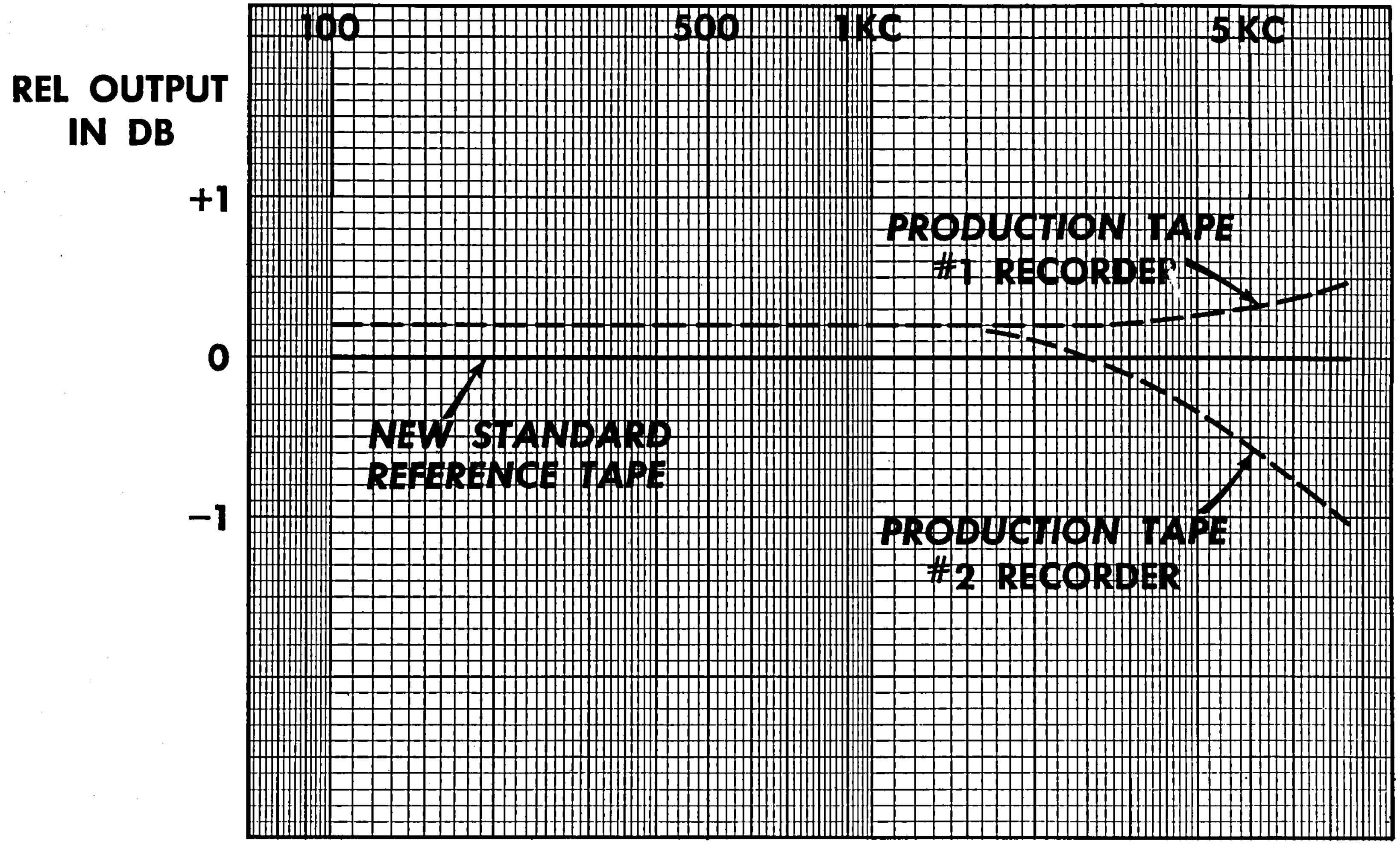
100
500
1KC
5KC
REL OUTPUT IN DB
+1
0
−1
PRODUCTION TAPE #1 RECORDER
NEW STANDARD REFERENCE TAPE
PRODUCTION TAPE #2 RECORDER

FIG 5

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Paper 16

A STANDARD MAGNETIC TAPE RECORDING FOR STANDARDIZING THE CHARACTERISTICS OF NAVY RECORDER-REPRODUCERS

F. Comerci, S. Wilpon, and R. Schwartz

Material Laboratory
New York Naval Shipyard

9 October 1953

ABSTRACT: A magnetic tape recording for standardizing the characteristics of Navy Recorder-Reproducers will be discussed. The magnetic surface induction (recorded level on the tape) vs. frequency characteristic, equalization, losses in recording and reproducing, as well as other fundamental factors involved in standardizing recorder-reproducer characteristics will be included in the discussion. The use of such a standard magnetic tape recording for standardizing of tape machines will be explained.

Introduction

The standardization of magnetic tape recording systems divides itself naturally into two categories. One is concerned with the magnetic tape used, and the other is concerned with the tape recorder-reproducer machine.

Standardized Tape

The standardization of the magnetic tape for Federal Services has, as been pointed out earlier today, accomplished through the specification, W-T-61a (NAVY SHIPS) and the "Standard Reference Tape". A discussion of the present status of tape standardization has been presented in paper number 14 of this Symposium.

Standardized Playback Machine

Therefore, only the second category, the tape machine itself need be considered to complete the standardization of the entire tape recording system. Upon standardizing on the tape machine, it will be possible to record program material on any reproducing unit with any of the qualified tapes and expect that when the tape is played back on any approved reproducer it will sound exactly as intended when recorded.

The Standard Tape Recording discussed here will perform this function for recorder-reproducers using 1/4 inch magnetic tape and operating at a tape transport speed of 7 1/2 inches per second. It can be employed on machines designed with full-track width heads, half-track heads, and for multiple channel recording; provided of course, that the record head track width is equal to or greater than the playback head track width. At the present time work is being done by the Material Laboratory along the same lines as presented in this paper to achieve standardization at other tape transport speeds. However, it is to be remembered that the discussion here is limited to tape speed of 7 1/2 inches per second.

Reasons for Standard Tape

Interchangeability in recorder-reproducers can be achieved most effectively by standardizing the signal recorded on the tape, with respect to frequency response, distortion and level. The specification of record and playback amplifier gain and equalization characteristics alone does not take into account losses in the various respective head designs used, in transfer of the signal to and from the tape, and in the level recorded on the tape. Therefore, it becomes necessary to specify and to measure a particular magnetic surface induction characteristic that is to find the (signal level recorded on a tape). It is logical to use a calibrated tape recording for comparative measurements, rather than a surface induction measurement as such, for three basic reasons. First, there is no satisfactory method available for measuring the absolute level of surface induction on the tape. Second, whichever method you use, the long gap or the short gap method, to measure the relative surface induction on the tape; there has been no complete proof of either one. Third, measurements using a calibrated tape recording would be much simpler to perform.

Standardizing on the signal recorded on a tape would give the manufacturers of tape recorders wide latitude in the equalization characteristics and the tape heads to be used. Performance-wise, certain restrictions must be put on these equalization characteristics, governed by factors of overall signal-to-noise ratio and saturation effects. Therefore, it was decided that in addition to a frequency response section, the calibrated recording should include several recorded signals. These signals would limit equalization to justifiable amounts and would facilitate performance of other measurements on a recorder-reproducer.

Characteristics of Standard Tape

A calibrated tape, designated the Standard Tape Recording has been made containing the following recorded signal sections:

(a) The first section contains a 7000 cycle signal for azimuth adjustment of heads. The azimuth alignment of the signal recorded on the tape is in agreement with the azimuth alignment of the signal recorded using a commercial alignment tape in this case manufactured by the L.S. Toogood Company, of Chicago. This method of azimuth alignment is in general agreement with the commercial broadcast field practice as far as broadcast work goes. Besides an absolute 90^{o} azimuth adjustment is not necessary so long as all Navy equipment are adjusted identically.

(b) The second section contains a 1000 cycle signal recorded for Maximum Surface Induction. This Maximum Surface Induction, by definition, is equivalent to the Surface Induction of the "Standard Reference Tape" for Maximum Record Level. This is defined in the tape specification-W-T-61a.

(c) The third section is the frequency response section. The frequencies are divided into bands of 15 seconds duration, extending from 20 to 10,000 cycles per second. The first and the last bands are 1000 cycles per second signals. The 1000 cycles per second signals are 15 db below the Maximum Surface Induction. This was done to prevent saturation when making measurements using audio signals rather than program material. The other frequencies are recorded at set levels relative to this 1000 cycle signal as determined through a consideration of:

1. Total losses in the record and reproduce processes.

2. The permissible equalization in recording as determined from the speech and music energy distribution spectrum.

3. The factor of high frequency noise in the playback amplifier.

4. Head gap widths most frequently encountered.

The expected total losses in a tape system for a tape speed of 7 1/2 inches per second can be seen from the overall frequency response without equalization of figure 1 (bottom curve). This response was estimated for effective gap widths of 0.5 mils, with a constant recording current input, and with an assumed perfect integrating network in the reproduce amplifier (6 db. drop per octave). A 0.5 mil gap width was chosen as a more or less average dimension as determined from a survey of catalogs, measurement of various heads, and available literature.

The permissible equalization in recording for such a system is also shown (top curve) in figure 1, with a rise of 15 db at 10,000 cycles. The dotted curve shows the overall response with pre-and post-equalization that one can normally expect from such a system that is the dotted curve up there. The magnetic surface induction characteristic shown which is the second curve from the bottom is for the frequency response section of this tape when measured by the short gap method as outlined by the CCIR. This measurement was made on a machine with the described record equalization and an effective playback head width gap of 0.46 mils.

A check on the levels recorded on this tape can be obtained over any period of time by referring to this curve and the "Standard Reference Tape". As the recorded section had less than two percent harmonic distortion, it can be used for distortion measurements over the frequency range covered.

(d) The fourth section contains a 3000 cycle signal with a flutter content of less than 0.5 percent peak to peak. (For measuring flutter on 1000 cycle flutter measuring equipment, the last 1000 cycle band of the frequency response section can be used).

(e) Finally, the last section of the tape contains a 400 and 4000 cycle band and a 100 and 7000 cycle band (with signal levels referred to the input in a four to one ratio) for intermodulation distortion measurements.

Procedure for Recorder Standardization

After standardizing the reproducer unit with this Standard Tape, the recorder unit can be standardized using any qualified tape by the following procedure:

(a) Set the recorder gain control (Maximum Record Level) to give the same output level on the reproducer as is obtained with the Maximum Surface Induction Section of the Standard Tape Recording. The bias current used is that obtained with the "Standard Reference Tape".

(b) Record over the frequency band at 15 db below the Maximum Record Level setting.

(c) Then, playing back this tape on the reproducer unit should give results comparable to that when the Standard Tape Recording is used. The allowable variation in results will be set forth in a specification for Navy recorder-reproducers.

With this Standard Tape Recording on hand at the Laboratory, copies can be prepared and calibrated so that a copy of the Standard Tape Recording will achieve the same degree of standardization as the original.

Conclusion

This Standard Tape Recording, by providing calibrated recorded signals serves to standardize the characteristics of the recorder and reproducer units, while the "Standard Reference Tape" and the tape specification W-T-61a(NAVY SHIPS) standardizes on the tape characteristic. Therefore, the entire tape recording and reproducing system, for a particular tape transport speed, can be standardized. The extent of this standardization is such that interchangeability of tape, tape recorders, and tape reproducers is possible and still produce recordings heard as they were intended to be, when they were originally made (within the limits of the equipment).

DISCUSSION SUMMARY

Discussion between Mr. D'Arcy of DeVry and Mr. Wilpon of Navy Material Laboratory brought out that the tape described above is considered to be a standard of reference for adjustment of tape recorders. It is calibrated by means of the CCIR short-gap method. The tape is then used to adjust the reproduce characteristic of a recorder. The recording characteristic is then adjusted for correct bias (using the "Standard Reference Tape" discussed in Paper No. 15), and finally for proper record pre-emphasis. A tape recorded on the recorder will then give the same playback response on the recorder as the Standard Magnetic Tape Recording described in Paper No. 16.

Mr. Camras of Armour Research asked if there was a theoretical shape which the reproducing characteristic would assume when adjusted with the Standard Magnetic Tape Recording. Mr. Wilpon advised that there was latitude to adjust the reproducing characteristic for losses that occur in playback on the reproducing system under adjustment. Then, the recording characteristic should be adjusted so that a "flat" input 15 db. below the -3 percent distortion, maximum input point will produce a "flat" response on playback. This allows for a maximum of 15 db. pre-emphasis at 10kc in recording.

Mr. D'Arcy noted that this procedure started with allowable pre-emphasis in recording (based on peak energy curves for speech and music, plus high frequency magnetization losses in recording).

Dr. Begun of Clevite-Brush cautioned against starting distribution of a "Standard Reference Tape" before making an attempt at coordination with industry through the American Standards Association. Coordination would lessen the confusion that is now occurring because of the issuance of special "standard" tapes by various groups. Mr. Wilpon agreed and noted that the Navy Material Laboratory had presented Paper No. 16 in order to give their plans for a standard tape wider publicity and to receive more industry comments before distributing copies. Mr. Comerci also added that the Navy was not trying to bypass standardization societies but was faced with the problem of buying tape recorders by means of a specification. This requires a "Standard Reference Tape" which has not been offered, as yet, by the technical societies. Therefore, the Navy has prepared their own based on what appeared most likely to be in a final standard. When the technical societies do issue a standard tape the Navy tape can be modified accordingly and the modifications will probably be small.

Mr. Bixler of Magnecord asked if the Navy was making use of CCIR study group recommendations which it was his understanding are becoming firm in the direction of standardizing a reproducing characteristic from an ideal head. Messrs. Wilpon and Comerci noted that the playback characteristic obtained with a good quality head was very close to the theoretical playback equalization recommended by the CCIR study group.

Mr. Kerr of Bureau of Ships called attention again to the fact that the recording on the tape was at the crossroads point between two approaches: one determined by the most desirable reproducing characteristic from the standpoint of maximum signal-to-noise ratio, hum factors, and gap effects; the other determined by the peak energy characteristics vs. frequency of the input signals, plus head losses and distortion characteristics in recording in order to obtain maximum signal storage at all frequencies on the tape. An overall system approach would seem to dictate some latitude in the choice of both record and reproduce equalization for different applications where the signal source characteristic and end use requirements may vary considerably.

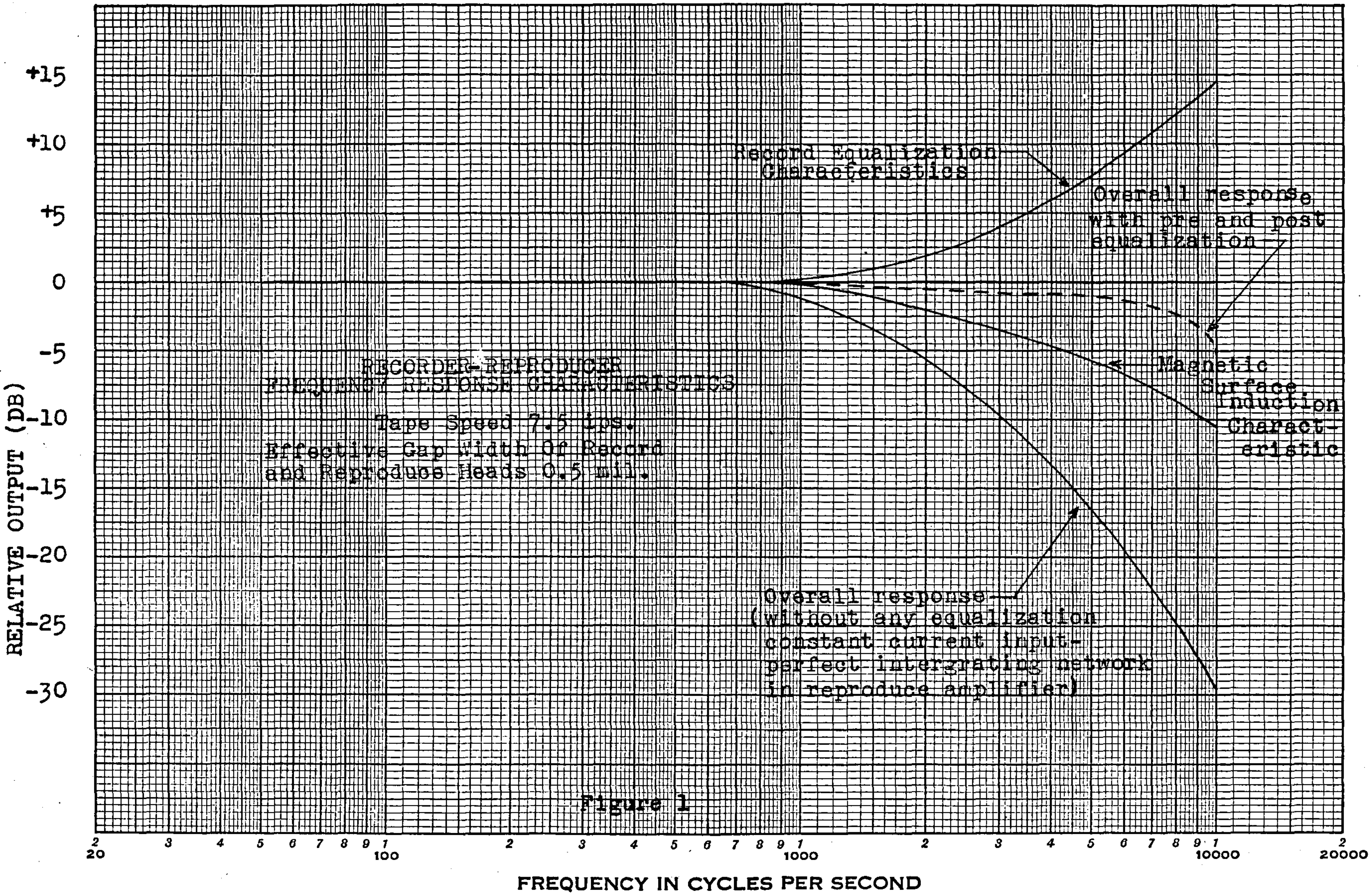
+15
+10
+5
0
-5
-10
-15
-20
-25
-30
RELATIVE OUTPUT (DB)
Record Equalization Characteristics
Overall response with pre and post equalization
Magnetic Surface Induction Characteristic
RECORDER-REPRODUCER FREQUENCY RESPONSE CHARACTERISTICS
Tape Speed 7.5 ips.
Effective Gap Width Of Record and Reproduce Heads 0.5 mil.
Overall response (without any equalization constant current input-perfect intergrating network in reproduce amplifier)
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure 1

Department of Defense Symposium on Magnetic Recording

Paper No. 17

EQUALIZATION OF MAGNETIC TAPE RECORDERS AND GENERAL RECORDER PERFORMANCE TESTS

Frank G. Lennert

9 October 1953

ABSTRACT: A discussion of equalization requirements in terms of an ideal system is presented. Effects of record and playback head gap size on the frequency characteristics are described, as well as some properties of tape which affect frequency response. A method is presented for establishing equalization curves for an audio recording system. Record and playback equalization curves now in use are described, and the manner in which these curves affect signal-to-noise ratio. Also described are record and playback characteristics for recorders employed in data applications. Methods are presented for measurement of tape recorder frequency response, distortion, system noise, speed variation, playing time accuracy, and signal-to-noise.

Ideal System

As a starting point for discussion, let us consider equalization requirements in terms of an "Ideal System" without losses. An "Ideal System" would consist of the following. A constant current amplifier connected to a record head; the record head producing a constant flux vs. frequency on the tape, and a playback head picking up the signals from the tape and feeding an amplifier whose amplification drops off at the rate of 6 db per octave across the band. The 6 db per octave playback amplifier is required because the output from the ideal playback head is directly proportional to frequency when reproducing a constant flux vs. frequency signal. Unfortunately, a number of factors are present which make a practical system differ considerably from this ideal.

Losses in Practical Systems

First, there are several possible losses associated with the record and reproduce heads, The electrical losses are produced by eddy current and hysteresis effects in the core and capacity effects in the windings. In a well designed and constructed head, these effects are not a problem in the audio range, but do enter the picture somewhat in instrumentation recorders operating in the 100 kc region.

The high frequency loss due to the width of the playback gap usually determines the upper frequency limit of the recorder. When the effective width of this gap equals the reproduced wave length, a null or cancellation will occur. The loss in decibels at other wave lengths on the tape is equal to

$$20 \text{ Log } \frac{\sin \pi \ \theta/\lambda}{\pi \ \theta/\lambda}$$

where θ is the effective playback gap length and λ is the reproduced wave length. From this expression a theoretical loss of 4 db will occur when a wave length of .0005 inch is reproduced with a head incorporating a gap length of .00025 inch. This would be the case at 15,000 cycles and a tape speed of 7-1/2 inches per second. The writer has found that reproduce heads with this gap length can be built with surprising uniformity, making reproduction down to .0005 inch wave length achievable in production equipment.

Heads incorporating larger gaps, although desirable from the standpoint of output, are seriously limited in high frequency range at the lower tape speeds.

The record head gap length does not bear the same relation to the frequency characteristic as that of the playback head. The magnetization left on the tape is determined primarily by the trailing edge of the gap and not by its length. The sharpness and, of course, straightness of this edge are paramount. The record head gap length is important from other aspects, however. An excessively small record gap would produce a decaying field through the oxide layer on the tape. This decaying field in turn would increase low frequency distortion since the oxide layer in direct contact with the gap would have to be recorded at a relatively high level to compensate for the only partially magnetized undercoat of oxide. The wider the record gap, the greater the demagnetization effect on the highest recorded frequencies. Therefore, excessively wide gaps are to be avoided. .001 inch to .002 inch has been found to be the most acceptable range. The so called demagnetization effect is created by partial erasure of a high frequency recorded signal at the time of recording by the high frequency bias field.

The remaining losses in a practical tape system are associated with the tape itself. The oxide particle size and uniformity of dispersion are large factors in the high frequency characteristic of the tape. Large particles or poor dispersion will result in reduced area of contact with the head gap. This reduced area of contact has little effect while recording and reproducing long wave lengths, but will drastically affect high frequency performance. Paper base tapes are unsatisfactory in this respect as the roughness of the paper, and subsequently the oxide coating, prevent proper contact with the head surface. Coating thickness is another factor which has an indirect bearing on the frequency characteristic. As the coating thickness is decreased, the bias requirement will decrease. Consequently, high frequency demagnetization will be reduced and high frequency record efficiency will increase. Unfortunately, low frequency distortion will increase with decreased coating thickness so reduction of coating thickness beyond a certain point is impractical.

Another factor, of course, is the characteristics of the oxide itself. Lower demagnetization losses can be accomplished on some of the new tapes which incorporate oxides selected for low bias requirements and high output. This higher performance oxide permits less coating thickness for the same low frequency output level as compared with previous professional tapes.

Because of variation in performance which is possible due to tape, it is best to equalize a recorder with a sample of tape known to be a "centerline" of the tape manufacturers' tolerances and to use only tape of that manufacture or of a known equivalent.

Audio Recorder Equalization

The equalization of audio recorders at a given tape speed requires a study of the noise and distortion characteristics of the system. A good approach to the problem is to evaluate the system with the tape equalization arbitrarily divided in record and playback. The established energy distribution curves for speech and music serve as a rough guide as to maximum permissible record equalization at any frequency. A noise spectrum analysis will insure that the noise is fairly distributed over the pass band. If this is not the case, the playback equalization should be adjusted until fairly even distribution of the noise exists. The record equalization can then be altered to complement the playback characteristic. These measurements can be weighted on the basis of ear sensitivity, and a better noise characteristic thereby obtained if discretion is used in the amount of correction applied. Such changes in the equalization, based on ear sensitivity, should be carefully checked by listening tests on wide range equipment.

The record system must now be studied from the standpoint of distortion and overload at all frequencies in the pass band. If the record equalization is not greater than the amount required to complement the energy distribution in speech or music, the overall distortion characteristic will be found satisfactory. If the equalization requirements are greater than that which can be tolerated on this basis, three possibilities exist. The first would be to lower the record level and thereby compromise the signal-to-noise ratio. The second would be to chance the system running into overload distortion at frequencies excessively pre-emphasized. The third would be to lower the record equalization to acceptable limits and raise the post-equalization at the expense of signal-to-noise ratio in the raised spectrum. At the professional primary and secondary speeds of 15 and 7-1/2 inches per second, these compromises are unnecessary for full range recording from 30 to 15,000 cycles. The full dynamic range of the tape is therefore available.

The record curves indicated in figure 1 and the playback curves indicated in figure 2 were established in conjunction with Ampex heads and professional red oxide tape. These heads display negligible magnetic and electrical losses in the pass band. The playback head gap length is .00025 inch. The bias was adjusted to the point of maximum record efficiency while recording a .015 inch wave length (1 kc at 15 inches per second). The overall response achievable under these conditions is as follows:

At	30 inches/sec.	±	2 db, 50 to 15,000 cycles
	15 inches/sec.	±	2 db, 30 to 15,000 cycles
	7-1/2 inches sec.	±	2 db, 40 to 15,000 cycles
	3-3/4 inches sec.	±	2 db, 40 to 7,500 cycles

The playback curves are easily accomplished by connecting a vacuum tube operating as a constant current generator to a capacitive load whose reactance equals the generator impedance at 65 cycles, and inserting a series resistance to effect the required high frequency correction.

The 30-inch curve, with the exception of the low frequency departure, is the characteristic required to compensate the "Ideal System". The slight low frequency departure from the ideal curve was found desirable for the elimination of low frequency thermal effects in playback amplifier input tubes operating at low levels. This departure is made up for by a slight rise in the low frequency playback head characteristic brought about by its physical dimension and by 2-1/2 db boost in the record amplifier at 50 cycles. A resistor of such value to affect a time constant of 50 microseconds has been placed in series with the 6 db per octave condenser to produce the desired high frequency characteristic at 15 and 7-1/2 inches. The 3-3/4 inch curve is accomplished by a relatively larger resistor effecting a time constant of 200 microseconds. The 15-inch per second record curve is such that possibility of overload does not exist for the most severe audio requirements. At 7-1/2 inches per second the record curve is considerably steeper than the 15-inch curve and reaches 17 db at 10 kc. Listening tests conducted with material recorded on equipment adjusted to this characteristic have shown it to be entirely satisfactory for high fidelity recording. This is the case because of the energy distribution encountered in normal speech and music, and because of a characteristic, of the tape, to compress the high frequency, high intensity peaks occasionally encountered, without appreciable distortion. Sound already pre-emphasized for special effects or from highly resonant microphones might present overload problems at 7-1/2 inches which, of course, would not occur at the 15-inch speed. The overall response of a typical Ampex 300 or 403 recorder can be adjusted to ± 1 db from 50 cycles to 15 kc at both 7-1/2 and 15-inch speeds. Slightly wider specifications are advertised to all manufacturing tolerance and insure the average machine being within its specifications.

Instrumentation Recorder Equalization

Instrumentation recorders fall into two general categories as pertaining to the subject under discussion.

Pulse systems and carrier systems are in the first category. These systems do not require equalization for the tape system. The second category contains the conventional magnetic recorders employing high frequency bias and recording a band width within the range of 100 cycles to 100 kc. These recorders incorporate similar electronic systems to audio recorders except for the distribution of equalization. The intelligence recorded on such instruments is usually of a nature that the energy level is fairly uniform over the pass band. This requires a record characteristic with a uniform overload and saturation characteristic in respect to frequency. An unequalized constant current amplifier driving the record head and producing essentially a constant flux recording best suits this requirement. Equalization required for flat overall response is therefore placed in the playback amplifier.

Recorder Performance Measurements

General audio recorder performance can be measured as follows. The frequency response can be measured by connecting an audio oscillator, such as Hewlett-Packard Model 200-C, to the input of the recorder and an a-c. V.T.V.M., such as Hewlett-Packard Model 400-C and 600 ohm load, to the output. It is necessary to use a sensitive meter as high frequency tape saturation due to record H.F. pre-emphasis requires that the frequency run be made at least 10 db below normal operating level at 15 inches per second tape speed and 20 db below at 7-1/2 and 3-3/4 inches per second tape speeds. The playback amplifier gain is not sufficient to bring the level of the response run up the VU meter "0" reading. A power amplifier or line amplifier with flat frequency characteristics and the required gain can be used with a VU meter, db meter or any a-c voltmeter in place of the V.T.V.M. for this measurement.

The oscillator must be checked for uniformity of output vs. frequency and corrections made to the overall responses of the system. If the frequency run is made as a simultaneous record and playback operation, it is advisable to check and make certain that high frequency record bias is not present in the metering circuit within 10 db of the response check level. In the event that bias is present in the metering circuit, it must be filtered out at the meter. Alternately, the frequency run can be played back after the record operation and thus avoid the possibility of bias interference. A high quality recorder should check within ± 2 db, 50 to 7,500 cycles at 3-3/4 inches per second.

Interchangeability of Tape Recordings

An important consideration, not to be overlooked, is the ability of a tape recorder to reproduce tapes recorded on other machines as well as itself. To insure that the frequency characteristic and head azimuth alignment is being maintained, standard alignment tapes are available which contain a high frequency tone for azimuth check and selected frequencies for response check. Caution should be exercised in the use of standard tapes, however. The playback equalization is set to a standardized curve. If a standard tape does not play back with a flat characteristic, the trouble should be investigated before altering the equalization curve. Frequently, dirt on the head or a partially erased tape is the cause of poor response reading. The condition of the standard alignment tape should always be questioned if the overall response of the machine is flat on record and playback but not flat on standard tape playback.

Distortion can best be checked by use of a wave analyzer and oscillator. A null type distortion meter is acceptable, but the system should first be checked for noise and bias leakage before the reading can be relied upon. If the H.F. bias does appear across the distortion meter terminals during simultaneous record and playback, it can be filtered out or the recording of the test signal can be played back without interference as a separate operation.

The 400-cycle distortion at operating level of the recorder should be approximately one percent; at 6 db above operating level it should be approximately three percent; and tape saturation will occur at 16 db above operating level. The record and playback amplifier should not contribute to the tape reading which will be primarily third harmonic. Any appreciable second harmonic usually indicates a magnetized head or misadjusted d-c balance control in the record head circuit. Distortion runs can also be made at other frequencies throughout the spectrum, such as 50 cycles and 5,000 cycles. Somewhat higher readings will be found at these frequencies because of record pre-emphasis. This is of no concern if NARTB equalization curves are employed, because they have been found to be quite conservative for recording speech and music.

Intermodulation tests using frequencies of 40 and 2,000 cycles or 100 and 7,000 cycles will give a reading of approximately four percent at the level which produces one percent harmonic on 400-cycle tone.

Overall system noise is measured as follows. First record a section of tape with 400-cycle tone at operating level. Then short or terminate the input connections, connect a V.T.V.M. such as Hewlett-Packard Model 400-C, to the output. Next, operate the recorder so that the tone will be erased by the erase circuit and any noise generated in the record circuit will be recorded on the tape.

Now play the tape back with the playback gain in normal operating position and measure the noise on the V.T.V.M. At 15 or 7-1/2 inches per second the wide band noise should be approximately 57 db below recommended operating level (one percent harmonic on 400-cycle tone), 63 db below three percent harmonic on 400 cycle tone, or 73 db below 400 cycles saturation. The noise level will be 10 to 13 db higher at 3-3/4 inches per second. Noise measurements while simultaneously recording and playing back usually result in erroneous readings due to H.F. record bias leakage into the meter circuit. This can be eliminated as in the case of the distortion check by filtering or delayed playback. Meter bounce due to extreme power line surges feeding the recorder power supply sometimes produce erroneous readings. This effect can be eliminated by a 25-cycle high pass filter between the V.T.V.M. and the recorder.

Playing time accuracy is an immediate problem where tapes are recorded and played back on different equipment. In order for a recorder or playback machine to have good timing accuracy it must be equipped with a synchronous motor and synchronous capstan shaft (tape driving shaft). In the event that the capstan shaft is not directly coupled to the motor, the capstan shaft speed can be checked by a stroboscopic sticker on the top of the shaft and a 60-cycle light source. If the capstan shaft is running at the correct speed and the tape is clamped with sufficient pressure to prevent slippage, the least possible timing error will result.* This error should not exceed a .2 percent on a high quality recorder.

Modulation noise, as the name implies, is a background noise, existing only in the presence of recorded signal and usually composed of a range of frequencies in a fairly narrow band on each side of the signal frequency. Modulation noise of this type is dependent on the coating uniformity of the tape and somewhat on the friction in the tape moving system. It can be measured by following the procedure outlined previously for noise testing, with the following exceptions. Connect an audio oscillator to the input and record 3,000 cycles at operating level. Insert a bridged "T" Null network between the output of the machine and the V.T.V.M. used for noise measurement. The bridged "T" filter should have a rejection at 3,000 cycles of at least 60 db and should not affect the frequencies outside the 2,500 to 3,500 cycle rejection band. The modulation noise should read at least 50 db below the 3,000 cycle signal level.

DISCUSSION SUMMARY

Mr. Selsted had emphasized that tape speed should always be specified when specifying pre-emphasis and post-equalization curves. Mr Wilpon of the Navy Material Lab. noted that the Standard Magnetic Tape described in Paper No. 16 was made for 7-1/2 inches per second tape speed.

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*Absolute synchronous tape speed is impossible because of change of length of tape with temperature and humidity. A special compensation system is available for maintaining synch with motion picture equipment. This system employs a 60-cycle modulated carrier on the tape and compensates the drive motor speed on playback to keep the tape speed correct.

During the paper presentation and in connection with tape speed of 15 inches per second, Mr. Selsted had commented that the pre-emphasis shown in figure 1 of only 4 db at 8,000 cycles seemed too low for narrow tracks as found on multichannel tape and on 35mm. motion picture prints (running at 18 inches per second). Over a period of several months Ampex has used pre-emphasis approaching the 7-1/2 inches per second tape characteristic on narrow track film releases in order to obtain a more satisfactory compromise of signal-to-noise ratio versus distortion at high frequencies. This also allows the playback curve to have a straight 6 db/octave attenuation as shown in figure 2 for the 30-inch per second tape speed.

Referring to the above, Mr. George Lewin of Signal Corps Pictorial Center noted that he had objected to such a proposed increase in pre-emphasis for 35mm. film recordings because of the heterodyning that can occur between the highly pre-emphasized high frequencies in the signal and the high frequency bias. In his experience, such "birdies" or "chirps" can be heard on playback but cannot be measured.

Mr. Selsted noted that the "birdies" were brought about partly by the non-linearity of the tape at the high frequencies. However, the compromise proposed by Ampex is producing excellent results in the field recording for "Oklahoma" in which six channels are being recorded on 35mm. stock using pre-emphasis as high as 12-1/2 db at 8,000 cycles. Users, including people associated with users at the MGM studios, have commented very favorably on the results, and final release by Magna-theatre Corporation will use narrow-band multiple tracks with this proposed characteristic on 65mm. film stock.

Mr. Selsted also noted that by taking advantage of the added signal output from a new oxide and by using characteristics weighted according to the hearing characteristics of the ear, that signal-to-noise improvements of 10-15 db have been obtained without a noticeable sacrifice in distortion or recorded quality.

Mr. D'Arcy of DeVry Corporation referred to the last meeting of the SMPTE sub-committee on magnetic recording standards and noted that when the increase in high frequency pre-emphasis had been proposed the opinion of the rest of the committee was that the lower pre-equalization (4 db at 8,000 cycles is currently used) should continue in use until the proposed increase has been tried out by a film studio on the West Coast.

In answer to a question from Mr. Bauer of Shure Brothers concerning amount of pre-emphasis at low frequencies, Mr. Selsted noted that Ampex used 2-1/2 db at 50 cycles, one manufacturer uses 5 db on tape recording equipment, and film makers use about 6 db. Primary reason is due to effects caused by head geometry at long wave lengths rather than appreciable reduction of hum on playback.

Mr. D'Arcy of DeVry Corporation quoted information from Dr. Frayne of Westrex to the effect that film systems appeared to be settling down to 3 db pre-emphasis at 100 cycles and 6 db pre-emphasis at 50 cycles.

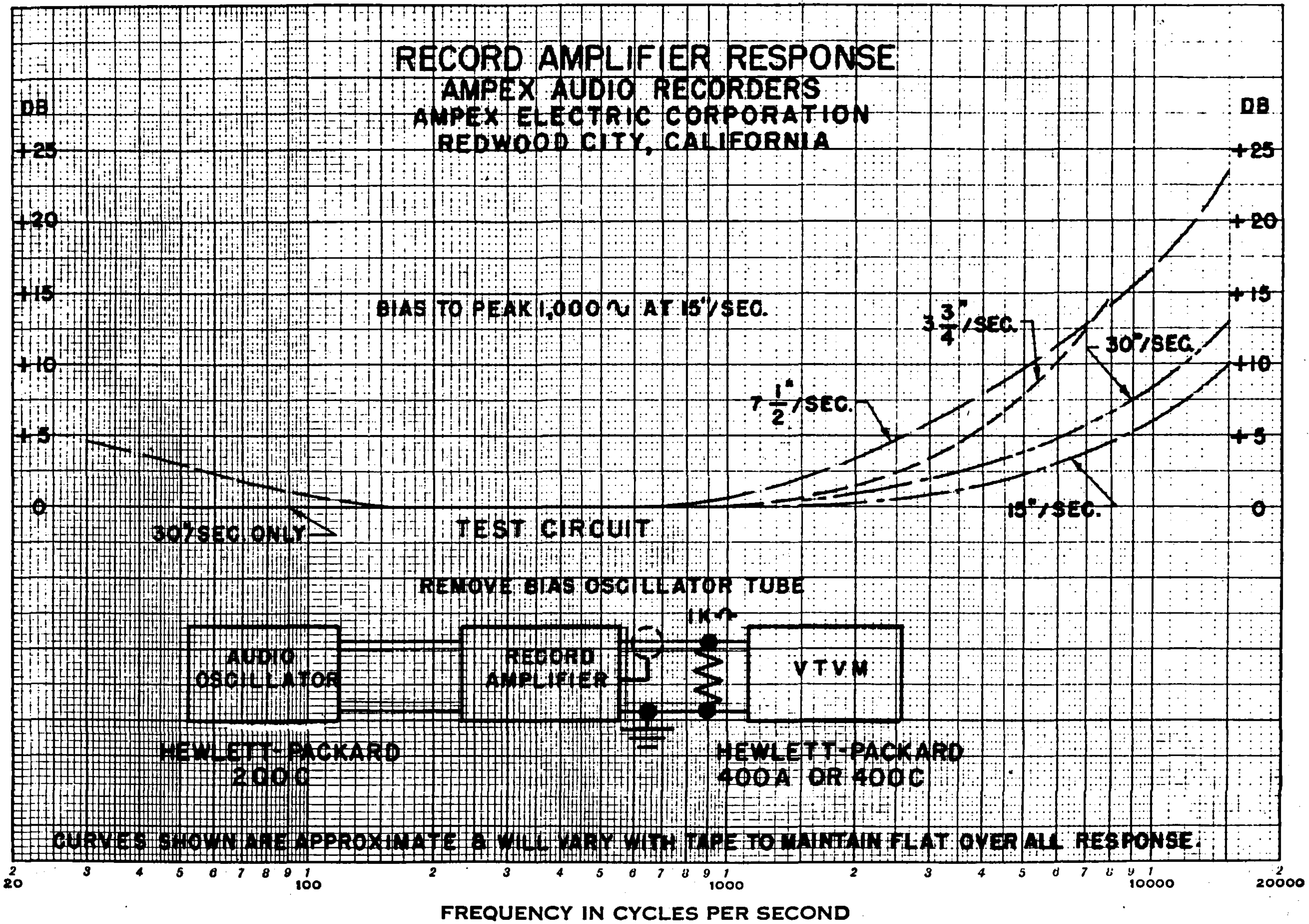

FIG. 1

A1253251_0534

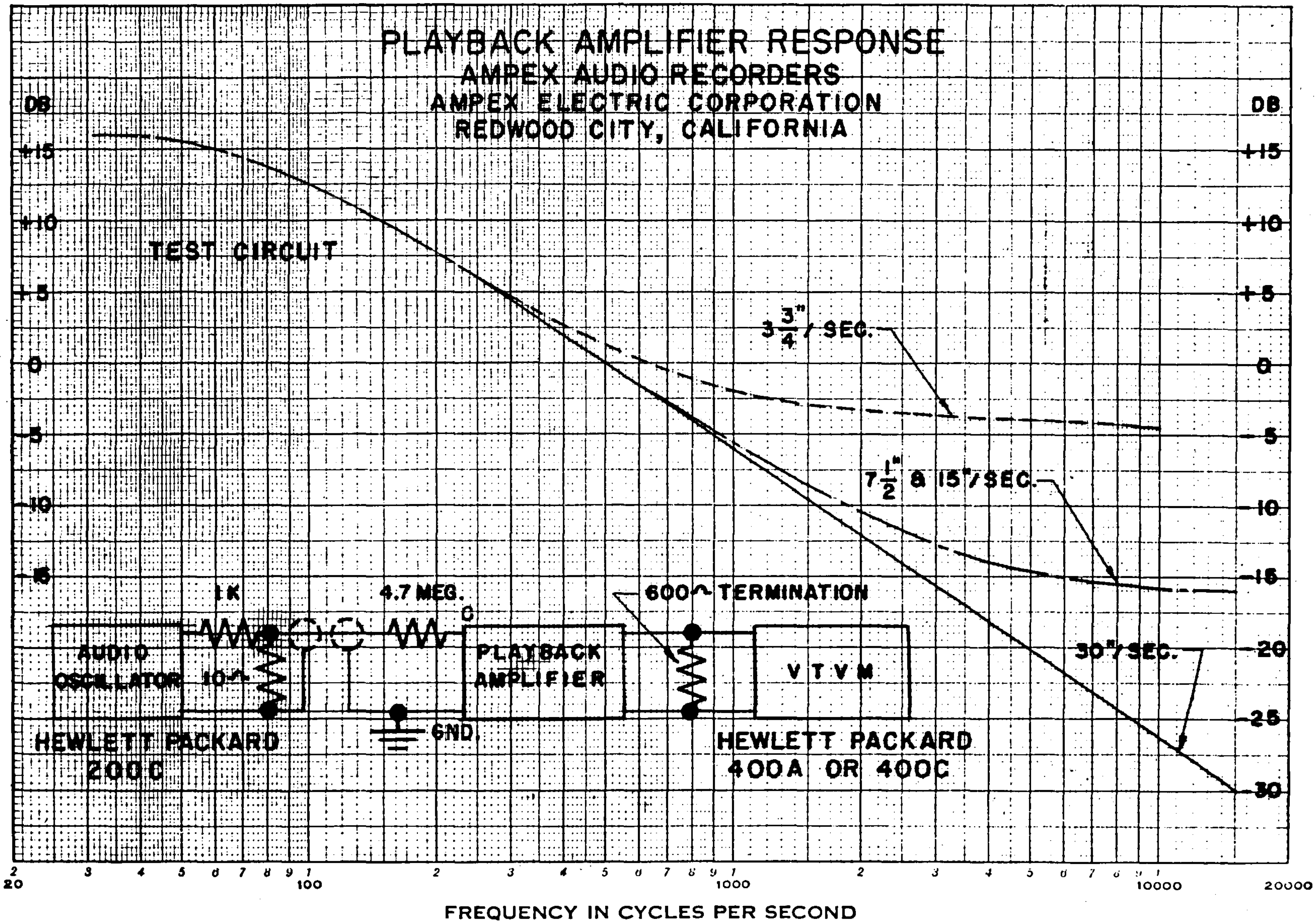
PLAYBACK AMPLIFIER RESPONSE
AMPEX AUDIO RECORDERS
AMPEX ELECTRIC CORPORATION
REDWOOD CITY, CALIFORNIA
DB
+15
+10
+5
0
-5
-10
-15
-20
-25
-30
TEST CIRCUIT
3 3/4"/ SEC.
7 1/2" & 15"/SEC.
30"/SEC.
1K
4.7 MEG.
600Ω TERMINATION
AUDIO OSCILLATOR
10Ω
PLAYBACK AMPLIFIER
V T V M
GND.
HEWLETT PACKARD 200C
HEWLETT PACKARD 400A OR 400C
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

FIG. 2

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Paper 18

METHODS OF MEASURING SURFACE INDUCTION OF MAGNETIC TAPE

J. D. Bick

Broadcast Audio Design Engineer
RCA Victor Division
Camden, New Jersey

9 October 1953

ABSTRACT: The term "surface induction" is defined as the recorded signal on the tape. If it can be measured, a method of obtaining the frequency characteristics of the recording system is available so that recorders and tape can be accurately calibrated and the standardization of recording characteristics facilitated.

Methods of measuring surface induction are presented with a discussion of their merits. Results of laboratory experiments are included to illustrate the problems.

Surface induction as defined by NARTB is "the flux density (B) at right angles to the surface of the tape." A recording having constant flux vs. frequency at the surface of the tape will have a surface induction which is proportional to frequency. The open circuit voltage output of an "ideal" short gap head is proportional to the rate of change of flux, or in other words proportional to frequency. Therefore, the open circuit voltage of the "ideal" short gap head is proportional to surface induction. This means that all curves labelled "surface induction" and corresponding discussions show an error of 6 db. per octave. For correctness insert the words "surface flux" wherever the words "surface induction" appear.

The surface induction of a recorded magnetic tape is a quantitative measurement of the signal stored on the tape. More precisely, it defines the field of flux at the surface of the tape where it is available for reproducing with a conventional playback head and system. A frequency characteristic of surface induction defines the characteristic of stored signal on the tape. All tapes recorded with the same characteristic of surface induction will give the same results on any conventional playback system. Therefore, the frequency characteristic of surface induction is useful as a means of interchanging tapes with proper playback corrections, of evaluating recording and playback system losses, and perhaps also as a means of establishing standards for the industry..

A disc recording with modulated grooves can be measured directly by optical means. Thus, the amplitudes of signals recorded in sequence or in a glide can be measured, giving the frequency characteristic of the record itself. This fact is very helpful in establishing standards both for recording systems and for playback systems.

Unfortunately, a magnetic recording is more intangible. We have no direct means of quantitative measurement of the tape, especially at the shorter wavelengths. However, there are various indirect methods of determining the surface induction, two of which are the subject of this discussion. They are somewhat laborious to perform, but they have one virtue. They can be performed on any suitable magnetic recorder in the field and are not merely relative measurements made on an arbitrary laboratory machine.

If we look at some typical curves of a magnetic tape recorder, it will become apparent how useful the surface induction curve is.

Figure 1 shows a set of curves for a typical RCA RT-11B tape recorder. The upper pair of curves shows the recording current pre-emphasis for each speed. The next pair of curves shows the surface induction for each speed; that is, the stored signal on the tape using this system. The next pair of curves shows the reproducing post-emphasis for each speed. These show the responses that would be obtained if the tape induced a constant current in the reproduce head. And finally, the lowest pair of curves shows the overall system response from 30 cps to 15 kc for the two speeds.

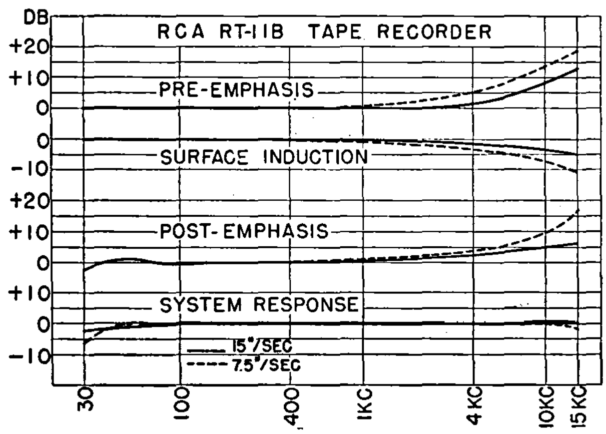

Figure 1. Curves for a typical RT-11B tape recorder.

This paper was originally presented at the Audio Fair in New York City, October 29-31, 1952, and is reprinted from the Journal of the Audio Engineering Society, Volume 1, Number 1, January, 1953. The contents are copyrighted by the Audio Engineering Society.

Having the surface induction curves, we can now evaluate the recording losses of the system as well as the reproducing losses. In the production of tape recorders, the losses vary somewhat in both recording and reproducing. But every machine is so adjusted that surface induction is the same, and overall response the same, only pre- and post-emphasis curves being altered to make up for these variations in losses. Therefore, tapes recorded on any machine can be reproduced on any other machine of this type with the same overall response.

In figure 2 we see a set of curves which will explain further the importance, in a given design, of adhering to a specific surface induction curve. This shows the performance curves for the same RT-11B magnetic recorder at 15 in./sec. The flat system response is noted. A program distribution curve, typical of peak levels contained in all kinds of program material including music and speech, is shown for reference. This is the 75-μsec curve which is the inverse of the FM pre-emphasis curve. Above this is the capability curve of the recorder which is represented by constant three percent distortion at the low end, and by tape compression at the high end. The 2-db compression curve is close to the knee of the overload point; that is, where a 1-db change of input causes a 1/2-db change of output and is somewhat below saturation. It is seen that there is a wide margin between the program distribution curve and the capability curve at high frequencies.

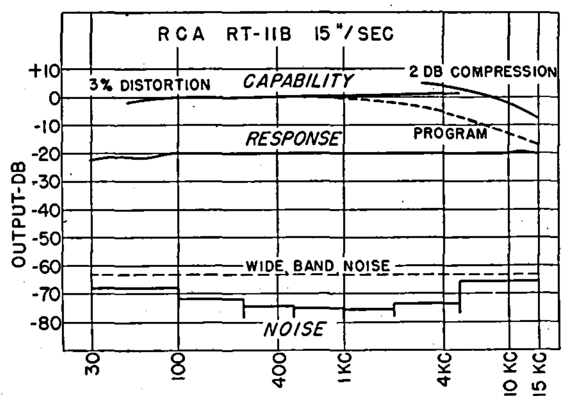

Figure 2. Curves for the RT-11B tape recorder at 15 in./sec.

At the bottom of the figure is the noise curve. At any frequency, the dynamic range is the difference between noise and capability.

In figure 3 we have the corresponding performance curves at 7.5 in./sec. speed. Again we have the flat system response. But now the margin between program distribution and capability has been reduced and the noise has come up somewhat.

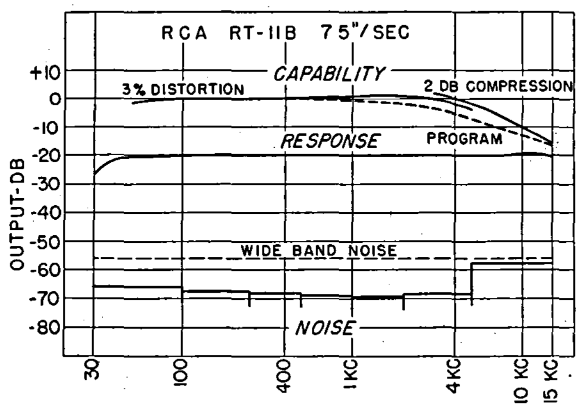

Figure 3. Curves for the RT-11B tape recorder at 7.5 in./sec.

Now, as a practical matter in designing tape recorders, the noise is largely due to the reproducing system; and hf noise can be reduced if we use more pre-emphasis. The capability curve, however, runs below the program distribution curve; this means that at high levels the highs become distorted or compressed sooner than the lows. Therefore, a given surface induction curve represents a compromise which gives the best dynamic range with flat system response.

We must choose our surface induction curves carefully with all this in mind, and we must take into account all other factors such as differences among tapes which exhibit various capability curves.

We have seen the usefulness of defining the surface induction curves. Now, how do we get them?

Various laboratories have attempted some of the techniques of measurement used in the methods to be described. One of the methods was specifically proposed by P.E. Axon of the BBC Research Department.[1] The plan to use surface induction as a basis for standards was proposed first by the BBC and by the Danish State Radio, as participating members of the CCIR. Formulation of the specific procedure for the two methods of measurement is set down in the Danish report[2] to CCIR of February 1952. Since that time, participating members of the CCIR and NARTB have been attempting to verify the methods in an effort to arrive at standards.

The two methods which will be described here may be referred to as the short-gap method and the long-gap method. The methods have been named in this manner to distinguish them readily. In the short-gap method, a reproduce head is used whose gap length is short with respect to the shortest wavelength to be measured. In the long-gap method, the head gap is long with respect to the measured wavelengths.

The two methods will be described in turn, together with experimental results; finally, the results will be compared. The short-gap method will be considered first.

Short-gap Method

The short-gap method consists in calibrating a suitable reproduce system for losses and in using the calibrated system to measure the output from a tape whose surface induction we wish to find. The method can be broken down into four steps: (1) determining wavelength losses; (2) measuring frequency losses; (3) measuring the output of the tape to be evaluated; and (4) computing the surface induction from the data of the first three steps.

In the experiments, a typical RT-11B reproduce head was used and connected open circuit to a relatively flat amplifier. This system was used for all measurements. In practice, an equalized system could be used as well, provided that computations were all made to take this into account.

The wavelength losses due to the gap effect were determined first (see figure 4). The gap loss is assumed to follow the equation

$$\text{Loss} = 20 \log \frac{\sin \pi\delta/\lambda}{\pi\delta/\lambda}$$

where δ is the effective gap length and λ is the wavelength of recorded signal. The figure shows the loss curve with its null at the frequency where $\delta = \lambda$. The method of

[1] P. E. Axon, Research Department, BBC Engineering Division, "Overall Frequency Characteristic in Magnetic Recording", BBC Quarterly, V, No. 1, Spring 1950.
[2] CCIR Question 63, Denmark, February 28, 1952, I.T. No. 2022.

determining wavelength loss consists in measuring δ and computing the losses from the equation. By definition, δ is equivalent numerically to the wavelength of the recorded signal at which the null occurs.

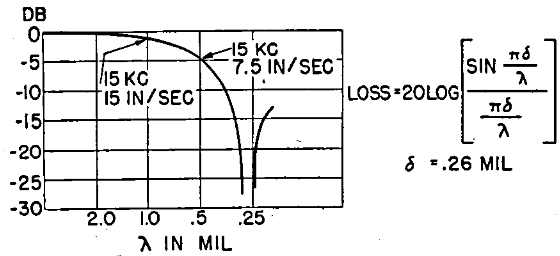

Figure 4. Wavelength losses, short-gap method.

In the experiments the tape was run at a speed of 1-7/8 in./sec., and the output of the reproduce system was explored with respect to recorded frequency. A distinct null was located at 7,100 cps from which an effective gap length of 0.26 mil was computed. In locating the null, it was found helpful to use filters in the output and to reduce the bias to a low value in order to reduce the recording losses. Complete removal of the bias, however, led to a false null at 2,500 cps, which is believed to be due to the geometry of the record head.

Having the value of δ, the wavelength losses at the speeds of 15 in./sec. and 7.5 in./sec. were computed from the equation. The equation is probably valid in this case because a distinct null was obtained. Therefore, the edges of the gap were reasonably parallel, and the tape was in good contact with both edges. The accuracy of the equation with variations in gap geometry is greatest when the loss is small. At 1/2-mil wavelength, the computed loss is not more than 5 db.

The next step in calibrating the reproduce system consists in measuring the frequency losses. In the experiments, four different methods were used to measure this, with substantial agreement among them. One method used tape; the others were electrical.

The first method, using tape, may be referred to as the change-of-speed method. A series of wavelengths were recorded and then played back through the system to be calibrated at speeds of 15 in./sec. and 7.5 in./sec. The outputs at corresponding wavelengths were noted, and a correction of 6 db was added to the readings at the lower speed to make up for the fact that the rate of change of flux for each wavelength was one-half that of the same signal at the higher speed.

In figure 5, the upper curves show the output obtained at the two speeds for corresponding wavelengths with correction of +6 db added to the 7.5 in./sec. curve. The difference between the curves represents the octave loss at each frequency, since the speed change was a factor of two. The total accumulated loss of a given frequency represents the sum of losses for all octaves down to the point where the curves coincide. For example, the accumulated loss at 15 kc equals the sum of losses at wavelengths of one, two, four, eight, etc., mils. This accumulated loss thus obtained at all frequencies is shown in the lower curve.

This method of measuring frequency loss has the advantage of using tape directly but the disadvantage of accumulative error as well as somewhat unsteady readings at shorter wavelengths.

A variation of this method can be used in which the speed is made continuously variable over a wide range. However, this is not available on machines in the field, whereas most machines have two speeds.

There are various electrical methods of approximating these frequency losses. Figure 6 shows the circuits for three of these methods. One method is to feed a constant current source through the playback head and measure the output of the system. The voltage across the head approximates the condition of induced voltage produced by a flat surface induction of the tape but with no wavelength losses. However, the flux path is not the same as it would be from tape, since all of the flux passes across the front gap where different frequency losses may be found. Also, care must be taken to prevent resonance of the head within the frequency range of the measurements, since this would cause incorrect evaluation of frequency losses.

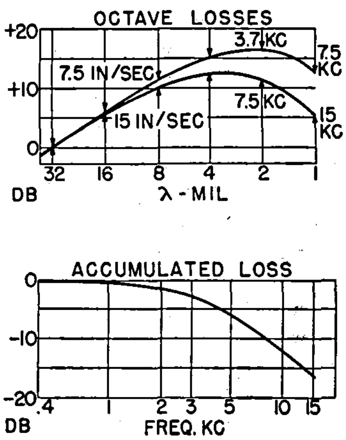

Figure 5. Frequency losses, short-gap method.

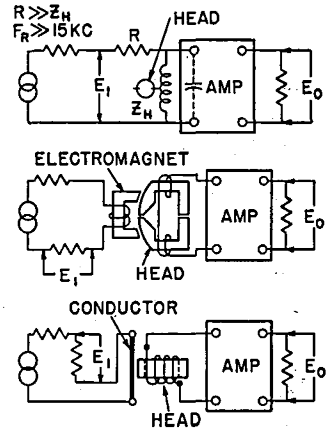

Figure 6. Electrical circuits for approximating frequency losses.

Another method--perhaps more accurate, in that the flux path in the head is the same as it would be from a recorded tape--is the use of an electromagnet placed across the head gap. In this method we have, in effect, a stationary magnet of fixed wavelength whose intensity can be varied at any frequency. To be accurate, this method requires evaluation of frequency losses in the electromagnet itself.

The last method also makes use of a stationary magnet of fixed wavelength and variable frequency across the gap. A conductor is placed parallel to the gap; a constant current passing through the conductor produces a constant induction. The conductor used is a brass strip of greater width than the length of the gap.

The four curves in figure 7 show the frequency losses of the system obtained with all four methods. The A curve shows the losses measured by feeding constant current through the head; the B curve shows those measured by the electromagnet method; and the C curve shows those measured by the conductor method. The B curve was corrected for electromagnet losses.

The D curve shows the losses measured by the method which uses tape at variable speed. This curve agrees very closely with the A curve. In fact, the curves all correlate within ±1 db. The D curve was used to calibrate the system for the curves to be shown later.

The reproduce system has now been calibrated, and the wavelength losses and frequency losses have been measured separately. The next steps can now be taken: measuring the output of the unknown tape and computing the surface induction by correcting the output for those losses. In this case, the tape used in the experiment was a recording having the standard characteristic for the RT-11B tape recorder at 15 in./sec. and 7.5 in./sec.

Figure 8 shows the resulting surface induction at the two speeds. The lower curves at each speed show the output of the system which has been graphically corrected by 20 db per decade. The dotted curves show the outputs corrected for frequency losses, and the upper curves are corrected for frequency and wavelength losses, giving the resultant surface induction.

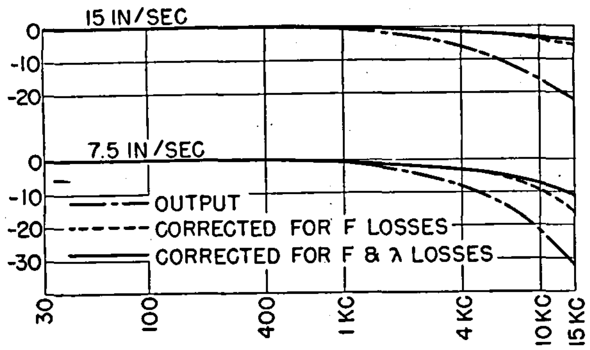

Figure 8. Surface induction at 15 in./sec. and 7.5 in./sec., short-gap method.

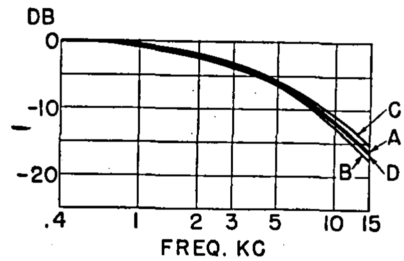

Figure 7. Frequency loss curves, short-gap method.

It should be noted that an additional wavelength loss of the order of ±1 db was found at the extreme lf end of the output curve. This could have been measured by using very low tape speeds. Actually, it is fair to assume in this region that the surface induction is proportional to recording current.

Long-gap Method

The long-gap method of measuring surface induction also consists in calibrating a reproduce system, but in this method a playback head is used that has an effective gap length which is long with respect to the wavelengths to be measured.

An ideal long-gap head connected open circuit and with constant induction has a voltage output with alternate maximum points and nulls, as shown in figure 9. The output curve is assumed to follow the equation:

$$E = K \sin \pi\delta/\lambda$$

The constant K includes the surface induction, the gap length, and the speed of the tape. From the equation

$$\frac{dE}{d(\delta/\lambda)} = K\pi \cos \pi\delta/\lambda$$

The maxima occur when $\delta = 1/2\lambda$, $3/2\lambda$, etc., or when $\delta = (n - 1/2)\lambda$. The minima occur when $\delta = n\lambda$. The value of E at the maxima equals a constant. Therefore, the locus of maxima with an ideal head is a straight line and flat. This line represents surface induction directly.

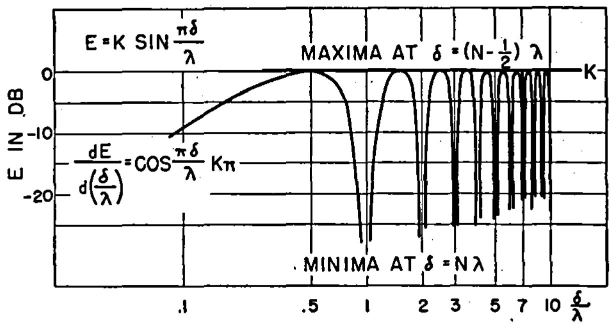

Figure 9. Theoretical output, long-gap method.

A non-ideal head together with its amplifier will have a locus of maxima other than a straight, flat line. This is due to frequency losses which can be corrected and to secondary wavelength losses which cannot be corrected at the present time.

It is to be noted that surface induction is measured by this method at discrete frequencies only, i.e., the frequencies where the maxima occur. Also, the lowest frequency measured is that of the lowest maximum. Therefore, the long-gap method is concerned with mf and hf measurement only.

The long-gap method can be divided into three steps: (1) measuring frequency losses; (2) measuring the output of the tape to be evaluated; and (3) computing the surface induction from the data.

In the experiments, a long-gap head was made and connected open circuit to a relatively flat amplifier. The head had a gap length of 18 mils, which caused the maxima to lie approximately 1 kc apart at 15 in./sec. A considerable effort was made so that the edges of the gap were as nearly parallel as possible. Actually, three heads were tried, the data showing the results of the best one in this respect.

In the first step, the frequency losses can be measured by any of the methods described for the short-gap method. In the experiments the change-of-speed method, with tape, was used exclusively.

Figure 10 shows the octave losses as measured and the accumulated frequency loss as computed from the measured losses. In measuring the octave loss with speed change of two, a gliding tone was recorded in the region of each maximum so that suitable output could be obtained.

In the next step, the calibrated system was used to measure the output of a gliding tone on a tape whose surface induction was to be determined. The surface induction was known to be the same as that which was measured with the short-gap method, so that a comparison could be made between the methods. This was insured by using the same record system and head, the same recording current characteristic and bias current, and the same piece of tape.

The curves in figure 11 show the output at 15 in./sec. corrected for the frequency losses. The heavy line drawn through the maxima is therefore the surface induction as found by this method. The locus of minima is shown indicating modulation noise below 3 kc and signal above 3 kc. The latter is due to incomplete cancellation because of lack of parallelism between the edges of the gap. This may cause a slight error in maximum readings. With an ideal head, the maxima would not fall off as rapidly at the high end.

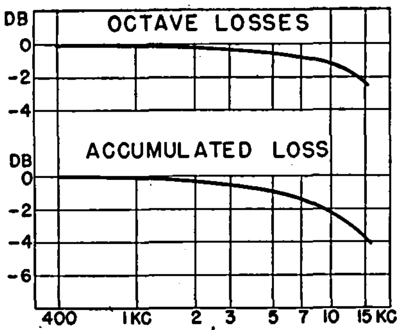

Figure 10. Frequency losses, long-gap method.

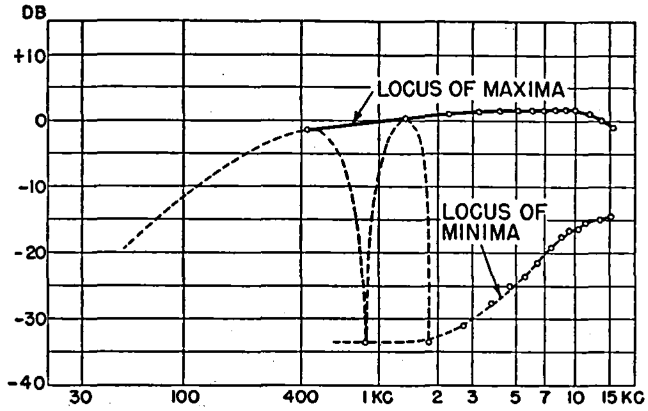

Figure 11. Surface induction at 15 in./sec., long-gap method.

Figure 12 shows similar curves, taken at 7.5 in./sec., of the surface induction at that speed. Again the output curve is corrected for frequency losses. Here the difference between maxima and minima is not more than 5 db at the shortest wavelength. The output of the system at the minima consists partly of noise but mostly of signal as determined by listening and by filtering. Because of an imperfect gap, the accuracy of surface induction at the short wavelengths is obviously not very great with this head.

The effect of parallelism between the edges of the gap can be illustrated in this way. The point where the maxima and minima converge represents an error in parallelism such that *n* wavelengths appear across one side of the gap and *n* + 1/2 wavelengths appear across the other side of the gap. With the experimental head, it appears that convergence would occur at about 0.4-mil wavelength or 40 wavelengths across one side of the gap and 40.5 wavelengths across the other side of the gap. This represents an angular error of 6 min and a linear error of 1.2 percent for the gap of the experimental head. Since this head is not suitable for measurement at 1/2-mil wavelength, it is evident that a degree of accuracy is required which may not be practical to obtain.

The problem of parallelism in long-gap heads can be reduced in various ways. It might be advisable to have a series of heads of successively shorter gaps, placing the maxima farther apart at the high end but improving the accuracy. Or the long-gap head could be made with a narrow track width so that for a given angular error in gap edges the linear error would be reduced. Neither method has been investigated at the time of writing.

A comparison of the results of the two methods of measuring surface induction is shown in figure 13. The upper set of curves shows the 15 in./sec. surface induction, and the lower set shows the 7.5 in./sec. surface induction. The solid curves represent the short-gap method and the dot-dash curves represent the long-gap method.

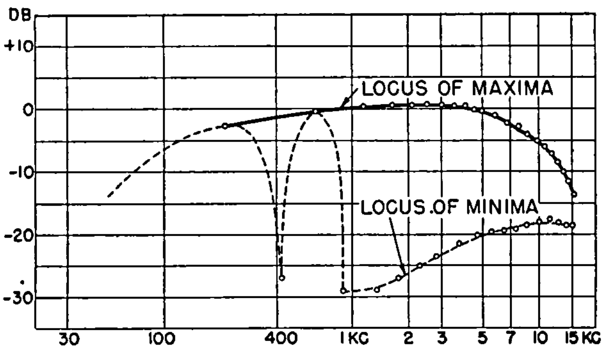

Figure 12. Surface induction at 7.5 in./sec., long-gap method.

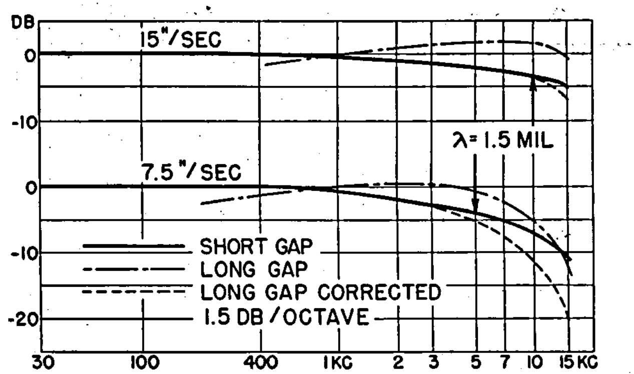

Figure 13. Comparison of the long-gap and short-gap methods of measuring surface induction.

The most striking difference between the curves is a difference of slope of about 1.5 db per octave. A 2 db per octave difference was found by the BBC and by the Danish participants in the CCIR. Various explanations have been offered for the difference in slope, and the matter is still under investigation.[3] It is apparent that there is a wavelength-dependent variable that does not appear in the assumed equation.

The short-dashed curve shows a correction of 1.5 db per octave in the long-gap curves. With this correction, the curves fit closely to about 1.5 mil wavelength with the short-gap curves. After this, the long-gap curves drop below the short-gap curves. It may be stated that measurements reported by the BBC and Denmark were carried out only to 1.5-mil wavelength. Up to this point the two methods agreed after the slope correction was applied.

In conclusion, it is felt that it is desirable to be able to measure surface induction. With the information gained, it is easier to evaluate recording and playback losses of a system as well as to evaluate tapes. Furthermore, it is desirable to be able to make the measurements in the field and be assured of substantial agreement of these measurements with others made on other machines.

Methods are being devised for making the measurements. Of the two methods described in this discussion, the short-gap method is easiest to perform and does not require a special head construction. Its accuracy is probably good if wavelength losses are held within 5 db. The long-gap method may be promising in the laboratory, but its accuracy must be improved at short wavelengths. Also we need to determine the nature of the 1.5 db per octave correction. Until this is explained fully, the validity of the long-gap method is questionable.

[3] W. K. Westmijze, Philips Research Laboratories, Eindhoven, Netherlands, "Gap-Length Formula in Magnetic Recording", Acustica, 2, No. 6: 292, 1952.

Other methods may be devised, and with them we may have further checks on our results.[4]

The writer acknowledges the guidance and suggestions of Mr. W. E. Stewart, Chairman of the Sub-committee on Magnetic Tape Recording of the NARTB, and Mr. W. H. Erikson, of Advanced Development Engineering, RCA Victor, as well as assistance in the project through design of special heads provided by Mr. L. W. Ferber, of Commercial Sound Engineering, RCA Victor.

[4] Daniel and Axon, "The Reproduction of Signals Recorded on Magnetic Tape", Proc. of I.E.E., May 1953, Part III.
[5] Naval Ordnance Lab. Contract N171s-85154; Final Report dated 17 June, 1949--"Analysis of Magnetic Recording with Frequency-Modulated Signals"

Since this writing, several independent measurements of surface induction have been checked with close agreement between members of the NARTB. A recorded tape provided by BBC with stated characteristic to 1.5 mil wave length agreed with the calibration shown in this paper within + or - 0.5 db.

The NARTB has adopted the method of measurement proposed by the CCIR and described in this paper.

DISCUSSION SUMMARY

In discussing with Mr. Bauer of Shure Brothers, the theoretical foundation for the 1-1/2 db per octave difference in slope between the long-gap and short-gap methods (see reference 3), Mr. Bick recalled Dr. P. E. Axon's original belief that the long-gap head did not disturb the induction of the tape to the degree that the short-gap head did. Therefore, the long-gap head measured the induction in air at the surface of the tape. This has since been disproved by measurements with a non-magnetic conductor type of head (see reference 4) which agreed more closely with the short-gap method. Also, Dr. Axon's belief disagreed with the belief that at low frequencies the induction is fairly well proportional to recording current and, since recording current is constant at these frequencies, it seems unreasonable that the curve of induction in air should have a slope. Some original interest in the long-gap method was based on the assumption that erase heads could be used for tape calibration. However, RCA experiments indicate that this would require considerable overdesign of the erase head gap.

In answer to Mr. Bauer, Mr. Bick observed that reference 4 compares all three methods of surface induction measurement and shows a greater consistency in measurements with the short-gap method.

Mr. Camras of Armour Research recalled his impression that the long-gap method was originally proposed as a short cut method of measurement without need of short gaps which are difficult to achieve. He asked if Mr. Bick's experience had shown any justification for continuation of the long-gap method of measurement, however, in view of the involved theory to explain its action and the increased accuracy of measurement now required. Mr. Bick answered two ways. As a member of National Association of Radio and Television Broadcasters, he pointed out that both methods are described in the NARTB standard on tape recording equalization. The choice is up to the individual laboratories.

As for RCA experience, it has been found that for measurements down to wavelengths as short as .0005 inch the long-gap method required much higher accuracy by linear percentage in the head than the short-gap method, and RCA was using the short-gap method.

Mr. Zenner of Armour Research pointed out that the equations predict a null at the point where the gap width equals a full wavelength. Recent European work has analyzed the gap effect more carefully and agrees with findings at Armour as reported in reference 5. This shows that the first null occurs at a wavelength slightly longer than the measured gap, the second null at a wavelength not exactly twice the first, etc. Mr. Bick cited similar experience at RCA.

Mr. D'Arcy of DeVry asked if these methods didn't measure relative induction on tape rather than absolute induction. Mr. Bick agreed but also was of the opinion that absolute measurements have been made, particularly when using the non-magnetic head method (reference 4). Such a head uses a spacer of very thin non-magnetic metal foil clamped between plastic holding blocks. The dimensions of the spacer and its distance from the surface of the tape are used to determine theoretically the expected output from magnetic induction (see reference 4). This type of head seemed to Mr. D'Arcy to offer a practical way to calibrate accurately a lower frequency, such as 400 cps, for use as a standard level film. Mr. Bick added that it was strictly a laboratory device because of the poor signal-to-noise ratio.

Dr. Weigand of Armour Research invited attention to the heads of the type described in Papers No. 2 through No. 5 as offering possibilities for calibration of magnetic recording since they sense flux amplitude directly instead of rate of change of flux.

- 5 -

LIST OF PERSONNEL FROM INDUSTRIAL ORGANIZATIONS ATTENDING MAGNETIC RECORDING SYMPOSIUM

1. Altec Lansing Corporation, Los Angeles, California
   Mr. John Hilliard

2. Ampex Corporation, 7338 Baltimore Avenue, College Park, Md.
   Mr. Grank G. Lennert — Mr. Walter T. Selsted
   Mr. Robert Sackman

3. Amplifier Corporation of America, 398 Broadway, New York City, New York
   Mr. Nathan M. Haynes

4. Ampro Corporation, 2835 N. Western Avenue, Chicago 18, Illinois
   Mr. H. W. Bauman

5. Armour Research Foundation, Institute of Technology, Technology Center, Chicago 16, Illinois
   Mr. Marvin Camras — Mr. C. E. Williams
   Mr. D. E. Wiegand — Mr. R. E. Zenner

6. Audio and Video Products Corporation, 730 Fifth Avenue, New York 19, New York
   Mr. Kenneth B. Boothe — Mr. Herman Norwood
   Mr. James Lemke

7. Audio Manufacturing Company, 25 Parker Avenue, Glenbrook, Connecticut
   Mr. Monroe Barnard

8. Avion Instrument Company, 299 State Highway #17, Paramus, New Jersey
   Mr. Leonard Beck — Mr. Fred Sher
   Mr. M. Landis — Mr. John H. Troll

9. Bell and Howell Company, 7100 McCormick Road, Chicago 45, Illinois
   Mr. Howard H. Brauer — Mr. Jack V. Waller
   Mr. Alfred Roberts, Jr.

10. Bell Telephone Laboratories, Inc., Summitt, New Jersey
    Mr. J. C. Barnard — Mr. C. R. Keith
    Mr. W. R. Goehner — Mr. J. Z. Menard

11. Boeing Airplane Company, Seattle 14, Washington
    Mr. Robert W. Nichols

12. Bing Crosby Enterprises, Incorporated, 9030 Sunset Boulevard, Los Angeles 46, California
    Mr. Thomas E. Davis — Mr. Wayne R. Johnson
    Mr. Francis C. Healy — Mr. John T. Mullin
    Mr. Robert D. Hopkin, Jr.

13. Burroughs Corporation, 511 North Broad Street, Philadelphia 23, Pennsylvania
Mr. T. C. Chen
Mr. Harry Kenosian

14. Brush Electronics Company, 3405 Perkins Avenue, Cleveland 14, Ohio
Mr. George Krinopolis
Mr. L. O. Nurmi
Mr. John F. Sheffs
Mr. Charles E. Snow

15. Clevite-Brush Development Company, 3405 Perkins Avenue, Cleveland 14, Ohio
Dr. Semi J. Begun
Dr. Waldo H. Kliever
Mr. Otto Kornei
Mr. James H. Leech

16. Computer Research Company, 3348 W. ElSegundo Boulevard, Hawthorne, California
Mr. Latimer Joseph Andrews
Mr. Clarence Morrison

17. Consulting Engineers:
Mr. A. W. Friend
381 Bala Avenue
Bala-Kenwyn, Pennsylvania

Mr. Polydoroff
Carry Building
Washington 5, D.C.

Mr. Simon Levin
123 West 44th Street
New York 36, New York

18. David Bogen Company, Incorporated, 29 Ninth Avenue, New York 14, New York
Mr. A. M. Zuckerman

19. Davies Laboratories, 4705 Queensbury Road, Riverdale, Maryland
Mr. Milton A. Davenport
Mr. L. Davies
Mr. Robert E. Hadady
Mr. Edgar Hotchkin
Mr. H. W. Lohr
Mr. Charles B. Pear
Mr. R. L. Peshel
Mr. Thomas D. Redington
Mr. J. R. Schulman

20. Daystrom Electric Company, 837 Main Street, Poughkeepsie, New York
Mr. Edward L. Benson
Mr. Robert F. Burns
Mr. Edgar L. Steed

21. Devenco Corporation, 150 Broadway, New York 38, New York
Mr. Edmund Schwartz
Mr. Albert D. Stern

22. DeVry Corporation, 1111 Armitage Avenue, Chicago 14, Illinois
Mr. E. W. D'Arcy
Mr. H. M. Fisher
Mr. Jack Powers

23. Dictaphone Corporation, Bridgeport 5, Connecticut
Mr. L. A. Engel
Mr. F. W. Roberts
Mr. M. P. Shorb
Mr. W. B. Sturtevant

24. DuKane Corporation, St. Charles, Illinois
Mr. Robert H. Larson Mr. William R. Torn
Mr. Michael Supitilov

25. E.D.L. Company, Gary, Indiana
Mr. R. Paul Ireland

26. E.R.A. Division, Remington-Rand, Incorporated, 1902 West Minnehaha Avenue, St. Paul 6, Minnesota
Mr. S. M. Rubens

27. Eastman Kodak Company, Camera Works, Rochester 4, New York
Mr. H. N. Fairbanks Mr. John A. Rodgers
Mr. Harry J. Krall

28. Electronic Teaching Laboratories, 1818 M Street, N.W., Wash. 7, D.C.
Mr. John E. Medaris

29. Gallant Engineering Company, Standard Oil Building, Wash., D.C.
Mr. E. A. Heider Mr. W. E. McDowell
Mr. Gallant

30. General Electric Company, Electronics Park, Syracuse, New York
Mr. W. P. Bartley Mr. W. R. Chynoweth

31. Gray Manufacturing Company, Hartford, Connecticut
Mr. Ronald Flemming

32. Industrial Research Product Company, 9400 Belmont Avenue, Franklin Park, Illinois
Mr. William Plice

33. International Business Machines Corporation, Poughkeepsie, New York
Mr. W. S. Buslick Mr. V. R. Witt
Mr. H. Nordyke

34. Jensen Manufacturing Company, 6601 South Laramie Avenue, Chicago 38, Illinois
Mr. C. R. Hohmann

35. Lockheed Aircraft Corporation, Post Office Box 551, Burbank, California
Mr. Charles Hugh Leete Mr. Alfred E. Sibley
Mr. Robert E. Rawlins

36. Macbeth Arc Lamp Company, 141 Berkley Street, Philadelphia, Pennsylvania
Mr. Iredell Eachus, Jr.

37. Magnecord, Incorporated, 225 West Ohio Street, Chicago 20, Illinois

Mr. O. C. Bixler
Mr. Peter Meisinger

38. Maico Company, Incorporated, Maico Building, 21 North Third Street, Minneapolis 1, Minnesota

Mr. J. W. Hogan
Mr. W. E. Stewart

39. Maryland Electronic Manufacturing Corporation, College Park, Maryland

Mr. Sheldon Isaacson
Mr. Joseph P. Welch
Mr. B. J. Murdock

40. McIntosh and Ingalls, Wyatt Building, Washington, D.C.

Mr. Frank McIntosh

41. Melpar, Incorporated, 452 Swann Avenue, Alexandria, Virginia

Mr. A. H. Ballard
Mr. T. E. Bayston
Mr. T. F. Burke
Mr. Harold Finn
Mr. Lawrence Lerner
Mr. Sidney Shapiro
Mr. Sinbach
Mr. Hugh Williams

42. Minnesota Mining and Manufacturing Company, 900 Fauquier Ave., St. Paul 6, Minnesota

Mr. P. W. Jansen
Mr. James E. Johnston
Mr. J. F. Morrisette
Mr. E. S. Seaman
Mr. Wilfred W. Wetzel

43. National Association of Radio and Television Broadcasters, 1771 N Street, N.W., Washington 6, D.C.

Mr. A. Prose Walker

44. National Union Radio Corporation, 350 Scotland Road, Orange, New Jersey (Reply to Post Office Box 352, Orange, New Jersey)

Mr. R. George
Dr. L. E. Loveridge
Dr. A. M. Skellett

45. North American Aviation, Incorporated, Downey, California

Mr. Boyd E. McKnight
Mr. Gerald D. Shere

46. Orradio Industries, Incorporated, T-120 Marvyn Road, Opelika, Alabama

Mr. J. Herbert Orr

47. Permoflux Corporation, 4900 West Grand Avenue, Chicago 31, Illinois

Mr. Samuel J. Hyman

48. Pierce Wire-Recorder Corporation, 5900 N. Northwest Highway, Chicago 31, Illinois

Mr. Emil Steinbach

49. RCA Victor Division, Camden 2, New Jersey
Mr. A. I. Aronson
Mr. J. D. Bick
Mr. Walter H. Erikson
Mr. Paul Wildow

50. Rangertone, Incorporated, 73 Winthrop Street, Newark, New Jersey
Mr. Paul M. Brubaker

51. Raytheon Manufacturing Company, Waltham, Massachusetts
Dr. A. J. DeVaud

52. Reed Research, Incorporated, Wash. 7, D.C.
Mr. Dwin R. Craig
Mr. Gregory J. Harmon
Mr. Pete Marenholtz
Mr. John F. Price
Mr. Thomas A. Roberts
Mr. John N. Street

53. Reeves Soundcraft Corporation, 10 East 52nd Street, New York 22, New York
Mr. William H. Deacy
Mr. Edward Schmidt

54. Revere Camera Company, 320 East 21st Street, Chicago 16, Illinois
Mr. Carl W. Claras
Mr. William S. Kabacker

55. Shure Brothers, 225 West Huron Street, Chicago 5, Illinois
Mr. Benjamin B. Bauer
Mr. Elmer V. Carlson
Mr. Lee Gunter

56. Stavid Engineering Corporation, Plainfield, New Jersey
Mr. Charles Fenwick

57. Sound, Incorporated, 221 East Cullerton Street, Chicago, Illinois
Mr. B. A. Bierwirth

58. Soundscriber Corporation, 146 Munson Street, New Haven, Connecticut
Mr. William Drake
Mr. William Lyon
Mr. Lincoln Thompson

59. Stromberg-Carlson Company, Rochester, New York
Mr. J. W. Gration
Mr. L. C. Holmes

60. Texas Instruments Division, 6000 Lemon Avenue, Dallas, Texas
Mr. B. E. Berkshire
Mr. Robert W. Kelly
Mr. Olson

61. U.S. Recording Company, Washington District of Columbia, 1121 Vermont Avenue, N.W., Washington 5, D.C.
Mr. Peter Altman
Mr. Samuel Bryan
Mr. Alfred L. Case
Mr. John D. Madaris

62. U.S. Time Corporation, Waterbury, Connecticut
Mr. J. R. Montgomery

63. Webster-Chicago Corporation, 5610 Bloomingdale Ave., Chicago 39, Illinois
Mr. Robert Dew
Mr. William B. Dibble

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64. Westrex Corporation, Hollywood Division, 6601 Romaine Street, Hollywood 38, California
Mr. John G. Frayne

65. Wilbur Machine Company, Incorporated, 42 Wall Street, Binghamton, New York
Mr. H. P. Gregory

LIST OF PERSONNEL FROM MILITARY ORGANIZATIONS
ATTENDING MAGNETIC RECORDING SYMPOSIUM

1. Air Force Security Center, Kelly Field, San Antonio, Texas
   Mr. Walter L. Anderson

2. Andrews Air Field Headquarters, AACS, Andrews Air Force Base, Maryland
   Major K. E. Lepp

3. Army Security Agency, Department of the Army, Wash. 25, D.C.
   Mr. Nathan Disenhaus
   2d Lt. Donald B. Falk
   Major Philip A. Finney
   Mr. Orlando V. Gallegos
   Mr. Fred J. Gartzke

4. Australian Military Mission, Wash. 25, D.C.
   Lt. Col. A. Jacoby
   Lt. Col. I. B. Johns

5. British Joint Services Mission, Wash. 25, D.C.
   Mr. Clifford Neal

6. Bureau of Aeronautics, Department of the Navy, Wash. 25, D.C.
   Mr. Robert E. Ankers, Jr.
   Cdr. George R. Fraser
   Mr. Irvin H. Gatzke
   Mr. V. V. Gunsoley
   Mr. William H. Lamar
   Mr. Thomas R. Meeker
   Mr. Leroy Mickey
   Mr. A. Lewis Miller
   Mr. Pendleton
   Mr. J. A. Solga

7. Bureau of Ordnance, Department of the Navy, Wash. 25, D.C.
   Mr. Charles H. Ludwig
   Mr. F. Saunders
   Mr. Benton H. Schaub
   Mr. Erich C. Schalla
   Mr. Robert E. Simpson

8. Bureau of Ships, Department of the Navy, Wash. 25, D.C. (Code 565E)
   Mr. Bruce K. Bray
   Mr. Philip M. Cowett
   Mr. John A. Croarkin
   Mr. Walter K. Dau
   Mr. P. J. Densberger
   Mr. Maxwell A. Kerr
   Mr. Everett L. Martin
   Mr. Harold S. Slightam
   Mr. Donald F. Spencer

9. Bureau of Ships, Department of the Navy, Wash. 25, D.C. (Identifying Code Numbers follow individuals' names)
   Mr. Robert K. Bransby(436)
   Lt. Alfred M. Bettis(855)
   Mrs. Frances R. Darne(816)
   Lt. Jervis J. Gennari(371)
   Mr. R. S. Garthune(520)
   Mr. Robert Hauptman(822C)
   Mr. Andrew P. Massey(946)
   Mr. Sheldon G. Meyers(847)
   Mr. Edward H. Ockert(844)
   Lcdr. A. T. Owens(855)
   Mr. Joseph M. Richards(947)
   Mr. Robert G. Stiles(824)
   Mr. Robert Wallis(238)
   Mr. Charles E. White(851)

10. Civil Aeronautics Administration, 17th and Constitution Ave., T-4 Building, Wash. 25, D.C.
   Mr. Frank Cervenka
   Mr. Charles C. Walker

11. David W. Taylor Model Basin, Wash. 7, D.C.
   Mr. C. R. Barrett
   Mr. F. B. Bryant
   Mr. V. E. Benjamin
   Mr. H. B. Davis
   Mr. T. E. Habib
   Mr. R. L. Parris
   Mr. H. L. Rich
   Mr. H. A. Soulant
   Mr. M. Strasberg

12. U.S. Department of Health (Federal Security Service), Wash. 25, D.C.
   Mr. R. Lowdermilk (Room 3650)

13. Engineering Experiment Station, Annapolis, Maryland
   Mr. Larry J. Argiro

14. Foreign Operations Administration, 815 Connecticut Ave., N.W., Wash. 25, D.C.
   Mr. Lawrence J. Tate

15. Material Laboratory, New York Naval Shipyard, Brooklyn 1, N.Y.
   Mr. Frank A. Comerci (Code 930)
   Mr. Sheldon I. Wilpon

16. National Advisory Committee for Aeronautics, Langley Field, Va.
   Mr. Francis B. Smith

17. National Bureau of Standards, Wash. 25, D.C.
   Mr. Seymour Edelman
   Mr. Hilbert W. Frey
   Mr. Irving Levine
   Mr. Henry A. Schmidt, Jr.
   Mr. Bernard D. Simmons
   Mr. Ernest R. Smith

18. National Security Agency, Wash. 25, D.C.
   Mr. R. O. Alde
   Mr. W. C. Banning
   Cpl. R. G. Baret
   Mr. W. R. Boenning
   Mr. Frank E. Boyd
   Lt. L. H. Browning
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   Pvt. M. Doell
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   Lcdr. Rigor
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   Mr. C. Russel Summers
   Mr. J. F. Sweeny
   Mr. R. E. Thayer
   Mr. Paul J. Weber
   Mr. L. G. Whipple

19. National Research Council, 2101 Constitution Ave., Wash. 25, D.C.
Mr. John S. Coleman

20. Naval Air Development Center, Johnsville, Pennsylvania
Mr. Albert A. Evry
Mr. J. H. Namaroff (Aeronautical, Elec. & Elec. Lab., Code EL-90)

21. Naval Air Missile Test Center, Point Mugu, Port Hueneme, Calif.
Mr. Lewis B. Johnson

22. U.S. Naval Ordnance Lab., White Oak, Md.
Mr. P. S. Bengston
Sgt. L. D. Cooley
Mr. Allen Erickson
Mr. R. L. Knodle

23. U.S. Naval Photographic Center, Naval Air Station, Anacostia, Wash. 25, D.C.
Mr. Joseph E. Aiken
Mr. Gerald J. Badgley
Mr. Joseph Beary
Mr. C. A. Dixon
Mr. J. C. Greenfield
Mr. J. Petes

24. U.S. Naval Proving Ground, Dahlgren, Va.
Mr. J. O. Dyal

25. U.S. Naval Research Lab., Wash. 25, D.C.
Mr. Frank E. Boyd
Mr. Robert H. Carson
Mr. Charles E. Chambers
Mr. David C. Coulter
Mr. John V. Ellison
Mr. L. H. Feher
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Mr. Victor R. Simas
Mr. Arthur Q. Tool
Mrs. Majorie Townsend
Mr. Henry K. Weideman
Mr. Charles F. White
Cdr. D. B. Wilder

26. U.S. Naval School of Aviation Medicine, Naval Air Station, Pensacola, Florida
Mr. Scott N. Morrill

27. U.S. Naval Underwater Sound Laboratory, Fort Trumbull, New London, Connecticut
Mr. William Saars

28. U.S. Navy Electronics Laboratory, San Diego 52, California
Cdr. W. B. Bernard
Mr. J. R. Chiles
Mr. Robert S. Gales
Mr. Stanley H. Sessions
Mr. J. N. Shellabarger
Mr. Robert H. Waldie

29. U.S. Navy Mine Countermeasures Station, Panama City, Florida
Mr. Ernest E. Erickson
Mr. Sanderson

30. U.S. Navy Motion Picture Exchange, New York Naval Shipyard, Naval Base, Brooklyn 1, New York
Lt. L. O. Orr

31. U.S. Navy Underwater Sound Reference Laboratory, Post Office Box 3629, Orlando, Florida
Mr. Donald T. Hawley

32. Office of Chief of Naval Operations, Electronics Division, Department of the Navy, Room 4A538, Pentagon, Wash. 25, D.C.
Lcdr. L. A. Franz

33. Office of Chief Signal Officer, Engineering & Technical Division (SIGGG-S), Department of the Army, Wash. 25, D.C.
Mr. T. E. Hedman
Mr. R. D. Miller

34. Office of Naval Intelligence, Department of the Navy, Wash. 25, D.C.
Mr. J. R. Morgan

35. Office of Naval Research, Department of the Navy, Wash. 25, D.C.
Mr. Henry Alexander
Lt. Floyd K. Becker
Mr. Henry W. Boehly
Lt. (jg) Edward L. Curtis
Mr. Stanley W. Doroff
Lt. James E. Lesch

36. Office of Standardization, Wash. 25, D.C.
Mr. Michael Ford
Mr. George Franks

37. Ordnance Corps, Diamond Ordnance Fuse Laboratory, Wash. 25, D.C.
Mr. Kenneth Zastrow

38. Physical Security Equipment Agency (Attn: Code EA-12), Post Office Box 682, Franklin Station, Wash., D.C.
Mr. R. Clark Giles

39. Chief, Film Distribution and Utilization Branch, Army Pictorial Service Division, Washington 25, D.C.
Mr. J. D. Maguire
Mr. James A. Moses

40. Psychological Warfare Center, Fort Bragg, North Carolina
Captain Victor U. Tervola

41. Signal Corps Engineering Labs., Department of the Army, Wash. 25, D.C.
Mr. James Snyder

42. Coles Signal Laboratory, Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey
   Mr. C. C. Comstock   Mr. R. A. Faralla

43. Signal Corps Pictorial Center, Long Island City, New York
   Mr. James Kennedy   Mr. George Lewin

44. Woods Hole Oceanographic Institute, Woods Hole, Massachusetts
   Mr. Frank Dietz   Mr. Henry Johnson
   Mr. Willard Dow   Mr. George Wheeler

45. Wright Air Development Center, Wright-Patterson Air Force Base, Ohio
   Lt. R. E. Kellogg   Dr. O. R. Rogers
   Mr. E. Lazur   Mr. L. N. Theroux

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