The Frequency Response of Magnetic Recorders for Audio*

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The total frequency response of a magnetic tape recorder depends on the amplifier responses, the heads, and the tape. Response standards have been established by NAB and CCIR for the reproduce chain, using an "ideal" reproduce head and a prescribed post-emphasis. Techniques are discussed and data shown for calibrating the reproduce chain; the ideal reproduce head is physically realizable.

The only standard for the record chain is that it must produce tapes which reproduce properly on a standard reproduce chain. Data show that the frequency-dependent response loss of the record chain may be made negligible. A record adjusting tape was chosen, and the required pre-emphasis derived.

Wavelength-dependent losses are appreciable; their causes are briefly discussed and found to be inherent in the tape and record heads used at the present state of the art.

I. INTRODUCTION

INFORMATION on the total frequency response of a magnetic recorder is useful for several purposes:

1. For standardization of reproduce response, in order to adhere to the established NAB or CCIR response for magnetic recorders, both in production recorders and in standard alignment tapes.
2. For general engineering design purposes, to enable one to reduce or eliminate frequency response losses in equipment design; and also so that equalizations need not be redetermined each time equipment is designed.
3. For purposes of analysis, to evaluate the various frequency-dependent and wavelength-dependent response losses, and to attempt to identify their causes.

Total frequency response losses in the magnetic recorder may be analyzed by either of two methods: the first, by reproduce and record losses; the second, by frequency-dependent and wavelength-dependent losses.[1]

This paper will be primarily from the viewpoint of the standardization and engineering design points above, for which purpose the analysis is most clearly presented by organizing into reproduce and record losses. This paper generally follows the work of Bick[2] and that of Lennert,[3] bringing the data up-to-date and supplying more data specifically relating to present-day Ampex heads and tape.

II. ANALYSIS OF THE "IDEAL" SYSTEM

The NAB (and also CCIR) standards for frequency response in magnetic recording[4] are based on the concept of an "ideal" reproduce system, plus a certain prescribed standard post-emphasis. After the ideal reproduce system is established, pre-emphasis is determined by measuring the ideal record response, applying the standard post-emphasis to the reproduce system and designing the pre-emphasis to make the total system flat. Since tape and recording losses vary, there is no such thing as a "standard" pre-emphasis.

The ideal system is defined here (in accordance with the NAB and CCIR standards) as one wherein a constant input voltage to the record system vs frequency will cause a constant flux to appear at the recording gap, which records a

* Revised manuscript received April 22, 1960. Presented in part October 7, 1959 at the Eleventh Annual Convention of the Audio Engineering Society, New York.

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1 Frequency-dependent losses will be called simply "frequency-losses," and are those losses which vary with frequency for a constant recorded wavelength; they are electrical effects such as amplifier response, self-resonance of head windings, and eddy current losses in cores. Wavelength-dependent losses will be called simply "wavelength-losses," and are those losses which vary with the recorded wavelength on the tape, for a constant frequency; they are effects related to the tape velocity and the mechanical dimensions of the heads and the tape, such as reproduce gap loss, record process resolution, tape thickness loss, and head-to-tape spacing loss. Recorded wavelength is defined as the velocity of the medium during recording, divided by the recording frequency.

2 J. D. Bick, J. Audio Eng. Soc. 1, 4-9 (1953).

3 F. G. Lennert, Trans. IRE-PGA AU-1, 20-25 (1953).

4 NARTB Recording and Reproducing Standards, Sec. 2, Magnetic Recording (June, 1953). CCIR, Recommendation No. 135, Standards of Sound Recording for the International Exchange of Programmes, single track recording on magnetic tape. Documents of the VIIth Plenary Assembly, London, 1953, Vol. 1, pp. 170-183. The "short-gap" method is used in this paper. The reproduce response discussed here for 7½ ips is an Ampex standard and has been proposed as an NAB standard, but it has not as yet been accepted by NAB.

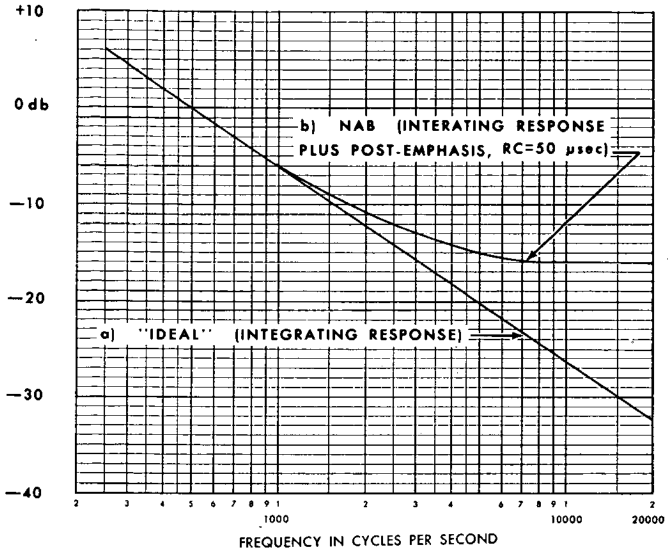

FIG. 1. Reproduce amplifier frequency response, measured at line output terminals, from constant input voltage applied to input terminals in place of reproduce head. Ampex Model 351.

constant flux on the tape. The constant flux from the tape produces a constant flux in reproduce. Since the reproduce heads in common use are of the differentiating type,[5] the reproduce head output must be passed through an integrating amplifier.[6] Then the output voltage from the head and integrating amplifier will be constant from a constant flux on the tape.

Since it is possible to measure reproduce frequency losses, and to measure the reproduce gap length and calculate from this the reproduce gap loss, the practical basis of measurements by the ideal method is the use of a reproduce head with frequency-loss and gap length loss which are either negligible or compensated. Except for reproduce gap loss, all wavelength-losses in reproduce, record, and the tape itself are arbitrarily assigned to, and compensated for, in the recording system, so that reproduce is uniform for all recordings. Since ideal record response is defined as the overall response corrected for frequency-losses, it is in fact the same thing as "total wavelength-losses, less reproduce gap loss." If the reproduce gap loss is negligible, ideal and wavelength responses are identical. The ideal concept is retained here due to its use in the NAB and CCIR standards.

The assumption that all wavelength-losses may be assigned to the record process is a practical necessity for two reasons: First, for standardization, the practical user only cares that all tapes reproduce "flat" on his system—he does not care how they got that way. Second, no method of measurement has yet been devised which will accurately separate the wavelength-losses into their record and reproduce components. The validity of this assumption is an entirely separate question, of interest only for analytical study, and will be briefly treated separately at the end of this paper.

Although several important low frequency/long wavelength effects do exist, they will not be considered in this paper; therefore, all data are discontinued at 250 cps.

A. Reproduce System Response

The reproduce system includes the reproduce amplifier and the reproduce head. It is assumed that no reproduce losses are attributable to the tape.

1. *Reproduce Amplifier Response*

The reproduce amplifier must be able to produce either of two frequency characteristics. The first will be called "ideal" response, and is that of an integrating amplifier (response falling 6 db/octave). The second, NAB response, is that of the previously mentioned integrating amplifier, modified by a rising frequency response characteristic of an *RC* circuit having a time constant of 50 μsec (3 db point at 3180 cps) plus any correction necessary for the frequency response of the reproduce head.

In order to demonstrate these responses, an Ampex Model 351 magnetic recorder was used. The high-frequency post-emphasis resistor (R31) was shorted to produce the ideal amplifier response, as shown in Fig. 1, curve *a*.

The NAB post-emphasis (to be added to the integrating response) is shown in Fig. 2, and the total NAB reproduce amplifier response is shown in Fig. 1, curve *b*. (This does not include any correction which may be necessary for the head response.) The NAB response was verified by making an inverse network, whose response, plus the NAB response, should be flat. Amplifier responses are in each case correct within the measuring error (about ±¼ db).

2. *Reproduce Head Response*

The reproduce head response deviations from ideal may be divided into frequency and wavelength-losses.

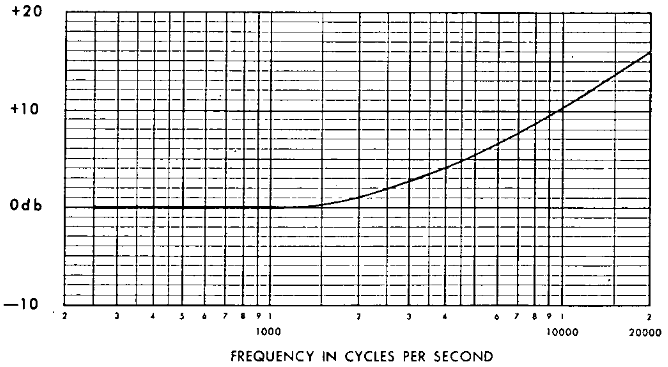

FIG. 2. NAB post-emphasis for 15-ips magnetic recording. *RC* = 50 μsec (+3 db at 3180 cps).

[5] A differentiating head is one which is sensitive to the rate of change of flux, so that an ideal reproduce head would have an output directly proportional to the frequency, which is to say rising at 6 db/octave.

[6] An integrating amplifier is one whose gain is inversely proportional to frequency, which is to say falling at 6 db/octave.

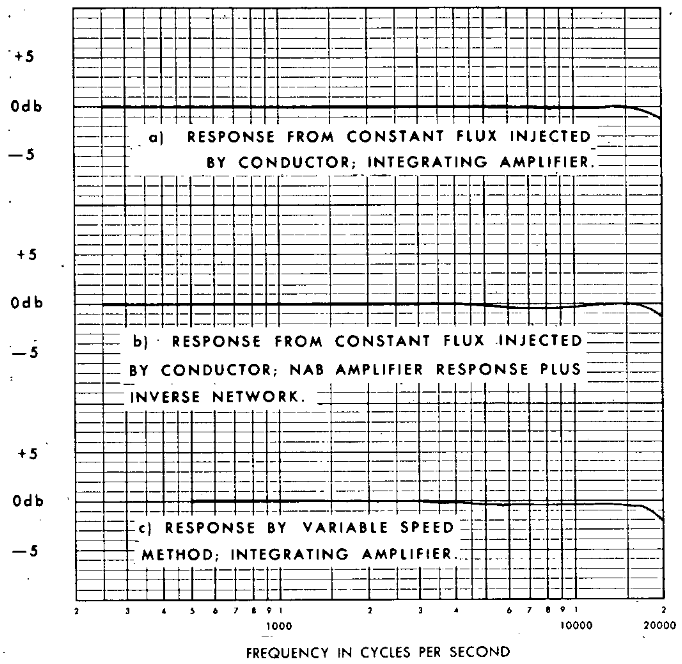

FIG. 3. Reproduce head frequency response, by flux injection (conductor) and variable speed methods. Ampex Model 351, ¼-in. full-track head.

a. Frequency Response of the Reproduce Head. Frequency response of the reproduce head may be measured by either of several methods.[2,4] The methods to be used here will be the "conductor in front of head" (flux injection) and the "variable speed." Figure 3, curves *a* and *b*, shows the results of the conductor method. A piece of No. 35 wire was held in place at the gap using a simple jig (even pressure-sensitive tape could be used). Constant current vs frequency was fed through the conductor, and the response measured, first with the amplifier set to the ideal (integrating) response, giving Fig. 3, curve *a*; then with the amplifier set to NAB response, using the inverse network, giving curve *b*. These agree within ¼ db, and show the response to be flat within ½ db to 15 kc, falling 1½ db at 20 kc.

This electrical measurement of the reproduce head frequency response characteristic may be verified by the variable speed method. The principle is that for a given recording of a sine wave, the frequency of the sine wave during reproduction is proportional to the speed of the tape in reproduction. Since an identical sine wave recording is used to produce various frequencies in reproduce, any variations in output vs frequency must be due to the frequency response of the reproducing system.

The magnetic recorder used in this paper has a two-speed drive system in 2:1 speed ratios, and it is possible to do the calibration in a succession of 2:1 steps. The practical difficulty is that the errors in measurement are cumulative. Therefore, the variable speed was accomplished by placing the machine in "Fast Forward" mode and using a cloth friction pad at the reel idler to manually control the speed; frequency was read on a frequency counter (Hewlett-Packard Model 521C). Speed can be maintained within 10% of the desired value by this means. (This is adequate since the response is such a gradual function of frequency in this measurement.)

Figure 3, curve *c*, shows the variable speed frequency calibration of the head and integrating amplifier for ideal reproduce response. The correlation with the conductor method is ½ db maximum deviation. The response is seen to be +0, −½ db from 250 cps to 16 kc; this is sufficiently small that no correction will be made to the NAB response (50 μsec post-emphasis).

b. Wavelength Response of the Reproduce Head. The only wavelength effects which are normally attributed to the reproduce process are the gap length effect at short wavelengths and the "head bump" ("contour effect") and fringing at long wavelengths (low frequencies).

The head bump is a phenomenon occurring when the recorded wavelength and the length of the magnetic core structure of the reproduce head are of approximately the same size. The data in this paper are discontinued at 250 cps; the head bump does not enter at the shorter wavelengths used here.

"Fringing" occurs when a recorded track is reproduced by a head narrower than the width of the recorded track. A rise in response will occur at long wavelengths, the amount depending on the ratio of recorded track width to the reproduced track width. The frequency at which the rise begins depends on the recorded wavelength and the width of the particular reproduce head. This effect does not occur in the present data as the recorded and reproduced track widths are identical. The effect will be several db if a full-track tape is reproduced by a half-track stereo, or "four track" (43-mil wide) head. (A full-track 15-ips standard tape reproduced with a 43-mil wide reproduce head will show a 7-db rise at 50 cps.)

The gap length of the reproduce head in Ampex Professional Audio Products recorders is 180 to 200 μin. For this gap length, the loss is negligible (½ db or less) at or below 15 kc at 15 ips (1-mil wavelength). At 7½ ips, the gap loss is 1 db at 11 kc, 2 db at 15 kc.[7] This loss should ideally be made up in the reproduce amplifier; in practice, the deviation is less than either the equipment specification (4 db at 15 kc) or the NAB tolerance and is left uncorrected in reproduce.

We see from this discussion that both the frequency response and the wavelength response of the reproduce head and amplifier combination are essentially ideal without any correction.

B. Record System Response

The record system includes the record amplifier, the

[7] W. K. Westmijze, Philips Research Repts. 8, 25 (1953), Reprint R213.

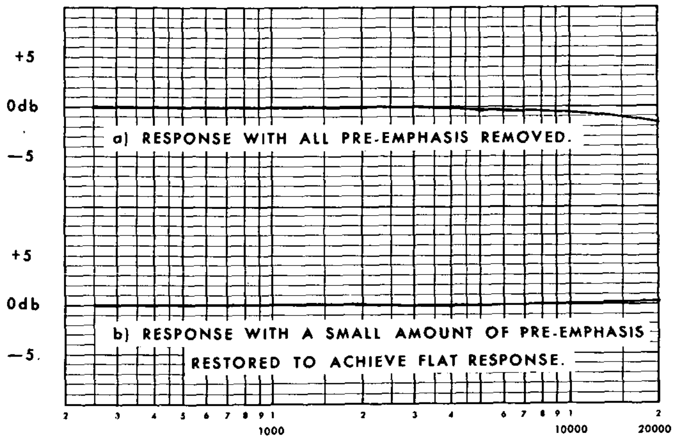

FIG. 4. Record amplifier frequency response. Current through record head, from constant voltage applied to "Unbalanced Bridge" input terminals. Ampex Model 351, ¼-in full-track head.

record head, and the tape. All wavelength losses are assumed to be associated with the record head and the tape, and wavelength losses of the record head and the tape are not separated

1. Record Amplifier Response

The record amplifier is required to produce either of two characteristics. The first is ideal response: constant input voltage to the recording amplifier produces a constant current through the record head. The second is "equalized for NAB" response; the response of the ideal amplifier plus whatever characteristic is necessary to produce flat over-all response with the NAB characteristic in reproduce. (This cannot be called "NAB record response," since it will depend on the tape and the bias current used, and therefore is in no way a *standard* response.)

The current through the record head from constant input voltage to the record amplifier (Ampex Model 351) is shown in Fig. 4, curve *a*. This was produced by removing the high-frequency pre-emphasis circuits; the response is +0, −½ db to 11 kc; −1 db at 17 kc; −1½ db at 20 kc. The record pre-emphasis normally also compensates for this small deviation from constant current response; therefore, the amplifier response was compensated by re-introducing a very small amount of the record pre-emphasis, to give a head current which is plus or minus ¼ db, 250 cps to 20 kc, as shown in Fig. 4, curve *b*.

The equalized response for NAB cannot, of course, be determined until the record system losses are determined.

2. Response of the Record Head Plus Tape

The deviations from ideal of the record head plus tape may be divided into frequency-losses and wavelength-losses.

a. Frequency Response. (*i*) *Frequency response of the record head.* The frequency response of the record head may be measured by means similar to those used to measure the reproduce head response: the "conductor in front of the head" (flux sampling) method, and the variable speed method.

Measurement was first done by the conductor method. A piece of No. 35 wire was formed into a hairpin loop, and held over the record gap with pressure-sensitive tape. (The Ampex record heads use a gap shim of 1-mil copper, which modifies the field configuration at the gap area. If a single conductor is used, as in reproduce, the gross field is measured, which has a slightly different frequency response from that just at the gap. Therefore, the hairpin loop was used to measure only the field in the gap region, where the recording is actually done.) The loop (similarly to the reproduce head) is sensitive to the rate-of-change of the flux, and its output voltage must be integrated to give flat output. A simple *RC* integrating circuit was used. (Low output voltage from the hairpin loop prevented measurements below 4 kc with the equipment available.)

Figure 5 shows the results of the measurement by the conductor method described above. Response is seen to be down 0.2 db at 10 kc, 0.3 db at 20 kc, which is essentially flat.

Variable speed record response measurement is theoretically possible but is complicated by the fact that small deviations in response appear to occur if the *bias* wavelength is not held constant. If the measurement is done in octave (2:1 speed) steps, this small error is cumulative and destroys the accuracy of the measurement. The frequency response measurements may be indirectly verified, however, by comparing the calculated wavelength response for one speed (over-all frequency response plus correction for measured frequency response loss, then converted to a wavelength scale) with the same data for another speed. The difference in responses represents the error in measuring the frequency loss. This verification can be seen in Fig. 7, under the discussion of wavelength response of the over-all system. The difference was found to be ½ db, which is within measuring error.

(*ii*) *Frequency response of the tape.* The frequency response of the tape itself has not been accurately determined. It appears that there is no frequency loss from the tape itself even into the megacycle region.

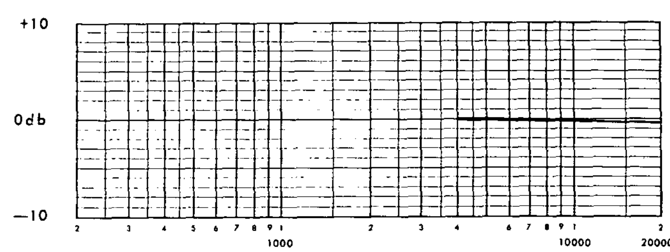

FIG. 5. Record head frequency response. Integrated output of hairpin loop over record gap, from constant current through record head. Ampex Model 351, ¼-in. full-track head.

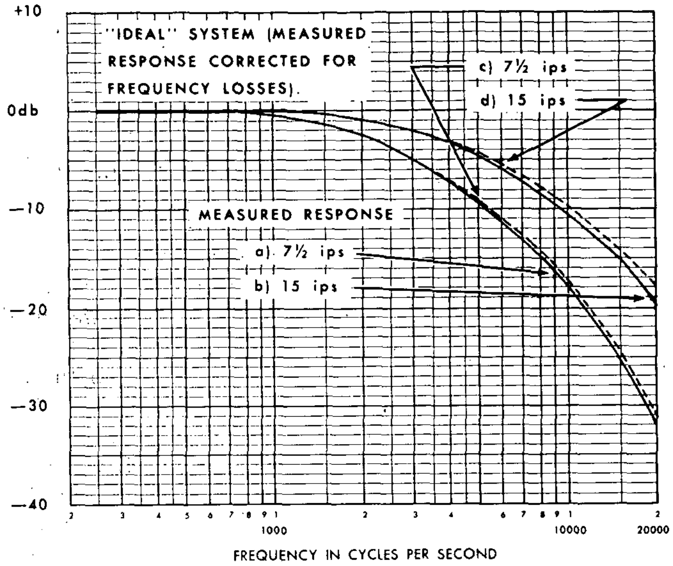

FIG. 6. Measured and ideal record/reproduce system frequency response. Output of reproduce head plus integrating amplifier, with constant input voltage applied to "Unbalanced Bridge" input. Ampex record adjusting tape, peak bias at 15-mil recorded wavelength. Ampex Model 351, ¼-in. full-track heads.

b. Wavelength Response of the Record Head Plus Tape. Since wavelength-losses except reproduce gap loss are arbitrarily assigned to the record head and the tape, the wavelength response of the record system is a function of the record head design, the tape, and the bias current used. These three parameters are closely linked together, but the effects have not yet been thoroughly examined; some data on the variation in response of various tapes and on the effect of the amount of bias current have been published.[8]

For the present work, a standard Ampex record head was used—a ring head with a 1-mil copper gap spacer.[9] The tape was a record adjusting tape supplied by Orr Industries Company of Ampex Corporation. The response of this tape is similar to that which will be found with current professional-type recording tapes, if their surface is made smooth. (Orr tapes are made smooth in manufacture by the Ferrosheen process.) Bias point was "long wavelength peak bias," defined as that bias current which produces the greatest remanent signal on the tape when recording a 15-mil wavelength signal (1000 cps at 15 ips, or 500 cps at 7½ ips) at a level 15 db or more below saturation output.[10]

Figure 6, curves *a* and *b*, shows the measured response of the record/reproduce system. The reproduce gap loss was shown previously to be small with the head used, and no correction will be made. The various frequency-losses were also shown to be small; however, correction will be made for this small deviation. When this is done (Fig. 6, curves *c* and *d*), we have the frequency response of the ideal system. The data of Fig. 6, curves *c* and *d*, can be redrawn on a wavelength scale, resulting in Fig. 7, the wavelength response of the record head plus tape, or ideal system. This shows the losses (for wavelengths between 0.37 and 60 mils, at any speed) which must be compensated by the equalization in the recorder. It also shows that almost all of the losses of the system are wavelength-losses; reproduce gap loss and the frequency-losses are negligible for ordinary purposes. The possible causes for these wavelength-losses will be discussed separately below.

C. Equalization Design

The ideal (wavelength) response data derived here may now be used to calculate the pre-emphasis required using the standard post-emphasis. Then these newly calculated pre-emphases will be compared with those derived previously.

1. *Pre-Emphasis Design from the Present Data*

Having no frequency-losses or reproduce gap length loss to be compensated, in this case, design of pre-emphasis requires only knowledge of the desired post-emphasis and the ideal (wavelength) losses. In general, this could be done for any speed such that the frequencies and wavelengths fell within the range which had been measured.

To determine the equalization necessary for NAB response, we need merely apply the NAB reproduce post-emphasis (Fig. 2) to the ideal system response converted to the appropriate speed (Fig. 7, or directly to Fig. 6 for 7½ and 15 ips). Then the difference between these re-

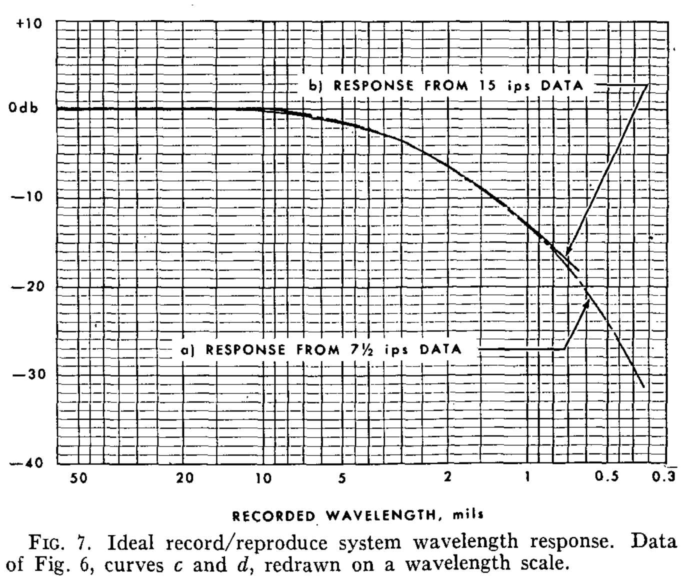

FIG. 7. Ideal record/reproduce system wavelength response. Data of Fig. 6, curves *c* and *d*, redrawn on a wavelength scale.

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[8] R. J. Tinkham, J. Audio Eng. Soc. 5, 99-103 (1957).

[9] Unlike the reproduce head, record resolution is not dependent only on the gap length. For long wavelength peak bias current with the present oxide thickness, the optimum record gap length is in the region of ½ to 1 mil. A shorter gap under these conditions does not improve record resolution—in fact, it is worse. There may, however, be some basically different configuration of record head which *would* improve record resolution.

[10] Since the output vs bias current curve is very broad near "peak" bias current, the adjustment is simplified by finding the bias currents for an output ½ db less than maximum; first by over-biasing, and then by under-biasing. The peak bias is the average of the over- and under-bias currents.

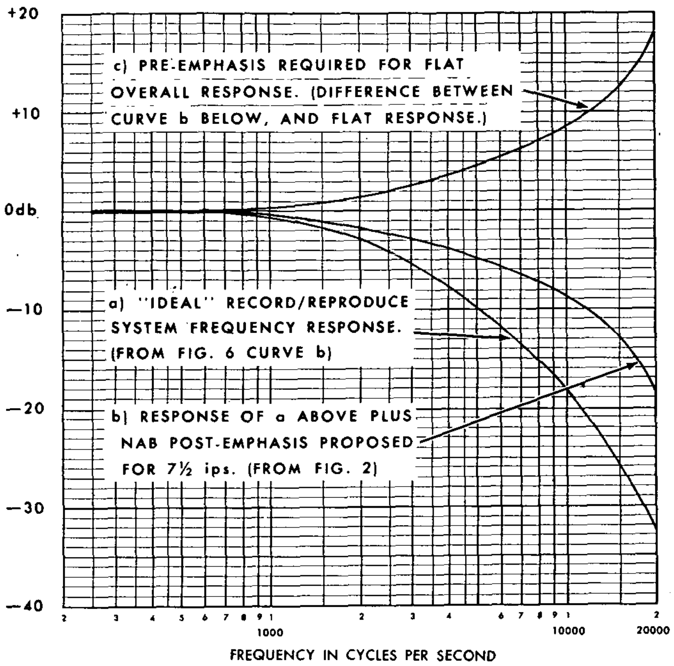

FIG. 8. Equalization calculation, for 7½-ips proposed NAB response. System and conditions as described in Fig. 6.

sponses and a flat response is the amount of record pre-emphasis necessary.

Figures 8 and 9 show (for 7½ and 15 ips, respectively) the equalization calculation: curve *a* is the ideal over-all response; curve *b* is the ideal response plus the NAB post-emphasis; curve *c* (the difference between curve *b* and flat response) is the required pre-emphasis necessary for flat reproduction on an NAB equalized reproduce system.

2. *Comparison with Previously Determined Pre-Emphasis*

Does the present calculation of pre-emphasis agree with that used previously by Ampex?

The heads originally used for determining the Ampex standard reproduce alignment tape had been specially constructed to be ideal and the standard alignment tape was in fact standard. The reproduce response of Ampex re-

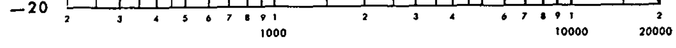

FIG. 9. Equalization calculation, for 15-ips NAB response. System and conditions as described in Fig. 6.

corders has always been designed for flat reproduction of the standard tape to maintain consistency with the NAB standard. Therefore, the Ampex reproduce systems have always followed the NAB ideal standard.

Figure 10 compares the old record pre-emphasis response used by Ampex (curves *a* and *c*) to the present responses (curves *b* and *d*) for 7½ ips (curves *a* and *b*) and for 15 ips (curves *c* and *d*). A large difference is seen—why?

The major change in response has come from changes in the physical and magnetic construction of the tape itself. One change is in surface finish of the tape. The oxide coating surface of all known magnetic tape is rough, as coated, causing short wavelength (high-frequency) response loss, due to lack of intimate contact between the tape and the heads. When the tape is played repeatedly, the surface becomes smooth through mechanical polishing. Figure 11

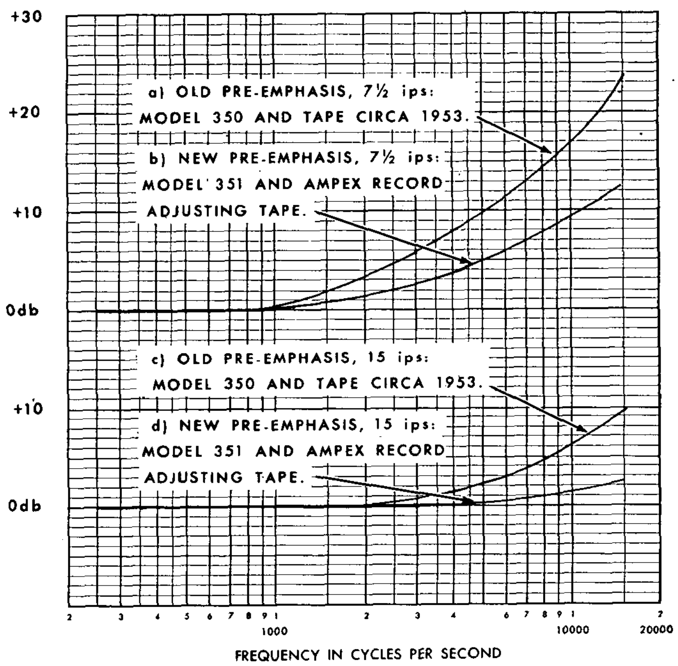

FIG. 10. Comparison of pre-emphases, 7½ and 15 ips. Curves *a* and *c* from Ampex Model 350 Instruction Manual, Fig. 7, "Record Amplifier Response"; 6/1/53. Curves *b* and *d*, from Ampex Model 351 Instruction Manual TM 2002, facing p. 7-30, "Record Amplifier Response."

shows the effect of polishing a roll of professional-grade tape, made by a major manufacturer. This is an extreme case measured by the author, showing that lack of polish caused a response loss of 3 db at 1-mil recorded wavelength (15 kc, 15 ips) and 6 db at ½ mil (15 kc, 7½ ips). The effect is more typically 1 to 2 db at 1 mil, and 3 to 4 db at ½ mil; this is still an appreciable loss.

A tape with a smooth surface has the main advantage that its response is stable from the very first play. The tape available when the original pre-emphases were determined had a rather rough surface, but tapes with smooth surfaces are now available commercially from Orr Industries Com-

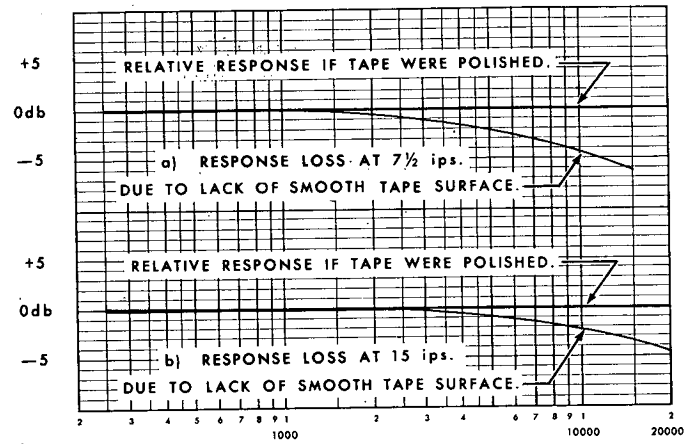

FIG. 11. Relative loss of frequency response due to lack of smooth tape surface. (Difference between response as manufactured and response after mechanical polishing by running the oxide surfaces against each other.)

pany of Ampex Corporation, (whose tapes are conditioned to be smooth by the Ferro-sheen process) and from others. Therefore, the new pre-emphasis curves were determined using smooth tapes, which accounts for part of the reduction in pre-emphasis.

Other changes in tape construction, and some small changes in record head manufacturing technique, account for the remaining difference.

The newly determined record pre-emphasis responses are now being used to design and adjust production recorders at Ampex. They have several advantages over the older responses.

1. The older responses are not appropriate to modern smooth-surfaced tapes. Their use gives a rising response at higher frequencies.

2. The new responses reduce the chance of high-frequency overload, as can be seen from Fig. 10. This is especially significant at the slower tape speeds, where high-frequency overload has sometimes been a problem.

3. The new responses are very close to simple 6 db/octave slopes, and the equalizer need only be a simple *RC* network. (The older responses rose more steeply, and required an *LC* network in addition to the *RC*.)

III. A BRIEF DISCUSSION OF WAVELENGTH-LOSSES

Since the losses shown in Fig. 6 (or Fig. 7) are considerable, we would like to know their cause, and whether they could be eliminated. We would also like to check the validity of the original assumption of the ideal method that all wavelength-losses (except reproduce gap loss) are attributable to the record process. Many studies of this question have been made, and they have been reviewed and discussed by Daniel *et al.*[11]

Let us start with Fig. 12, curve *a* (taken from Fig. 7), showing the wavelength response. A common misconception is that the reproduce gap loss is a large contributor. We have shown above that the gap loss is small; Fig. 12, curve *b*, shows wavelength response corrected for the small gap loss.

A large wavelength-loss which is reasonably proven is the "thickness loss" described by Wallace.[12] He shows that a loss of response occurs in the reproduce process at shorter wavelengths when the tape is *separated* from the reproduce head. For analysis, let us think of the oxide coating as though it were very many thin layers instead of one thick layer, and assume the oxide to be magnetized uniformly through its thickness (i.e., each hypothetical thin layer magnetized the same as all other layers, with no separation loss in recording). Then apply the separation loss to each hypothetical thin layer, and sum the responses from the

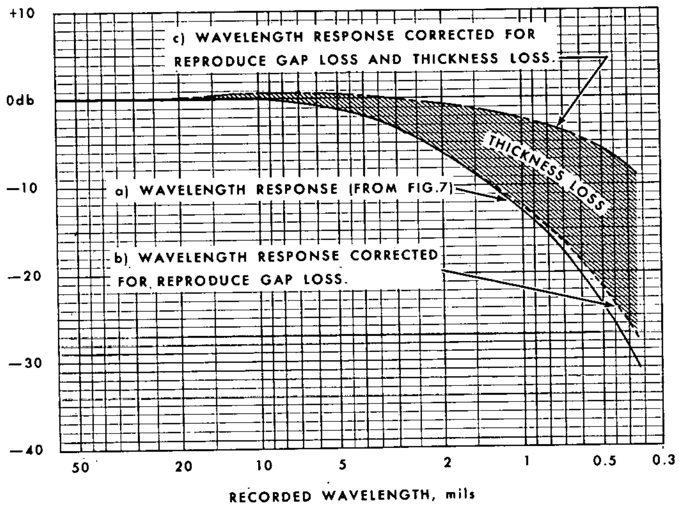

FIG. 12. Wavelength response corrected for reproduce gap loss and thickness loss.

many thin layers. Wallace[12] shows that when the oxide thickness is comparable with the recorded wavelength, only the surface layer of oxide contributes useful flux. As the wavelength becomes longer, more and more of the oxide thickness contributes useful flux, until at a wavelength approximately 50 times the oxide thickness the full thickness of the oxide contributes useful flux. The effect of this loss is shown in Fig. 12, curve *c*, where the correction has been made for the tape thickness used (approximately ½ mil). The thickness loss is seen to account for a large portion of the losses in this wavelength range. To the extent that we are correct in assuming uniform magnetization it is a *reproduce* loss, but since it depends on a property of the tape itself, it is convenient to consider it with the other "record head and tape" losses.

What other effects may occur to account for the remain-

[11] E. D. Daniel, P. E. Axon, and W. T. Frost, J. Audio Eng. Soc. **5**, 42-52 (1957).

[12] R. L. Wallace, Jr., Bell System Tech J. **30**, 1145-73 (1951).

ing losses? Wallace[12] also discusses "separation loss," *per se*. We feel that this effect is small, except for tapes with rough surfaces, as shown previously in Fig. 11. Another frequently mentioned loss is "self-demagnetization loss"; Daniel[11,13] has shown that this loss is small at these wavelengths.

The remainder of the loss is probably associated with the nonuniformity of the recording field, and the rate of extinction of the recording field,[11] which are problems inherent in a simple ring-type recording head when used with oxide coatings whose thickness is comparable to the shortest recorded wavelength. The assumption in the thickness loss calculation that the oxide is uniformly magnetized is not fully justified, and the thickness loss that Wallace shows may overestimate the loss from this cause. This would mean that the record head loss is actually greater than shown in Fig. 12, curve *c*.

The wavelength-losses are seen to be largely due to thickness loss and to the relative inefficiency with which a simple ring-type recording head operates at short wavelengths. These losses are, as was originally assumed, all functions of the tape and the record head; they cannot be eliminated with techniques available at the present state of the art.

IV. SUMMARY

We have defined an ideal system in accordance with the NAB and CCIR standards. Measuring techniques are described, and it is shown that means exist for measuring the frequency losses in the record and reproduce heads electrically (i.e., without tape). These measurements agree with those using tape itself. The practical Ampex heads measured were found to be essentially ideal.

Since over-all response depends on the tape, a record adjusting tape was chosen which is representative of present-day commercially available tapes. The over-all ideal response was then determined, and from this the pre-emphases for NAB response were calculated.

It was found that the present work agrees with the previously determined NAB reproduce standard; but that, due to changes in the tape (the use of smooth tape and other tape changes), the present record responses are considerably different from those determined previously. The new responses have been incorporated in Ampex production equipment and have the advantages of being appropriate to the characteristics of present-day tape, of reducing high-frequency overloading effects (especially at lower speeds), and of being more easily realizable responses.

The losses were found to be almost entirely wavelength-losses. These were discussed briefly and found to be inherent in the tape and simple ring-type record head used at the present state of the magnetic recording art.

[13] E. D. Daniel, Proc. Inst. Elec. Engrs. (London) **100**, Pt. III, 168-175 (1953).

ACKNOWLEDGMENTS

The author wishes to thank Walter Selsted, Vice President—Research, for whom much of the original measurement work was done. He also wishes to thank William Pottberg for construction of special heads, and R. Z. Langevin and R. K. Morrison for verifying many of the response measurements.

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