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EQUALIZATION OF MAGNETIC TAPE RECORDERS FOR AUDIO AND INSTRUMENTATION APPLICATIONS*

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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 octabe 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.

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 length of the playback gap usually determines the upper frequency limit of the recorder. When the effective length 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" is reproduced with a head incorporating a gap length of .00025". This would be the case at 15,000 cycles and a tape speed of $7\frac{1}{2}$ 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" 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.

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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" to .002" 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 a 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 effect 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 the 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 of a known equivalent.

Let us now consider the problems of equalizing the audio recorder. 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 noise exists. The record equalization can then be altered to compliment the playback characteristic. These measurements can be weighed 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 compliment 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 7½ 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 Fig. 1 and the playback curves indicated in Fig. 2 were established in conjunction with Ampex heads and M.M.M. type 111 tape, construction 5 RBA. These heads display negligable magnetic and electrical losses in the pass band. The playback head gap length is .00025". The bias was adjusted to the point of maximum record efficiency while recording a .015" wave length (1 Kc. at 15 inches per second). The overall response achievable under these conditions is as follows:

At	30"/Sec.	±2Db, 50 to 15,000 cycles
	15"/Sec.	±2Db, 30 to 15,000 cycles
	7½"/Sec.	±2Db, 40 to 15,000 cycles
	3¾"/Sec.	±2Db, 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.

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 2½ Db. boost in the record amplifier at 50 cycles. A resistor of such value to effect 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 7½ inches. The 3-3/4 inch curve is accomplished by a relatively larger resistor effecting a time constant of 200 microseconds. The 15" per second record curve is such that possibility of overload does not exist for the most sever audio requirements. At 7½" per second the record curve is considerably steeper than the 15" 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 7½" which, of course, would not occur at the 15" 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 7½" and 15" speeds. Slightly wider specifications are advertised to allow manufacturing tolerance and insure the average machine being well within its specifications.

The background noise on a high quality professional recorder, using the tape characteristic described, ranges from 60 to 64 Db. below 3% harmonic distortion. This is true at 7½", 15", and 30" per second. The noise at 3-3/4" per second is approximately 10 Db. higher. The point of approximately 1% harmonic distortion has been found most desirable for operating level and is approximately 6 Db. below the 3% distortion point.

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.

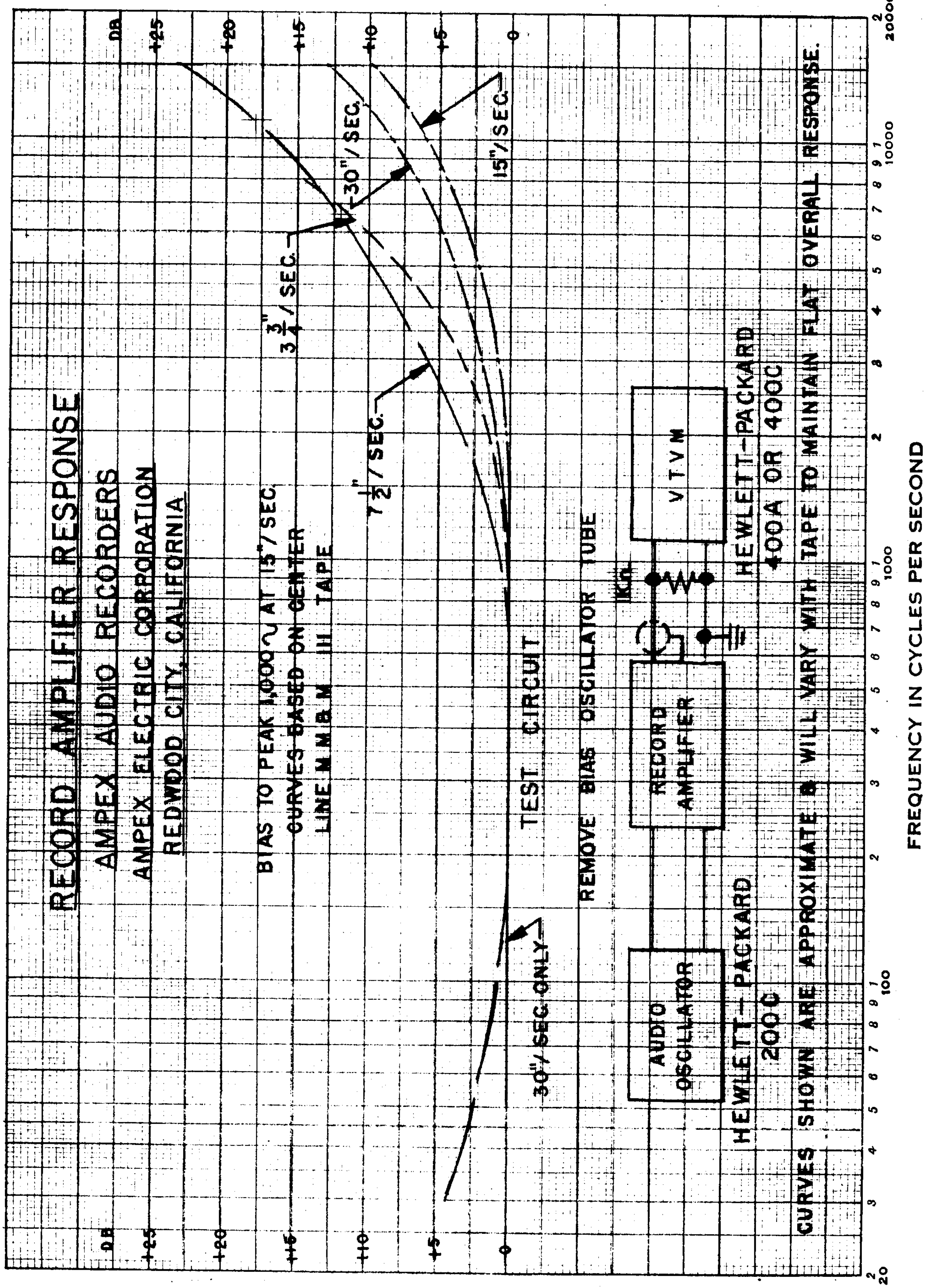
RECORD AMPLIFIER RESPONSE
AMPEX AUDIO RECORDERS
AMPEX ELECTRIC CORPORATION
REDWOOD CITY, CALIFORNIA
BIAS TO PEAK 1,000 ~ AT 15"/SEC.
CURVES BASED ON CENTER
LINE M M B M 111 TAPE
$3\frac{3}{4}$"/SEC.
$7\frac{1}{2}$"/SEC.
30"/SEC.
15"/SEC.
30"/SEC ONLY
TEST CIRCUIT
REMOVE BIAS OSCILLATOR TUBE
1KΩ
AUDIO OSCILLATOR
RECORD AMPLIFIER
VTVM
HEWLETT-PACKARD
200C
HEWLETT-PACKARD
400A OR 400C
CURVES SHOWN ARE APPROXIMATE & WILL VARY WITH TAPE TO MAINTAIN FLAT OVERALL RESPONSE.
DB
+25
+20
+15
+10
+5
0
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Fig. 1

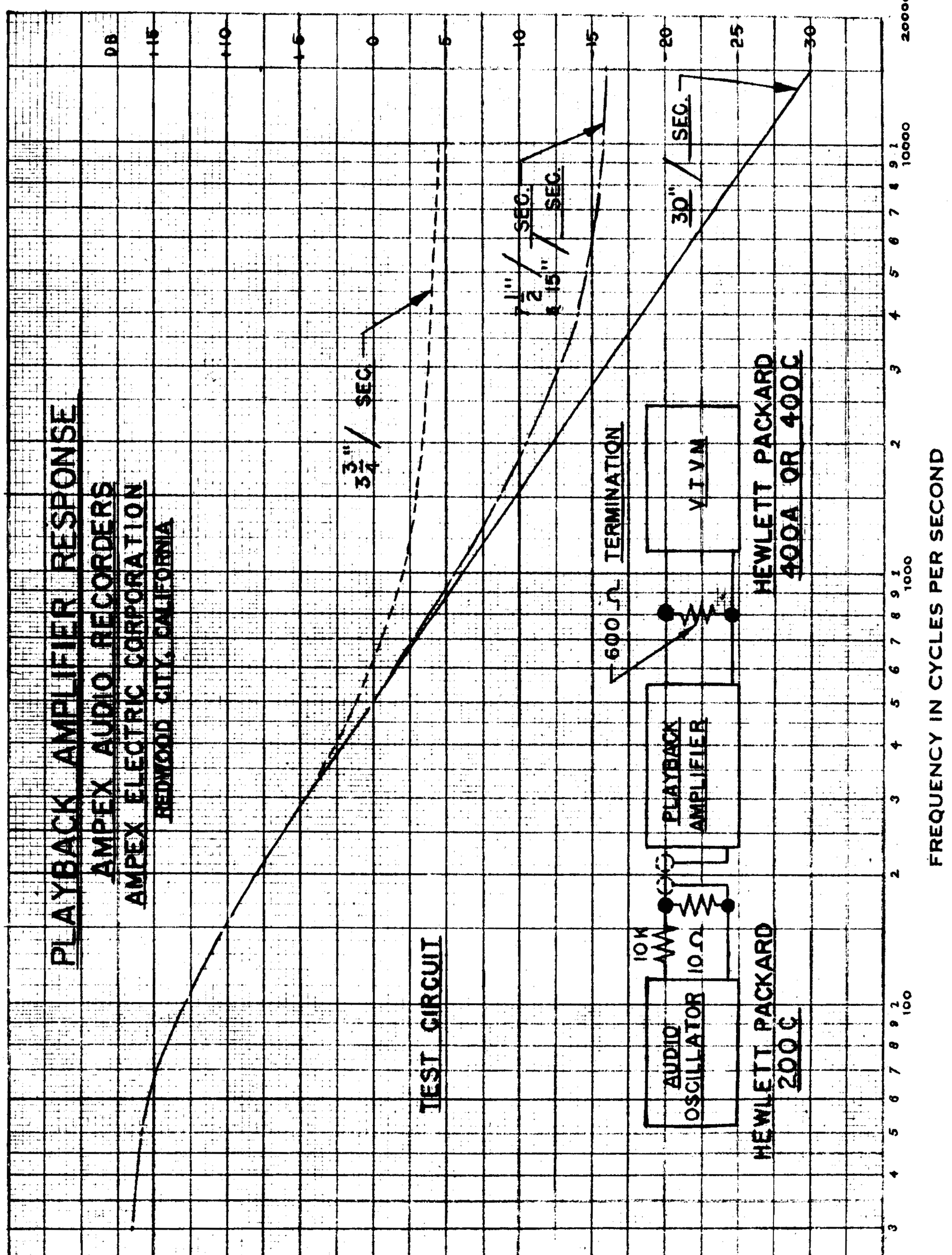
PLAYBACK AMPLIFIER RESPONSE
AMPEX AUDIO RECORDERS
AMPEX ELECTRIC CORPORATION
REDWOOD CITY, CALIFORNIA
DB
TEST CIRCUIT
AUDIO OSCILLATOR
HEWLETT PACKARD 200 C
10K
10 Ω
PLAYBACK AMPLIFIER
600 Ω TERMINATION
V T V M
HEWLETT PACKARD 400A OR 400C
FREQUENCY IN CYCLES PER SECOND

Fig. 2