

THE USE OF FLUX LOOPS FOR CALIBRATION OF MAGNETIC REPRODUCERS

BY

Alastair M. Heaslett
Ampex Corporation

INTRODUCTION

In any system involving magnetic tape and ring core magnetic heads, a basic need exists for standardization of recorded flux versus frequency characteristics to permit interchange of recorded material. Thus, when setting up a recording and reproducing system, it is necessary to perform a series of measurements and adjustments to align the system.

The result of this alignment must be a system which when reproducing other tapes made to the same standard, or when recording tapes to this standard, will reproduce the recording with an appropriately flat frequency response, and conversely produce a recording, which when reproduced ideally, is also flat.

From a practical standpoint, it is fortunate that the standards established for recorded tape interchange in audio effectively demand a specific relationship between flux and frequency on the recorded material.

It is outside the scope of this paper to discuss the reasons why any one standard is as it is, except to comment that in some instances standards laid down many years ago are becoming slightly outmoded and in some senses restrictive.

SYSTEM STANDARDIZATION

In all the currently used audio standards for magnetic tape systems, the equalization required to correct for tape (and head losses) is divided into two parts, post and preemphasis.

This is just an elegant way of saying that some of the losses are corrected during recording and some during playback. The division of the quantities of equalization used between recording and playback should not be an arbitrary one, basically it depends on whether you want good high level high frequency response, or good high frequency noise. The two are unfortunately, in the limit, exclusive.

The recording standard will always specify how the remanent flux versus frequency recorded on the recorded tape should be.

Thus, if such a tape were reproduced by an ideal reproducer a flat system output, voltage (or current), versus frequency would result.

Today anyone can purchase such a tape, play it on their reproducer and adjust that reproducer for a flat response.

Subsequently, when recording, the recording equalization and bias is adjusted so that the output from the reproducer is again flat.

This process ensures that the flux/frequency response of the recorded tape is identical to the standard. (See Figure 1)

Clearly, a standard tape is a very important link in the system since it duplicates the "ideal" tape and hence verifies the reproducing systems right from the reproduce head gap to the output terminals.

However, there may be some times when the standard tape does not give enough information or doesn't supply it for long enough. (As one who has had the privilege of aligning all channels of a 24 channel machine from scratch can attest.)

In addition, there may come a time when, despite your efforts, the reproduce equalization cannot be set correctly. This might indicate a problem with the electronics, or with the head, or with both, or it may be that the alignment tape has come to the end of its useful life or even been damaged. This is where the flux loop appears as a diagnostic aide and useful tool in general maintenance.

THE FLUX LOOP

Essentially a flux loop is a means of generating flux and applying it to a magnetic head in such a way as to induce a field in the magnetic head which closely approximates the field from a moving length of tape. (See Figure 2)

Flux loops take many shapes, but the most common is simply a few turns of fine wire wound closely together on a non-ferrous rectangular former. One straight edge of the winding is brought close to the front gap of the head under test with the length of the coil aligned with the gap. The length of the winding brought against the head should be greater than the track width of the head being checked, it may indeed extend over several tracks simultaneously. The other dimensions of the loop are not overly important except that they should be somewhat longer than the head dimensions.

The principle which makes the loop work is quite simple. If a current is passed through the winding, each wire generates a magnetic field directly proportional to the current. The flux generated is concentric to the wire axis. The field from several wires will add evenly at any given point in space around the bundle of conductors; i.e. the total field produced is virtually multiplied by the number of conductors. This is strictly only true at a point whose distance from the bundle is many times the wire bundle diameter.

The direction of the flux depends upon the direction of current flow in the wires. Thus if sinusoidal current flows in the wires, a sinusoidally varying field will result.

When the coil is brought close to a highly permeable object such as a magnetic reproducing head, some of the flux from the coil will tend to travel in the magnetic head core instead of the air. This flux will thus couple the turns of wire wound on the head cores.

In fact, the flux from the flux loop will be doing exactly what the flux from a piece of tape would do. It is not a very efficient process, but nonetheless, a considerable amount of flux is induced into the head.

Thus, if the current in the loop is held constant and the frequency varied, the full flux field versus frequency response of the magnetic head and reproducing amplifier can be measured.

Note that only those sides of the flux loop parallel to the magnetic head gap can induce flux in the head. (Those not in parallel do induce some because the bundle of conductors is not infinitely thin, nor is the head totally insensitive to flux coming from directions other than perpendicular to its gap line.) However, the remote end of the loop is producing flux in opposition to the end in contact with the head. This is the reason for separating the two by some respectable distance. Otherwise, the remote field will tend to cancel that from the side of the loop closest to the head.

LIMITATIONS

Useful though the flux loop is, it has some fundamental limitations which should be understood.

- a. The flux loop does not show the effect of head gap loss. This, if necessary, must be evaluated separately.
- b. The flux loop does not make any allowance for head to tape separation.
- c. There are slight errors at very high frequencies with multi-turn loops due to skin effect. These errors however are less than 0.1db to at least 20 kHz and are therefore negligible in the audio band.
- d. The flux loop does not give any indication of the long wavelength, "pole contour" ripple which all magnetic reproducing heads are cursed with.

Of the four listed errors the most significant for normal studio tape speeds (15 in/s 7 1/2 in/s) is that due to gap loss. A graph showing gap loss against frequency for typical gaps is shown in Figure 3. for 7 1/2 ins/sec: For 15 ins/s double all the frequencies, for 3.75 in/sec halve all frequencies (and pro rata for other speeds).

NOTE: The actual off tape flux response is obtained by measuring the free field flux response and then correcting this response with the gap loss correction for the head being tested.

PRACTICAL FLUX LOOPS

One of the requirements for making the flux loop useful is a means of keeping the current in the loop constant with frequency. Since the loop is an inductance, its impedance will rise with frequency. However, its impedance up to quite high frequencies is very small, and placing a 600 ohm resistor in series with the coil and connecting the whole thing to an audio oscillator will normally be more than adequate. Obviously, the oscillator must have a constant output with frequency, or must be adjusted to constant amplitude for each frequency output. (See Figure 4)

The current in the loop will stay constant in this case simply because the 600 ohm resistor is many times the impedance of the coil.

A typical multi-turn loop will have from 5 to 15 turns of 40 A.W.G wire. This will give flux levels of around 60 to 180nWb/m when driven with 2V RMS through a 600 ohm resistor. If more turns, or finer wire, are used, the coil impedance, or resistance, may tend to become significant.

Two typical flux loops are shown in Figures 5A & 5B. Figure 5B, known as the "super loop" is large enough to cover all the tracks on a 2" head stack.

A third loop, shown in Figure 6, was made to use on consumer cassette heads when in situ.

If the flux loops illustrated seem a little inelegant, the author has used masking tape and five turns of loose wire in an emergency!

USING THE FLUX LOOP

The flux loop shown in Figure 7 has been clipped to a reproduce head stack. The loop is connected to a standard 600 ohm output impedance audio frequency oscillator. The loop is terminating the oscillator directly and the oscillator has a constant output voltage with frequency.

What now does one expect to see in the way of a frequency response from the reproduce amplifier output terminals?

For initial simplicity let us assume that the gap loss can be ignored, then let us assume that the reproduce amplifier and head are set up exactly to conform to the NAB standard.

Figure 8a shows the required flux/frequency response of the tape (the curve is shown with its ideal asymptotes). This flux/frequency response would produce the head output voltage shown in Figure 8b. This curve shows the characteristic rising response at low frequencies and levels out high frequencies. This is because the head output voltage

is proportional to rate of change of flux. Thus in the frequency range where the flux on the tape has constant amplitude, the head output rises at 6db/octave. When the frequency reaches a point where the flux falls at 6 db/octave on the tape, the head output stays constant.

Now the voltage/frequency response of the reproduce amplifier is normally the inverse of Figure 8b as shown in Figure 8c. The result overall, if the reproduce amplifier truly mirrors the head output, is a flat frequency response.

However, the flux loop will induce a constant flux/frequency in the head; this will thus not produce a flat output response with frequency. Rather, the reproduce amplifier output voltage will rise at 6 db/octave at high frequencies and be flat at medium frequencies, and fall off at 6 db/octave at low frequencies (see Figure 9).

Obviously if the precise curve which ought to be measured is known, and the gap loss is known, or can be estimated, then the reproduce amplifier can be adjusted for minimum departure from the ideal curve. This applies at least at high frequencies; at low frequencies where pole contour effects would be occurring, the reproduce amplifier and head can only be set to the low frequency portions of the curve and the equalization readjusted using an alignment tape, or during overall record reproduce.

The precise curves which should result (which assume no pole contour ripple, no gap loss and no head/tape spacing loss, are shown in Table 1 for all the major equalization standards. Appendix 1 shows how to calculate these curves for equalization standards whose transition frequencies are known.

The most important curves, NAB 50 μ s/3180 μ s, (15 and 7 1/2 in/s).

IEC/CCIR 35 μ s/ ∞ (15 in/s)

IEC/CCR 70 μ s/ ∞ (7 1/2 in/s)

and AES/17.5 μ s/ ∞ (30 ips) are also shown plotted in Figure 10. Note that all the curves have been normalized to the flat midband asymptote.

PRACTICAL MEASUREMENTS

In use, the value obtained from the system must be compared to that from the tables or curves and due allowance made for any significant gap loss.

This process sounds easy enough, and certainly familiarity with the required curve for a particular equalization and speed will make life easier. However, there are two ways to make the assessment of errors much easier. The first, which assumes the use of an AC voltmeter external to the reproduce amplifier, as does the classic method, simply involves placing a network between the amplifier and voltmeter, which provides the inverse of the expected ideal frequency response (Figure 11).

This method works satisfactorily for one channel at a time, but becomes very tedious for more than one channel.

The advantage is that instead of having a rising curve to match, the overall response should appear flat with frequency.

The second method, just as simple, leads itself to multiple channel use and also permits using the internal VU meters on the machine.

Both methods however, can compensate easily only for the high frequency rise. Any low frequency boost, such as is used in the NAB equalization, can only be provided with an active circuit to any degree of accuracy.

Figure 12 shows the basic idea for the second method. The oscillator should have a resistive output impedance. In this case, the oscillator shown has a standard 600 ohms output resistance.

If a capacitor is shunted across the oscillator terminals when the oscillator is also loaded by a flux loop; which we have arranged to look like 600 ohms, then at low frequencies where the impedance of the capacitor is large compared to the 600 ohm source and load, the current in the flux loop will be constant with frequency,

As the frequency is increased, the capacitor impedance eventually provides an alternate path for current and hence the current in the loop is reduced.

In fact the current in the loop will eventually fall at 6 db/octave, in exactly the same way as the flux on a normally recorded tape will fall at 6 db/octave.

Thus at high frequencies at least, with the appropriate capacitor value, the output expected from the reproduce amplifier is constant with frequency. This is a lot easier to see, and any error or deviations from ideal easier to see, than following a rising curve.

The values of capacitor needed for the various equalizations are shown in Table 2, which assumes a true 600 ohm oscillator output resistance and flux loop input resistance. If the oscillator output resistance is not 600 ohms, Appendix 2 shows how to calculate the exact value of capacitor.

However, in practice, the easiest way to check the capacitor value is to monitor the voltage across the flux loop and capacitor.

Set the oscillator frequency to one tenth of the high frequency turnover required (see Table 1 for these frequencies). Adjust the oscillator level to give some convenient reference level and then increase the oscillator frequency to ten times the turnover frequency. The voltage measured should have dropped to one tenth of its reference value, or 20 db down. (Purists will be able to calculate that it should be 20.06 db).

If the attenuation seen is too great, the capacitor is too big; if the attenuation is insufficient, the capacitor is too small.

Intermediate points may be checked, if desired, by referring to Table 1, i.e. at 10 kHz for the NAB 50/3180 μ s equalization, the level in the table is 10.3 db above reference. The meter across the flux loop should thus read 10.3db below the reference.

The ultimate in luxury would be a small switch box with the different capacitors selected with a switch.

Since this process only flattens out the high frequency end of the response for your inspection, the low frequency response will still fall off, ideally as shown in the Table when a low frequency rolloff is called for in the standard.

In a practical situation, the reproduce amplifier and reproduce head will not produce a perfectly flat response. For example, the high frequency resonance of the head may have been deliberately tailored to offset gap loss. The flux looped response will not be subjected to the gap loss and hence the high frequency response may still rise. In some consumer cassette machines, in fact the high frequency response can only be achieved by resonating the head at 14 to 15 kHz to offset the gap loss. Very narrow gaps tend to be costly and also reduce the head efficiency.

Ideally the machine should be set up with a reproduce alignment tape and then the flux response taken. This will give some record of the response of head and amplifier with both test tape and head gap in normal condition. This may then be referred to when either or both are in doubt.

The technique makes preliminary adjustment more accurate, and for multi-channel machines considerably decreases the time required for alignment.

CONCLUSIONS

The technique of using a flux loop can provide considerable reduction of errors due to defective or wornout heads and can provide a reasonable cross check of the useful life of an alignment tape. It cannot provide a substitute for an alignment tape except under very well controlled laboratory conditions where all the errors due to gap loss and head tape contact loss can be accurately determined. This technique is in fact the one most often used to calibrate a reproducing system when making alignment tapes.

It does not show long wavelength "ripples" due to pole contour effects, these can only be seen accurately during an overall record/reproduce response check.

Specific frequencies may, of course, be checked using an accurate Reproduce Test Tape.

The method of "equalizing" the flux loop has been shown to provide easier interpretation of frequency response and is capable of being easily set up to give good accuracy.

A.N.S.I.	0.00	0.00	50.05	0.00	50.05	50.05	100.10	TRANSITION
FREQUENCY	9094.57	4547.28	3183	2273.64	2273.64	1768.39	1326.29	FREQUENCIES HZ
HZ	$\infty/17.5$	$\infty/35$	3180/50	$\infty/70$	3180/70	3180/90	1590/120	TRANS.TIME CONSTANTS μ s
16.	+ .000	+ .000	-10.328	+ .000	-10.328	-10.328	-16.035	
20.	.000	.000	-8.610	.000	-8.610	-8.610	-14.157	
25.	.000	.000	-6.996	.001	-6.996	-6.996	-12.311	
31.5	.000	.000	-5.470	.001	-5.470	-5.469	-10.450	
40.	.000	.000	-4.091	.001	-4.090	-4.090	-8.607	
50.	.000	.001	-3.013	.002	-3.012	-3.011	-6.990	
63.	.000	.001	-2.123	.003	-2.121	-2.119	-5.461	
80.	.000	.001	-1.432	.005	-1.429	-1.426	-4.076	
100.	.001	.002	-.966	.008	-.962	-.957	-2.990	
125.	.001	.003	-.639	.013	-.633	-.624	-2.113	
160.	.001	.005	-.394	.021	-.384	-.370	-1.372	
200.	.002	.008	-.247	.033	-.230	-.209	-.873	
250.	.003	.013	-.144	.052	-.118	-.085	-.494	
315.	.005	.021	-.066	.083	-.026	+.027	-.179	
400.	.008	.033	+.001	.132	+.065	.149	+.114	
500.	.013	.052	.063	.205	.162	.291	.406	
630.	.021	.083	.140	.321	.294	.492	.775	
800.	.033	.132	.249	.507	.490	.792	1.280	
1000.	.052	.205	.398	.768	.757	1.194	1.912	
1250.	.081	.316	.616	1.147	1.140	1.753	2.733	
1600.	.132	.507	.974	1.747	1.743	2.593	3.884	
2000.	.205	.768	1.442	2.489	2.486	3.575	5.140	
2500.	.316	1.147	2.085	3.442	3.440	4.767	6.576	
3150.	.492	1.702	2.964	4.653	4.652	6.203	8.218	
4000.	.768	2.489	4.114	6.123	6.122	7.864	10.039	
5000.	1.147	3.442	5.400	7.661	7.661	9.539	11.820	
6300.	1.702	4.653	6.917	9.384	9.384	11.364	13.721	
8000.	2.489	6.123	8.643	11.265	11.265	13.317	15.726	
10000.	3.442	7.661	10.362	13.084	13.084	15.182	17.623	
12500.	4.608	9.323	12.154	14.945	14.945	17.073	19.534	
16000.	6.123	11.265	14.194	17.035	17.035	19.184	21.659	
20000.	7.662	13.084	16.072	18.942	18.942	21.103	23.587	
25000.	9.323	14.945	17.972	20.860	20.860	23.029	25.518	
31500.	11.139	16.901	19.953	22.854	22.854	25.028	27.521	

OUTPUT OF 'IDEAL' REPRODUCING HEAD
AND REPRODUCE AMPLIFIER WHEN
EQUALIZED AND WITH CONSTANT FLUX
IN THE CORE OF THE REPRODUCE HEAD

TABLE 1

AMPEX
TRAINING
DEPARTMENT
A-0009

TABLE 1A

The time constants shown in the main table are currently being used as follows:

$\infty/17.5\mu s$	30 in/sec. AES
$\infty/35\mu s$	30 and 15 in/sec. IEC and CCIR
3180/50	NAB 15 and 7 1/2 in/sec.
$\infty/70$	7 1/2 in/s IEC/CCIR
3180/70	7 1/2 in/s Din and optional consumer standard IEC/CCIR
3180/90	3 3/4 in/s NAB IEC/CCIR also NAB (1965) 1 7/8 in/s
1590/120	1 7/8 in/sec Phillips compact cassette



TABLE 2

<u>High Frequency Time Constant μs</u>	<u>High Frequency Transition at Hz</u>	<u>Capacitor for 600Ω Source and Load μF</u>	<u>Standard</u>
17.5	9094.6	0.0583	AES 30 in/s
35.0	4547.3	0.117	IEC/CCIR 15 in/s
50.0	3183.1	0.167	NAB 15/7 1/2 in/s
70.0	2273.6	0.233	IEC/CCIR 7 1/2 in/s
90.0	1768.4	0.300	NAB/IEC/CCIR 3 3/4 in/s
120.0	1326.3	0.400	NAB/CCIR 1 7/8 in/s

For 600 ohm source resistance and 600 ohm flux loop.

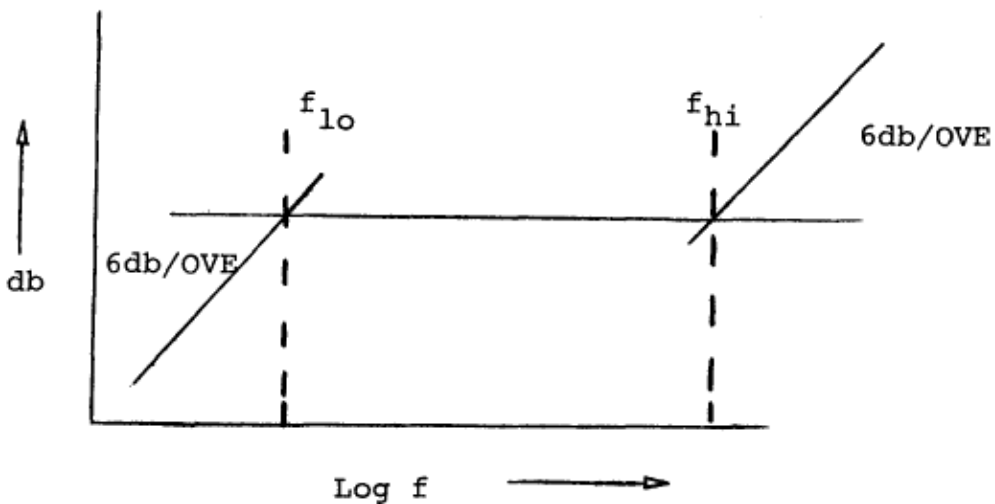
Appendix I

Most standards quote the required transition time constants. The time constant is related to the transition frequency by

$$f = \frac{1}{2 \pi T}$$

eg. a transition time constant of 50µs corresponds to 3183.1 Hz transition frequency.

For a network whose transfer response has Bode asymptotes as shown in Figure 13 with both high and low frequency transitions f_{hi} and f_{lo} .



Then the response at any frequency f , relative to the midband flat asymptote is,

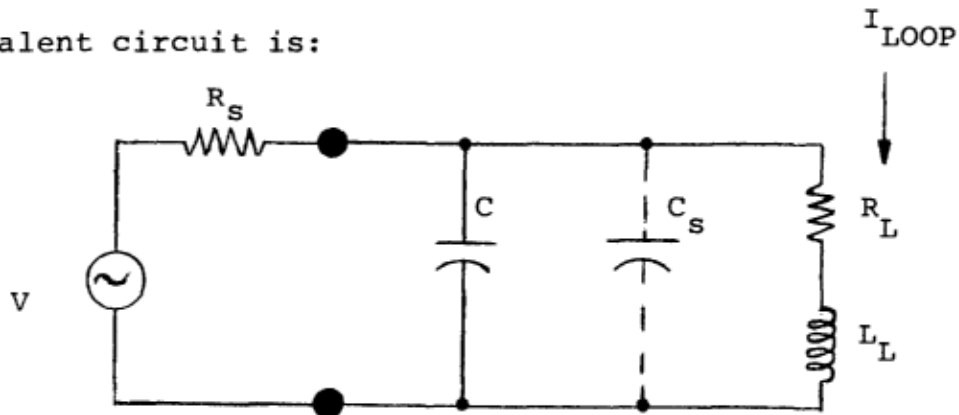
$$G(f) = \frac{f}{f_{hi}} \sqrt{\left[\frac{(f_{hi}^2 + f^2)}{(f_{lo}^2 + f^2)} \right]}$$

Or if the answer is required in db relative to the midband asymptote,

$$G(f)_{db} = 20 \log_{10} \frac{f}{f_{hi}} \sqrt{\left[\frac{(f_{hi}^2 + f^2)}{(f_{lo}^2 + f^2)} \right]} \quad 11$$

Appendix 2

The equivalent circuit is:



where the oscillator is represented by its open circuit voltage V and its output resistance R_S .

The flux loop is shown as a resistance in series with an inductance. The inductive reactance is assumed to be less than 1/50th of the resistance R_L up to the highest frequency to be used.

Typical loops will have inductances less than 20pH which has an impedance of only 12 ohms at 100 kHz and hence may be ignored in the audio band.

In addition, the connecting cable capacitance C_S must be lumped in with the shunt capacitor C .

The frequency response of the simplified network will be:

$$\frac{I_{\text{loop}}}{V_{\text{OSC}}} = \frac{1}{(R_L + R_S) \left(1 + j\omega C \frac{R_L R_S}{R_L + R_S}\right)}$$

or in more practical terms when the value of R_L and in parallel is much smaller than the impedance of the capacitor, the current in the coil will be constant for constant V_{OSC} , and at a frequency given by $1/2\pi C \frac{(R_S R_L)}{R_S + R_L}$ the current will be $1/\sqrt{2}$ of the low frequency value.

This is the network's transition frequency. Thus, the time constant required, i.e. 50 μ s, must be equal to the product of C, which must include cable capacitance, and the value of and RL is parallel.

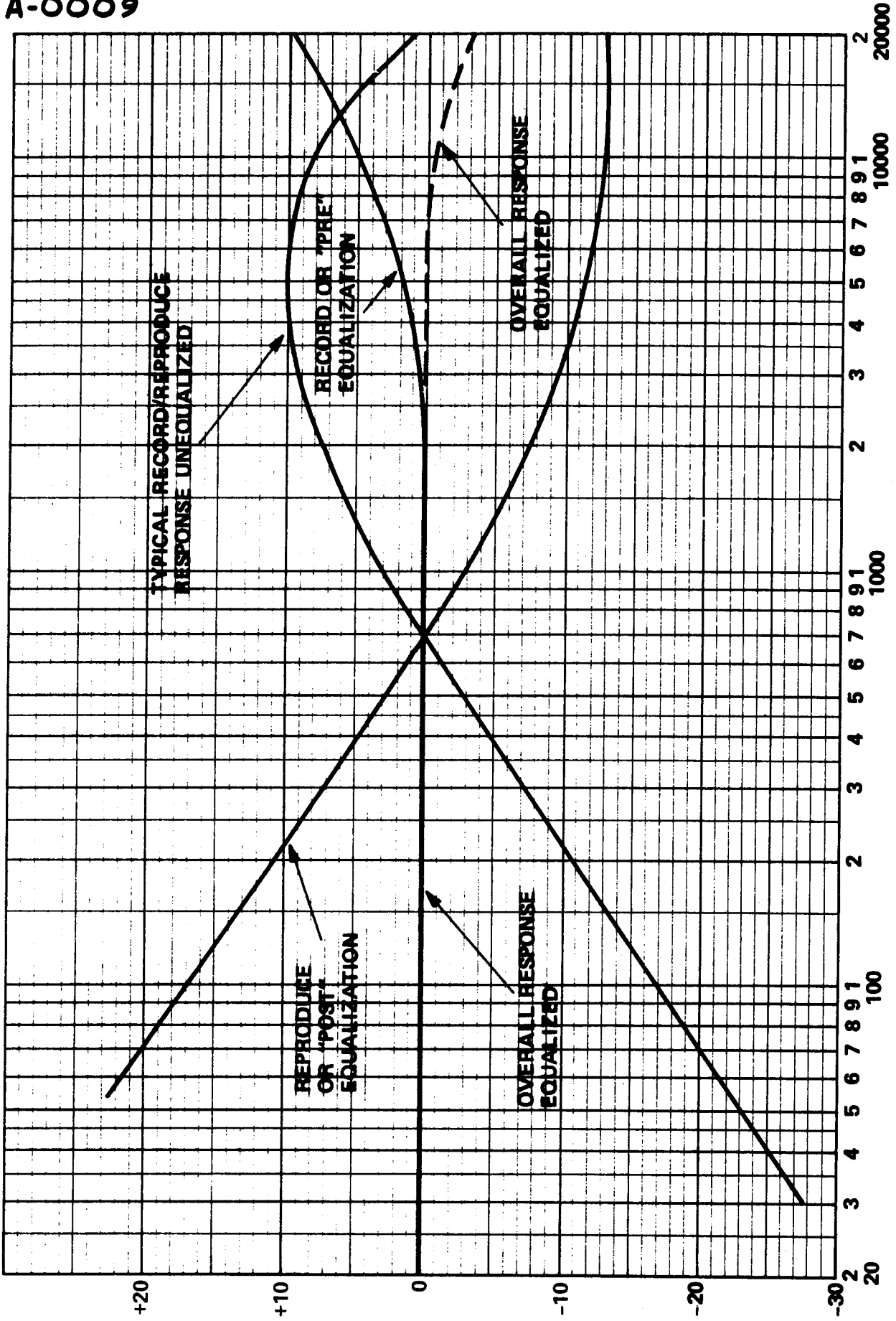
Thus

$$C = \frac{T}{\frac{R_S R_L}{R_S + R_L}}$$

Therefore if R_L and R_S are both equal to 600 ohms the value of C required will be

$$C = \frac{T}{300} \mu\text{f. when } T \text{ is in microseconds.}$$

Other values of R_S and R_L may thus be used, providing the value of C is altered to suit.



FREQUENCY IN HERTZ

Figure 1

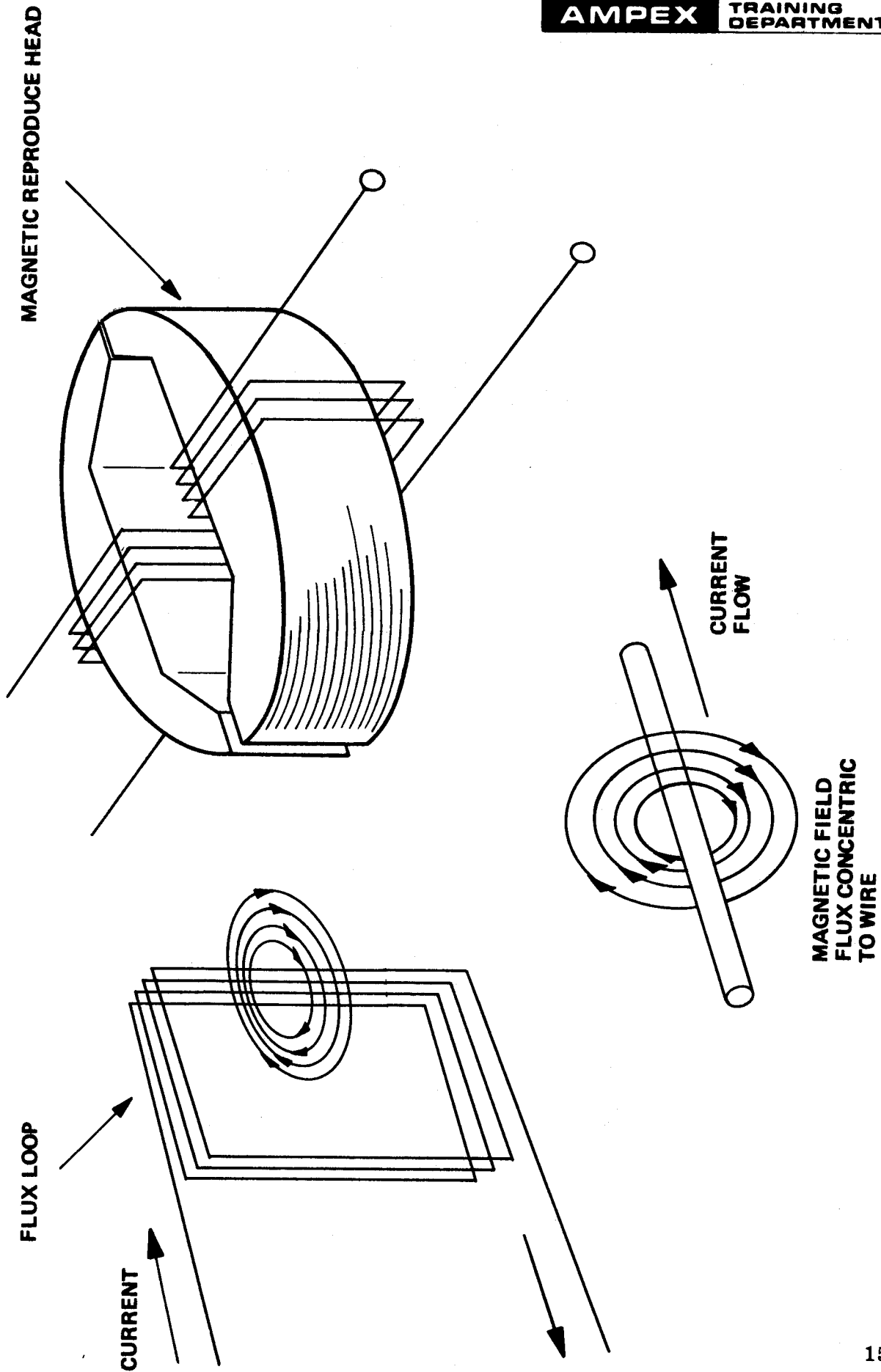


Figure 2

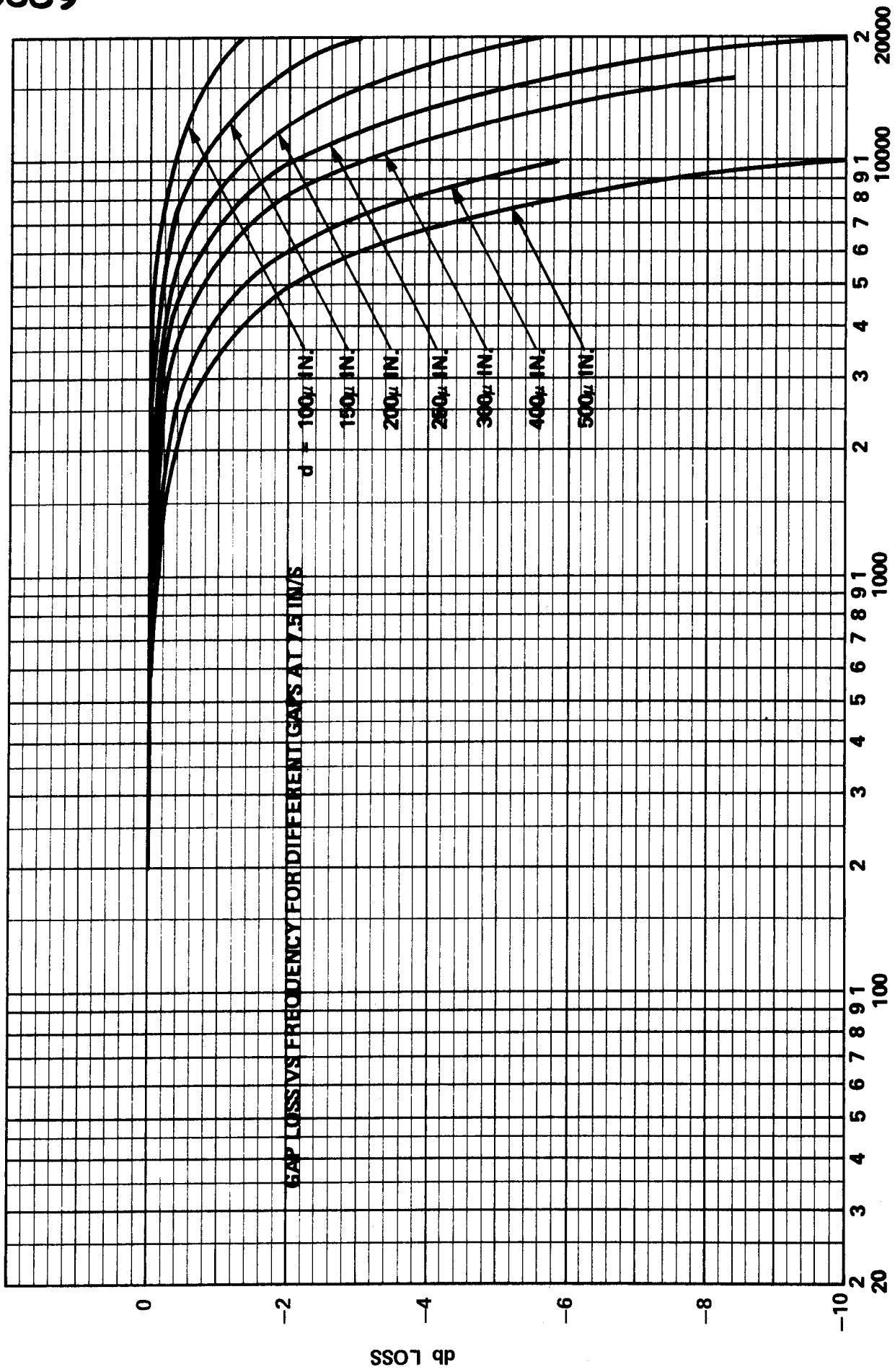


Figure 3

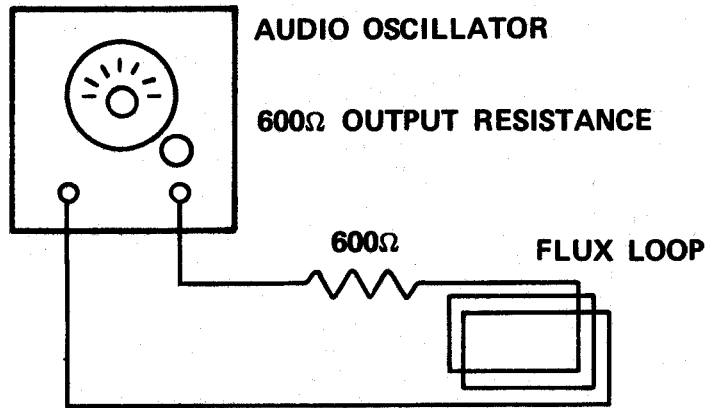


FIGURE 4

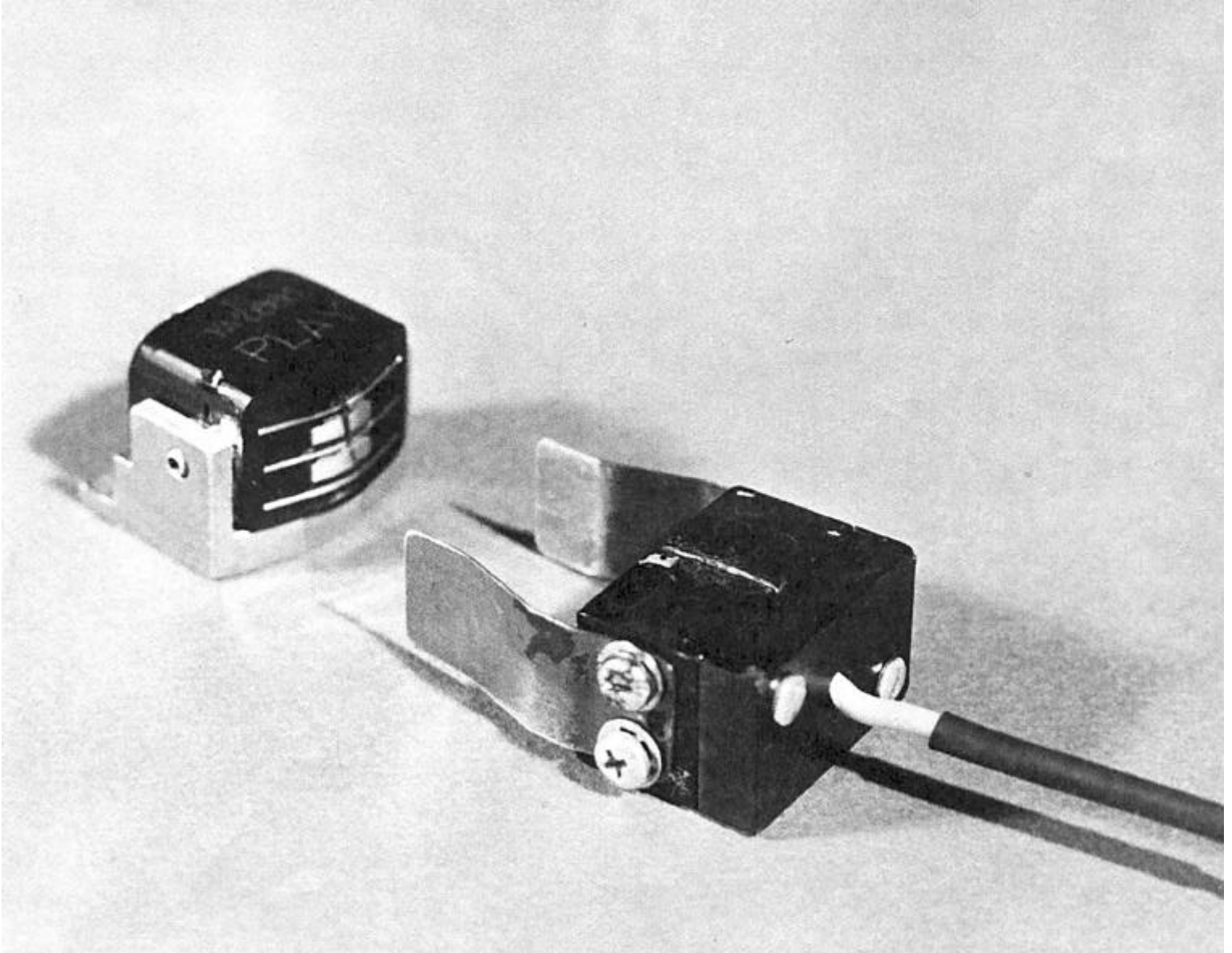


Figure 5A

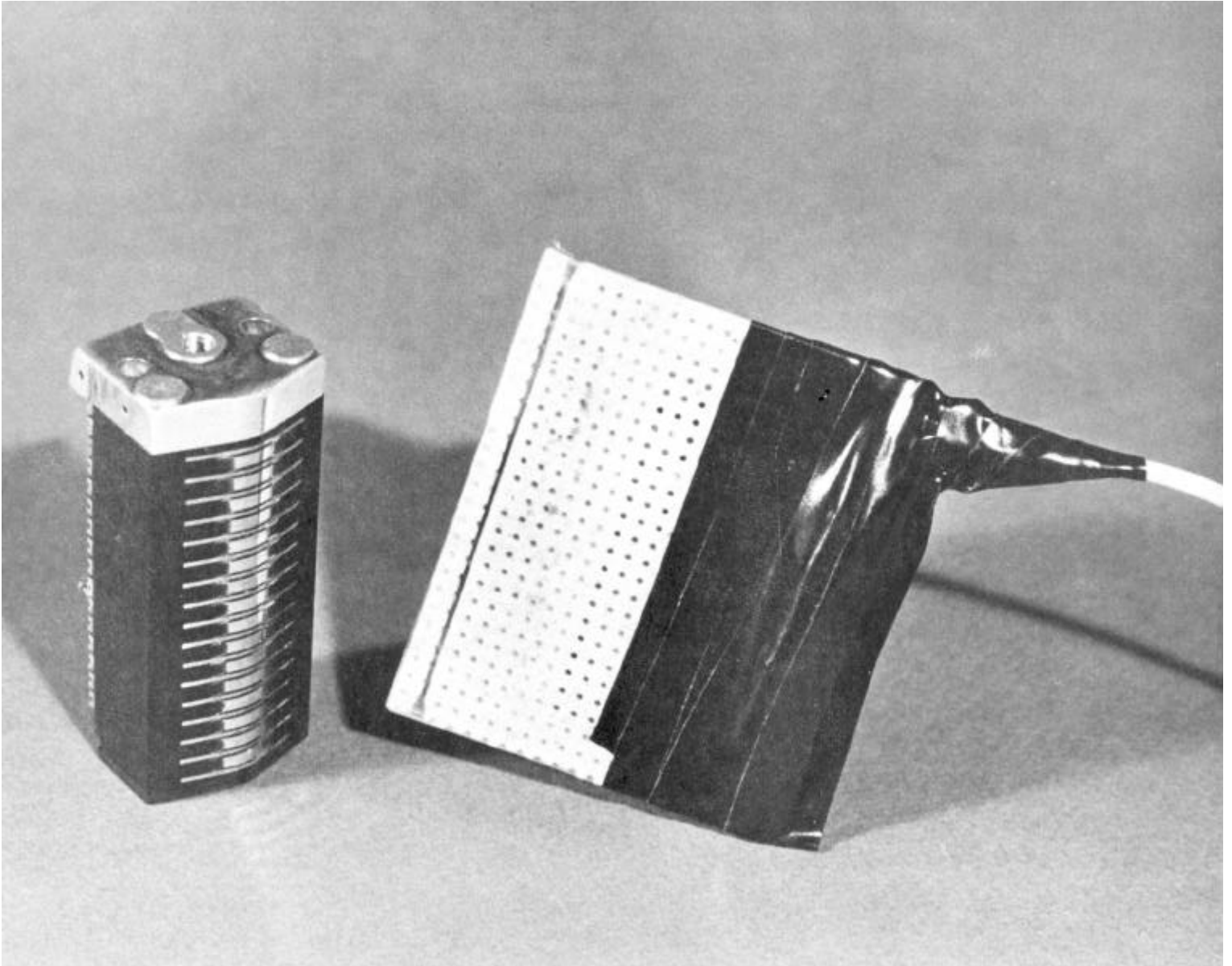


Figure 5B

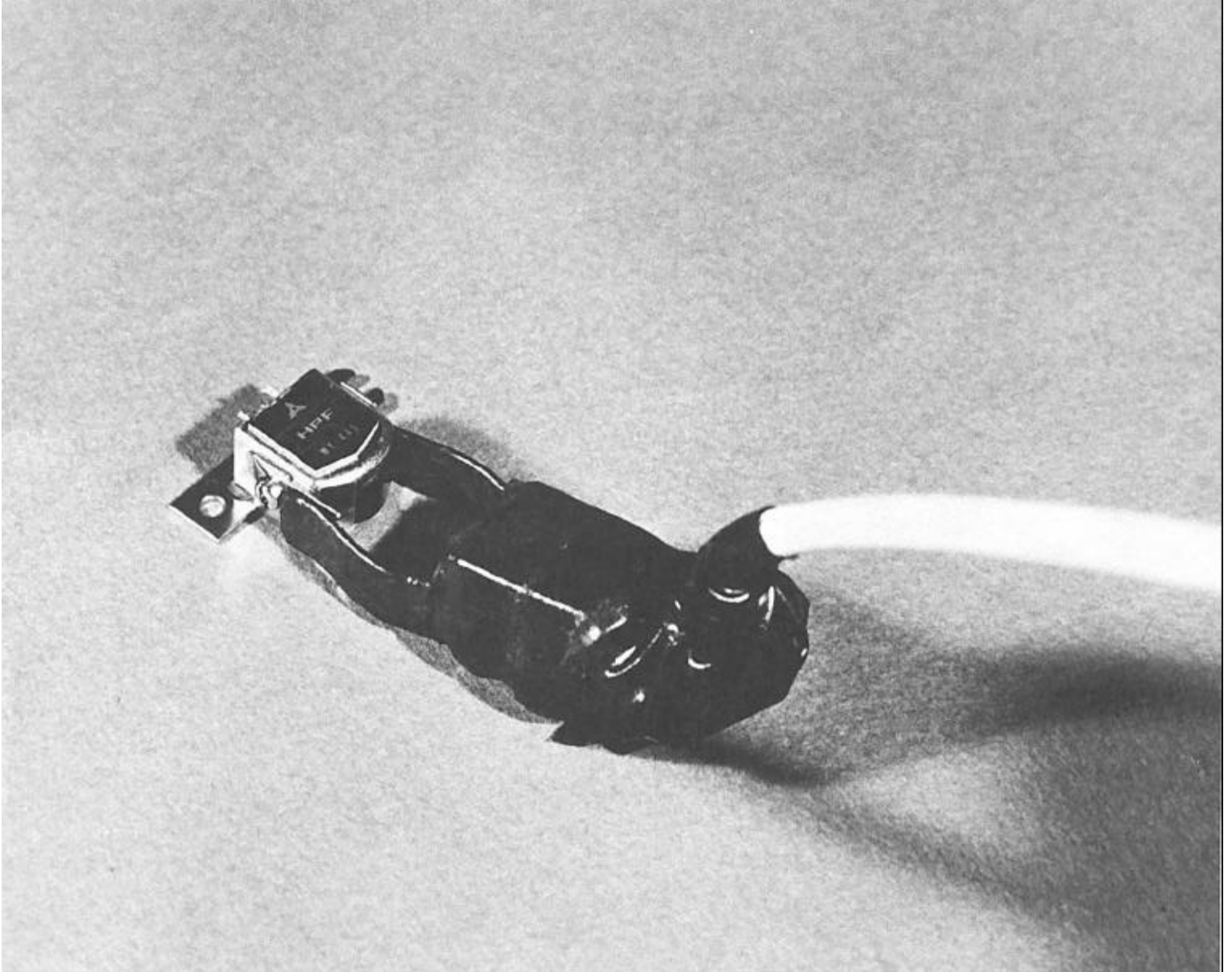


Figure 6

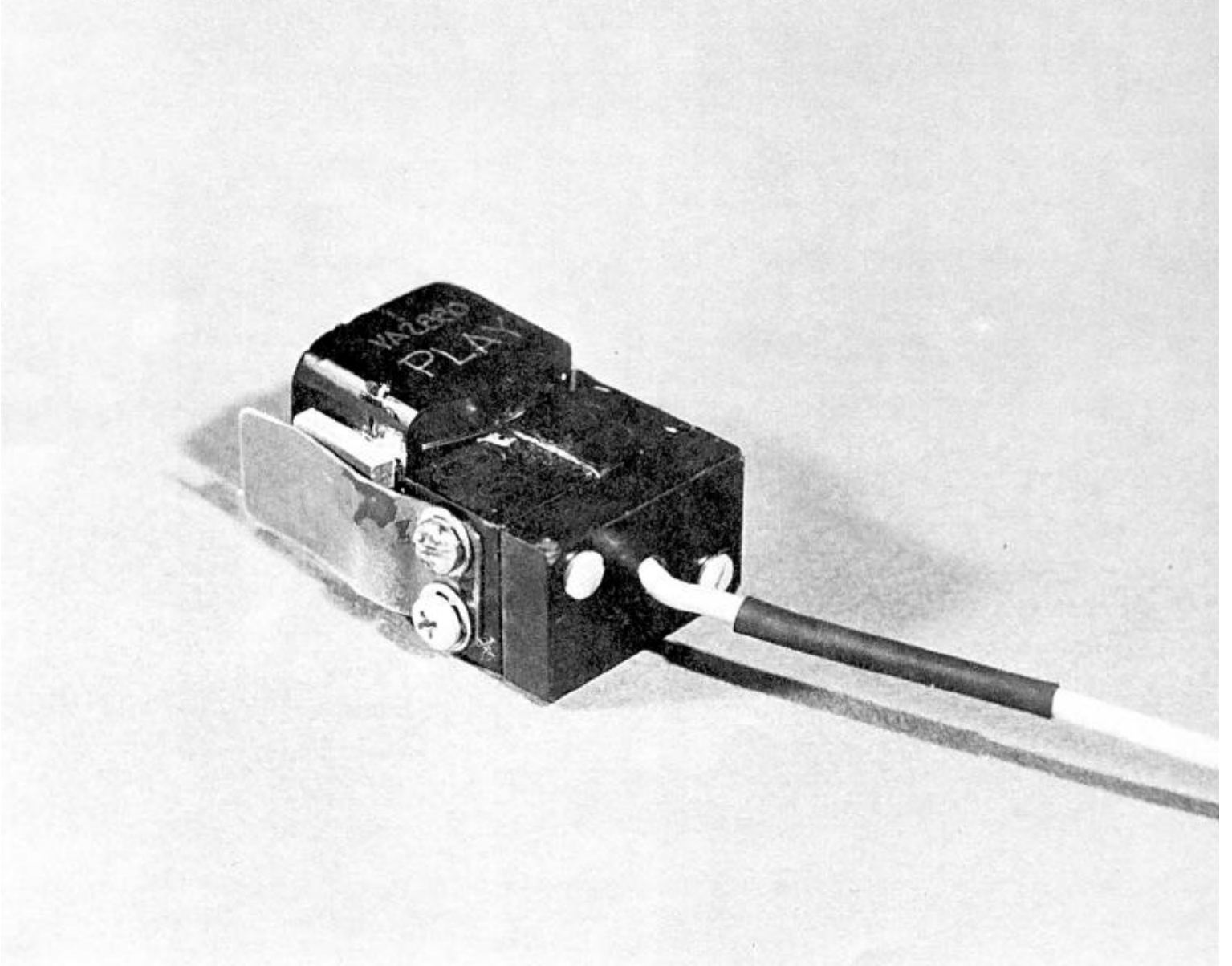


Figure 7

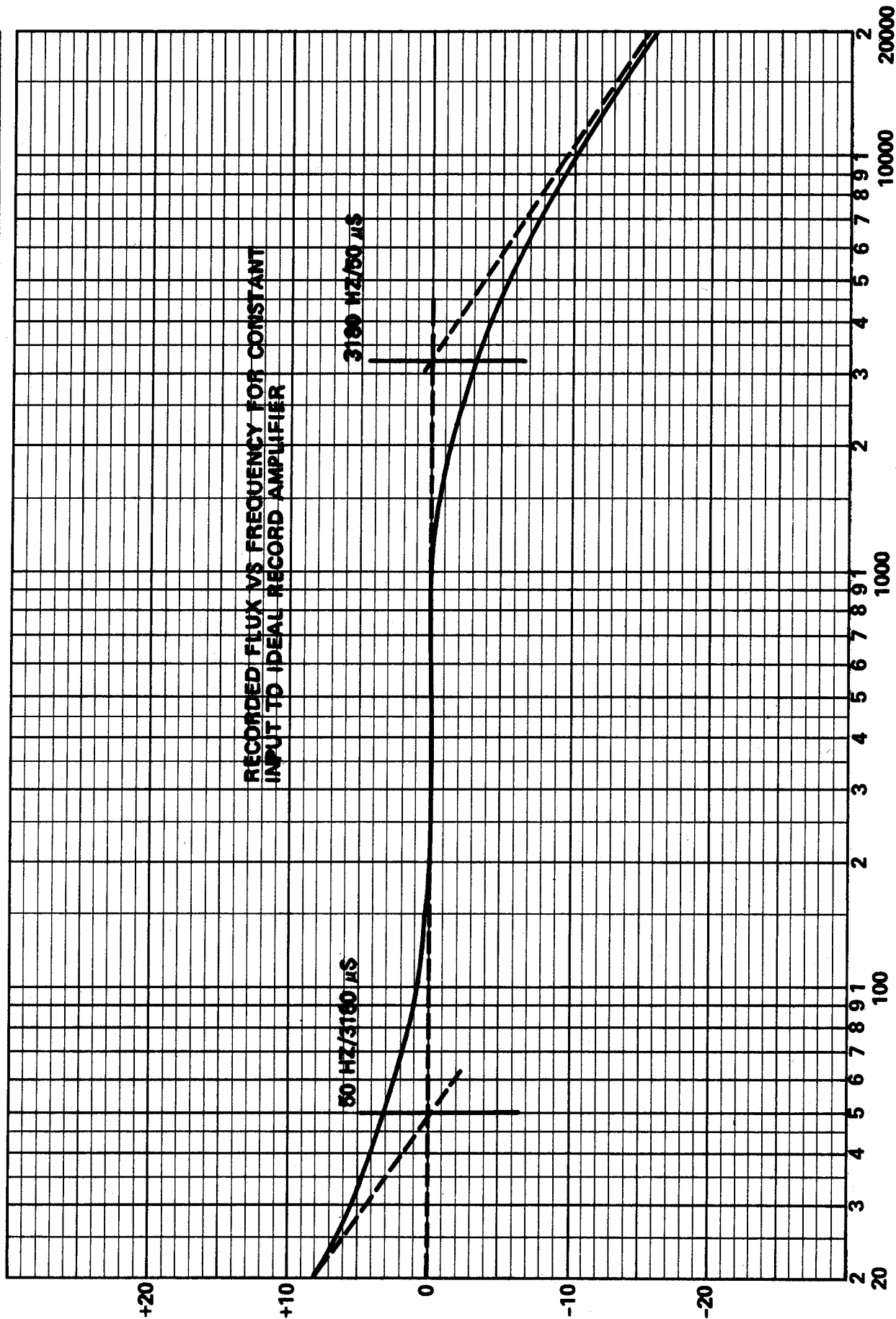


Figure 8A

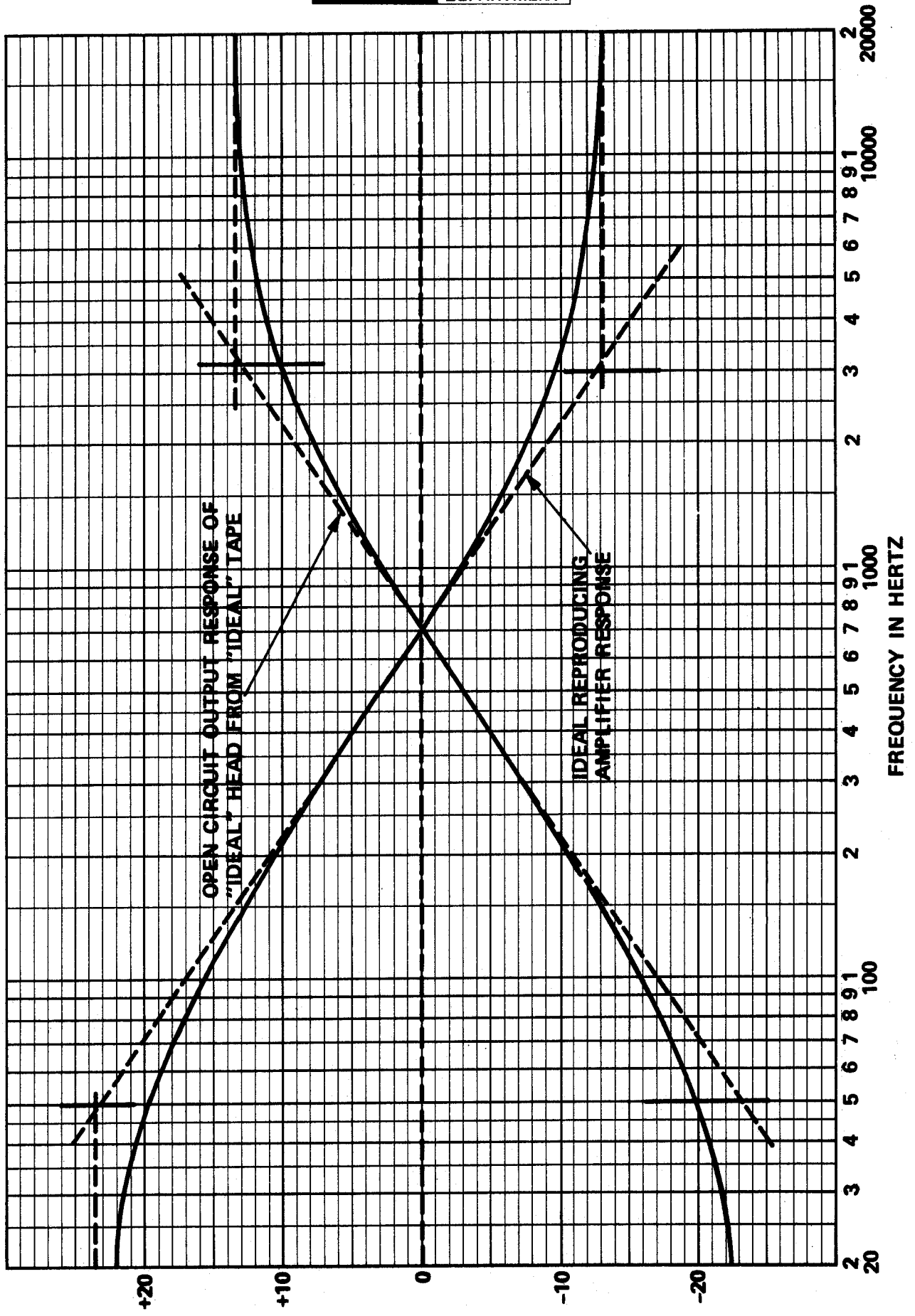


Figure 8B and 8C

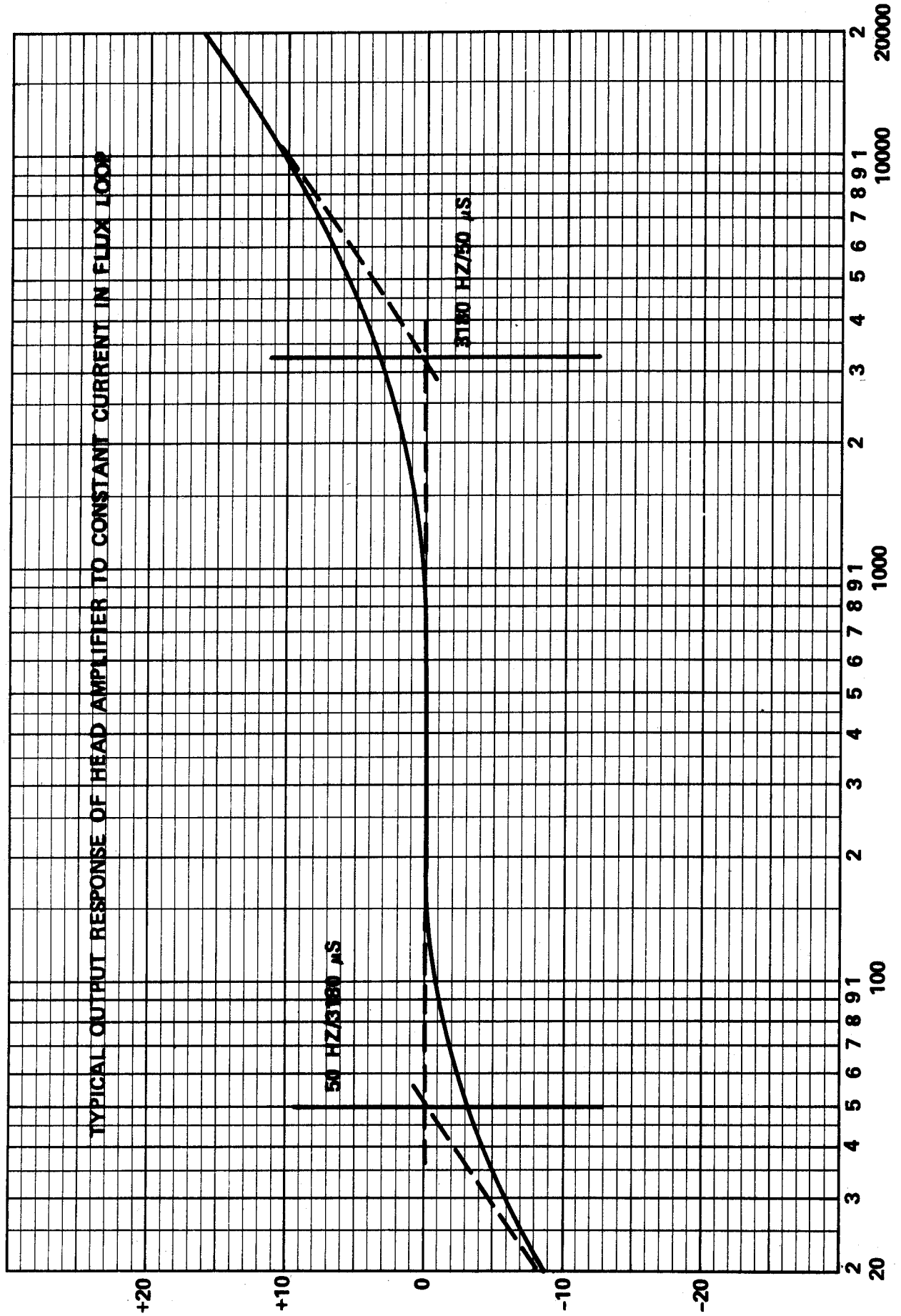


Figure 9

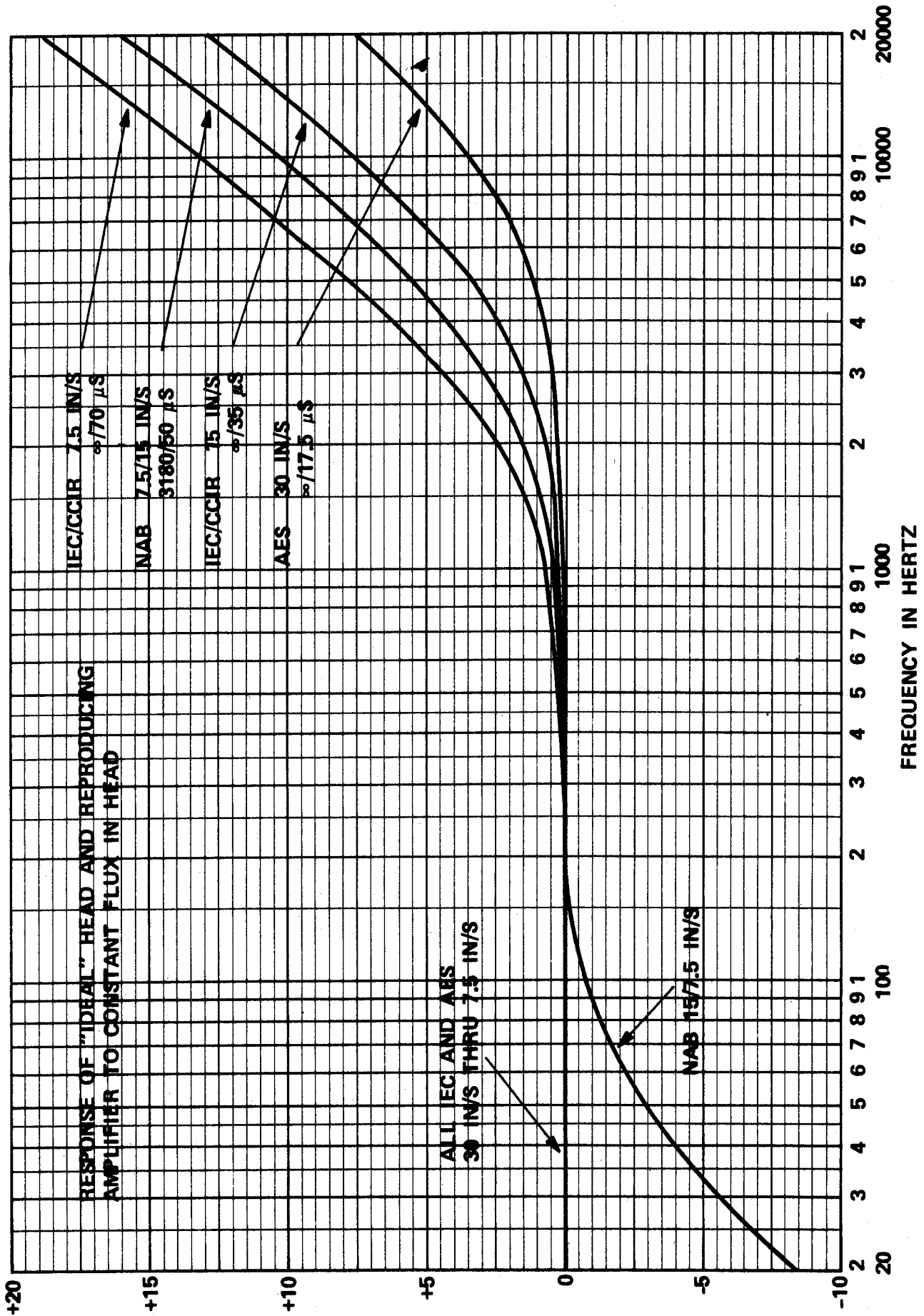


Figure 10

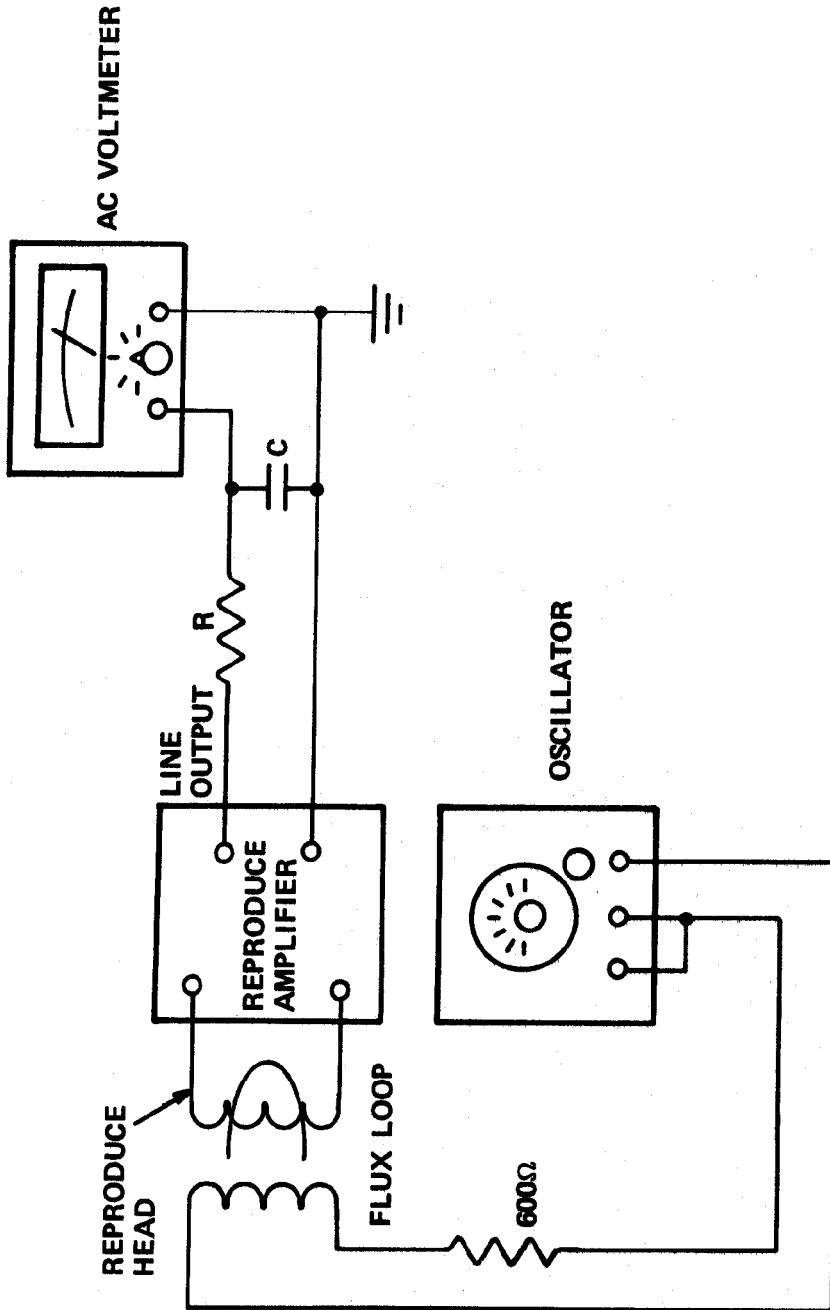


FIGURE 11

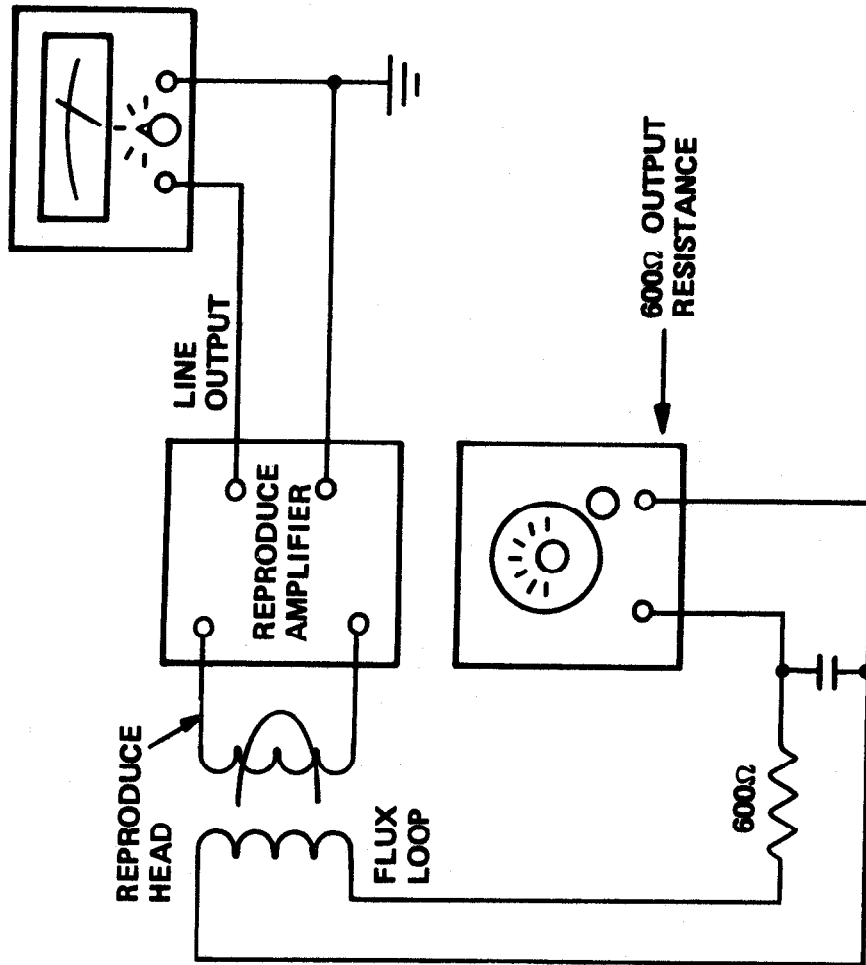


FIGURE 12