SISDE-14

Systems and Means for Enciphering
and Deciphering Magnetically-
Recorded Signals

(SISDE-14)

ENGINEERING REPORT NO. 20

Investigation of Telegraphone as a Means for Introducing a Time Delay in a Signal Network

February 9, 1932

WAR DEPARTMENT

SIGNAL CORPS
LABORATORIES

FORT MONMOUTH
OCEANPORT, N. J.

SIGNAL CORPS LABORATORIES
FORT MONMOUTH, NEW JERSEY

ENGINEERING REPORT NO. 20

Investigation of Telegraphone as a Means for Introducing a Time Delay in a Signal Network

February 9, 1932.

This report consists of 12 pages.

SIGNAL CORPS LABORATORIES
FORT MONMOUTH, NEW JERSEY

WDH:D

February 9, 1932.

ENGINEERING REPORT NO. 20

SUBJECT: Investigation of Telegraphone as a Means for Introducing a Time Delay in a Signal Network.

OUTLINE OF REPORT

I. PURPOSE:

II. PROCEDURE:

- A. Test Set and Testing Technique.
- B. Materials employed and Method of Disposing.

III. RESULTS:

- A. Insertion Loss of the Telegraphone.
- B. Fidelity
  - 1. Frequency
  - 2. Amplitude
  - 3. "Masking"
- C. Physical Make-up of the Record.

IV. DISCUSSION:

- A. Choice of Material.
- B. Disposal of Material.
- C. Insertion Loss.
- D. Filter Action.
- E. Amplitude non-linearity.
- F. "Masking"
- G. Dispersion
- H. Time Delay Attainable.

V. CONCLUSIONS.

I. PURPOSE: The purpose of the work reviewed in this report is the investigation of the performance of the telegraphone as a means for introducing a variable time delay in a signal network, together with the determination of the factors affecting this performance, and a study of methods of improving it. The ultimate objective is to utilize the information obtained in the design of subaqueous sound ranging equipment. The investigation was pursued in accordance with instructions from the Signal Corps Laboratories and was designated as Project 85-E in the Sound Section.

E.R. #20 Investigation of Telegraphone as Means for Introducing a Time Delay in a Signal Network. Sheet #2.

II. PROCEDURE:

A. Test Set and Testing Technique.

An experimental test set was designed which was used to measure the "insertion loss" in decibels of the telegraphone as a function of all the variables known to influence this loss. These factors are: (1) kind of material used, (2) method of utilizing the material, (3) method of disposing recording (T), erasing (E), and receiving (R) coils with respect to the magnetic material, (4) speed of coils relative to magnetic material taking the record - hereinafter referred to as speed, (5) signal frequency, and (6) signal strength. The test set permitted these factors to be studied in detail. A sketch showing this set in rough outline is shown in Fig. 1.

The "insertion loss" was measured by a substitution method, that is, the telegraphone under controlled experimental conditions was inserted in a signal network and then an attenuation box under the same conditions was substituted for the telegraphone to reduce the signal to the same extent as had the telegraphone itself.

Further, a study was made of the actual physical make-up of the magnetic record by means of magnetic compasses and small exploring coils. Various modes of recording were investigated. The actual procedure will be discussed more fully as needed in presenting results.

B. Materials employed and method of Disposing Materials.

1. Following employed in disk form.
    - a. Low carbon cold rolled steel sheet from Allegheny Steel Co.
    - b. Allegheny Electric Metal - 47% Ni, 52% Fe, 0.5% Mn, traces of S, C, etc., - from Allegheny Steel Co.
    - c. Hyflux Chromesteel from Indiana Steel Products Co.
    - d. High carbon crucible steel saw blank from Henry Disston and Sons.
    - e. High carbon crucible steel Formoss saw.

2. Following employed as single wire wound on the periphery of a bakelite drum.
    - a. Soft iron annealed wire 0.042".
    - b. High carbon steel drill rod 0.042".
    - c. Piano wire in following diameters: 0.007", 0.013", 0.024", 0.031", 0.038", and 0.068".
    - d. Piano wire in three grades from Hammacher, Schlemmer and Co. 0.013" diameter.

3. Following employed by winding on the periphery of a bakelite drum a single layer piano wire band 1/2" wide: 0.007", 0.013" and 0.038".

E.R. #20 Investigation of Telegraphone as Means for Introducing a Time Delay in a Signal Network.

Sheet #5.

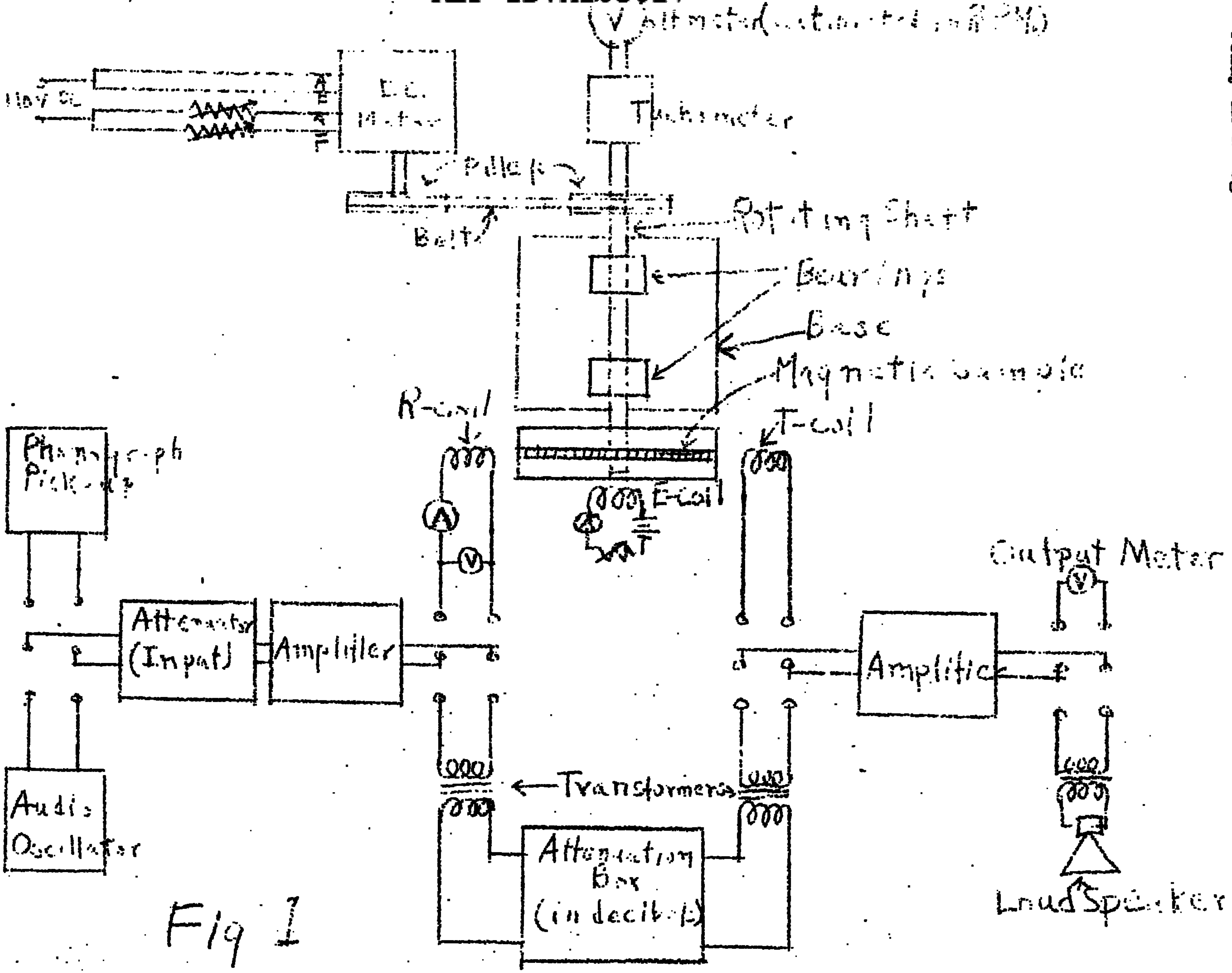

Fig 1

4. Wound a strip 30" long, 3/4" wide, and 1/16" thick with approximately 3000 turns of 0.007" piano wire and secured this strip to the periphery of a 9" bakelite drum for transverse recording.

5. Placed a cast iron spacer between two saw blanks for double disk radial recording.

III. RESULTS:

A. Insertion Loss of the Telegraphone.

Table I gives the results obtained when employing the different materials and using different methods of disposing them. In order to give the measurements any meaning for comparison purposes, it was necessary to fix on a speed, impressed frequency, and signal strength. Choice here was dictated by considerations of the frequencies and signal strengths met in practice as well as the time delay desired. The speed chosen was 70 ft. per second, the frequency employed was 400 cycles, while the signal strength employed was represented by a current of 25 ma. through a 500 ohm T-coil. In column I is given the insertion loss under these specified conditions. In general the frequency at which least attenuation occurs depends upon speed. This is shown by Fig. 2 where the minimum attenuation takes place at 200 cycles for 600 r.p.m., 400 cycles for 1200 r.p.m., and 600 cycles for 1800 r.p.m. The disk diameter was 15 inches. From these relations it follows that the length of sound track used for recording one cycle for minimum attenuation was approximately constant, namely, 2.3 inches in the present case. This constant length of sound track used in recording a single cycle of some frequency - determined by speed - for least attenuation is given for the various materials tested in Column II, Table I. Further, we arbitrarily define the high frequency cut-off as the frequency for which the attenuation is 25 db greater than the minimum. To each speed there corresponds a high frequency cut-off. The length of sound track occupied by one cycle is again found to be very nearly independent of speed. Column III, Table I, gives this length for the various materials and affords a direct measure of the ability of a material to be used in transmitting high frequencies. The background of noise arising from the rotation of the magnetic material by the coils was highly objectionable in the case of transverse recording due to imperfections and irregularities in the winding as well as when single turns of wire were used due to the joint. However, when employing disks or the wire bands, this background noise was of the same order of magnitude as the output amplifier noise.

Table I

Disks	I Insertion Loss	II Inches per cycle	III Inches per cycle
Formoss Saw	70	2.2	0.5
Cold Rolled Steel	68	2.4	0.6
Allegheny Electric	63	3.1	0.55
Disston Saw	53	2.2	0.5
Hyflux Chromesteel	51	2.2	0.4

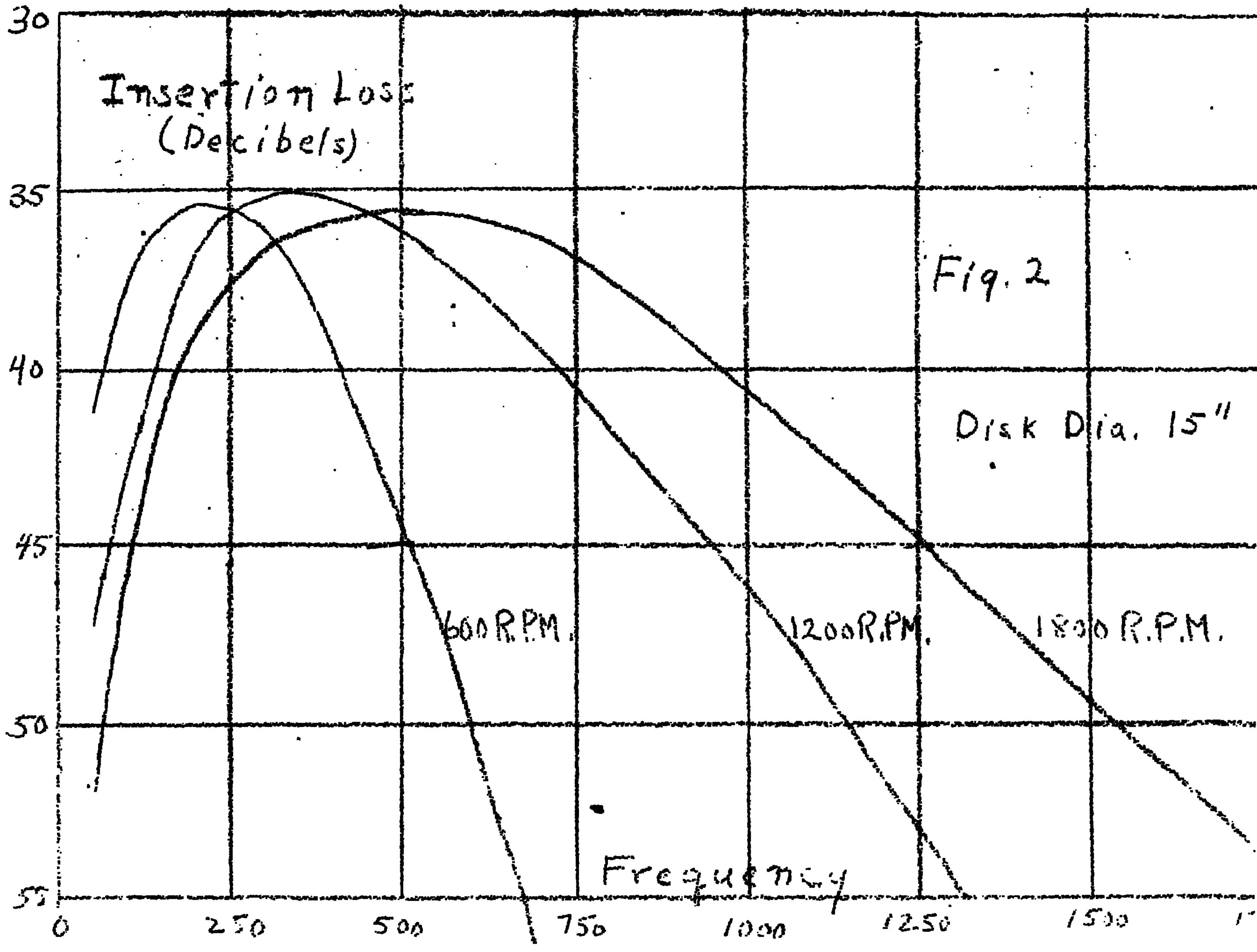
Insertion Loss
(Decibels)
30
35
40
45
50
55
0
250
500
750
1000
1250
1500
Frequency
600 R.P.M.
1200 R.P.M.
1800 R.P.M.
Disk Dia. 15"

Fig. 2

Wire	I Insertion Loss	II Inches per cycle	III Inches per cycle
Soft Iron	58	2.3	0.9
Drill Rod	52	2.4	0.55
Piano Wire .068"-.038"	43	2.4	0.3
Piano Wire .031"-.007"	40	2.3	0.3
Wire Band 1/2 inch wide			
30 T of .013" Piano	35	2.3	0.3
70 T of .007" "	35	2.3	0.3
Double Disk Radial Recording	Infinity	-	-
Transverse Recording on wound strip	35	2.3	0.4
Transverse Recording when strip was cut to form elementary U-shaped magnets	Infinity		

B. Fidelity of the Telegraphone.

A discussion of this factor resolves itself into a study of three contributing causes of a lack of fidelity.

1. Frequency. The curves of Fig. 2 were taken when employing a band of 40 turns of 0.013" piano wire. Insertion loss is plotted against frequency for several values of speed. It becomes evident from an examination of this family of curves that very serious distortion of a complex signal must normally be expected due to the excessive attenuation of the higher frequencies. Also attenuation is seen to depend upon speed which fact might well be used in the design of a low-pass filter whose characteristics depend on speed. Speech signals transmitted over the telegraphone are not unintelligible but the device certainly plays havoc with quality.

2. Amplitude. The curves of Fig. 3 show the voltage measured across the output of an amplifier connected to an R-coil plotted against the voltage impressed across the T-coil for four different frequencies, 300 cycles, 400 cycles, 500 cycles, and 600 cycles. Up to an input voltage of 10 volts the response is nearly linear. The diagonals marked 35 db. etc., are constant attenuation lines. For these curves

E.R. #20 Investigation of Telegraphone as a Means for Introducing a Time Delay in a Signal Network. **Sheet #7**

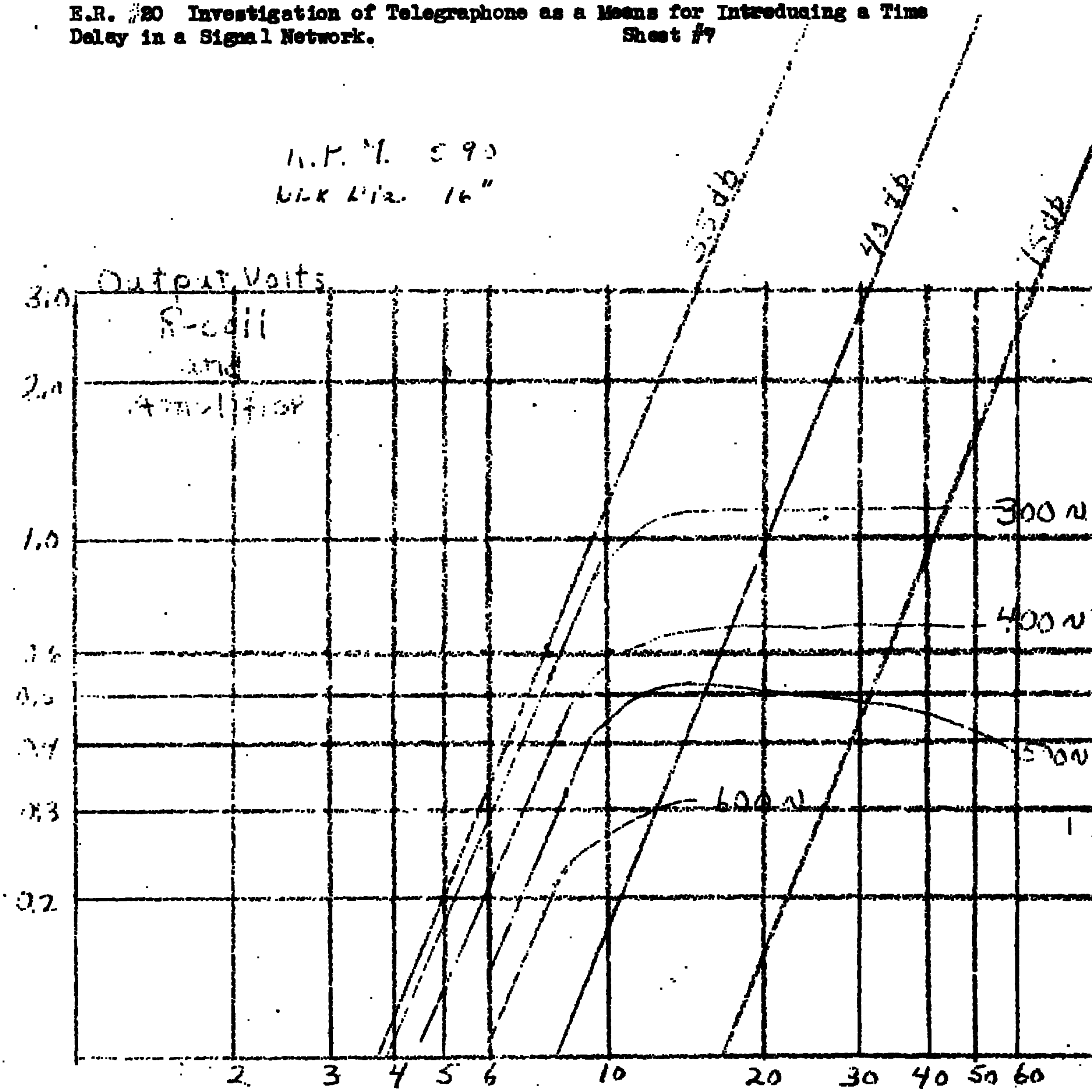

Fig 3

speed was maintained constant. Obviously, for faithful reproduction over a wide range of amplitude insertion loss should remain constant irrespective of amplitude. The departure from this condition shown in Figure 3 predicts distortion arising from this cause.

3. Masking of high frequencies by the simultaneous recording of a low frequency. The curves Fig. 2 are misleading in that they presuppose only a single recording frequency. This factor of "masking" has not been investigated in detail by quantitative measurements. But when music or speech is being transmitted by the telegraphone and then simultaneously a low constant frequency is impressed, there is a marked deterioration in quality due to poorer transmission of the high frequencies necessary for high quality. This deterioration increases as the amplitude of the "masking" low frequency is increased. In short, the principle of superposition does not hold for the telegraphone as an element in a signal network. Thus the device is worse than the curves of Fig. 2 would indicate.

C. Physical Make-up of the Magnetic Record.

When recording a pure frequency on a disk by means of a U-shaped T-coil with both poles in one side of the disk, and disposed for longitudinal recording, i.e., longitudinal as opposed to radial, it was found that a series of consequent magnetic poles appeared on both surfaces of the disk. When the lines of force in the impressed record lie parallel to the direction of motion of the record material with respect to the T-coil, we define the record as a "longitudinal" or "tangential" one, and when at right angles to the direction of motion as "radial". The first pole to influence virgin magnetic material results in a "longitudinal" record differing in phase by 180° from that one impressed by the second or trailing pole which leaves the final and also a longitudinal record. The nature of this record is indicated in the Fig. 4 below which shows a cross section of the disk.

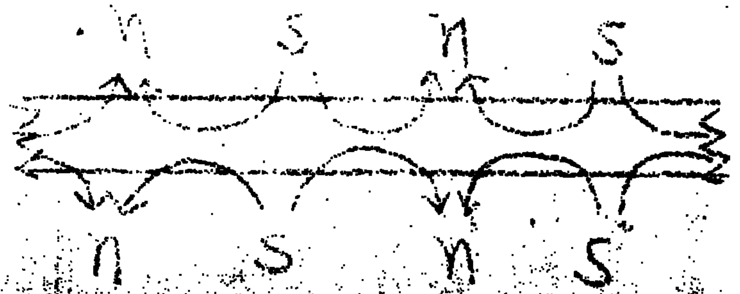

Fig 4

These conclusions were reached as a result of experiments involving observations on the polarity of the impressing magnet and experiments employing iron filings, compass, needles, and small exploring coils used in pairs and capable of being moved about independently on either side of the disk. The system of "wave-lengths" in the steel could thus be explored. These exploring coils were connected in series and then to the input of an amplifier. A complete cycle was thus found to be recorded in the length of sound track computed for it on the basis of a knowledge of speed and frequency.

Single pole T-coil recording was also accomplished only it is less effective than double pole tangential recording due to the high reluctance magnetic path used and the increased pick-up due to stray magnetic fields. This kind of recording resulted in a longitudinal record.

IV. DISCUSSION:

A. Choice of Material. From Table I it will be seen that the materials which are "hardest" magnetically should be employed in the telegraphone for highest efficiency. High retentivity is the prime desideratum in the choice of material rather than high permeability or a compromise between high permeability and retentivity. In general, high permeability materials retain very feeble magnetic records.

E.R. #20. Investigation of Telegraphone as Means for Introducing a Time Delay in a Signal Network. Sheet #10.

B. Disposition of Material. For the present the best method found for disposing the material was in the form of a wire band on the periphery of a drum. This method was chosen because materials can more readily be prepared in this form than in disk form, eddy currents are thereby partially eliminated, overall efficiency is greatly increased (See Table I), it is relatively simple to adjust the amount of magnetic material employed, a true running mechanical assembly can readily be arranged, the filaments thus longitudinally disposed are properly proportioned to give us inherently stable elementary magnets, and a superior frequency characteristic is attained. (See Table I Column III)

C. Insertion Loss. The low efficiency actually observed may be viewed in either of two ways. A recording process such as this one involves at the T-coil relatively large amounts of energy while the energy abstracted by the material depends upon changes in the magnetic hysteresis losses due to motion of the magnetic material. With the material at rest the losses looking into a T-coil are (1) ohmic due to the resistance of the copper, (2) iron losses due to hysteresis in the cores of the T-coil, pole pieces, and the material for recording, and (3) eddy current losses. Normally, the hysteresis losses are high. The <u>change</u> introduced in these hysteresis losses in the magnetic sample by the <u>motion</u> of the material gives us the actual power abstracted by the moving material from the electrical input circuit. Needless to say, it is a hopeless and thankless task to attempt to deal with these losses by conventional methods of mathematical analysis. Or, we may view the system as a transformer with extremely loose coupling between primary (T-coil) and secondary (R-coil) windings and with a species of wave propagation introducing a time delay between the windings. The coefficient of coupling is indeed low if we employ the insertion loss as a measure of it.

D. Filter action of Telegraphone. The fact that the telegraphone as set up does not transmit high frequencies well is to be explained on the basis that the length of sound track involved in recording a single cycle is so short that the elementary magnets involved in the record are essentially of an unstable form. The condition for stability - a high ratio of length to diameter - is violated at high frequencies. The relation of cut-off frequency to speed shown in III,B,1, indicates that this explanation is in the main correct. Another factor of course is the increase in eddy current losses at the higher frequencies. Equalizing networks are the remedy needed to give us a flat frequency characteristic for a reasonable frequency range, only these of course do not add signal components already lost.

E. Non-linearity with regard to amplitude. The telegraphone when inserted in a signal network is a non-linear element excepting for small signal amplitudes. Why this is so is best understood by referring to the Fig. 5.

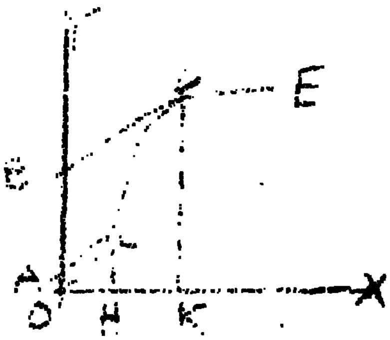

Fig 5

O represents the point in the B-H plane about which we work our material. The position of O is determined by the erasing bias and the polarizing bias. That is, the state of virgin material with no a.c. signal is represented by the point O. An impressed signal represented by OH brings the material to a state represented by point C and after the material passes from the influence of the T-coil, the final state is represented by the point A. Similarly an impressed signal represented by OK, leaves the material in a state represented by B. OA and OB measure the influence of the signal on the material. The fact that $\frac{OK}{OH} \neq \frac{OB}{OA}$ for large ranges in X is essentially responsible for amplitude distortion. Theoretically, it is possible to employ proper biasing fields to minimize this distortion. The present work has not indicated that it can be eliminated, but future work might well look into the possibility of transmitting faithfully a wide range of signal amplitudes.

F. "Masking". "Masking" might well be studied in more detail by the use of filter circuits to study the attenuation. One frequency suffers as a result of the simultaneous impressing of another. Whether anything can be done to correct it is another question.

G. Dispersion. Dispersion as such in the telegraphone does not appear to be a serious factor in introducing distortion. The velocity of travel of all signals once they are recorded is not likely to be seriously different for different frequencies unless there should be an unsuspected "flow" in the record itself. This is not impossible as a pole appearing on the surface of the material - which in the last analysis is the only inkling we have that there is a record at all - might conceivably settle into an equilibrium position which depends on what other signals are being recorded. This statement may also be applied to the case of "masking". Thus the time delay suffered by a signal may depend not only on the relative positions of T and R coils but on the accidental "environment" of the signal, that is, the presence or absence of other frequencies which may or may not be simply related in wave-length to it. The non-linear properties of the transmitting medium offer alibis for a multitude of telegraphone sins.

H. Time Delay Attainable. Time delays of the order of 10^5 microseconds may be attained with a very reasonable mechanical and electrical design of the apparatus. Of course longer delays than this become possible if we use the instrument as designed for dictaphone purposes but for continuous recording and reproducing 0.1 second is a reasonable value. This is the chief advantage of the device in a network.

V. <u>CONCLUSIONS:</u> The detailed conclusions with regard to performance of the telegraphone are given under results and discussion. The instrument as it stands with the improvements in design resulting from present choice and disposal of material leads itself well to the introduction of relatively long time delays in signal networks. However, signals are thereby distorted and this is objectionable for some applications especially when the accurate preservation of original phase relations is essential. Causes of distortion have been examined, measurements taken, and methods of minimizing studied. The fundamental causes of distortion lie in the non-linear properties of the magnetic material and in the conditions which must be met for stability in a permanent magnet. However, in spite of the inherent faults of the device it may prove useful - even with its distortion - in underwater sound application because of its ability to introduce a variable and known time delay in a signal network.

W. D. H.

W. D. HERSHBERGER
Associate Physicist.

APPROVED:

S. H. ANDERSON
Chief, Sound & Light Section.