NOTES ON THE TRANSMISSION CAPABILITY AND PERFORMANCE OF 2-WIRE VS. 4-WIRE VOICE FREQUENCY TRUNK CIRCUITS

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Introduction

During the past few years, we have observed efforts by several large telephone companies in converting two-wire voice frequency circuits to four-wire voice frequency operation. While this may be economical for these telephone companies, four-wire may not be economical in the telephone systems of the REA borrowers.

The purpose of this paper is to inform you that:

(a) With D-66 loading all present transmission objectives are met entirely on a two-wire basis.

(b) More stringent, future transmission requirements can also be met on a two-wire basis when this becomes necessary.

(c) Without additional compensation the use of four-wire voice circuits is not economical.

Echo Return Loss and Singing Point

In the A. T. & T. Company's Bluebook, "Notes on Distance Dialing," 1961, Section Six, echo return loss and singing point objectives are given for toll connecting trunks. This information is reproduced in Chart I for ease of reference. There are no comparable objectives for EAS trunks because of the much shorter distances which are normally involved.

Chart I shows that two-wire voice frequency trunks have to meet an echo return loss of 18 db and a singing point of 10 db. These values apply when the circuits are being acceptance tested and therefore the test termination used is a 900 ohm resistor in series with a two microfarad capacitor effectively at the Class-5 office and the Class-4 office.

From the same Chart I, we also see that there is an additional requirement. This requirement says that during the design stage (that is, when the paper computations are made) if a typical Bell system subscriber loop is assumed at the Class-5 office, then at the toll center a value of 15 db echo return loss should be obtained at the Class-4 office. The "average Bell system loop" which gives 11 db return loss in the echo range is shown in Appendix III. In any paper design when the 15 db ERL is obtained at the toll center by computation, then it is assumed that this trunk will meet the 18 db ERL upon acceptance testing using the 900 ohm and two microfarad terminations.

We now make reference to Tables I and II and the enclosed Figures 1-4. Typical 22 gauge and 19 gauge, two-wire D-66 loaded trunk applications are shown using the low cost E-6 type repeaters. Two cases are considered there. In the first case the E-6 repeater is at the Class-5 office and there is no repeater at the Class-4 office. In the second case an additional E-6 repeater is located at the Class-4 office set for 3 db gain and this is the maximum gain for this repeater. All the examples shown are VNL + 2 trunks. They represent the "worst cases" inasmuch as this is the maximum circuit length which will meet VNL + 2 loss objectives. This also means that for circuit lengths shorter than this the performance will be even better.

These things are now evident from the measurement data in Tables I and II:

(a) The echo return loss using the average bell system loop is much better than the 15 db which has to be met.

(b) The echo return loss using the 900 ohm + 2 microfarad terminations is much (much) better than the 18 db which has to be met. The actual values are as high as 33.5 db.

(c) The singing point using 900 ohm and 2 microfarad terminations is much better than the 10 db which has to be met. Actual values are as high as 23 db.

(d) The circuits are operating at VNL + 2 db and they are unconditionally stable.

Thus, one can see that this type of two-wire design not only meets VNL + 2 db, echo return loss and singing point objectives, but the actual performance is much better than what is needed. The reason for this, of course, is the D-66 loading system and, in addition, the good characteristics of E-6 repeaters which are a rather good match for D-66 loading. One also concludes from Tables I and II that the performance of this two-wire system is as good and in some respects even better than that obtained from modern day, well-engineered carrier systems.

<u>What About Future Requirements?</u>

A question which arises and which is a natural one is "what about future requirements?" Would they be more stringent? Will this two-wire design be able to meet such requirements? These are good questions inasmuch as when engineering for the present one should not lose track of the future when permanent types of plant are involved.

The answer to this particular question is given in Table III. In this table one simple addition has been made to the two-wire D-66 design. An impedance compensator has been added at the toll center. This impedance compensator is a simple 22 MH loading coil and a building-out capacitor including the low frequency corrector. This is nothing else but an LBO of an E-6 repeater.

Table III shows that the addition of this simple and inexpensive compensator increases both the echo return and the singing point tremendously. For the 22 gauge ERL is 33.5 db while for the 19 gauge it is 36.5 db. The respective values for the singing poi t are 28 and 24 db.

When one considers that in 1965 we have to meet 18 db ERL and 10 db SP it becomes very clear that this two-wire design has a pretty substantial margin built into it. This means that when more stringent objectives come about one does not have to junk the two-wire and go to four-wire. The performance will be there just for the asking with a very simple modification. This, in my view, represents continued economy for the telephone systems of the REA borrowers.

Four-Wire Voice Circuits

In Table VI a four-wire voice frequency circuit is shown. The particular gauge shown is 19 gauge but this is not the important thing here because a gauge much finer than this could have been used also. The point which is made here in favor of the four-wire voice frequency operation is that under the condition of 900 ohm and two microfarad terminations only the echo return loss is very good at 29.5 db and it remains approximately the same regardless of the circuit net loss whether it be 2 db or 3 db, etc. This particular characteristic is a good feature for a circuit to have. Many people, however, have the erroneous impression that this is peculiar to four-wire circuits. That is, in order to get high enough values of echo return loss one must resort to four-wire circuits. This is not necessarily so when the type of loading system used is taken into consideration. For example, with some types of loading systems about the only way that modern-day transmission objectives can be met is by abandoning the two-wire operation and going to four-wire. With other types of loading systems two-wire operation can result in especially good performance. This is the case with the D-66 loading system and this is one of the major reasons for having recommended its use in the first place.

Now then, if a comparison is made between the four-wire echo return loss and singing point performance in Table VI and the two-wire performance in Table III, we can see that the two are as good and the two-wire performance is even better! In view of this it becomes very difficult to justify the use of four-wire circuits, at least in the telephone systems of the REA borrowers.

Low Loss Circuits

Often cases arise where non-toll completing circuits must operate at low losses. This may come about, for example, in tandem connections. There it may be desired to operate the total connection at a 4 db loss and this means that each link must operate at one-half of this loss or 2 db. Getting circuits, two-wire voice frequency circuits, that is, to operate at such low losses and at the same time remain stable during dialing, signaling, ringing, talking and idle conditions becomes indeed a problem. For this reason the approach has been to go to four-wire operation.

With D-66 loading circuits can be operated at extremely low losses on a two-wire basis. How this is done is shown in Chart II for 24, 22 and 19 gauge exchange cables. In all cases the low cost E-6 repeater is used at one terminal location only or at both circuit ends depending upon how low it is desired to make the circuit loss. This chart shows that with repeaters at both ends the circuit can operate as low as .8 db and this value also includes office losses.

Therefore with the D-66 loading the circuits can be strictly on a two-wire basis and a very low net circuit loss can be realized and there is no need for the less economical four-wire operation or other specialized solutions.

Delay Distortion

Data transmission is now virtually revolutionizing the way that large enterprises conduct their day-to-day business and this promises to be the case for many more daily transactions large or small. This service for transmitting data is now provided by the message telephone network. It is estimated that by 1970 maybe as much as 50 percent or more of the total revenue of the largest telephone companies in the United States will be from data transmission.

Because of the requirements imposed by delay distortion certain types of loading systems cannot be used for data transmission. One of the important features of D-66 loading, however, is that it can be used for rather high speed voice frequency data transmission. The actual performance is shown in Figure 1 for the various gauges and various cable mutual capacitance values. For .083 microfarads per mile nominal cable the envelope delay between 1,000 to 3,000 cps is 27 microfarads per mile.

Circuit Frequency Response

On the matter of frequency response very little needs to be said about this with D-66 loading. There is very little deviation between 1,000 to 3,000 cps and very good response even up to 4,000 cps. Some very typical frequency response performance which can be expected with D-66 loading can be seen in Figures 2 and 3.

The wideband response of the D-66 makes it possible not only to use to advantage the frequency response inherent in the 500 type telephone set both transmitting and receiving, but also to match the frequency response of carrier systems of modern design. Modern design carrier systems meet the response requirements of CCITT and have an effective bandwidth (that is, 3 db down points relative to 1,000 cps) at 300 and 3,400 cps. This can be seen in Figure 4 for a W. E. Co. "N-2" carrier system. Thus, the D-66 will be a good match when connecting with such carrier systems. Other types of loading systems with narrower bandwidths than that of the carrier system will not.

Voice Frequency Extensions

Voice frequency extensions for a technique where the circuit operates by carrier or radio multiplex equipment for a portion of the distance and from there on it connects to voice frequency facilities. The voice frequency portion need not be four-wire. The reason for this, again, is because it is not needed for transmission reasons. All present DDD objectives and other requirements are met solely on the basis of two-wire D-66 operation and more stringent future objectives can also be met when this becomes necessary. All the considerations, all the discussion given above on circuits which are entirely on a voice frequency basis are also applicable to these voice frequency extensions.

Voice frequency extensions find wide spread use in the telephone systems of the REA borrowers because they are more economical. For example, they allow the connecting company to use carrier or four-wire voice for their portion of the route where they so desire and the REA borrower can use two-wire voice to connect with them and this may be vastly more economical to him.

The thing to remember with two-wire voice frequency extensions is that they allow the connecting company to use the most economical instrumentalities to them and also those which may be the most economical for the REA borrower and also all transmission objectives are met.

Some actual performance which is expected with two-wire D-66 voice frequency extensions off carrier is shown in Table VII. The particular measurements were made at the Bell toll center at Iron Mountain, Michigan. The telephone company connecting with Bell is the Ontanagon Telephone Company, Ontanagon, Michigan. The echo return loss performance shown is much better than the objectives needed to be met.

Circuit Length Capability

Two-wire voice frequency circuits D-66 loaded with the economical E-6 repeaters will accommodate quite a range of distances. In Chart III the maximum cable lengths which meet VNL + 2 objectives for toll connecting trunks and 4 db for EAS trunks are shown for 24, 22 and 19 gauge exchange cables. It can be seen that with as fine a gauge as 24 circuits as long as 8.5 miles will meet VNL + 2 objectives. With the 22 gauge this length becomes as much as 14.8 miles. For the EAS applications the respective distances become 13.3 and 21.6 miles.

Summary and Conclusion

From a technical standpoint there is no advantage to four-wire voice frequency operation when using D-66 loading.

Two-wire voice frequency operation with D-66 loading not only meets but will actually give better results than the present objectives and requirements which have to be met.

For the future the two-wire D-66 system stands ready to provide even better transmission service because it has this built-in transmission flexibility.

Because four-wire voice frequency operation is normally less economical in the telephone systems of the REA borrowers, two-wire justification should be required in all cases where four-wire operation is actually used.

TABLE I

MEASURED ECHO RETURN LOSS AND SINGING POINT - db
2-WIRE, 22-D-66, E-6 REPEATERED
(WORST CASES)

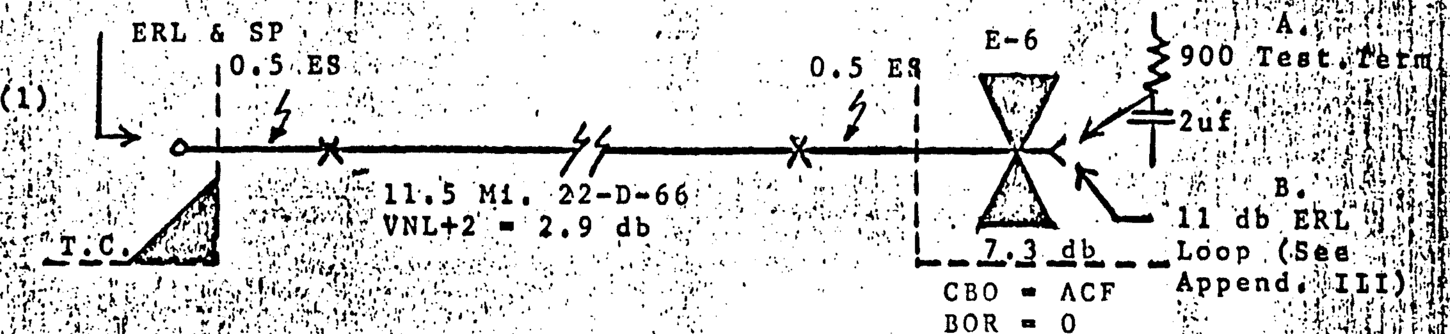


FIGURE 1

ECHO RETURN LOSS		SINGING POINT	
900+2	AVG. LOOP	900+2	AVG. LOOP
21.5	14.8	14	7

NET CIRCUIT LOSS

Freq. - CPS	LOSS
300	3.0
500	2.4
1000	1.9
2000	2.1
3000	3.4

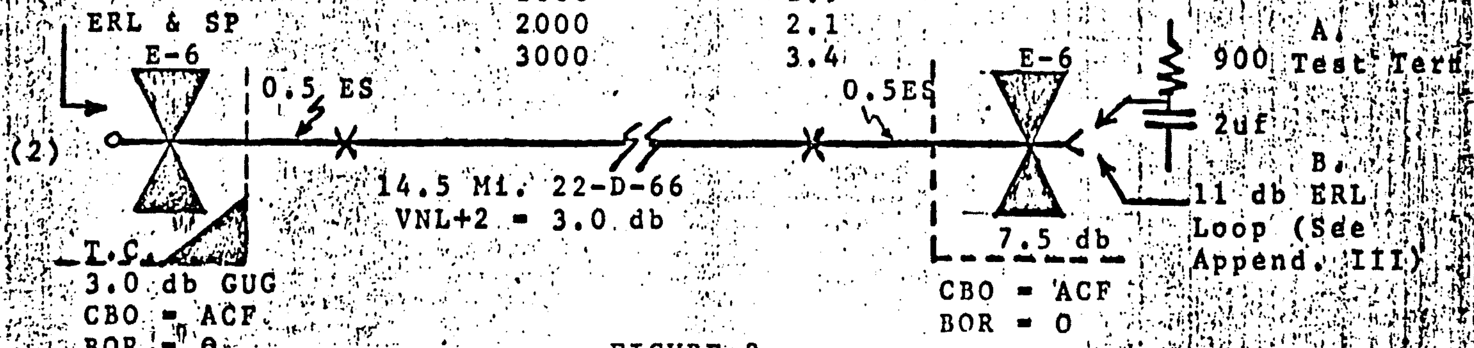


FIGURE 2

ECHO RETURN LOSS		SINGING POINT	
900+2	AVG. LOOP	[illegible]+2	AVG. LOOP
29	[illegible]	23	9

NET CIRCUIT LOSS

[illegible] - CPS	LOSS
[illegible]00	3.5
500	2.6
1000	[illegible]

TABLE II

MEASURED ECHO RETURN LOSS AND SINGING POINT IN db
TOLL CONNECTING, VNL+2 TRUNKS
2-WIRE, 19-D-66, E-6 REPEATERED
(WORST CASES)

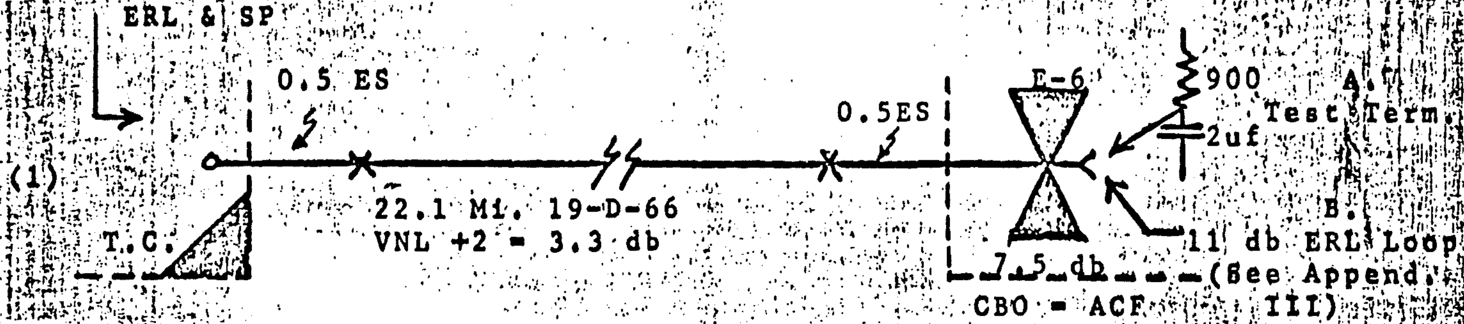


FIGURE 3

ECHO RETURN LOSS		SINGING POINT	
900+2	AVG. LOOP	900+2	AVG. LOOP
24.5	16.5	16	8

NET CIRCUIT LOSS

Freq. - CPS	LOSS
300	3.8
500	2.8
1000	2.2
2000	3.0
3000	5.0

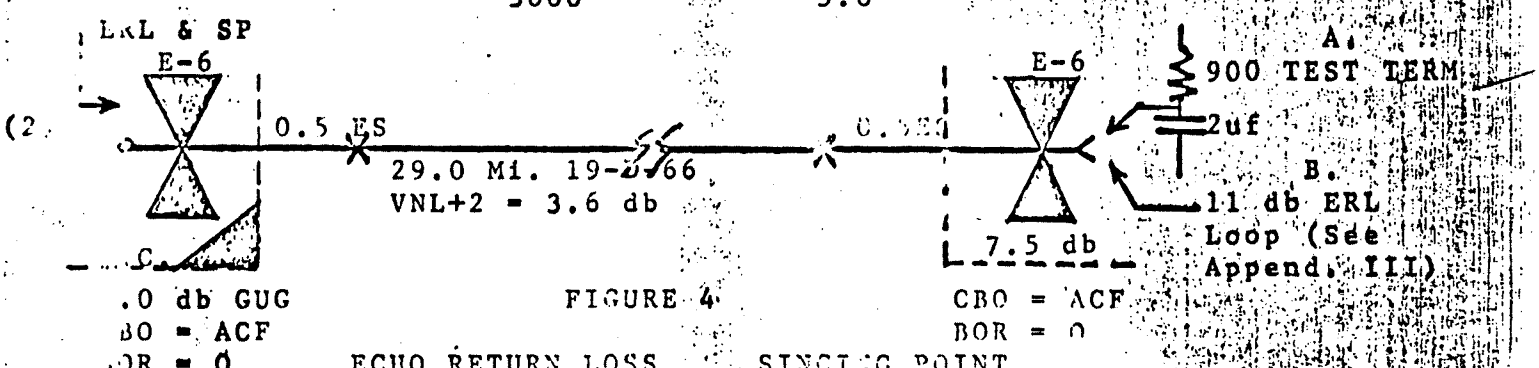


FIGURE 4

ECHO RETURN LOSS		SINGING POINT	
900+2	AVG. LOOP	900+2	AVG. LOOP
33.5	17.5	18	12

NET CIRCUIT LOSS

Freq. - CPS	LOSS
300	4.7
500	3.3
1000	2.8
2000	3.2
3000	6.2

TABLE III

MEASURED ECHO RETURN LOSS - WORST CASES

2-WIRE, D-66 LOADED, E-6 REPEATERED TRUNKS

HAVING IMPEDANCE COMPENSATORS AT TOLL CENTER

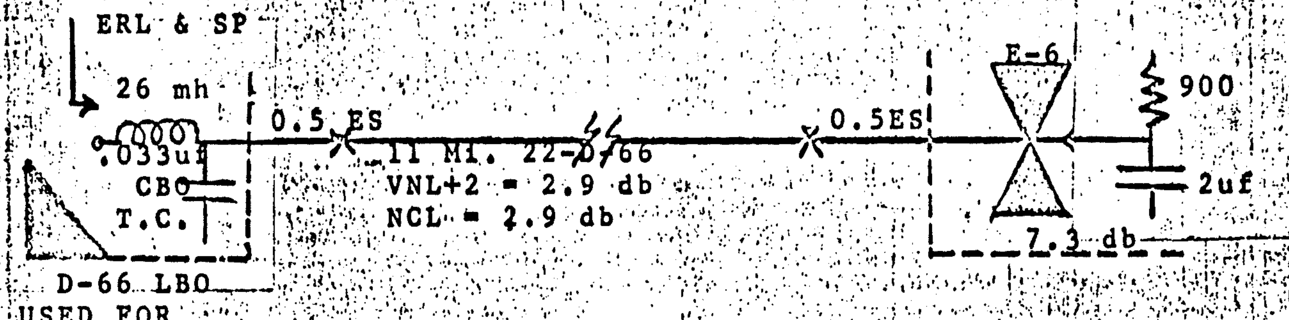
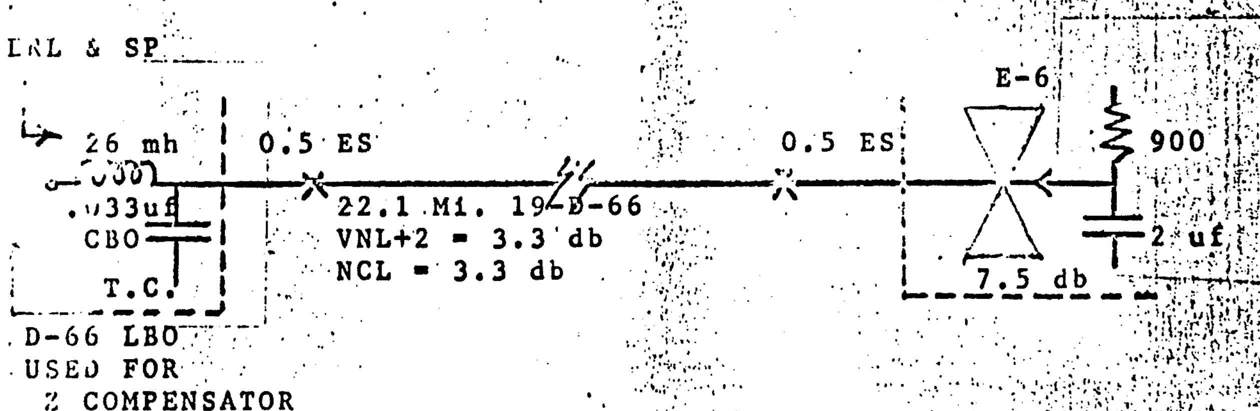


FIGURE 1

<u>ECHO RETURN LOSS</u> <u>900+2 uf</u>	<u>SINGING POINT</u> <u>900+2</u>
33.5 db	28



<u>ECHO RETURN LOSS</u> <u>900+2 uf</u>	<u>SINGING POINT</u> <u>900+2</u>
36.5	24

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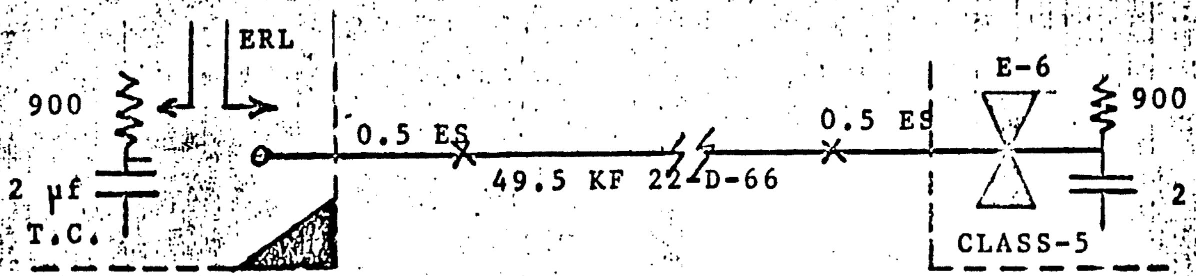
TABLE IV

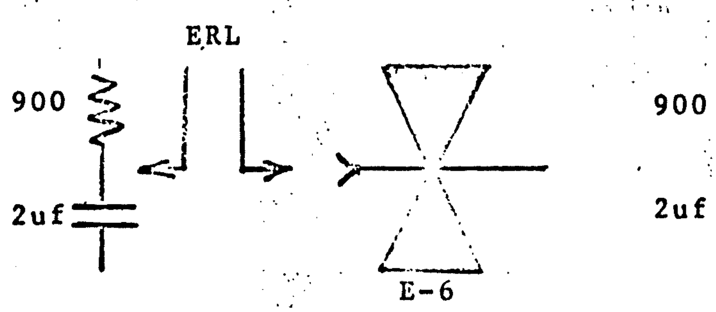
ECHO RETURN LOSS-TERMINAL E-6 REPEATER AT C-5 OFFICE TERMINATED IN 900+2



E-6 GAIN-UNIT GAIN-db	ERL-db
1	21.5
2.1	21.5
3.0	21.5
4.0	21.5
5.1	21.5.
6.0	21.5

TABLE V

ECHO RETURN LOSS E-6 REPEATER GAIN-UNIT (ONLY) vs. 900 + 2.16 uf



E-6 GAIN UNIT	ECHO RETURN LOSS-db
1	36
2.1	34.5
3.0	31
4.0	28.5
5.1	25.5
6.0	23

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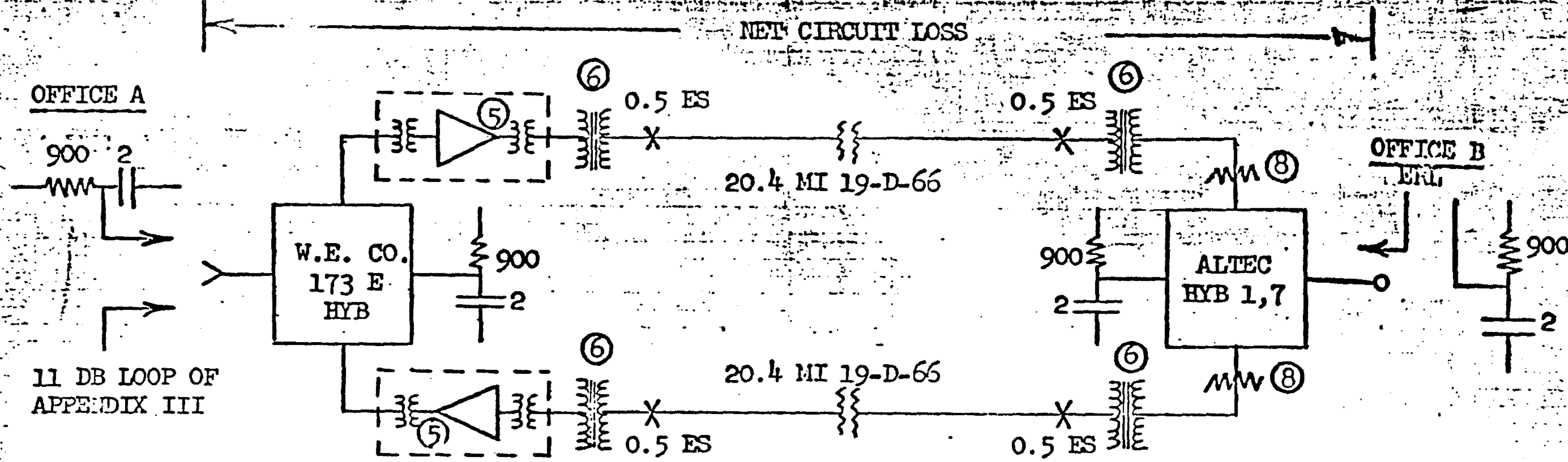
TABLE VI
ECHO RETURN LOSS PERFORMANCE
4-WIRE VOICE CIRCUIT



NET CIRCUIT-LOSS	ECHO RETURN LOSS AT OFFICE B, OFFICE A TERMINATED IN: 900 + 2	AVG LOOP
2 db	29.5	15
3 db	29.5	17

CIRCUIT RESPONSE @ 2 db NCL

FREQ-cps	LOSS-db
300	1.4
500	1.9
1000	2.0
2000	2.7
3000	4.0

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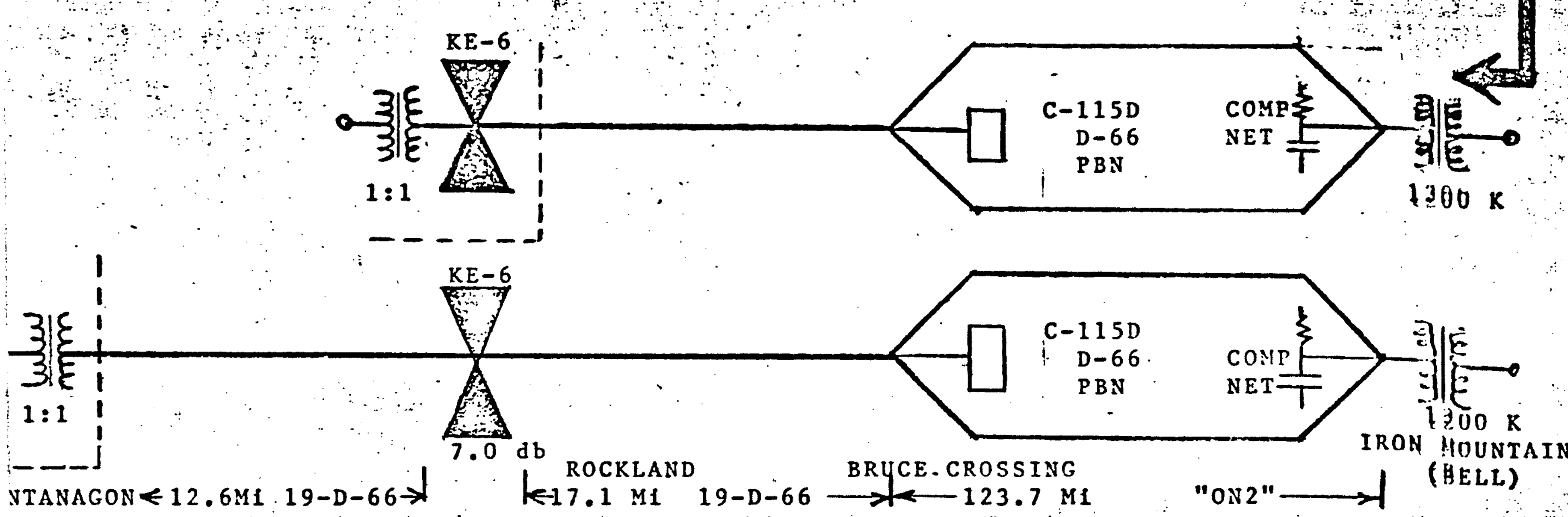
NOTES:

5. Altec Lansing Co. 455 BX Amplifiers
6. Altec Lansing Co. 15192 1:1.5 Z Ratio Repeat Coils
7. 2 uf Capacitor in A&B Leads (Terminals 8 and 9 in Appendix V. Coil B)
8. 3400 Ohm Resistors For Shunting Hybrid Input Impedance to 900 Ohms.

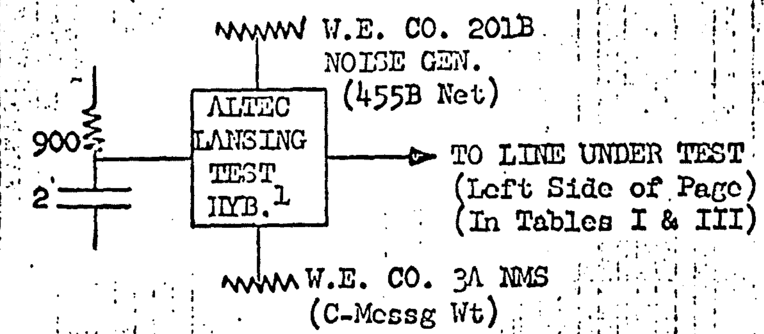
TABLE VII

ECHO RETURN LOSS - TOLL CONNECTING TRUNKS
ONTANAGON TELEPHONE COMPANY, ONTANAGON, MICHIGAN
"ON2" CARRIER PORTION OPERATED AT NET GAIN



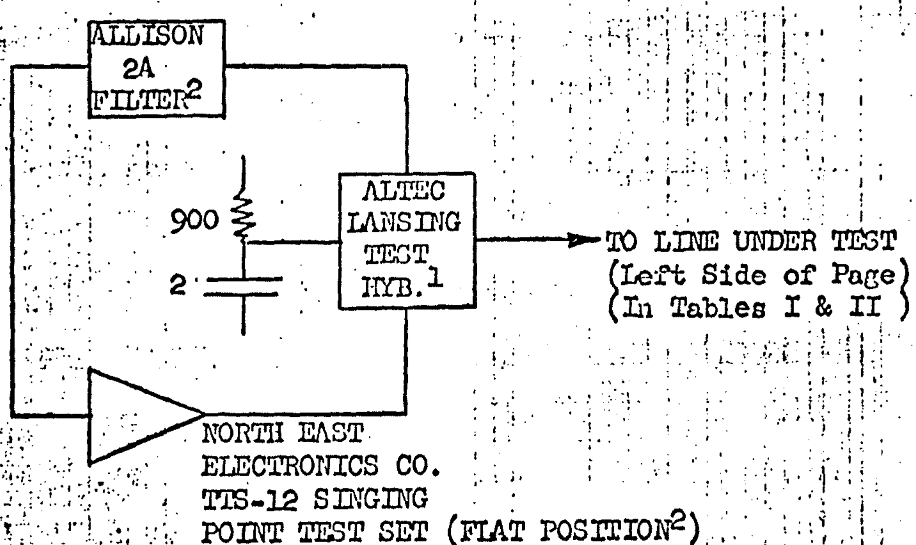
TRUNK NO.	CLASS-5 OFFICE TERMINATED IN 900+2 uf BARE CABLE ONLY	CLASS-5 TERMINATED IN 900 OHM THROUGH C.O. TRUNK EQPT. (DX)	CLASS-5 OFFICE TERMINATED IN 500 TEL. SET THROUGH C.O. TRUNK EQPT.
1 ROCKLAND	29	28.5	14
2 "	30	25	14
3 "	32	25	14
1 ONTANAGON	23	22	13
2 "	22	21	13
3 "	22	20	13
4 "	22	21	14
5 "	22	20.5	13
6 "	22	20.5	13
7 "	22	21	14

APPENDIX I
TEST HYBRID & EQUIPMENT CONFIGURATION FOR ERL MEASUREMENT



APPENDIX II

SINGING POINT MEASUREMENT SETUP

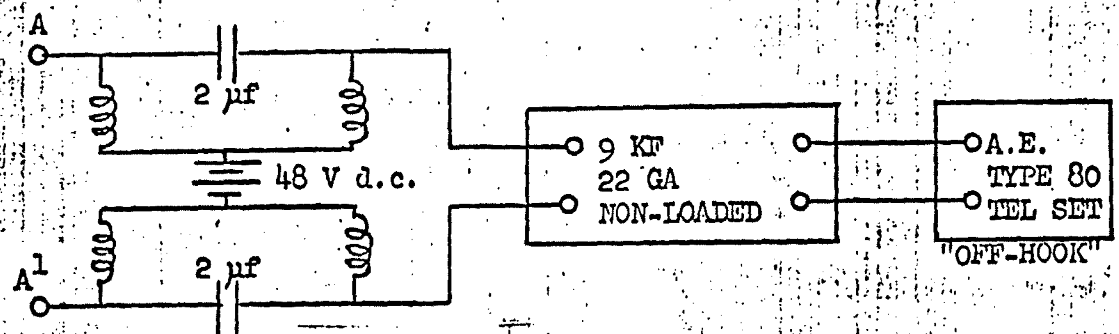


NOTES:

1. Altec Lansing Co. type 15189 repeating coils connected as hybrids. 600 ohms on 4-wire sides, 900 ohms on 2-wire sides

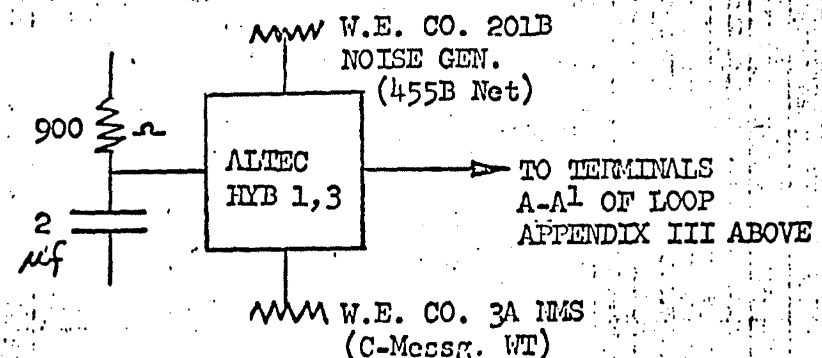
2. Allison Co. type 2A filter connected as bandpass as follows: LC = 150 cps x 1.3
HC = 2400 cps x 1.42
For bandpass filter response refer to Appendix VI

APPENDIX III
AVERAGE LOOP CONFIGURATION
(REFER TO TABLES I & II)



TRANSMISSION BRIDGE
FEDERAL TYPE B-60140 RELAYS

APPENDIX IV
ECHO RETURN LOSS-AVERAGE LOOP



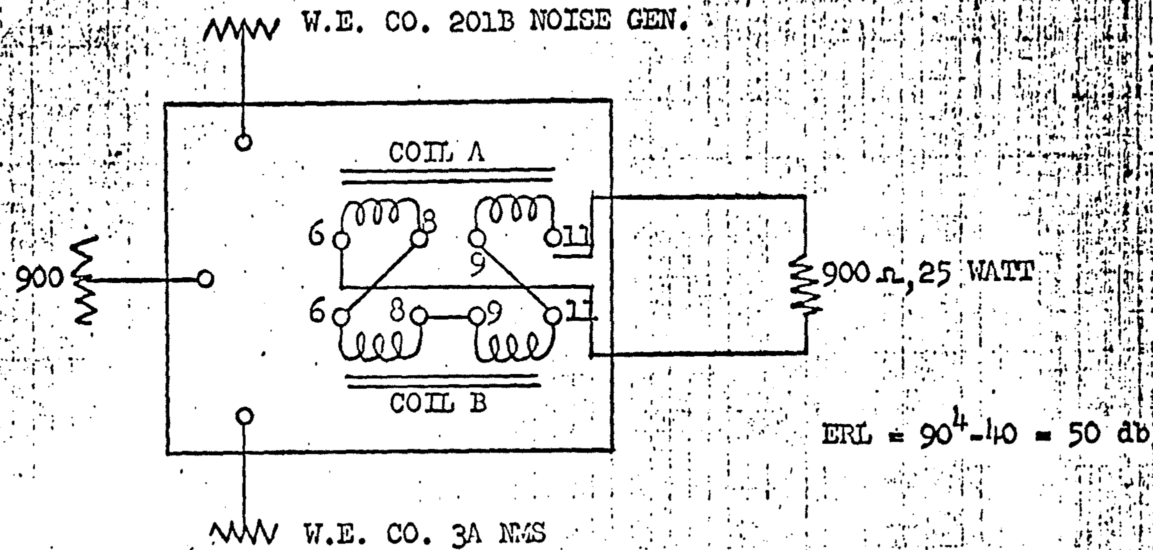
ECHO RETURN LOSS = 90[4] dbrn-C-79dbrn-C = 11 db

NOTES:

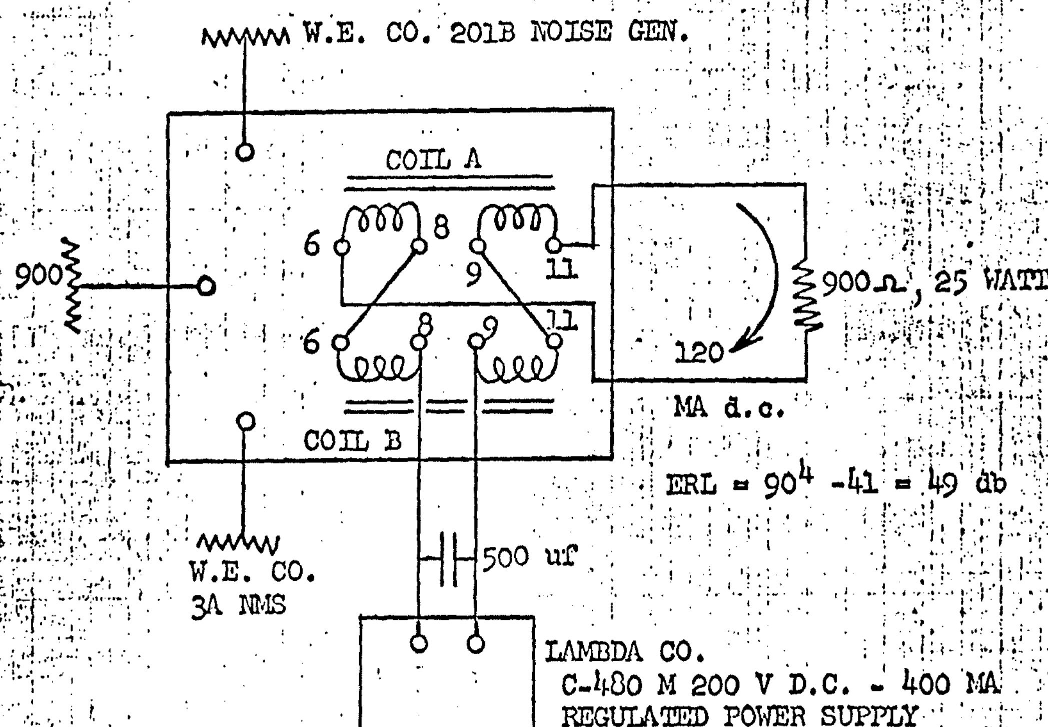
3. Saturation Test. Refer to Appendix V

4. 90 dbrn-C is calibration level (with "line side" terminals of hybrid open or short-circuited)

APPENDIX V
SATURATION TEST ALTEC HYBRID[1]



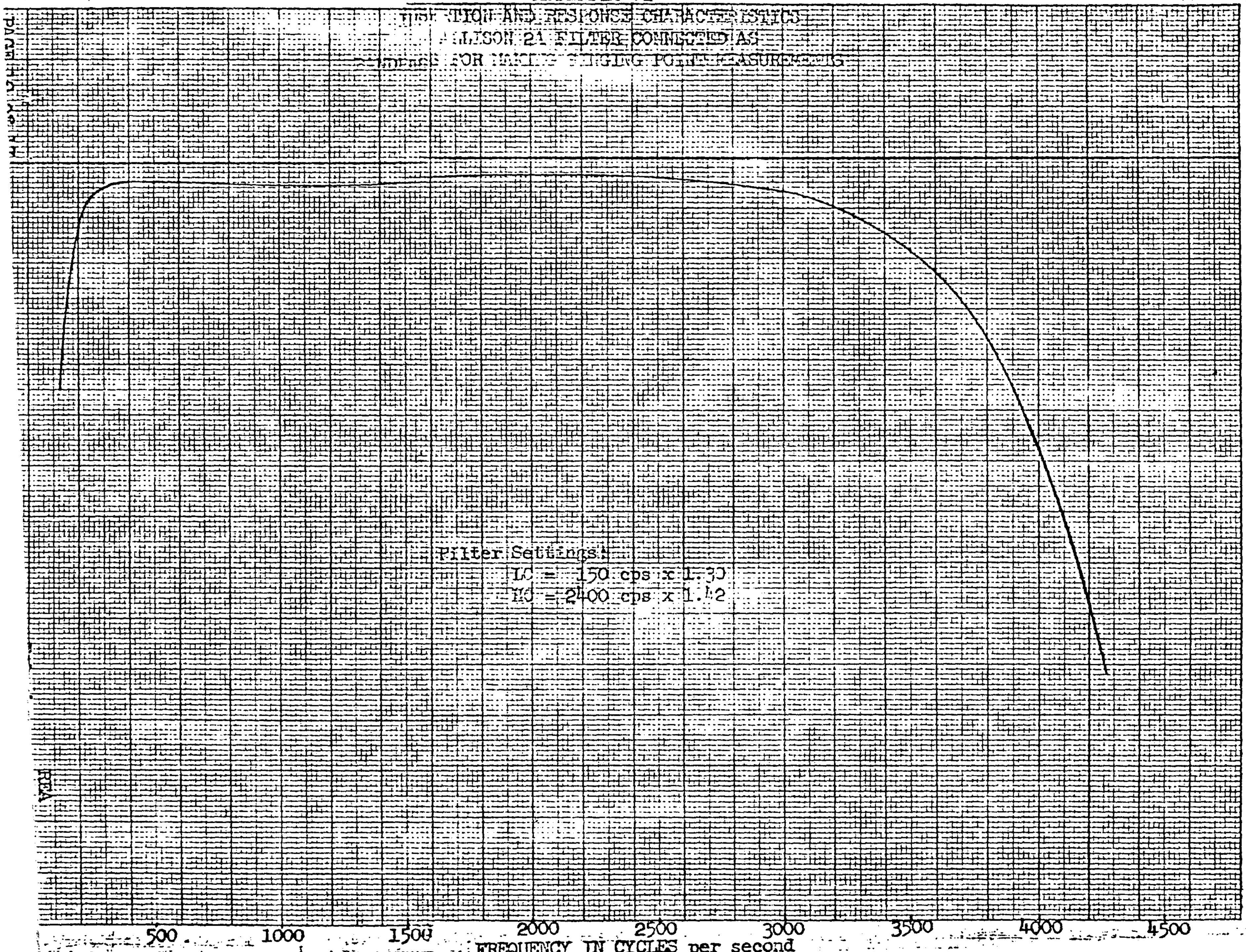
A. NO D.C. THROUGH "LINE SIDE" WINDINGS OF HYBRID



B. WITH 120 MA d.c. THROUGH "LINE SIDE" OF HYBRID

REA

APPENDIX VI


ALLISON 21 FILTER CONNECTED AS
Filter Settings:
LC = 150 cps x 1.30
HC = 2400 cps x 1.42
REA
500
1000
1500
2000
2500
3000
3500
4000
4500
FREQUENCY IN CYCLES per second

	ECHO RETURN LOSS		SINGING POINT	
	AVERAGE	STANDARD DEVIATION	AVERAGE	STANDARD DEVIATION
WO-WIRE TRUNKS	18 db	2.5 db	10 db	2.0 db
WO-WIRE TRUNKS IN SAME BUILDING	24 db	2.0 db	18 db	2.0 db
BELL SYSTEM CARRIER OR EQUIVALENT	22 db	3.0 db	15 db	2.0 db

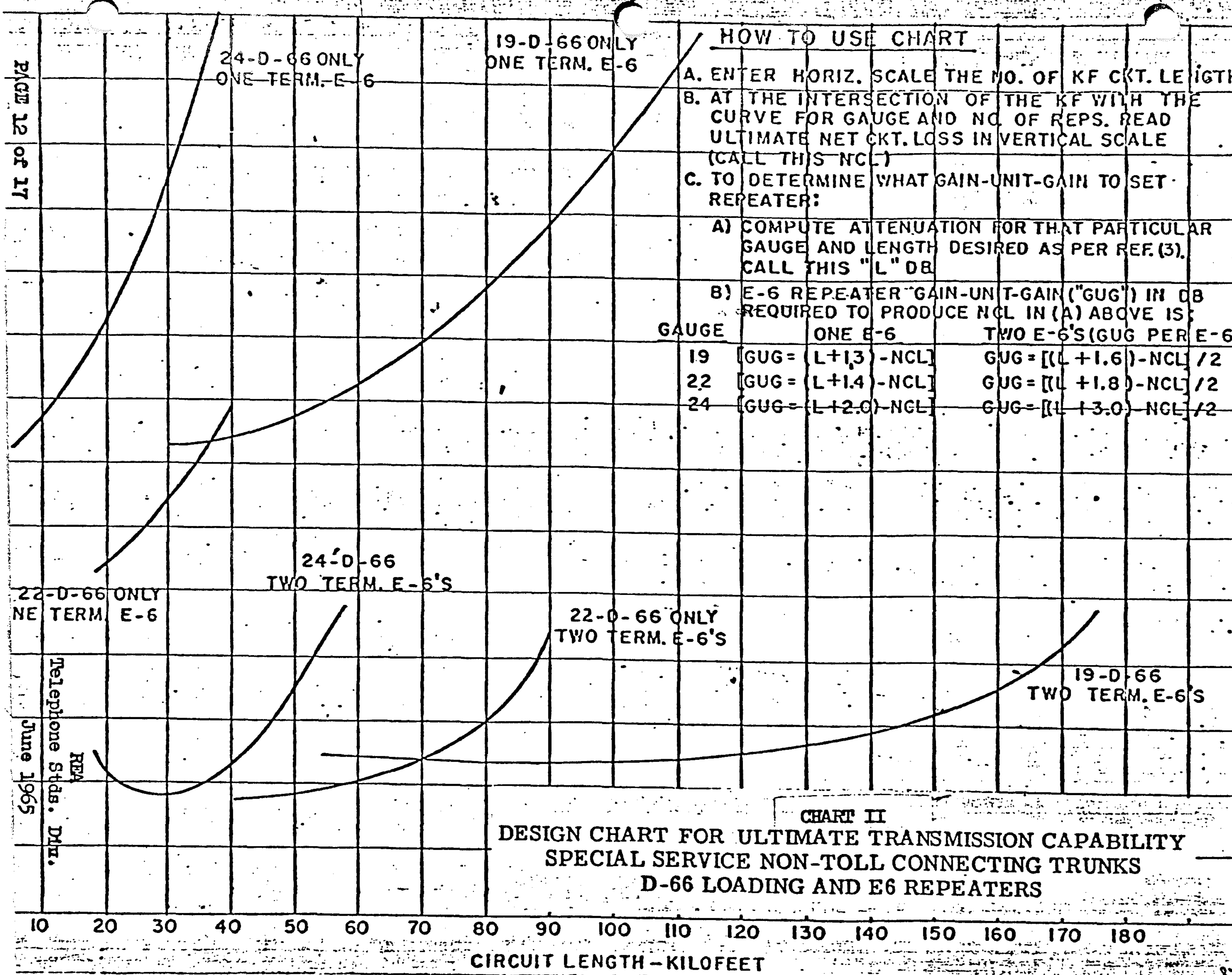
.08 ECHO RETURN LOSS ON TERMINAL TRUNKS IS MEASURED WITH A NOISE GENERATOR AND A 3A NOISE MEASURING SET OR EQUIVALENT. THE NOISE GENERATOR IS OF THE RANDOM NOISE TYPE AND THE OUTPUT SHOULD BE SHAPED WITH A WEIGHTING NETWORK TO RESEMBLE THE ENERGY SPECTRUM FROM A TELEPHONE TRANSMITTER. THE NOISE MEASURING SET IS USED WITH C-MESSAGE WEIGHTING. IF A FLAT OR UNWEIGHTED MEASURING SET IS USED, AN EXTERNAL C-MESSAGE WEIGHTING SHOULD BE UTILIZED.

8.10 IF THE AVERAGE ECHO RETURN LOSS AS OUTLINED IN PARAGRAPHS 8.07 AND 8.09 IS OBTAINED UNDER TEST, IT IS EXPECTED THAT THE DESIGN ECHO RETURN LOSS OF 15 DB (STANDARD DEVIATION OF 3 DB) WILL BE MET UNDER SERVICE CONDITIONS WITH ACTUAL SUBSCRIBER LOOP TERMINATIONS.

CHART I

DDD OBJECTIVES IN A T & T CO. BLUEBOOK
NOTES ON DISTANCE DIALING 1961, SECTION 6

RFA



HOW TO USE CHART

A. ENTER HORIZ. SCALE THE NO. OF KF CKT. LENGTH

B. AT THE INTERSECTION OF THE KF WITH THE CURVE FOR GAUGE AND NO. OF REPS. READ ULTIMATE NET CKT. LOSS IN VERTICAL SCALE (CALL THIS NCL)

C. TO DETERMINE WHAT GAIN-UNIT-GAIN TO SET REPEATER:

A) COMPUTE ATTENUATION FOR THAT PARTICULAR GAUGE AND LENGTH DESIRED AS PER REF. (3). CALL THIS "L" DB

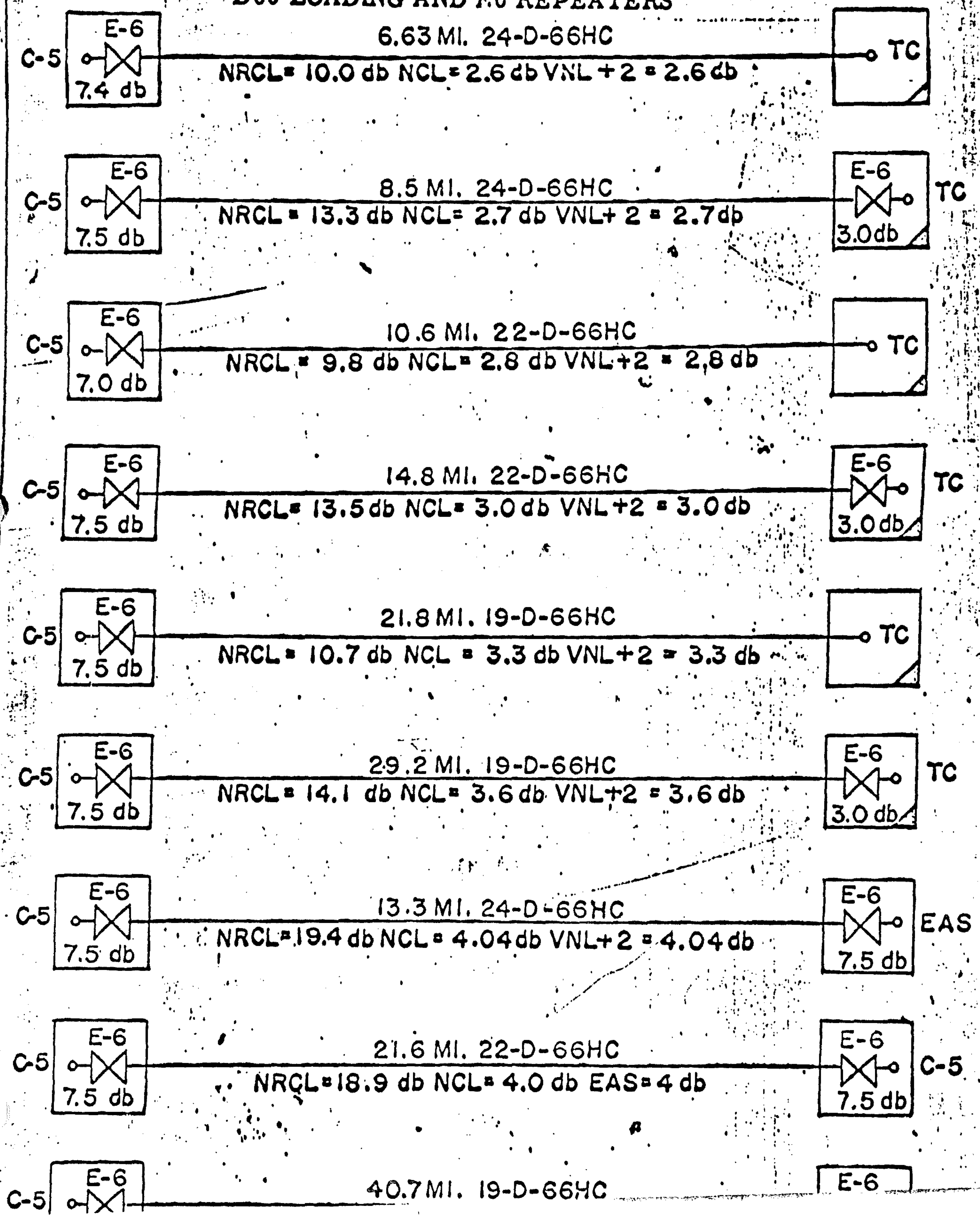
B) E-6 REPEATER GAIN-UNIT-GAIN ("GUG") IN DB REQUIRED TO PRODUCE NCL IN (A) ABOVE IS:

GAUGE	ONE E-6	TWO E-6'S (GUG PER E-6)
19	[GUG = (L+1.3) - NCL]	GUG = [(L + 1.6) - NCL] /2
22	[GUG = (L+1.4) - NCL]	GUG = [(L + 1.8) - NCL] /2
24	[GUG = (L+2.0) - NCL]	GUG = [(L + 3.0) - NCL] /2

CHART II
DESIGN CHART FOR ULTIMATE TRANSMISSION CAPABILITY
SPECIAL SERVICE NON-TOLL CONNECTING TRUNKS
D-66 LOADING AND E6 REPEATERS

CHART III

MAXIMUM CABLE LENGTHS WHICH MEET VNL+2 OBJECTIVES FOR TOLL CONNECTING LINKS AND 4 DB FOR EAS TRUNKS D66 LOADING AND E6 REPEATERS



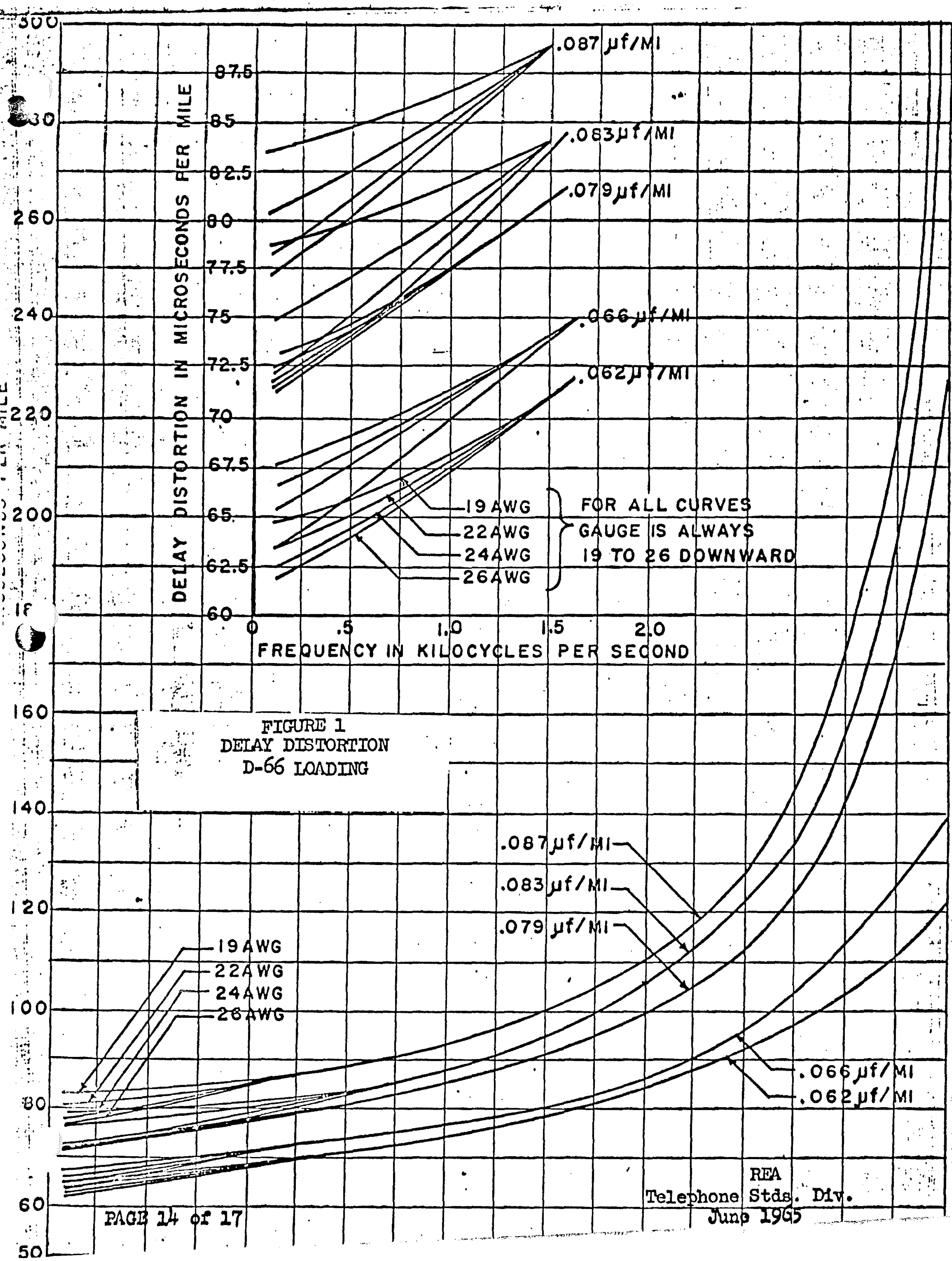


FIGURE 1
DELAY DISTORTION
D-66 LOADING

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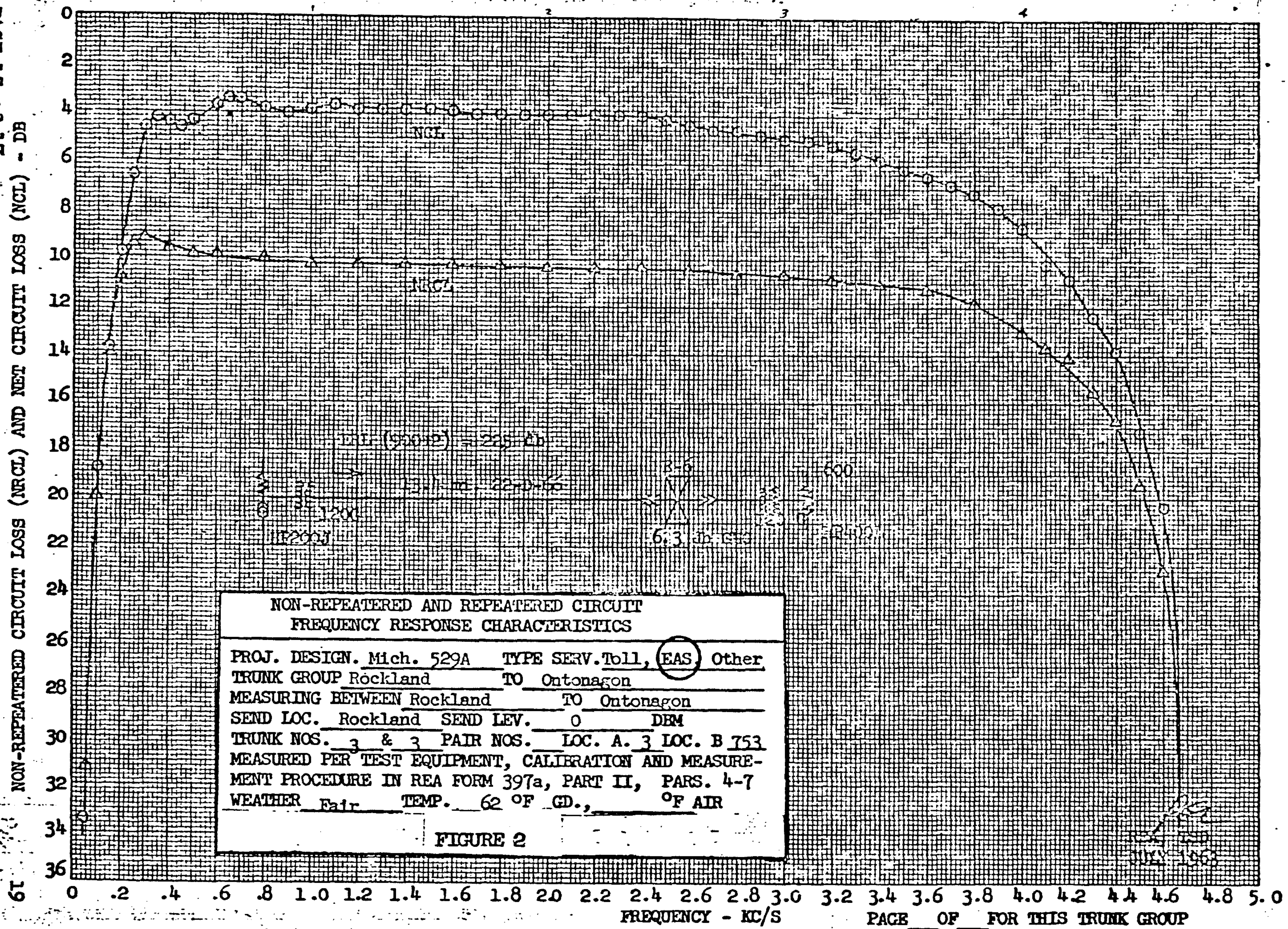
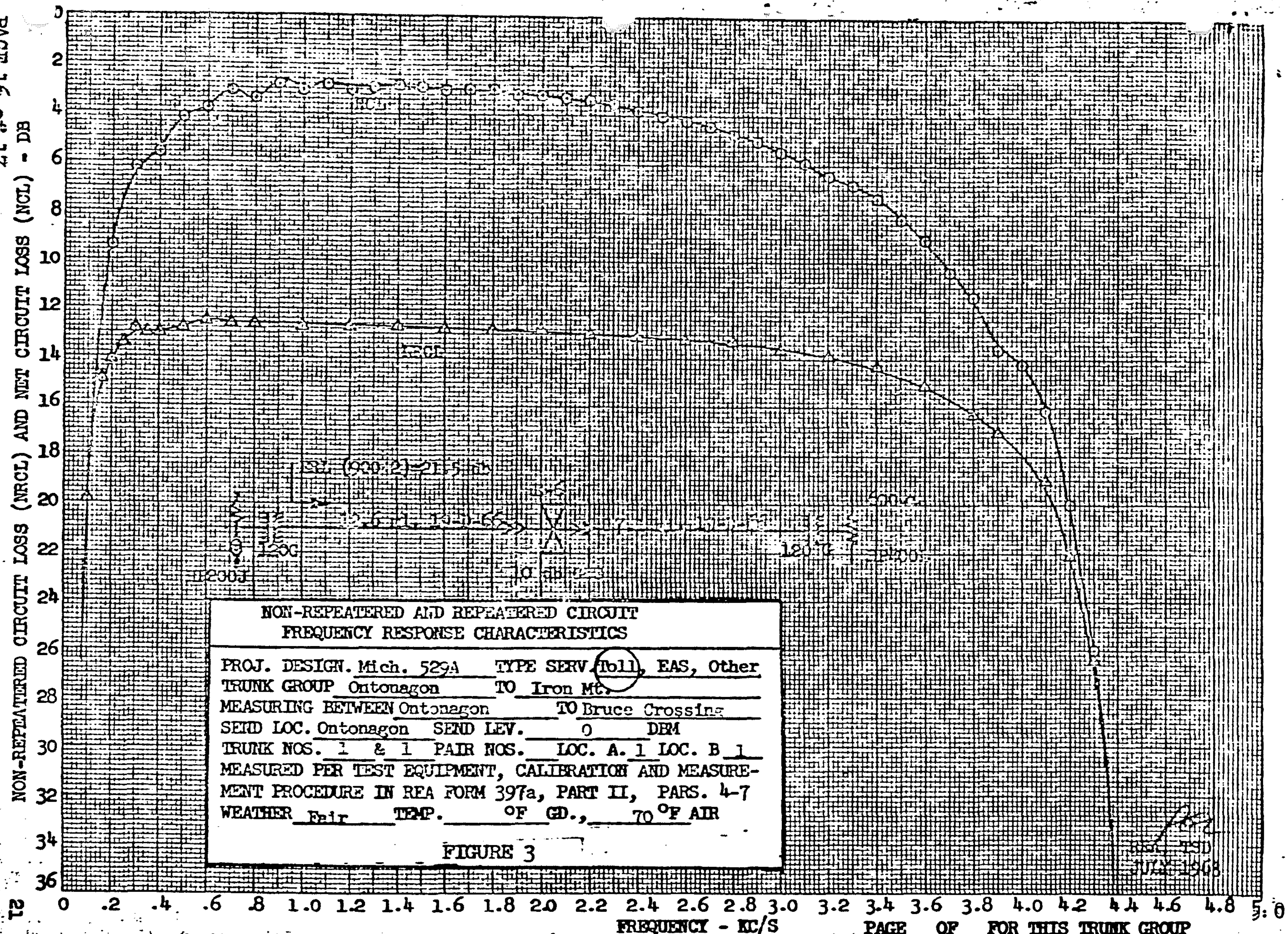

NON-REPEATERED CIRCUIT LOSS (NRCL) AND NET CIRCUIT LOSS (NCL) - DB
FREQUENCY - KC/S
NCL
NRCL
NON-REPEATERED AND REPEATERED CIRCUIT
FREQUENCY RESPONSE CHARACTERISTICS
PROJ. DESIGN. Mich. 529A TYPE SERV. Toll, EAS, Other
TRUNK GROUP Rockland TO Ontonagon
MEASURING BETWEEN Rockland TO Ontonagon
SEND LOC. Rockland SEND LEV. 0 DBM
TRUNK NOS. 3 & 3 PAIR NOS. LOC. A. 3 LOC. B 753
MEASURED PER TEST EQUIPMENT, CALIBRATION AND MEASUREMENT PROCEDURE IN REA FORM 397a, PART II, PARS. 4-7
WEATHER Fair TEMP. 62 °F GD., °F AIR
FIGURE 2
PAGE OF FOR THIS TRUNK GROUP



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