Some Very Long Telephone Circuits of the Bell System

By H. H. NANCE

RECENT papers[1] have discussed at length the use of toll cables for the handling of certain long distance traffic. These cables, which are being used in areas of dense traffic, have been made possible by many developments in cable design, repeaters and loading coils. Coincident with these developments have gone others which are finding their application in the extensive establishment of improved open wire circuits for use over very long distances. The purpose of the present paper is to discuss some of the considerations involved in the overall design and maintenance of these very long open wire circuits. These circuits are often referred to as "backbone" circuits and supply a network of trunk lines for the entire Bell System. The most important of these routes are shown in Fig. 1.

The first transcontinental line was completed in the summer of 1914 and early in the following year three transcontinental telephone circuits were placed in commercial service. These circuits were constructed of copper wire 165 mils in diameter loaded with 250 millihenry coils at intervals of 7.88 miles and had telephone repeaters located at points about 500 miles apart. The opening of these first circuits, while marking a most important stage in the progress of long distance telephony, has been followed by many developments which have made possible increased overall transmission efficiency and improved quality. A discussion of these developments is given in a paper on "Telephone Transmission Over Long Distances," by H. S. Osborne.[2]

Two outstanding characteristics of these new open wire circuits are that they are non-loaded and that the repeaters are of an improved type, the number being increased in consequence of the higher attenuation. With these long non-loaded circuits increased speed of propagation and smoother characteristics are obtained resulting in less echo effect and better volume. Better attenuation-frequency characteristics are obtained and the quality is further improved due to the elimination, to a large extent, of transients. Changes in line attenua-

[1] "Philadelphia-Pittsburgh Section of New York-Chicago Cable," by J. J. Pilliod, *Bell System Technical Journal*, Vol. I, No. 1, July. 1922; *Journal of A.I.E.E.*, August, 1922. "Telephone Transmission Over Long Cable Circuits," by A. B. Clark, *Journal A.I.E.E.*, January, 1923; *Bell System Technical Journal*, Vol. II, No. 1, January, 1923.

[2] For detail discussion see paper on "Telephone Transmission Over Long Distances," by H. S. Osborne, *Journal A.I.E.E.*, Vol. XLII, No. 10, October, 1923.

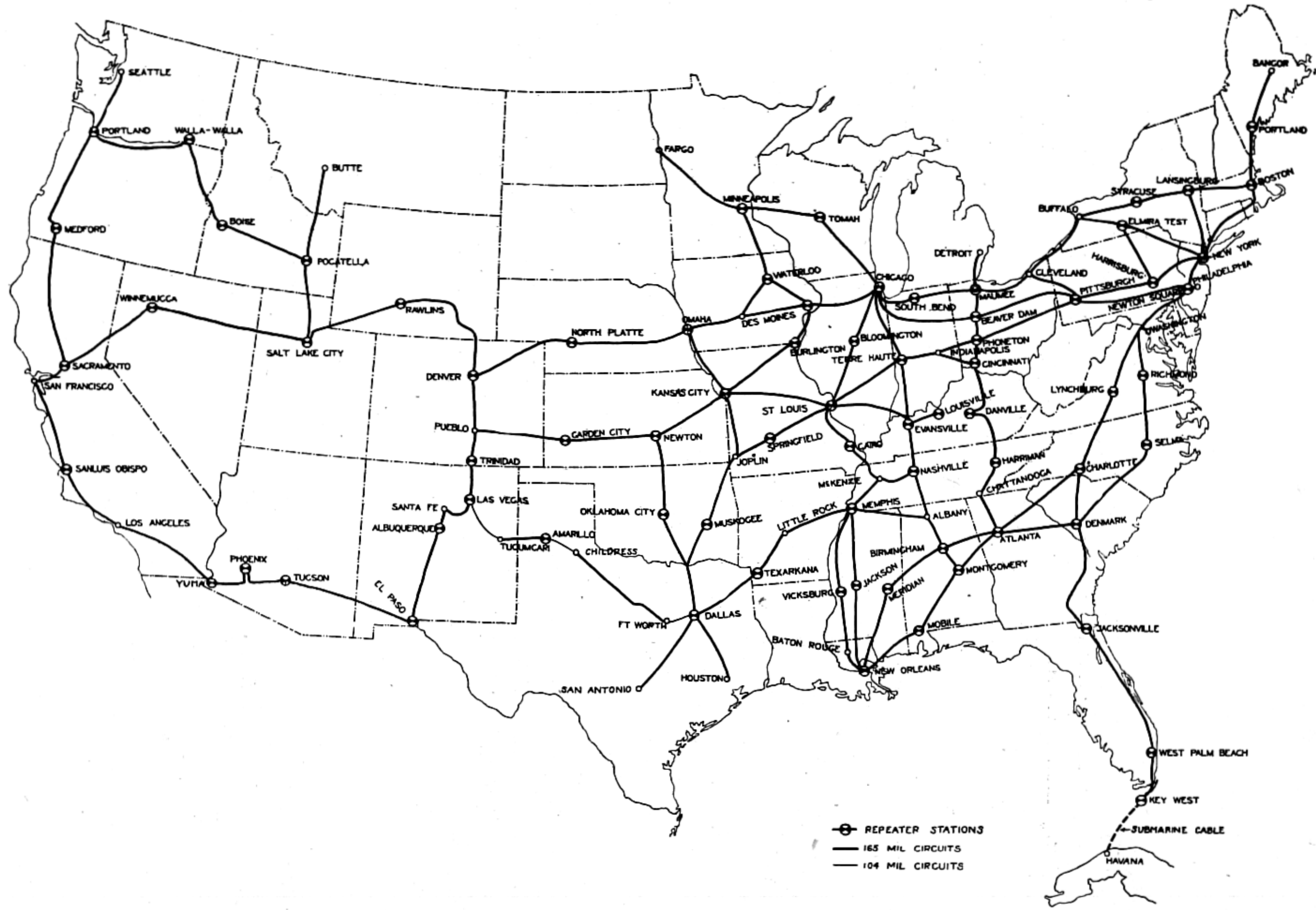
SEATTLE
PORTLAND
WALLA-WALLA
BUTTE
MEDFORD
BOISE
POCATELLA
WINNEMUCCA
RAWLINS
SALT LAKE CITY
SACRAMENTO
SAN FRANCISCO
SANLUIS OBISPO
LOS ANGELES
YUMA
PHOENIX
TUCSON
EL PASO
DENVER
PUEBLO
TRINIDAD
LAS VEGAS
SANTA FE
ALBUQUERQUE
TUCUMCARI
AMARILLO
CHILDRESS
OKLAHOMA CITY
GARDEN CITY
NEWTON
NORTH PLATTE
FARGO
MINNEAPOLIS
TOMAH
WATERLOO
OMAHA
DES MOINES
BURLINGTON
KANSAS CITY
ST LOUIS
SPRINGFIELD
JOPLIN
MUSKOGEE
FT WORTH
DALLAS
SAN ANTONIO
HOUSTON
TEXARKANA
LITTLE ROCK
McKENZIE
MEMPHIS
VICKSBURG
JACKSON
MERIDIAN
BATON ROUGE
NEW ORLEANS
MOBILE
BIRMINGHAM
MONTGOMERY
ATLANTA
ALBANY
NASHVILLE
CAIRO
EVANSVILLE
LOUISVILLE
DANVILLE
HARRIMAN
CHATTANOOGA
CHICAGO
SOUTH BEND
BLOOMINGTON
TERRE HAUTE
INDIANAPOLIS
PHONETON
CINCINNATI
BEAVER DAM
MAUMEE
DETROIT
CLEVELAND
BUFFALO
SYRACUSE
ELMIRA TEST
HARRISBURG
PITTSBURGH
NEWTON SQUARE
PHILADELPHIA
NEW YORK
LANSINGBURG
BOSTON
PORTLAND
BANGOR
WASHINGTON
RICHMOND
LYNCHBURG
SELMA
CHARLOTTE
DENMARK
JACKSONVILLE
WEST PALM BEACH
KEY WEST
SUBMARINE CABLE
HAVANA
REPEATER STATIONS
165 MIL CIRCUITS
104 MIL CIRCUITS

Fig. 1

tion with weather conditions are also considerably reduced. Furthermore, the use of this type of circuit fits in with the application of carrier current systems for which it is advantageous to use non-loaded 165 mil circuits where these are available.[3]

With the improved repeaters and balancing networks it is possible to obtain a higher degree of balance at the various repeater points. The improved transmission characteristics of these repeaters also contribute toward better quality. Both of these improvements are important in view of the increased number of repeaters in the circuit.

The use of this improved type circuit has been extended during the last few years to connect a large number of the important cities in the United States. A few of the longer circuits are:

Circuit	Approximate Length of Circuit Statute Miles	No. of Through Line Repeaters
Boston-Chicago	1,180	4
Chicago-Denver	1,090	3
Chicago-Los Angeles	2,890	12
Chicago-San Francisco	2,440	8
Dallas-St. Louis	670	2
Denver-San Francisco	1,350	4
Jacksonville-Havana	640	3
New York-Chicago	940	3
New York-Havana	1,710	8
New York-New Orleans	1,400	6
New York-St. Louis	1,020	5
Kansas City-Denver	750	2

One of the most recently established of these circuits is the Chicago-Los Angeles circuit routed over the southern transcontinental line. This and other through circuits on this line from Denver via El Paso to Los Angeles were established last year in order to provide for the growth in transcontinental traffic and to make available a second route as protection for the through service to the Pacific Coast. A brief description of these circuits will be given as typical of the long open wire circuits on this and other routes.

In the following, certain data based on actual experience with circuits on the southern transcontinental route, and in certain instances on circuits on the central transcontinental route are given. These data, however, are in general representative of results obtained on circuits of the same type throughout the Bell System.

From Denver west, a phantom group of four 165 mil wires provides for a Chicago-Los Angeles circuit, a Denver-El Paso circuit,

[3] Refer to paper entitled "Practical Application of Carrier Telephone and Telegraph in the Bell System," by Arthur F. Rose, *Technical Journal*, April, 1923.

an El Paso-Los Angeles circuit and another circuit between Denver and Los Angeles with stations at intermediate points along the line. East of Denver facilities of the same type on an existing through route via Kansas City to Chicago with four intermediate repeater stations are used for the Chicago-Denver portion of the Chicago-Los angeles circuit. The facilities and equipment arrangements permit rapid changes at the various repeater stations so that the circuit layout may easily be changed to take care of temporary rearrangements necessitated by trouble and to set up different layouts for the evening and night loads which at present are heavier than the day load.

Duplex telegraph equipment has been installed at various stations along the new route from Denver to Los Angeles for operating four direct current telegraph circuits derived by compositing the open wire circuits. In addition, a 10-channel carrier current telegraph system has been installed. Thus a total of 17 circuits, 3 telephone and 14 telegraph, operating on four wires are at present available over the new route for the through service. This requires a considerable

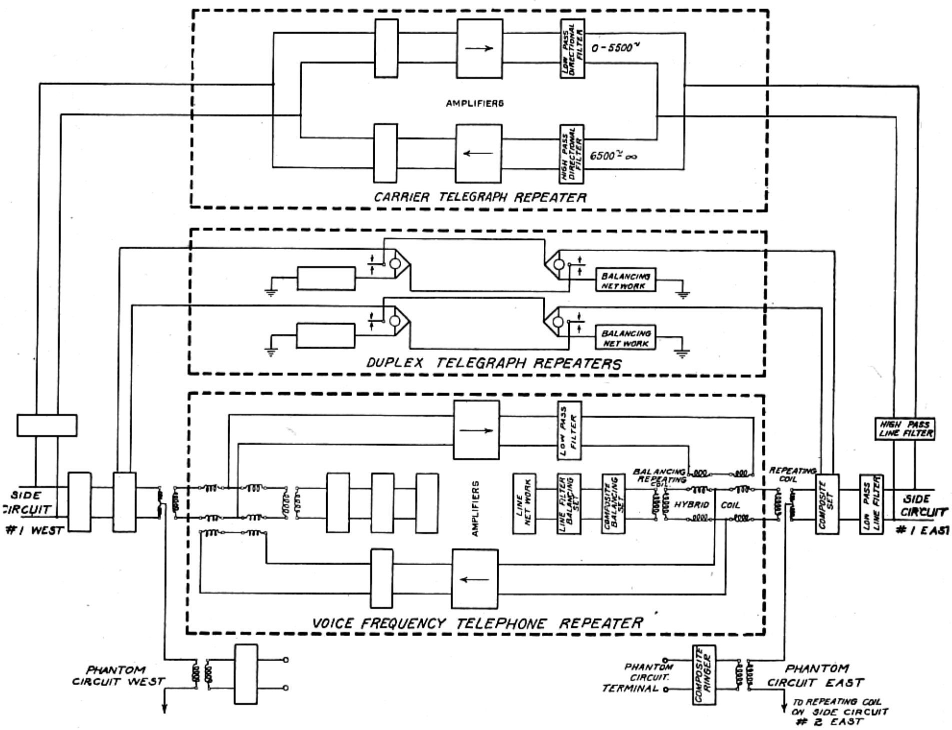

Fig. 2—Simplified Equipment Layout—Intermediate Repeater Station—Chicago-Los Angeles Circuit

amount of equipment at each of the repeater stations as illustrated by Fig. 2 which shows a simplified equipment layout at a typical repeater station. In addition to this number of circuits, a carrier current telephone system or an additional carrier current telegraph system can be provided and operated over these same wires at such time as traffic growth may warrant.

In view of the importance and number of services routed over the through wires, careful consideration was given to construction features. Copper line wire 165 mils in diameter affording high mechanical strength as well as low transmission loss was provided. For a

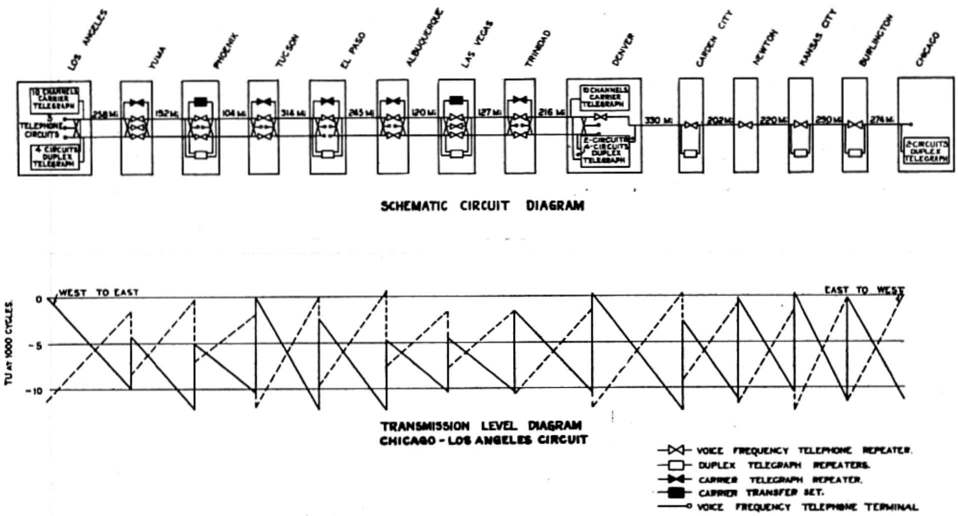

Fig. 3

large part of the distance an existing pole line over this route was used, but a new line was constructed in certain sections where the existing line was carrying full capacity load or was otherwise not suitable, and in other sections to avoid, as far as practicable, the use of intermediate or toll entrance cable. In a number of cases an important consideration in rerouting was the avoidance of exposures to electric light and power circuits. Considerable pole replacement work also was done in some of the existing pole line sections to strengthen the structure. The wires were transposed in accordance with a design[4] providing low crosstalk values at the freqiencies used in carrier operation as well as within the voice range.

In determining the location of repeater stations for the telephone circuits, direct current telegraph and carrier systems, it was neces-

[4] "Carrier Current Telephony and Telegraphy," E. H. Colpitts and O. B. Blackwell, *Journal A.I.E.E.*, Vol. XL, No. 5, May, 1921.

sary to consider the economical limit of attenuation loss in each repeater section, the degree of balance to be obtained between the line impedances of the different sections and the corresponding balancing network impedances, and the proper transmission levels, as well as the limited choice of points where it would be practicable to maintain these stations from an economy and maintenance force standpoint. Fig. 3 shows the layout of through circuits on the southern transcontinental line and a transmission level diagram of the Chicago-Los Angeles telephone circuit, indicating the location and spacing of repeater points, attenuation losses in the different sections and amplification of repeaters.

Impedance Characteristics. It has been practicable in the construction of the new facilities to avoid long sections of intermediate or entrance cable except at a few points and in general, very smooth impedance characteristics of the different repeater sections have been obtained. At the points where appreciable lengths of cable could not well be avoided, a special type of loading[5] has been designed

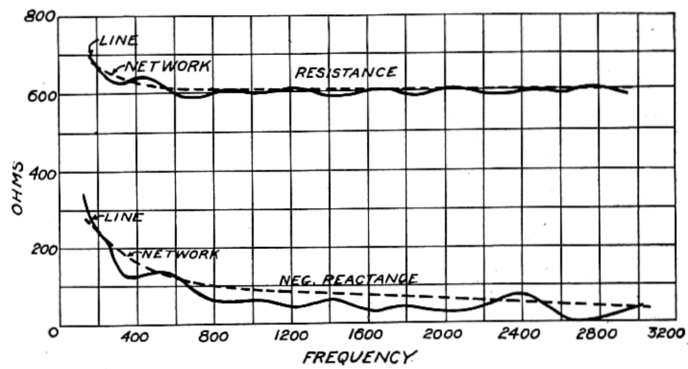

Fig. 4—Impedance Characteristic 216 Mile Repeater Section Non-Loaded 165 mil Physical Circuit (Circuit Terminated to Appear as Infinite Line)

for the purpose of raising the impedance of the cable circuits to values that match the impedance of the open wire at the carrier frequencies as well as at voice frequencies. This loading also is of particular benefit in reducing the attenuation loss at carrier frequencies which in non-loaded cable may be comparatively high.

The impedance characteristic of a typical repeater section 216 miles long is shown by the heavy lines in Fig. 4. The circuit in this case is terminated at the distant end by a network which makes it

[5] Refer to paper on "Carrier Current Telephony and Telegraphy," by Colpitts and Blackwell, previously noted.

appear as an infinitely long line. The slight irregularity indicated by the humps in the impedance curve is due to a short section of non-loaded entrance cable at the distant end. Fig. 5 shows the same section of line terminated at the distant end by the impedance of the repeater into which it normally works. The impedance character-

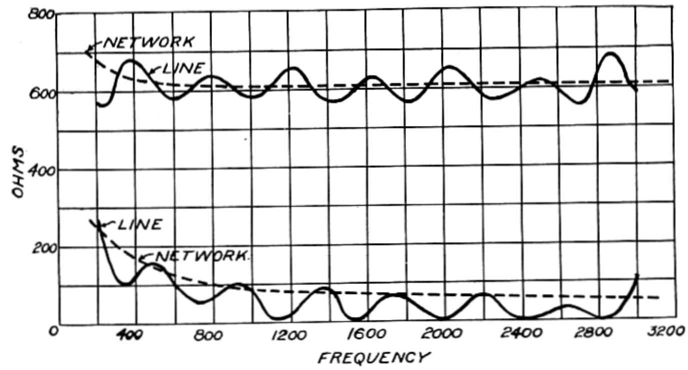

Fig. 5—Impedance Characteristic 216 Mile Repeater Section Non-Loaded 165 mil Physical Circuit (Terminated at Distant End by Passive Impedance of Adjacent Repeater)

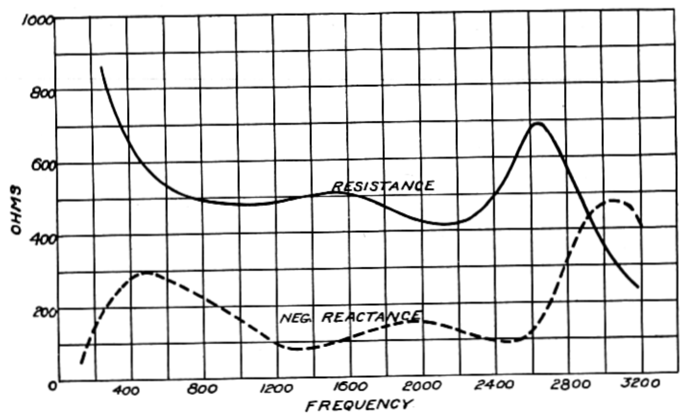

Fig. 6—Passive Input Impedance Characteristic of Improved "22" Type Repeater

istic of the repeater is shown in Fig. 6. The dotted curves in Figs. 4 and 5 are the impedance components of the network used to balance the line circuit. This network is of the precision type,[6] designed for use in connection with long non-loaded open wire circuits which employ repeaters amplifying a wide band of frequencies.

[6] "Telephone Repeaters," by B. Gherardi and F. B. Jewett, A.I.E.E. Transactions, Vol. XXXVIII, No. 11, November, 1919. See also "Impedance of Smooth Lines and Design of Simulating Networks," Ray S. Hoyt, *Technical Journal*, April, 1923.

Transmission Characteristics of Line and Repeater. Fig. 7 shows the attenuation frequency characteristic of a typical repeater section expressed in *TU*.[7] The amplification frequency characteristic of the telephone repeater shown in Fig. 8 is such as to compensate for the inverse characteristic of the line circuit so that the over-all transmission characteristic of the circuit will be uniform over the important frequencies of the speech range as illustrated by Fig. 9.

Signaling. On the shorter of these circuits employing only a few repeaters, signaling current is relayed at each repeater point, new energy being sent into the adjacent section of the line by the operation of relays associated with the repeater. 135-cycle current is used for the signaling current sent over the line, this being the frequency commonly used for signaling over composited circuits. On longer circuits employing several repeaters, the time lag of the ring can be decreased by a system employing a combination of amplified and relayed ringing at alternate repeater stations. At points where the ring is amplified, it is necessary to increase the repeater amplification at 135 cycles in order that sufficient ringing energy may reach the relaying repeater point to operate the ringing relays. This is accomplished by making slight changes in the input circuit of the repeater to increase its efficiency at the lower frequencies as illustrated by the dotted curve in Fig. 8. Best results are obtained by relaying at alternate repeater points.

At each relayed ringing point a certain time interval is required for the operation of the relays and for this reason the length of time during which the ringing current is applied to the line may become less and less for each succeeding repeater. If the ring, therefore, is not of sufficient duration, it is likely that sufficient ringing energy to operate the line signal will not be received at the distant terminal. This has introduced some operating difficulties and made it necessary to exert great care in the maintenance of the apparatus at the intermediate as well as at the terminal stations involved and careful overall checking and lining up of the circuit as a whole.

There has been developed a system employing signaling currents of voice frequency which has largely overcome these difficulties. The signaling current is amplified by the repeaters with approximately the same efficiency as the voice currents so that relaying is unnecessary. Particular attention has been given in the design of the system to preventing false operation of the signals from voice or extraneous currents.

[7] See article in this issue "The Transmission Unit and Telephone Transmission Reference System," by W. H. Martin.

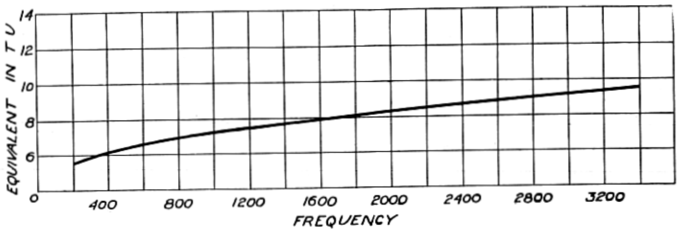

Fig. 7—Transmission-Frequency Characteristic 216 Mile Repeater Section of Non-Loaded 165 mil Physical Circuit

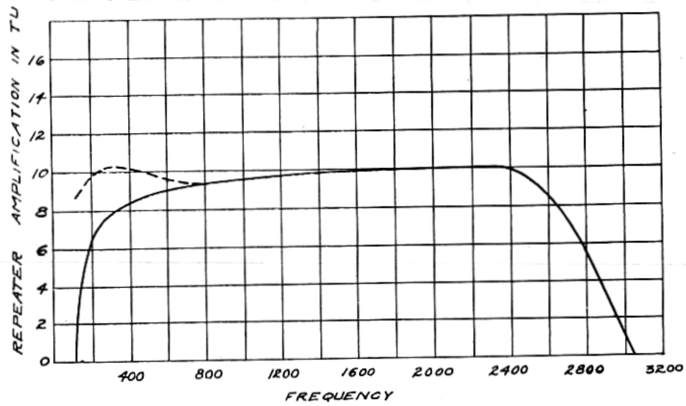

Fig. 8—Amplification-Frequency Characteristic of Improved "22" Type Repeater

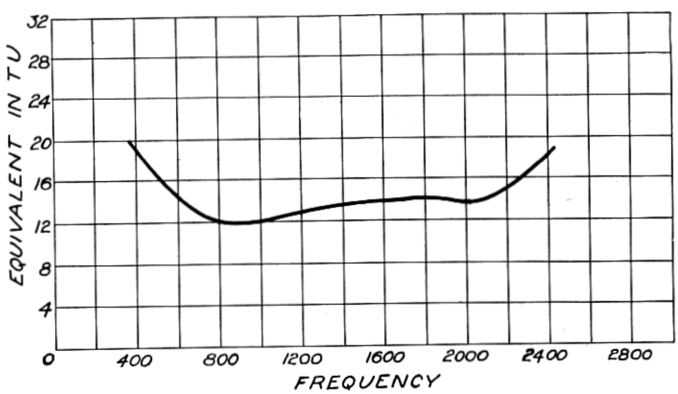

Fig. 9—Overall Transmission-Frequency Characteristic of Long Non-Loaded 165 mil Circuit Denver to Los Angeles

At the present time this system of voice frequency signaling is employed for regular use on the Chicago-Los Angeles circuit and a few others. The system employing 135-cycle current alternately relayed and amplified at repeater points also is installed on these circuits and probably will be retained for emergency use and to permit temporary changes in circuit layout.

Maintenance. The continuity of the many important services routed over the facilities used in making up these long circuits is dependent upon continuous and efficient maintenance methods and performance. Coordination of the work of the different offices is most essential in order to obtain best results, especially on the longer direct circuits and on those built up by the connecting together of several circuits, as there are a large number of variable factors. To assist in obtaining best results, accurate records of the circuit make-up

TOLL CIRCUIT LAYOUT RECORD FORM E 888

CIRCUIT NO. 1 Chicago (MP) A Los Angeles B — EQUIVALENT COMPUTED 12.0 MEASURED 12 — CIRCUIT ORDER 5617 ITEM 3 — DATE IN SERVICE — CARD ISSUE NO. 1 DATE 4-17-24

CONTROL OFFICE Chicago CLASSIFICATION VL

FROM 1	TO 2	CABLE OR LINE 3	PAIRS OR PINS 4	SIZE OF WIRE 5	LOADING 6	LENGTH 7	EQUIV. 8	REPEATING COILS: ON SIDE 9	ON PHYS. 10	ON PHAN. 11	FOR EX 12	CX 13	RINGER 14	OTHER 15	TOTAL LOSS (COLUMNS 9 TO 15) 16
C (Chicago	Morl Pk.	1 Chgo-MP Ca	127	16	M	7.60	1.4							RL	80)
D Morl. Pk.	P7415	Chicago-Omaha	9-10	165	N	175.3	6.1		55D			TS		KX	1.05
E P7415	P7445-1/2	" - "	9-10	165	N	.7	.0								
F P7445-1/2	Davenpt.	Cable	7	13	N	.06	.0							KX	.10
G Davenpt.	P7445-1/2	"	63	13	N	.06	.0								
H P7445-1/2	P7557	Chicago-Omaha	35-36	165	N	2.1	.1								
J P7557	P7741-1/2	" "	25-26	165	N	4.5	.2								
K P12976	P9047-1/2	St. L.-Dav.	5-6	165	N	83.4	2.9								
L P9047-1/2	Burlington	Cable	5	10	N	.51	.2		75A			TS			.90
M Burlington	P9047	"	15	13	N	1.03	.5		75A			IS			.90
N P9047	P7903-1/2	St.Louis-Dav.	15-16	165	N	29.5	1.0								
P P1	P612	Burl.-Kan.Cty	5-6	165	N	14.7	.5								
O P612	P1578	" " "	5-6	165	N	23.0	.8								
R P1578	P5634	" " "	5-6	165	N	96.2	3.4								
S						TOTAL		Required Equ. 12.0						TOTAL	

TELEPHONE REPEATER DATA

STATION 17	CLASS 18	RINGING 19	IMP. 20	TOWARD A: GAIN OR STEP 21	MEAS. 22	NET 23	B.O.S. 24	SINGING POINT 25	MEAS. 26	TOWARD B: GAIN OR STEP 27	MEAS. 28	NET 29	B.O.S. 30	SINGING POINT 31	MEAS. 32	RINGING ON 2-W SIDE OF 4-W TERM. EQ. 33	DISTRIBUTION: OFFICES	DIV.	DIST.	TBR.	TMS.	EFTE
																	Chicago	*	*	*	*	
T				Req.				Req.		Req.				Req.			Morl.Pk.			2		
U Morl. Pk.	CC		H							3		17E		25			Burlingt.			*		
V Burlgtn.	TL1	Amp.	N	11.8		17F	BL	25		11.8		17F	BZ	25			Omaha		*			
W Kans.City	TL1	135	N	11.9		17F	BU	25		11.9		17F	DQ	25			Kans.Cty		*	*		
Z Newton	TL1	Amp.	N	11.8		17F		21		11.3		17E		25			(Over)					

Fig. 10

from end to end, including a complete description of the types of equipment and transmission data are prepared and furnished to the terminal and repeater stations. These are made on cards of convenient size, as illustrated by Fig. 10, which is one of the five cards for the Chicago-Los Angeles circuit. To insure proper functioning of the circuit and satisfactory overall transmission and signaling one of the terminal offices of each circuit is designated as the controlling office for that circuit and is responsible for the direction and supervision of tests and adjustments required on the circuit as a whole. In addition to the duties in connection with the maintenance of the circuit as a whole each office along the circuit is responsible, of course, for the proper physical maintenance of the plant in its territory.

High grade maintenance is necessary to reduce to a minimum, service interruptions, noise and crosstalk and fluctuations in circuit characteristics and equivalents. An important part of this work consists of frequent periodic inspections, measurements [8] of insulation resistance, loop resistance, resistance balance, transmission, noise and crosstalk and equipment parts which are subject to variation.

In order to make many of the measurements and tests it is necessary to remove the circuit from service. This would result in considerable lost circuit time if each of the stations made such measurements and tests independently. In order to minimize this lost circuit time, therefore, it has been found desirable in the case of long telephone circuits of this type to institute what is known as "co-ordinated testing" procedure. Under this procedure a definite time is set aside for the periodic tests and all repeater stations and both terminal stations co-ordinate their work under the direction of the controlling office. The success of this system is dependent upon each station doing its part of the work correctly and within a specified time allowed for each test. The method of conducting the tests is illustrated in the following description.

1. *Roll Call*—The tester at the controlling office first calls the roll, starting with the first station and proceeding through to the distant terminal, each station replying by name and giving the temperature and weather conditions.
2. *Repeater Amplification and Vacuum Tube Tests*—The tester at each station measures the amplification in both directions given by the telephone repeater at that point and checks the condition of the vacuum tubes.
3. *Balance Tests*—At each repeater station the degree of balance between the line circuit and the balancing network circuit is checked in both directions. Since it is necessary that each section of the circuit be terminated at the opposite end from the station making the balance tests, alternate repeater stations terminate the circuits and the other stations proceed with their balance measurements. The procedure is then reversed.

[8] For description of these tests and their application see article in this issue "Electrical Tests and Their Applications in the Maintenance of Telephone Transmission," by W. H. Harden.

4. *Transmisson Equivalent*—When the balance tests have been completed, a measurement of the overall transmission loss is made between the terminal stations.
5. *Talking Test*—In order that the quality and volume of transmission from a service standpoint may be determined, a talking test is made over the entire circuit using standard subscriber sets at each end.
6. *Signaling*—As a final check, ringing tests are made over the circuit in both directions to insure that satisfactory signaling is being obtained.

This testing routine has been perfected to such an extent that the circuit need not be kept out of service for more than about 15 minutes even in the case of the longest circuits. Results of measurements over the period of a year on the Chicago-San Francisco circuit are shown in Fig. 11. The overall transmission measurements, which

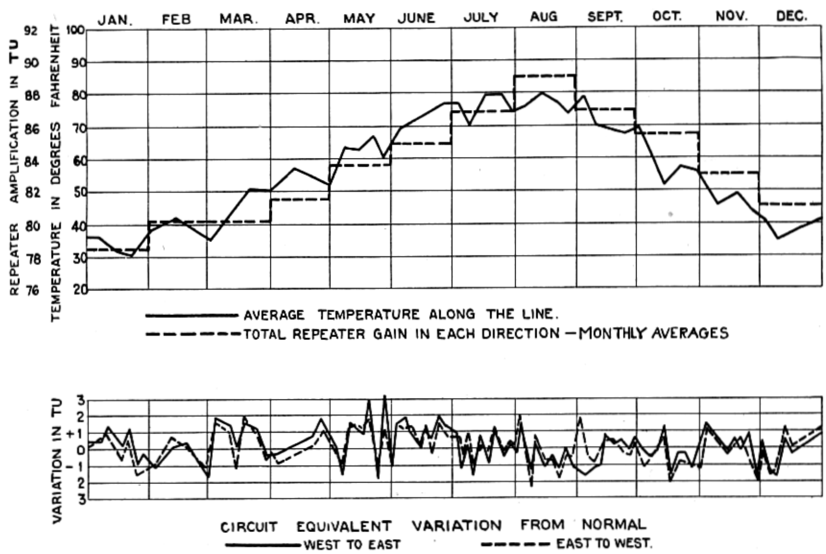

Fig. 11—Monthly Ranges in Temperature and Repeater Gain on the Chicago-San Francisco Circuit

are shown as variations from normal, were made at the conclusion of semi-weekly tests and after any necessary adjustment in repeater amplification had been made to compensate for changes in attenuation loss. The other curves show the average temperature along the line at the time of tests and the average total repeater amplification from which can be noted the amount of amplification required to offset the variation in transmission equivalent due to seasonal temperature changes.

Conclusion—As mentioned earlier in this paper the data and results given in the foregoing, although applying particularly to circuits on the southern and central transcontinental routes, are also representative of the conditions on other long circuits of the same type. The establishment of these high quality circuits, which are also available for the application of carrier systems and which in certain cases have been so equipped, constitutes another important step in bringing together all sections of the country by telephone.