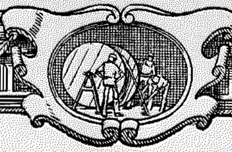

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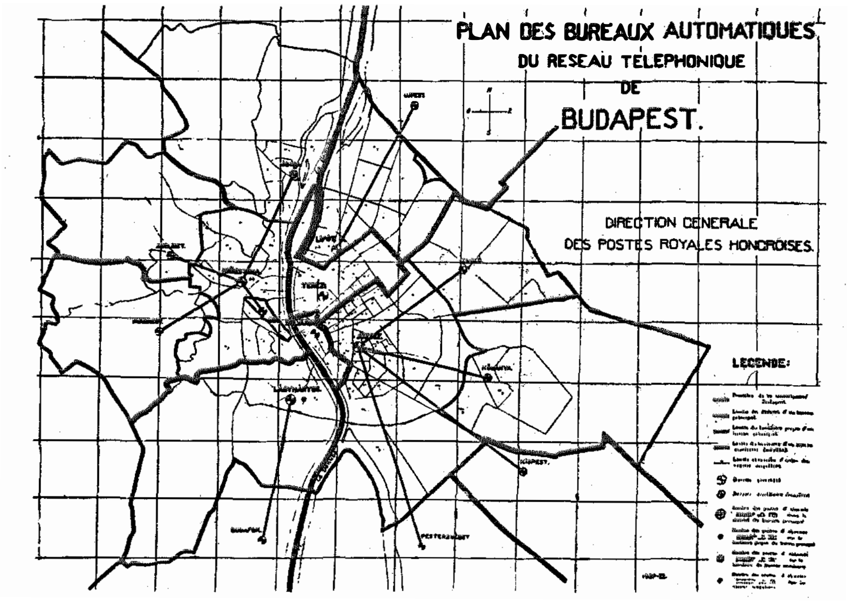
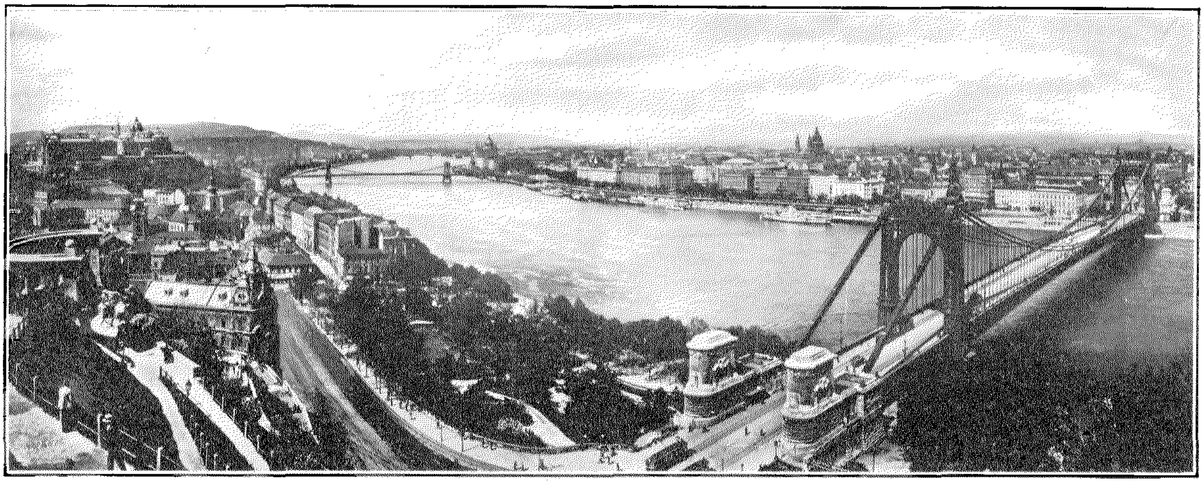


Budapest Exchange Area



Panorama of Budapest

Budapest Telephone Area

Development and Transition from Manual to Automatic

By JENÖ RÉDL
Technical Chief-Director, Hungarian Post Office

THE Hungarian Post Office has ever been on the alert to take advantage of the world's progress, and its present Administration has ever been quick to adopt improvements in its service. Thus special attention has been given to the telephone system of Hungary. It is the object of this article to present an account of the development of the Budapest area, with particular reference to the transition from manual to automatic operation.

Before proceeding further, however, it is appropriate to place on record the part played by Mr. Kolossváry, Secretary of State, who for the last forty years has been the head of the Technical Department of the Hungarian Telegraph and Telephone Administration, for he has done much to encourage advance. Moreover, it may here be recalled that in 1904, at the regular meeting of the International Telegraph Congress, which that year was held in London, the Hungarian and French delegates suggested that it would be useful also to have International meetings, at which technical problems could be decided. Accordingly, in 1908, the Hungarian Administration issued invitations to a meeting to be held in September of that year at Budapest.

Budapest was amongst the first towns in Europe to make commercial use of the telephone, the first Hungarian exchange being cut-over there on May 1st, 1881, only five years after the historic exhibition of Graham Bell's invention in Philadelphia, at the World Exhibition of 1876.

At the time of the opening of the Budapest exchange there were only three other exchanges in Europe, i.e., Friederichsberg in Germany, opened November 12th, 1877; Paris, opened June 26th, 1879; and London, opened October, 1879. The concession for the first Paris exchange—Avenue de l'Opéra—was awarded to a Hungarian, Francis Puskás, who had associations with Graham Bell and Edison. Francis Puskás was responsible for the first exchange in Budapest.

Budapest so soon developed its modest initial equipment that when the State bought it in 1897, it had 4,000 subscribers connected, whilst 500 more were eagerly awaiting service.

In the early stages of its telephone history, the Budapest area consisted of numerous small exchanges, but with the advent of the multiple switchboard these were centralized, Budapest being among the first of the European towns to take advantage of the new multiple system.

When the State took over the equipment, the original network of steel wire single conductors with earth return was speedily replaced by bronze wire metallic circuits and paper insulated lead-covered underground cables in concrete ducts. At the end of the year 1903, Budapest was furnished with its first exchange of the common battery type; it was of Western Electric development and manufacture. (The International Western Electric Company was the predecessor of the International Standard Electric Corporation.) This exchange, Teréz, had a capacity of 10,000 lines, and was accommodated in a specially designed building. By the spring of 1904 all the subscribers in Budapest, numbering about 6,900, were connected with this new central exchange, the telephone system thus functioning as a single office area. At the close of 1904 the new toll exchange was installed in the same building. As the number of subscribers increased, it became necessary to extend the Teréz exchange until 16,000 lines were connected, and as still further connections were required, a second exchange was introduced into the area. This exchange, which was named József, was also of Western Electric (now International Standard Electric) design, and was completed just before the Great War. It had a capacity of 15,000 lines, and, being furnished with modern equipment to satisfy the most exacting requirements, it attracted the attention of experts from abroad, who expressed their admiration of the performance. War-time conditions, however, made it impossible to take immediate advantage of this equipment, and it was brought into service gradually, the capacity not being reached until 1919.

In 1919 the toll exchange, which had been considerably extended, was transferred to the József building. In 1921, the capacity of the two exchanges, Teréz and József, had been practically exhausted and a relief exchange of 4,000 lines was ordered; this exchange was later extended to 6,000 lines. For nearly ten years following 1914, however, the telephone system in Budapest suffered from the unfavourable conditions of insufficient maintenance and lack of development. Not only was the introduction of a third exchange postponed, but the existing exchanges, particularly Teréz exchange, part of which is twenty-five years old, deteriorated more rapidly, owing to the abnormal conditions, so that the service was inevitably impaired.

During this period of plant retrogression, great advances had been made in the telephone art, so that when the time arrived to rebuild the telephone system, the old plans had to be entirely revised. In making their plans for ten years following 1921, the Postal Administration naturally included the provision for a modern telephone area for Budapest, and decided that the most up-to-date automatic system should be installed. The ultimate aim of establishing a full automatic system could be realized only by degrees. A change-over from the flat rate to a message rate tariff was necessary, because it was important to calculate the switch quantities for the new automatic exchange to correspond with the reduced traffic which would result from message rate service. The first step, therefore, in the investment, was the installation of service meters. This innovation was preceded by an important reform of the manual service, i.e., the substitution of the trunk indicator system for the former order wire system; and was required as a preliminary to changing over to the message rate tariff in order to eliminate the possibility of wrong connections being metered against the subscriber. These changes resulted in an improved service, since there was naturally a decrease in the average number of calls per day, and consequently a decrease in the operators' load. Actually the load was relieved to the extent of nearly 40%, so that it became possible to provide a quicker and better service, while complaints of wrong connections were almost eliminated. To draw up correctly the ten years' development scheme for the Budapest area, it was necessary to forecast the probable growth. Consequently, studies were carried out in 1920 and 1921, with the object of determining what degree of development might be expected by the end of 1930.

Population

According to official records, the population of Budapest showed in the last decades an increase as indicated in Table No. 1.

The new telephone network is, however, intended to include not only Budapest, but also the surrounding boroughs, even before these are definitely united with the Capital from an administrative point of view. Therefore, it was essential also to investigate the probable increase in population in these communities. The respective data are shown in Table No. 2. In these tables only the most important places are included; some boroughs closely connected with Budapest are not mentioned. If these are included, there were living in 1910 in the neighbourhood of the Capital 239,562 persons. It has been estimated from the above data and other facts that Budapest's population in 1930 will be approximately one million. This cannot be regarded as an over-estimate, as at the end of 1926 a rough census disclosed that the population of Budapest, excluding the Army and the Police within its boundaries, amounted to 970,000. If, for the neighbouring boroughs only a small increase in population is assumed, say to 300,000 by 1930, then for the purposes of the telephone development scheme, the total population of the area in question may be estimated to be 1,300,000.

TABLE No. 1

Year	Population	Increase of the population in comparison to the previous counting		Annual Increase	
		Number of inhabitants	%	Number of inhabitants	%
1869	280,349	......	....	......	..
1880	370,767	90,418	32.2	8,220	2.9 11 years
1890	506,384	135,617	36.6	13,562	3.7 10 years
1900	733,358	226,974	44.8	22,697	4.5 10 years
1906	791,748	58,390	7.9	10,469	1.6 5 years
1910	880,371	88,623	11.2	17,724	2.2 10 years
1920	930,247	49,876	5.6	4,988	

Increase in Population of Budapest, 1869-1920

Telephone Subscribers

The gradual increase in the number of Budapest telephone subscribers can be seen from Table No. 3, and Figure 1. On the basis of these data and certain important circumstances, the increase in the proportion of the number of subscribers to the number of inhabitants was calculated year by year, and the result for 1930 was found to be 4 subscribers per 100 of population. This computation, notwithstanding various difficulties, was confirmed by recent experience, the proportion attaining 3.5% per 100 in 1925 and 3.7% in August, 1927. Thus the assumption of the proportion reaching 4% in 1930 is well founded.

In the light of the present facts, it can be stated that in 1930, Budapest's 1,300,000 inhabitants will have 52,350 main stations with 4 subscribers to every 100 of the population while the proportion, taking into account the extensions, will be 6 to 100. These results are confirmed by other more detailed studies.

Location of Exchanges

Further investigations involving consideration of the existing cable network as well as the density of telephone traffic were carried out to determine the best sites for the exchanges. Thus

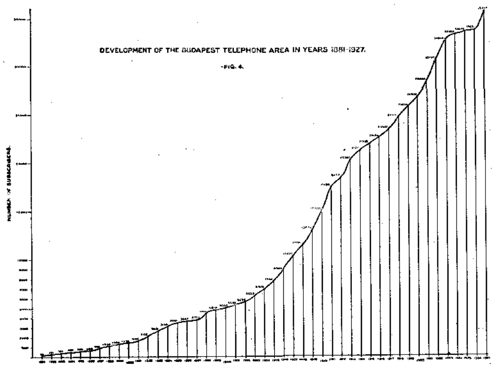


Figure 1—Development Budapest Telephone Area, 1881-1926.

TABLE No. 2

Place	Number of Inhabitants			
	1890	1900	1910	1920
Rákospalota........	6,264	11,742	25,135	35,586
Pestujhely..........	.....	......	5,545	7,860
Ujpest.............	23,521	41,836	55,174	55,825
Rákosszentmihály...	979	3,105	6,550	9,459
Czinkota...........	1,876	3,134	7,616	12,141
Pestszentlörino......	390	5,952	7,812	11,552
Kispest............	4,523	19,777	30,154	50,244
Erzsébetfalva.......	4,754	15,717	30,959	40,325
Csepel.............	2,246	4,563	9,454	13,522
Budafok............	5,243	7,267	10,943	13,470
Albertfalva.........	592	791	1,118	1,210
Budakeszi..........	3,635	4,211	5,228	5,153
Nagykovácsi........	1,803	2,012	2,226	2,238
Békásmegyer........	1,340	2,027	3,535	4,369
Budaörs...........	5,281	6,100	7,383	8,033
Pesthidegkut........	1,393	1,559	2,126	3,292
Total............	63,840	129,793	210,958	274,279
Increase	Number of Inhabitants	65,953	81,165	63,321
	%	103.3	62.5	30

Increase in Population of Boroughs Surrounding Budapest, 1890-1920.

it was possible to ascertain that, besides the existing Teréz and József exchanges, the telephone area shows obvious points of density in the inner town at Köbánya, along the Krisztina Boulevard on Mount Sváb, in the Hüvösvölgy and the Lágymányos, and that these spots must be chosen for exchanges. This conclusion was supported by a study of the development of existing exchanges. The exact location of the points of greatest traffic density was therefore first determined. In fixing the number, sites and sizes of the exchanges, an endeavour was of

TABLE No. 3

Year	Main Stations			Substations			Per 100 Inhabitants			Note	
	Number	Annual Increase		Number	Annual Increase		Main Substation		Telephone set		
		Number	%		Number	%	Number	%			
1881	50	.....	....	......	....	....	...	...	...	Years of unsystematic development	Reliable data for the substations are not available
1882	291	241	482	......	....	....	...	...	...		
1883	344	53	18	......	....	....	...	...	...		
1884	402	58	17	......	....	....	...	...	...		
1885	535	133	33	......	....	....	...	...	...		
1886	608	73	14	......	....	....	...	...	...		
1887	959	351	58	......	....	....	...	...	...		
1888	1,050	91	9	......	....	....	...	...	...		
1889	1,300	250	24	......	....	....	...	...	...		
1890	1,436	76	6	......	....	....	0.3	...	0.3		
1891	1,666	230	16	......	....	....	...	...	...		
1892	2,122	456	27	......	....	....	...	...	...		
1893	2,631	509	24	......	....	....	...	...	...		
1894	3,166	535	20	......	....	....	...	...	...		
1895	3,481	315	10	......	....	....	...	...	...		
1896	3,667	186	5	......	....	....	...	...	...		
1897	3,773	106	3	......	....	....	...	...	...		
1898	4,461	688	18	......	....	....	...	...	...		
1899	4,819	358	8	......	....	....	...	...	...		
1900	5,040	221	5	750	....	....	0.7	0.1	0.8	Years of quiet development	
1901	5,339	299	6	837	87	13	...	...	...		
1902	5,699	360	7	972	135	14	...	...	...		
1903	6,259	560	10	1,180	208	23	...	...	...		
1904	6,926	667	11	1,379	199	18	...	...	...		
1905	7,790	844	12	1,745	366	26	...	...	...		
1906	8,999	1,209	14	2,237	492	29	...	...	...		
1907	10,227	1,228	14	2,724	487	23	...	...	...		
1908	11,441	1,214	12	3,124	400	15	...	...	...		
1909	13,024	1,683	15	3,488	364	11	...	...	...		
1910	15,020	1,996	15	4,088	600	18	1.8	0.7	2.5		
1911	17,486	2,466	16	5,288	1,200	30	...	...	...	Years during which the possibility to connect new stations to the area gradually decreased	Years of economic depression
1912	18,477	991	6	6,502	1,214	23	...	...	...		
1913	20,387	1,910	10	7,615	1,113	17	...	...	...		
1914	21,311	924	5	8,427	812	10	...	...	...		
1915	21,938	627	3	8,957	530	6	...	...	...		
1916	22,684	746	3	10,157	1,200	13	...	...	...		
1917	23,502	818	4	11,220	1,063	10	...	...	...		
1918	24,717	1,215	5	12, 307	1,087	9	...	...	...		
1919	25,854	1,137	5	12,883	576	4	...	...	...		
1920	26,903	1,049	4	13,117	234	2	2.9	1.5	4.4		
1921	28,663	1,760	6	14,905	1,788	13	...	...	...		
1922	30,737	2,074	7	15,949	1,044	7	...	...	...		
1923	32,869	2,132	7	16,659	710	5	...	...	...		
1924	33,389	520	2	17,211	552	3	...	...	...		
1925	33,620	241	0.7	15,060	(–2,151x)	(–12x)	3.5	1.7	5.2		
1926	33,831	211	0.6	15,987	927	6	...	...	...		
1927 VIII 31	35,874	2,043	6	......	....	....	3.7	...	...	Cessation of economic depression	

(x) Consequence of the new tariff with charges according to the number of effected conversations.

Development of Budapest Telephone Area, 1881-1926.

course made to decentralise the service as much as possible, in order to take full advantage of the automatic system in building up the area on an economic basis. Following this principle, provision was made for the erection of the necessary number of satellites in connection with the more important centres. According to numerous calculations, it was previously estimated that the number of subscribers in 1930 would be approximately 52,000; but in view of the fact that no estimate could be made of the necessary investment to meet development after the contemplated period of ten years, and further, since it was essential to ensure the possibility of connecting new subscribers continuously, the equipment was planned to carry 25% more traffic than that assumed at the end of the ten years period, that is, the exchanges will have a capacity of 52,000 + 25% = 65,000 lines. Moreover, it will be possible to extend the number of lines to 100,000 by extending the existing exchanges and adding further satellites without being compelled to erect new exchanges.

The network was planned on the same principle. Most of the concrete blocks, channels, the distributing conduits, and trunk cables will be installed immediately for the 65,000 line network, and the extension to 100,000 will be effected by the aid of branch cables. The frontispiece shows the location of the exchanges and the areas served by them. The present traffic is handled by Teréz exchange of 16,000 lines, the auxiliary Lipót exchange of 6,000 lines in the same building as Teréz, and the József exchange of 15,000 lines, the three manual exchanges together having a total of 37,000 lines. On completion of the network as designed, the following exchanges will be automatic:

Teréz in its original site with a capacity of	20,000 lines
József in its original site with a capacity of	20,000 lines
Belváros in the G. P. O. Building with a capacity of	10,000 lines
Lipót on the Vaci Road in a new building with a capacity of	5,000 lines
Krisztina on the Krisztina Road in a new building with a capacity of	7,000 lines
Lágymányos on the Horthy Miklós Road in a new building with a capacity of	3,000 lines

TABLE No. 4

Planned capacity of the exchange	Main Exchange	Satellite	Number of stations in 1920	Increase coefficient in average	Number of stations in 1930	25% spare	Total number with spare	In comparison of the planned capacity						
	Name of the exchange							Available		Excess		Real spare in %		
								Station	%	Station	%	Main exch.	Satellite	Total
20,000	Teréz		8,820	1.81	16,257	4,063	20,320			320	1.6	23.4		23.4
16,000	József		7,134	1.82	12,985	3,245	16,230			230	1.4	23.6		
800		Zugló	217	3	651	163	814			14	1.8		23.2	
1,000		Köbánya	304	2.5	760	190	950	50	5				30	
800		Kispest	153	3.7	566	142	708	92	11.5				36.5	
1,400		Pesterzsébet	290	3.7	1,073	269	1,342	56	4				29	
4,000		Zugló Pesterzsébet	964		3,050	764	3,814	186	4.6				29.6	
20,000	József	Zugló Pesterzsébet	8,098		16,035	4,009	20,044			44	0.3			24.7
10,000	Belváros		4,646	1.78	8,252	2,063	10,315			315	3.2	21.8		21.8
3,600	Lipót		926	2.5	2,318	576	2,894	706	19.4			35.6		
1,400		Ujpest	436	2.5	1,090	273	1,363	37	2.6				27.6	
5,000	Lipót	Ujpest	1,362		3,408	849	4,257	743	14.8					39.8
4,000	Krisztina		1,914	1.82	3,488	871	4,354			354	8.9	16.1		
1,000		Vár	419	1.82	763	191	954	46	4.6				29.6	
600		Svábhegy	150	3	450	113	563	37	6.1				31.1	
600		Zugliget	153	3	459	115	574	26	4.3				29.3	
800		Obuda	326	1.82	593	149	742	58	7.2				32.2	
3,000		Vár Obuda	1,048		2,265	568	2,833	167	5.5				30.5	
7,000	Krisztina	Vár Obuda	2,962		5,748	1,439	7,187			187	2.7			22.3
2,600	Lágymányos		668	3	2,004	501	2,505	95	3.7			23.7		
400		Budafok	104	3	212	78	390	10	0.3				25.3	
3,000	Lágymányos	Budafok	772		2,316	579	2,895	105	3.5					28.5
65,000	Total:		26,660		52,016	13,002	65,018			18	0.03			24.97

Proposed Extension of 65,000 Line Budapest Exchange Area.

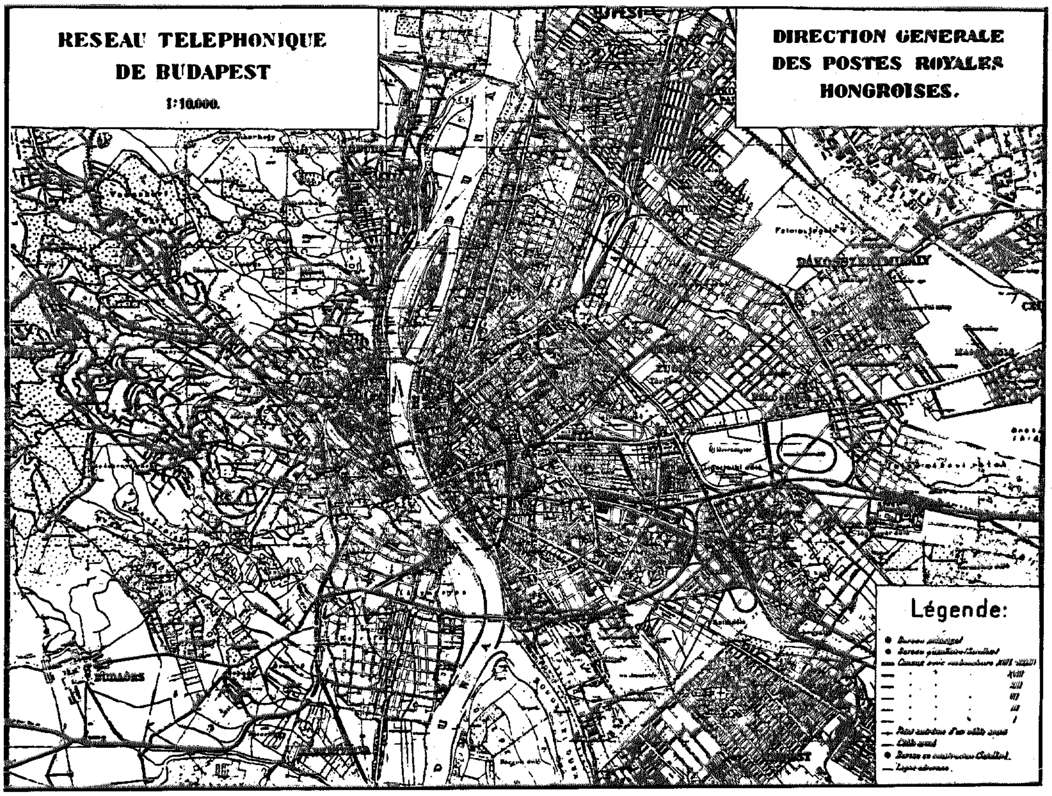


Figure 2—Map of Budapest

When this project has been completed, there will exist in the Budapest Telephone Area six automatic exchanges which, taken together, will have a capacity of 65,000 lines. The Belváros and Teréz exchanges will operate as complete and independent units. The Krisztina exchange will have four satellites; Vár in the Home Office buildings, with a capacity of 1,000 lines; Svábhegy in a new building, with a capacity of 600 lines; Zugliget in a new building, with a capacity of 600 lines; and Obuda in a new building with a capacity of 800 lines.

The József exchange will have four satellites: Zugló in a new building with a capacity of 800 lines; Köbánya in a new building with a capacity of 1,000 lines; Kispet in a new building with a capacity of 800 lines; and Pesterzsébet in a new building, with a capacity of 1,400 lines.

The Lipót exchange will have one satellite, Ujpest in a new building, with a capacity of 1,400 lines. The Lágymányos exchange will have one satellite, Budafok, in a new building, with a capacity of 400 lines. The capacities of the satellites are of course included in the capacities of the main exchanges. The geographical layout is supplemented by Table No. 4, which indicates the capacity of the main exchanges and satellites of the 65,000 line area, the distribution of subscribers, and the percentage of spare lines. Table No. 5 gives a general summary of the exchanges of the 100,000 line area. From this figure it is clear that it is not intended to set up new exchanges, so long as the five-digit exchange system is not fully exploited, but new primary and secondary satellites will be added as required.

Figure 2 shows the layout of the Budapest area. It must be mentioned that an essentially underground system will be provided with con-

TABLE No. 5

Main Exchange	Primary	Secondary	Capacity				First figure of the calling numbers	Exploitation (main lines)
	Satellite		65,000		100,000			
	Name and Place		Lines		Area			
			Detailed	Total	Detailed	Total		
Teréz			20,000	20,000	20,000	20,000	1 and 2	20,000
József			16,000		16,000			
	Zugló		800		800			
	Köbánya		1,000		1,000			
	Kispest		800		800			
	Pesterzsébet		1,400	20,000	1,400	20,000	3 and 4	20,000
Belváros			10,000	10,000	10,000	10,000	8	10,000
Krisztina			4,000		8,000			
	Svábhegy		600		1,000			
		Farkasrét(x)			500			
		Budaörs(x)			500			
	Zugliget		600		1,000			
		Budakeszi(x)			500			
		Hidegkut(x)			500			
	Obuda		800		2,000			
	Vár		1,000		2,000			
	Tabán(x)				2,000			
	Naphegy(x)			7,000	2,000	20,000	5 and 6	20,000
Lipót			3,600		6,000			
	Ujpest		1,400		2,000			
	Angyalföld(x)				1,000			
		Rákospalota(x)		5,000	1,000	10,000	9	10,000
Lágymányos			2,600		6,000			
	Budafok		400		1,000			
	Kelenföld(x)				2,000			
		Tétény(x)		3,000	1,000	10,000	7	10,000
For stations of service or other special purposes						10,000	0	10,000
Total:				65,000		100,000		100,000

(x) Refers to the extension from 65,000 up to 100,000 lines.

Numerical Capacity of the Budapest Telephone Area. (5-Figure System.)

crete block channels, distributing conduits, lead-covered paper-insulated cables or armoured cables of from 600 down to 26 pairs of conductors. In the fully developed town districts the overhead lines will totally disappear and will remain only in the suburbs, although even here they will be very much restricted. At present the number of subscribers served by underground cables is 30,000, and at the time of the cut-over of the first automatic exchange, this will increase to 35,000.

Choice of the Automatic System

It will be appreciated that in the early planning stages the question of choice of a particular automatic system could be disregarded, but a point has been reached in the present exposition where it becomes necessary to discuss problems with which the choice of a system is closely connected. It is a fact that the Hungarian Postal Administration studied automatic exchanges as far back as 1908. In 1913 and again in 1922, engineers were sent out to investigate the subject in various European towns, and detailed reports by experts were produced on their return. Finally, in 1924, the Administration investigated all the particulars of the question once more, and on that occasion the delegate (the writer of this article), who drew up the development plans, studied various working automatic exchanges and the factories manufacturing the equipment in Austria, Germany, Belgium, Switzerland and Holland, and further secured full information from London and Paris where the Administrations were engaged in selecting an automatic system. In arriving at the final decision, the following salient points were taken into consideration:

1. Technical perfection.
2. Reliable service.
3. Freedom from disturbance in gradual transition from manual to automatic working.
4. Flexibility and adaptability to special requirements.
5. Economical exploitation.
6. Facility of extension.
7. Simple and economical maintenance.
8. Fostering of home industries.
9. Manufacturing expenses—first cost.

Taking all these points into account, we came to the conclusion that the systems based on the principle of direct control of the selectors were not suitable for our purpose, the chief reason being that the rigid numbering scheme would not permit of ready adaptation to varying traffic conditions. It would be beyond the scope of this article to compare the advantages and disadvantages of the various systems, but in support of the decisions it might be mentioned that in those places where direct control systems have been adopted, certain auxiliary equipments have been employed by means of which the systems have really been converted to indirect control. As an example we would mention the Director System adopted for the London area by the British Post Office. If it is agreed to reject the principle of direct control, i.e., that the selectors must not be operated directly by impulses originated by the subscriber, it becomes unnecessary to accept the 100-point type of selector used in such a system. This selector must be of light construction, and is rigidly bound to the decimal system of numbering. On the contrary, selectors can be employed of more robust construction having as many contacts in the bank as economically expedient, thus making larger groups possible. The movements of such a selector are not controlled by the comparatively weak impulses originated by the subscriber (which impulses vary according to the characteristics of the subscriber's line), but by common power drive mechanisms through the medium of the apparatus used for receiving, storing and retransmitting the initial impulses. These pieces of apparatus might be called "registers," "senders," or any other name. The control of the selectors is not only indirect in the above sense, but also acts on the revertive principle, because the impulses are stored by the senders and transmitted as the selectors are free to receive them, the condition of the selector thus governing the transmission of the impulses from the sender. The objection may of course be raised that power-driven systems necessitate the use of transmission equipment, and that selectors having a capacity of more than 100 lines involve re-numbering. This reasoning does not affect the main issue of better service, since it does not alter the numerous advantages arising from the use of more robust switches of greater capacity and a system with facilities for translation.

Last, but not least, the fact that 200 and 300 point selectors are used, is an advantage by which the area can be increased from the designed 65,000 lines to 200,000 lines, without inserting the fourth selector.

At the time when choice had to be made between the systems, only the Panel System of the Western Electric Company, and the Rotary System of the International Standard Electric Corporation possessed the advantages that we have briefly outlined. The then newly developed Swedish Ericsson System had not been in practical use. (The first exchange of this type was cut-over in Rotterdam in the spring of 1924). The Panel System, having been planned for cities much larger than Budapest, was not considered suitable for the purpose; none of the larger cities in Europe had adopted this system, as it is designed for a capacity of 1,000,000 subscribers.

Three Hungarian manufacturers tendered for the erection of exchanges of Standard Electric Rotary, Strowger and Ericsson systems, respectively. The Administration recommended to the Hungarian Government the Rotary System, which has already proved very satisfactory at the Hague, Zurich, Antwerp, Brussels and elsewhere. The Administration were also influenced in their decision by the fact that only the United Incandescent Lamps and Electrical Company, Limited, and the Hungarian licensee of the International Standard Electric Company could guarantee that at least 80% of the equipment would be manufactured in Hungary. The justice of this decision was confirmed by the fact that Paris, Oslo, Copenhagen, Bucharest and Madrid have since all adopted the Standard Electric

Rotary System. In addition, it is in use in other cities of France, Norway and Spain, as well as in Australia, Belgium, China, Czecho-Slovakia, the Dominican Republic, Great Britain, Holland, Hungary, Italy, Mexico, New Zealand, Poland, South Africa and Switzerland. There are approximately three-quarters of a million lines of Standard Electric Rotary equipment in service or on order.

General Requirements for Automatic Exchange Service

Requirements which automatic exchanges have to fulfill, according to the general conditions specified by the Postal Administration, are:

1. At the partial or total cut-over of the automatic exchanges, facilities must immediately be provided and maintained to enable all subscribers of the area to call each other and talk with each other without hindrance for an unlimited period, whether they are connected to an automatic or to a manual exchange.

2. Undisturbed toll facilities for all subscribers in the area.

3. The automatic equipment must be suitable for installation of party lines at any future time.

4. A subscriber connected to an automatic exchange, if calling an automatic or manual subscriber, is not to have anything else to do than to lift his receiver and then dial the wanted number by operating the dial mounted on his telephone set. Connecting and ringing, release, busy signalling, metering, etc., must be performed automatically.

5. After lifting his receiver, the calling subscriber must get a special tone signal which indicates that his line is connected to a free register.

6. If the calling subscriber does not get connection immediately, because all connecting circuits or group-selectors are engaged, the connection has to take place without the renewal of the call according to the principle of continuous hunting.

7. A tone signal must be given to the calling party at the commencement of the transmission of ringing current to the called party's bell.

8. Ringing must continue with regular intervals until the called party answers, and must then stop immediately.

9. If called party's line is busy, calling party must receive a regularly interrupted busy tone.

10. Noises which disturb the conversation, or jarring sounds must not be heard in the receivers during the connecting process, and connections between two parties engaged in conversation must be free from this trouble.

11. Release must take place automatically when the calling party replaces his receiver. All apparatus engaged in the connection must return to the home position.

12. At the end of the conversation the calling party must become free, even if the called party does not replace his receiver, that is, if the connection in the final circuit is not broken down. In this case an alarm signal must be given to the maintenance staff of the exchange, who shall restore the final selector to normal.

13. Effective connections must be metered at the end of conversation. Should the Postal Administration wish to charge for the conversations according to certain periods of time, the metering equipment must be capable of providing for repeated metering at certain intervals.

14. Special calls—toll recording operator, complaints operator, telegrams, fire, first aid, police—must not be metered.

15. One and the same number must serve for the calling of the called party, even if the latter has more than one station, that is, the exchange equipment has to be made so that the calling party shall be able to get connection with one free station by dialling the one calling number and shall receive the busy tone signal only when all the stations of the called party are engaged.

16. P. B. X. operators must be able to call directly every station in the area and vice versa.

17. The exchange maintenance staff must receive a signal if a call originates for a subscribers' station which is not yet connected, or is temporarily disconnected, or is recorded as defective, or has changed its calling number, or can be called only by name.

18. The exchange maintenance staff must receive a signal when a calling subscriber lifts his receiver, but does not dial any number, or when subscribers' lines are on contact or short circuited. Such faulty calls are not allowed to engage a register for too long a period; the registers must become free automatically after an interval of 30 seconds from the taking of the register.

19. The exchange maintenance staff must receive a signal if a subscriber in the area does not get connected on account of circuit failure. The calling subscriber must be released from the defective circuit automatically and obtain a new connection circuit and register without replacing his receiver and lifting it again. The defective circuit and all circuits which are connected with it must remain in the condition in which the defect occurred, to enable the maintenance staff to ascertain the nature of the fault.

20. All the principal circuits necessary for building up a connection must be capable of being disconnected electrically from all other circuits, and switched over to a routine test circuit for the purpose of seeking and correcting faults.

21. All necessary monitoring, checking and supervisory equipments must be provided for the determination and prevention of faults, the breaking down of abnormal connections, and the most economical distribution of traffic between the several groups of machines, and must enable the supervisory staff of the exchange to speak personally with the subscribers in case of faulty dialling. The equipments of the wire chiefs' desks, monitoring desks, supervisory desks, and service observation desks, as also the several alarm and time alarm equipments, serve these purposes.

22. Alarm signals are necessary in the following cases:

(a) Short circuits.
(b) Blown fuses.
(c) Irregular functioning of selectors from whatever cause.
(d) Ringing current failure.
(e) Main current failure.
(f) Incorrect operation of rack motors.
(g) Defective dialling by subscribers.

If no night service is given at the exchange, it must be possible to switch the alarm signals over during the night to the person responsible for supervision.

23. Test jacks must be provided on the distributing frames and racks.

24. Facilities must be provided for jumpering the subscribers' lines, trunk lines and connection circuits to suit traffic conditions.

25. Charts must be provided on the switchrack to show the numbers of the switches and the incoming and outgoing ends of the trunk lines, to enable the maintenance staff to trace the connections without difficulty.

Gradual Transition from Manual to Automatic Service

Instead of the three manual exchanges now in use in Budapest, six automatic exchanges and ten satellites will be installed. Technical reasons, and moreover reasons of finance, necessitate a gradual transition to the full automatic area, so that during the period of transfer combined automatic and manual connections will have to be effected. Transitional equipment therefore is necessary to handle the traffic between the manual and automatic offices in the simplest and best way.

(a) *First Stage.*

The first stage in the automatic installation programme consists of the replacement of Teréz manual exchange, the capacity of which (16,000 lines) is exhausted. The area served by Teréz exchange comprises departments IV, V, and VI, on the left bank of the Danube, where the business activity is concentrated, and nearly all the districts on the right bank of the Danube. Therefore, in the first stages of the project provision must be made for automatic service to this section of the town area.

After completion of the first stage, which is already under installation, three main exchanges are to be cut into service:

1. Krisztina main exchange with:
   Vár
   Obuda
   Svábhegy
   Zugliget
   } Satellites – 6,000 main lines.
2. Belváros main exchange 10,000 main lines.
3. Teréz main exchange – 10,000 main lines.

Total – – – 26,000 main lines.

Manual exchanges still in use:
(1) József with – – – 15,000 main lines.
(2) Lipót with – – – 6,000 main lines.

Total – – – – 21,000 main lines.

Thus the capacity of the area will be 47,000 main lines.

The following principles govern the provision of service in this area:

(*a*) A subscriber on an automatic exchange must be able to get connection automatically with every subscriber in the area whether the called subscriber belongs to an automatic or a manual exchange.

(*b*) Calls incoming from an automatic to a manual exchange must—in accordance with (*a*)—be directed to a requisite number of group and final selectors installed in the manual exchanges and not to operators. For this purpose the terminals in the arcs of the final selectors have to be connected to the manual multiple of the corresponding called numbers.

(*c*) Connections between subscribers on manual exchanges have to be effected in the normal manner.

(*d*) Calls incoming from a manual to an automatic exchange have to be handled by a semi-automatic method. Such calls arriving at the manual "A" positions are directed by the operators to the semi-B positions installed in their own exchange, the semi-B operators completing the connections by means of digit keys. These manual exchanges have to be equipped with finders to hunt for the calling semi-B positions, and with registers and group selectors to effect the connections controlled by the semi-B positions.

As a result of such an arrangement, the connections of the subscribers on the automatic offices are uniform, and these subscribers are not obliged to ask for manual exchanges. Further, there is no necessity of installing costly equipments which would be of a transitional character and which would have to be discarded after completing the automatic area. The installation of carriage call indicator equipment for the calls incoming from automatic exchanges to manual exchanges was not considered advisable. There are no spare B boards having a suitable multiple which could easily be altered for this purpose, and the installation of new boards would be very costly, considering that they are only required temporarily.

All solutions which would entail the installation in the automatic offices of manual switchboards, even of a temporary character, for the calls incoming from the manual offices, were rejected. It was therefore decided that the most suitable solution of the problem of dealing with incoming automatic traffic is to employ group and final selectors in the manual exchanges where the necessary space is available. These can be put to good use when the exchange has been converted to automatic. It is true that such an arrangement considerably increases the expense of the initial stage, but this increase will be offset by the fact that in the following stages, 35% to 40% of the switches needed for the automatic installation will be already available. There were several reasons for using separate semi-B positions instead of giving the "A" operators dialling facilities. It is true that the dialling does not considerably increase the operators' load (the coefficient for a five-digit call is increased from 1.5 to 1.75), and it is undoubtedly a great advantage that the connection can be established by the operator who receives the call. However, it did not seem reasonable to train operators in the use of the dial, besides which local conditions were not suitable for the fitting of dials on the manual boards. This is more particularly the case at Teréz exchange where during the gradual transition period it is necessary to ensure uninterrupted operation, and where the installation of dials on key-boards already overloaded with accessories would be almost impossible, and in any case very costly, considering the short time the equipment would be needed. It has therefore been decided that the installation of semi-B positions at Lipót exchange, which is located in the same building as Teréz, would be the more convenient arrangement. These semi-B positions, the quantity of which is governed by ultimate traffic considerations, will handle the traffic outgoing to automatic from Teréz without difficulty during the short period of cutting over from manual to automatic. When Teréz manual office has been entirely replaced, these semi-B positions will be used only for the automatic traffic outgoing to Lipót exchange which will still be in commission.

In connection with the first stage, arrangements were made to provide the new 400 line toll exchange which is to be equipped with automatic facilities and installed simultaneously with the automatic exchanges. To ensure uniform loads on the recording operators' positions, automatic call distributors are embodied in the scheme. Key sets are to be provided at the toll line positions to enable toll calls to automatic subscribers to be completed direct. This has involved provision for the requisite number of line finders, trunk finders and register finders in connection with the toll board circuits. Figure 3 shows the connections between the automatic exchanges and the connections between them and the local manual exchanges and toll exchange.

With regard to the location of the exchanges already dealt with, it may be pointed out that on account of local conditions Teréz exchange,

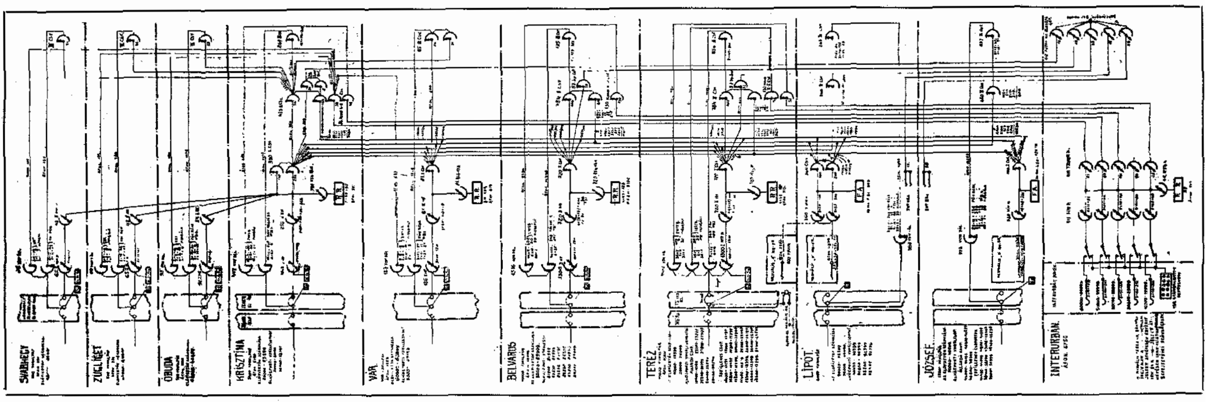


Figure 3—Diagram of Connections of All Exchanges (Automatic, Manual, Toll). First Stage, 47,000 Lines.

which will have an ultimate capacity of 20,000 lines, will be installed with only 10,000 lines during the initial stage, and on a provisional site. The 20,000 line exchange will be permanently installed in the present Teréz manual switching room which will not become available until the manual exchange has been replaced. In the latter stages, the provisional 10,000 line Teréz automatic exchange will be removed, and its automatic equipment utilised for the new exchanges under installation.

The main and intermediate distributing frames, as well as message register racks, cabling and power plant, will be designed for the requirements of the 20,000 line exchange, and installed at once in their final positions.

(b) *Second Stage.*

The first part of the programme will be completed with the replacement of Teréz manual exchange by automatic equipment. The next stage consists of the following:

1. Complete installation of Teréz 20,000 line exchange quite independently of the provisional exchange of 10,000 lines. This will result in 10,000 new lines.
2. Installation of Lipót 3,600 line automatic exchange and its 1,400 line satellite Ujpest, making in all 5,000 lines.
3. Extension of the automatic equipment at József manual exchange for the incoming automatic traffic, and of its semi-automatic equipment for the traffic outgoing to automatic. These extensions will be carried out to meet the requirements of the 65,000 line area.

After the cut-over of the new automatic exchanges mentioned under items 1 and 2, the provisional 10,000 line automatic equipment at Teréz and Lipót manual exchanges will disappear, their automatic equipment being available for the next automatic installation. At the end of the second stage the area will have 41,000 automatic lines. Of the manual exchanges, József

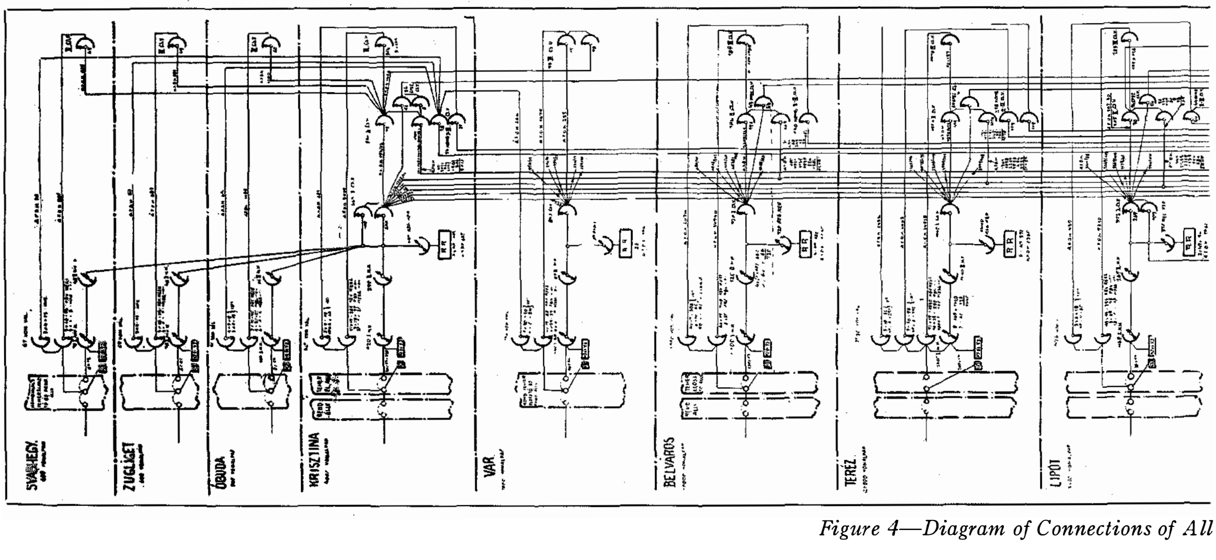


Figure 4—Diagram of Connections of All

exchange, having 15,000 lines, will then alone be in service. The total capacity of the area will therefore be 56,000 lines.

(c) *Third Stage.*

In this period the automatic equipment recovered from the closed exchanges will be employed as follows:

1. Installation of the 2,600 line Lágymányos exchange and its 400 line satellite Budafok, a total of 3,000 new automatic lines.
2. Extension of Krisztina main exchange to 4,000 lines and each of its satellites amounting to 7,000 lines; an extension of 1,000 lines.

The automatic equipment of the József manual exchange remains unchanged, because it attained its capacity under the 65,000 line area scheme in the second stage. The total capacity of the area is thus 60,000 lines, 45,000 of which are automatic.

(d) *Fourth Stage.*

The area of the automatic exchanges indicated above, overlaps the districts belonging to József manual exchange, so that ultimately only one manual exchange of reduced capacity remains to be converted to automatic. This has to be carried out in two parts, to facilitate an economical use of the available premises.

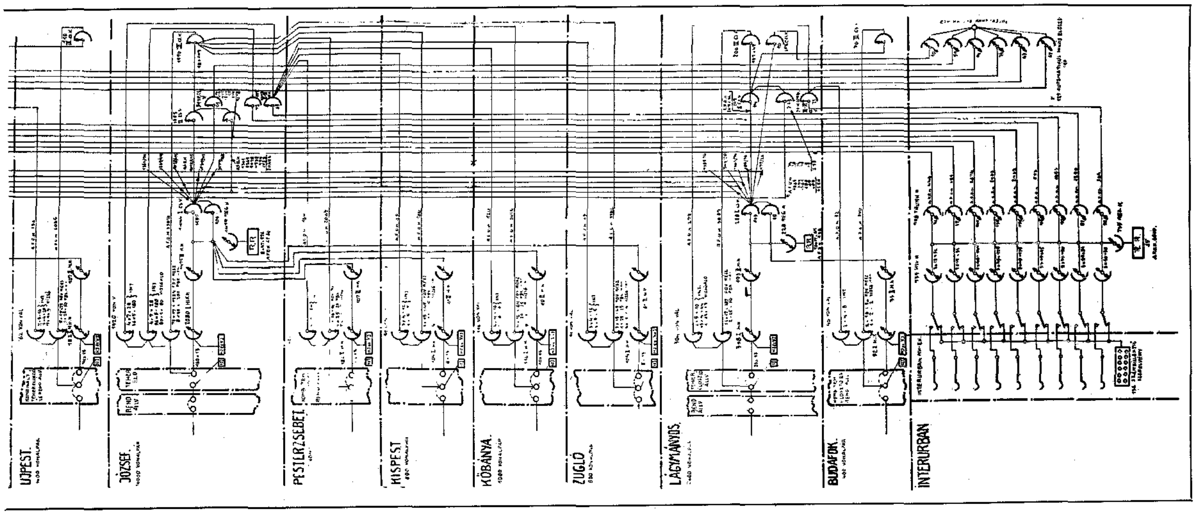
1. First, the subscribers' telephone sets have to be equipped with dials, and the automatic exchange equipment extended so that the subscribers on József exchange will be able to secure connection with every subscriber connected to any other exchange in the area, in exactly the same manner as the automatic subscriber. At the same time trunk circuits must be connected to the levels of the first group selectors reserved for the traffic to József, each trunk leading to the "A" operators who receive the local calls. If a József subscriber calls a subscriber on the same exchange, he has only to dial the first digit of the number of the called subscriber, thereby securing the services of the "A" operator who establishes the required connection. Thus the semi-automatic boards become superfluous because both incoming and outgoing automatic traffic is handled on a full automatic basis.
2. Finally, the quantity of the third group selectors and final selectors must be increased so that not only the incoming and outgoing traffic, but local calls also can be handled automatically, as well as the switching of the incoming toll calls. In connection with this work, the satellites Zugló, Köbánya, Kispest and Pesterzsébet are to be completed, after which the József manual subscribers will be cut over to József automatic exchange and its satellites. This completes the full automatic area, all the manual exchanges disappearing. The attached junction diagram, Figure 4, shows the connections in the 65,000 line automatic area.

Numbering System

In the choice of the numbering system the guiding points have been:

1. To reduce the change of existing numbers as little as possible.
2. To enable the automatic subscriber to call every other subscriber of the area, whether automatic or manual, by direct dialling.
3. That after the 5-digit numbers become insufficient, the only change in numbering will be to add a sixth digit or a letter before them.

As the numbers in the existing Teréz, József and Lipót exchanges differed only in the letters T, J, and L put before them, it was necessary to change the numbers of existing lines in a simple



Exchanges. Second Stage, 65,000 Lines.

way. Considering this, the numbers over 10,000 in the Teréz exchange were left unchanged, and 20,000 was added to the numbers 0 to 9,999. In this way, Teréz exchange was given the numbers 10,000 to 29,999. The new numbers of the József exchange were derived by adding 30,000 to the old ones, so that the subscribers of this exchange obtained the new numbers 30,000 to 49,000. Applying the same method to the Lipót exchange, 90,000 was added to the old numbers; in consequence, the new numbers have the group numbers 90,000 to 99,999. This simple and general change of the numbering was made before the introduction of automatic service; by this means, during the gradual transition to automatic service, there was a change of number only in the case of subscribers who were to be transferred to the new automatic main exchange: Krisztina, Belváros and Lágymányos, or their satellites. The numbers beginning with 0 were not given to subscribers, but were used on special services—complaints, toll recording, fire station, ambulance, police, service supervision, etc. This enabled those services to be called by dialling two figures, 01, 02, 03, 04. . . .09.

TABLE No. 6

Levels of I. group Selectors	NUMBERING		Name of Exchange
	I. 5 digit numbers (up to 99,999 lines)	II. 6 digit numbers (over 100,000 lines)	
1	01,02 . . . etc. for special calls	01,02 . . . etc. for special calls	
2	90,000 – 99,999	200,000–209,000 290,000–299,999	Lipót
3	80,000 – 89,999	170,000 – 189,999	Belváros
4	70,000 – 79,999	270,000 – 289,999	Lágymányos
5	50,000 – 69,999	150,000 – 169,999	Krisztina
6		250,000 – 269,999	Reserved for Future Exchange
7	30,000 – 49,999	130,000 – 149,999	József
8		230,000 – 249,999	Reserved for Future Exchange
9	10,000 – 29,999	110,000 – 129,999	Teréz
10		210,000 – 229,999	Reserved for Future Exchange

Distribution of the Numbers on the Levels of the First Group-selectors.

The numbering system described above, i.e., the distribution of the numbers on the levels of the first group selectors, is shown in Table No. 6, both for the use of 5-digit numbers up to 99,999, and for the use of 6-digit numbers up to 299,999.

Switch Calculations of Automatic Exchanges

The basis of the switch calculations of the exchanges in the 65,000-line area was as follows:

(a) *Exchanges of the 65,000 stage*	*Number of Lines*
Krisztina area, automatic	7,000
Teréz exchange, automatic	20,000
Lipót area, automatic	5,000
József area, automatic	20,000
Lágymányos area, automatic	3,000
Belváros exchange, automatic	10,000
Total	65,000

The distribution of lines in the various areas is:

(1) *Krisztina area.*	
Krisztina automatic main exchange	4,000
Vár automatic satellite	1,000
Obuda automatic satellite	800
Zugliget automatic satellite	600
Svábhegy automatic satellite	600
Total	7,000
(2) *Lipót area.*	
Lipót automatic main exchange	3,600
Ujpest automatic satellite	1,400
Total	5,000
(3) *József area.*	
József automatic main exchange	16,000
Köbánya automatic satellite	1,000
Zugló automatic satellite	800
Kispest automatic satellite	800
Pesterzsébet automatic satellite	1,400
Total	20,000
(4) *Lágymányos area.*	
Lágymányos automatic main exchange	2,600
Budafok automatic satellite	400
Total	3,000

(b) *Estimated average busy-hour calls per line.* 1.5

(c) *Average holding time of a local connection.* . . . . 2 minutes

(d) Estimated average busy-hour calls to toll recording in the calculation of the local equipment 0.05

(e) *Average holding time* of a call to toll recording . 1 minute

(f) *Average busy-hour* calls to toll recording per line referred to a holding time of 2 minutes, ½ x 0.05 0.025

Note: The 1.5 average busy-hour calls include this 0.025, consequently the average busy-hour calls beginning from the second group selectors are 1.5—0.025 . . 1.475

(g) *Average holding time of the registers* . . . . 25 seconds.

(h) We suppose that the calls outgoing from an exchange are distributed among the various exchanges in the relation of their number of lines.

(i) The traffic of other special calls, as complaints, telegram-service, wire-chief, is considered only in the calculation of the number of group selectors for special calls.

(k) The first line-finders, cord-circuits, toll circuits, and the trunk lines to toll recording, are calculated on
the probability basis...............P = 0.001
Registers on the basis..............P = 0.0001
Group and final selectors...........P = 0.01

Detailed calculations were then made for the equipment required for local calls, special calls, and toll connections.

In the calculation of the semi-B positions required in the first stage, it was supposed that an operator could handle 340 calls in the busy hour and give good service. In actual practice expert operators can master 450-500 calls an hour in these positions. Every semi-B position has 20 trunks.

Equipment. The automatic exchanges of the local Budapest telephone area are equipped with 100 point finders of the latest type, with 300 point group-selectors, 200 point final selectors, and with horizontal type sequence switches—all gear driven. The registers are of the all-relay type.

Circuit connections of the exchanges are shown in Figures 3 and 4.

Automatic Main Exchanges. The calls of the subscribers of the automatic main exchanges are directed on first line-finders and cord-circuits. The cord-circuits include second line-finders, first group-selectors, and register-choosers.

The distribution of the calls to the various main exchanges or areas is made from the first group-selectors, the ten levels of which correspond to ten directions. The other group-selectors, i.e., second group-selectors, third group-selectors, and the final selectors, together with the first group-selectors, are controlled, during building up of the connections, by the register.

Groups of final selectors with 300 lines are provided as P. B. X. (Private Branch Exchange) Finals. Of these 300 lines, only 200 have numbers in the numbering system; the 100 further lines have no numbers, being used as second, third, etc., lines of the P. B. X. group.

Automatic Satellite Exchanges

There are three different types of automatic satellites:

(1) Of the first type are: Obuda, Zugliget, Svábhegy, Ujpest, Budafok.
(2) Of the second type are: Kabanya, Zugló, Kispest, Pesterzsebet.
(3) Of the third type is: Vár.

The first two types are similar in that the calls originated by their subscribers are taken up by first and second line-finders in the satellite, and directed on to first group-selectors in the main exchange.

The incoming calls to satellites (including the calls originated in the same exchange) are directed, in the first type, from the second group-selectors in the main exchange on to third group-selectors in the satellite; but in the second type, the third group-selectors are still in the main exchange, and the satellites are equipped with final selectors only.

The Vár satellite has, from the point of local and outgoing calls, the feature of a main exchange, i.e., it has local cord-circuits and registers, with the difference that the local calls, corresponding to the line capacity 2,000 are directed from the first group-selectors on to the third group-selectors—the second group-selectors stage being omitted. With regard to incoming calls, the Vár satellite has the same feature as the first type, i.e., all incoming calls are directed from second group-selectors in the main exchange to third group-selectors in the Vár satellite.

Among the satellite final selectors there are also P. B. X. groups, containing 300 subscribers' lines, to be used in the same manner as in the main exchange.

Automatic Toll and Other Special Equipment

1. The toll operator is enabled to connect to the subscribers of the automatic exchanges by plugging into an individual jack corresponding to the automatic main exchange or area containing a 10,000 group of subscribers. The selected jack is picked up by a line-finder, a register-chooser connects an idle register, and a trunk-finder extends the line to the corresponding area. It is to be noted that as the area is determined by the jack chosen, the first group-selector may be left out and the call directed to a combined second and third group-selector in the automatic main exchange. On each level of these combined second and third group-selectors there are five groups of trunks each containing six trunks leading to a certain 200 subscribers' group of final selectors, i.e., the group-selector selects on each level a group of 1,000 subscribers, therefore the ten levels correspond to a group of 10,000 subscribers. Accordingly, the group-selectors of a

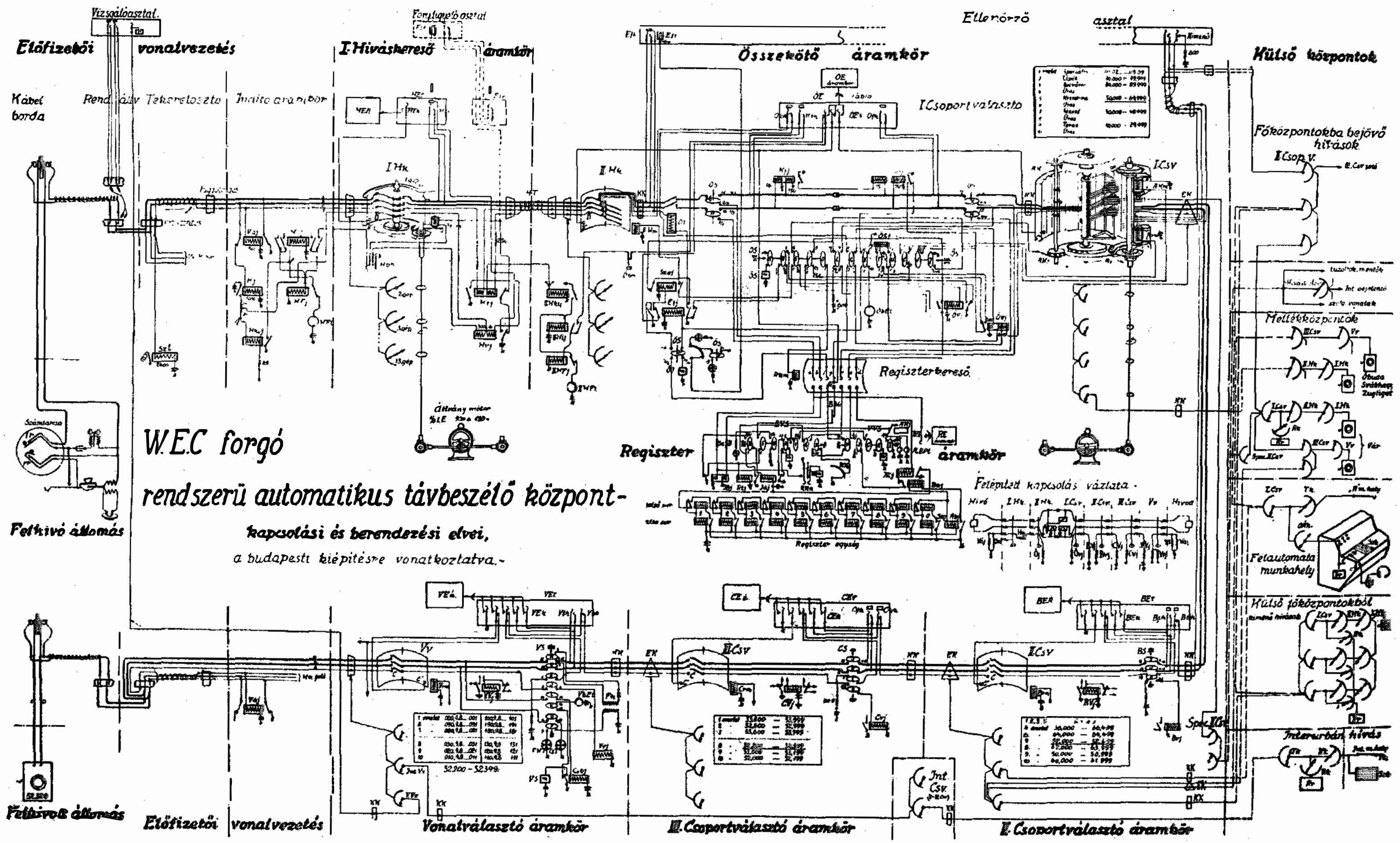


Figure 5—Circuit Schematic of the Automatic and Semi-Automatic Exchanges.

20,000 line area work in two main groups.

If the subscriber of a satellite exchange is wanted on a toll connection, then the call is directed from combined second and third group-selectors in the main exchange to final selectors in the satellite. The toll circuits are independent of the local circuits, and are connected with them only on the arc of the final selectors. The toll connections have preference over local connections, and the toll operator is enabled to break down an existing local connection.

If the last line of a P. B. X. group is busy in a toll connection, the electrical conditions of the line before the last are changed in such a manner that if a second toll call arrives, the final selector does not step on to the last line, but stops on the line before the last, and the operator, who breaks down the local connection existing on this line, then accomplishes the toll connection.

2. The toll recording positions are reached by all subscribers dialling two digits (01). In these calls the first group-selector selects, on its first level, an idle special second group-selector, and this second group-selector selects on its tenth level an idle trunk to the toll exchange, where the trunk ends in a call distributing switch which hunts for a free position.

The calls to toll recording, originating in the Vár satellite, go a different way, as the first group-selector selects on its fifth level an idle trunk to the Krisztina exchange where the incoming second group-selector selects on its tenth level an idle special third group-selector, and this third group-selector works in a manner similar to the special second group-selector in the former case.

3. The other special calls, complaints (03), telegram-service (02), reports of linemen (09) are operated in a way similar to the calls to toll recording, with the only difference that corresponding to the second digit, the calls are directed to trunks on different levels of the special group-selector.

Detailed description of equipment and operation of circuits would lead too far. A short summary of the equipment used for control, test and supervision may, however, be useful.

In the main exchanges there are the following control, supervision, and test desks:

(a) *Monitoring Desk.* For a maximum of 10,000 lines, two positions with the following equipment:
  (a.1) Line jacks of the outgoing trunks for testing purposes.
  (a.2) Lamps and jacks of the cord circuits for P. G. (permanent glow) calls.

This equipment is provided to release the register, and to give a signal to the maintenance personnel from the cord-circuit when the call fails to get through on account of a line-fault, or the subscribers' mistake.

  (a.3) Lamps and jacks of the dead line circuits.
  (a.4) Lamps and jacks of the dead level circuits.
  (a.5) Lamps and jacks of automatic lines for incoming service calls.
  (a.6) Jacks of automatic lines for outgoing service calls.
  (a.7) Lamps and jacks of direct service lines.
  (a.8) Voltmeter circuit for trunk testing.
  (a.9) Busy lamps of second line-finder groups.
  (a.10) On each position:
    4 monocord circuits.
    2 double cord circuits.
    1 test plug of the voltmeter test circuit.

(b) *Lamp Frame.* 1 unit for maximum 10,000 lines near the monitoring desk, with the following equipment:
  (b.1) 1 lamp for each cord-circuit.
  (b.2) 1 key and 1 lamp for each register. When the key is operated, the cord-circuit lamp glows and indicates the cord attached to this register. If the connection fails to go through on account of some circuit-fault, the lamp of the cord-circuit taking part in the connection, flickers. The circuits engaged in this connection are held over, but the calling subscriber is released and gets a free register again. If the calling subscriber does not hang up his receiver at the end of the conversation, the cord-circuit lamp glows.

(c) *Service Observation Desk.* The service observation desk provides for the following:
  (a) Observation of the connecting phases and duration of calls originated by subscribers.
  (b) Control of any register-circuit.
  (c) Metering of the number of calls and call minutes going through any circuit-section.
  (d) To make experimental calls to find the quality of the exchange-service.
  (e) Observation of calls originated by or directed to certain subscribers, in the case of complaints.
  (f) Registering the number of times all circuits of a group are busy.

The parts of this equipment are:

  (c.1) Service observation circuit for the observation of the traffic of 2 x 14 = 28 first line-finder circuits.

(c.2) Service observation circuit for the observation of five register circuits.
(c.3) Concentration of all alarm-signals.
(c.4) Registering-ammeter with the possibility of connection with any section of group—or final—selector circuits for registering the conversation-minutes going through the section.
(c.5) Outgoing automatic service lines.
(c.6) Incoming automatic service lines.

(d) *Supervisor's Desk.* The supervisor's desk, a specialty of Budapest, is equipped as follows:
(d.1) Lines under supervision.
(d.2) Lines to be called with number and name.
(d.3) Lines to be called with permission only.
(d.4) Disconnected lines.
(d.5) Transferred lines.
(d.6) Lines with number changed, not contained in the directory.
(d.7) Disconnected line circuits, their numbers given to other subscribers.
(d.8) Incoming automatic service lines.
(d.9) Outgoing automatic service lines.
(d.10) Direct service lines.

(e) *Wire-chief's Desk.* The wire-chief's desk, up to 10,000 lines, 1 or 2, two-position desks equipped as follows:
(e.1) Test final circuits.
(e.2) Test-lines to the M. D. F. (Main distributing frame).
(e.3) Lamps and keys for special complaint-calls.
(e.4) Lamps and keys for special calls of linemen.
(e.5) Incoming automatic lines.
(e.6) Outgoing automatic lines.
(e.7) Direct service lines.
(e.8) Lamps and keys of dial testing circuit.
(e.9) Busy lamps of the first line-finders groups.
(e.10) Each position has:
1 voltmeter test circuit.
1 double cord circuit.
Test plugs (with lineman's control circuit).

The wire-chief's desk is combined with a special card-catalogue desk containing the fault cards of the subscribers.

The satellite exchanges are equipped with the following desks:

1. The Vár exchange similar to the main exchanges.
2. The other satellites have each a combined desk, one position having equipment like that under (a), (b), (c), (e) above, but with suitable reduction.

Preparations Prior to the Introduction of Automatic Service

To facilitate the period of transition, the following was accomplished:

(1). Courses and lectures were held for the engineers, test and maintenance staff, for a year or so. As an example, Figure 5 was shown to explain the operation of the automatic system.

(2). Popular pamphlets were issued giving directions for the use of subscribers.

(3). Practical teaching in dialling on models of various types. Demonstrations were given in a comprehensible manner of the operation of an automatic exchange, as shown in Figure 6.

(4). Public lectures were given accompanied by moving pictures. Figure 7 is a reproduction of part of the film explaining how a connection is made.

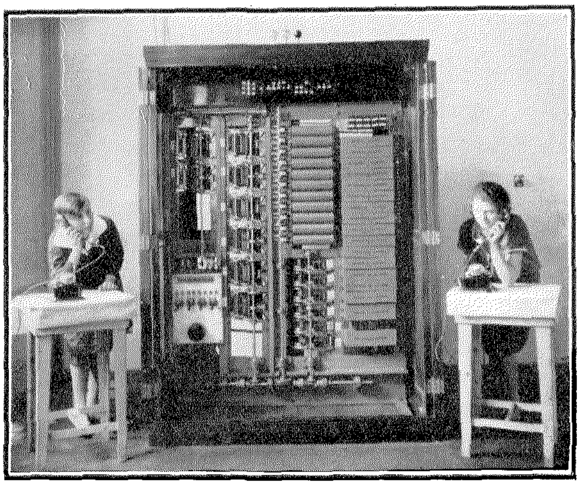


Figure 6—Model of Automatic Equipment Used for Demonstration Purposes.

Conclusion

The first stage of the installation of the automatic telephone exchanges in Budapest has been brought to a conclusion after nearly three years of preparation, manufacture and installation. The equipment was cut into service without the least trouble.

On April 28, 1928, 2,400 subscribers were connected to the Krisztina exchange, and their satellites; and on May 12 the number was increased to 2,600. On June 9, a total of 1,100 subscribers were connected to the Belváros exchange, that number having been increased by 5,000 on June 24. (The floor plan of the Belváros exchange is shown in Figure 8.) During July, the Teréz automatic exchange was cut-over with 9,400 subscribers. It will be evident, therefore, that in all there have been cut into service 20,000 automatic subscribers. The whole cut-over was made by the experts and personnel of the Hungarian Post-Office Administration, and of the Standard Electric R/T (Standard Villamossági Reszvény Társaság), Budapest, Hungary, the manufacturers of the equipment. On the 21st of July the manual Teréz exchange—which had been in service for nearly twenty-five years—was closed, and the Hungarian Post-Office Administration took leave of the old equipment and its personnel at an appropriate gathering (Figure 9).

It is gratifying to note that the transition period has been satisfactorily passed without any serious trouble, and also that the subscribers have taken to the automatic service with great pleasure.

The provision of progress lamps on the registers made it possible for any dialling errors of the subscribers to be followed at the beginning. By means of line jacks, it was possible to get in touch promptly with the subscribers and to draw their attention to such errors as were being made.

Instruction was accepted in a friendly manner. Subscribers of the manual exchanges are at present overwhelming the Administration with requests for automatic service. These wishes cannot for the time being be fulfilled. The installation of automatic exchanges will be continued until the end of the year 1931; the transition of the József manual exchange to full automatic service is not, however, to be expected before that time.

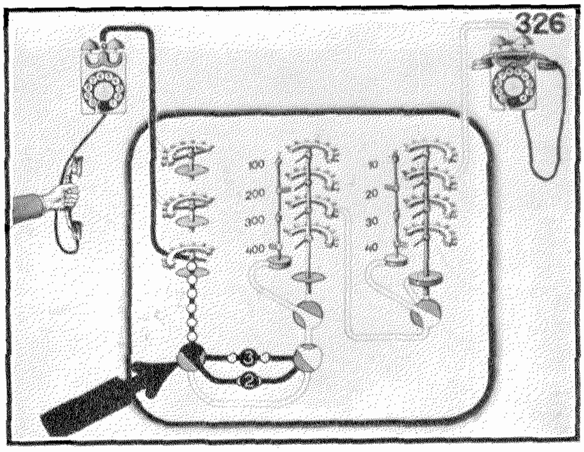


Figure 7—Illustration of the Cinema Film.

Calculations which were made in the years 1920 and 1921 have been fully verified. It is only in the Krisztina area, on account of an increase in building activity in this part of the town, that there has been an unforeseen increase in the number of subscribers that it will be necessary to consider in the further installation of the automatic exchange equipment. Therefore, the Krisztina exchange, in which case provision was made for extensions, will be equipped with 8,000 lines. The Lágymányos exchange will be equipped with 3,600 lines. On account of these developments it has been necessary to prepare plans for a 70,000 line instead of a 65,000 line area, and to modify the quantity of exchange equipment that will be required.

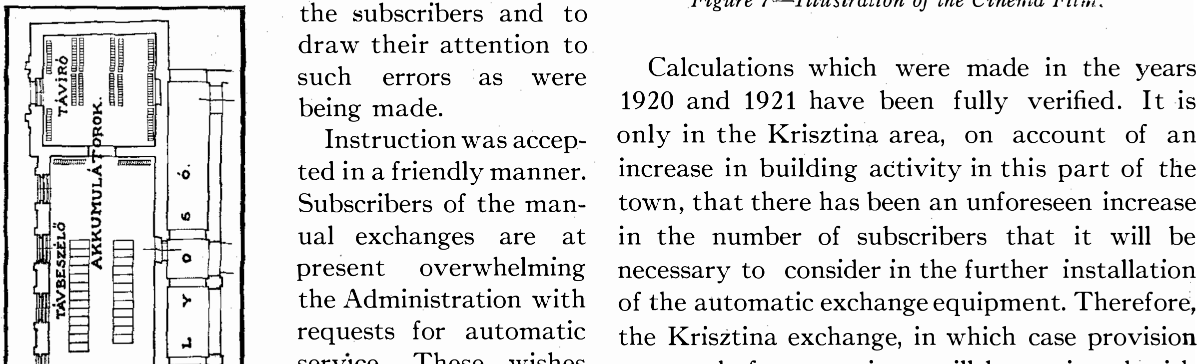


Figure 8—Floor Plan of the "Belváros" Exchange.

In veiw of the results which have been obtained, especially the small number of faults, it can be stated with assurance that these automatic exchanges—produced almost entirely by Hungarian manufacturers—will fufilll the expectations of the Budapest public.

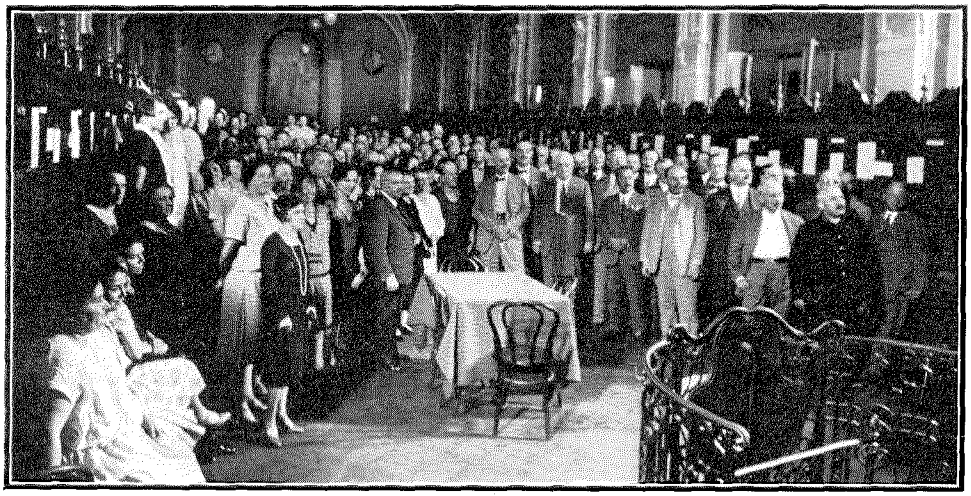


Figure 9—Last Evening in the Old Manual Teréz Exchange.

Handwörterbuch Des Elektrischen Fernmeldewesens

NOTWITHSTANDING the phenomenal growth of electrical communication in the last decade, there is a general lack of a comprehensive encyclopedia of terms used in the communication art. Two quarto volumes, HANDWÖRTERBUCH DES ELEKTRISCHEN FERNMELDEWESENS, edited by Dr. Ernst Feyerabend, Dr. Hugo Heidecker, and Professor Franz Breisig of the Reichspostministerium and Mr. August Kruckow, President of the Reichspostzentralamt, have been published in German recently by Julius Springer, Berlin. Not only have technical subjects such as theoretical electricity, telegraph, telephone and wireless technique, and the construction of lines and conduits been treated, but material of biographical, commercial, legal, and international interest also has been included. Undoubtedly the information contained in these volumes will prove highly useful to the engineer, the manufacturer and the industrialist as well as to the journalist and the statesman.

A New High Power Radio Broadcasting Equipment

By D. B. MIRK

Les Laboratoires Standard, International Standard Electric Corporation

THE trend of modern design in broadcasting transmitters is towards higher power stations with better quality transmission. Three main factors have contributed towards this movement:

(1) Broadcasting is now an everyday part of a nation's life, and as such must be regarded as one of the Public Services. It serves a large and fast increasing percentage of the population, and consequently the demand for "good quality, good strength" programmes is becoming more and more insistent.

(2) The limitation of wavelengths in the broadcast range to 84 exclusive wavelengths, and their allocation as agreed by the Union Internationale de Radiophonie, means that each European country is endeavouring to make the utmost of its exclusive wavelengths. The tendency is therefore to make the broadcasting stations operating on these wavelengths of as high power as is economically possible.

(3) The utility of a broadcasting station is largely determined by the extent of the area which it serves with "good quality, good strength" signals. Provided the area fed is more or less densely populated, as is usually the case in the neighbourhood of large towns, the increase in the power of the broadcasting station has the advantage of serving a greater number of listeners at a lower relative cost per unit.

Accordingly, to meet this demand, a High Power Broadcasting Equipment has been developed by the International Standard Electric Corporation. The equipment was manufactured by Standard Telephones & Cables, Ltd., and was erected and tested at their Works at New Southgate, London.

The latest broadcasting technique makes it possible to obtain up to 100 per cent linear modulation. The advantages of deep modulation are not generally understood, and it is thought that some explanation may not be out of place here.

Electrical disturbances are constantly present in the ether, and if these disturbances are of the same order of frequency as the carrier, the receiving equipment picks them up at the same time as the carrier. The disturbances beat with the carrier in much the same way as the side bands do, thus producing the audible noises familiar in all radio receivers. The noise is therefore proportional to the carrier, and consequently every effort should be made to increase the power in the side bands, as in this way the received signal strength may be increased without the attendant increase of noise which is more or less inevitable with increased carrier.

It is well known that for 100 per cent modulation the average or mean power is 1.5 times the carrier power, and that the power rises to a peak value of four times the carrier power.[1] This peak power is really the limiting factor in the rating of any broadcast transmitter. For 100 per cent modulation we must rate the unmodulated carrier power at one-fourth of the peak power which the transmitter is capable of handling, but if smaller percentages of modulation are required, then the carrier power can be correspondingly increased, provided the design is capable of dealing with the increased average power which will result from an increased carrier with smaller percentage modulation. Therefore, for a given peak power, it must be decided whether the transmitter should be designed for a large carrier with small percentage modulation or maximum percentage modulation and a smaller carrier. It can be shown that the lower carrier with maximum modulation gives the greater received signal. As stated above, the signal-to-noise ratio is also greater for the condition of maximum modulation. The equipment, therefore, has been designed for 100 per cent linear modulation. The estimated peak power available, corresponding to the highest point of the straight part of the load characteristic, is 180 K.W. Consequently, the antenna carrier

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[1] R. A. Heising, Proceedings of the Institute of Radio Engineers, August, 1921.

power to permit of 100 per cent linear modulation was estimated at 45 K.W. Subsequently it was found on test that 100 per cent linear modulation could be obtained with a carrier power of 50 K.W.

The Design of Broadcasting Transmitters

It has been said that the governing feature from the point of view of public service is the provision of high quality reliable broadcasting with the minimum of interference. It may therefore seem reasonable to base the design of the broadcast transmitter on the public demand. This would mean that, since best present-day receiving sets are only responsive over a frequency range of approximately 50 to 5,000 cycles, a transmitter capable of successfully reproducing this band of frequencies would fulfill the requirements. However, since the technique of successful high quality reception is becoming more universally appreciated, both by listeners and manufacturers, the deficiencies of the receiving set will no doubt gradually be remedied, and consequently the broadcast transmitter should be designed to be capable of fulfilling the conditions which may possibly be required by the listener some years hence. It is generally agreed that the normal human ear cannot appreciate as music, frequencies below 30 or above 10,000 cycles. It is felt that a broadcast transmitter which is capable of reproducing this range of frequencies will meet all future requirements, and that this, therefore, should be the aim of modern design.

Broadcasting must also be regarded as a commercial enterprise, and in this respect economics naturally play an important part in the design of a transmitter. This means that the equipment must be efficient from the point of view of power consumption, simple to operate, and designed so that possible interruption due to fault or breakdown is reduced to a minimum.

Lastly, every possible precaution should be taken to prevent interference in any way with other broadcasting or commercial transmitters.

To meet these requirements then, a transmitter must be designed to have the following features:

(a) *High Quality Transmission.* Technically, this means that the input response curve of the transmitter must be sensibly linear over a range of audio frequencies from 30 to 10,000 cycles, and that the transmitter must be capable of 100 per cent linear or distortionless modulation. The radiated carrier should be free from any variation.

(b) *Power Supply.* One of the chief maintenance costs of a broadcasting transmitter is the power supply cost. Therefore every endeavour should be made to reduce to a minimum the actual power taken from the mains, without reducing the quality or reliability of the transmission.

(c) *Simplicity of Operation.* The operation of the transmitter should be simple and methodical, so that the staff requirements can be reduced to a minimum. Further, the transmitter should be easy to maintain, and in this respect, facilities should be provided for automatically removing any voltages which in the event of the occurence of a fault are likely to damage costly apparatus. Every precaution should be taken, and safety devices should be incorporated, to prevent the operators coming into contact with any dangerous voltage.

(d) *Continuity of Programme.* The possibility of faults should be reduced to a minimum, and facilities should be provided so that if a fault occurs, indication is given immediately to show the location of the fault. Further, audible and visible indication should be given to the staff immediately the transmitter ceases to operate properly. Where possible, the equipment should be designed so that it is capable, either by means of duplication or running at reduced power, of continuing its programme in the event of faults.

(e) *General.* The range of wavelength used for broadcasting is roughly from 300 to 600 metres. If possible, therefore, the transmitter should be designed to cover this wavelength band, and it should operate satisfactorily and efficiently over the complete range without recourse to elaborate changes in the tuned circuits. Short wavelengths are now being used extensively for commercial communication; and to prevent interference with these services, every effort must be made to reduce the strength of the radiated harmonics from the broadcast transmitter to the lowest possible value.

In the design of the high-power broadcasting transmitter described hereinafter, every endeavour has been made to meet these requirements.

Description of the Radio Broadcasting Equipment

The radio broadcasting equipment contains all the apparatus necessary to pick up the speech or music in the studio and deliver it in the form of modulated radio frequency currents to the antenna. It comprises essentially the speech input equipment, the radio transmitter, the power supply equipment, and the control apparatus. A block schematic of the complete equipment is shown in Figure 1.

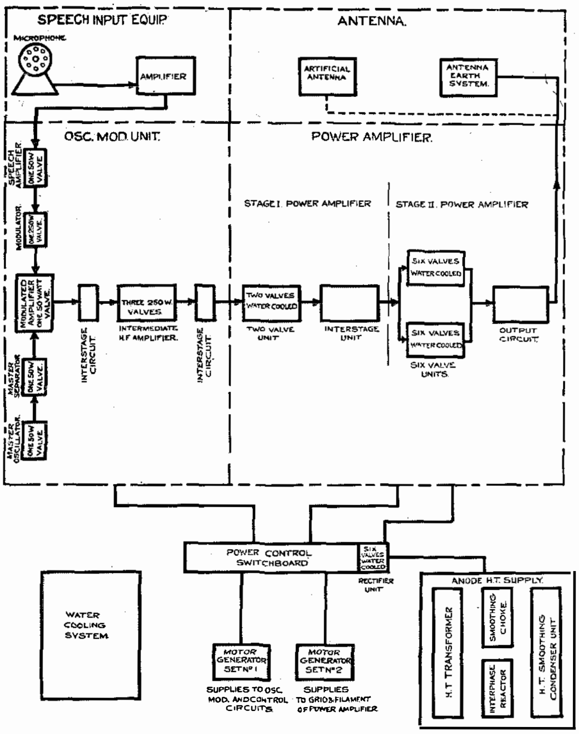

Figure 1—Block Schematic of Radio Broadcasting Equipment.

System of the Transmitter. The system used is one of modulation at low power, with subsequent high frequency amplification. The carrier power is generated in a low power master oscillator. The oscillator in this case does not synchronise its frequency with a higher power oscillator, but provides the sole drive for the equipment. The subsequent stages merely amplify the master oscillator output, and are designed so that they cannot in any way affect its operation. Modulation takes place at a slightly higher level than the master oscillator output, after which the modulated wave is amplified by three stages of high frequency amplification, the output from the last stage feeding the antenna. Provision is made to prevent frequency modulation with consequent distortion, as a result of any reaction on the master oscillator through valve capacity or otherwise, from the modulated amplifier or the power amplifiers. Figure 2 shows a simplified schematic of the transmitter.

The principles of efficient high frequency amplification are well known; [2] hence, only a brief reference to the operation of the amplifiers will be necessary. Generally, amplifiers may be described under two groups; those which forbid and those which allow the passage of grid current. The first group is the type generally used for audio frequency amplifiers where it is essential to operate on the straight part of the charac-

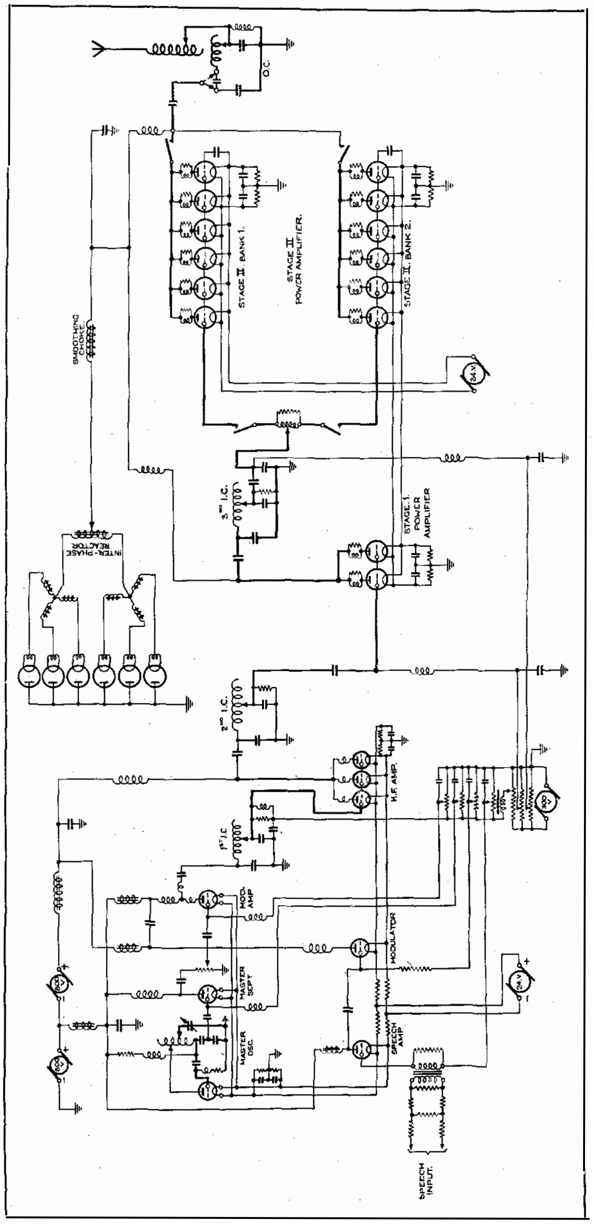

Figure 2—Simplified Schematic of the Radio Transmitter.

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[2] A. A. Oswald and J. C. Schelling, Proceedings of Institute of Radio Engineers, June, 1925.

teristic, and to limit the grid driving voltages to prevent the grid becoming positive. This type of amplifier has a very low efficiency. In the second group, used for high frequency amplifiers, grid current is permitted, and a much larger efficiency is obviously available with attendant production of distortion and harmonics. For audio frequency amplification, these harmonics cannot be eliminated, and consequently grid current is never permissible. With high frequency amplification, however, this method of operation results in the production of high frequency harmonics which are well separated from the fundamental or carrier wave. Hence, it is comparatively easy, by the use of suitably designed interstage and output circuits, to eliminate them, and to prevent their radiation from the transmitting antenna. The value of the grid polarising potential is therefore selected at or near the point of anode current cut-off, and the grids are driven with large alternating potentials. During each radio cycle, the grid swings positive to such an extent that appreciable grid current flows.

Circuit Design. The system of modulation adopted is equivalent to that devised by Heising, commonly known as "Choke Control." A 50 watt valve, which is designated the "modulated amplifier," and which works as a high frequency amplifier, is modulated by a 250 watt modulator valve. The anode feed current to this valve passes through an audio frequency choke, the voltage across this choke being varied at audio frequency by the modulator valve. The design is such that for 100 per cent linear modulation, and with a constant high frequency grid drive, the output current of the modulated amplifier varies linearly with the anode voltage from zero to twice the normal operating anode voltage. The modulator valve is capable, without any departure from the linear characteristic, of varying the anode voltage of the modulated amplifier valve from zero to twice its normal direct current operating voltage. As the mean power output of the modulating system is raised by 50 per cent, for 100 per cent modulation, the modulator valve must be capable of supplying power equal to half the input power to the modulated amplifier. These requirements are met by the use of a 250 watt modulator valve. This valve is fed through a low frequency modulation choke from a 1,600 volt direct current supply, and the modulated amplifier valve is fed through another choke from an 800 volt direct current supply. The chokes are connected through a 10 microfarad condenser.

Considering now the circuits of the high frequency amplifiers, all the interstage circuits, and the output circuit, represented as I.C., and O.C., respectively, in Figure 2, are of the same type of parallel tuned resonant circuit. The function of these circuits is to receive the energy from the anodes of the valves of one stage and to deliver it at the correct level to the grids of the valves of the next stage, or to the antenna. The design must be such that the interstage circuit meets the output impedance requirements of the valves of the one stage, and the input impedance requirements of the valves of the next stage or of the antenna. The interstage and output circuits may be described as consisting of two legs, one leg having a capacity, and the other having an inductance and capacity in series (see Figure 3). The driving voltage for the grids is taken across the coupling condenser C.2 in the second leg. As explained previously, the large driving voltage applied to the grids of the high frequency amplifier causes the grids to become alternately highly positive and highly negative, the former condition resulting in the passage of considerable grid current. This method of operation results in a considerable variation of the grid filament impedance. This variation tends to be reacted back through the grid coupling condenser and the interstage circuit, thus affecting the anode circuit of the previous stage. To prevent this reaction, the grid circuit is heavily damped by a resistance of much lower value than

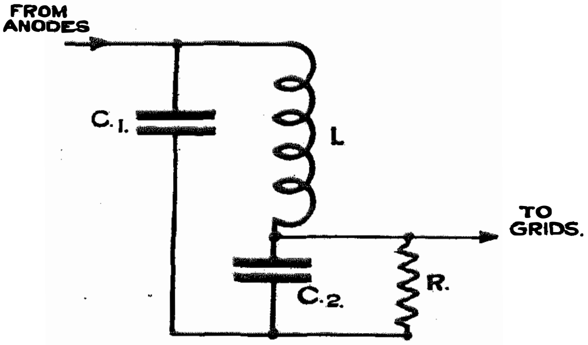

Figure 3—Type of Interstage Circuit used in the Radio Transmitter.

the minimum value of grid filament impedance. It is inserted across the grid coupling condenser, thus reducing to a minimum the effect of the variation of the grid filament impedance on the previous circuit. Owing to the fact that the reactance of a condenser is inversely proportional to the frequency, C_1 and C_2, both present a low reactance to currents at harmonic frequencies. This type of interstage circuit and output circuit has therefore exceedingly good harmonic eliminating qualities.

Three stages of high frequency amplification are employed: the first stage has three 250 watt radiation cooled valves, the second stage two 15 K.W. water cooled valves, and the third stage twelve 15 K.W. water cooled valves.

Layout and Arrangement. The layout of a broadcasting station of this power is so much dependent on the space available, the situation and location of the station, and the facilities required at the station, that it is not possible to specify any rigorous arrangement. Figures 4 and 5, however, are intended to indicate the type of layouts which would be suitable, and to show the floor space required for their respective arrangements.

The radio units of the Broadcasting Equipment are designed as isolated free-standing units, each unit being completely enclosed; they are arranged in line, with about 2 feet 6 inches separation between units. The power panels are built into a Power and Control Switchboard which faces, or is adjacent to, the radio units. The high tension enclosure containing the high tension transformer and filter unit, which forms part of the 12,000 volt direct current supply equipment, is located behind the rectifier unit, which is part of the power and control switchboard. Another enclosure is mounted behind the radio units containing the output circuit and the artificial antenna. With this type of layout it is possible to isolate all the running machinery from the radio transmitter. Furthermore, since the rectifier equipment for the 12,000 volt direct current anode supply, comprising the rectifier unit, high tension transformer, smoothing choke, condensers, etc., is located in one enclosure, the lengths of all connecting leads are reduced to a minimum, thus avoiding high frequency pick-up with the possibility of consequent carrier noise.

All the cables for the various power circuits are

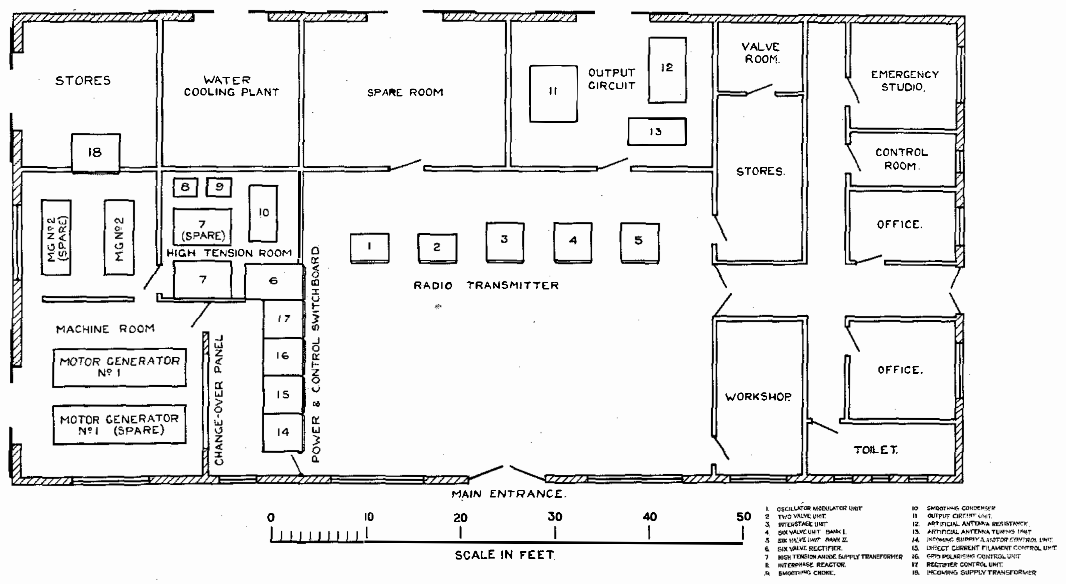

Figure 4—A Suggested Layout for the Equipment.

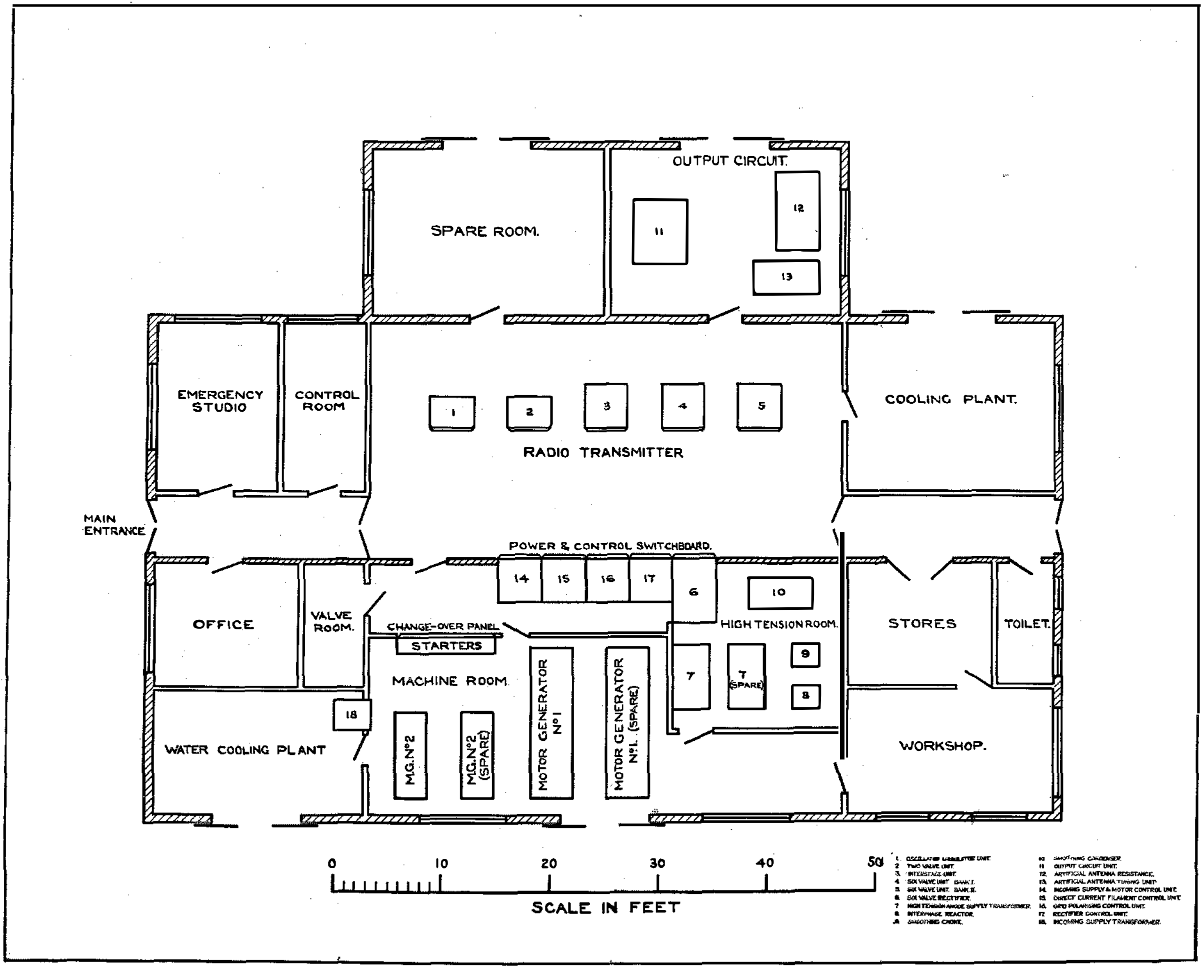

Figure 5—An Alternative Suggested Layout for the Equipment.

lead covered, and are run in trenches in the floor. The only bus bars visible are the high frequency connections between the radio units, and from the radio units to the output circuits. All these high frequency bus bars are run overhead in the form of transmission lines of concentric copper tubes, the outer one being earthed.

The main idea governing the station layout has been to consider the radio equipment quite apart from the power equipment. Hence all the machines and apparatus connected with power supply are located together and isolated as much as possible from the radio units. At the same time full consideration has been given to the necessity of easy operation, and consequently the power boards are arranged so that the operator attending to the radio units is also able to control all the power apparatus.

Speech Input Equipment. The function of the speech input equipment is to pick up the speech or music in the studio, transform it into electrical energy, amplify this energy to a suitable level for application to the radio transmitter, and provide facilities for controlling this level and for checking the quality.

The speech or music is picked up in the studio by a condenser microphone, which, with its associated amplifier, is mounted on a pedestal. The audio frequency currents from the condenser microphone equipment are passed through a three-stage low frequency amplifier before application to the radio transmitter. This amplifier, with the necessary controls, measuring and indicating instruments, together with the radio receiver and monitoring arrangements, is assembled in the control desk (Figure 6). This desk is located in the control room, and it is so arranged that all the controls are within easy reach of an operator sitting centrally in front of the desk.

The apparatus is mounted on steel panels assembled in three sections. The top panel in the left-hand section is the volume indicator panel. This is intended to assist the operator in controlling the amplification of the speech input amplifier in such a way as to keep within proper limits the wide variation in volume of the speech currents delivered to the radio transmitter. If this control were not exercised, the extremely wide change of energy produced by the sounds in the studio would cause the transmitter to be frequently overloaded, while at other times the transmitter would be almost inaudible. The indication of the volume level is given by a sensitive meter in the plate circuit of a valve which, for the convenience of the operator, is mounted on a gain control panel located in the centre section of the desk. Immediately below the volume control panel is a panel which carries the meters whereby the various filament and anode currents can be measured. Below the meter panel is the signal and control panel. A series of jacks is provided on this panel to give facilities for connecting up the appropriate lines for local or outside broadcasting.

Communication between the studio and the control room is obtained by means of local telephones, attention being attracted by a buzzer mounted on the signal and control panel and operated by a key located at some convenient point in the studio. A lamp is provided in the studio in place of a buzzer, to avoid disturbing the programme.

While the whole of the speech input equipment is designed to reproduce all frequencies uniformly, the characteristic of most receivers and loud speakers is usually far from straight. The deficiency is as a rule particularly noticeable on the lower frequencies. It is therefore generally desirable, under present conditions, to modify the characteristic of the speech input equipment, so as to emphasise the frequency components between 1,000 and 30 cycles. A special equalizer, located on the bottom panel of the left-hand section, has accordingly been provided, which effects this modification while leaving the characteristic practically unaltered from 1,000 cycles upwards. The advisability of its use or otherwise can only be determined by actual experience; hence, a key is provided on the panel which enables it to be cut in or out at will.

The top panel in the centre section of the desk is the amplifier panel containing three stages of low frequency amplification. The circuits are designed to give an exceptionally good characteristic with freedom from distortion. Potentiometers for controlling the gain are mounted on a separate gain control panel located below the amplifier panel. The potentiometers enable the gain of the equipment to be varied with maximum flexibility in small uniform steps; the operation of the potentiometers is noiseless.

Figure 6—The Speech Input Equipment.

The top panel in the right-hand section is the receiving panel, comprising a detector and two stages of low frequency amplification. Below the receiving panel is mounted the monitoring amplifier panel which consists of one stage of amplification designed to work from the speech amplifier into a "Kone" loud speaker. In addition to observing the volume level it is desirable for the operator to maintain a constant check on the quality of the speech currents delivered to the radio transmitter, in order that he may detect any distortion due to overloading of the speech amplifier, and also observe any faults arising in the studio. At the same time, it is necessary for him to listen to the output of the radio transmitter, so that by making a rapid comparison of the input and the output, he may detect any distortion occurring in the radio transmitter proper. Experience has shown that continuous listening with a telephone head-set is inconvenient to the operator, and after a time causes him to lose the necessary fine discrimination of tone. The "Kone" loud speaker is therefore used for monitoring, either from the amplifier panel, or from the radio receiver panel, so that a rapid comparison may be made between the outputs of the speech input equipment, and of the radio transmitter.

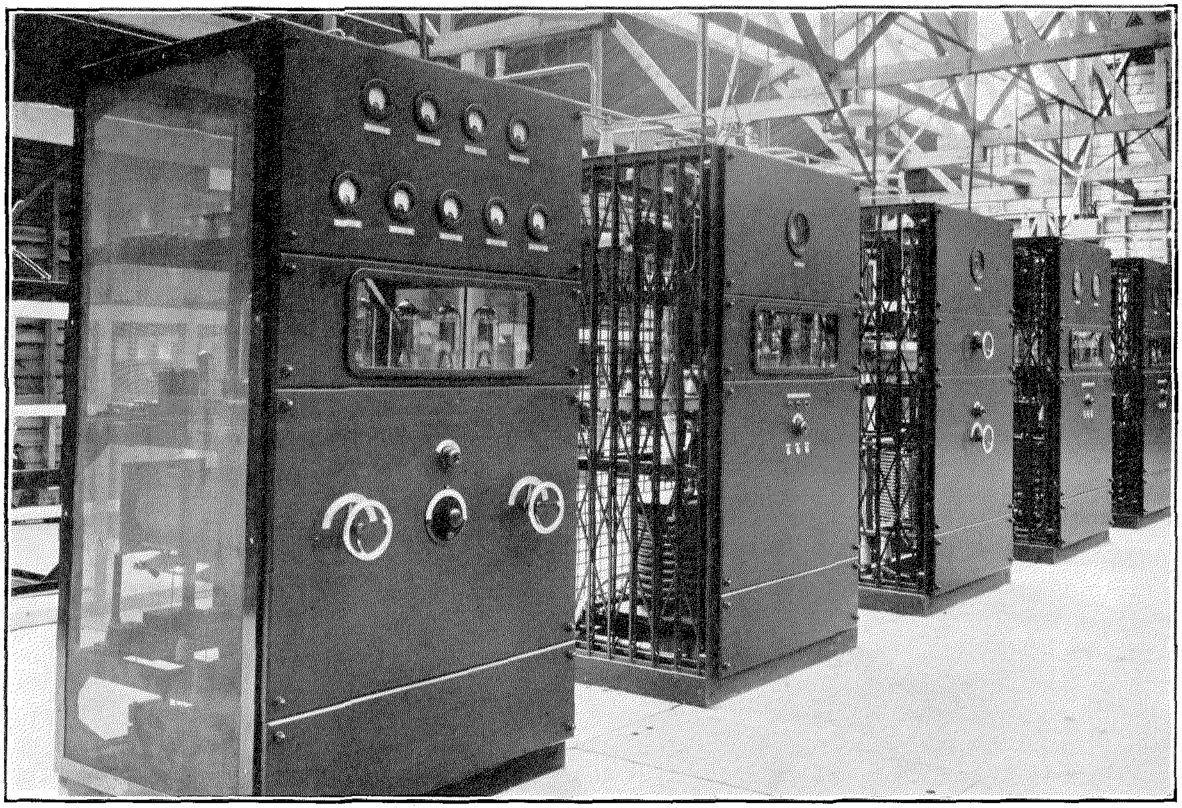

Figure 7—The Radio Transmitter Units.

Radio Transmitter. Figure 7 represents the radio transmitter, the five units, starting from the left, being the Oscillator Modulator Unit, the Stage I Power Amplifier Unit, the Interstage Unit, and the two Stage II Power Amplifier Units. From the point of view of accessibility and maintenance, the free-standing isolated unit type of equipment has very marked advantages for a broadcast transmitter of this power. Each unit is completely enclosed, access to the apparatus being gained through doors or gates in which safety switches are incorporated. It is impossible to have any high voltage on the unit unless these doors are closed; consequently, adequate protection is provided for the operators. The front panels are of polished black slate.

The Oscillator Modulator Unit contains all the apparatus necessary for (a) the generation of the high frequency carrier at low power; (b) the modulation of the high frequency carrier by the audio frequency currents received from the speech input equipment; and (c) the amplification of the modulated energy to the requisite power level for application to the grid of the Stage I Power Amplifier.

The radio frequency carrier wave is generated at a low power level by a quartz crystal-controlled master oscillator. To obtain the maximum frequency stability possible, the temperature of the box containing the master oscillator is maintained constant by the use of a sensitive thermostat. In addition, the box containing the master oscillator is completely shielded from external fields. A coupling stage is inserted after the master oscillator, to prevent the master oscillator being affected by any variations in the load taken by the modulated amplifier during modulation. This coupling stage, designated the "Master Separator," is a 50-watt valve worked very lightly. Its purpose is to present a constant impedance to the output of the master oscillator. Allowing for as much as 10 per cent variation in each of the anode and filament voltages, the change of frequency will be less than 10 cycles. Further, neither temperature variation, nor even change of valves will cause the frequency change to exceed 10 cycles. The crystal-control may be switched out, and the oscillator used in a self-excited circuit if desired. The design is such as to give very good frequency stability even when used as a self-excited oscillator.

The 250-watt modulator valve is fed by a 50-watt speech amplifier valve, the circuits being so designed that virtually perfect reproduction is obtained over the complete audio frequency band. The modulated amplifier which receives its high frequency feed from the master separator through a resistance potentiometer, employs one 50-watt valve arranged to be modulated in accordance with the output of the modulator. An intermediate high frequency amplifier, consisting of three 250-watt valves, arranged in parallel, raises the level of the energy to that required for application to the grids of the Stage I Power Amplifier. Special precautions are taken throughout the Oscillator Modulator Unit to ensure that the carrier wave is entirely free from ripple. Smoothing systems are incorporated in the anode, grid, and filament supplies of all valves. The unit is completely shielded from any external interference.

The power amplifier comprises the remaining four units and the output circuit. Two stages of power amplification are necessary to increase the level of the output from the oscillator modulator to the level necessary for feeding the antenna. Fourteen water cooled valves are used, each capable of delivering 15 K.W. at 12,000 volts. The cooling water is fed to the anodes through rubber hose coils which provide a sufficient length of water path to reduce the leakage current to earth to a small value. Each water cooled valve is provided with an anti-singing device which is designed to prevent any possibility of intervalve oscillation.

Stage I Power Amplifier has two valves arranged in parallel, and Stage II consists of two units, each containing six valves in parallel. Stage II receives its drive from Stage I through the medium of the interstage unit. Normally the two Stage II units are operated in parallel, but by a simple switching arrangement it is possible to use only one six-valve unit, the antenna power being consequently halved. The switching is so arranged that the unit which is not in use is absolutely isolated from all voltages; thus, in the event of any fault occurring in the Stage II Power Amplifier, it is possible to isolate the bank concerned, and to run on the other bank while making necessary adjustments or replacements without causing any serious break in the programme. Figures 8, 9 and 10 are side views of the Stage I Amplifier, the Interstate Unit and one unit of the Stage II Amplifier, respectively.

The two units of Stage II are fed through a specially designed anti-singing network. This device is so arranged that it presents a low impedance to the feed currents from Stage I, but presents a high impedance to any parasitic oscillations which might be set up between the two six-valve units.

The output circuit is mounted in a framework, Figure 11, and is housed in an enclosure behind the radio units, the enclosure being fitted with safety gates. The tuning and aerial coupling condensers are connected to their respective bus bars through links which can be readily removed to obtain the correct condenser value for a given wavelength. The tuning condenser is arranged in two parts working in conjunction with a switch. By throwing over the switch it is possible to double the impedance of the output circuit, and so to present the correct impedance to the Stage II Amplifier when only one bank of valves is used.

The tuning of the interstage circuit is accomplished by adjusting the inductances through hand-wheels on the front of the oscillator modulator and interstage units. The output circuit is finally tuned by varying the inductance by means of a handle projecting through the output circuit enclosure.

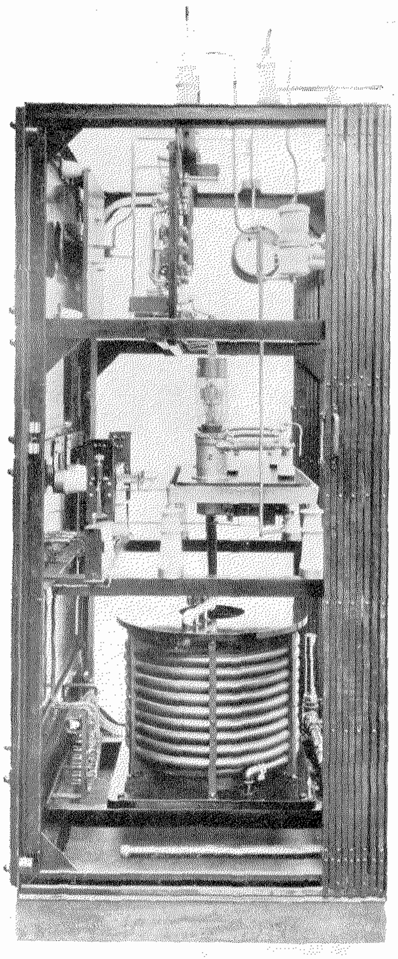

Figure 8—Side View of the Stage I Amplifier Unit.

Full protection has been provided for valves and other equipment of a costly nature, but at the same time, great consideration has been attached to the importance of producing an equipment with every facility for continuous running without interruption. With this end in view, every means has been provided for giving a quick and clear indication of the location and cause of any fault which may occur, so that any possible trouble may be rectified with the utmost ease. All the valves in the unit are protected against anode current overload by relays in the anode circuits. In the power amplifier, which uses water cooled valves, a separate relay is associated with each valve; in the event of an overload, these relays remove the anode voltage from the valves. The water cooled valves are protected against failure of the water supply by a special water flow alarm which removes the filament, grid, and anode voltages from the valves in the event of a failure of the water flow. Provision is also made against excessive cooling water temperature, a thermometer being supplied which removes the filament, grid and anode voltages from the valves when the temperature of the water exceeds a safe value.

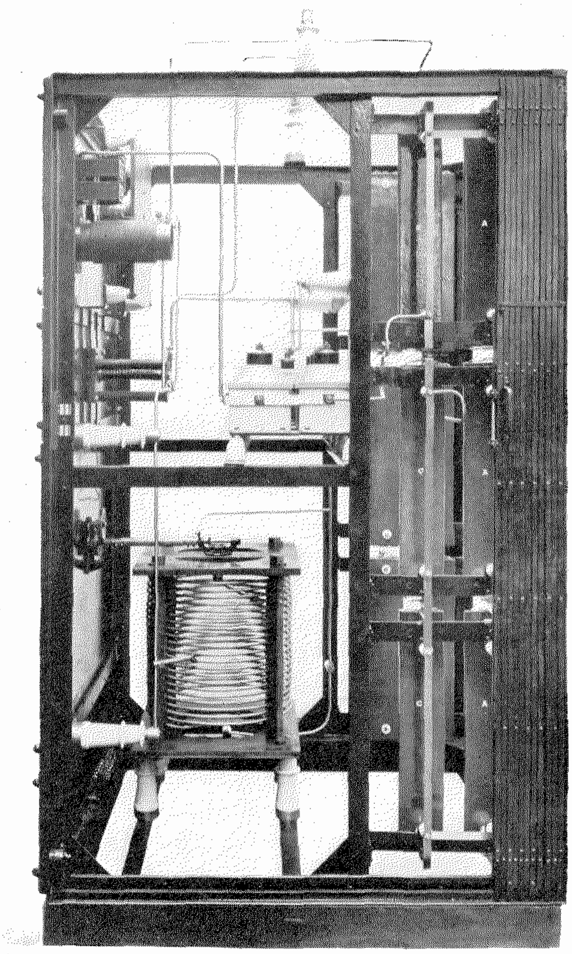

Figure 9—Side View of the Interstage Unit.

Spark gaps are provided throughout the equipment, which break down in the event of any excessive voltage, and remove the anode voltages from the valves.

Power Supplies

The equipment is designed to operate from a 415-volt 3-phase 50-cycle incoming supply.

The valves used in the Oscillator Modulator Unit are radiation cooled valves operating at anode potential of 800 and 1,600 volts. Machines are used for supplying the filaments, grids and anodes of the oscillator modulator valves. All the power amplifier valves are water cooled, and they derive their filament and grid supply from machines also, but their anode supply of 12,000 volts is obtained from a High Tension Thermionic Rectifier Equipment.

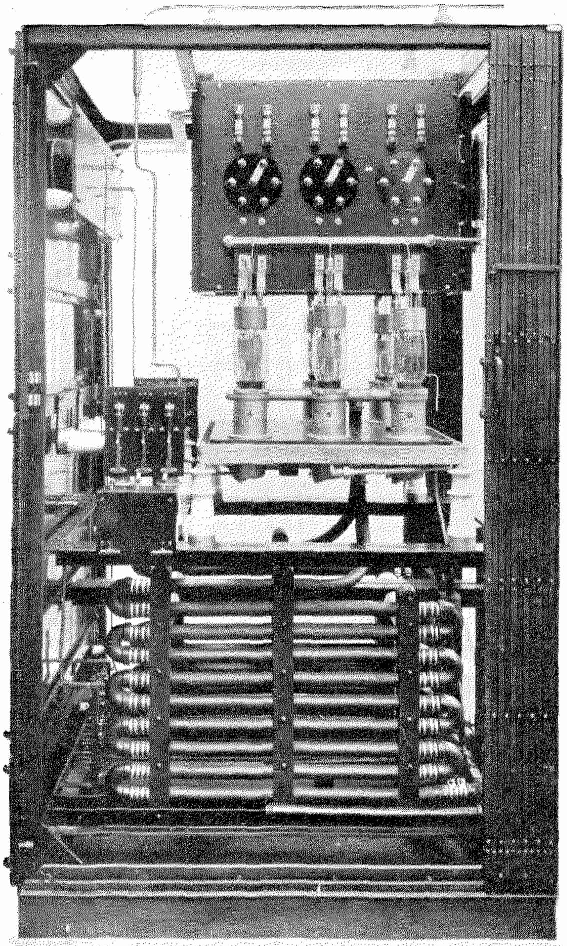

Figure 10—Side View of a Stage II Amplifier Unit.

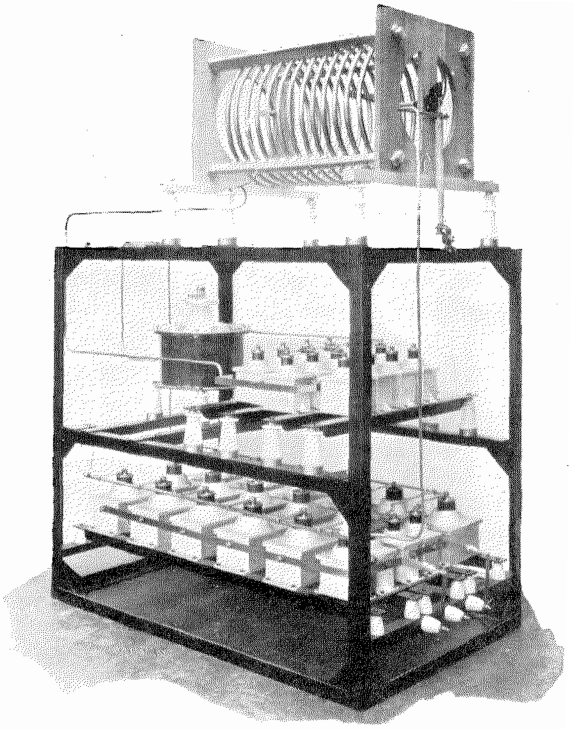

Figure 11—The Output Circuit.

Motor Generators. Two motor generator sets are used. Set No. 1 has two generators directly coupled to a squirrel cage induction motor. One generator has a double commutator and gives direct current outputs at 800 and 1,600 volts for supplying the anodes of the valves in the Oscillator Modulator Unit. The second generator gives a 24-volt direct current supply for the filaments of the oscillator modulator valves, and in addition supplies the power for the various control circuits.

Set No. 2 has two generators directly coupled to a squirrel cage induction motor. One generator supplies the filaments of the power amplifier valves with direct current at 24 volts; the other generator provides the grid bias voltage for all the valves used in the equipment.

These motor generator sets are specially designed so that the ripple of the generator is very small. In addition, however, filter circuits are incorporated in all the supplies to reduce the ripple further, and thus to ensure that the carrier wave is entirely free from noise.

12,000 volts D.C. Anode Supply. The total direct current required for feeding the anodes of the water cooled valves of the power amplifier is of the order of 14 amperes. This is obtained by transforming the alternating supply to the necessary voltage and rectifying it with a thermionic valve rectifier; then, by means of a properly designed filter circuit, the harmonics in the rectified wave are reduced so that the percentage ripple remaining in the direct current supply is negligibly small. As the transmitter is designed for a three-phase supply, it is evident that the best conditions for the reduction of ripple would be obtained by adopting a system using a polyphase rectifier. Each phase of the rectifier, however, necessitates the use of one valve. For an equipment of this size, economic considerations limit the number of valves used to six. With a six-phase rectifier, each valve theoretically passes current for one-sixth of a cycle, whereas with a three-phase rectifier the current flows for one-third of a cycle. From this point of view, the six-phase rectifier is less efficient than the three-phase rectifier. However, the advantages of both six-phase and three-phase rectification may be realised by using a "three-phase double star" rectifier system. This type of rectifier has therefore been adopted; the scheme of connections is shown in Figure 1. The system consists essentially of two three-phase rectifiers connected in parallel, with the transformer arranged so that the two secondary stars have a phase difference of 180°. The total current through each rectifier must be kept constant in order that each may act as a true three-phase rectifier. This result can be accomplished by fitting a choke in the output of each rectifier and, more economically, by the use of one choke connected between the two star points, the rectified output being taken from the centre point of this choke. The direct currents in the two halves of the choke oppose each other, thus producing no resultant flux in the choke. The function of this choke, which is called the interphase reactor, is to prevent large ripple currents flowing round the circuit consisting of the two three-phase rectifiers in series, the main smoothing choke preventing large ripple currents flowing through the two rectifiers in parallel and the load.

Only those ripple frequencies which are even multiples of the supply frequency appear in the potential wave at the mid-point of the reactor. Those frequencies which are odd multiples of the supply frequency have opposite phases in the two halves of the rectifier, and consequently cancel out. Therefore, with a three-phase 50-cycle supply, the lowest frequency present in the rectified wave is 300 cycles, and its voltage amplitude is only 5.7 per cent of the direct current voltage. The 150-cycle ripple, which is present in the simple three-phase rectifier system to the extent of a voltage amplitude of 25 per cent of the direct current voltage, is thus eliminated.

The three-phase double star system, therefore, gives the same percentage ripple in the rectified supply as the six-phase rectifier, while it is as efficient as the three-phase rectifier, in that each valve passes current for one-third of a cycle.

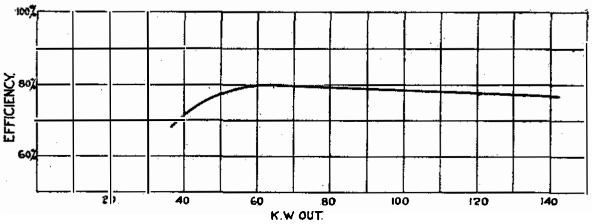

Figure 12—Efficiency Curve of the H. T. Thermionic Rectifier Equipment.

Figure 12 shows a measured efficiency of 77 per cent for an output of 14 amperes at 12,000 volts direct current, the efficiency being measured as a ratio of the direct current output of the rectifier to the power input to the high tension transformer, plus the power dissipated in the rectifier filaments.

The rectifier consists of a High Tension Transformer, Interphase Reactor and Induction Regulator, a Rectifier Unit and a Filter Unit. The transformer is provided with switches and tappings on the primary, to give a direct current voltage variation on the anodes from 4,800 to 12,000 volts in ten steps, and an induction regulator is supplied to vary the voltage between any two of these steps. It is therefore possible to obtain a continuously variable voltage from 4,800 to 12,000 volts. The incorporation of these

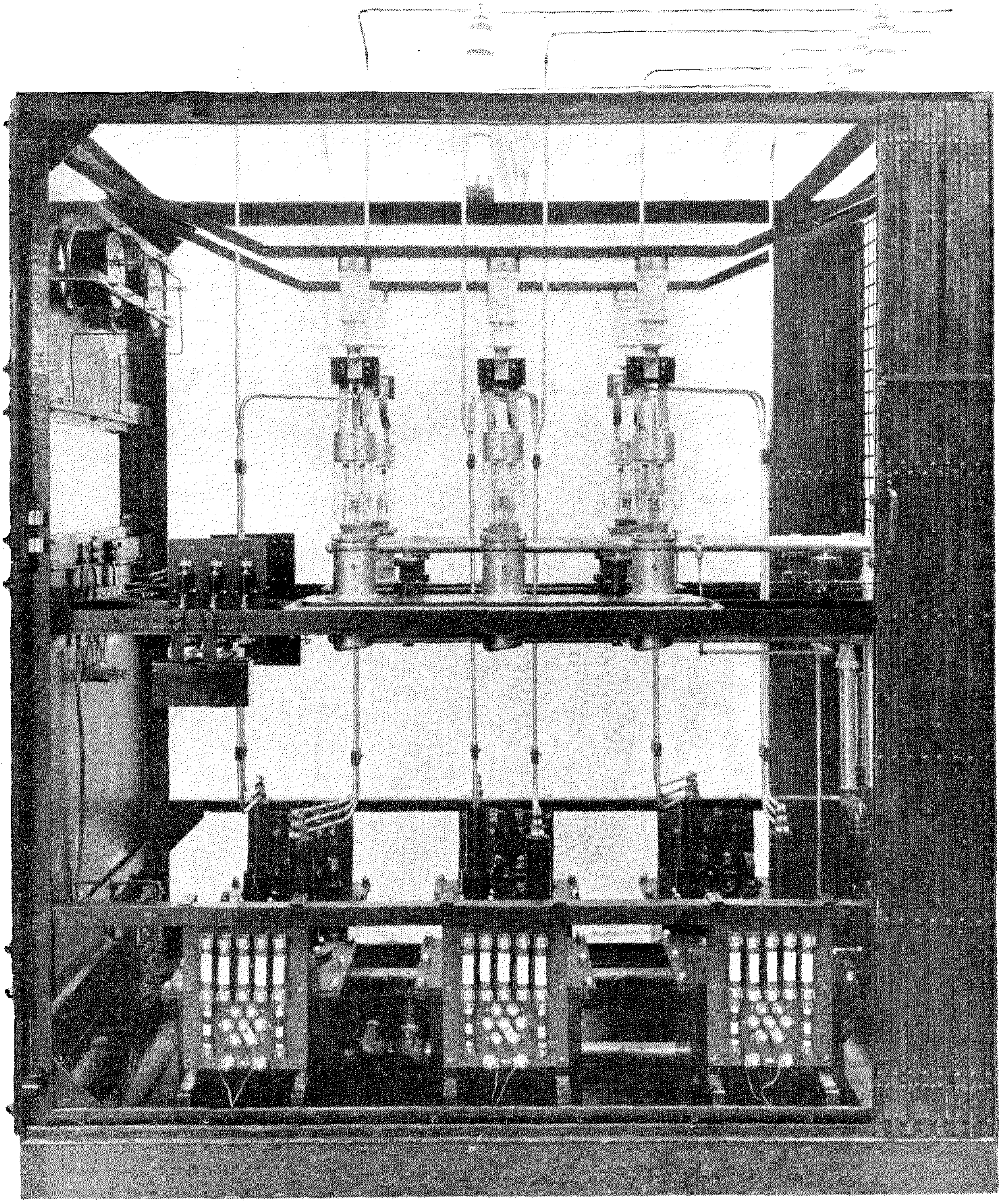

Figure 13—Side View of the Rectifier Unit.

switches and the induction regulator, together with the facilities for running either one or two "6-valve units" enables a very flexible output to be obtained from the transmitter. Furthermore, the fine control of the anode voltage by the induction regulator enables the output of the station to be kept absolutely constant during the entire broadcast programme.

The six water-cooled valves, together with six filament transformers and the associated apparatus, are assembled in the Rectifier Unit shown in Figure 13. In the case of a high power rectifier using water-cooled valves, it simplifies design to connect the anode of the rectifier to earth, thus obviating the necessity of supplying hose coils for insulating the anodes. Each valve has a separate filament transformer which is highly insulated, the filaments being at high potential for both alternating and direct current, the primary of the transformers being connected to the 415-volt incoming supply. The valves are protected against current overload, excessive cooling water temperature, and the failure of water flow, in the same manner as the 15 K.W. water-cooled amplifier valves.

The filter unit consists of an oil-immersed choke coil and a high tension smoothing condenser, so designed to reduce the ripple in the 12,000 volts direct current supply to less than 0.1 per cent. A smoothing condenser of 15 microfarads capacity is supplied. This large value is used, not only for its effect in reducing the ripple, but also to present a low impedance to the audio frequency currents supplied to the amplifiers during modulation. This low impedance prevents the 12,000-volt anode supply from varying, and thus from causing remodulation and consequent distortion.

Power and Control Switchboard. The Power and Control Switchboard consists of four polished black slate panels, which, together with the Rectifier Unit, are assembled in line, side by side, Figure 14. The panels are arranged so that the station is started up by successive operations moving from the first to the fourth panel. At the rear of each panel the associated switchgear and control apparatus is assembled in an iron framework. The Power and Control Switchboard with the Rectifier Unit presents the appearance of one complete unit, nineteen feet four inches long and six feet six inches high. The control of all the power circuits of the equipment and all the normal switching operations and adjustments are carried out here. The direct current for the filaments can be easily controlled by the generator field rheostats, thus enabling the valves to be slowly warmed up before the anode voltage is applied. In the same way, a three-phase resistance enables control to be obtained of the alternating current for the filaments of the rectifier valves.

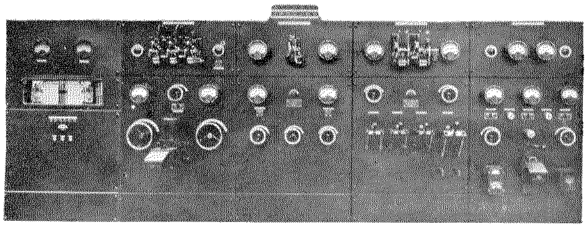

Figure 14—Front View of the Power and Control Switchboard.

All the control and protective relays are mounted on a relay rack, or central control panel, in an accessible position on the framework at the back of the switchboard, so that in the event of any trouble in the control or protective circuits, the fault can be located immediately by simple tests. The front view of the relay rack with the relay covers removed is shown in Figure 15. The main function of the apparatus mounted on this rack is to ensure that the filament, grid, and anode supplies are applied in the correct sequence, and to remove the voltages concerned in the event of any fault occurring. Briefly, the action of the control and protective circuit is to remove the high tension voltage in the event of the failure of the filament or grid voltage or of the operation of any of the gates, emergency, or overload devices. It also serves to remove the grid voltage in the event of the failure of the filament voltage; and to remove the filament voltage if the flow of water fails or is insufficient, if the temperature becomes excessive, or if the main supply of water fails.

Located at the top of the switchboard is a bank of indicating lamps, having a name plate designating the purpose of each lamp. Should any of the above failures occur, a lamp is lit, thus showing the location and nature of the fault immediately. It is impossible to apply power again as long as any of the lamps remain alight, that is, until the fault is cleared.

An electric clock gives a direct reading of the number of hours the filament and anode of each valve have been working.

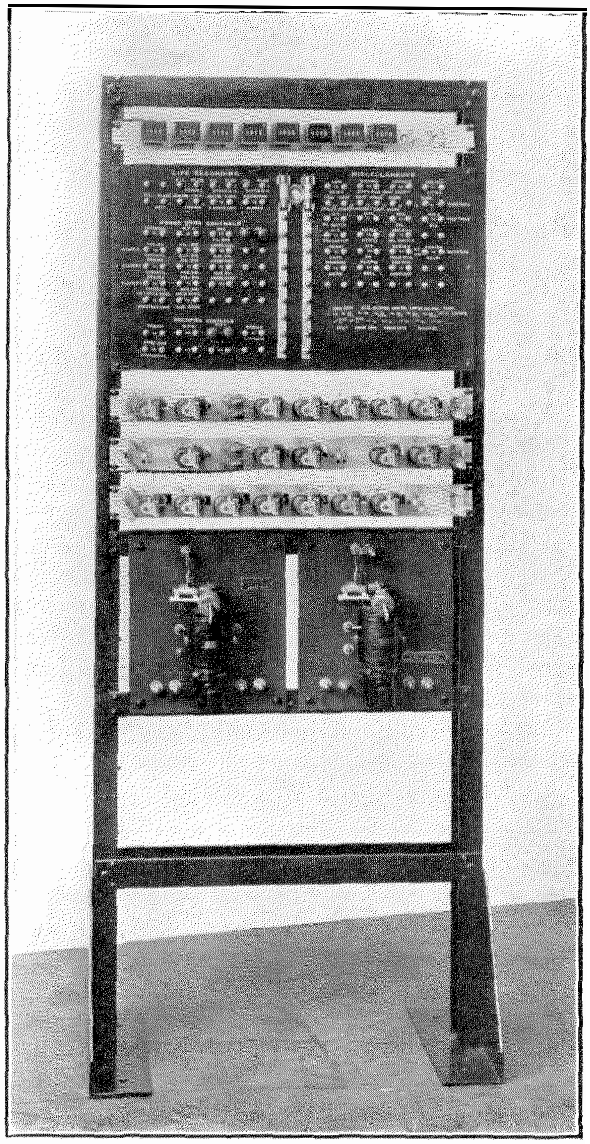

Figure 15—Relay Rack, Front View.

The Power and Control Switchboard is built into a wall, so that all the live switchgear is situated in a room behind the switchboard panels, access to which is obtained through a safety gate.

Water Cooling System. Provision is made for a water supply of two gallons per minute for each water-cooled valve, that is, a total supply of 40 gallons per minute, or 2,400 gallons per hour. The efficient cooling of such a quantity of water is a problem in itself, and may be approached from many angles, depending on the local conditions. It is advisable, in order to prevent scaling of the anodes, to use either distilled or rain water, and as the cost of the former is high, and a supply of the latter in some countries is inadequate, the cooling system adopted should be as efficient as possible, and not one where losses may occur due to evaporation.

For the testing and operation of the transmitter at New Southgate, London, where there was a plentiful supply of cooling water, the cooling system installed consisted of a water circulating system comprising a motor-driven pump, an elevated tank on a tower structure, a tank at ground level, a filter, and a pipe run. The elevated tank has a capacity of 600 gallons, and the ground tank a capacity of 5,000 gallons. Water is drawn from the ground tank by means of the pump, and is fed to the elevated tank, about 40 feet above the ground. When the equipment is running, water flows by gravity from the elevated tank through the valves, and returns to the ground tank through which the heated water has to circulate before being re-used. A float apparatus fitted with two floats is contained in the top tank. When the water in the top tank falls to a certain value the topmost float causes two contacts to be closed, which start up the pump motor. The pump motor continues to run until the water in the top tank has risen to the correct level. The second, or lower float is arranged so that when the water falls below a certain level, two contacts are opened which cause the station to shut down. Thus, in the event of any serious failure in the water supply, sufficient water is left in the tank when the station is closed to circulate round the valves and to allow the anodes to cool. This system operates very successfully. It has the disadvantage, however, of having a large area tank exposed to the atmosphere, and in a location where the air is not too pure, extraneous matter may find its way into the water, and either cause a stoppage of the flow at the filters, or probably cause deposit on the anodes. Furthermore, the proper working of the system is dependent on the radiation of heat from the surface of the tank, and in warmer countries this may not be sufficient. Another suitable system using a double water circuit is therefore suggested. In this system the primary water supply to be cooled circulates through brass tubes, around the outside of which cold water is circulated from the secondary water supply. The secondary water supply may be a cooling pond or tank or a natural lake or river, if such is in the vicinity. With this system only a comparatively small quantity of pure water, either distilled or rain water, is required. The secondary cooling water need not be of any special purity. Two pumps are provided, one to circulate the water round the primary circuit and the other to circulate the water through the secondary circuit.

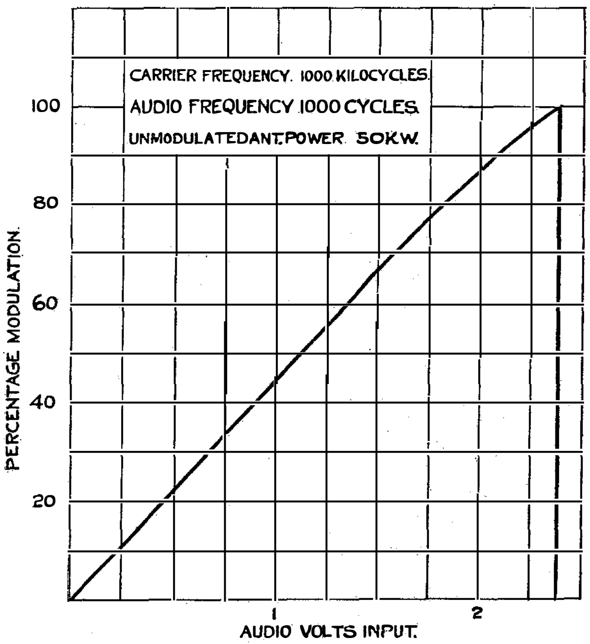

Figure 16—Overall Modulation Characteristic.

Monitoring Equipment. As it is essential that the operators should be able to judge the quality of the broadcast transmission, a monitor is incorporated. This is tapped across a part of the output circuit, and consists of a 50-watt valve arranged as a diode rectifier, its output being a non-inductive resistance, across part of which is connected a "Kone" loud speaker. The monitoring equipment is designed to have a characteristic which is practically linear from 30 to 10,000 cycles.

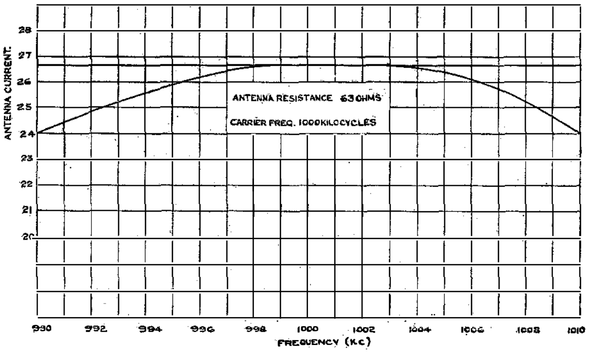

Figure 17—Overall Band-width Characteristic of the Radio Transmitter.

Performance of the Radio Transmitter

To avoid interfering with the reception of the London Broadcast Programmes, it was found necessary to make most of the tests on the transmitter with an artificial antenna. This consists of a variable inductance, a variable capacity, and a variable non-inductive resistance load, capable of dissipating 75 K.W. of energy, this representing the completely modulated power corresponding to 50 K.W. telephone carrier power.

Figure 16 is a modulation characteristic taken with an audio frequency of 1,000 cycles, and an unmodulated antenna power of 50 K.W. It shows that the transmitter is capable of 100 per cent linear modulation. The ideal transmitter would give this curve for all audio frequencies between 30 and 10,000 cycles; that is, for a constant audio input, the antenna output should be constant for all frequencies between 30 and 10,000 cycles. This necessitates, first, that the high frequency circuits should be designed so

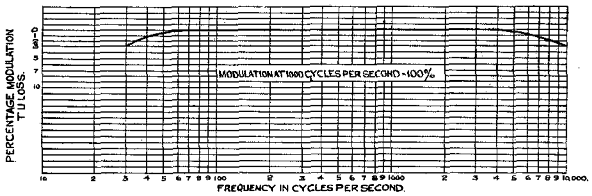

Figure 18—Overall Frequency Characteristic of the Radio Transmitter.

that they are capable of responding equally to all frequencies from 10,000 cycles below the carrier frequency to 10,000 cycles above. Figure 17 shows that the response or band-width of the transmitter, though not linear, does not depart from linearity sufficiently to be noticed. Secondly, it is necessary that both the low frequency and high frequency circuits should be capable of equal response for all frequencies from 30 to 10,000 cycles. Figure 18 is the overall characteristic of the radio transmitter over this band of audio frequencies for a constant audio input corresponding to 100 per cent modulation at 1,000 cycles. It shows that the divergence from linearity is so small that it could not be detected by the most sensitive ear.

The overall efficiency, that is, the ratio of antenna power to total power taken by the station from the mains, is about 20 per cent. This efficiency is considered exceedingly good for a high quality broadcasting equipment of this power.

It is well known that the operation of a number of valves in parallel is a likely cause of trouble. In the design of the equipment, therefore, every endeavour was made to reduce this tendency to a minimum. In this respect it has been pointed out that devices were incorporated to prevent intervalve oscillation, or oscillation between the two banks of valves in the last stage. Furthermore, it was anticipated that some trouble might be occasioned from what is familiarly known as "Rocky Point" effect, which results in a very heavy anode overload in the valve. Considerable precautions were taken, therefore, in the way of individual valve overload relays, etc., to prevent much damage being done in the event of this occurrence. Not the slightest evidence of "Rocky Point" effect has been given during the testing of the transmitter. The transmitter proved to be perfectly stable, and gave a consistently excellent performance over a wavelength range of 280 to 600 metres. Interruptions in the continuity of a programme can only be caused by absolutely abnormal circumstances, such as any other power plant might encounter.

It may be stated that the performance of the transmitter shows it to fulfill all the herein mentioned requirements.

A Solution of the Problem of the Broadcasting Microphone

By A. H. REEVES

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SINCE the inception of broadcasting six or seven years ago, the microphone has always been the weakest point in the radio transmitter, just as the loud speaker has always been the weakest link in the receiving apparatus. So difficult has been the problem that there has not heretofore been available a single microphone capable of meeting simultaneously the demands of quietness, uniform efficiency at all useful frequencies, and linearity of response. Where a measure of success has been obtained in one direction, it has always been at the expense of a requirement in some other direction, and too often the apparatus has been inconsistent and unreliable in its performance.

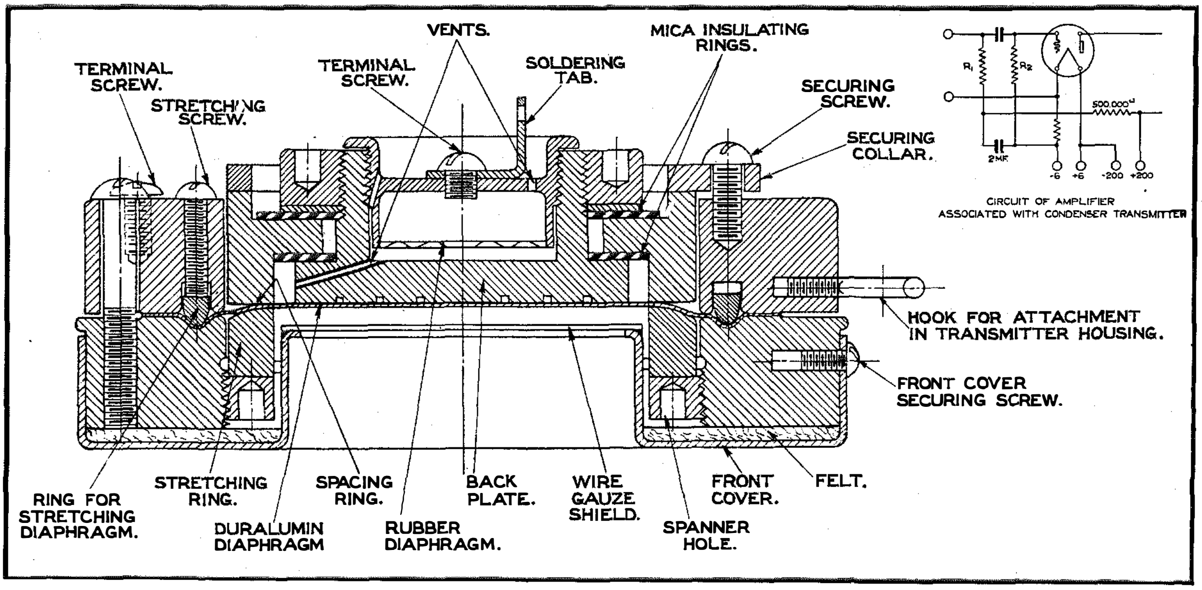

Figure 1—Section of MS. 1670 Condenser Transmitter and Circuit of Early Amplifier.

Recent development work of the International Standard Electric Corporation has produced a reliable pick-up device free from spurious noise, capable of reproducing uniformly a frequency range from 30–10,000 periods per second, and having perfect linearity of response to all amplitudes which are capable of being handled by the amplifying valves employed. Extreme quietness has been made possible by the combination of a special high frequency circuit with a novel balancing arrangement for eliminating noise in the high frequency generator. The net result is an improvement in noise energy ratio of twenty-five times over the best known earlier type of equipment.

The condenser transmitter has always been known to be singularly free from distortion, and a number of different types have been used at different times, both in circuits using steady polarising voltages, and in high frequency circuits.

The first tendency in developing the condenser transmitter used by the International Standard Electric Corporation was towards the production of a reliable instrument passing a wide range of frequency. This development, carried out by Wente in the United States, resulted in the production of a highly reliable and robust piece of apparatus passing a frequency range from 30 to above 10,000 cycles per second. A section of the MS. 1670 Condenser Transmitter developed by Wente is shown in Figure 1, together with the circuit in which it was normally employed. This instrument, used with a steady biasing potential in the above circuit, suffered from the disadvantage that its efficiency was so low that the thermal agitation, in the resistances feeding it, was sufficient to cause appreciable background noise. A source of further noise was the presence of moisture or dust introducing leakage paths in parallel with the high resistance associated with the amplifier input; and maintenance of amplifiers in a condition of minimum noise was therefore difficult. In spite of these difficulties, condenser transmitters of this type were successfully used in a number of studios, notably at WEAF in New York, Birmingham, Zurich and Prague. Wherever it was used, the fidelity of this instrument, due to its wide frequency range and freedom from asymmetry, was recognised to be unsurpassed. A typical frequency response characteristic for one of these instruments as used previously (in the circuit of Figure 1) is shown in Figure 2. Deviations from this characteristic in manufacture are relatively small, a remarkably homogeneous product resulting. The increase in efficiency of this instrument at the base served to compensate for the shortcomings common to all early apparatus; it is not so certain that such a characteristic would now have advantage over a flat characteristic, and for this reason in developing the new equipment a flat characteristic has been aimed at.

Owing to the difficulties of maintaining an amplifier free from noise, the MS. 1670 condenser transmitter, as the next step in development, was abandoned for one passing a narrower frequency range, but having an increased sensitivity. A characteristic of one of these instruments, the ES. 619 condenser transmitter, is shown in Figure 3.

The new equipment has been developed by reverting to the MS. 1670 transmitter and employing a new type of circuit to eliminate noise.

Referring to Figure 1, in the earlier circuit used changes of capacity between the diaphragm and the back plate resulting from sound waves impinging on the diaphragm, cause fluctuations of voltage across the transmitter itself—the charge on the condenser transmitter from the 200 volt battery being maintained substantially constant due to the high value of the time constant of the circuit formed by the condenser transmitter and the resistance effectively in series with it. These fluctuations are applied directly to the grid of the first valve of a low frequency amplifier. The capacity of the transmitter being about 300 micro-microfarads, the leakage resistances R_1 and R_2, in order to avoid distortion and reduction in sensitivity, must have values of the order of at least 15 megohms, which means that a very high degree of insulation is necessary in order to avoid noise caused by irregular leakage. If precautionary measures are not taken, the leakage noise may easily mask the irreducible noise caused by the e.m.f. of thermal agitation in the resistances R_1 and R_2.[1] Under the conditions mentioned, the latter results in a noise equivalent to approximately 5 R.M.S. microvolts applied between the grid and filament of the first amplifier tube and is, with good tubes and components, the most important factor in noise production.

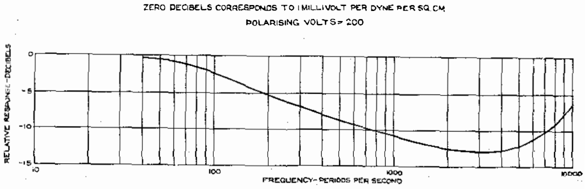

Figure 2—Characteristic of MS. 1670 Condenser Transmitter.

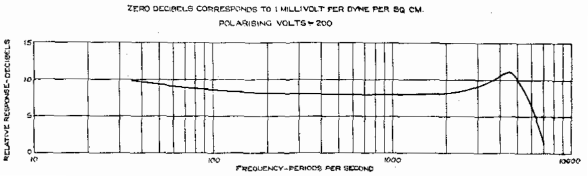

Figure 3—Characteristic of ES. 619 Condenser Transmitter.

The outline of the new circuit is shown in Figure 4. The essential principle involved is the utilisation of the changes in capacity of the transmitter to alter the tuning of an inductance-capacity circuit coupled to a radio frequency oscillator. The condenser transmitter is used as a tuning condenser across a small inductance; an

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[1] J. B. Johnson, "Thermal Agitation of Electricity in Conductors," *Physical Review*, July, 1928.

oscillator of fixed frequency, high as compared with the highest audible frequencies to be considered, is coupled weakly to this tuned circuit. The constants are adjusted until the condenser transmitter circuit is not exactly in tune with the oscillator; the working point on the resonance curve in practice is at X, Figure 5. When sound waves arrive at the diaphragm of the transmitter, the capacity of the latter changes, and the tuning point is correspondingly altered, thus changing the amplitude of the high frequency voltage across the transmitter. It is evident that there is now, in effect, a carrier frequency modulated by the arriving sound wave, exactly as is the outgoing wave of a broadcasting station. It only remains to rectify the high frequency voltage, after which output at speech frequency will result.

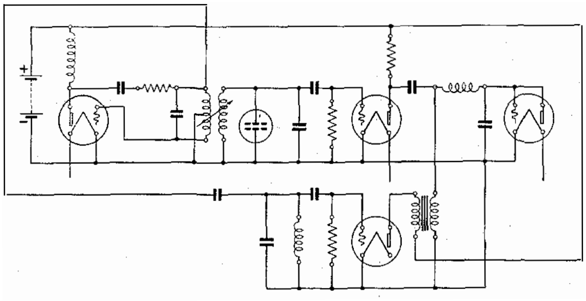
Figure 4—Circuit of High Frequency Equipment Associated With Condenser Transmitter.

It will be seen that the working point X, Figure 5, is approximately at the steepest part of the resonance curve and not at its apex—an adjustment which gives comparatively large changes in high frequency amplitude for small changes in capacity. In this way a sensitivity to the arriving sound wave is provided, which is considerably in excess of that obtained by the earlier method of Figure 1. In addition to this considerable advantage, there are others which, in fact, surpass the first in importance. One of these is that the very high resistances previously required, are now unnecessary. It would be possible to operate the new circuit without using any leaks at all; this scheme, however, would not be very convenient in practice, as a grid bias battery of a high and very constant voltage would be necessary on the rectifier tube. To avoid this, a grid leak of one megohm is used with a blocking condenser in series with the H.F. input, causing the grid current itself automatically to give the optimum grid bias. Since the resistances are only one megohm in value, and of wire-wound construction, they are perfectly reliable.

The second advantage is the fact that the original high impedance to audio frequencies between grid and filament is now eliminated. By reference to Figure 4, it will be evident that this impedance is now quite low, the reactance of both the series blocking condenser and the tuning inductance at frequencies between 35 and 10,000 cycles being less than 5,000 ohms. This fact considerably reduces noise voltage at audio frequency due either to external pick-up, to slight variations in the apparatus components on the input side of the rectifier, or to thermal agitation. Even at the carrier frequency and the frequency of the resulting side bands, the impedance is considerably less than fifteen megohms, being in fact under fifty thousand ohms.

An occasional source of a large amount of tube noise is also practically eliminated by this means; viz., the component of the rectifier tube noise due to leakage between the plate and grid. In practice, however, there would be no excuse for employing a valve having a defect of such comparatively rare occurrence.

The net result of the above circuit changes is an improvement in speech-noise ratio over the circuit of Figure 1 of at least 14 decibels; and it is possible to obtain a further appreciable reduction varying between 6 and 10 decibels, because the bulk of the residual noise is contributed by the oscillator, and this can be considerably reduced by means of a special balancing circuit. The oscillator valve noise modulates the high frequency at its source, thus giving rise to audio

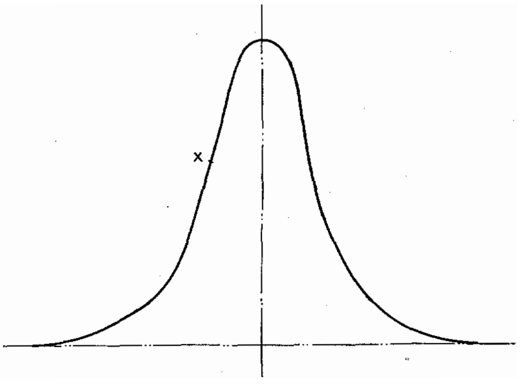

Figure 5—Resonance Curve.

frequency noise after rectification. The output from the oscillator is supplied to a subsidiary rectifier, across the input of which is an inductance-capacity circuit similar to that across the input of the main rectifier which contains the condenser transmitter. The second circuit is also approximately tuned, with a clamped variable condenser, to the oscillator frequency, and coupled to the oscillator circuit sufficiently to receive the necessary voltage across its terminals. The output of the subsidiary rectifier, therefore, contains the same noise in its output circuit as does that of the main rectifier, but unlike the latter, it has no music or speech in its output. The output from the two rectifiers are combined in opposition by means of a transformer, so that any modulated tones in the oscillator output itself arrive in opposite phase from the two oscillators, and are therefore balanced out. The speech, which affects only the input of the main rectifier, remains unchanged. The total improvement over the circuit of Figure 1 is therefore between 20 and 24 decibels.

The method of obtaining grid bias will now be considered in further detail. The normal peak value of high frequency voltage on the grid is of the order of 45; a mean negative grid bias of this order, therefore, is required on both rectifier tubes, to avoid overloading. Such a bias could be obtained by means of a separate grid battery, but this would necessitate very accurate regulation of voltage. An accidental 10% variation, for example, would give a change of 4½ volts on the grid, which would probably put the apparatus out of operation altogether.

The method used eliminates this difficulty. The high frequency voltage is applied to the rectifier grids through two series condensers, each of the order of one microfarad; grid-filament leaks of one megohm each are added. Assuming that the grid voltages start from the zero value, when the first positive half-cycle arrives on the grids, large grid currents immediately flow, giving the grids a negative charge. This effect will be increased by each subsequent positive impulse, as the escape of charge by means of the grid leaks, the latter being of high value, is much slower than the rate of charge by grid current. The mean grid bias will continue to become more negative until its value is only slightly less than the peak voltage of the input high frequency e.m.f. This action, giving approximately the best bias value for working conditions, will take place regardless of the value of high frequency input voltage.

Figure 6—Condenser Transmitter Recently Developed by the International Standard Electric Corporation.

A further advantage of the new circuit is the fact that the normal peak voltage across the transmitter is only 45, whereas 220 is the usual value for the old circuit. This greatly reduces risk of trouble due to the breakdown of the condenser transmitter itself.

The two chief advantages of the condenser transmitter already mentioned, namely, good quality, and the absence of "blasting," are maintained in the high frequency equipment.

The particular apparatus developed by the International Standard Electric Corporation according to the above design is shown in Figure 6. This form, intended for studio work only, contains the transmitter and the amplifier mounted together in one unit. A single flexible screened cable supplies the necessary D.C. power to the apparatus, and also contains the low frequency output leads. The dimensions of the box are 13¾ x 10¼ x 11¼ inches. The power input of the present model requires 6 volts at 5 amperes, 150 volts at 70 milliamperes, and 25 volts (grid bias) at 10 milliamperes, the negative low tension and the positive grid bias leads being common. The box and the leads are screened to avoid external pick-up noises.

Several difficulties of theoretical interest were encountered during the development work. It may be thought on first consideration that an oscillator frequency of about the same value as that ordinarily employed in "carrier" work would be suitable for the present apparatus. This is not the case, however, if attenuation of the high audio frequencies is to be avoided. Calculation shows that the effects of operation, not at the apex of the resonance curve, but at a point on its steep part, in general causes the two side bands to be out of phase with each other. This phase inequality increases up to a certain point as the audio frequency increases, and so causes the audio frequency currents, due to each side band separately after rectification, to be to some extent in opposition. This effect increases attenuation at the high audible frequencies to a point greatly in excess of that obtained when working at the top of the resonance curve. In order to meet this difficulty, and at the same to maintain a resonance sharp enough to give good sensitivity, a carrier frequency of the order of 600 kilocycles has to be used. With this value, and with the circuit adjustments finally employed, the extra attenuation due to the high frequency circuits at 10,000 cycles is less than 2 decibles.

The second point of interest is the effect of any variable contacts in the neighbourhood of the high frequency circuits, whether connected to these circuits or not. Any such contact is liable either to form a closed loop, thus obtaining e.m.f. from the oscillator by magnetic induction, or to pick up high frequency voltage by capacity coupling. In either case, when the contact changes, there is produced a reactive effect on the circuit itself, owing to the change in absorption in energy from it, causing a crack or a splutter in the output of the low frequency stages. To overcome this source of trouble it has been found necessary for every metal part, even though small, either to be connected definitely to some part of the circuit, or to be thoroughly insulated from it. Even a component, such as a screw fixing the handle of the box, if allowed to make variable contact with the handle, has at times been found to be a source of noise. Nevertheless, when once the necessary precautions were taken, no further trouble was experienced.

A further difficulty presented itself when the other noises had been reduced to a low level. The source was found to be variable contacts between the filaments and the filament hooks in the tubes themselves, particularly in the case of the oscillator tube. Just before the completion of the present development work this defect of many of the present tubes had been realised and overcome by a new method of construction, the remedy applied by the International Standard Electric Corporation being to weld the filaments directly to the hooks. After some slight difficulties, owing to the sag of the filament under these new conditions, had been overcome, the new tubes were found to be quite satisfactory.

Metal bases were found unsuitable for the tubes used in this apparatus on account of their sudden expansion during the process of heating up, causing "cracks" in the output circuit; bakelite bases were found to be free from this defect and are now used throughout. A similar effect and also a cause of occasional noises, was traced to the sudden expansion of several of the components during the heating resulting from switching on the batteries. The mechanical vibrations produced in this way caused the tube elements, and also the inductances and variable condensers to vibrate, again giving objectionable noises. The remedy used in this case, up to the present time has been to use anti-microphonic sockets for the tubes, and to support together every component sensitive to vibration on a separate panel which is itself mounted on rubber. When this had been done, no further difficulty of this kind was experienced.

During the laboratory investigations of the equipment, and its comparison with other types of microphones, some method of measurement of the background noise had to be devised which would give results of practical interest. The important criterion is evidently the ratio of the speech volume to the background noise in the output circuit. In order to measure this, it is necessary first to define exactly what is meant by the ratio concerned. A logical and convenient definition appeared to be the degree of attenuation, expressed as a simple current ratio, which the speech energy has to undergo before becoming only just audible through the background noise.

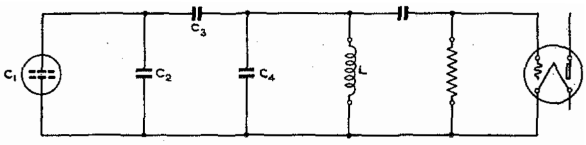

Figure 7—Noise Measuring Circuit for H. F. Condenser Transmitter Circuit.

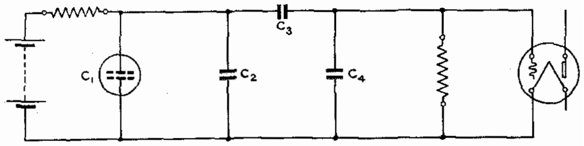

Figure 8—Noise Measuring Circuit for Ordinary Condenser Transmitter Circuit.

In order to carry out experiments on these lines, it is necessary, therefore, to have some means of attenuating the speech without interfering with the noise level; the best way of doing this depends on the particular type of microphone under test. Several cases will here be considered separately.

For the condenser microphone as described, using the high frequency equipment, the circuit shown in Figure 7 was found to be the most suitable, the H.F. voltage being induced magnetically into inductance L as before. C_1 represents the condenser microphone. By C_2 is denoted the capacity of about five yards of lead covered cable used to connect the microphone to the measuring apparatus. C_3 is a small coupling condenser; C_4 is a compensating condenser, adjusted to such a value as to give a total effective capacity across the inductance L equal to that of the condenser transmitter alone.

It is evident by inspection of the circuit that the effect of the series condenser C_3 is two-fold. In the first place, the H.F. voltage arriving at the condenser transmitter is reduced by it according to the simple attenuation ratio of the network. Secondly, any variable component of this voltage, due to changes in C_1, will itself be attenuated before arriving at the grid of the rectifier tube by this same attenuation ratio. It is thus clear, without any calculation, that the effective change in capacity at the grid in comparison with the actual change of C_1 will be proportional to the square of the attenuation coefficient. Expressed mathematically, if the resultant capacity shunting L of the system C_4, C_1, C_2, C_3 is represented by C_0,

$$\frac{{}^dC_0}{{}^dC_1} = \left\{ \frac{C_3}{C_1 + C_2 + C_3} \right\}^2$$

This means that the ratio of the capacity change across L, due to a given speech wave impinging on the transmitter, to the capacity change produced by the same speech wave when the transmitter is directly across the inductance (as in the normal circuit) is equal to

$$\left\{ \frac{C_3}{C_1 + C_2 + C_3} \right\}^2$$

Nothing else in the circuit has been altered. The total capacity across L is normal and therefore the background noise, being due to the tube, is also normal.

By this means it is clear that the speech can be attenuated at the input of the equipment by a known amount, leaving the background noise unchanged. The operation required is to adjust C_3 and C_4 until the speech is only just audible through the noise level, keeping the tuning point the same as before, and increasing the amplification to a value sufficient to render easily audible the noise background. With this adjustment, the noise level, and not lack of speech volume, is the limiting factor to the audibility of the speech.

The expression

$$\left\{\frac{C_1 + C_2 + C_3}{C_3}\right\}^2$$

is then a measure of the speech-noise ratio.

If it is desired to measure the speech-to-noise ratio of the condenser transmitter, using the normal circuit of Figure 1, the easiest circuit to employ is that shown in Figure 8.

It will be evident by reference to the diagram, that the effect of this arrangement, as before, is to reduce the effective change in capacity between the grid and filament of the amplifier tube by a known ratio in comparison with the actual change in capacity of the transmitter. As before, to keep the circuit conditions constant, and therefore the background noise at its normal value, the resultant capacity between grid and filament is made equal to the original capacity of the transmitter.

For frequencies of the order of 1,000 cycles, at which the conductances due to the leak resistances may be neglected in comparison with the capacitances of C_1 and C_4, the attenuation coefficient is given approximately by the factor

$$\left\{\frac{C_3 + C_4}{C_3}\right\}\left\{\frac{C_1 + C_2}{C_1}\right\}$$

as C_2 is very small compared with C_3 in practice. As in the previous case, the measurement is carried out by adjusting the values of the capacities until the speech is only just audible through the noise. The speech-noise ratio is then given by

$$\left\{\frac{C_3 + C_4}{C_3}\right\}\left\{\frac{C_1 + C_2}{C_1}\right\}$$

When testing a microphone of the carbon type, it is in general impossible, or very difficult, to attenuate the speech directly in a known ratio without also changing the background noise, except by increasing the distance between the speaker and the microphone. This latter method is in general not satisfactory because, among other difficulties, the speech waves may become of the same order of magnitude as the room noise. The problem was finally solved by allowing the speaker to talk into two equidistant microphones simultaneously; one, the apparatus under test, and the other, any good type of carbon microphone. Separate amplifier systems were used, and the gains adjusted until the volume indicator showed equal output volumes. The microphone to be tested was then put into a different room in a small soundproof box, the speech output of the comparison microphone amplifier having been switched into a series connection with the amplifier output of the microphone under test. The final step was to attenuate the former output until it just sank into the background noise. As the attenuation required was of the order of 40 decibels, the noise due to the comparison apparatus could be neglected. The resulting background was due entirely to the tested microphone, of which the noise was unchanged in extent. As the two speech volumes had initially been adjusted to be equal, it is evident that the speech-noise ratio of the instrument under test was equal to the attenuation added to the comparison microphone.

Some experimental results on the present equipment may be of interest:

Output Volume. The sensitivity of the equipment is given exactly by Figure 9, but more useful information is probably conveyed by stating that with an average speaker at a distance of five feet from the instrument the output level is minus 20 decibels. (As zero level corresponds to 5.9 milliwatts, minus 20 decibels corresponds to a maximum instantaneous peak power of 0.059 milliwatts.)

Frequency Characteristics. Tests have been made at the London Laboratory on the complete equipment by the standard thermophone method. The results show that the high frequency circuit compared with the ordinary method of using the transmitter, produces a change of less than 2 decibels in the characteristic at all frequencies up to 10,000 cycles. An overall characteristic of the complete high frequency equipment is shown in Figure 9. Up to 8,000 cycles, the characteristic lies within ± 1½ decibels, and above that there is a small rise which is an asset rather than otherwise, owing to the deficiencies of receiving apparatus.

Background Noise. Measurements of the speech-to-noise ratios, as defined above, of the high frequency equipment, and also of several well-known types of microphone, are given below, on the basis of the same normal speaker at a distance of 5 feet from the apparatus.

	Comparative Speech-noise Ratios Decibels	Improvement Introduced by the new equipment Decibels
"Standard" double button carbon microphone.	40	20
High sensitivity condenser transmitter (ES.619 type)...	46	14
MS.1670 transmitter employed in the circuit of Figure 1....	37	23
MS.1670 transmitter with high frequency equipment (minimum observed).............	60	..
High quality carbon microphone without diaphragm.........	41	19

In practice these results have been found to mean that no background noise can be detected under conditions of normal operation in the studio—a very important improvement over other types of apparatus.

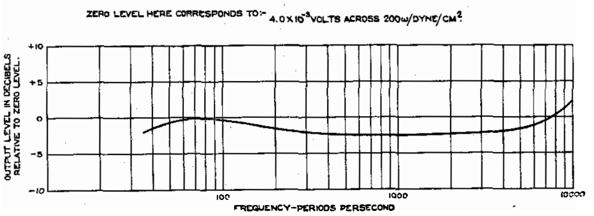

Figure 9—Overall Characteristic of Equipment.

In addition to the above tests, experiments were made under normal studio conditions for detection of non-linear distortion, if present. At the same time, a high quality diaphragmless carbon microphone was in operation at the side of the condenser transmitter equipment. Under conditions in which the former instrument was caused to blast by the brass band in the studio, no overloading whatever could be detected in the condenser transmitter apparatus.

Carrier Current Systems and Their World-Wide Application

By J. S. JAMMER

Carrier Engineer, International Standard Electric Corporation, New York

IN 1925 there was but one carrier current system in Australia. Now, there are in that country 51 such systems which have been furnished by the International Standard Electric Corporation. In addition, Spain is using, or is planning to use in the immediate future, 18 Standard Electric Carrier Systems; New Zealand has five and Japan, South Africa, Poland, France, Argentine, Mexico, Brazil, Cuba and Norway have one or more. Such a tremendous application of these systems throughout the world clearly indicates that the carrier method of providing high-grade telephone and telegraph channels is considered a sound commercial proposition.

Carrier is no longer an experiment but has taken its place along with the cables, open wire lines and radio as one unit in a group of communication systems. Early installations of carrier demonstrated very quickly that the fundamental design of the systems is such as to make it readily adaptable to the varied conditions encountered in the international field. The economic advantages of carrier as well as the high grade of performance were quickly grasped not only by the operating units of the International Telephone and Telegraph Systems but by Government Communication Administrations and privately operated telephone companies.

A small portion of the carrier equipment used in the International field has been made by the Western Electric Company at Chicago (U.S.A.) but the greater portion by far has been supplied by the Standard Telephones and Cables, Limited, London. While a carrier system is not complex to install or maintain, it does require a very high degree of precision and skill in manufacture and it has been gratifying to note that on occasions where portions of one system have been produced in two separate factories, the units fit together as a complete system as accurately as if they had been selected for the purpose.[1]

Now that carrier has come to be universally adopted, it seems desirable to review briefly the method on which these systems operate and to outline the various types of systems which are manufactured by the companies of the International group.

Fundamentals of Carrier Operation

Briefly, a carrier system is a means of obtaining more than one telephone or telegraph circuit from a given pair of wires. Such multiplex systems are termed "carrier" because they use alternating currents of comparatively high frequencies which are, in a sense, used to carry the messages. Each channel uses a different carrier frequency. These currents of different frequencies are transmitted over the same line and are separated at the sending and receiving ends by means of selective circuits.

This action of transmitting impulses of different frequencies over a given medium without mutual interference and the separation of the different frequencies for the purposes of reception might possibly be made more clear if we consider the analogy of the ordinary radio receiving set. In this latter case we have a number of broadcasting stations transmitting on different frequencies through a single medium but the receiver can be tuned, or in other words, adjusted to be efficient only at the frequency of the particular message involved. If we carry the analogy still further, the multiplex transmission used in carrier systems and the separation of the different frequencies is similar to the breaking up of white light into its various frequency components by means of a prism.

The fundamental steps involved in effecting carrier transmission either of telephone or telegraph signals consists of first, generating each of the high frequency currents to be used as carriers, then impressing upon each carrier the variations characterizing telephone or telegraph signals. This later action is termed "modula-

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[1] J. S. Jammer, "Australia First to Use Type C-2-F Carrier System," Electrical Communication, Vol. VII, No. 1, July, 1928.

tion.'' The next step consists of separating the several modulated carrier currents at the terminals on the basis of the difference in frequencies, thus rendering multiplex operation possible. This is termed ''selectivity.'' The final step in transmission over a carrier system consists of restoring, at the receiving end, from the modulated carrier current the original characteristics of the individual message. This process has been called ''demodulation.''

Let us consider a little more in detail the four steps mentioned above. With regard to the first step, or the generation of the carrier currents, in most cases vacuum tubes are used as oscillators. However, in the case of the voice frequency carrier telegraph system, motor generator sets have been designed to produce the carrier currents.

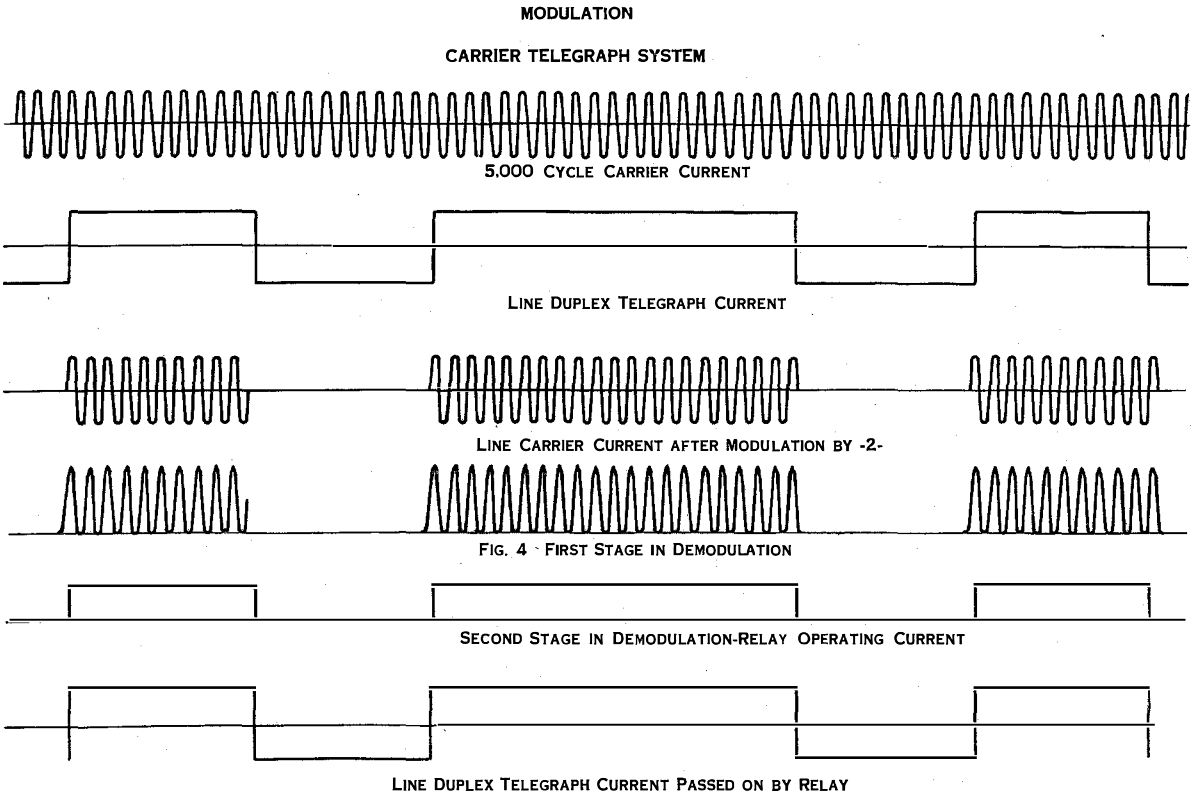


Figure 1—Operation of Carrier Telegraph System.

With regard to modulation, this action may be considered broadly as a process whereby the amplitude of a carrier current is caused to fluctuate in accordance with the variations of a signalling or voice current. This variation in amplitude results in the generation of so-called side band frequencies which are of a high frequency comparable with that of the carrier and within the band assigned to an individual channel. It is these side band currents which are actually used for the transmission of the signal.

In the present form of carrier telegraph systems, modulation consists merely of making and breaking the high frequency current in accordance with the impulses of a telegraph signal, thus sending spurts of alternating current on to the line, corresponding in duration to the dots and dashes. Figure 1 pictures the operation in a general way. First we have the unmodulated carrier or high frequency current and secondly, the telegraph signalling current. The third step shows how the high frequency current is interrupted in accordance with the impulses of the telegraph signal. These spurts of high frequency are transmitted to the distant station where they are separated from the other currents

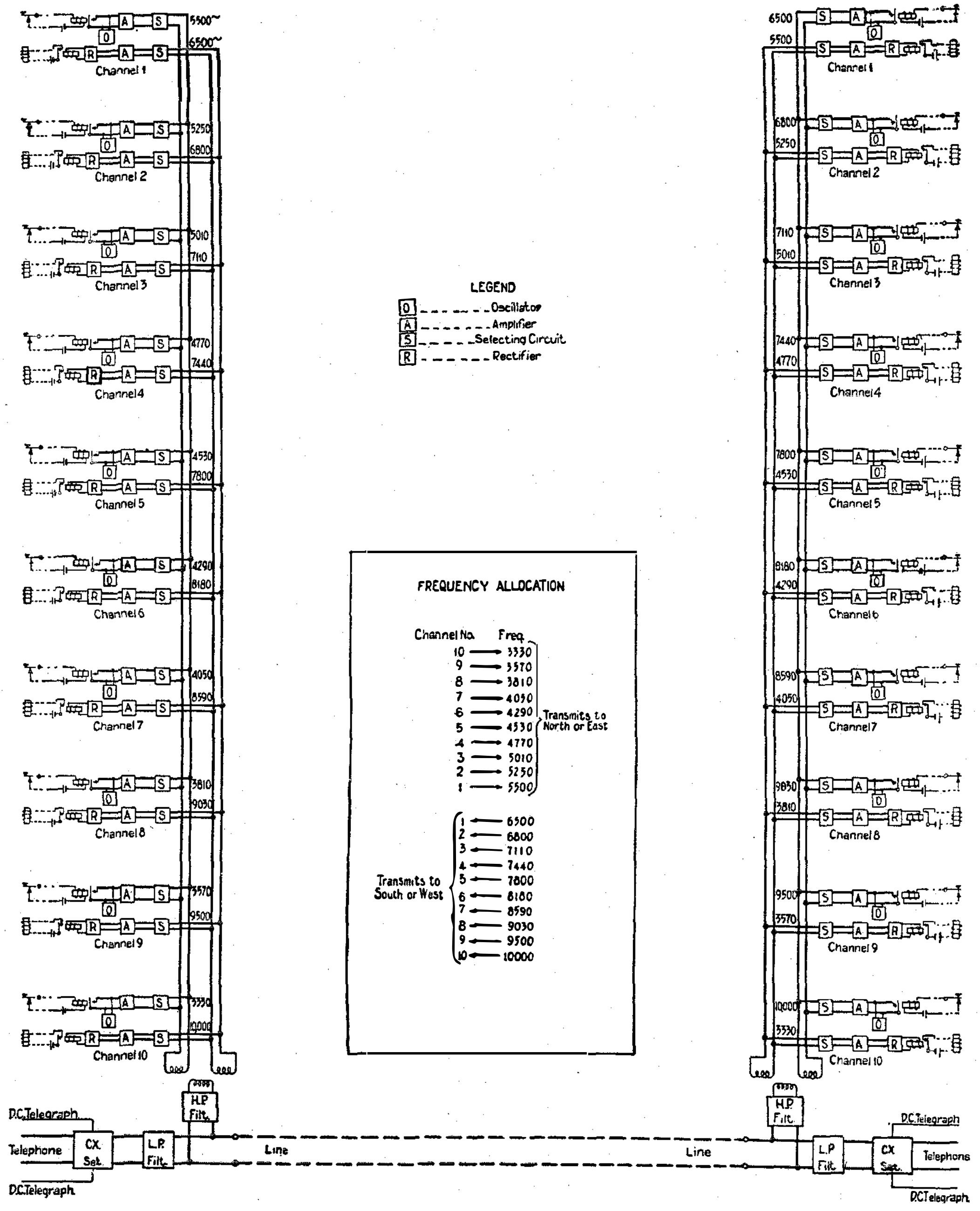


Figure 2—Schematic of Complete 10-Channel Type B Carrier Telegraph System.

which may have been on the line. The individual channel currents are then rectified and this rectified current in turn operates a relay which reproduces telegraph signals similar to those which were used at the sending station for modulating the carrier current. Figure 2 shows in simplified form the arrangement of the circuit.

In telephony, modulation consists similarly in varying the amplitude of a high frequency current in accordance with the speech current generated by the ordinary telephone transmitter. This variation in amplitude results in the generation of currents of different frequencies, the so-called side band frequencies; and it is these side band currents which are used for the transmission of the signal. Figure 3 shows graphically the process which takes place in a carrier telephone modulator. Figure 4 gives a simplified schematic circuit of a multiple telephone system.

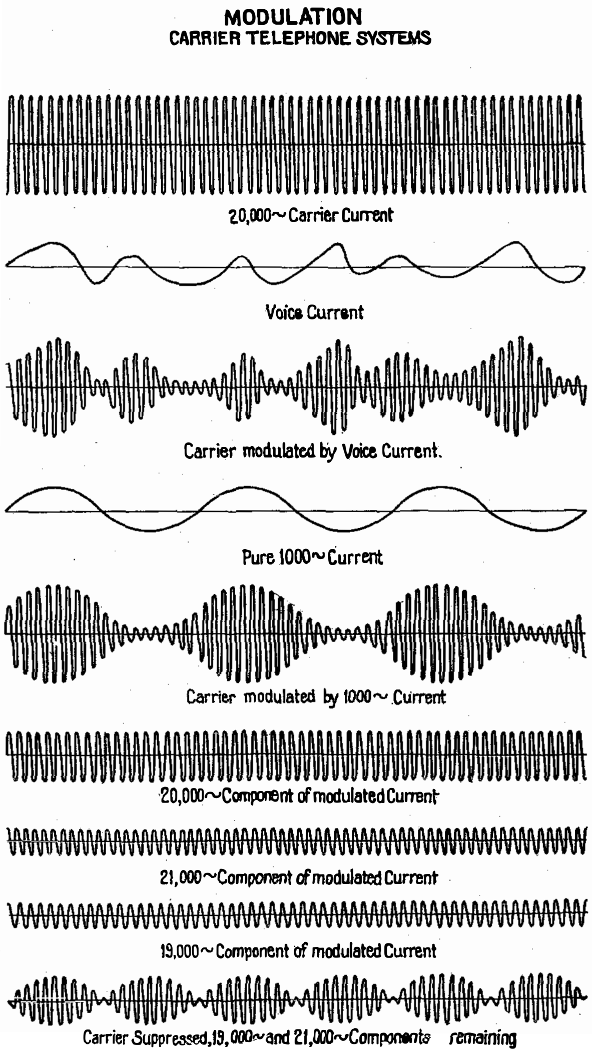


Figure 3—Modulation of Carrier Telephone Systems.

Let us turn now to the third step mentioned above, namely, "selectivity." In telephony and communication systems generally, frequencies are used for transmission which vary from a few cycles, as in telegraphy, through the telephone range of approximately 200 to 2,500 cycles, and upward throughout our present carrier range which has been limited to about 30,000 cycles. Even higher frequencies are used for radio transmission. In fact, light waves may be similarly regarded, and their vibration frequencies of many millions of millions of cycles may be considered as the upper extreme of the frequencies with which we are accustomed to deal in daily life. As has been mentioned before, the analogy to light offers, furthermore, a convenient conception of selectivity. It is of course well known that the various colors may be selected from each other by colored glass, or by the action of a prism on white light, thereby separating the various color-frequencies composing it, red, orange, yellow, green, etc., to form a rainbow or frequency spectrum. In a similar manner the electrical frequency range may be considered as a frequency spectrum, extending in the carrier case from a frequency of about 3,000 to 30,000 cycles; and electrical selecting circuits or filters may be employed to pick out a frequency or band of frequencies and to suppress the adjacent frequencies as desired. In this way the different frequencies or bands of frequencies resulting from the modulation of different carrier currents may be applied to a single circuit, and picked apart at the receiving end of a system to be individually treated or demodulated.

Selecting circuits are employed at both the transmitting and receiving ends of carrier systems to separate the various channels and to prevent interference with the normal telephone circuit. They consist of inductance coils and condensers connected in such a manner that certain groups or bands of frequencies are transmitted; usually, they are constructed to be non-adjustable and are mounted so that only the terminals are accessible.

We come now to the fourth step in carrier transmission, namely, demodulation. In the carrier telegraph sysem, relatively simple means of demodulation are employed. As noted in connection with modulation, the line current may be considered as acting in "spurts" of single frequency alternating current. This current, after being selectively received in its proper tuned circuit, is amplified and finally led to a vacuum tube amplifier-rectifier. The tube is so connected that when there is no current input there is no corresponding output current. When the received carrier current is applied to the input, amplification takes place only during the positive half of the alternating current wave. This current may be analyzed into various frequency components, chief of which is a direct current. By means of a shunt condenser, the high-frequency components are suppressed and the direct current, corresponding in duration to the original signalling pulse, remains to operate a relay.

Demodulation in the carrier telephone system is accomplished in a somewhat different manner and the action in general may be regarded as a shifting or displacing of frequency in the reverse direction to that in modulation.

Summarizing briefly, modulation may be thought of as elevating the band of essential speech frequencies to a position adjacent to the carrier frequency, and demodulation may be regarded as a process of restoring this band to its normal position in the frequency scale.

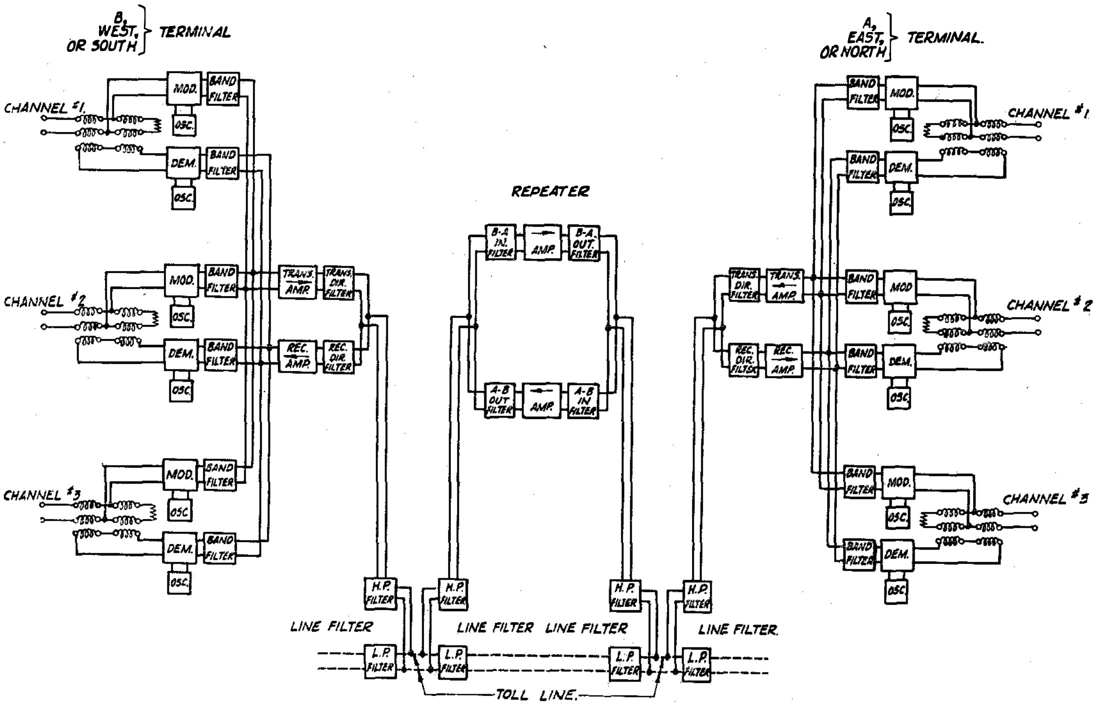


Figure 4—Simplified Schematic of a Multiple Telephone System.

As mentioned previously, carrier systems utilize a range of frequencies above those used for normal telephone service; and in order to prevent interference between the normal telephone channel and the carrier channels, so-called "line filters" are used to separate the carrier frequencies from the voice frequencies. This process is similar to that normally used for separating the low telegraph frequencies from the voice frequencies through the medium of a telegraph composite set.

High frequency currents superposed on line wires behave in accordance with the same general laws of transmission as the usual telephone frequency currents. Measurements of attenuation and impedance, for example, check very satisfactorily with theory. However, the attenuation of a telephone line increases rapidly with frequency and these greater line losses at carrier frequencies are offset by the amplifying action of the terminal and intermediate repeater equipment.

By using different carrier frequencies for transmission in opposite directions and thus eliminating the necessity of line balance, relatively large terminal and repeater amplifications are possible.

Carrier Application

Carrier systems are mostly employed on open wire non-loaded lines. Practice has shown that very little, if any, alteration in the usual line construction is required for the installation of one or two systems on a pole line; but if it is desired to utilize a line at maximum efficiency, which means installing the greatest possible number of carrier channels, it is sometimes necessary specially to transpose the lines to reduce carrier frequency crosstalk. As a rule, if a number of carrier systems can be profitably used on a given line, the cost of additional transpositions is slight in comparison with the gains which may be derived by employing carrier.

Cable circuits give rise to a much higher transmission loss than open wire circuits at carrier frequencies; hence it is desirable to use lines involving the minimum of cable. A certain amount of intermediate cable on open wire lines is, as a rule, unavoidable, but carrier systems will operate satisfactorily through moderate lengths of leading-in cable. If a long section of cable is encountered, it is necessary to load the cable for carrier frequencies. Loading units are available as required for this purpose.

The economy in using carrier systems depends largely upon the length and type of circuits required. On the basis of the present average labor and material costs in the carrier using parts of the world, it seems that single channel carrier telephone systems will be cheaper in first cost and involve lower annual charges than open wire or cable circuits for distances greater than, say, 40 miles, and three-channel telephone systems will "prove in" for distances of, say, 150 miles or more. Suppose, for instance, that three telephone circuits are required over a distance of 400 miles; that a pole line exists on the route; and that the three circuits can be obtained by stringing two pairs of copper wires to form a phantom group. In this case, in order to favor the copper circuits, let us charge against them only the cost of the wire, insulators and labor, neglecting any portion of the cost of poles and crossarms. Let us also assume, for this hypothetical case, that the effective life of the aerial line will be ten years with a 35% scrap value, and that the telephone repeaters and carrier equipment will depreciate 100% in ten years. This latter assumption is very conservative as the carrier gear is rugged, has no moving parts and, except for the possibility of obsolescence, could well be used effectively for twenty years or more.

For comparative purposes, figures representing costs will be given in arbitrary units. On this basis, with a cost of 200 units per mile for the copper wire, the 400-mile phantom group (comprising two pairs) will cost, say, 160,000 units, and let us add 4,500 units for the repeaters required to make the channels a 10 TU equivalent. We thus have a total first cost of, say, 164,500 units for the aerial circuits. The carrier system, which will provide as good or better grade service, will cost approximately 85,000 units so that, by its use, a net saving in first cost roughly of 80,000 units may be effected. Annual charges may be better appreciated in tabular form:

Annual Charge	Rate	Amount			Carrier
		Aerial Line	Telephone Repeaters	Total for Aerial Circuits	
			First Cost		
		160,000	4,500	164,500	85,000
			Annual Charges		
Interest	8 %	12,800	360	13,160	6,800
Taxes	1.5%	2,400	67	2,467	1,275
Insurance	.5%		23	23	425
Administration	.5%	800	23	823	425
Depreciation(Line)	4.5%	7,200			
Depreciation (Repeaters)	7 %		315	7,515	
Depreciation (Carrier)	7 %				5,950
Maintenance (Line)	4.0%	6,400			
Maintenance (Repeaters)	10.0%		450	6,850	
Maintenance (Carrier)	7.0%				5,950
Total		29,600	1,238	30,838	20,825

Thus it is seen that for this example, which is intended to represent the average, carrier as compared with aerial circuits presents a tremendous economic advantage, being roughly half the first cost of aerial circuits and effecting approximately a 30% reduction in annual charges.

Where the stringing of additional circuits on existing pole lines increases the chance of failure on the pole line or adds abnormally to maintenance costs, carrier systems will prove in on distances even shorter than those mentioned. These systems, because of simplicity of installation and compactness of the equipment, find application also for short distance working to meet temporary requirements as well as in cases where through their use the installation of toll cable or other expensive plant may be deferred. In a number of cases, in fact, it has been found that the savings in annual charges made possible by the use of carrier systems and the consequent postponement of large expenditures for new lines, results very quickly in writing off the first cost of the carrier equipment.

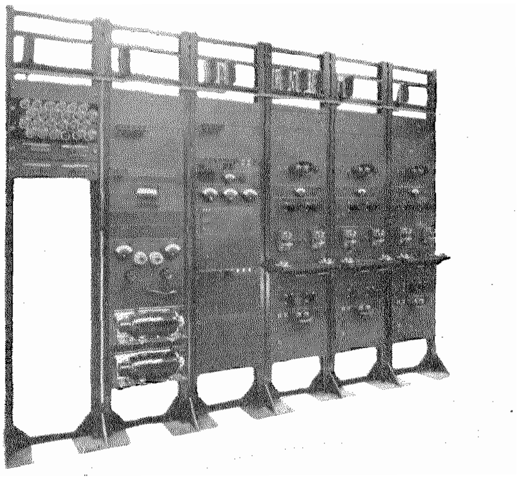


Figure 5—Voice Frequency Carrier Telegraph System—Front View of Terminal Equipment for 6-Channels.

The increased circuit facilities provided by carrier systems are of the same high standard as those obtained through the use of the best grade of long distance circuits of the more usual forms. The carrier circuits are stable and reliable and provide a greater degree of secrecy and freedom from ordinary interference than do open wire circuits. Carrier channels terminate in the usual switching facilities and are fully interchangeable with the usual trunk circuits and present the same degree of flexibility of operation.

There are three types of carrier systems manufactured by the International's associated companies, namely, voice frequency carrier telegraph, high frequency carrier telegraph and high frequency carrier telephone.

Voice Frequency Telegraph

The voice frequency carrier telegraph system has been designed primarily for use on cable circuits for providing a number of telegraph channels within the voice frequency range. It employs one or more circuits of a telephone cable where idle circuits are available or where some of the telephone circuits required to carry the peak telephone load are idle during a part of the day. The system is arranged for four-wire working and makes use of voice frequency repeaters, as in ordinary telephony.

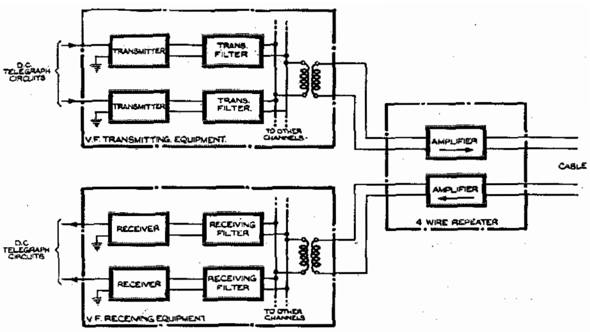


Figure 6—Voice Frequency Telegraph System—Schematic Diagram of Terminal for 4-Wire Operation. (Showing Two Channels Only in Each Direction.)

Operating on a four-wire basis, the same carrier frequencies can be utilized for communication in both directions. The actual number of duplex channels that can be made available depends to some extent upon the nature of the cable. In the case of extra light loaded cable, it is possible to obtain twelve duplex telegraph channels over two cable pairs. The system, in special cases, can be used also for two-wire working, either on cable circuits or open wire lines; but one group of carrier frequencies must be used for transmitting in one direction and another group for transmitting in the opposite direction, so that the number of duplex channels which can be provided on a single pair is halved. Figure 5 shows the assembly of apparatus comprising a voice frequency carrier telegraph system and Figure 6 shows a simplified diagram of the circuit.

The high frequency telegraph system has been designed for use on open wire lines and will provide ten duplex channels in addition to the facilities normally provided by the wires. The system uses a band of frequencies between three and ten kilocycles and is arranged for two-wire working only, different carrier frequencies being used for transmission in the two directions.

Where copper wires are used as single telegraph circuits, an economic study indicates that a tremendous saving can be effected if two such wires are combined to form a telephone trunk and telegraph facilities are derived through the use of a carrier telegraph system superposed on the wires as a pair. Such a case recently has been met with in Australia where two grounded telegraph wires were in operation on the transcontinental line between Adelaide and Perth. In order to provide a transcontinental telephone circuit, these two wires will be used as a metallic circuit for telephone service with a superposed carrier telegraph. When completed, there will be three carrier telegraph systems in operation in Australia which, in tandem, extend from Sydney to Perth, a total distance of approximately 3,000 miles. Figure 2 shows a simplified diagram of a ten channel carrier telegraph system.

Telephone Carrier

Four types of carrier telephone systems are now available to meet the various requirements. Two of these systems provide one extra telephone channel and are known as single channel carrier systems designated as type D and type C-2-F. There are also two types of systems, which provide three additional telephone channels and which are known as type C-N-3 and type C-S-3.

Taking up these systems in turn, the Type D single channel system has been especially developed for use on comparatively short lines. It is a relatively inexpensive and economical system which as a rule proves in on distances of more than twenty-five or thirty miles and is suitable on distances of 200 to 250 miles, depending upon the size of the conductors available. Because of the short distance involved, the line is not, as a rule, subjected to severe variation and as a result, the system requires no daily adjustments. Because of this and the fact that the equipment is compact and readily portable, this system may be used also to meet temporary service requirements, inasmuch as the equipment can readily be shifted from one office to another.

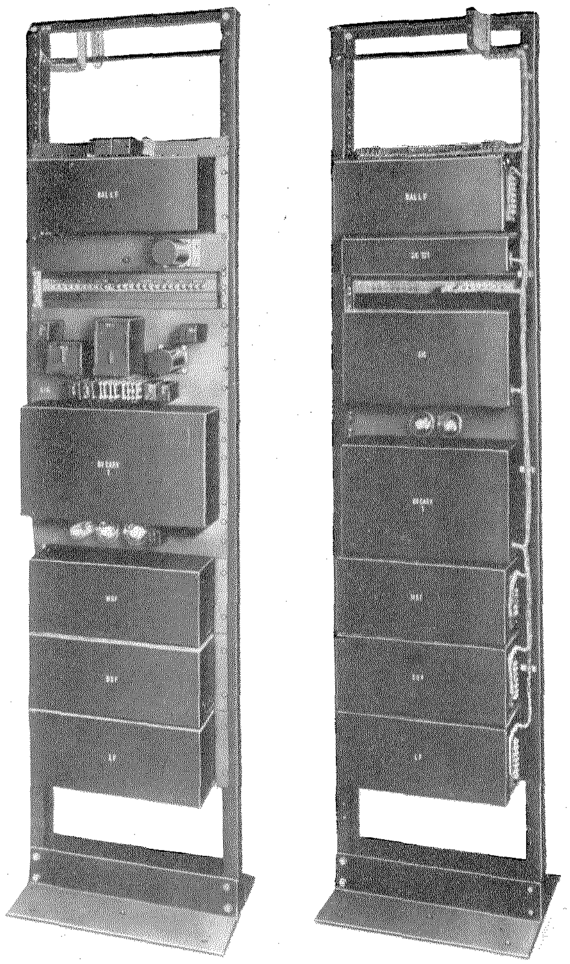


Figure 7—Front View. *Figure 8—Rear View.*
D-1 Carrier Telephone System Terminal Equipment.

The frequency range of the type D system is approximately from three to ten kilocycles and because of this comparatively low frequency, it is possible to operate a large number of systems of this type on the same pole line without excessive retransposition. In cases where the saving is sufficient, it is possible to transpose a pole line so as practically to fill it with type D equipment, which often finds application on heavily overloaded routes prior to the introduction of toll cables. Figures 7 and 8 show the form in which the equipment comprising a type D terminal is mounted, and Figure 9 shows a schematic of the circuit.

For circuits requiring an additional telephone channel of a length greater than can be handled by the type D system, the type C-2-F carrier telephone system is used. This system has been designed to provide one two-way telephone channel in addition to the existing voice frequency telephone and telegraph circuits; and, while the system will prove in from a cost standpoint at distances of from 100 to 150 miles, it can be extended to operate up to distances of roughly 750 miles. Here again the equipment is completely self-contained and, since it employs approximately the same frequencies as the type D system, very little daily maintenance is required. The chief application of the type C-2-F systems has been either as feeders to trunking centers or as forerunners to three channel systems in cases where it is desired to test the potential traffic requirements on a given route.

Since the equipment comprising the C-2-F system is self-contained, it oftentimes is found useful where temporary relief on special occasions is required, or where traffic is growing rapidly or suffers seasonal variations. Figures 10 and 11 show the assembly of the terminal and the repeater equipment and Figures 12 and 13 show simplified schematics of the terminal and repeater circuits.

The type C-N-3 and C-S-3 carrier telephone systems provide three two-way telephone channels in addition to the facilities obtained from existing lines. They are similar in every respect except that the frequency bands allotted to the various channels in the two systems have been staggered to simplify transposition. Suppose, for instance, it is desired to operate two three-channel systems on the two side circuits of a phantom group. Without excessive transposition, the crosstalk at carrier frequencies between two such closely associated physical circuits would ordinarily be great; and, in order to overcome this difficulty, the frequency bands allotted to the system operated on one side circuit are arranged to be staggered between the bands allotted to the system on the other side. In this way any crosstalk which may occur between the two lines will not cause interference between the systems.

These three channel systems provide the same

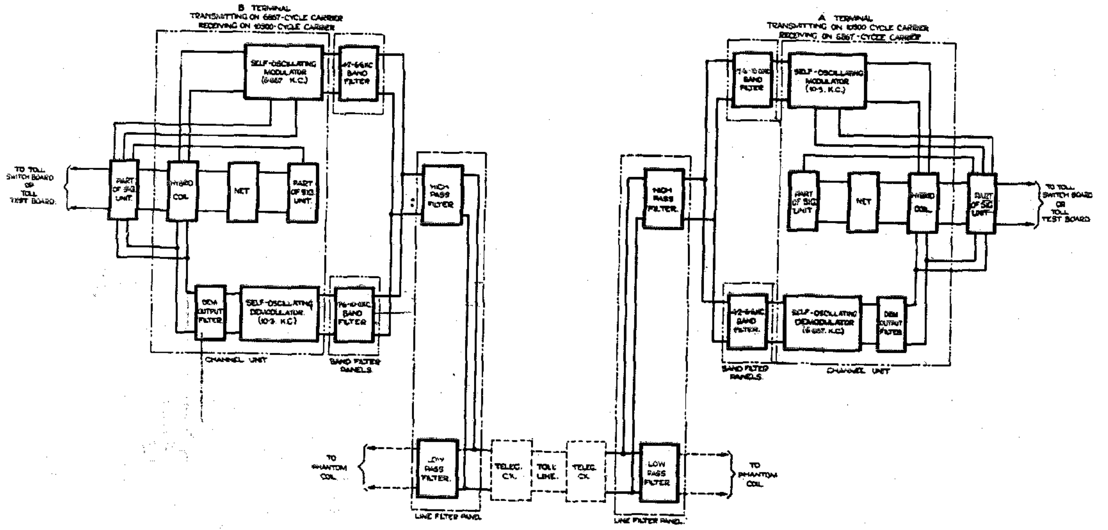


Figure 9—Schematic of D-1 Carrier Telephone System.

high grade transmission as is obtained from the single channel systems; they terminate in the switchboard in the usual manner and are operated exactly the same as any other high grade long distance trunk.

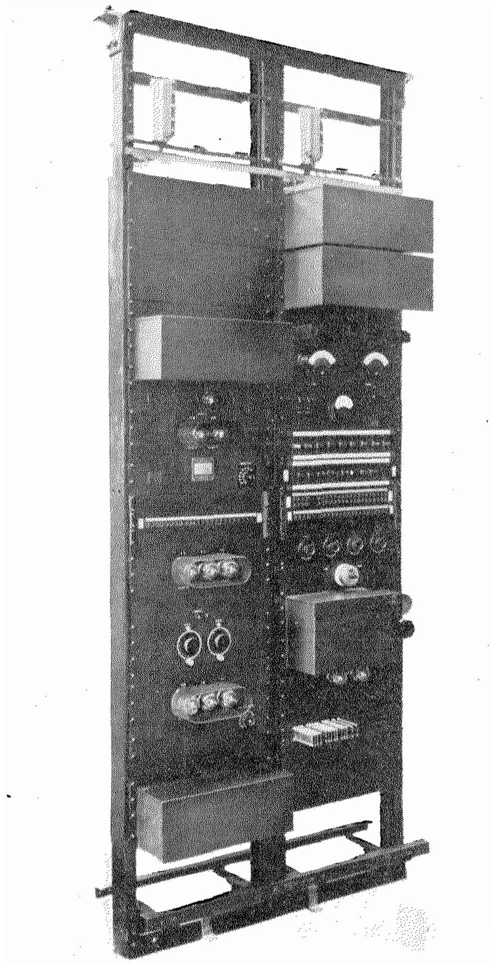


Figure 10—C-2-F Carrier Telephone System—Terminal Equipment.

As a rule, a three-channel system will prove in on relatively short distances and, through the use of carrier repeaters, its range can be extended up to any limit. The longest three-channel system now in service in the International field is between Sydney and Brisbane, a distance of about 750 miles.

Figures 14 and 15 show the terminal and repeater equipment of the three-channel system and Figure 4 gives a simplified general schematic of the two terminals with one intermediate repeater.

All of the carrier telephone systems employ the single side band suppressed carrier method of transmission. The carrier is suppressed by using what is known as a balanced or "push-pull" modulator. This consists of two vacuum tubes arranged with a common filament circuit and the input circuit so designed that the voice current is introduced in a push-pull manner making the potential on the grid of one tube positive and the other negative at a particular instant. The carrier supply is introduced so that the instantaneous potentials on both tubes are equal and of the same polarity.

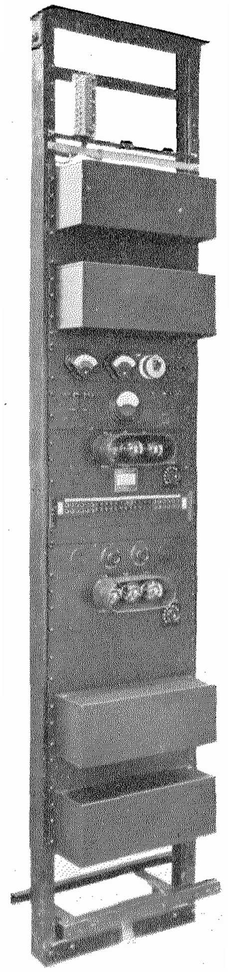


Figure 11—C-2-F Carrier Telephone System—Repeater Equipment.

If, therefore, the general characteristics of the two tubes are similar, the output current due to the carrier supply alone will be equal for each tube circuit, and the combined output induced in the secondary of the transformer circuit can be made zero by proper connection of the coils. The effect is, therefore, to suppress the carrier frequency itself. This is true not only for the steady-state with no voice input, but even when the voice current is being received on the input and the circuit is effectively unbalanced, with the voice, and side band frequencies flowing in the output. The action involves the fact that the carrier frequency currents in the two output circuits are at all times oppositely directional, whereas the product terms resulting in the side band currents are so phased as to produce cumulative action.

By transmitting but a single side band, it is possible to keep the energy level of the side band component well above the noise level on the line and at the same time not overload the terminal and repeater equipment. Another feature of the suppressed carrier method of transmission is the improved stability obtained over a system in which the carrier is transmitted.

With the exception of the voice frequency

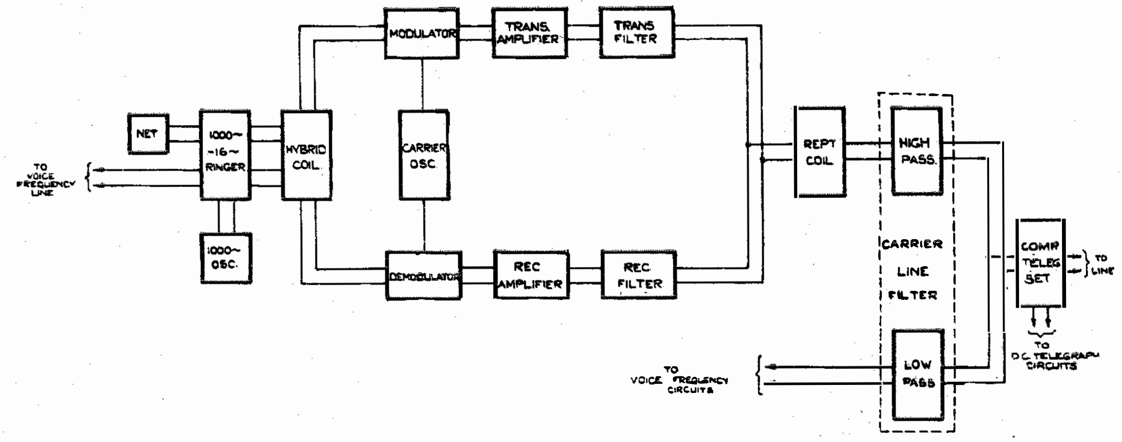
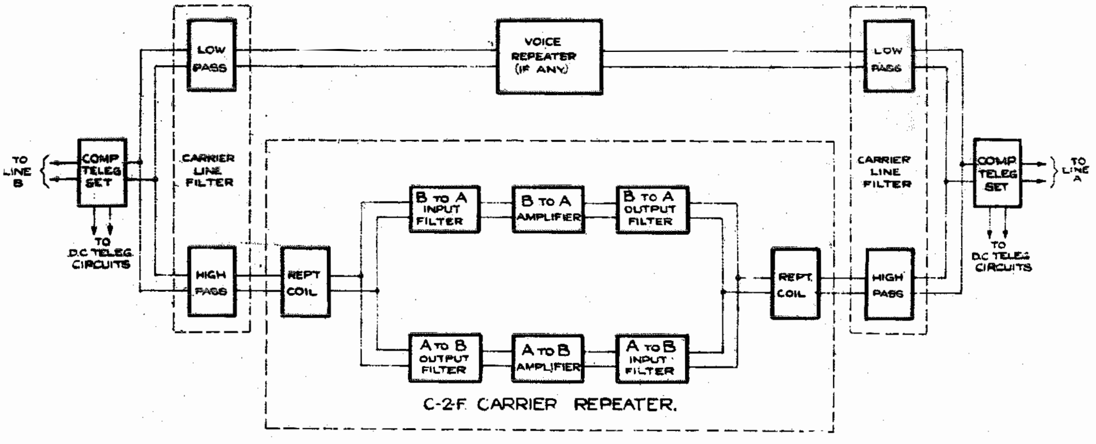


Figure 12—C-2-F Carrier Telephone System—Layout of Terminal.



NOTE:-
COMPOSITE SETS ARE REQUIRED ONLY WHEN
THE VOICE CCT IS REPEATERED OR WHEN
THE TELEG CCTS. ARE TERMINATED.

Figure 13—C-2-F Carrier Telephone System—Layout of Repeater.

carrier telegraph, which is normally a four-wire system, all of the carrier systems operate on two wires with a so-called group frequency method of operation. Using a different group of frequencies in the two directions simplifies the transposition problem since only far-end crosstalk is involved and, in addition, enables the circuits to be worked at greater overall gains. A channel of communication for ordinary telephone or telegraph service must of course be two way and it can be made so either by using the conductors bi-directionally or by using two pairs of conductors, one pair for transmission in one direction and the other, for transmission in the opposite direction. This latter is the so-called "four-wire circuit" and in voice frequency telephone operation, permits the use of much higher gains than does a two-wire circuit. Consequently a long four-wire repeater circuit can be operated at a low transmission equivalent. That advantage is economically realizable with small gauge conductors in long cables but it is not so with open wire lines when used for voice frequency operation. A big advantage of the carrier systems is that they are designed on a basis that is equivalent to a four-wire circuit but actually operate on two wires. Each carrier channel has two carrier frequencies, one for operation in the A to B direction and the other for the B to A direction. It is apparent, therefore, that through the agency of the carrier the advantages of four-wire operation can be and, in actual practice, is economically secured for aerial lines. This

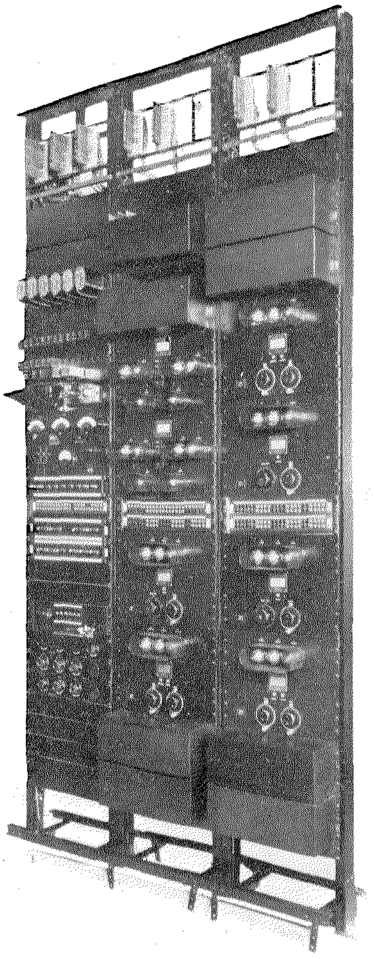


Figure 14—Three Channel Carrier Telephone System—Terminal Equipment.

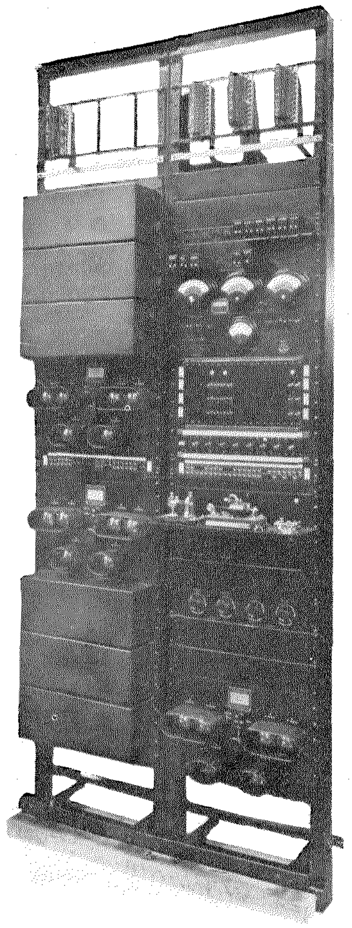


Figure 15—Three Channel Carrier Telephone System—Repeater Equipment.

means that for very long trunk circuits an exceptionally good equivalent can be obtained over a carrier channel while the repeatered physical circuit operating on the same pair of wires may necessarily, because of the difficulties in repeater balance, be operated at an equivalent many times that of the carrier channel. For this reason in some cases a long existing trunk line is broken up to provide intermediate circuits and a carrier system superimposed to take care of the through traffic. Such a condition has recently been met with between Sydney and Melbourne where the through circuits are now provided entirely by carrier and the original physical circuits have been broken up to take care of the way stations.

With the exception of the type D single channel system, the carrier telephone systems utilize one thousand cycle ringing current. The ringing to and from the switchboard is carried out in the normal way which, in most cases, involves the use of 16 cycle current but on an outgoing ring this 16 cycle current operates a relay chain which impresses interrupted 1,000 cycle current on the carrier channel, the 1,000 cycle ringing current being supplied from a local generator. At the distant terminal the incoming 1,000 cycle ringing current operates a relay chain which in turn causes the local ringing current to be transmitted to the switchboard. The ringing system is not an inherent part of the carrier channel and, if the carrier is used as an intermediate portion of a long trunk on which voice frequency ringing is employed, it is not necessary to provide ringing equipment with the carrier as it will effectively transmit any frequencies between 250 and 2,500 cycles. The type D system employs a form of voice frequency ringing but in order to avoid the necessity of providing a local 1,000 cycle ringing generator, the ringing current is obtained by shifting the carrier frequency at the transmitting terminal 1,000 cycles away from the carrier frequency at the receiving terminal and thus producing the same net result as is obtained through the ordinary forms of the voice frequency ringing systems.

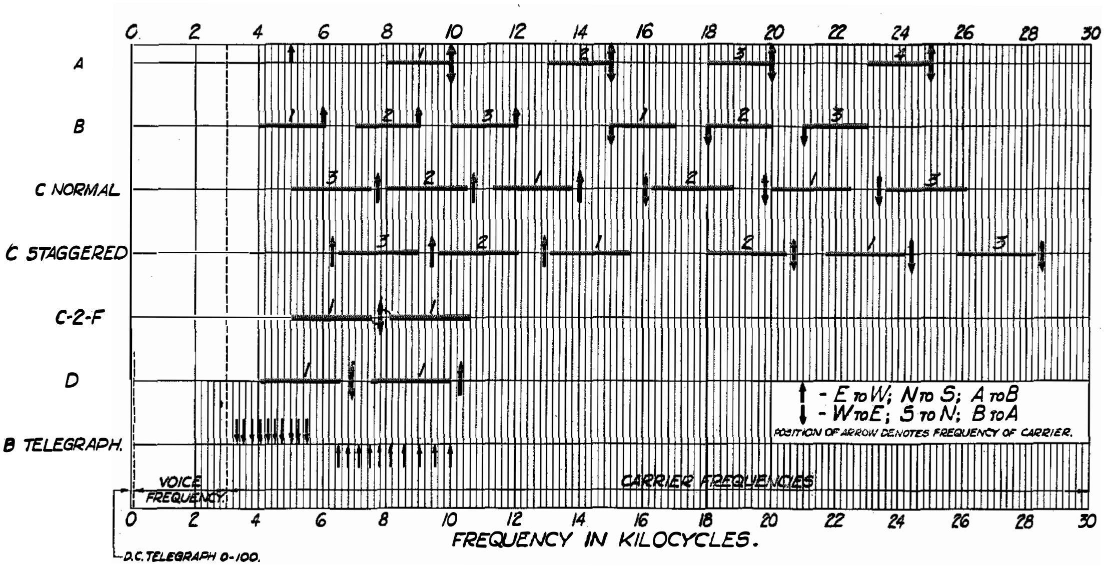


Figure 16—Frequency Allocation of Carrier Systems.

In order that the frequency allocation of the various types of carrier systems may be more readily appreciated, Figure 16 shows graphically the bands of frequencies allotted to the various types of systems.

Circuits Available Through Carrier Operation

Having considered briefly the principles and economics of carrier operation, as well as various types of systems, it seems pertinent to point out some of the facilities which may be provided by these improved efficiency systems. By improved efficiency is meant not only improved quality, transmission and stability—features which have been mentioned above—but the increased number of circuits which can be obtained from existing copper lines.

For example, using the more widely known communication systems, one telephone and two telegraph circuits can be obtained from one pair of wires; but, using a three channel carrier telephone system on these same wires, four telephone and two telegraph channels or, in the case of a carrier telegraph system, one telephone and twelve telegraph channels may be obtained. Of these twelve telegraph channels, two are the direct current circuits which can be operated under favorable conditions at a speed of, say, 60 words per minute. *The ten carrier telegraph channels, however, can each be operated with a printing telegraph system which will provide four telegraph message channels per carrier channel,* so that we can have as many as 40 telegraph messages being transmitted over the carrier telegraph system simultaneously. Each of these 40 messages can be transmitted at the rate of 60 words per minute. Furthermore, since the channels are duplex, we can transmit 40 messages in each direction at the same time, or 80 telegraph messages simultaneously. Including the two duplex direct current channels, we then have one pair of wires being used for the simultaneous transmission of one telephone message and eighty-four telegraph messages.

If we use a pair of wires for telegraph purposes only, the telephone channel can be replaced by a two-wire six channel voice frequency carrier telegraph system, so that we obtain a total of sixteen carrier channels which, when equipped with four channel printing telegraph apparatus and added to the two direct current channels, give us a total of sixty-six two-way channels, or permit of the simultaneous transmission of 132 messages on a single pair of wires.

Carrier facilities can be carried still further. By using on one pair of wires a three channel carrier telephone system and superimposing a voice frequency carrier telegraph system on each carrier telephone channel, we can obtain a total of 170 two-way channels or transmit over a single pair of wires, 340 telegraph messages simultaneously.

Let us consider the maximum facilities which can be obtained from four copper wires comprising a phantom group. If the circuits are used mostly for telephone service, we provide two physical and one phantom telephone circuit; in addition a three channel carrier telephone system can be superposed on each physical circuit, giving a total of nine telephone and four telegraph channels from four wires. If more telegraph channels are required, a voice frequency telegraph system can be used on one of the carrier telephone channels and we net eight telephone channels and 52 two-way telegraph channels. If we replace another telephone channel by a second telegraph system, we net seven telephone channels and one hundred two-way telegraph channels; similarly, we can net six telephone and 148 two-way telegraph channels of five telephone and 196 two-way telegraph channels. If we go to the extreme of telegraph application by using all the telephone channels for telegraph purposes, we can provide on four wires a total of 364 two-way telegraph channels which will permit of the simultaneous transmission of 728 messages. As each of these channels is capable of carrying 60 five-letter words per minute, we are thus enabled to transmit a total of 43,680 words per minute over four wires.

The Brussels International Telegraph Conference September, 1928

By SIFFER LEMOINE

IN THE year 1925, an International Telegraph Conference was held in Paris to consider and pass upon certain changes in the International Telegraph Regulations.

Many changes in these Regulations were agreed to, but one proposal which was of fundamental importance, had to be deferred owing to difficulty in arriving at a satisfactory solution. This proposal, which for many years had claimed the earnest study of the governments of the world, and of the private communication interests, involved the question of charging for code messages. In view of its importance, the proposal was considered at a special Conference of the International Telegraph Union which was held at Cortina, Italy, in August, 1926. It was also brought up at the Radio Telegraph Conference held at Washington in the fall of 1927 and was considered at the special Conference of the International Telegraph Union which was held at Brussels under the auspices of the Belgian Government in September, 1928. The latter Conference was attended by delegations of a great majority of the governments who are members of the International Telegraph Union and by an unofficial delegation of the United States Government as well as by representatives of the principal cable, telegraph and radio telegraph companies of the world.

At the Brussels Conference, a change in the International Telegraph Regulations relating to coded messages, to take effect October 1, 1929, was agreed on. While far from ideal, a great number of the governments represented felt that the change was the best which was possible under the circumstances. The following proposition was accordingly adopted:

Ordinary messages in plain language are to be charged for as at present and code messages are to be divided into two categories, namely, Category A and Category B.

Category A is to consist of code words not exceeding ten letters, including at least one vowel if the word is composed of at most five letters; at least two vowels if the word is composed of six, seven or eight letters; and three vowels if the word is composed of nine or ten letters. Words composed of nine or ten letters must contain at least one vowel in the first five letters and two vowels in the remainder of the word; or vice versa, two vowels in the first five letters and one vowel in the remainder of the word.

Category B is to contain code words of not more than five letters without any restriction as to their formation.

The service indication of words in Category B is to be "CDE" which indication is not charged for. There is to be a minimum of four words per message in this class. Numbers or groups of numbers are not permitted in this category.

Telegrams in Category A are charged for at the full rate; in Category B, the charge is to be two-thirds of the full rate for messages in the extra-European system. For messages in the European system the rate for Category B is to be three-fourths of the full rate. The European system includes all countries of Europe and those territories outside of Europe which are declared by the respective administrations to belong to the European system. The extra-European system includes countries other than those in the European system, and therefore applies to telegrams between North and South America or between North and South America on the one side and all other parts of the world on the other.

Mr. Goldhammer, Vice-President of the Commercial Cable Company, was one of the American Government Delegates. All America Cables was represented by Messrs. Davidson and C. H. Russell, and the Commercial Cable Company by Messrs. H. F. Russell, Heiskell and Lindow.

The Belgian Government was most hospitable in its arrangements for the entertainment of the delegates, and the courtesy of the Government and the excellence of the arrangements were greatly appreciated.

On the afternoon of September 19th, a large number of delegates visited the plants of the Bell Telephone Manufacturing Company at Antwerp and Hoboken, and were afterwards entertained at tea at the Club House at the Company's sports grounds. The arrangements for this visit were excellent in every respect.

Visit of the Delegates of the International Telegraph Conference to the Club House of the Bell Telephone Manufacturing Company, Antwerp.

Hoboken, September 19, 1928.

Transformers as Band Pass Filters

By E. K. SANDEMAN

European Engineering Department, International Standard Electric Corporation

FOR practical purposes it is possible to replace a transformer having self capacity by a network which consists of a half section of a known type of band pass filter. In the absence of dissipation, therefore, the transformer when working between its image impedances, passes a band of frequencies with no attenuation (i.e., with uniform voltage step-up).

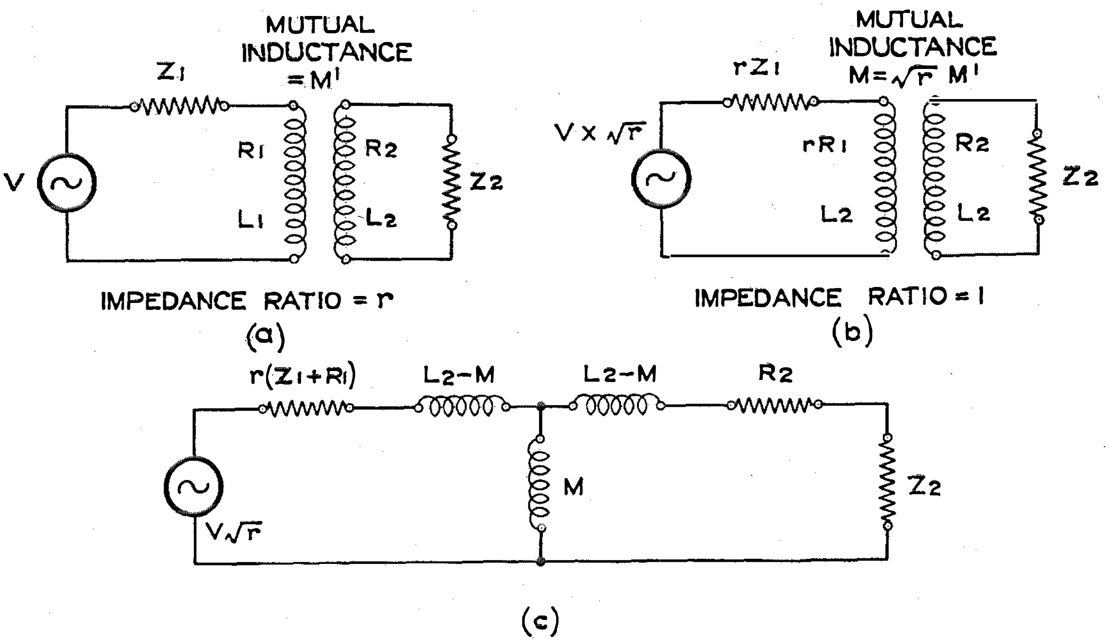


Figure 1—Transformer and Equivalent Networks.

Design formulæ are developed for a simple transformer working between its image impedances, and for a transformer associated with a series capacity. The ideal theory is applicable in practice to carrier and long wave transformers for frequencies lying between 5,000 and an upper limit of approximately 100,000 cycles for impedances the order of 20,000 ohms, and to audio frequency transformers for ordinary telephony. It fails for high quality audio frequency transformers passing wide ranges, and is of doubtful value for radio frequency transformers for wave lengths below 3,000 metres, except where the valve anode impedances are not higher than 10,000 ohms.

Part I—Theory of the Transformer Considered as a Band Pass Filter

In an article on Telephone Transformers,[1] W. L. Caspar shows that the performance of a transformer may be conveniently determined by considering the performance of a unity ratio transformer derived from it. In Figure 1 at (a) is

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[1] "Telephone Transformers," Electrical Communication, Vol. II, No. 4.

shown a transformer operating between impedances Z_1 and Z_2, having primary inductance and resistance L_1 and R_1, secondary inductance and resistance L_2 and R_2, a mutual inductance M, and an impedance ratio $r=\frac{L_2}{L_1}$. At (b) and (c) are shown the stages by which the circuit at (a) is replaced, first, by one containing an equivalent unity ratio transformer and finally, by one containing an equivalent T network, the conditions to be satisfied at each replacement being that the current in Z_1 shall be unaltered.

In the case where the frequency and the self capacity are such that the effect of the self capacity has to be taken into account, and where uniform transmission over a range of frequencies is required, the circuit may be represented as in Figure 2. Here C is the total self capacity, including primary self capacity transferred to the secondary.

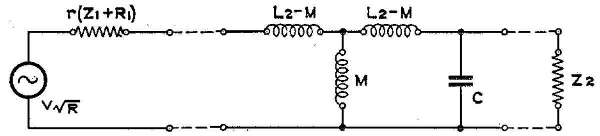

Figure 2 (at left)—Equivalent Network of Transformer Having Self Capacity.

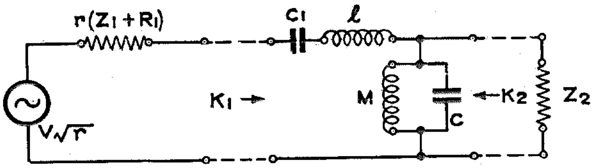

Figure 3 (at right) Approximate Network for Transformer Having Capacity.

Neglecting R_2 and inserting an ideal transformation according to filter theory, it may be shown that if (L_2-M) is very small compared to M, as is actually the case in practice, the circuit of Figure 3 may be used to replace the circuit of Figure 2 without appreciable alteration of performance. The quantity $2\,(L_2-M)$ will be called the magnetic leakage inductance l.

Since $l=2\,(L_2-M)$
and $M=K\sqrt{L_1\,L_2}=KL_2$ in a unity ratio transformer, it follows
that $l=\frac{2}{K}(1-K)\,M$.

The leakage inductance l is now all on the same side of M. Experiment shows that for all practical purposes, valid results will be obtained by assuming R_2 to be directly in series with Z_2.

Referring to the article by Mr. Otto J. Zobel in the Bell System Technical Journal for January, 1923, page 42, it is evident that this case corresponds to a ladder filter structure of type VI. 2.

In order that such a filter may transmit a band of frequencies with zero attenuation it must be terminated at half section, mid series or mid shunt, and the termination faced by the corresponding iterative impedance. The network in Figure 3 may be regarded as being terminated on the left hand (primary) side, at mid series, and on the right hand (secondary) side at mid shunt. Under these conditions,

$$l=\tfrac{1}{2}L'_1,\quad M=2\,L_2,\quad C=\tfrac{1}{2}C_2.$$

Hence if f_1 is the lower cut-off frequency and f_2 the upper cut-off frequency, R being the mean line resistance (i.e., at $f=\sqrt{f_1\,f_2}$), from page 42 of Mr. Zobel's article,

$$l=\frac{R}{2\pi(f_1+f_2)}, \qquad M=\frac{2(f_2-f_1)R}{4\pi\;f_1^2}, \qquad C=\frac{1}{2\pi(f_2-f_1)R}$$

(1) (2) (3)

The full elements of the filter are

$$L'_1=\frac{R}{\pi(f_1+f_2)}, \qquad L_2=\frac{(f_2-f_1)R}{4\pi\;f_1^2}, \qquad C_2=\frac{1}{\pi(f_2-f_1)R}$$

(4) (5) (6)

Mid series impedance (Primary image impedance).

$$K_1=\left(Z_1\,Z_2+\frac{Z_1^2}{4}\right)^{\frac{1}{2}}$$

$$= \left[L'_1 j\omega \text{ x } \frac{1}{Cj\omega + \frac{1}{L_2 j\omega}} + \frac{(L'_1 j\omega)}{4} \right]^{\frac{1}{2}}$$

$$= \left[\frac{\frac{R\, 2\pi f}{\pi(f_1+f_2)}}{\frac{2\pi f}{\pi(f_2-f_1)R} - \frac{1}{\frac{(f_2-f_1)R.2\pi f}{4\pi\, f_1^2}}} - \frac{R^2 4\pi f^2}{4\pi^2(f_1+f_2)^2} \right]^{\frac{1}{2}}$$

$$= \left[\frac{\frac{fR^2}{f_1+f_2}}{\frac{f^2}{f(f_2-f_1)} - \frac{f_1^2}{f(f_2-f_1)}} - \frac{R^2\, f^2}{(f_1+f_2)^2} \right]^{\frac{1}{2}}$$

$$= \left[\frac{f^2\,(f_2-f_1)}{(f_1+f_2)\,(f^2-f_1^2)} - \frac{f^2}{(f_1+f_2)^2} \right]^{\frac{1}{2}} R \ldots\ldots.(7)$$

and when f is the geometric mean of the two cut-off frequencies (i.e., at mid band when $f^2 = f_1\, f_2$),

$$K_1 = \left[\frac{f_1\, f_2^2 - f_1^2\, f_2}{(f_1+f_2)\,(f_1\, f_2 - f_1^2)} - \frac{f_1\, f_2}{(f_1+f_2)^2} \right]^{\frac{1}{2}} R$$

$$= \left[\frac{f_2}{f_2+f_1} - \frac{f_1\, f_2}{(f_1+f_2)^2} \right]^{\frac{1}{2}} R$$

$$= \frac{f_2}{f_2+f_1} R = \text{primary image impedance at mid band} \ldots\ldots\ldots\ldots. (8)$$

Mid shunt impedance (Secondary image impedance).

$$K_2 = \frac{Z_1\, Z_2}{K_1}$$

$$= \left[\frac{1}{\frac{(f_1+f_2)\,(f^2-f_1^2)}{f^2\,(f_2-f_1)} - \frac{(f_1+f_2)\,(f^2-f_1^2)^2}{f^2\,(f_2-f_1)^2}} \right]^{\frac{1}{2}} R \ldots(9)$$

and when $f^2 = f_1\, f_2$

$$K_2 = \frac{\frac{f_2}{f_2+f_1} R^2}{\frac{f_2}{f_2+f_1} R} = R \ldots\ldots\ldots\ldots\ldots.(10)$$

That is, R is the secondary image impedance at mid band.

DEVELOPMENT OF DESIGN FORMULÆ

Generally, for a given core, the self capacity C and the coupling factor K do not vary appreciably for appreciable changes in the number of turns on each winding.

As a preliminary step in design, it is first necessary that these quantities, which form the basic design data, should be determined by making measurements on a transformer, experimental or otherwise, using the core in question.

The problems facing the transformer designer are dictated chiefly by the required frequency range to be passed and the impedances between which the transformer is required to operate.

Since $l = \frac{2}{K}(1-K)M$, equation (1) may be written

$$\frac{2}{K}(1-K)M = \frac{R}{2\pi(f_1+f_2)} \ldots\ldots\ldots\ldots.(11)$$

Repeating (2) and (3)

$$M = \frac{2(f_2-f_1)R}{4\pi\, f_1^2} \ldots\ldots\ldots\ldots\ldots.(12)$$

$$C = \frac{1}{2\pi(f_2-f_1)R} \ldots\ldots\ldots\ldots\ldots.(13)$$

Since C and K are constants of the transformer, the above three equations relate four variables R, M, f_1 and f_2; there is thus one degree of freedom permitting either a choice of the value of any one of these variables or a choice of the relation between any two of them. It is convenient to derive from equations (11), (12) and (13) certain dependent relations which are most immediately applicable in each of the different initial conditions imposed.

$$\text{From (11), } f_2+f_1 = \frac{R}{\frac{4\pi}{K}(1-K)M} \ldots\ldots.(14)$$

$$\text{From (13), } f_2-f_1 = \frac{1}{2\pi\, R\, C} \ldots\ldots\ldots\ldots(15)$$

$$\therefore\; 2\, f_2 = \frac{K\, R}{4\pi(1-K)M} + \frac{1}{2\pi RC} \ldots\ldots(16)$$

$$2\, f_1 = \frac{K\, R}{4\pi(1-K)M} - \frac{1}{2\pi\, RC} \ldots\ldots(17)$$

Substituting (15) and (17) in (12),

$$M = \frac{\dfrac{2R}{2\pi RC}}{\dfrac{4\pi}{4}\left[\dfrac{KR}{4\pi(1-K)M} - \dfrac{1}{2\pi RC}\right]^2}$$

$$\therefore MC\left[\frac{K^2R^2}{16(1-K)^2M^2} - \frac{K}{4(1-K)MC} + \frac{1}{4R^2C^2}\right] = 1$$

$$\therefore \frac{MCK^2R^2}{16(1-K)^2M^2} - \frac{K}{4(1-K)} + \frac{M}{4R^2C} = 1$$

$$\therefore \frac{M^2}{4R^2C} - \frac{MK+4(1-K)M}{4(1-K)} + \frac{CK^2R^2}{16(1-K)^2} = 0$$

$$\therefore \frac{1}{R^2C}M^2 - \frac{4-3K}{1-K}M + \frac{CK^2R^2}{4(1-K)^2} = 0$$

$$\therefore M = \frac{\dfrac{4-3K}{1-K} \pm \sqrt{\dfrac{(4-3K)^2}{1-K} - \dfrac{K^2}{(1-K)^2}}}{\dfrac{2}{R^2C}}$$

$$\therefore M = \frac{R^2C}{2(1-K)}\left[4-3K \pm \sqrt{(4-3K)^2-K^2}\right] \quad \ldots\ldots\ldots\ldots(18)$$

The negative sign of the root is taken in order to make f_1 positive; this may be seen from equation (26).

Again from (12), $4\pi M f_1^2 = 2 f_2 R - 2 f_1 R$

and from (13), $\frac{1}{\pi C} = 2 f_2 R - 2 f_1 R$

$$\therefore 4\pi M f_1^2 = \frac{1}{\pi C}$$

$$\therefore M = \frac{1}{4\pi^2 C f_1^2} \quad \ldots\ldots(19)$$

From (13), $R = \frac{1}{2\pi(f_2-f_1)C}$ ....(20)

Substituting (19) and (20) in (11)

$$\therefore \frac{\frac{2}{K}(1-K)}{4\pi^2 C f_1^2} = \frac{R}{2\pi(f_1+f_2)}$$

$$\therefore \frac{\frac{2}{K}(1-K)}{4\pi^2 C f_1^2} = \frac{1}{4\pi^2(f_2^2-f_1^2)C}$$

$$\therefore f_2^2 - f_1^2 = \frac{f_1^2}{\frac{2}{K}(1-K)}$$

$$\therefore f_2^2 = \frac{1+\frac{2}{K}(1-K)}{\frac{2}{K}(1-K)} f_1^2$$

$$= \frac{1-\frac{K}{2}}{1-K} = \frac{2-K}{2-2K} f_1^2 \quad \ldots\ldots(21)$$

$$\therefore f_2 = \sqrt{\frac{2-K}{2-2K}} f_1 \quad \ldots\ldots(22)$$

From (21) $(2-2K) f_2^2 = (2-K) f_1^2$

$$\therefore 2 f_2^2 - 2 f_2^2 K = 2 f_1^2 - f_1^2 K$$

$$\therefore 2 f_2^2 K - f_1^2 K = 2 f_2^2 - 2 f_1^2$$

$$\therefore K = \frac{2 f_2^2 - 2 f_1^2}{2 f_2^2 - f_1^2} \quad \ldots\ldots(23)$$

Again, from (4)

$$f_1 = \tfrac{1}{2}\left[\frac{KR}{4\pi(1-K)M} - \frac{1}{2\pi RC}\right]$$

$$= \frac{1}{2R}\left[\frac{KR^2}{4\pi(1-K)M} - \frac{1}{2\pi C}\right] \quad ..(24)$$

From (18),

$$R^2 = \frac{2M(1-K)}{C\left[4-3K-\sqrt{(4-3K)^2-K^2}\right]} \quad \ldots(25)$$

Substituting from (25) into (24)

$$\therefore f_1 = \frac{1}{2\sqrt{\dfrac{2M(1-K)}{C\left[4-3K-\sqrt{(4-3K)^2-K^2}\right]}}}$$

$$\left[\frac{2KM(1-K) \qquad\qquad 1}{4\pi(1-K)MC\left[4-3K-\sqrt{(4-3K)^2-K^2}\right] 2\pi C}\right]$$

$$f_1=\tfrac{1}{2}\sqrt{\frac{C}{2M}\cdot\frac{1}{1-K}\left[4-3K-\sqrt{(4-3K)^2-K^2}\right]}$$

$$\left[\frac{K}{2\pi C\left[4-3K-\sqrt{(4-3K)^2-K^2}\right]}^{1}+\frac{1}{2\pi C}\right]$$

$$f_1=\frac{1}{4\pi\sqrt{MC}}\sqrt{\frac{1}{2-2K}}\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}$$

$$\left[\frac{K}{4-3K-\sqrt{(4-3K)^2-K^2}}-1\right]\ldots\ldots.(26)$$

Similarly from equation (16) it may be shown that

$$f_2=\frac{1}{4\pi\sqrt{MC}}\sqrt{\frac{1}{2-2K}}\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}$$

$$\left[\frac{K}{4-3K-\sqrt{(4-3K)^2-K^2}}+1\right]\ldots\ldots.(27)$$

Equations (25) and (26) may be written

$$f_1=\frac{1}{4\pi\sqrt{MC}}\sqrt{\frac{1}{2-2K}}$$

$$\left[\frac{K}{\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}}-\right.$$

$$\left.\sqrt{(4-3K)-\sqrt{(4-3K)^2-K^2}}\right]\ldots\ldots.(28)$$

$$f_2=\frac{1}{4\pi\sqrt{MC}}\sqrt{\frac{1}{2-2K}}$$

$$\left[\frac{K}{\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}}+\right.$$

$$\left.\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}\right]\ldots\ldots.(29)$$

It is evident from equation (22) that division of equation (29) by equation (28) should afford the relation $\frac{f_2}{f_1}=\sqrt{\frac{2-K}{2-2K}}$

As this forms a valuable check it has been included below.

$$\frac{f_2}{f_1}=\frac{\frac{K}{A}+A}{\frac{K}{A}-A}\quad\text{where } A=\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}$$

$$\therefore\ \frac{f_2}{f_1}=\frac{K+A^2}{K-A^2}$$

$$=\frac{K+4-3K-B}{K-4+3K+B}\quad\text{where } B=$$

$$\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}$$

$$=\frac{4-2K-B}{4K-4+B}$$

$$\therefore\ \frac{f_1}{f_1+f_2}=\frac{4K-4+B}{4K-4+B+4-2K-B}$$

$$=\frac{4K-4+\sqrt{16-24K+K^2}}{2\,K}$$

$$=\frac{2K-2+\sqrt{2K^2-6K+4}}{K}$$

$$=\frac{2-2K-\sqrt{(2-K)\,(2-2K)}}{-K}$$

$$=\frac{2-2K-(2-2K)}{2-2K-2+K}\sqrt{\frac{2-K}{2-2K}}$$

$$\therefore\ \frac{f_1}{f_1+f_2}=\frac{1-\sqrt{\frac{2-K}{2-2K}}}{1-\frac{2-K}{2-2K}}=\frac{1}{1+\sqrt{\frac{2-K}{2-2K}}}$$

$$\therefore\ \frac{f_2}{f_1}=\sqrt{\frac{2-K}{2-2K}}$$

Part II—Design of Unequal Ratio Transformers

The design of an actual unequal ratio transformer is thus preceded by the design of an hypothetical unity ratio transformer operating between equal impedances R.

The value R should be considered to include not only the impedance of the load into which the transformer operates, but also the value of the internal resistances of the windings, R_1 and R_2.

The value of R in Part I represents the secondary impedance into which the actual transformer operates while the secondary inductance of the actual transformer

$$L_2 = \frac{M}{K} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (30)$$

The primary inductance

$$L_1 = \frac{L_2}{r}$$

where r is the impedance step up which should satisfy the relation

$$r = \frac{Z_2 + R_2}{Z_1 + R_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (31)$$

It is to be noted that the mutual inductance of the unequal ratio transformer is always less than that of the equal ratio transformer from which it is derived in the ratio of $\sqrt{r}$. This does not mean, as might appear to be the case, that the resonances are altered. The parallel resonance is really secondary resonance, and the secondary inductance is unaltered. The series resonance is unaltered because the secondary leakage inductance (for constant K) is unaltered, and the primary leakage inductance, seen through the transformer, is stepped up to the same value as in the unity ratio case.

The following four cases of limited design requirements may be solved directly from the theory in Part I.

Case I. To Design a Transformer to give flat reproduction between two impedances Z_1 *and* Z_2. *Given self capacity* C *and coupling factor* K.

Although termed impedances Z_1 and Z_2 are considered to be of zero angle.

An estimation of the value of R_1 and R_2 should be made, when r follows from equation (31) and also

$$R = Z_2 + R_2.$$

Then from equations (18), (24), and (16)

$$M = \frac{R^2 C}{2(1-K)} \left[4 - 3K - \sqrt{(4-3K)^2 - K^2} \right]$$

$$f_1 = \frac{1}{2} \left[\frac{KR}{4\pi(1-K)M} - \frac{1}{2\pi RC} \right]$$

$$f_2 = f_1 + \frac{1}{2\pi RC}$$

also $L_2 = \dfrac{M}{K}$

$$L_1 = \frac{L_2}{r}$$

Case II. To Design a Transformer to pass a band of a given width. Given $f_2 - f_1$, C *and* K.

From (11) the secondary impedance

$$R = \frac{1}{2\pi(f_2 - f_1)C}$$

also

$$M = \frac{R^2 C}{2(1-K)} \left[4 - 3K - \sqrt{(4-3K)^2 - K^2} \right]$$

$$L_2 = \frac{M}{K}$$

$$L_1 = \frac{L_2}{r} \quad \text{where } r = \frac{R}{Z_1 + R_1}$$

f_1 and f_2 are calculated by the same formulæ as in Case I.

Case III. Given f_1, C *and* K.

From (19)

$$M = \frac{1}{4\pi^2 C f_1^2}$$

From (22)

$$f_2 = \sqrt{\frac{2-K}{2-2K}}\, f_1$$

$$R = \frac{1}{2\pi\,(f_2 - f_1)C}$$

L_1 and L_2 follow as in Case II.

Case IV. Given f_2, C *and* K.

From (22)

$$f_1 = \sqrt{\frac{2-2K}{2-K}}\, f_2$$

From (19)

$$M = \frac{1}{4\pi^2 \, C \, f_1^2}$$

$$R = \frac{1}{2\pi \, (f_2 - f_1) \, C}$$

L_1 and L_2 follow as in Case II.

It is evident that none of the above four cases leads directly to a complete provision of the requirements which would be put forward in the general practical case, although for some individual practical cases they afford satisfactory solutions.

The general practical case evidently involves at the same time, the width of the passed range and also its location.

The width of the passed band involves the self capacity C and the secondary impedance R independently of any other variables, as is brought out by equation (15).

When the value of $f_2 - f_1$ has been determined by the value of C (probably dictated by the case used) and the choice of R, the location of the range is determined by the value of K, as is shown by equation (22). This may perhaps be made clearer by the following:

Put $f_2 - f_1 = D$, so that $f_1 = f_2 - D$; then

$$f_2 = \sqrt{\frac{2-K}{2-2K}}\, f_1 = \sqrt{\frac{2-K}{2-2K}}\,(f_2 - D)$$

$$\therefore \quad f_2 = \frac{D}{\sqrt{\frac{2-K}{2-2K}} - 1}$$

It is therefore evident that if the application of the four ideal cases above leads neither to a solution nor to an acceptable compromise, steps must be taken to improve either C or K as indicated above.

A further extension of the lower cut-off frequency is possible by tuning the transformer; this is discussed in Part III.

It should be noted that the lower cut-off is in general not sharp, and, provided the loss at f_r, the lowest frequency in the range of interest, does not exceed whatever may be the tolerable amount, it is possible in certain cases to accept a value of f_1 higher than f_r.

The loss at f_r may be calculated as follows:

From Figure 2, the loss at f_r is equal to that caused by a bridged impedance Z between impedances of R, where Z is the impedance of M and C in parallel.

$$\text{Hence } Z = \frac{jL\omega}{1 - LC\omega^2} = \frac{1}{Y} \text{ say.}$$

Loss introduced by a shunt between two impedances, Z_1 *and* Z_2.

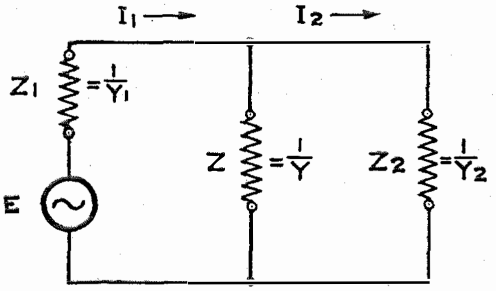

Figure 4—Illustrating Shunt Impedance.

Referring to Figure 4, in the absence of the shunt,

$$I_2 = \frac{E}{Z_1 + Z_2} = \frac{E}{\frac{I}{Y_1} + \frac{1}{Y_2}}$$

In the presence of the shunt,

$$I_1 = \frac{E}{Z_1 + \frac{1}{Y + Y_2}}$$

$$I_2 = \frac{Y_2}{Y + Y_2} I_1 = \frac{Y_2 \, E}{(Y + Y_2)\left(\frac{1}{Y_1} + \frac{1}{Y + Y_2}\right)}$$

Current ratio

$$\frac{I_2}{I_1} = \frac{E}{\frac{1}{Y_1} + \frac{1}{Y_2}} \times \frac{\frac{Y + Y_2}{Y_1} + 1}{Y_2 \, E}$$

$$= \frac{Y + Y_1 + Y_2}{Y_1 + Y_2}$$

Putting $Y_1 = Y_2 = \frac{1}{R} = G$ the loss in TU due to the shunts M and C

$$= 20 \log_{10} \left| \frac{Y + 2\,G}{2G} \right|$$

where the heavy lines indicate that only the argument of the complex quantity between them is to be taken into account.

Part III—Theory of Tuned Transformer

By inserting a condenser in series with the primary of a transformer, the passed range may be increased by the lowering of f_1.

The circuit to be considered is given in Figure 5.

Referring again to page 42 of Mr. Zobel's article in the Bell System Technical Journal, for January, 1923, it is evident that this corresponds to a ladder filter of type VII.

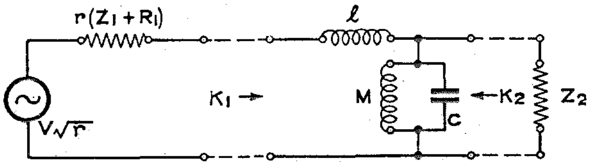

Figure 5—Equivalent Network for Transformer with Series Tuning.

As in Part I, from page 42 of the above,

$$C_1=2\,C_{1k}=\frac{f_2-f_1}{2\pi f_1 f_2 R}\ \ldots\ldots\ldots\ldots(101)$$

$$l=\tfrac{1}{2}\,L_{1k}=\frac{R}{2\pi(f_2-f_1)}\ \ldots\ldots\ldots\ldots(102)$$

$$M=2\,L_{2k}=\frac{(f_2-f_1)R}{2\pi f_1 f_2}\ \ldots\ldots\ldots\ldots(103)$$

$$C=\tfrac{1}{2}\,C_{2k}=\frac{1}{2\pi(f_2-f_1)\,R}\ \ldots\ldots\ldots(104)$$

The full elements of the section being

$$L_{1k}=\frac{R}{\pi(f_2-f_1)}\qquad L_{2k}=\frac{(f_2-f_1)\,R}{4\pi f_1 f_2}$$

$$C_{1k}=\frac{f_2-f_1}{4\pi f_1 f_2 R}\qquad C_{2k}=\frac{1}{\pi(f_2-f_1)\,R}$$

This filter is of the constant K type and hence the mid-band image impedance is R on both sides.

Substituting in equation (103) the relation $l=\frac{2}{K}(1-K)M$ and repeating parts of (101), (103) and (104).

$$\frac{2}{K}(1-K)M=\frac{R}{2\pi(f_2-f_1)}\ \ldots\ldots\ldots\ldots(105)$$

$$M=\frac{(f_2-f_1)R}{2\pi f_1 f_2}\ \ldots\ldots\ldots\ldots(106)$$

$$C=\frac{1}{2\pi(f_2-f_1)R}\ \ldots\ldots\ldots\ldots(107)$$

$$C_1=\frac{f_2-f_1}{2\pi f_1 f_2 R}\ \ldots\ldots\ldots\ldots(108)$$

K and C being taken as constants, the above four equations relate five variables R, M, f_1 and f_2, and C_1; there is then one degree of freedom, as before, permitting either a choice of the value of any one of these variables or a choice of the relation between them. Also as before, it is convenient to derive certain dependent relations.

From (105 and (107)

$$\frac{2}{K}(1-K)\frac{M}{R}=CR\ \ldots\ldots\ldots\ldots\ldots(109)$$

$$\text{whence } R^2=\frac{2}{K}(1-K)\frac{M}{C}\ \ldots\ldots\ldots\ldots\ldots(110)$$

$$M=R^2C\frac{K}{2(1-K)}\ \ldots\ldots\ldots\ldots\ldots(111)$$

$$\text{and } C=\frac{M}{R^2}\cdot\frac{2}{K}(1-K)\ \ldots\ldots\ldots\ldots\ldots(112)$$

From (106) and (108)

$$\frac{M}{R}=C_1 R\ \ldots\ldots\ldots\ldots\ldots(113)$$

whence

$$R^2=\frac{M}{C_1}\ \ldots\ldots\ldots\ldots\ldots(114)$$

$$M=C_1 R^2\ \ldots\ldots\ldots\ldots\ldots(115)$$

$$\text{and}\qquad C_1=\frac{M}{R^2}\ \ldots\ldots\ldots\ldots\ldots(116)$$

From (111) and (115)

$$C_1=\frac{K}{2(1-K)}C\ \ldots\ldots\ldots\ldots\ldots(116a)$$

From (106) and (107)

$$R(f_2-f_1)=2\pi\, f_1\, f_2\, M=\frac{1}{2\pi C} \quad\ldots\ldots(117)$$

$$\therefore\ f_2=\frac{1}{4\pi^2\, MC\, f_1} \quad\ldots\ldots\ldots\ldots\ldots(118)$$

Substituting in (107)

$$\therefore\ C=\frac{1}{2\pi\left(\dfrac{1}{4\pi^2\, MC\, f_1}-f_1\right)R}$$

$$\therefore\ \frac{1}{4\pi^2\, MC\, f_1}-f_1-\frac{1}{2\pi\, RC}=0$$

$$\therefore\ f_1^2+\frac{1}{2\pi\, RC}f_1-\frac{1}{4\pi^2\, MC}=0$$

$$\therefore\ 4\pi^2\, f_1^2+\frac{2\pi\, f_1}{RC}-\frac{1}{MC}=0$$

$$\therefore\ f_1=\frac{-\dfrac{1}{RC}+\sqrt{\dfrac{1}{R^2C^2}+\dfrac{4}{MC}}}{4\pi} \quad\ldots\ldots\ldots(119)$$

From (105) and (106)

$$M=\frac{R}{2\pi(f_2-f_1)\dfrac{2}{K}(1-K)}=\frac{(f_2-f_1)R}{2\pi\, f_1\, f_2} \quad\ldots\,(120)$$

$$\therefore\ f_1\, f_2\cdot\frac{K}{2(1-K)}=f_2^2-2\, f_1\, f_2+f_1^2$$

$$\therefore\ f_2^2-\left(2+\frac{K}{2(1-K)}\right)f_1\, f_2+f_1^2=0$$

$$\therefore\ f_2^2-\frac{4-3K}{2-2K}f_1\, f_2+f_1^2=0$$

$$\therefore\ f_2=\frac{1}{2}\left[\frac{4-3K}{2-2K}+\sqrt{\frac{(4-3K)^2}{(2-2K)}-4}\,\right]f_1 \ldots(121)$$

$$\text{and}\quad f_1=\frac{1}{2}\left[\frac{4-3K}{2-2K}-\sqrt{\frac{(4-3K)^2}{(2-2K)}-4}\,\right]f_1 \ldots(122)$$

Part IV—Design of a Tuned Transformer

Case V.

To design a tuned transformer to give flat reproduction between two impedances Z_1 *and* Z_2. *Given* R, *self capacity* C, *and coupling factor* K.

As in Case I, from equations (111), (116), (118) and (119)

$$M=R^2C\frac{K}{2-2K}$$

$$f_1=\frac{-\dfrac{1}{RC}+\sqrt{\dfrac{1}{R^2C^2}+\dfrac{4}{MC}}}{4\pi}$$

$$f_2=\frac{1}{4\pi^2\, MC\, f_1}$$

$$C_1=\frac{M}{R^2}$$

$$L_2=\frac{M}{K}$$

$$L_1=\frac{L_2}{r}$$

Case VI.

To design a tuned transformer to pass a band of a given width. Given f_2-f_1, C *and* K.

From (107), (111), and (116)

$$R=\frac{1}{2\pi(f_2-f_1)C}$$

$$M=R^2C\frac{K}{2(1-K)}$$

$$C_1=\frac{M}{R^2}$$

$$L_2=\frac{M}{K}$$

$$L_1=\frac{L_2}{R}$$

f_1 and f_2 may be calculated by the same formulæ as in Case I.

Case VII.

Given f_1, C *and* K.

From (121), (118), (116) and

$$f_2=\frac{1}{2}\left[\frac{4-3K}{2-2K}+\sqrt{\frac{(4-3K)^2}{(2-2K)}-4}\,\right]f_1$$

$$M=\frac{1}{4\pi^2\,C\,f_1\,f_2}$$

$$R=\sqrt{\frac{2}{K}\,(1-K)\,\frac{M}{C}}$$

$$C_1=\frac{M}{R^2}$$

Case VIII.

Given f_2, C *and* K.

From (122)

$$f_1=\frac{1}{2}\left[\frac{4-3K}{2-2K}-\sqrt{\frac{(4-3K)^2}{(2-2K)}-4}\,\right]f_2$$

The values of the two remaining quantities then follow as in Case VII.

Part V—Specific Examples

1. It is required to design an untuned transformer to give uniform reproduction within its pass range and to operate between impedances of 500 and 24,500 ohms. The self capacity of the transformer + the parallel capacity of the associated apparatus on the secondary side (e.g., the input of a valve) has a value of 100 micro-micro-farads, which is an average value occurring in practice. The coupling factor is .995, which is rather higher than the average value occurring in practice but which can be secured by special winding. The resistances of the low and high windings are estimated at 1,750 and 25 ohms, respectively.

The data for design of the unity ratio transformer are then

$$R=26{,}250,\quad C=10^{-10}\text{ Farads},\quad K=.995$$

Applying the formulæ for Case I,

$$M=\frac{26{,}250^2\times10^{-10}}{2(1-.995)}\left[4-3\times.995-\sqrt{(4-3\times.995)^2-.995^2}\right]$$

$$=6.88\left[1.015-\sqrt{(1.015)^2-.99}\right]$$

$$=5.6\text{ henrys}$$

$$f_1=\frac{1}{2}\left[\frac{.995\times26{,}250}{4\pi\times.005\times5.6}-\frac{1}{2\pi\times26{,}250\times10^{-10}}\right]$$

$$=\frac{1}{2}(74{,}200-60{,}600)=6{,}800∽.$$

$$f_2=f_1+\frac{1}{2\pi\times26{,}250\times10^{-10}}$$

$$=67{,}400∽.$$

$$L_2=\frac{M}{K}=5.625\text{ henrys}$$

$$L_1=5.625\times\frac{525}{26{,}250}=0.1125\text{ henrys}$$

$$\text{Loss at }100∽=20\log_{10}\left|\frac{\dfrac{1}{j\,5.6\times628}+\dfrac{2}{26{,}250}}{\dfrac{2}{26{,}250}}\right|$$

$$=20\log_{10}\left|\frac{2-j\,7.45}{2}\right|$$

$$=20\log_{10}4.54$$

$$=13.1\text{ TU}$$

Such a transformer, while suitable for use in carrier wave circuits, intermediate frequency amplifiers or long wave amplifiers, would not be suitable in an audio frequency circuit which was required to transmit high quality music. As the argument immediately following indicates, it is not practically possible to construct a transformer operating into 25,000 ohms which will give an ideally uniform reproduction down to a frequency as low as say 30∽, while maintaining uniform reproduction up to 10,000∽. The value of K, taken above, is as high or higher than can be realised by ordinary methods of sectionalising windings and cannot therefore be increased.

Substituting the value of K = 0.995 in equation (22)

$$f_2=\sqrt{\frac{1.005}{0.01}}\,f_1=10f_1\text{ nearly.}$$

In order to reproduce a range from 30 to 10,000 cycles, a value of K given by equation (23) must be obtained.

$$K=\frac{2\times10^8-2.30^2}{2\times10^8-30}$$

that is, greater than .999995.

In practice, for audio frequency transformers which are required to give high quality reproduction, the value of M is made larger than the value given by equation (18) and, in a particular case, may be as much as 15 times larger.

Examining the effect of this in the present case f_2, being inversely proportional to $\sqrt{M}$, is reduced from 67,400 to approximately 17,400, and similarly, f_1 is reduced to 1,750. At 30∽ the loss is substantially that due to the bridged impedance M, the effect of self capacity being negligible.

The loss at 30∽

$$= 20 \log_{10} \left| \frac{\dfrac{1}{j\,5.6\times15\times188.5} + \dfrac{2}{26{,}250}}{\dfrac{2}{26{,}250}} \right|$$

$$= 20 \log_{10} \left| \frac{2 - j\,1.65}{2} \right|$$

$$= 20 \log_{10} 2.06$$

$$= 6.26 \text{ TU}$$

Such a transformer does not give uniform reproduction within its pass range, but frequencies in the upper part of the audio frequency range of importance (up to 10,000∽) are reproduced with uniform efficiency because the upper resonance is well above 10,000∽ and because the impedance of the shunting capacity (100 μ μF) is large (159,000 ohms at 10,000∽) compared to the terminating resistance.

2. It is required to design a tuned transformer to give uniform reproduction within its pass range and to operate between impedances of 500 and 24,500 ohms.

The data for the design of the unity ratio transformer are

$R = 26{,}250$, $C = 10^{-10}$ farads, $K = .995$.

Applying the formulæ of Case V.

$$M = 26{,}250^2 \times 10^{-10} \times \frac{.995}{2 - 1.99} = 6.846 \text{ henrys}$$

$$f_1 = \frac{\dfrac{-1}{26{,}250\times10^{-10}} + \sqrt{\dfrac{1}{26{,}250^2\times10^{-20}} + \dfrac{4}{6.846\times10^{-10}}}}{4\pi}$$

$$= \frac{-3.8095\times10^5 + \sqrt{1.4512\times10'' + .05834\times10''}}{4\pi}$$

$$= \frac{-3.8095+3.8846}{4\pi} \times 10^5 = \frac{7510}{4\pi}$$

$$= 597.6\backsim$$

$$f_2 = \frac{1}{4\pi^2\times6.846\times10^{-10}\times597.6}$$

$$= 61{,}820\backsim$$

It is therefore evident that, for the value of $K = .995$, it is only possible with an untuned transformer to realise a maximum ratio between f_2 and f_1 equal to about 10, but with the use of low frequency tuning this ratio may be extended to 100, an advantage of no mean value. This may be seen more directly by substituting the value of K in equations (22) and (121).

If the tuning condenser is placed on the high side of the winding,

$$C_1 = \frac{M}{R^2} = \frac{6.85}{26{,}250^2} = .994\times10^{-8} = .00994\mu\text{F}.$$

If it is placed on the low side,

$$C_1 = .00994 \times \frac{26{,}250}{525} = .497\ \mu\text{F}.$$

3. It is required to design a transformer with low frequency tuning in which

$$f_1 = 500{,}000\backsim,\ K = 0.5,\ C = 40\mu\ \mu\text{F}.$$

Applying the formulæ of Case VII,

$$f_2 = \frac{1}{2}\left[\frac{4-1.5}{2-1} + \sqrt{2.5^2-4}\right] f_1$$

$$= 2\, f_1 = 1{,}000{,}000\backsim.$$

e.g., as a radio transformer, wave lengths from 300 to 600 metres would be passed.

$$M = \frac{1}{4\pi^2\times4\times10^{-11}\times0.5\times10^{12}}$$

$$= 1268 \text{ micro-henrys}$$

$$R = \sqrt{\frac{2}{.5}\times.5\times\frac{1268\times10^{-6}}{4\times10^{-11}}}$$

$$= 8000 \text{ ohms approximately.}$$

This is too low an impedance for most high frequency valves, and explains the difficulty which has been experienced in designing transformers for wavelengths below 3,000 metres, to work between impedances of the order of 20,000 or 50,000 ohms and to pass a wide band of wavelengths.

$$C_1 = \frac{1268\times10^{-6}}{8000^2} = 158\mu\ \mu\text{F}.$$

Toll Operating Room—No. 3 Toll Board. Tokyo Central Telephone Office. The Recording Boards Are in the Foreground.

Tokyo and Kobe Toll Cable

By SANNOSUKE INADA

Director General of Telegraph and Telephone Engineering, Department of Communications, Japan

BECAUSE of economic and technical considerations, the application of toll telephone cables heretofore has been limited in Japan to short hauls, such as Tokyo-Yokohama, Kyoto-Osaka, Osaka-Kobe and Moji-Kurosaki, where suburban toll traffic was most congested. Nevertheless, in view of the progress made in telephone transmission engineering, it was decided in connection with the third telephone expansion program of 1920, that a cable between Tokyo and Okayama could be provided economically. The circuits involve the main trunk lines of the Empire and cover a distance of approximately 800 kilometers (about 200 ri).

Work was started on the new cable in the fiscal year 1922. Although the construction schedule had to be somewhat altered, owing to the Earthquake, on the whole, the initial plan has been followed and construction has been progressing in a satisfactory way so that, of the total distance, the line between Tokyo and Kobe was opened for traffic on November first, 1928, just before the Coronation. As a result, a speedier dispatch could be arranged for important conversations relative to the Coronation, and toll conversations between Tokyo, Osaka and the others of the Six Large Cities, as well as other cities and towns along the route, can now be carried on far more easily than formerly.

Since the telephone cable just opened for traffic is one of the largest cable systems in the world, outside of the United States of America, and is an epoch-making achievement in long distance telephone communications in Japan, a summary will be given in this paper of its design features and the installation work involved, as well as plans for the future extension of the cable system.

Fundamental Considerations

Toll telephone circuits in Japan heretofore have consisted mostly of bare overhead wire lines. Bare overhead wire is, however, extremely difficult to maintain and cannot be secured absolutely against storms or various troubles arising from human acts (see Table No. 1). Moreover, the use of a mixed line, consisting of short lengths of cable and aerial bare wire, renders the quality of conversation poor.

The development of commerce and industry, the resulting transportation and traffic congestion, and the advancement in other fields of endeavor caused a great demand for telephone service between cities and towns separated by long distances. The demand could not be met with perfect smoothness or full satisfaction even with additions made year after year to the toll lines which then existed.

If an attempt had been made to furnish the many telephone line additions required by stringing of overhead wire, the maintenance difficulties would have been great and the cost of construction for the project as a whole would have been prohibitive. Consequently, it was found necessary to supersede aerial bare wire lines by some other form of construction.

Telephone conversations through cable, prior to the time when telephone repeaters and loading coils were developed fully, were limited to a few tens of kilometers, with consequent limitation in the use of cable circuits. Improvements in vacuum tube repeaters and loading coils, however, have made the transmission of speech, through cable circuits, possible for a distance up to 8,000 kilometers. Thus, along with the great advance in long distance speech transmission, troubles due to storms, rain, snow, etc., have been reduced with resultant economy in maintenance by the adoption of cable circuits. As a consequence, in Europe and America, various countries, one after another, are installing cable for their important toll trunks, so that the present project may be said to result from the demands of the age.

With aerial wire lines, telephone circuits may be added each year according to demand, up to the limited capacity of the pole line. Consequently the annual construction cost is comparatively, not large. In a cable, however, due to its construction, the number of circuits cannot be limited to the present need, but it is necessary to provide a large cored cable to care for future growth; and as a consequence, a greater initial investment cannot be avoided.

For the reasons mentioned, in making up the present budget for the telephone expansion project, a decision was reached to install a cable line between Tokyo and Okayama, this route being the most important of all the toll trunks. The route was divided into several divisions; and construction work has been continued since the fiscal year 1922 for each division separately so that there might be no interference with the general telephone expansion program. As a result, the portion between Tokyo and Kobe was completed this fall.

Table No. 1—Number of Troubles per 100 Km. of Telephone Wire.

YEAR.................	1916	1917	1918	1920	1921	1922	1923	1924	1925	1926	1927	Ave.
No. troubles per 100 Km. of wire...............	4.5	4.3	5.3	4.8	5.0	6.5	2.5	4.8	4.0	3.7	4.0	4.5
Duration, Hours.........	23	26	32	31	41	47	19	31	23	21	23	29

Design

Circuit. Intermediate loading coils are inserted in the cable circuit at distances of approximately 1830 meters to reduce the attenuation rate of speech current, and telephone repeater stations are employed at distances of from 100 to 150 kilometers. When the distance between two terminal stations does not exceed 400 kilometers, so-called two-wire system telephone circuits are used, each circuit consisting of two wires (a pair) of a cable and equipped with two-wire system telephone repeaters, suitably spaced. When this distance exceeds 400 kilometers, so-called four-wire system telephone circuits are used as standard, each circuit consisting of four wires (two pairs) of a cable and equipped with four-wire system telephone repeaters, suitably spaced. Thus, two-wire circuits are used between Tokyo and Nagoya; four-wire circuits between Tokyo and Kyoto, also between Tokyo and Osaka.

Speech current, attenuated in passing through a cable circuit, is amplified by telephone repeaters. It will attenuate again before reaching the receiving end, but the location of repeaters is so selected according to the length and kind of circuit that the speech will reach the terminal in such volume that it can be heard without any difficulty. Figure 1 shows the location of telephone repeaters for the main circuits between Tokyo and Kobe.

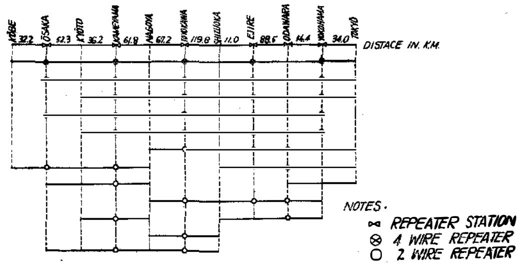

Figure 1—Layout of Toll Cable Between Tokyo and Kobe.

Cable Plan. As mentioned above in determining the number of pairs in a cable, it is necessary to take into consideration future circuit requirements. In Japan, the rate of increase of telephone lines has been very great, especially in various localities between Tokyo and Kobe; and it is thought impossible to meet all the demands for many years over ten with a single cable. Adopting the largest size allowable from the standpoint of construction and considering the status of traffic at the time of planning (1921), the number of circuits required between principal cities for the next ten years is forecast as follows:

	No. of ccts.	No. of ccts. at end of 1921
Tokyo-Osaka	54	6
Tokyo-Kyoto	6	1
Tokyo-Kobe	12	1
Tokyo-Nagoya	18	6
Tokyo-Shizuoka	12	4
Nagoya-Osaka	27	11
Nagoya-Kyoto	12	4
Nagoya-Kobe	6	0
Yokohama-Kobe	3	0
Yokohama-Osaka	6	0
Yokohama-Kyoto	3	0

In addition the number of telephone lines of shorter lengths was estimated for inclusion in the cable. It was decided to use a cable containing a total of 184 pairs of wire: 54 pairs of 1.3 mm. wire suitable for two-wire system circuits; 130 pairs of 0.9 mm. wire for four-wire system circuits and two-wire system circuits of short length. The cable is quadded, paper insulated and lead covered. (Figure 2.)

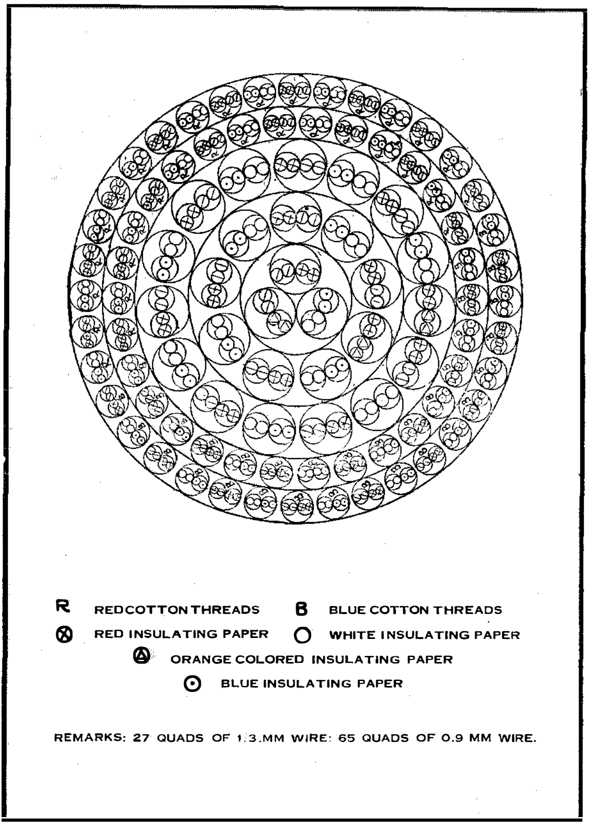

Figure 2—Cross-section of 184 Pair, Phantomed, Lead-Covered and Paper-Insulated Cable.

Loading Coil Arrangement. It is planned to equip every point of loading (i.e., each of points 1830 meters apart on the cable) with one loading coil case for 27 quads (all for two-wire system), one case for 35 quads (all for four-wire system), and one case for 30 quads (21 quads for four-wire system and 9 quads for two-wire system). The coils are designed to give the following inductance value to each conductor of a quad:

Kinds	Standard Value of Inductance Millihenrys		Remarks
	2-wire system	4-wire system	
For side cct.	177	178	Measured by A.C., 2 milliamps., 1800 cycles. Allowable limits, ±2%
For phantom cct.	107	64	

For a phantom circuit formed by each loading unit, leakage between the coils including the leads, when measured with an alternating current of 900 cycles and 2 milliamperes, is within the following limits:

Kind of Ccts.	Max. (in C.G.S. units)	Average
Between side ccts.	100	40
Between side and phantom ccts.	200	80

In the initial installation, one loading coil case for 27 quads was installed at every point of loading in each division completed, thus opening telephone traffic in the division and utilizing the completed cable as much as possible. With the completion of the cable installation between Tokyo and Kobe, loading coils for 35 quads were added, thereby opening four-wire system toll telephone traffic over lines going to Kyoto, Osaka and Kobe from Tokyo and Yokohama. When it is necessary, loading coils for 30 quads will also be added. The loading coils adopted are of the most up-to-date types used in both Europe and America with cores of compressed iron particles.[1]

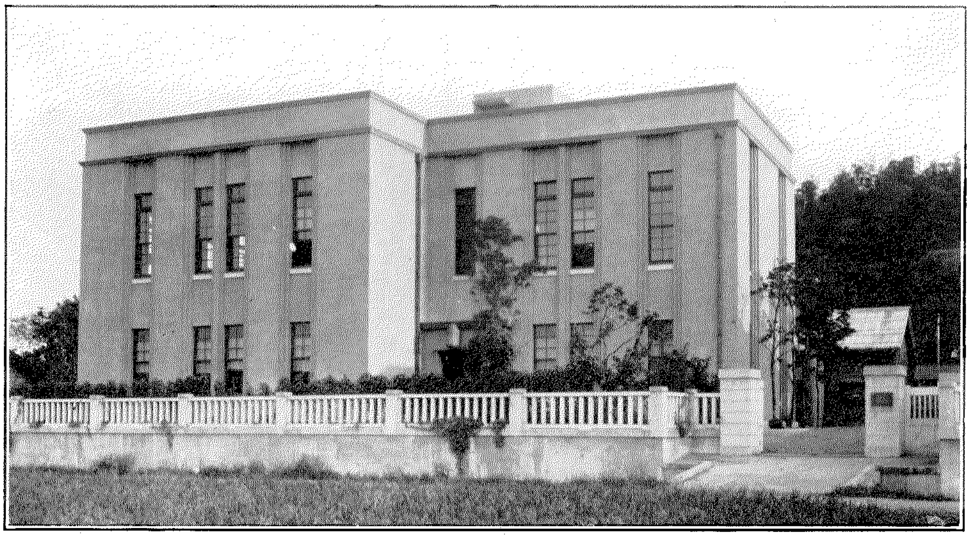

Figure 3—Repeater Station, Odawara.

Telephone Repeater Stations. The telephone repeater stations are so designed that the station buildings and the various equipment can be accommodated to the second cable line when in the future it is added between Tokyo and Osaka. Repeaters are equipped as shown by the accompanying table for the circuits needed at present, and they will be increased in number as the necessity arises.

Name of Station	Number of Repeaters		
	2-Wire System	4-Wire System	Total
Yokohama.	. .	46	46
Ashigara.	49	. .	49
Yeziri.	25	44	69
Toyokawa.	26	44	70
Kameyama.	50	44	94
Osaka.	11	45	56
Total for Six Stations.	161	223	384

The two-wire repeaters are of the newest type consisting of the usual vacuum tube two-way amplifier. It is provided with auxiliary equipment such as current supply circuits, alarm circuits, intermediate signaling circuits, etc., and is suitable for a gain of 19 tu[2]. A four-wire repeater is made up of two sets of amplifiers, each containing two vacuum tubes. One set is

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[1] For a description of this type of coil see paper, "Development and Application of Loading for Telephone Circuits," by Thomas Shaw and William Fondiller, Electrical Communication, Vol. IV, No. 4 and Vol. V, No. 1, 1926.

[2] R. V. L. Hartley, "The Transmission Unit," Electrical Communication, Vol. III, No. 1, 1924.

used for transmitting in one direction and the other set for transmitting in the opposite direction. Under normal conditions the repeater is suitable for a gain of 42 tu at 1,000 cycles per second. It is equipped with auxiliary current supply and alarm circuits, as is a two-wire repeater; and in the case of a terminal station where it is necessary to connect four-wire circuits directly with subscribers' circuits, terminal equipment is provided.[1]

In a telephone repeater station, power equipment and testing equipment are provided in addition to repeaters, as indicated above. The power equipment receives A.C. power from some outside source and converts it into D.C. power by means of a motor-generator set, charges a battery and supplies current to the repeaters. To provide for power failure, a spare generating equipment is installed. (Figures 3, 4 and 5).

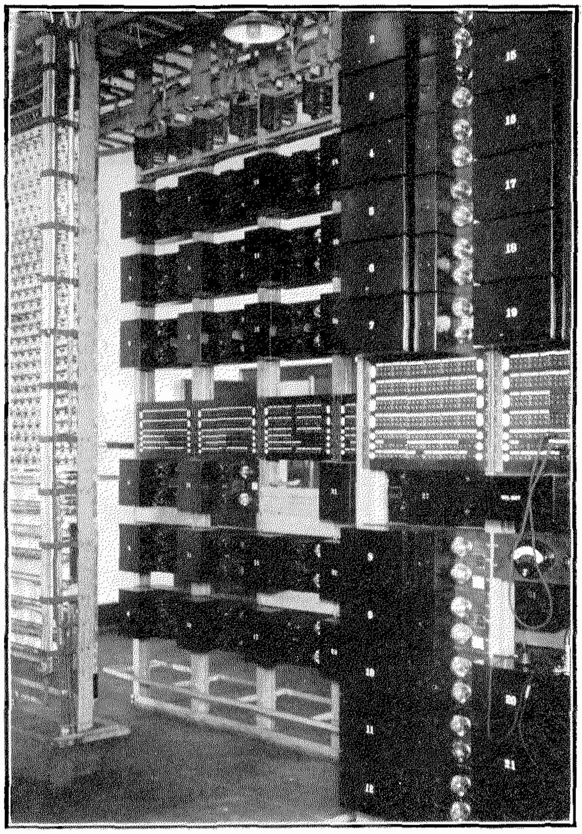

Figure 4—Repeaters, Odawara.

Construction Features and Progress

There are certain advantages and disadvantages in an underground, as compared with an overhead cable line. In various countries in Europe, underground systems are generally adopted, while in America overhead systems, as a rule, are employed.

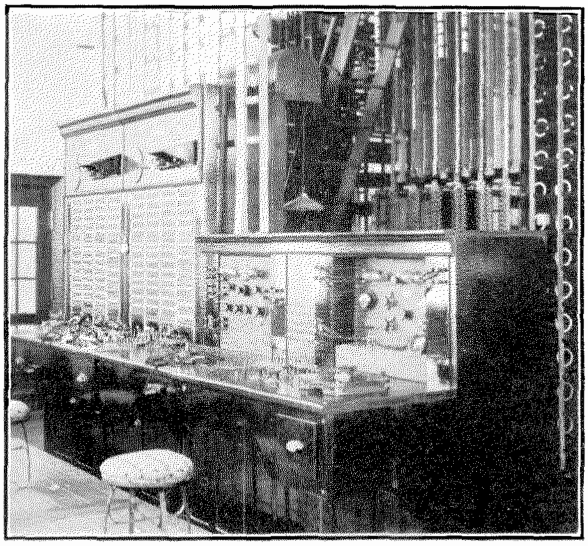

Figure 5—Repeater Station—Testing Equipment.

In Japan, after due consideration to the budget and the construction facilities, parts of sections where overhead construction should not result in trouble are made aerial while other parts employ underground construction. Thus, between Tokyo and Kobe about one-half of the cable line is placed over head and the other half, underground.

In order to provide for an additional aerial cable line in the future, the overhead parts of the system are constructed as follows:

Poles: Poles of 7.3 meter length impregnated with copper sulphate or creosote are used as standard. When the length exceeds 10 meters, steel towers are used.

Pole Spacing: Standard spacing is 30 meters and when it exceeds 70 meters the cable is suspended by a catenary line.

Suspension: A special steel stranded wire having a cross section of 65 square millimeters and tensile strength of 7,300 kilograms is used.

Towers for Loading Coils: Reinforced concrete construction is used chiefly, and in order to

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[1] "Paris-Strasbourg Cable," Electrical Communication, Vol. VI, No. 1, 1927.

allow room for six loading coils, each tower is provided with a platform 5.5 meters by 4.5 meters. (Figures 6 to 9 inclusive.)

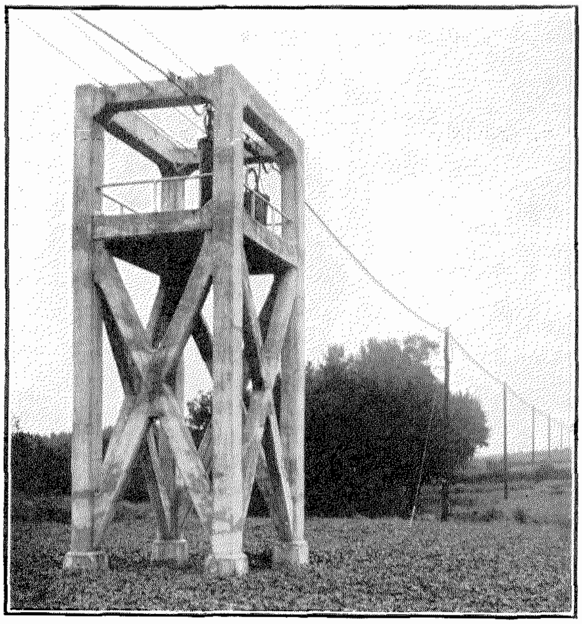


Figure 6—Reinforced Concrete Aerial Cable and Loading Coil Platform.

The underground system is constructed as follows:

A line of cast iron pipes, each having an internal diameter of 75 millimeters, is buried in places where the water line is near the surface of the earth, and in other places two-holed earthen conduits or two-holed concrete conduits are used. In case cast iron pipes are used under a paved road or in other places where access is difficult, a spare pipe line is installed. Where roads are much curved or where conduits cannot be advantageously installed, armored cables are used.

Manholes are constructed either of reinforced concrete or of bricks, and provisions are made to prevent water from entering them. In manholes, where it is necessary to place loading coils, provision is made, corresponding to the overhead line procedure, to install six in one hole by constructing it 2.6 meters long, 1.8 meters wide and 3 meters deep, internal dimensions. Manholes located in places where it is required to test the cable are constructed to internal dimensions of 1.8 meters long, 1.2 meters wide and 1.3 meters deep. Manholes in other places are constructed to smaller dimensions.

In places where the cable crosses rivers, a field investigation was made in each case to determine whether overhead or underground construction should be adopted. In some cases, steel towers were put up on both banks and in rivers, suspending the cable from catenary lines; and in other cases, special bridges for the cable were constructed, or the cable was strung along existing bridges. (Figures 10, 11, and 12.)

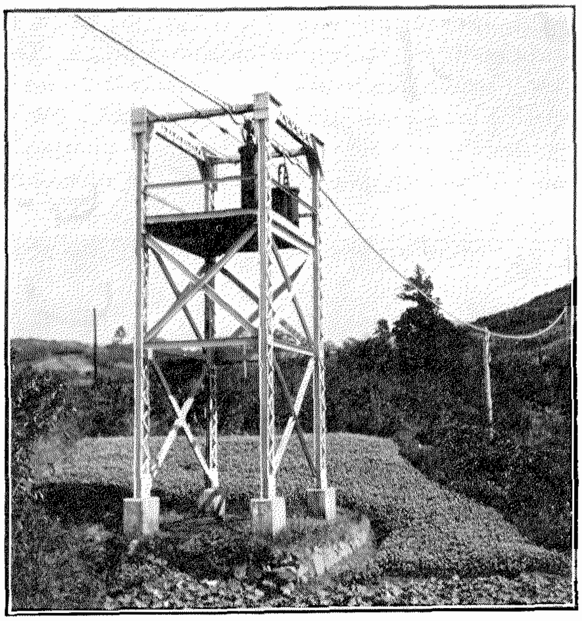


Figure 7—Structural Steel Loading Coil Platform.

Progress of Installation Work

It was initially planned to complete the construction work between Tokyo and Odawara in 1923; between Odawara and Shizuoka and between Nagoya and Kyoto in 1924; between Shizuoka and Hamamatsu and between Kyoto and Osaka in 1925; between Hamamatsu and Nagoya in 1926, and between Osaka and Kobe in 1927, thus completing a route from Tokyo to Kobe. Owing however, to the Kanto Earthquake of September, 1923, the start of work in Tokyo Teishin District was delayed. As a consequence, a part of the cables, loading coils, etc., which was purchased for the Tokyo-Odawara division and which had not been used, was installed between Nagoya and Kyoto. Traffic was thus, at first, opened in the Nagoya-Kyoto-Osaka division. Other minor changes were made in the construction schedule. Work was completed as shown in the table given below, the route between Tokyo and Kobe being finished on November 1, 1928.

In general, the cable route is selected for laying along highways; but in parallel with the latter are the telegraph, telephone, light and power lines of bare overhead construction, or railways of the Teishinsho, Government Railway Department, prefectures, or private companies. In addition, the route has the sea on one side and mountains on the other, and in some places it crosses large rivers. In view of this situation, the cable had to be laid in safe zones separated a reasonable distance from the obstacles mentioned, with each loading point spaced exactly at 1830 meters. Accordingly, in selecting the route, a careful survey was made for alternative routes. Many changes in routes were made, owing to reconstruction of highways or bridges or the building of a house. In each case, the route between two repeater stations had to be

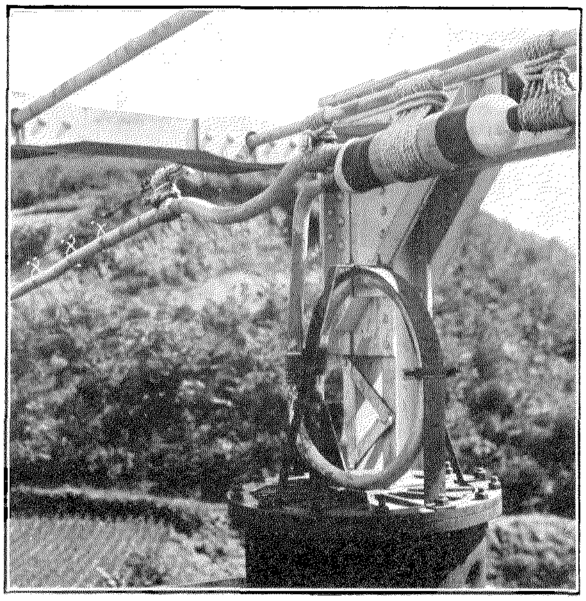


Figure 8—Cable Joint, Coil and Stub, on Loading Coil Platform.

Figure 9—Reinforced Concrete Loading Coil Hut.

Division	Length, Kilometers			Date of Completion	Remarks
	Underground	Aerial	Total		
Tokyo-Yokohama	34.0	..	34.0	Sept. 11, 1927	Yokohama Repeat. Sta. opened for traffic on Sept. 11, 1928
Yokohama-Ashigara	32.0	24.4	56.4	Nov. 21, 1926	Ashigara Repeat. Sta. opened for traffic on Nov. 21, 1926
Ashigara-Numazu	9.9	28.7	38.6	Sept. 11, 1927	
Numazu-Shizuoka	30.0	30.9	60.9	Nov. 16, 1927	Yeziri Repeat. Sta. opened for traffic on Sept. 15, 1928
Shizuoka-Mitsuke	31.0	35.5	66.5	Oct. 6, 1928	
Mitsuke-Toyokawa	14.6	38.7	53.3	July 1, 1927	Toyokawa Repeat. Sta. opened for traffic on July 1, 1927
Toyokawa-Nagoya	23.9	43.3	67.2	June 16, 1927	
Nagoya-Kameyama	16.2	45.6	61.8	Aug. 16, 1925	Kameyama Repeat. Sta. opened for traffic on Aug. 16, 1925
Kameyama-Kyoto	56.6	29.6	86.2	Aug. 16, 1925	
Kyoto-Osaka	52.3	..	52.3	Oct. 30, 1926	Osaka Repeat. Sta. opened for traffic Nov. 1, 1928
Osaka-Kobe	32.2	..	32.2	Nov. 1, 1928	
Total	332.7	276.7	609.4		

re-surveyed because of the necessity for maintaining proper spacing for the loading coils. The decision was finally made to lay the cable as follows:

Tokyo-Yokohama Section: Underground system. The cable was laid in the national highway before it was reconstructed last.

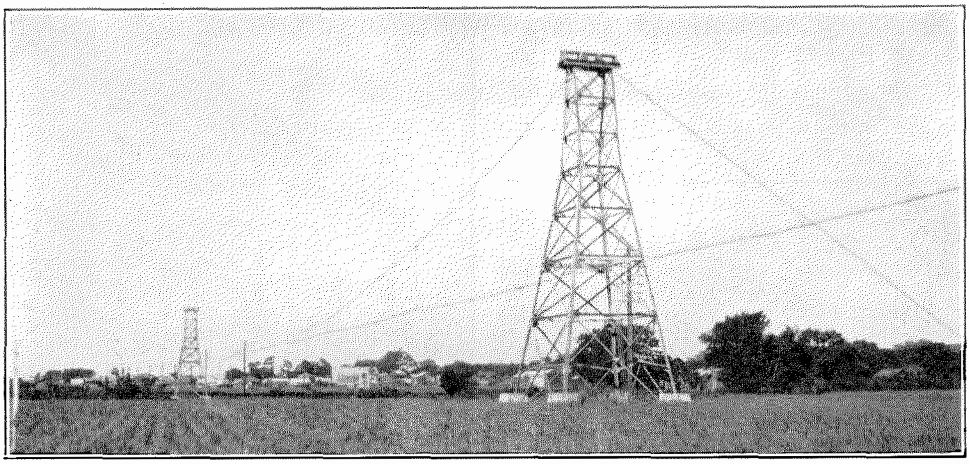


Figure 10—Steel Tower for Cable Crossing the Sakai River near Hakone.

Yokohama-Odawara Section: Partly underground in the national highway and partly overhead along it.

Odawara-Numazu Section: Since neither the old nor the new national highway in the Hakone is suitable for an underground system, the section between Hakone-Yumoto and Ashino-yu is mostly of overhead construction through Takanosu Pass; and the rest also is mostly of overhead construction, generally along the national highway.

Numazu-Shizuoka Section: The cable between Numazu and Suzukawa is mostly hung overhead along the railway; between Suzukawa and Yui it is buried underground in the national highway; between Yui and Okitsu it passes aerially over Sassui Pass; and thence, it is run to Shizuoka mostly along the national highway, partly underground and partly aerial.

Shizuoka-Tenryukawa Section: Partly underground and partly overhead along it.

Tenryukawa-Miyu Section: As it is difficult to cross Lake Hamana, the cable is laid partly underground in a prefectural highway called Old Hime-Kaido and partly overhead along it, across Honsaka Pass.

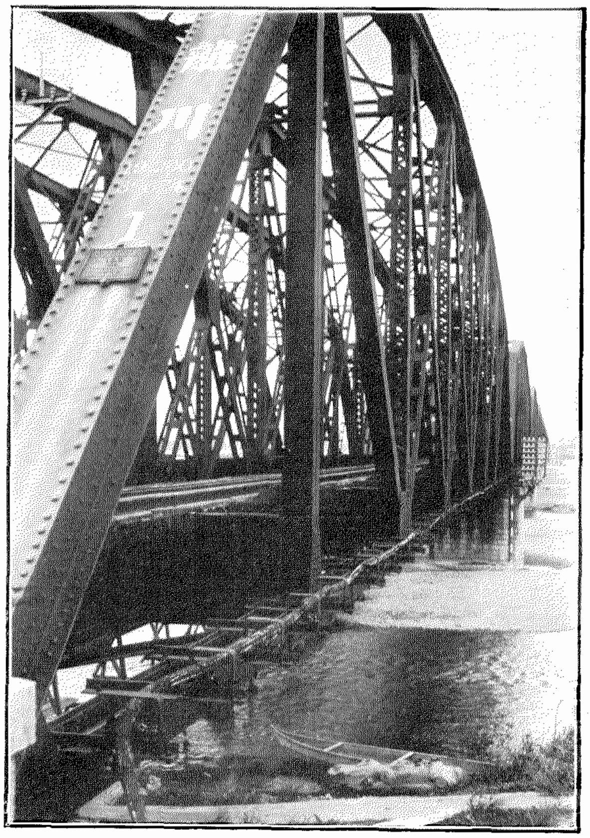


Figure 11—Armoured Cable Placed on Railroad Bridge Across the Tenryu River.

Miyu-Nagoya Section: Mostly overhead along national highway between Miyu and Okazaki, and the prefectural highway through Tenpaku between Okazaki and Nagoya; underground from city limit of Nagoya to Nagoya Station.

Nagoya-Kyoto Section: Underground within the city limit of Nagoya, and thence overhead to Seki, along the Kansai railway line; overhead along the national highway from Seki to Kusatsu through Suzuka Pass; except over the Pass where an armored cable is used; underground from Kusatsu to Kyoto.

Kyoto-Osaka Section: All underground in a prefectural highway called Old Saikoku Kaido.

Osaka-Kobe Section: All underground in the national highway lately reconstructed.

Many dangers and difficulties were encountered in the transportation and installation of the cables and loading coils inasmuch as the cable route traversed high and steep mountain paths such as Hakone, Housaka and Suzuka, and large rivers such as Akagawa, Fujikawa, Oikawa, Tenryukawa, Kisogawa, Ibigawa, Setagawa, and Yodogawa. Fortunately, the work has been completed without any serious accident.

Supply of Principal Materials

Cable.—As previously mentioned, the cable adopted is suitable for phantom working and consequently differs from suburban toll cable heretofore used in Japan for short distances, such as between subscribers in the same city or within the city boundary for lines incoming to a city. Since home manufacturers had no experience in the manufacture of the type of cable required, the part employed between Tokyo and Odawara and also between Nagoya and Osaka, totaling approximately 98,500 meters, was supplied by the Western Electric Company, U.S.A. It was found afterward, however, that the Sumitomo Electric Wire and Cable Works, Ltd., the allied Cable Company of the Nippon Electric Company, Ltd., and others, after careful researches into the method of cable manufacture, could produce cables which were not inferior to those imported. Consequently, the cable of home manufacture was adopted for the entire remaining parts, totaling 542,400 meters.

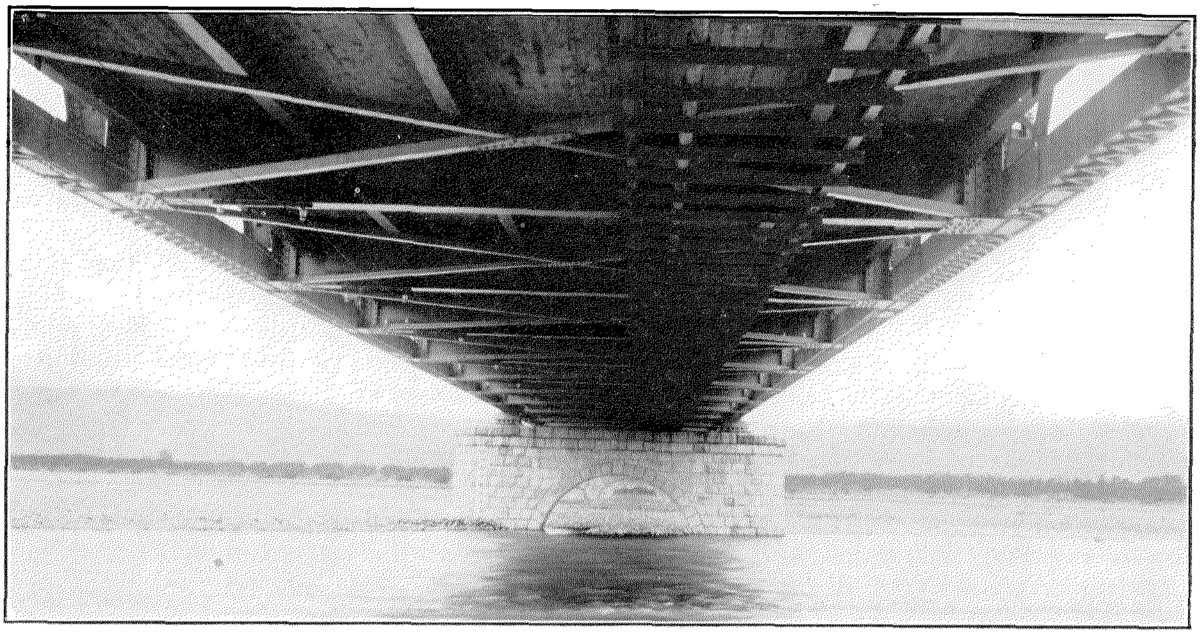


Figure 12—Toll Cable Placed Under Bridge—Oi River.

Loading Coils.—The first loading coils used were imported. Subsequently, however, the Nippon Electric Company, Limited, Tokyo, has been producing coils not greatly different from those made in the United States of America, and, they have since been purchased along with the imported product.

Between Tokyo and Kobe, 698 cases of loading coils were used. It is planned to install loading coils for 30-quad use between Tokyo and Osaka in the fiscal year of 1929.

Telephone Repeaters.—As no home manufacturer had had experience in the manufacture of telephone repeaters, all the apparatus and materials installed initially at Kameyama Repeater Station were supplied by the Western Electric Company, through the Nippon Electric Company. In subsequent installations, however, only apparatus and materials which could not be manufactured in Japan were imported. In the other cases, articles made in Japan were adopted.

Miscellaneous.—Such materials as cable hangers, used in suspending the aerial portions of the cable, hanger connectors and cable rings, estimated to be required between Tokyo and Shizuoka, were imported. Subsequently, trial supplies were ordered from home makers and, inasmuch as they proved satisfactory, the home product has since been used exclusively.

Future Plans

In view of the fact that the cable just opened for traffic between Tokyo and Kobe will, in the near future, have no spare lines because of the demand for toll telephone circuits, it is planned to install a second cable. There is a necessity also for extending the present cable in various directions within ten years (Figure 13). In the direction of the southwest it will be extended from Kobe via Okayama and Hiroshima to Shimonoseki and thence to Fukuoka and Kumamoto across the strait, branching out to Nagasaki. In this division traffic is expected to be opened in 1929 between Kobe and Okayama and also betwen Moji and Fukuoka; in 1927 traffic was opened between Fukuoka and Kurume. In the direction of the northeast the cable will be extended from Tokyo via Utsunomiya and Sendai to Aomori, thence across the strait to Hakodate, and via Odaru and Sapporo to Asahigawa. The cable between Tokyo and Koyama was scheduled for completion in 1928; the cable between Koyama and Utsunomiya, also between Odaru and Sapporo, for completion in 1929. The extension between Aomori and Hakodate was completed in 1926 by the connection of the land and submarine cables. In addition, most of the divisions considered as toll trunks, such as those from Tokyo to Matsumoto via Kofu, from Nagoya to Toyama via Gifu, Fukui and Kanazawa, from Kyoto to Fukuchiyama, from Osaka to Tanabe via Wakayama, and from Okayama to Takamatsu, will be changed over from the existing bare wire lines to cables, thus insuring safety and smoothness in telephone conversations between the all important cities of the country.

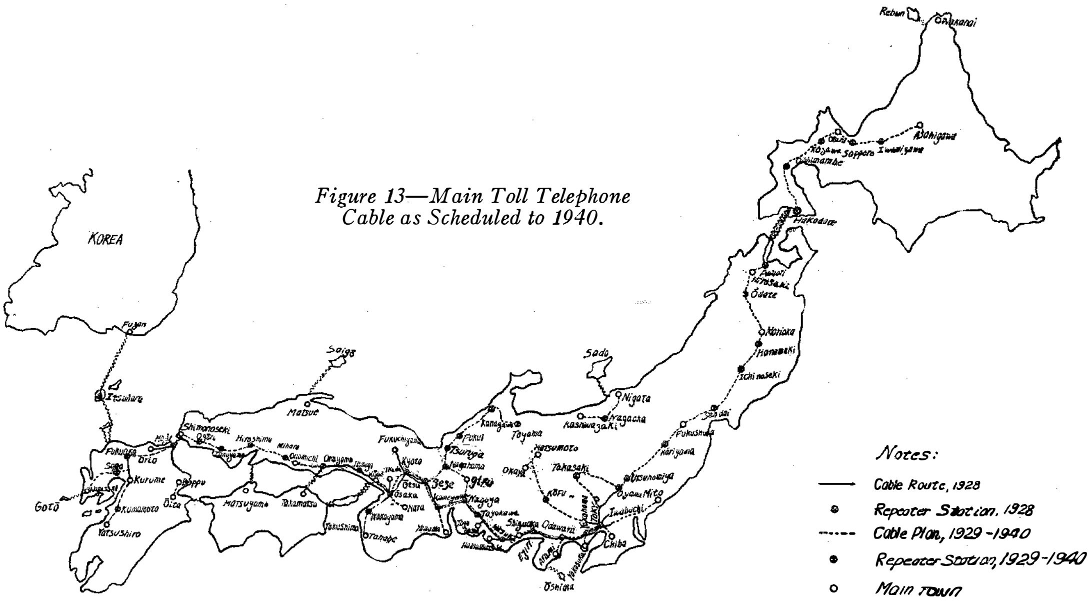


Figure 13—Main Toll Telephone Cable as Scheduled to 1940.

South American Transcontinental Telephone Circuits Connecting Argentina, Uruguay and Chile.

By F. A. HUBBARD

Assistant Chief Engineer, International Telephone and Telegraph Corporation

DURING the year 1927 the International Telephone and Telegraph Corporation acquired control of telephone properties in Argentina, Uruguay, and Chile. It obviously was desirable to provide long distance telephone service between these territories as early as possible. But natural barriers,—the Rio de la Plata in the one case, and the Andes in the other,—made the construction of such long distance lines a matter of considerable time and expense. It so happened, however, that All America Cables, Inc., another operating company of the International System, already had wires inter-connecting Buenos Aires, Montevideo and Santiago for telegraph purposes; and it was decided to investigate the possibility of superposing telephone service on these wires. These lines form part of the Company's main cable route to Buenos Aires, Rio de Janeiro and other points on the east coast of South America.

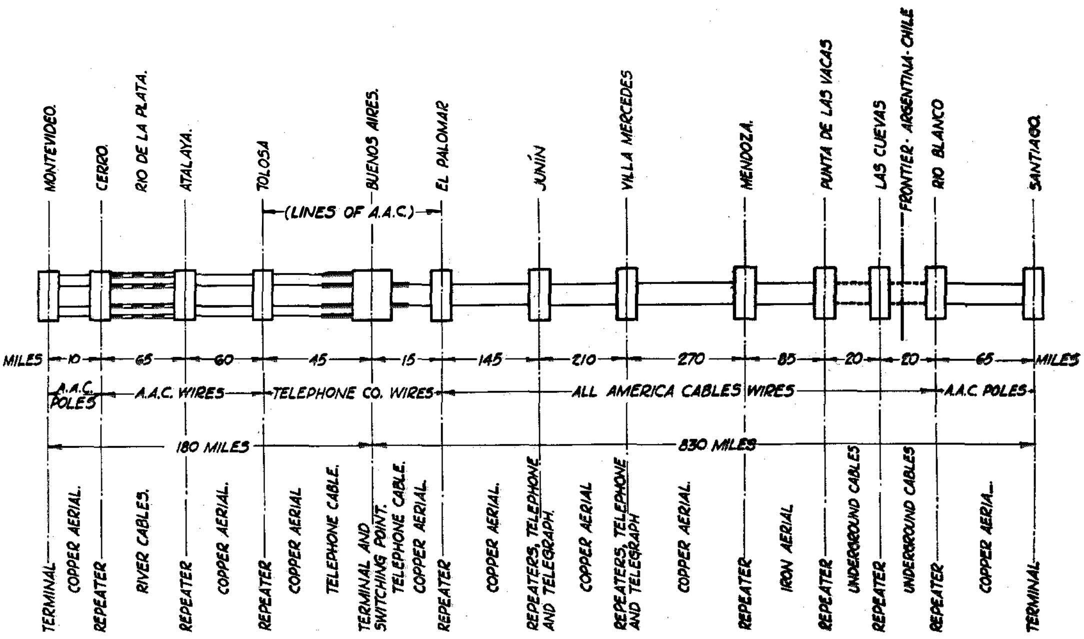
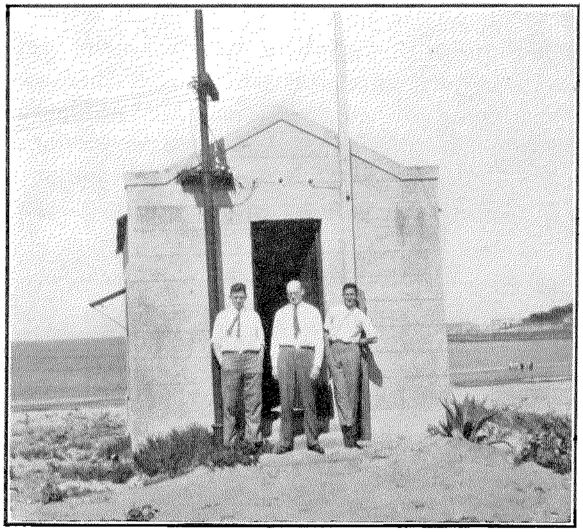


Figure 1—Layout of Transcontinental Line.

The layout of the circuit is indicated in Figure 1. Study of it showed that there were two sections that were particularly unsuited for telephone purposes,—the river cables under the Rio de la Plata, and the mountain section, particularly the 40 miles of single-conductor rubber-covered cables. A third very unpromising stretch, the entrance to Buenos Aires, was avoided by the use of Telephone Company wires, as indicated in the sketch. From Rio Blanco to Santiago a separate pair of copper wires was strung on the All America poles, thus avoiding the complication of a telegraph repeater station 20 miles from the former. For the rest, except for the short stretch from Montevideo to the cable hut, the main wires of the cable company were used.

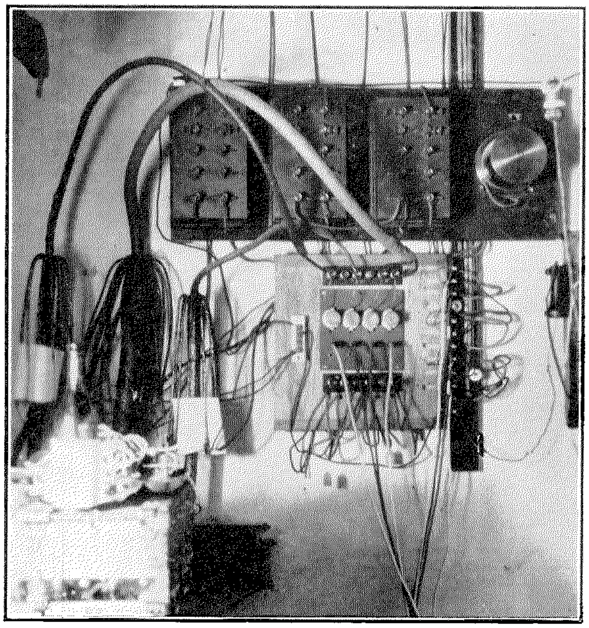
During the latter part of the year 1927 a certain amount of preliminary work was accomplished, particularly the transposition of the major part of the main line, and the assembly of certain repeater and composite equipment at Buenos Aires. It was not, however, until the middle of January, 1928, that it was possible to make a definite beginning. Since the Buenos Aires-Montevideo connection was of the first importance, and since the technical difficulties presented by the more than 65 miles of river cables,—inaccessible, of course, except at the ends,—promised to be the most severe, the most intensive part of the laboratory study was concentrated there.



Cerro Cable Hut—Rawlings, Hubbard and King.

Comparatively little work has been done on the characteristics of such cables at telephone frequencies, though some studies were made in connection with the preliminary stages of the design of the Key West-Havana telephone cables. This was described in a paper presented before the American Institute of Electrical Engineers on February 15, 1922, by Messrs. Martin, Anderegg, and Kendall, and in a mathematical study by Messrs. Carson and Gilbert, published in December, 1921, in the Journal of the Franklin Institute. The most significant fact brought out by these studies was the rapid increase in effective resistance of the sea return path with increase in frequency. This was shown to be due to a "crowding in" of the return currents around the core of the cable, which was found to force these currents into the steel armor wires and into a relatively very small cross-section of water immediately around the cable itself. It will be remembered that in view of this the Key West-Havana cables were provided with a heavy copper tape in contact with the sea water, and that the sea return resistance proved to be substantially equal to the resistance of this tape for frequencies above about 500 cycles. By the provision of this return conductor, and the addition of inductance by means of a layer of iron wire, excellent telephone circuits were produced. Naturally neither of these expedients could be applied in this case, since the cables had to be used as they were.

As indicated in the sketch, there were four cable conductors, of which two (known as No. 3 and No. 4) made up a bi-core cable, being armored together. These conductors weighed 250 lbs. to the nautical mile (about 3 millimeter



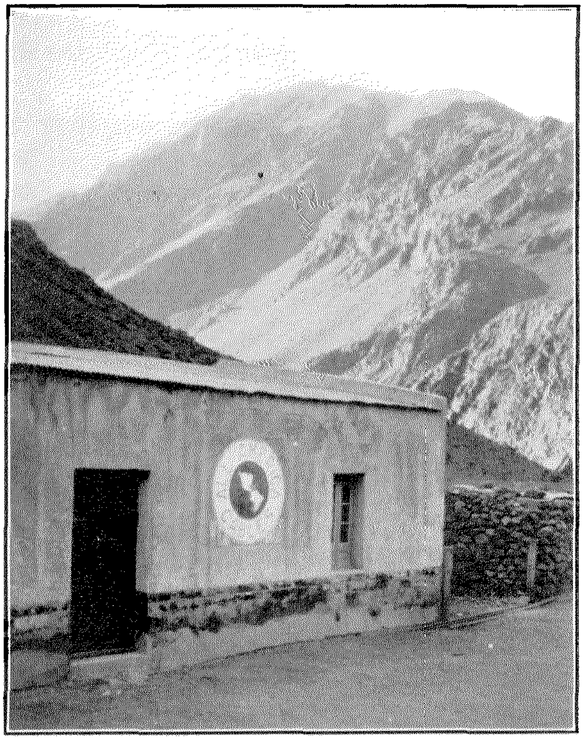
Cerro Hut Interior—Termination of River Cables.

diameter, equivalent to between No. 8 and No. 9 AWG). The capacity of each conductor to ground was in the vicinity of 0.31 microfarad per nautical mile. One of the other cables (No. 2) was approximately the same as Nos. 3 and 4, but was in an individual sheath. The other cable (No. 1) had a 600-lb. conductor, about 4.6 millimeter, No. 5 AWG. This cable had a somewhat higher capacity in the neighborhood of 0.35 microfarad per nautical mile. All the cables were provided with a thin brass tape for protection against the teredo.

The simplest solution seemed to be the use of the four conductors to form a 4-wire circuit of the ordinary type. Such a circuit would require some investigation, since no data were available on the characteristics of a metallic loop comprised of two entirely separate cables; and there might be expected some difficulties from telegraph noise, or interference with the telegraph circuits. These complications were vastly increased, however, and the simple 4-wire circuit entirely ruled out, by a decision that, if possible, two separate circuits should be provided, instead of one. The reason for this decision was the expectation that in view of the great community of interest between Buenos Aires and Montevideo, and the poor communications previously available between them, the opening of a good service would result in a volume of traffic that would speedily congest a single circuit. That this expectation was justified is shown by the fact that within six months after the opening of the service it was handling on the average more than 50 calls per working day,—a fair load for two circuits.

It was necessary, therefore, to evolve two circuits from the four conductors described. At the same time speed was of cardinal importance. It was desired to open the whole system, including the line to Chile, before the middle of the year. Many interesting investigations on the cable characteristics, therefore, had to be abandoned, and the studies limited to absolutely essential measurements and to the design and construction of amplifiers and equalizers which, if possible, should make the cables usable for telephone purpose.

The first experimental work involved determining the attenuation characteristics of all the possible combinations of cable conductors, in order to show which indicated the most promise. The attenuation of each conductor was measured with ground return, and all the possible combinations of metallic circuits were tried. The first method used was the well-known one of the open and short-circuited impedance. This proved very useful at the low frequencies but beyond 600 cycles it was valueless because the differences became extremely small. The curves were therefore extended by means of straightaway current measurements with thermocouples at the two ends, using a calibrated amplifier on the receiving end when the loss became too great for direct thermocouple measurement. The various methods showed a sufficiently close agreement for the necessities of the case.



Lineman's House and Repeater Station at Punta de Las Vacas—7,500 feet elevation.

The only one of the combinations that showed any immediate promise was the bi-core, used as a metallic circuit, and even this was none too encouraging. The bare line attenuation at 1,000 cycles was 29 decibels. This was sufficiently high, but it was considerably lower than any of the others. Also, it lacked the characteristic steep slope that all the other combinations showed, the attenuation at 2,000 cycles being only 34 db. The attenuation curve is shown in Figure 2: it resembles in shape that of an ordinary non-loaded paper-covered cable, although it was somewhat steeper, due probably to dissipation in the dielectric.

It was decided, therefore, to try a 2-wire circuit on this pair of conductors, equalizing as nearly as possible at 2,000 cycles. Fortunately, the impedance characteristic proved to be very smooth; and though the design of networks to match it presented some difficulties, on account of a reactive component decreasing with frequency, an excellent singing point was finally obtained. In fact, more trouble was experienced with the balance of the composite sets, which had to be adjusted carefully to permit advantage to be taken of the accuracy of the basic networks.

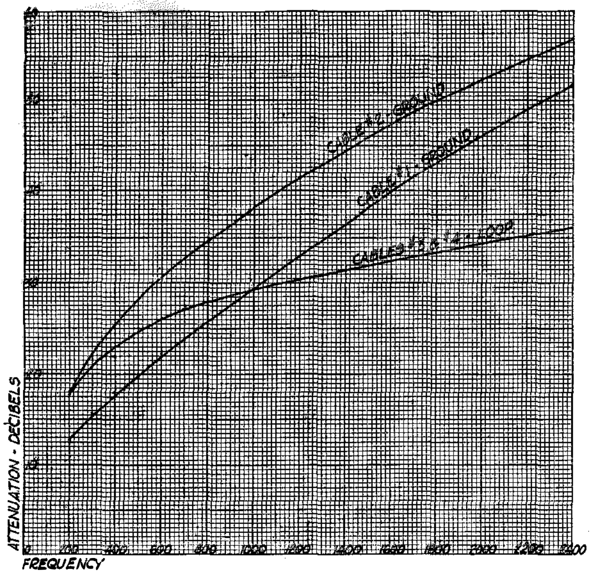


Figure 2—Attenuation of River Cables.

In order to set up a commercial circuit over this line, it was necessary to provide more gain at the ends than could be obtained from the ordinary repeaters that were available. They were therefore rebuilt to introduce a second stage on the receiving side. The possible gain when transmitting into the cable was of course limited by overloading considerations, particularly at the Montevideo end, which was only about 10 miles from the city. A total gain in each direction of about 40 db was obtained, so that the attenuation of the cable was somewhat more than offset; and the overall circuit loss between Montevideo and Buenos Aires finally proved to be about 12 db.

One satisfactory circuit being thus assured between these points, work was commenced on the line to Chile. With the necessity for an early opening of the system, and with the approach of winter, it was obviously impossible to undertake any experimental work in the mountains as had been hoped. Under these circumstances it was decided to select repeater stations arbitrarily, on the basis of estimates of probable attenuation, and to hope for the best. No great amount of actual traffic was anticipated between Chile and Buenos Aires.

Accordingly, repeaters were placed at the two ends of the cable section, which, as has been mentioned, was forty miles long, and at its middle. Fortunately, linemen's houses were located at each of these points. Others were placed as indicated in Figure 1. A great deal of trouble was anticipated with the use of the single conductor cables, since in some cases the two sides of the circuit would not even be near each other, but followed different routes,—the idea in so installing them being, of course, to provide for maximum safety against avalanches. This arrangement appeared likely to make the balancing problem extremely difficult, and to cause serious inductive interference from other telegraph circuits in the vicinity and from the electrification of the Transandine Railway on the Chilean side.

If these problems had assumed the proportions that seemed entirely likely, the whole job would have had to wait until an intensive experimental study could be made, and the layout accordingly revised. Fortunately, however,—perhaps as a compensation for some other difficulties that arose in places where they were least expected,—the tentative layout worked reasonably well from the first, and was never changed. The impedance characteristics of the peculiar cable circuits proved to be fairly smooth, and empirical networks, designed and constructed on the spot, permitted gains of 12 or 14 db at each repeater. A certain amount of power hum was noticeable, but not enough to be serious. The linemen's houses, especially the one at Las Cuevas, 10,000 feet above sea level, were not especially commodious as repeater stations, with the batteries and charging engines to be accommodated; but on the whole they did very well.

Meantime, work was resumed on the second circuit on the river cables. The metallic loop between the two remaining cables, No. 1 and No. 2, showed an attenuation of about 35 db at 1,000 cycles, which climbed steeply to over 50 db at 2,000 cycles. It is not entirely clear why the attenuation curve of this metallic circuit showed such a steep slope, substantially parallel to that of circuits with ground return. It had been hoped that the avoidance of the "crowding-in effect," together with the influence of the inductance of the loop,—since the sides of the circuit were at a distance from each other,—might result in a more favorable characteristic.

The only alternative was some form of 4-wire system, using separate lines for talking in the two directions, since in such a system the gain is not limited by conditions of balance. In this case, however, as only two conductors were available, it would be necessary to use ground return in each direction. It seemed improbable that such a system would work, because the common ground return would constitute a coupling between the incoming and outgoing sides of the circuit; and as these would be at a difference in level of over 50 db, it seemed likely that this coupling would be sufficient to establish a singing circuit through the repeaters. Still, it was hoped that the crowding-in effect, which increases so greatly the attenuation, might operate to advantage in this case by confining the return currents so closely to the sheaths of their respective cables as to prevent them from interfering with each other.

Accordingly such a circuit was made up, using cable No. 2 and its sheath for transmission from

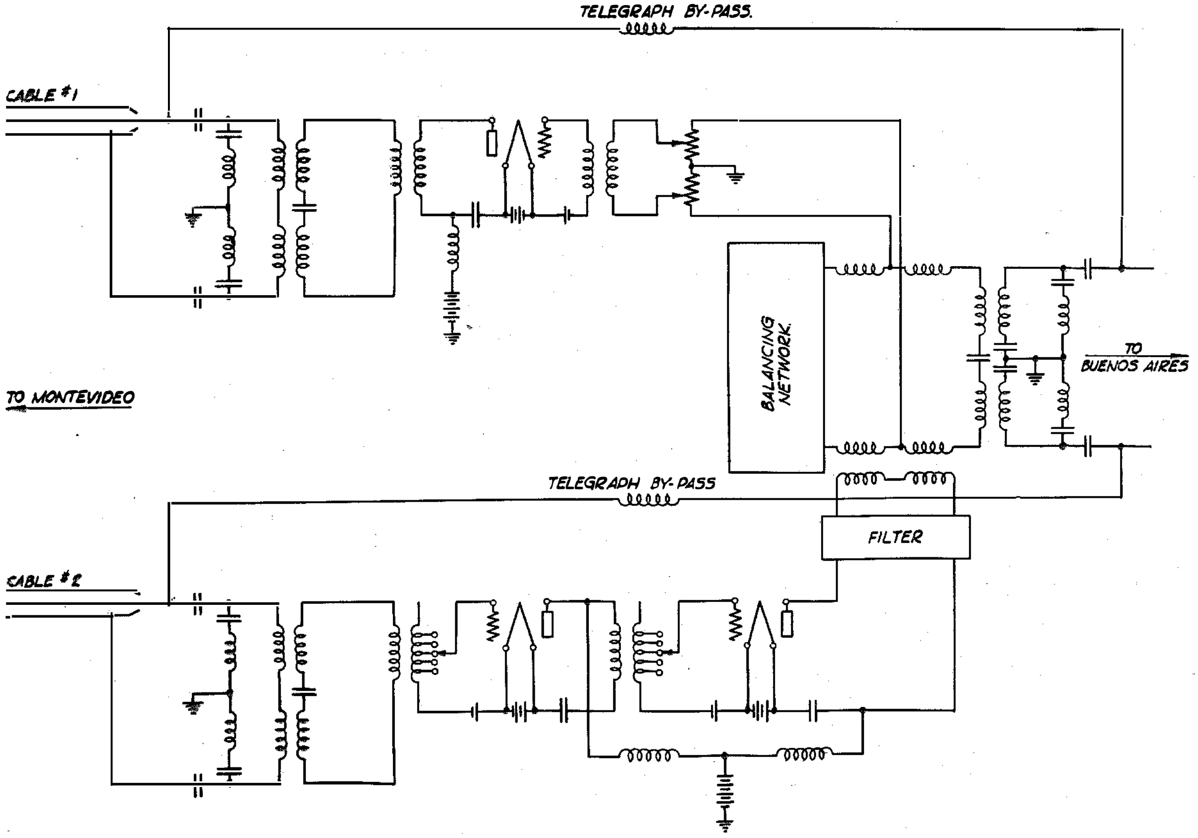


Figure 3—Schematic of 4-Wire Repeater at Atalaya.

Montevideo to Buenos Aires, and cable No. 1 and its sheath for transmission in the reverse direction. The sheath of the bi-core cable was left connected to the office grounds at the two ends, to which all the sheaths had been connected; and thus probably served as the principal return path for the telegraph currents. A simplified schematic of the repeater and composite set at one end of this unique circuit is shown in Figure 3; and the characteristics of the two cables are included in Figure 2.

The hoped-for effect actually took place. In spite of the fact that at the Argentine end the cables lay together in a trench for a quarter of a mile or more before reaching the water and separating, it was found possible to use a receiving gain of about 45 db, and a transmitting gain of about 12, without any signs of singing. The gains required at the Montevideo end were somewhat less, as the attenuation of the No. 1 cable was about 7 db less than that of No. 2, being about 46 db at 2,000 cycles, against 53 for No. 2. The gains available were thus more than sufficient to cancel the loss in the cables and composite set, giving a circuit only slightly inferior to the one first obtained on the bi-core cable.

Considerable trouble was experienced with telegraph interference from the Rio cable, which had a telegraph repeater at Atalaya, and which lay close to the Montevideo cables as far as the river. Since this was a long-distance cable, it was not possible to apply to it the noise-killing apparatus that was so effective on the other lines. It was found, however, that with the aid of the sea earth,—an auxiliary conductor armored with the main conductor, and grounded some 15 miles from shore,—the interference was entirely eliminated. The only remaining trouble was a slight amount of static noise during thunderstorms.

This was almost the only case in which severe telegraph interference was experienced. The compositing equipment, of ordinary types, eliminated most of it; and additional noise-killers, comprising retardation coils and condensers in the telegraph transmitters, took care of the rest, but they were not required in every case. There was some effect from the composite sets upon the duplex balance and the quality of the recorder signals, and certain precautions had to be taken to avoid cross-fire between the two sides of the circuit.

While the second river circuit was being worked out, the land-line repeater stations had been put in order; and on June 22, five months after starting the experimental work, the complete system was formally opened for commercial service.

Mount Tolosa with the Glaciers—Near the Head of the Pass Over the Andes.

Phase Compensation (I)
A Simple Account of Phase Compensation

By E. K. SANDEMAN

European Engineering Department, International Standard Electric Corporation

THE literature of phase compensation gives the impression that intricate mathematical processes are unavoidable in order to achieve a proper understanding of the subject. Further, there is conveyed an entirely erroneous idea of the fundamental difficulties, which actually are not very great. In practice, difficulties begin to become apparent only when special circuits are employed to reduce the total amount of apparatus required. It is therefore felt that no excuse is necessary for presenting, at this stage, a simple account of the what, why, and how of phase compensation, which will be easily comprehensible to anyone possessing an elementary knowledge of transmission theory. For simplicity, in this discussion, it will be assumed that all steady frequencies are transmitted with the same efficiency.

In an ordinary transmission line possessing the constants R, G, L, and C per unit length, the propagation constant is given by

$$p=\beta+j\alpha=\sqrt{(R+j\omega L)\ (G+j\omega C)}$$

Under steady state conditions the current at any point in the line distant l from any chosen reference point is given by

$$I=I_0e^{-(\beta+j\alpha)l}=I_0e^{-\beta l-j\alpha l}=I_0e^{-\beta l}\ \diagdown\!\overline{\alpha l}$$

where I_0 is a vector representing a sinusoidal current at the reference point. The phase of the current along the line, therefore, changes by the angle α per unit length, and if a length of line λ is chosen such that the phase change along it is 2π, i.e., so that $\lambda=2\pi$, then one complete rotation of phase has taken place, or alternatively the length of line λ contains a wave length, i.e.,

$$\lambda=\frac{2\pi}{\alpha}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Every time the current at the reference point passes through a complete cycle, which takes place f times a second, where f is the frequency, a complete wave length is launched on the transmission line. There are therefore f such wave lengths launched per second, so that each wave travels forward with the velocity:

$$V=\lambda f=\frac{2\pi f}{\alpha}=\frac{\omega}{\alpha}\ \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The velocity V defined by equation (2) gives the rate of travel of a wave crest which is part of an infinite sinusoidal wave train, whereas the telephone engineer is concerned only with the rate of travel of finite wave trains. As an example of a finite wave train any part of an ordinary speech wave may be taken.

From the principles developed by Fourier it is possible to consider a finite wave train as being made up of an infinite number of infinite sinusoidal wave trains which for all time and space have a zero resultant, except at the time and place where the finite wave train exists. The wave crests of the infinite wave trains travel with the velocity V as defined by equation (2).

In general the finite wave train does not move with the velocity V and no one velocity can be assigned to it, since, as it moves it expands or contracts along its direction of travel. The position of the finite wave train at any instant is evidently defined by the envelope of the infinite wave trains composing it. By taking the infinite wave trains in pairs contiguous in the frequency range, and considering the rate of travel of their envelopes, it is possible to arrive at a very close idea of the behaviour of any finite wave train travelling through a medium of known characteristics.

Group Velocity. In Figure 1, 1, 2, 3, etc., are the crests of an infinite sinusoidal wave train of wave length λ travelling at velocity V from the left towards the right, and a, b, c, etc., are the crests of another infinite wave train contiguous in the frequency range. If the two infinite wave trains are considered to be part of a finite wave train, not shown, then their frequencies, and so their wave lengths, will differ only by an infinitesimal amount. The wave train a, b, c may therefore consistently be considered to be of wave length $\lambda + d\lambda$ and to travel at a velocity $V + dV$ from left to right. By simple addition of the amplitudes of the two wave trains the full line curve at B is obtained, an infinite wave train whose amplitude varies periodically from maximum to minimum and vice versa. Thus an infinite train of finite wave groups becomes discernible, each identified by an indefinitely re-repeated envelope, indicated by the dotted line. The physicist is accustomed to consider the individual wave crests as being the essential entity, rather than the envelope; hence, group velocity[1] has been used for the rate of travel of such a wave system. It probably will be easier to keep in mind the idea of *envelope velocity* while using *group velocity* to mean the same thing in order to be consistent with classical theory.

The highest crest in the resultant group in Figure 1 (the crest at the middle of the group) is coincident with the two wave crests 4 and d, which are in phase with each other. The velocity of crests a, b, c, etc., *relative* to crests 1, 2, 3, etc., is dV. The time taken for crest c to overtake crest 3 is $\frac{d\lambda}{dV}$ and, when crests c and 3 become coincident the centre of the group will travel the distance λ backwards relative to crests 1, 2, 3, etc. Consequently the velocity of the group relative to crests 1, 2, 3, etc., is

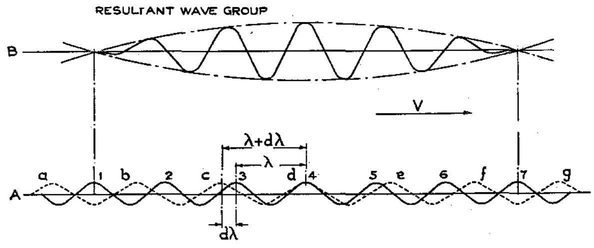


Figure 1—Wave Group.

$$-\frac{\lambda}{\frac{d\lambda}{dV}} \quad \text{or} -\lambda\frac{dV}{d\lambda}$$

and therefore the velocity γ of the group is,

$$\gamma = V - \lambda\frac{dV}{d\lambda}$$

The above proof will be found in Franklin and Termans' "Transmission Line Theory."

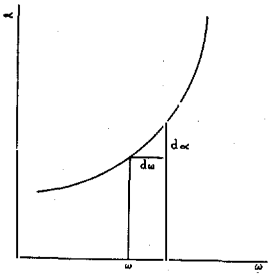


Figure 2—Phase Shift Curve.

Now consider a transmission system in which the phase shift per unit length at any frequency f is defined by the curve of Figure 2.

When ω changes to $\omega + d\omega$, the wave length changes from

$$\lambda = \frac{2\pi}{\alpha} \qquad (3)$$

to

$$\lambda + d\lambda = \frac{2\pi}{\alpha + d\alpha} \qquad (4)$$

and the velocity of propagation changes from,

$$V = \frac{\omega}{\alpha} \qquad (5)$$

to

$$V + dv = \frac{\omega + d\omega}{\alpha + d\alpha} \qquad (6)$$

Subtracting (3) from (4) and (5) from (6)

$$d\lambda = \frac{2\pi}{\alpha + d\alpha} - \frac{2\pi}{\alpha}$$

$$dV = \frac{\omega + d\omega}{\alpha + d\alpha} - \frac{\omega}{\alpha}$$

$$\therefore \frac{dV}{d\lambda} = \frac{\frac{\omega + d\omega}{\alpha + d\alpha} - \frac{\omega}{\alpha}}{\frac{2\pi}{\alpha + d\alpha} - \frac{2\pi}{\alpha}}$$

$$= \frac{\omega}{2\pi} - \frac{d\omega}{d\alpha}\frac{\alpha}{2\pi}$$

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[1] *Vide.* "Hydrodynamics," by Horace Lamb (1895 edition), p. 383; Lord Rayleigh "On Progressive Waves," Proceedings of the London Mathematical Society, 1877, p. 21. Stokes, Smith's Prize Examination, 1876.

So that,

$$\gamma = V - \lambda \frac{dV}{d\lambda}$$

$$= \frac{\omega}{\alpha} - \frac{2\pi}{\alpha}\left[\frac{\omega}{2\pi} - \frac{d\omega}{d\alpha}\,\frac{\alpha}{2\pi}\right]$$

$$= \frac{\omega}{\alpha} - \frac{\omega}{\alpha} + \frac{d\omega}{d\alpha}$$

$$= \frac{d\omega}{d\alpha}$$

Time of Travel. The time taken by any group envelope to traverse unit length of medium is therefore,

$$t = \frac{1}{\gamma} = \frac{d\alpha}{d\omega}$$

The time taken for the group envelope to traverse l units of the medium is therefore,

$$T = l\frac{d\alpha}{d\omega} = \frac{d(l\alpha)}{d\omega} = \frac{da}{d\omega}$$

if $a = l\alpha$.

Conditions for Freedom from Phase Distortion. If $\frac{a}{\omega}$ is a constant $\frac{da}{d\omega}$ isalso a constant, and each group envelope travels at the same rate and maintains its position with regard to other groups. The form of the original finite wave train is therefore preserved intact. The line OA in Figure 3 represents a system in which such a state of affairs exists.

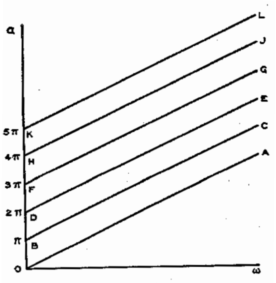

Figure 3—Distortionless Phase Shift Conditions.

The line BC represents a system in which all infinite wave trains are retarded by π in addition to being retarded in proportion to their frequency. It does not require any proof to demonstrate that the effect of this is only to reverse the sense of the received wave; it is in effect equivalent to a single commutation. The lines DE, FG, HJ and KL are respectively equivalent in effect to 2, 3, 4 and 5 commutations. Where the effect is the same as an even number of commutations, the received wave train is indistinguishable from the transmitted wave train, and where the effect is equivalent to an odd number of commutations, reversal of sense occurs.

Effect of Phase Distortion. When $\frac{a}{\omega}$ is not a constant, any finite part of each group envelope traverses the system in the time $\frac{da}{d\omega}$. The minimum value of $\frac{da}{d\omega}$ will be termed t_1. Since all group envelopes outside the finite wave train cancel one another, in the first place only that part of each group will be considered which is initially delimited by the same co-ordinates of space and time as the finite wave train under examination. This is consistent with existing practice. In general, therefore, when a finite wave train is initially applied at the transmitting end of a system, the first appearance at the receiving end occurs at time t_1 after the leading disturbance of the wave train enters the system. Similarly it is immediately evident that the received wave will continue to arrive at least until a time t_2 after the final disturbance of the finite wave train enters the system, where t_2 equals the maximum value of $\frac{da}{d\omega}$ in the pass range of the system. On this basis it is evident that the spreading out or distortion of the original finite wave train is proportional to the value of $t_2 - t_1$.

It has been found convenient to specify the tolerable amount of phase distortion in terms of the value of $t_2 - t_1$. The C. C. I.[1] has laid down that this shall not exceed 30 milliseconds. It is questionable whether this criterion is generally applicable for all types of transmission system, since it discriminates in no way between group envelopes carried by different parts of the frequency spectrum. It is, however, equally valid for all types of circuit having phase shift-frequency curves of the same form as the type of circuit on which it was originally determined by articulation tests—a long distance cable system.

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[1] Comité Consultative International.

Carson[1] has demonstrated that when a steady tone of frequency f is suddenly applied to the input of an uncompensated cable circuit, the wave builds up to one-third its final value at the receiving end after a time $= \frac{da}{d\omega}$ for the line at frequency f. The first impulse always reaches the receiving end after time t_1 referred to above. The interval from the time the first impulse arrives at the receiving end to the time the wave attains one-third its final amplitude is referred to as the time of build-up of the wave. Since in an uncompensated circuit $\frac{da}{d\omega}$ always increases with frequency, t_2 referred to above is equal to $\frac{da}{d\omega}$ for the highest frequency transmitted. It follows, therefore, that the 30 milliseconds referred to for the maximum permissible value of $t_2 - t_1$ is also the time of build-up of the highest frequency in the transmitted range. This is only true for circuits in which the dependency of the total phase angle a on frequency is substantially of the form occurring in a loaded cable circuit before phase compensation is applied. It is definitely not true after the application of phase compensation. For this reason all further reference to time of build-up has been omitted from the present account.

A secondary effect of phase distortion which is of comparatively minor importance, arises from the fact, referred to above, that each group envelope is infinite, while the effects considered up to now have only taken account of that part of each group envelope initially defined by the same co-ordinates of space and time as the finite wave train. Before traversing the system, the parts of all group envelopes lying outside the finite wave train, have a zero resultant, owing to their mutual phase relations. It is evident that when these phase relations are destroyed, the resultant will no longer necessarily be zero, and in actuality it never does reach zero, though it reaches a negligible value so quickly that for most practical purposes it may be neglected entirely.

Phase Correction. In Figure 4 the curve OAB represents the relation between phase shift a and the circular frequency ω for a hypothetical circuit. Since $\frac{a}{\omega}$ is not a constant, $\frac{da}{d\omega}$ is not a constant, and phase distortion exists.

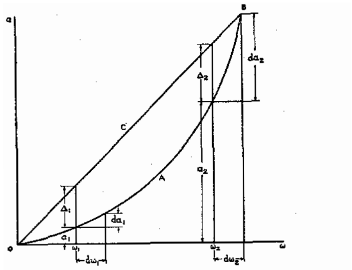

Figure 4—Phase Shift Diagram Illustrating Difference in Time Delay.

It will be assumed that it is not possible to reduce the phase shift of a system, but only to increase it. In such case the straight line OCB represents the phase shift of the distortionless system obtained by adding a minimum amount of phase shift to the system represented by OAB. A very natural error is to assume that the degree of distortion of the system OAB in the range ω_1 to ω_2, is represented by the magnitudes of the frequency ordinates intercepted between the curve OAB and the straight line OCB, eg., by Δ_1 and Δ_2. From what has gone before it is evident that such is not the case, but that with certain reservations the criterion of phase distortion in the range ω_1 to ω_2 is the quantity $\frac{da_2}{d\omega_2} - \frac{da_1}{d\omega_1}$. Its importance in phase correction lies in the fact that it is possible for the corrected curve to lie quite close to a straight line, while owing to the changes in direction of the curve the difference in its slope may be considerable. Especially is this true in long circuits where the phase shift of the highest frequency is large, and the slope of the straight line representing the ideal correction curve is therefore also large.

In the technique of phase compensation it is therefore usual to work only in terms of $\frac{da}{d\omega}$ which is referred to as the time delay, and in what follows time delay and $\frac{da}{d\omega}$ are regarded as

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[1] "The Building-up of Sinusoidal Currents in Long Periodically Loaded Lines." By John R. Carson, Bell System Technical Journal, Vol. III, No. 4, October, 1924, p. 558.

being synonymous. It is found in practice, as is to be expected from the above analysis, that time delays in different systems add directly in exactly the same way that attenuations in different systems add, and with identical limitations. For instance, if two symmetrical systems having respectively terminal impedances Z_1 and Z_2 and attenuations (image transfer constants) β_1 and β_2 at any frequency are joined together, the overall attenuation at that frequency will only equal $\beta_1+\beta_2$ if $Z_1=Z_2$, and the systems are correctly terminated at their free ends. Under the above conditions, if the time delays of each system at any frequency are t_1 and t_2 respectively, then the overall time delay at that frequency will be t_1+t_2. If Z_1 does not equal Z_2 then any suitable form of transformer, passive network or amplifier may be used to secure correct impedance matching at the junction of the two systems.

It is evident therefore that if any means exist for producing a system having any required relation between time delay and frequency, such a system may be added to any system in which the time delay varies with frequency in such a way that the overall time delay is independent of frequency. Probably the first system which suggests itself to the mind is a succession of reactive shunt and series elements. This possesses the disadvantage that its attenuation is liable to vary with frequency in an undesirable way, so that equalising networks, and probably extra amplifiers, must be added to compensate for the unwanted attenuation. Fortunately, there exists a type of structure which is capable of affording phase shift without attenuation, the lattice network, of which the two types normally used are shown in Figures 3 to 8 of the succeeding paper which discusses their design.

It will be noted that the "A" type networks contain half as many elements as the "B" type networks, and for purposes of cost computation, it is customary to work in terms of a unit type section which equals one A network or half a B network.

In general, a number of networks are inserted in cascade to form one delay network. For one hundred miles of medium heavy loaded cable (cut-off = 2,860 cycles) compensated to 2,400 cycles, between 50 and 60 unit type sections are necessary if the speech currents traverse the delay network only once.

By an arrangement due to Nyquist it is possible to cause the speech currents to traverse the same delay network twice so that the delay of the network is effectively doubled and only half as many unit type sections are required. The circuit is shown in Figure 5. The incoming currents are applied to one pair of opposite corners (1 and 2) of a Wheatstone Bridge, the four arms of which contain respectively the input to the delay network and three resistances Z_0 equal to the characteristic impedance of the delay network. The far end of the delay network may be left open or may be short-circuited. The outgoing circuit is connected to the other pair of opposite corners (3 and 4) of the bridge. A hybrid coil may be substituted for the bridge, when the same principles apply. Since the bridge is in balance for all instantaneous currents, at the moment any voltage occurs across 1 and 2 there is no voltage across 3 and 4, and no current flows into the outgoing circuit. A voltage, however, does occur across the terminals 2 and 3, the input to the delay network, and currents traverse the delay network in the direction of the arrow. On reaching the open (or short-circuited) end of the delay network, the currents are reflected and cause currents to circulate the bridge mesh, and equal voltages to appear across the terminals 1 and 2, and 3 and 4. In this way currents are supplied to the outgoing circuit, delayed by twice the delay of the network and attenuated uniformly by the bridge circuit. Provided the impedance of the incoming and outgoing circuits are each adjusted to Z_0, no further reflection occurs. The difficulty in the way of employing this circuit lies in the necessity for constructing the elements of the

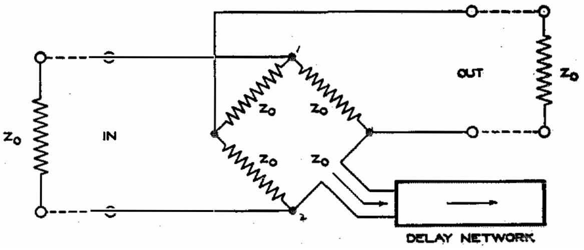

Figure 5—Nyquist Reflection Circuit.

delay network to very close limits, and on this account it is not certain that its use could be justified on a commercial scale. It has, however, been found invaluable for experimental purposes.

So many curves illustrating phase distortion and its correction have been shown from time to time that it is proposed to show here only a few typical results which serve to demonstrate the principles oulined above, and which possess a certain novelty by virtue of their imperfections.

In Figure 6 is shown a measured curve of time delay taken on two hundred miles of medium heavy loaded cable (cut-off = 2,860 cycles) and also the compensated curve of time delay obtained by adding networks as found necessary by calculation of the line time delay from the line constants (i.e., the networks were constructed before any measurements had been made on the line). The delay curve of the networks alone is shown in Figure 7, and it is interesting to note how nearly its ordinates added to the ordinates of the lower curve of Figure 6 give the ordinates of the upper curve of the latter. The irregularities on the time delay curve are due to minor reflections caused by irregularities in the elements of the delay network, the Nyquist reflection circuit having been employed to economise in the number of networks used. A delay curve taken straight through the same set of networks without the reflection circuit is completely free from any trace of these irregularities. The top curve in Figure 6 represents over compensation, and, by removing networks, the time delay curve of Figure 8 was obtained.

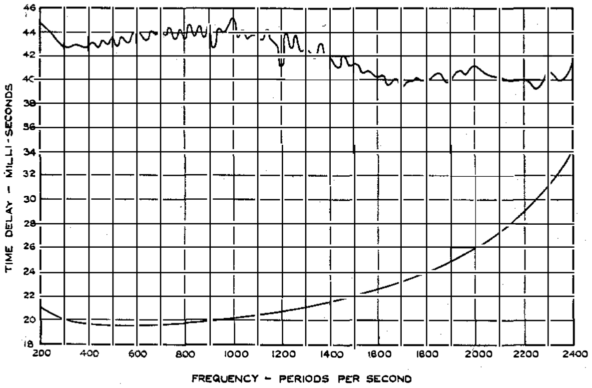

Figure 6—Time Delay Curve on Two Hundred Miles of Medium Heavy Cable Circuit and Corrected Time Delay (First Attempt).

The deviation over the range is now reduced from 14 milliseconds to 3 milliseconds. Owing to the multitude of small steep changes in time delay, which correspond to a number of resonances with small damping, such a system does not represent a distortionless one. When a finite wave train is transmitted there is a tendency for the wave to continue in a reduced but constant amplitude after the proper duration of the wave train has expired. One of the best practical results obtained is shown in Figure 9, the frequency of the intermittently applied wave being 2,000 cycles. The bottom oscillogram is the input voltage, the middle oscillogram is the voltage at the output of the uncompensated line, and the top curve is the voltage resulting at the output of the compensating networks, i.e., after the wave has traversed both line and compensating networks.

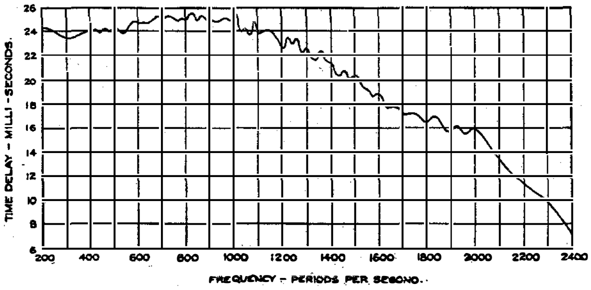

Figure 7—Time Delay Curve of Correcting Network Alone (First Attempt).

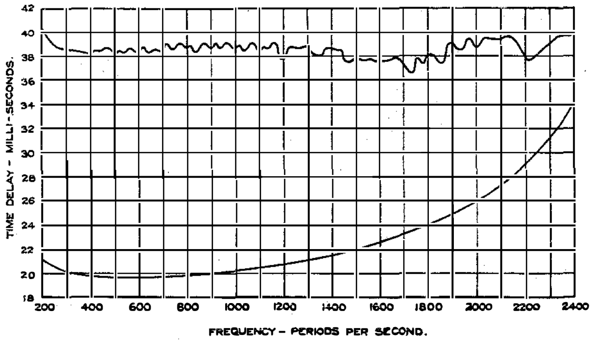

Figure 8—Overall Time Delay Curve of Line and Corrected Time Delay. (Second Attempt.)

From the above, it is evident that the technique of phase compensation is subordinate to a comparatively simple theory, and that its successful practice depends largely on the design of appropriate lattice type networks. This is dealt with in the succeeding paper.[1]

Economic Aspects. The economic aspect of phase compensation involves a series of interacting factors in different fields embracing the whole scope of the telephone art. If these factors were capable of being expressed as mutually comparable functions of determinable quantities, the problem would be simplified but still difficult. Actually such is not the case. Superficially, phase compensation enables a circuit with a relatively low cut-off frequency—and therefore *a priori* with relatively heavy loading, low attenuation and low repeater cost—to give the same performance on transients as a high cut-off circuit, having by the same reasoning high repeater cost. If the cost of phase compensation is less than the difference in cost between the high cut-off circuit, and low cut-off circuit, phase compensation would appear to be desirable. This reasoning quite neglects the fact that the high cut-off circuit is also a high velocity circuit and that therefore the echo problem does not become acute until a much greater distance is reached than with the low cut-off, low velocity circuit. Further, phase compensation may increase the time of travel by as much as 50% over a large part of the frequency range, and this does not tend to improve the echo problem. The introduction of echo suppressors introduces additional cost and increases maintenance charges. Ideally, some compromise should be arrived at by which the necessary grade of intelligibility is furnished for all lengths of circuit, and the total annual charges are a minimum. The process of arriving at this result involves not only the additional considerations of repeater spacing, repeater amplification, and cross talk, but also the size of conductor and the cable lay up, as well as, most important of all, the frequency of occurrence of circuits of different lengths.

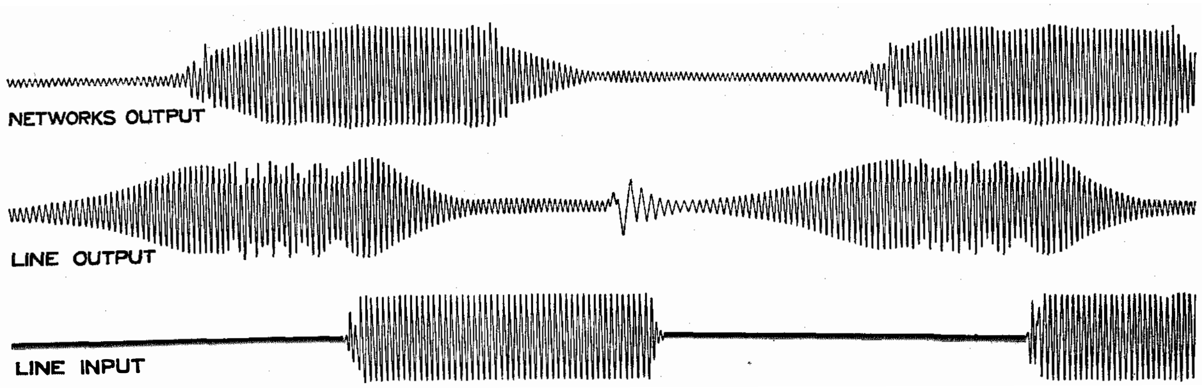

Figure 9—Oscillogram Showing Effect of Phase Distortion and Phase Compensation.

Long distance circuits run in the same cable systems as short ones. Where conflict occurs, the economic requirements of the much more common short circuits must be satisfied most completely in the final compromise, unless a very motleyed arrangement is to be tolerated.

Phase distortion is largely a result of lumped loading. Compensation would not be necessary on extra light loaded circuits, if the loading were continuous, for any realisable European circuit. Hence another factor must be considered in the field of application of phase compensation.

The exact place of phase compensation is difficult to assess, since in every case the best performance is furnished by a non-phase compensated circuit. Its introduction into commercial use appears to depend entirely on whether it can be made so cheap that the low price of the circuit using it will render relatively poorer performance tolerable.

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[1] Phase Compensation (II). Design of Phase Compen-
R. sating Networks, by A.A. Rendall.

Phase Compensation (II)
Design of Phase Compensating Networks

By A. R. A. RENDALL

European Engineering Department, International Standard Electric Corporation

FROM the principles demonstrated in the previous paper it follows that the determining factor in the consideration of phase distortion and its correction, is $\frac{da}{d\omega}$. It is the object of this paper to deduce $\frac{da}{d\omega}$ for the networks most commonly used for phase compensation. The formulæ are derived by the elementary manipulation of circuit equations.

As the first step it is necessary to know the value of $\frac{da}{d\omega}$ for the structure to be compensated over the band of frequencies efficiently transmitted. This data may be obtained either by measurement or computation. A subsequent paper describes a method of measuring $\frac{da}{d\omega}$, and an appendix to this article gives the calculation of this quantity for a loaded line of the type commonly used for long distance telephony.

Any network used for phase compensation must satisfy the following conditions:

1. The characteristics of the network must be such that a time delay frequency characteristic complementary to that of the line may be obtained.
2. The attenuation due to the network should be as small as possible and unifom over the frequency range. Networks can, of course, be designed that will equalise the cable circuit both for phase and attenuation, but this is a complication which will not be dealt with here.

The type of network which has been found most suitable for this purpose is the so-called lattice structure, shown in Figure 1.

This structure and its equivalent forms fulfill the conditions laid down. As will be shown, provided Z_1 and Z_2 are inverse networks, i.e., $Z_1Z_2 = Z_R^2$, and each are pure reactances, the iterative impedance of the structure is a pure resistance and its attenuation is zero throughout the frequency range. When the elements are dissipative, as they must be in practice, the characteristics depart from the ideal, but not by amounts large enough to cause any serious departure from their theoretical performance.

The system of Figure 1 may be replaced by that of Figure 2.

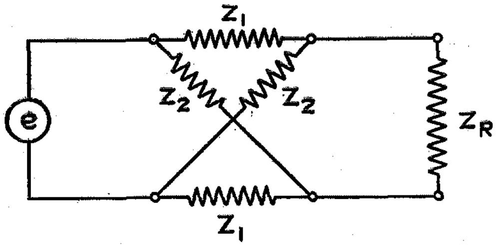

Figure 1—Lattice Network.

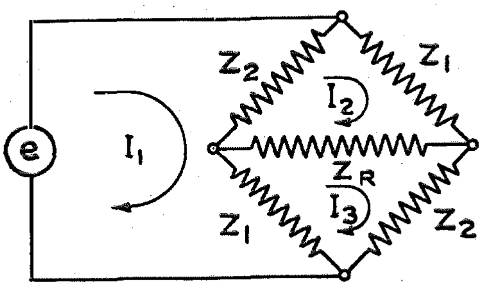

Figure 2—Lattice Network—Bridge Form.

Writing down the equations for the meshes:

$$e = (I_1 - I_2)\ Z_2 + (I_1 - I_3)\ Z_1 \ldots\ldots\ldots\ldots \quad (1)$$

$$0 = I_2\ Z_1 + (I_2 - I_3)\ Z_R + (I_2 - I_1)\ Z_2 \ldots\ldots \quad (2)$$

$$0 = I_3\ Z_2 + (I_3 - I_2)\ Z_R + (I_3 - I_1)\ Z_1 \ldots\ldots \quad (3)$$

Hence,

$$e = I_1\ (Z_1 + Z_2) - I_2\ Z_2 - I_3\ Z_1 \ldots\ldots\ldots\ldots \quad (4)$$

$$0 = -I_1\ Z_2 + I_2\ (Z_1 + Z_2 + Z_R) - I_3\ Z_R \ldots\ldots \quad (5)$$

$$0 = -I_1\ Z_1 - I_2\ Z_R + I_3 (Z_1 + Z_2 + Z_R) \ldots\ldots \quad (6)$$

Adding equations (2) and (3) we get:

$$0 = -I_1\ (Z_1 + Z_2) + I_2\ (Z_1 + Z_2) + I_3\ (Z_1 + Z_2) \ldots (7)$$

Consider first the case when Z_1+Z_2 is not equal to 0,

then

$$I_1=I_2+I_3 \quad \ldots\ldots (8)$$

Substituting in (4) and (5) we get:

$$e=I_1\,Z_2+I_2\,(Z_1-Z_2) \quad \ldots\ldots (9)$$

$$0=-I_1\,(Z_2+R)+I_2\,(Z_1+Z_2+Z_R) \quad \ldots\ldots (10)$$

Eliminating I_2 and substituting $Z_R{}^2$ for $Z_1\,Z_2$

$$e\,(Z_1+Z_2+2Z_R)=I_1\,(Z_R\,Z_2+Z_RZ_1+2Z_R{}^2) \quad \ldots\ldots (11)$$

$$e=I_1\,Z_R$$

or $$\frac{e}{I_1}=Z_0=Z_R \quad \ldots\ldots (12)$$

Where Z_0 is the input impedance of the network.

Substituting for I_1 in (9):

$$e=\frac{e}{Z_R}Z_2+I_2\,(Z_1-Z_2) \quad \ldots\ldots (13)$$

from which

$$I_2=e\frac{Z_R-Z_2}{Z_R(Z_1-Z_2)} \quad \ldots\ldots (14)$$

$I_3=(I_1-I_2)$ from equation (8) ……(15)

$$=e\frac{Z_1-Z_R}{Z_R(Z_1-Z_2)} \quad \ldots\ldots (16)$$

Current in $Z_R=I_R=I_2-I_3$

$$=e\frac{Z_1+Z_2-2Z_R}{Z_R(Z_1-Z_2)} \quad \ldots\ldots (17)$$

∴ Current ratio

$$=\frac{I_1}{I_R}=\frac{Z_1-Z_2}{Z_1+Z_2-2Z_R} \quad \ldots\ldots (18)$$

Now $Z_1\,Z_2=Z_R$.

Therefore $$\frac{I_1}{I_R}=\frac{(\sqrt{Z_1}-\sqrt{Z_2})\,(\sqrt{Z_1}+\sqrt{Z_2})}{(\sqrt{Z_1}-\sqrt{Z_2})^2}$$

$$=\frac{(\sqrt{Z_1}+\sqrt{Z_2})}{(\sqrt{Z_1}-\sqrt{Z_2})}$$

on multiplying top and bottom by

$$(\sqrt{Z_1}+\sqrt{Z_2})$$

$$\frac{I_1}{I_R}=\frac{(Z_1+Z_2+2Z_R)}{Z_1-Z_2} \quad \ldots\ldots (19)$$

Now if Z_1 and Z_2 are pure reactances, let $Z_1=jX_1$ and $Z_2=jX_2$ such that

$$\sqrt{X_1\,X_2}=Z_R=K.$$

Hence, $$\frac{I_1}{I_R}=\frac{j(X_1-X_2)+2K}{j(X_1+X_2)} \quad \ldots\ldots (20)$$

$$=\frac{(X_2-X_1)-2jK}{(X_1+X_2)}$$

Hence $(\text{Modulus})^2$

$$=\frac{(X_2-X_1)^2-(2jK)^2}{(X_1+X_2)^2}$$

$$=\frac{(X_2+X_1)^2}{(X_1+X_2)^2}$$

Modulus = 1.

$$\text{Angle of Current Ratio}=\mathrm{Tan}^{-1}\frac{2K}{X_2-X_1}$$

But $X_2=\dfrac{K^2}{X_1}$

$$\therefore \text{Angle}=\mathrm{Tan}^{-1}\frac{2KX_1}{K^2-X_1{}^2}.$$

Hence

$$\frac{I_1}{I_R}=1\,\underline{\Big|\;\mathrm{Tan}^{-1}\frac{2KX_1}{K^2-X_1{}^2}} \quad \ldots\ldots (21)$$

$$=1\,\underline{\Big/\;\mathrm{Tan}^{-1}\frac{2\dfrac{X_1}{K}}{1-\dfrac{X_1{}^2}{K^2}}} \quad \ldots\ldots (22)$$

$$=1\,\underline{\Big/\;2\,\mathrm{Tan}^{-1}\frac{X_1}{K}}=1\,\underline{\big/\,\alpha} \quad \ldots\ldots (23)$$

Where α is the angle through which the current is rotated in passing through the network.

The above reasoning holds for all cases except when $X_1=-jX_2$. However, it may be shown that the final equations hold also for this case.

Case $Z_1+Z_2=0 \quad Z_1=jX \quad Z_2=-jX$

$$X^2=Z_R{}^2$$

Substitute in equations (4) and (5),

$$e=jXI_2-jXI_1 \quad \ldots\ldots (24)$$

$$0=jXI_1+Z_RI_2-Z_RI_3 \quad \ldots\ldots (25)$$

Multiply (24) by Z_r and (25) by jX and subtract

$$\frac{e}{I_1}=\frac{X^2}{Z_R}=Z_R=Z_0 \quad \ldots\ldots (26)$$

Substituting for X in (25),

$$-jZ_RI_1=Z_R(I_2-I_3)$$

or
$$I_1=j(I_2-I_3).$$

Now I_2-I_3 is the current in the output impedance Z_R.

Therefore $$\frac{I_1}{(I_2-I_3)}=j \qquad (27)$$

This signifies that the attenuation is zero and that the phase angle is $\frac{\pi}{2}$. Now equation (26) agrees with (12) and putting $X_1=K$ in (23) gives,

$$\frac{I_1}{I_R}=1\,\underline{\big|\tfrac{\pi}{2}}$$

Therefore equation (23) holds for all cases.

From equation (23) the $\frac{d\alpha}{d\omega}$ for the network can readily be derived. It will be noted that as in the previous article $\frac{d\alpha}{d\omega}$ is used to indicate that quantity for unit length, $\frac{da}{d\omega}$ signifies the total $\frac{d\alpha}{d\omega}$ for any length. One section of network is here taken as unit length.

Equation (23),

$$\tan\frac{\alpha}{2}=\frac{X_1}{K}$$

$$\therefore\ \frac{d\alpha}{dX_1}=\frac{\frac{2}{K}}{1+\frac{X_1^2}{K^2}} \qquad (28)$$

or
$$\frac{d\alpha}{dX_1}=\frac{2K}{K^2+X_1^2} \qquad (29)$$

The simplest form of lattice network is that given by an inductance in the series arm and the equivalent inverse network, a condenser, in the cross arms. The only other type of practical importance is that which has resonance in the series arm and a shunt resonance in the cross arms.

The series and cross arms of the networks can be substituted one for the other without affecting the electrical properties of the network. This change may be imagined to be accomplished by a physical twisting of the network. Hence the A type networks, shown in Figure 3, 4, and 5 are mutually equivalent forms as are also the B type networks of Figures 6, 7, and 8.

Throughout this discussion the single element networks of Figures 3, 4, and 5 will be designated A type and the two element networks of Figures 6, 7, and 8, B type.

A Type Networks.

$$Z_1=jX_1=j\omega L \qquad (30)$$

$$Z_2=jX_2=\frac{1}{j\omega C} \qquad (31)$$

Now $\sqrt{Z_1Z_2}$ must equal K for all frequencies. This is accomplished in this case if $\sqrt{\frac{L}{C}}=K$.

From (29),

$$\frac{d\alpha}{dX_1}=\frac{2K}{K^2+X_1^2}$$

From (30),

$$\frac{dX_1}{d\omega}=L.$$

$$\therefore\ \frac{d\alpha}{d\omega}=\frac{2KL}{K^2+\omega^2L^2} \qquad (32)$$

It will be noted that L and K completely define the A type section.

Figure 9 gives a family of curves relating $\frac{d\alpha}{d\omega}$ to frequency for different values of L, assuming K = 700 ohms.

B Type Networks.

$$Z_1=jX_1=\frac{1-\omega^2L_1C_1}{j\omega C_1} \qquad (33)$$

$$Z_2=-jX_2=\frac{j\omega L_2}{1-\omega^2L_2C_2} \qquad (34)$$

If the resonant frequency for the series and cross arms is the same then,

$$L_1\,C_1=L_2\,C_2 \qquad (35)$$

and $$Z_2=\frac{j\omega L_2}{1-\omega^2L_1\,C_1} \qquad (36)$$

A TYPE

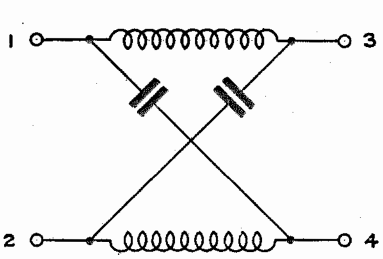

Figure 3—Alternative Forms of A Type Networks.

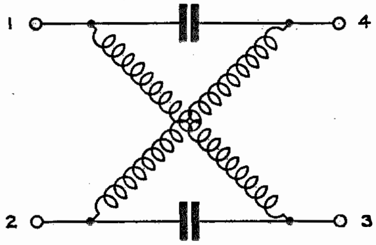

Figure 4—Alternative Forms of A Type Networks.

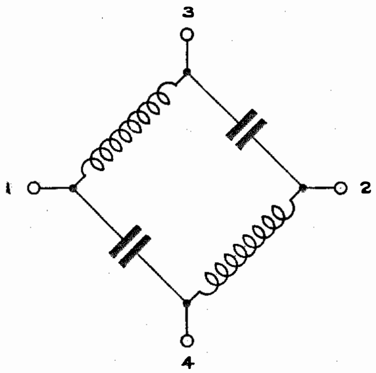

Figure 5—Alternative Forms of A Type Networks.

B TYPE

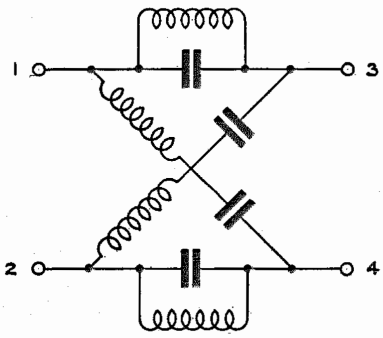

Figure 6—Alternative Forms of B Type Networks.

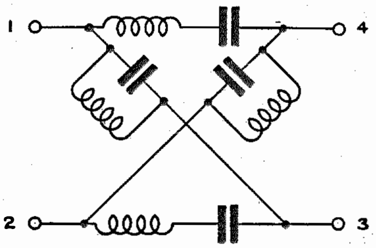

Figure 7—Alternative Forms of B Type Networks.

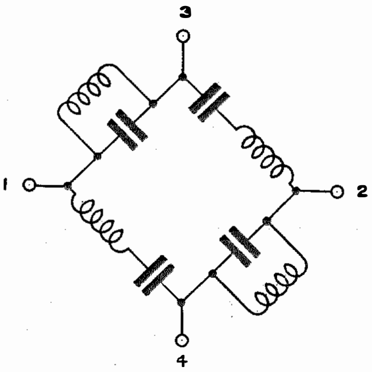

Figure 8—Alternative Forms of B Type Networks.

$$\therefore Z_1 Z_2 = \sqrt{\frac{L_2}{C_1}} = \sqrt{\frac{L_1}{C_2}} = K \quad \ldots\ldots\ldots\ldots (37)$$

If we define the resonant frequency by ω_0 then,

$$\omega_0^2 L_1 C_1 = 1 \quad \ldots\ldots\ldots\ldots (38)$$

$$\omega_0^2 L_2 C_2 = 1 \quad \ldots\ldots\ldots\ldots (39)$$

$$\text{If } \frac{\omega}{\omega_0} = n \quad \ldots\ldots\ldots\ldots (40)$$

$$\text{then} \quad \omega^2 L_1 C_1 = \omega^2 L_2 C_2 = n^2 \quad \ldots\ldots\ldots\ldots (41)$$

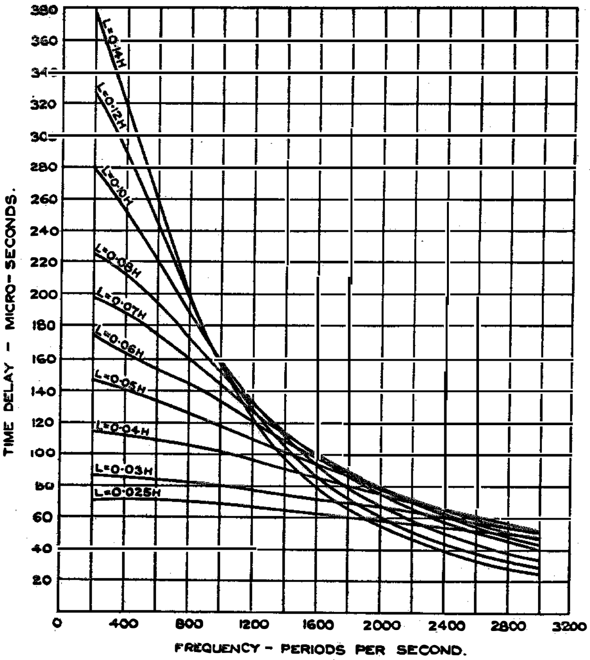

Figure 9—Delay-frequency Characteristic—A Type Networks.

$$\text{From (28)} \quad \frac{d\alpha}{dX_1} = \frac{\frac{2}{K}}{1+\frac{X_1^2}{K^2}} \quad \ldots\ldots\ldots\ldots (42)$$

$$X_1 = \omega L_1 - \frac{1}{\omega C_1}$$

$$\frac{dX_1}{d\omega} = L_1 + \frac{1}{\omega^2 C_1}$$

$$= \frac{\omega^2 L_1 C_1 + 1}{\omega^2 C_1} \quad \ldots\ldots\ldots\ldots (43)$$

$$\frac{d\alpha}{d\omega} = \frac{\frac{2}{K}\,\frac{(\omega^2 L_1 C_1 + 1)}{\omega^2\, C_1}}{1+\left[\frac{\omega^2 L_1 C_1 - 1}{\omega C_1}\right]^2 \frac{1}{K^2}} \quad \ldots\ldots (44)$$

$$\frac{d\alpha}{d\omega} = \frac{\frac{2}{K}\,\frac{\omega^2 L_1 C_1 + 1}{\omega^2 C_1}}{1+\frac{(n^2-1)^2}{\omega^2 C_1^2 K^2}}$$

$$\text{Since } K = \sqrt{\frac{L_2}{C_1}},$$

$$\frac{d\alpha}{d\omega} = \frac{2\sqrt{\frac{C_1}{L_2}}\,.L_1\,\frac{(\omega^2 L_1 C_1 + 1)}{\omega^2 L_1 C_1}}{1+C_1\frac{(n^2-1)^2}{\omega^2 C_1^2 L_2}}$$

$$= \frac{2\sqrt{C_1 L_1}\,\sqrt{\frac{L_1}{L_2}}\;\frac{(n^2+1)}{n^2}}{1+\frac{L_1}{L_2}\;\frac{(n^2-1)^2}{\omega^2 L_1 C_1}}$$

$$\text{Let } m = \sqrt{\frac{L_1}{L_2}} \text{ we get}$$

$$\frac{d\alpha}{d\omega} = \frac{\frac{2}{\omega_0}\, m\left(1+\frac{1}{n^2}\right)}{1+m^2\frac{(n^2-1)^2}{n^2}} \quad \ldots\ldots\ldots\ldots (45)$$

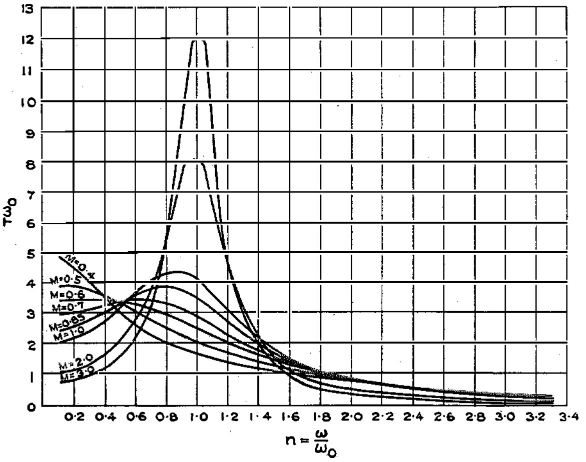

Figure 10—Delay-frequency Characteristic—B Type Networks

It will be seen that K, m, and w_0 completely define the B type networks just as K and L define the A type networks.

Figure 10 plots a family of curves for $\frac{d\alpha}{d\omega} . \omega_0$

against n for different values of m. Thus $\frac{d\alpha}{d\omega}$ does not depend upon K but for physical realisation of the network a value must be assigned to this constant, which is the iterative impedance of the network. $\frac{d\alpha}{d\omega}\omega_0$ is plotted for convenience as this quantity depends on m and n only. For any particular network the value of ω_0 is determined by the frequency at which the maximum value of $\frac{d\alpha}{d\omega}$ is required to occur. Dividing the ordinates of the curve by ω_0 gives $\frac{d\alpha}{d\omega}$ in seconds.

Figure 11 shows the typical $\frac{d\alpha}{d\omega}$ curve for a loaded line. It is evident that if networks have to be added to build up this curve to a straight line, then the $\frac{d\alpha}{d\omega}$ characteristic for the compensating networks must be of the form shown on the lower half of Figure 11. It is further evident that by adding certain sections of type A network and others of type B, such a curve could be arrived at. The fitting in of these networks is largely by "cut and try," but experience leads rapidly to a comprehension of the behaviour of the networks.

As an example, the structures designed for the phase correction of the London-Fenny Stratford loop (186 miles M.H.L. circuit) circuit are given.

The particulars of this circuit are as follows:

Loading coil inductance . . = 0.177 henrys.
Loading coil spacing...... = 1.13 miles.
Loading section capacity = 0.07 microfarads.
Cut-off frequency........ = 2,860 cycles/sec.

SUMMARY OF NETWORKS USED

Reference No.	No. of Sections	Type	L_1 Henry	m	f_0
1	32	A	.1 H	....	....
2	16	B	....	.85	1200
3	4	B	....	4	2080
4	4	B	....	3	1700
5	10	B	....	.7	1100
6	1	B	....	2.5	1400

The constants of the B type networks in terms of m, f, and K follow from the definitions of these parameters.

$$C_2 = \frac{m}{\omega_0 K} \qquad L_2 = C_2 \frac{K^2}{m^2} \qquad L_1 = L_2 m^2$$

$$C_1 = \frac{C_2}{m^2}$$

The actual time delay occasioned by these networks can be calculated from equations (42) and (55). In the appendix, the values of time delay shown below are given for the circuit.

The following table illustrates the correction in time delay due to the addition of the networks referred to above.

It will be seen that the delay distortion of the cable circuit has been reduced from 14.5 to 2 milliseconds in the range 400-2,400 p.p.s. by the addition of phase compensating networks. To accomplish this, 32 type A and 35 type B networks were required. Since a type B network contains twice as many components as a type A, and consequently costs twice as much, the expenditure on phase compensation can be conveniently expressed in terms of type A sections, or "unit sections."

Hence 102 unit sections were required to compensate the 186 miles of M.H.L. circuit or

Delay in Milliseconds for Following Frequencies:

System	400	800	1200	1600	2000	2200	2400
32 No. 1 Networks	8.06	6.04	4.24	3.00	2.18	1.92	1.64
16 No. 2 Networks	5.84	7.78	7.26	4.48	2.76	1.92	1.60
4 No. 3 Networks	.16	.26	.50	1.44	3.10	2.32	.78
4 No. 4 Networks	.30	.52	1.24	4.32	1.96	1.08	.64
10 No. 5 Networks	4.52	4.80	3.70	2.24	1.44	1.16	.94
1 No. 6 Networks.	.11	.25	.90	.67	.20	.12	.08
186 Miles M.H.L. side	19.5	19.8	20.6	22.50	26.00	29.00	34.00
Total delay	38.49	39.45	38.44	38.65	37.64	37.52	39.68

54 per 100 miles of circuit (approximately a repeater section).

The number of sections required to effect a given degree of phase compensation on any given circuit can be approximately arrived at by calculation.

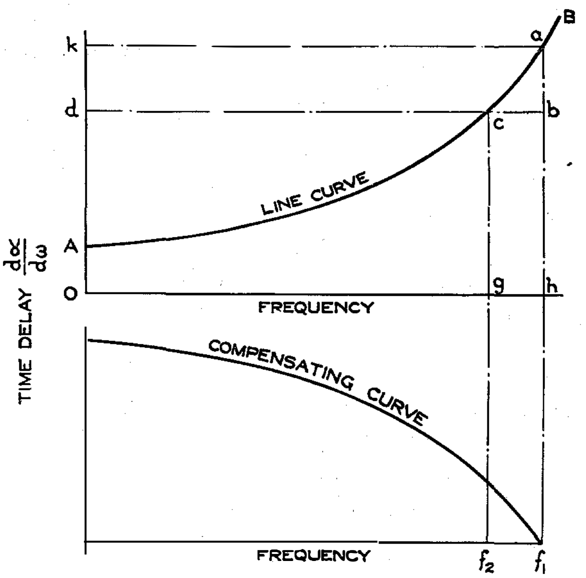

Figure 11—Delay and Compensating Frequency Characteristic for a Lumped Loaded Line.

In Figure 11, AB is the time delay characteristic of the circuit to be corrected. If f_1 is the highest frequency efficiently transmitted, then the curve Aa must be built up to ka if the circuit is to be completely equalised for delay. Thus networks must be provided which will fill in the area Aak.

Assume that the circuit need not be absolutely equalised but that some phase distortion t is admissible. Let ab equal t, and then let perpendiculars bd, bh and cg be drawn. Then if we phase compensate so that the ordinates are built up to the line cd, the amount of distortion will be ab, the permissible margin, up to the frequency f_1. Compensation will be complete up to some frequency f_2, less than f_1. Consequently, the actual effect of the permitted distortion is that compensation has to be carried to a lower frequency f_2 which can be described as the effective frequency limit of compensation. In this case the area Acd is that to be compensated.

If the actual area contributed by each network is considered, the number of networks necessary to effect the desired compensation can be determined.

Take the time delay curve $\frac{d\alpha}{da\omega}$ for a type A or B network and deduce the total area under the curve obtained by plotting $\frac{d\alpha}{d\omega}$ against ω, then

$$\text{Area} = \int_{\omega=\infty}^{\omega=0} \frac{d\alpha}{d\omega}\, d\omega \qquad (46)$$

$$= \Big|\, \alpha \,\Big|_{\omega=\infty}^{\omega=0} \qquad (47)$$

From equation (23),

$$\alpha = 2 \tan^{-1}\frac{X_1}{K}$$

For a type A section $X_1 = \omega L$,

$$\therefore \alpha = 2 \tan^{-1}\frac{\omega L}{K}$$

$$\therefore \text{Area} = \Big|\, 2 \tan^{-1}\frac{\omega L}{K} \,\Big|_{\omega=\infty}^{\omega=0}$$

$$\text{Area} = \pi \qquad (48)$$

For a type B network,

$$\alpha = 2 \tan^{-1}\frac{X_1}{K}$$

$$X_1 = \frac{\omega L_1}{1-\omega^2 L_1 C_1}$$

$$\therefore \text{Area} = \Big|\, 2 \tan^{-1}\frac{\omega L_1}{1-\omega^2 LC} \,\Big|_{\omega=\infty}^{\omega=0} \qquad (49)$$

$$= \Big|\, 2 \cot^{-1}\left(\frac{1}{\omega L} - \omega C\right) \,\Big|_{\omega=\infty}^{\omega=0} \qquad (50)$$

if $\omega = 0$ area $= 2 \cot^{-1} \infty = 0$

if $\omega = \infty$ area $= 2 \cot^{-1} - \infty = 2\pi$

$$\therefore \text{Area} = 2\pi \qquad (51)$$

Hence the type B section provides twice the area that a type A provides, and consequently in this sense also one type B equals 2 type A networks, or 2 unit networks. Thus for compensating a given delay curve, that is, filling in a certain area over a delay-frequency curve, type A sections alone can be considered as regards number and cost.

It now remains to determine the actual value of the areas Aak and Acd shown on Figure 11.

Suppose that a phase distortion of 30 milliseconds is permissible, as recommended by the C. C. I. In the appendix it is shown that for any loaded line of cut-off ω_c, the time delay per loading section is given by,

$$\frac{d\alpha}{d\omega} = \omega_c \sqrt{1-r_1^2} \qquad \text{(52)}$$

where $r_1 = \frac{2\pi f_1}{\omega_c}$.

Hence referring to Figure 11,

$$ah = \frac{2}{\omega_c \sqrt{1-r_1^2}} \qquad \text{(53)}$$

$$cg = \frac{2}{\omega_c \sqrt{1-r_2^2}}$$

$$\text{where} \quad r_1 = \frac{2\pi f_1}{\omega_0}, \quad r_2 = \frac{2\pi f_2}{\omega_0} \qquad \text{(54)}$$

$$\therefore \frac{2}{\omega_c \sqrt{1-r^2}} - \frac{2}{\omega_c \sqrt{1-r_2^2}} = 30 \times 10^{-3}$$

$$\therefore \frac{1}{\sqrt{1-r_2^2}} = \frac{1}{\sqrt{1-r_1^2}} - \omega_c\, 15 \times 10^{-3} \qquad \text{(55)}$$

For any given circuit ω_c, the cut-off frequency and f_1 the highest frequency efficiently transmitted are known, hence r_2 can be obtained from (55).

The area to be compensated = Acd = Ogcd − ogcA.

Area ogcA is the area under the $\frac{d\alpha}{d\omega}$ curve for the loaded line up to a frequency f_2 (circular frequency ω_2), i.e.,

$$\text{Area ogcA} = \Big|\, \alpha \,\Big|^{0}_{\omega_2}$$

From equation (74) of the appendix and the following,

$$\cos\alpha = \left(1 - \frac{\omega^2 LC}{2}\right) \qquad \text{(56)}$$

$$\sin\frac{\alpha}{2} = \frac{\omega\sqrt{LC}}{2} \qquad \text{(57)}$$

$$\alpha = 2\sin^{-1}\frac{\omega\sqrt{LC}}{2} \qquad \text{(58)}$$

where L and C are the circuit constants as defined in the appendix,

$$\text{Area ogcA} = \left|\, 2\sin^{-1}\frac{\omega\sqrt{LC}}{2} \,\right|^{0}_{\omega_2} \qquad \text{(59)}$$

$$= 2\sin^{-1}\frac{\omega_2\sqrt{LC}}{2} \text{ per loading section} \qquad \text{(60)}$$

$= 2\sin^{-1} r_2$ (see equation (90) of appendix)

Area Ogcd = (value of $\frac{d\alpha}{d\omega}$ at ω_2) ω_2

$$= \frac{2\omega_2}{\omega_c\sqrt{1-r_2^2}} \text{ per loading section} \qquad \text{(61)}$$

$$= \frac{2r_2}{\sqrt{1-r_2^2}} \text{ per loading section} \qquad \text{(62)}$$

Hence area Acd $= \frac{2r_2}{\sqrt{1-r_2^2}} - 2\sin^{-1} r_2$ per loading section ……(63)

Hence for any value of r the number of unit type sections can be obtained by dividing this area by π. It will be noted that the area to be compensated depends upon r only. Figure 12 shows a curve relating the number of unit sections required to the value of r. The ratio r, it should be remembered, is the ratio of the highest frequency transmitted, or the highest frequency to which it is desired to phase compensate, to the cut-off frequency of the cable.

The number of sections derived from the above considerations is the theoretical minimum.

Referring back to the practical example, 102 unit sections were required to compensate 164 loading sections up to 2,400 cycles and the cable cut-off was 2,860 cycles per second. Hence $r = 0.84$.

From Figure 12 the number of unit sections required theoretically = 63. Therefore the "efficiency" of the actual design was 61.5%. This efficiency factor results from the inability to usefully employ the whole of the area provided by the networks for phase compensation. In general an efficiency of about 65% is obtained. Therefore, the theoretical number of unit sections required per loading section as given in Figure 12 should be increased by this factor in order to obtain the number actually required.

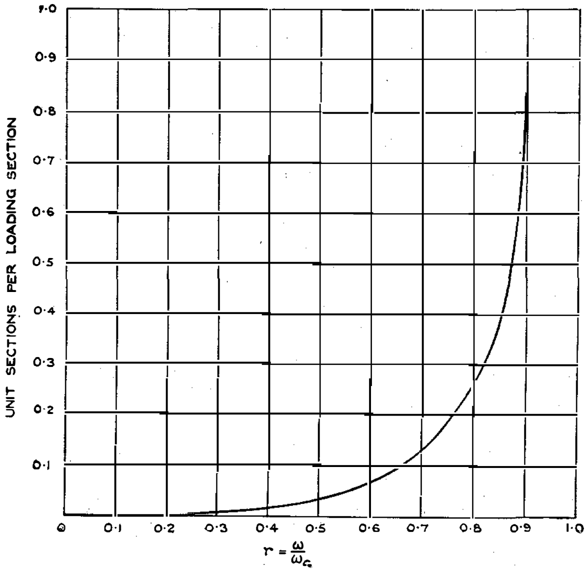

Figure 12—Curve Giving Number of Compensating Sections Required for Phase Equalisation to a Given Fraction of Cut-off.

There are a few points to consider in the actual construction of the networks. Referring to Figure 2 and equations (8), the current flowing in the upper impedance Z_1 is I_2, and in the lower impedance Z_1 is $I_1 - I_3$.

By equation (8) these two currents are equal. Similarly, the currents flowing in both the Z_2 impedances are equal.

Suppose that Z_1 is a pure inductance L, and Z_2 a pure capacity C. Then equations (1) to (3) would be written.

$$e = (I_1 - I_2)\, j\frac{1}{\omega C} + (I_1 - I_3)\, j\omega L \ldots\ldots\ldots\ldots (64)$$

$$0 = I_2\, j\omega L + (I_2 - I_3)\, Z_R + (I_2 - I_1)\, j\omega C \ldots\ldots (65)$$

$$0 = I_3\, \frac{1}{j\omega C} + (I_3 - I_2)\, Z_R + (I_3 - I_2)\, j\omega L \ldots\ldots (66)$$

Now supposing the two inductances L are replaced by two windings on the same core, each winding having a self-inductance L_s, and let the mutual inductance between the winding be M. Consider M to be positive if the current is in the same direction in both windings.

Equations (64) – (66) are then,

$$e = (I_1 - I_2)\, \frac{1}{j\omega C} + (I_1 - I_3)\, j\omega L_s + I_2\, j\omega M$$

$$0 = I_2 j\omega L_s + (I_1 - I_3)\, j\omega M + (I_2 - I_3) Z_R + (I_2 - I_1)\, \frac{1}{j\omega C}$$

$$0 = I_3\, \frac{1}{j\omega C} + (I_3 - I_2)\, Z_R + (I_3 - I_1)\, j\omega L_s - I_2\, j\omega M$$

Since $I_1 - I_3 = I_2$

The equations become,

$$e = (I_1 - I_2)\, \frac{1}{j\omega C} + (I_1 - I_3)\, j\omega\, (L_3 + M) \ldots . (67)$$

$$0 = I_2\, j\omega (L_s + M) + (I_2 - I_3)\, Z_R + (I_2 - I_1)\, \frac{1}{j\omega C} . (68)$$

$$0 = I_3 \frac{1}{j\omega C} + (I_3 - I_2) Z_R + (I_3 - I_1) j\omega\, (L_s + M) . (69)$$

Hence the equations (67), (68) and (69) are equivalent to equations (64), (65) and (66) if,

$$L_s + M = L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (70)$$

If the coil is taken out of the network and measured, the inductance of the two windings in series aiding, an inductance would be obtained equal to

$$2L_s + 2M \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (71)$$

Hence if the inductance of the two windings in series aiding is made equal to $2L_1$, the condition expressed by equation (70) is satisfied. The same argument can be applied for the type B networks. Hence, the result of practical importance: if the impedance elements Z_1 contain inductance, then the inductances for the two arms need not be separate but can be wound on the same core.

The same applies to the impedance elements Z_2, but of course, inductance elements of Z_2 must not be on the same core as those of Z_1.

It is essential that the impedance elements should be within close limits of the design value, otherwise impedance irregularities will exist between sections and consequently phase and attenuation irregularities will result in the train of sections. In particular it is important that the resonant frequencies of the series and cross arms of the B networks should be as nearly as possible equal.

APPENDIX I.

Calculation of $\frac{d\alpha}{d\omega}$ *for a loaded line.*

A loaded telephone line is essentially a number of recurrent sections, as indicated in Figure 13. Each section consists of distributed capacity, resistance and inductance and in addition lumped inductance. The distributed inductance and resistance may be neglected for the range of frequencies normally transmitted on commercial telephone circuits without serious error.

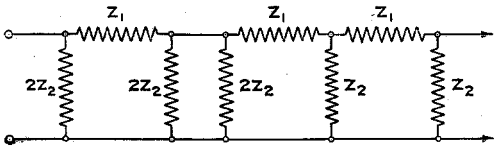

Figure 13—Recurrent Structures Terminated at Mid Shunt.

The problem therefore is to determine the phase constant per section of this network when terminated by an infinite number of similar sections, that is, when terminated by its characteristic impedance.

Let this characteristic impedance be Z_k.

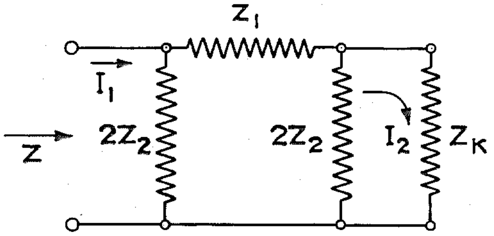

Figure 14—Recurrent Structures Terminated at Mid Shunt.

Then if Z_k is the characteristic impedance $Z=Z_k$.

$$Z=\frac{2Z_2\left[Z_1+\dfrac{2Z_2Z_k}{2Z_2+Z_k}\right]}{2Z_2+Z_1+\dfrac{2Z_2Z_k}{2Z_2+Z_k}}=Z_k$$

Hence $Z_k=\sqrt{\dfrac{Z_1Z_2}{1+\frac{1}{4}\frac{Z_1}{Z_2}}}$

And the current ratio,

$$\frac{I_1}{I_2}=\frac{\dfrac{Z_1}{2}+Z_2+\sqrt{Z_1Z_2+\dfrac{Z_1^2}{4}}}{Z_2}\quad\ldots\ldots(72)$$

In the case of the loaded cable, if we neglect resistance, leakance and distributed inductance, the loading section may be represented by the network of Figure 15.

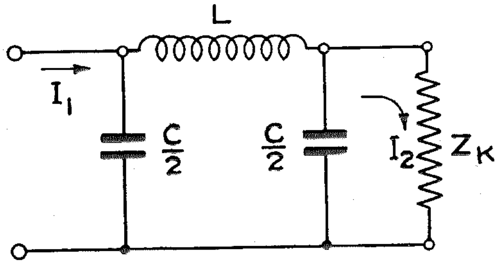

Figure 15—Equivalent Network for a Loading Section with Mid Shunt Termination.

Then at any frequency ω,

$$\frac{I_1}{I_2}=\frac{\dfrac{j\omega L}{2}-\dfrac{j}{\omega C}+\sqrt{\dfrac{L}{C}-\dfrac{\omega^2L^2}{4}}}{-\dfrac{j}{\omega C}}$$

$$=\left(-\frac{\omega^2LC}{2}+1\right)+j\omega C\sqrt{\frac{L}{C}-\frac{\omega^2L^2}{4}}\quad\ldots(73)$$

Therefore the phase rotation per loading section is given by,

$$\tan\alpha=\frac{\sqrt{\omega^2LC-\dfrac{\omega^4L^2C^2}{4}}}{1-\dfrac{\omega^2LC}{2}}\quad\ldots\ldots(74)$$

Now $\quad\tan\alpha=\dfrac{\sqrt{1-\cos^2}}{\cos\alpha}$

Therefore by inspection

$$\cos\alpha=1-\frac{\omega^2LC}{2}$$

$$\therefore -\frac{d\alpha}{d\omega}\sin\alpha=-\omega LC$$

$$\frac{d\alpha}{d\omega}=\frac{\omega LC}{\sin\alpha}$$

$$\sin\alpha = \sqrt{1-\cos^2\alpha} = \omega\sqrt{LC}\sqrt{1-\frac{\omega^2 LC}{4}}$$

$$\therefore \frac{d\alpha}{d\omega} = \frac{\sqrt{LC}}{\sqrt{1-\frac{\omega^2 LC}{4}}} \dots\dots\dots\dots\dots\dots (75)$$

Let f_c be the cut-off frequency of the cable, which is defined by:

$$f_c = \frac{1}{\pi\sqrt{LC}} \dots\dots\dots\dots (76)$$

And f be any frequency under consideration.

$$\text{Also,} \qquad \frac{f}{f_c} = r$$

$$\text{hence} \qquad \frac{\omega}{\omega_c} = r \dots\dots\dots\dots\dots\dots (77)$$

$$\text{Now from (76),} \qquad \omega_c = \frac{2}{\sqrt{LC}} \dots\dots\dots\dots (78)$$

$$\therefore \quad \omega_c^2 LC = 4 \dots\dots\dots\dots\dots\dots (79)$$

Multiplying both sides by $r^2 = \frac{\omega^2}{\omega_c^2}$

$$\text{we get} \qquad \omega^2 LC = 4r^2 \dots\dots\dots (80)$$

Now from (75),

$$\frac{d\alpha}{d\omega} = \frac{\sqrt{LC}}{\sqrt{1-\frac{\omega^2 LC}{4}}}$$

$$= \frac{2}{\omega_c\sqrt{1-r^2}} \text{ per loading section} \dots (81)$$

Hence it will be seen that at low frequencies where r^2 is small compared with 1 the delay $\frac{d\alpha}{d\omega}$ is given by $\frac{2}{\omega_c}$. This is true down to frequencies of the order of 200 cycles when the effect of line resistance begins to become apparent. As the frequency increases this delay is multiplied by a factor $\frac{1}{\sqrt{1-r^2}}$.

In Figure 16 are plotted the measured values and calculated values of delay for the following circuit.

London-Fenny Stratford Looped.

Length (186 miles=299.4 km.)		164 loading sections
Average capacity per load section		.06915 mfd.
Loading coil inductance		.177 henry
Loading section inductance		.001 henry
Cut-off frequency	f_c	2,860 p.p.s.
	w_c	18,000 p.p.s.

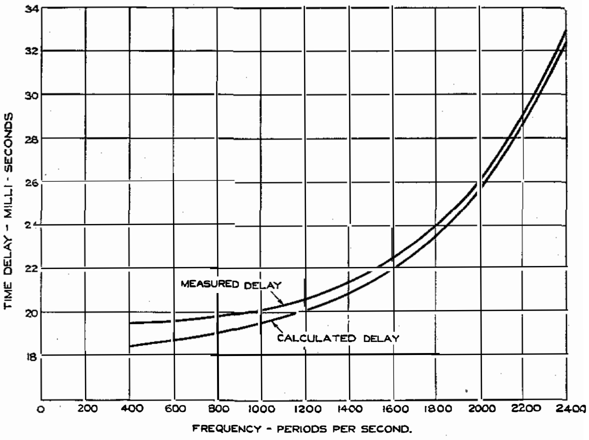

Figure 16—Measured and Calculated Delay Frequency Characteristics for an Actual Loaded Circuit.

Frequency	$r=f/f_c$	Calculated Delay milliseconds	Measured Delay milliseconds
400	.14	18.4	19.5
800	.28	19.0	19.8
1200	.42	20.1	20.6
1600	.56	22.0	22.5
2000	.70	25.6	26
2200	.77	28.5	29
2400	.84	33.6	34

It will be observed that the measured delay exceeds the calculated delay by an increasing amount as the frequency is reduced. This excess delay is due to repeating coils and repeaters in the actual line, which have not been considered in the calculation of delay.

Hence at the lower frequencies of the voice range where r^2 is small compared with 1 the delay $\frac{d\alpha}{d\omega}$ is $\frac{2}{\omega_c}$. This is true down to about 200 p.p.s. for medium heavy loaded circuits; below this value conductor resistance is of importance and the assumptions made are not valid.

The value $\frac{2}{\omega_c}$ written in another form $\sqrt{LC}$ is the smooth line time delay per unit length or $\frac{1}{\sqrt{LC}}$ is the smooth line velocity.

The effect of the lump loading is to multiply this delay $\sqrt{LC}$ by a factor $\frac{1}{\sqrt{1-r^2}}.$ It is interesting to compare this quantity with the mid section impedance of a loaded line. On the same assumptions as made above $Z_k = \sqrt{\frac{L}{C}}\frac{1}{\sqrt{1-r^2}}.$

Hence, again, $\sqrt{\frac{L}{C}}$ is the smooth line impedance (neglecting resistance and leakance) and $\frac{1}{\sqrt{1-r^2}}$ is the factor due to the "lumped" loading.

Phase Compensation (III)
The Nyquist Method of Measuring Time Delay $\frac{da}{d\omega}$

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THE Nyquist[1] method of measuring time delay has been used by the authors in the work on phase compensation described in the preceding papers in this issue of *Electrical Communication.* As set up by them it enables precise measurement of time delay to be made at any one frequency in a minute and a half. The limit of accuracy obtainable with the apparatus used corresponded to an error of ±25 microsecond (±0.000025 second). Usually it was not considered necessary to take readings to such small limits.

The method follows logically from the fact that $\frac{da}{d\omega}$ is the rate of travel of the envelope of two frequencies differing from one another by an interval so small that the time delay is a constant over the interval. If the time delay is not a constant over the frequency interval chosen, then the Nyquist method of measuring time delay gives $\frac{\Delta a}{\Delta\omega}$, which is the mean value of $\frac{da}{d\omega}$ over the interval.

Referring to Figure 1, O_1 is an oscillator generating a low frequency f_1. For simplicity f_1 may be considered to be smaller than the value of the frequency change necessary to cause a rotation of 2π through the structure under measurement, though this is not essential to the method. The case where this is not true is dealt with in detail later. $2\pi f_1$ is the value of $d\omega$ by which da is divided to give $\frac{da}{d\omega}$.

O_2 is an oscillator generating a frequency f_2 which determines the frequency at which $\frac{da}{d\omega}$ is to be measured.

f_1 and f_2 are supplied to M_1, which is a balanced modulator suppressing f_1 and delivering to the structure to be measured the products of modulation f_2, f_2+f_1 and f_2-f_1. The modulated f_2 after traversing the structure is demodulated in D_1, which supplies the frequency f_1 to one coil of the air core dynamometer shown. The other coil is supplied with f_1 from the same oscillator O_1, through the phase shifter P and an amplifier A. Where the two ends of the circuit are not at the same place and where no separate channel is available for transmitting f_1, the modulator M_2 and the demodulator D_2 (shown dotted) are used to transmit f_1 over the physical circuit being examined. When the currents in the dynamometer are in quadrature no deflection is

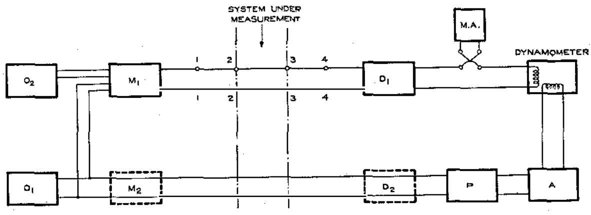

Figure 1—Schematic of Method.

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[1] United States Patent No 1,645,618

obtained; and in practice it is thus possible to detect changes in the phase of the f_1 component of the output of the demodulator with an accuracy depending on how nearly the phase shifter can be read. The dial of the phase shifter is 6½ inches in diameter, which means that without a vernier it is easily possible to read to an accuracy of ±0.25 degrees of arc. If f_1 is 30 cycles, it will appear from what follows that this corresponds to an accuracy of $\pm\frac{0.25}{360\times 30}$ seconds. By making f_1 larger, a greater accuracy is obtainable, but as this increases the value of $d\omega$, it is not always a permissible expedient. It should be mentioned that with a departure from quadrature of 0.25 degrees the dynamometer gives an easily readable deflection with a dissipation in each of its coils, of 50 milliwatts, which is the power conveniently obtainable in practice. It is necessary to use an air core dynamometer in order to avoid changes of zero with change of current amplitude.

Method of Measurement. The structure is removed and a resistance attenuating structure is inserted between terminals 1,1 and 4,4. If the ends of the system 2,2 to 3,3 are widely separated, this step must be completed before the parts of the apparatus are sent to their respective ends of the circuit. Suitable values of f_1 and f_2 are chosen, and the phase shifter P adjusted until the currents in the dynamometer coils are in quadrature; θ_1, the angle of phase shift contributed by the phase shifter, is then read off. The structure to be measured is then inserted, and the phase shifter adjusted until the currents in the dynamometer are again in quadrature; the angle on the phase shifter is then θ_2.

$$\text{Then } \frac{da}{d\omega} = \frac{\theta_2-\theta_1}{360^\circ \times f_1}, \text{ if } \theta_2 \text{ and } \theta_1 \text{ are in degrees}$$

$$= \frac{\theta_2-\theta_1}{2\pi\, f_1}, \text{ if } \theta_2 \text{ and } \theta_1 \text{ are in radians.}$$

Proof. θ_2 and θ_1 are read off the phase shifter in degrees. The first formula will now be proved; the second follows from the first by multiplying numerator and denominator by $\frac{2\pi}{360}$.

The output from Modulator M_1 consists of a wave having a frequency f_2 whose amplitude varies sinusoidally at a frequency f_1 (Figure 2). The envelope of the wave of frequency f_2 is therefore two sine waves, as is well known to those familiar with the process of modulation. From the introductory article on phase compensation in this issue, it follows that any identified part of this envelope traverses the system 2,2 to 3,3 in a time $t=\frac{da}{d\omega}$.

The number of complete wave envelopes, or wave groups, in the system 2,2 to 3,3 at any moment is therefore $f_1 \times t$. On detection the output wave of frequency f_1 from the modulator D_1 is in phase with the envelope wave form entering D_1. The change of phase of the output wave of frequency f_1 from D_1, because of the system, is therefore

$$\theta_2-\theta_1=360\, f_1 t$$

$$\therefore t=\frac{da}{d\omega}=\frac{\theta_2-\theta_1}{360\, f_1}.$$

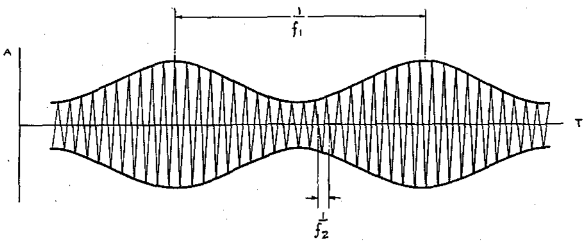

Figure 2—Modulated Wave.

By writing down all the equations for the processes of modulation and demodulation, the same answer is obtained. It is considered, however, that the above proof is sufficiently rigid in itself.

The only component of the practical system calling for comment is the phase shifter. This contains two fixed coils at right angles in space, supplied by the oscillator O_1 with equal alternating currents of frequency f_1, made permanently in quadrature by the use of a capacity and a resistance respectively in series with each coil. A third coil rotating about the common diameter of the two fixed coils therefore receives a current which varies in phase directly with its angular position in space. This type of phase shifter is capable of introducing a phase change of any value between 0 and 360°.

The accuracy of any measurement, apart from the limits of observational error given above as

±25 microseconds, depends only on the accuracy with which the value of the frequency f_1 is known.

The determination of an initial setting for the phase shifter, with a 700 ohm resistance line between terminals 1,1 and 4,4 eliminates any errors through time delay in the apparatus itself. This, incidentally, is less than a millisecond, and negligible for most purposes. The output circuit and transformer of the modulator, and the input transformer of the demodulator, present impedances to the structure under measurement which are identical with the corresponding impedances of a four wire repeater. The use of the above method of measurement, therefore, arbitrarily defines the time delay of any structure measured as the difference in time delay observed when a 700 ohm resistance line is inserted between 1,1 and 4,4, and when the structure under examination is inserted between 1,1 and 4,4. Any time delay introduced as a consequence of the departure of the terminal impedance of the structure from a pure resistance of 700 ohms is regarded as part of the time delay of the structure. The importance of this is generally small, but the statement of the principle assists to clarity of thought.

Consideration shows that two positions of the phase shifter can always be found which will give a balance on the dynamometer, one being 180° away from the other. These positions may be distinguished from one another by the fact that if the phase shifter handle be rotated clockwise, the dynamometer needle will move to the right at one balance position, and to the left at the other balance position of the phase shifter. It is, of course, essential that corresponding balance points should be obtained for the two readings—(a) resistance line in circuit, (b) the structure under measurement in circuit. To avoid confusion it has become the practice to accept a balance only if the dynamometer needle moves to the right when the phase shifter handle is rotated clockwise.

The most common value for f_1 is 30 cycles, when the delay is so small that the difference between the two phase shifter readings taken as above is not sufficient to reduce the percentage error to a reasonable value, the low frequency may be increased up to, say, 100 cycles. This will necessitate readjusting the condenser and resistance in series with the phase shifter coils, and will make one revolution of the phase shifter correspond to a time delay of 10 instead of 33.3 milliseconds. A time delay of 1 millisecond will then correspond to 36° instead of 11° with a corresponding reduction in observation error. In Figure 3 is shown a time delay measurement on an element of a constant delay network having a delay of approximately one millisecond.

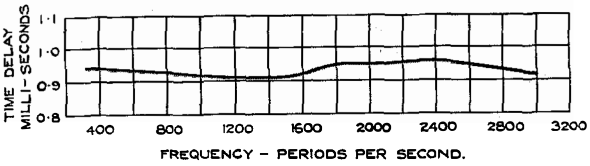

Figure 3—Delay Measurement on Constant Delay Network.

When a long line or a network having a very considerable delay (e.g., 100 milliseconds), is measured, if $f_1 = 30$ cycles, then the position of the phase shifter at balance represents approximately three whole revolutions. If the approximate time delay is known, no difficulty arises; otherwise an absolute reading of time delay cannot be obtained, as the number of rotations of the phase shifter is not known. A way of overcoming this difficulty is to use a very low frequency, say, 1 cycle, for which one revolution of the phase shifter corresponds to 1,000 milliseconds. The limitation of the present phase shifter will not permit this procedure. An alternative is to increase the frequency f_1 in a small step, say from 30 cycles to 31 cycles. The phase shifter is then readjusted and a new reading taken. The change in phase shift δ will be one-thirtieth of the previous shift, and provided the phase shift change per cycle in the structure is less than 360° this phase shift change will appear as the rotation of the phase shifter consequent upon changing the frequency from 30 cycles to 31 cycles.

If the true phase shift for 30 cycles is

$$\theta = n.360^\circ + \phi$$

the change in phase shift is

$$\delta = \frac{\theta}{30} = \frac{n.360}{30} + \frac{\phi}{30}$$

so that $n = \dfrac{30\delta - \phi.}{360}$

Example. On testing a line of unknown delay, using 30 cycles, a rotation of 60° on the phase shifter separates the readings taken with and without the line, i.e., $\phi = 60°$. With 31° the corresponding angle is 86°, so that $\phi + \theta = 86°$ and $\theta = 26°$.

$$\therefore n = \frac{30 \times 26 - 60}{360} = 2.$$

Hence the correct reading in the first instance is $60° + 2 \times 360° = 780°$ equivalent to 77.2 milliseconds delay. It is to be noted that n can only be an integer, so that it is not necessary to have abnormal accuracy in the oscillator. Standard oscillators hold their calibration indefinitely to an accuracy of 0.1 per cent.

Even when the value of the delay is known approximately, a little difficulty occurs in deciding which way the phase shifter has moved when the delay is being determined. For instance, with a network having an expected delay of 15 to 18 milliseconds, it is found that the value of ϕ is 170° if the phase shifter has moved in one direction, and $360° - 170° = 190°$ if the phase shifter has moved in the other direction. Which is correct? If the network is easily accessible, the quickest solution is to reduce the number of sections, when the direction of the movement of the rotor of the phase shifter will be immediately obvious from a new time delay measurement. In the case of a line this is not possible. If the sign of $\frac{da}{d\omega}$ is known (for all ordinary lines it is, of course, positive) then the easiest solution is obtained by resetting the high frequency oscillator (O_2) to a different frequency and taking another measurement of delay, when the new position of the rotor will give a clue to which of the two readings is correct. Failing this, recourse is necessary to the method of altering the low frequency as above outlined.

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Page 132, column 2—Substitute a_r/a for a_r in the left hand side of the equation.

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