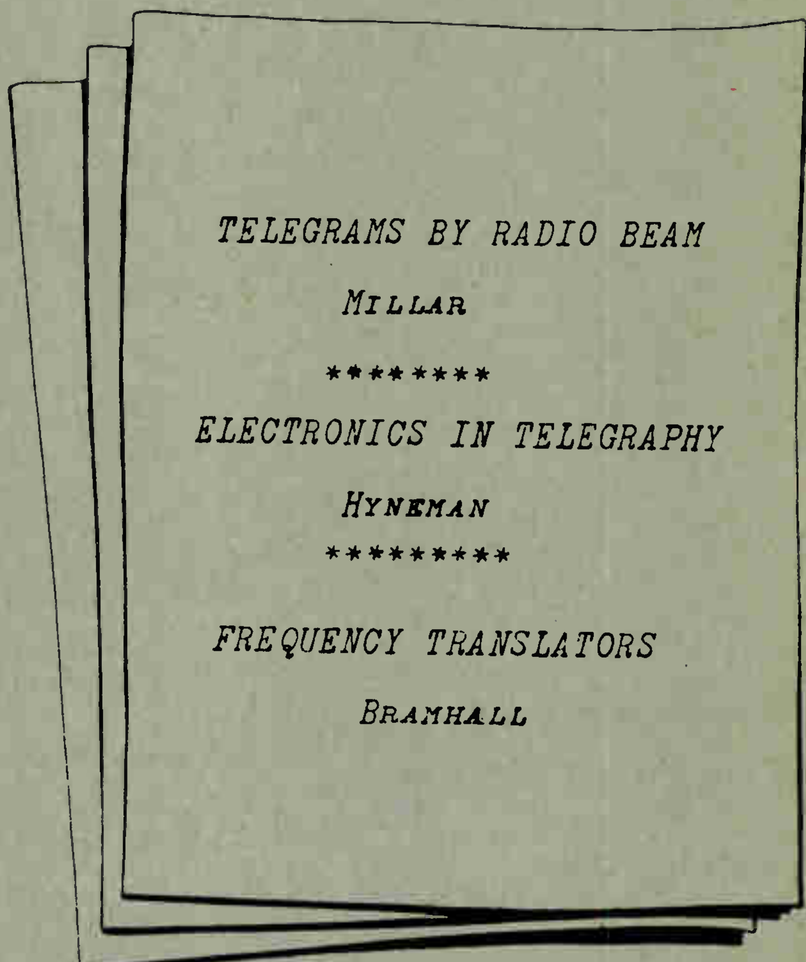
VOL. 1 NO. 1 JULY 1947

WESTERN UNION

Technical Review



THE COMMITTEE ON TECHNICAL PUBLICATION

THE WESTERN UNION TELEGRAPH COMPANY
60 HUDSON ST. . . . . NEW YORK 13, N.Y.

F O R E W O R D

This, the first issue of the Western Union TECHNICAL REVIEW, inaugurates a project by which it is hoped that technically minded employees may become better informed regarding some of the fundamentals which underlie the technological progress of their Company.

Science and its practical application have revolutionized ways of living since Morse blazed the trail with his telegraph. In present day life, the needs of the public and competition force industry to search constantly for new ways and new products, and to utilize the latest results of scientific skill. Long ago the telegraph industry discarded the Morse key and sounder -- its early symbol of distinction -- to make way for modern methods.

Mechanization is synonymous with progress. Electronics, facsimile and microwave radio have become commonplace in Western Union language and thinking. Changes in methods and facilities are taking place rapidly -- so rapidly that there is need for a new medium to give the Company's personnel a better understanding of the tools now being placed in use, and a better ability to use these tools easily and effectively.

This TECHNICAL REVIEW is primarily intended for employees who are concerned with the installation, maintenance or operation of technical equipment. The publication will be issued quarterly and at first will constitute a medium for distributing reprints of technical papers which have been presented before engineering or scientific societies or published in established periodicals. Later it is planned to include specially written technical articles, and it is hoped that field employees as well as headquarters engineers will be counted among the authors.

The Committee on Technical Publication, which will issue this periodical, will welcome comments and suggestions that may be helpful in the planning of future issues.

TWO THOUSAND TELEGRAMS PER MINUTE

BY MICROWAVE

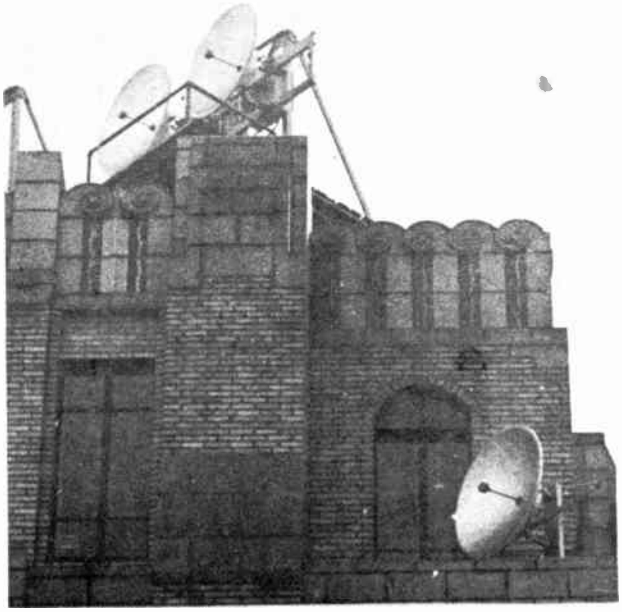
By Col. J. Z. Millar

One of the most revolutionary advances in telegraph engineering is the application of super-high-frequency radio methods to the transmission of Western Union messages. During the next five years, the establishment of radio beam telegraphy between the major cities of the United States is planned. These radio links will replace pole lines which have higher maintenance and replacement cost, and will provide a vastly increased number of telegraph channels. They will also improve service by virtually eliminating circuit interruptions caused by storms and other electrical disturbances. This policy is the result of highly successful experiments culminating in the regular daily transmission of commercial telegrams over a microwave system during the past several months.[1]

Repeater Station Tower at Ten-Mile Run

The first practical microwave system for transmitting a large number of messages was constructed between New York and Philadelphia in the spring of 1945. The RCA-Victor Division of Radio Corporation of America engineered and installed the radio equipment, while Western Union provided the terminal facilities including voice band translation apparatus and telegraph carrier channels. The frequency was near 4000 mc. In July 1946, the original test apparatus was replaced by factory-made equipment of latest design.[2]

While this plan is being adapted first to long distance communication, with relay stations using parabolic reflectors every 25 to 60 miles, it may be mentioned that radio beam telegraphy is not restricted to such long distance circuits. Engineers are not overlooking the possibility of using radio transmission to reach local areas and way points.



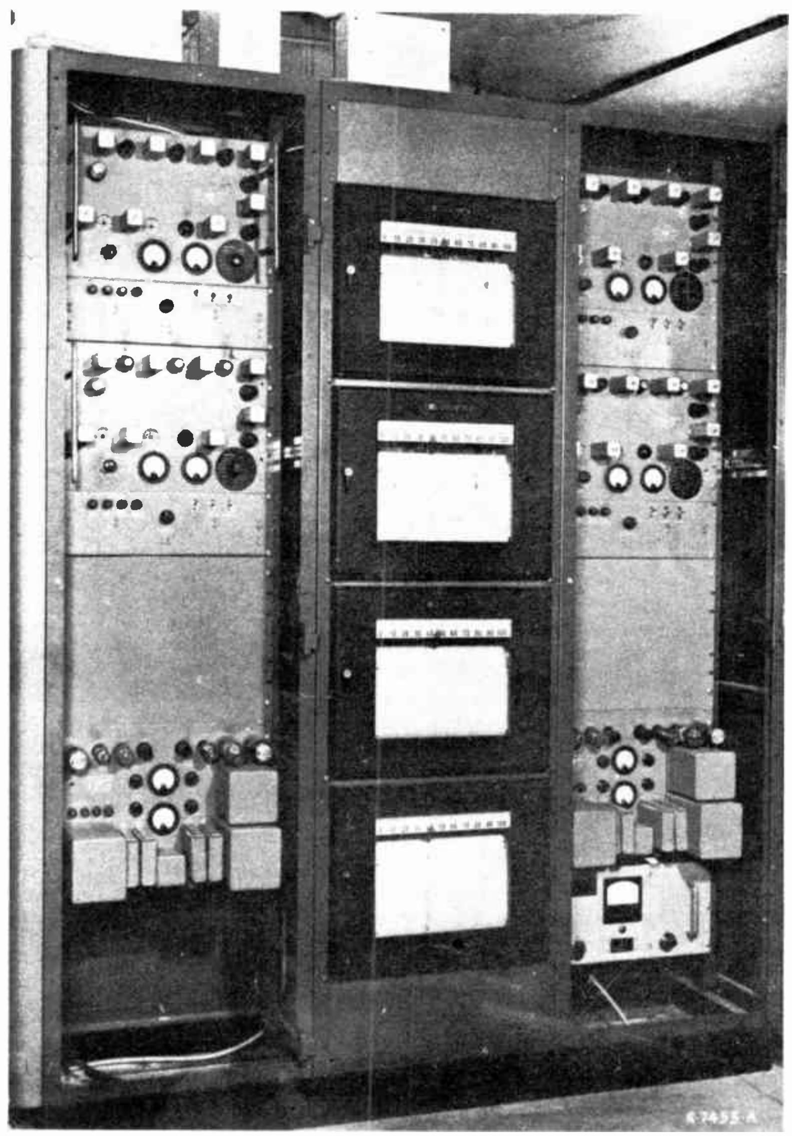
Antenna Installation at Philadelphia.

In another development, which would use somewhat longer waves, contact can be maintained between the central office and specially-equipped vehicles cruising local areas and delivering telegrams directly to the customer.

Western Union has also conducted simultaneous comparative propagation tests between Neshanic, N.J., and New York using several frequencies to obtain continuous long time records of signal strength. These records will be used to select the best of the following frequency bands which have been tentatively allocated to common carrier operation by the FCC: 3700-4200 mc.; 5850-6350 mc.; 10,500-11,500 mc.

A few words concerning the types of telegraph equipment usually connected at the ends of typical circuits will serve to give the reader a clearer picture of Western Union practice. Even though the tendency for the past 40 years has been toward mechanization, a number of manually-operated Morse circuits still are in use. Next, teleprinters (using the start-stop method of operation) are used extensively between main and branch offices and in customers' offices.

The heaviest loads which occur on long distance trunk lines, however, are



Propagation Test Receiving and Recording Equipment.

carried over the "Multiplex". In this system four printer sub-channels are interlaced by time division. Advantage can then be taken of the available high line signaling speed while holding each printer down to its normal speed of 65 to 75 words per minute.

A variation of the Multiplex is the Varioplex which provides for the channeling of as many as 40 widely separated teleprinters over a single Multiplex system. In the Varioplex, if more than four terminal stations become active, the total capacity of the system is shared equally between those desiring to transmit.

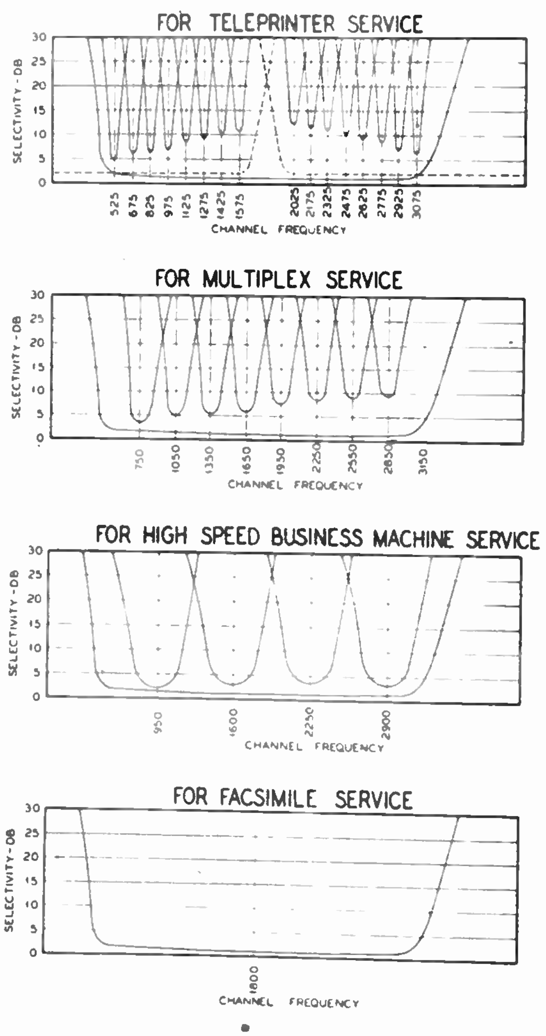
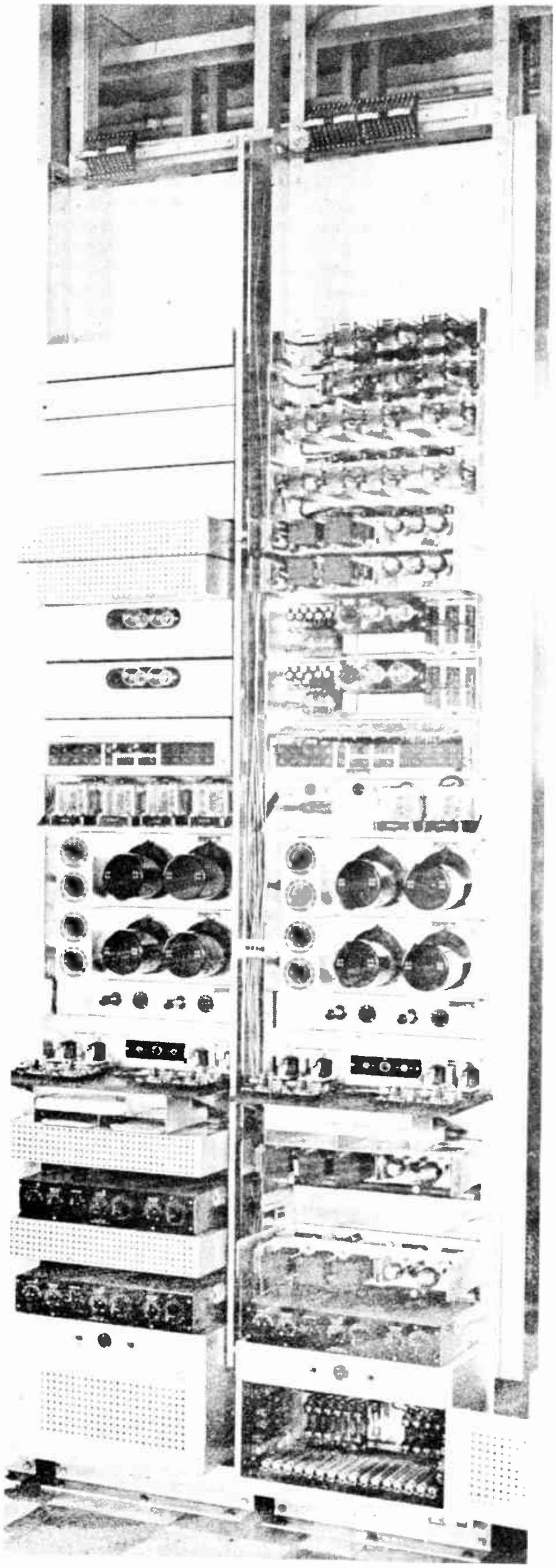


Fig.1 - Voice-Band Sub-Division Plan.

Since 1937, frequency-modulated telegraph carriers have been used. Fig. 1 shows how voice-width bands are divided into such carrier channels. Any voice-band may be thus sub-divided, or the full bandwidth may be used for facsimile or administrative telephone service. Sixteen narrow-band telegraph channels, each satisfactory for a Morse circuit, a teleprinter circuit, or a two-printer Multiplex circuit are obtained. The carrier frequencies are spaced 150 cycles apart and are deviated plus and minus 35 cycles by the telegraph signals. The voice bands also may be sub-divided into lesser numbers of channels for other services such as the four-printer Multiplex, the Varioplex, high-speed ticker Multiplex, or the interconnection of business machines.

Frequency-modulated systems are less subject to rapid signal level changes and to interference effects, and consequently are freer from distortion of the telegraph signals than are amplitude modulated (on-off) systems. Thus by FM methods, the quality of signal



Four Telegraph Carrier Channel Terminals with Covers Removed.

transmission has been improved to the point where it is possible to transmit over wire circuits several thousand miles long without using regenerative telegraph repeaters.

The grouping of various types of telegraph circuits into voice-bands has been found convenient for the reason that some trunk systems make use of pairs of wires for the transmission medium; others, telephone channels derived from Western Union wire carrier systems, or leased telephone circuits. And now radio beam transmission is available. Thus, grouping provides a method for translating and "stacking" voice-bands until all of the available signaling spectrum is filled. This method also facilitates the patching or switching of entire groups of circuits in case of failure without reconnecting each telegraph channel individually.

The largest bandwidth utilized in Western Union wire line practice is approximately 32 kc. which is sufficient frequency spectrum to provide 8 two-way voice-bands (on a four-wire basis). Following this practice it was decided to design the initial radio beam for 32 voice-bands and increase the number of systems for any required capacity over this value. This number of voice-bands would result in a total capacity of 2048 simultaneous transmissions, half in one direction and half in the other, and since each telegram requires about one minute for transmission, each office could receive over 1000 messages per minute.

In its present networks, large as they are, Western Union does not immediately require all this intercity

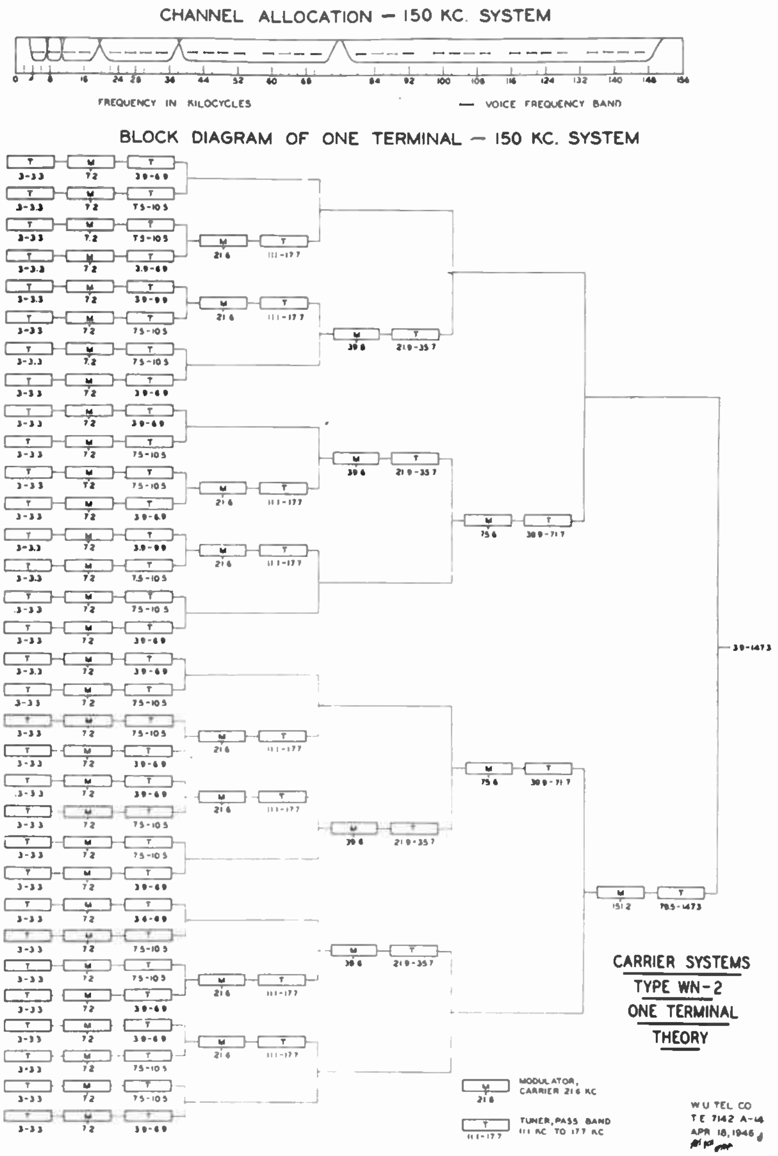
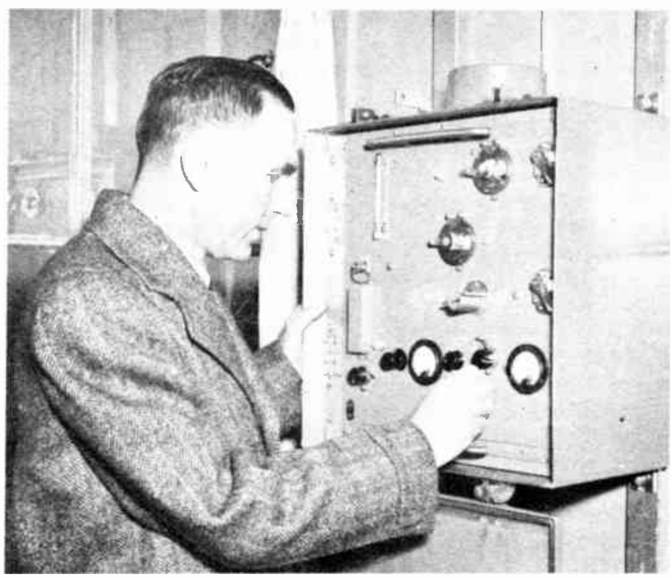


Fig.2 - WN-1 Carrier System Block.

capacity. Therefore, approximately half of the available voice-bands will be reserved for alternate route transmission. The anticipated growth of Telefax will require many additional voice-bands, but these can be provided for by the establishment of additional beam systems.

Fig.2 shows the arrangement of tuners and modulators used to translate the 32 voice-bands to appropriate positions in the spectrum. This is a single side band suppressed-carrier system. For such a scheme, it is necessary that the base oscillators from which the modulator frequencies are obtained be precise, otherwise the telegraph carrier frequencies sent by a terminal would not fall within the discriminator characteristics at the receiving terminal. Also, the amplitude-frequency characteristics and the total distortion within each derived voice-band must be held to reasonable limits, and the signal-to-noise ratio should be greater than 35 db. It will be noted that a signaling spectrum of 150 kc. is required.

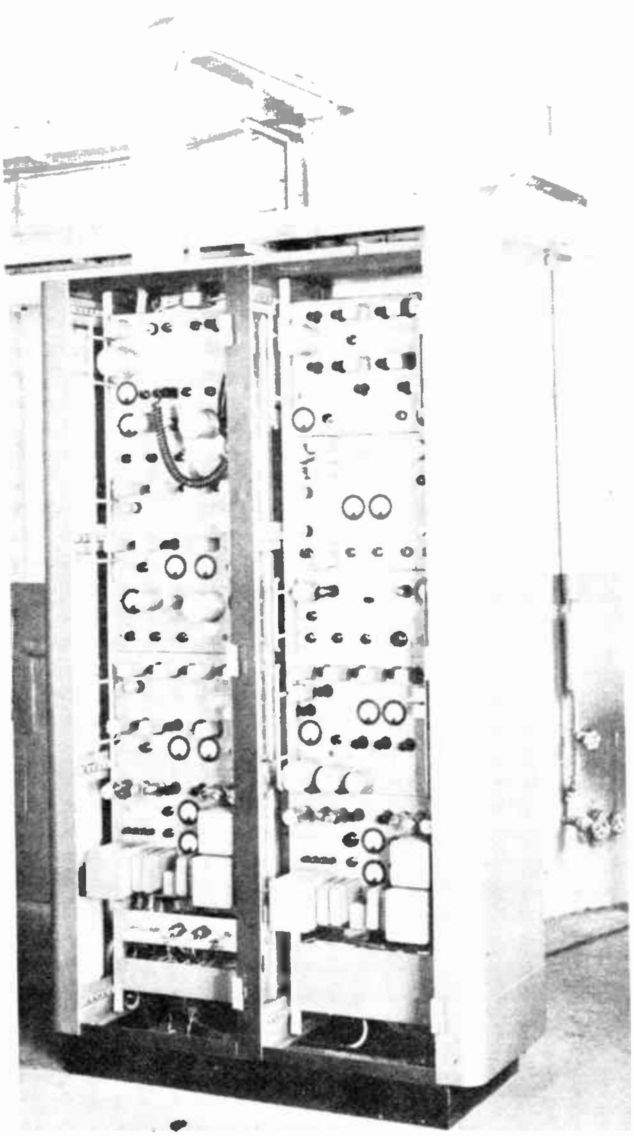
In the radio link it is important to have low distortion to avoid cross-talk between voice-bands. The system which met the distortion and other wideband



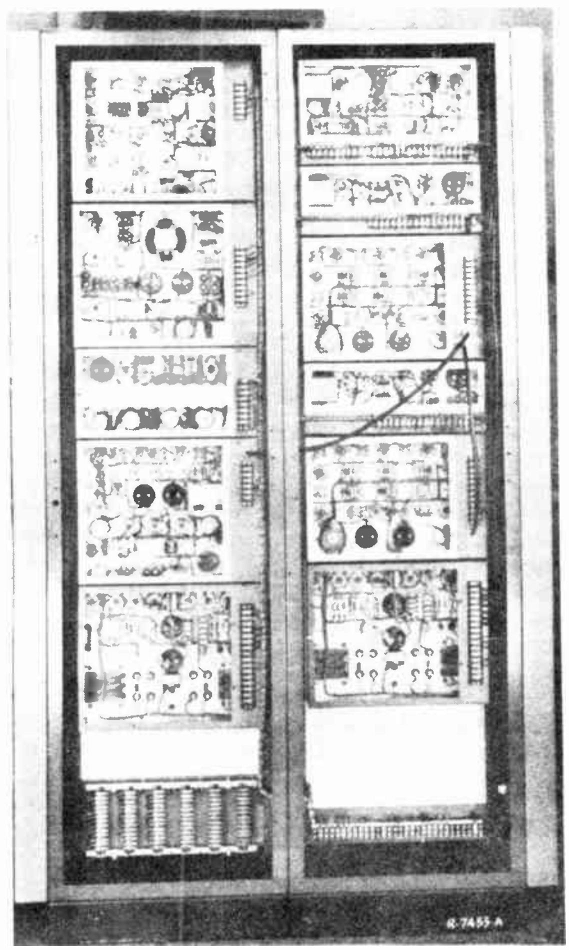
Weatherproof Microwave Equipment Cabinet Used for Remote Amplifiers.

transmission requirements best was the invention of Leland E. Thompson of RCA.[3] In this system, a wide signaling frequency band of 150 kc. is handled with a signal-to-noise ratio of 53 db in each derived voice band and a distortion of less than a few tenths of a per cent, the exact amount depending upon the number of repeaters. Double modulation is used, that is, the 150 kc. band of input frequencies from the voice-band equipment frequency-phase modulates a 1 mc. sub-carrier, and this sub-carrier in turn frequency modulates the final carrier, for example, 4000 mc.

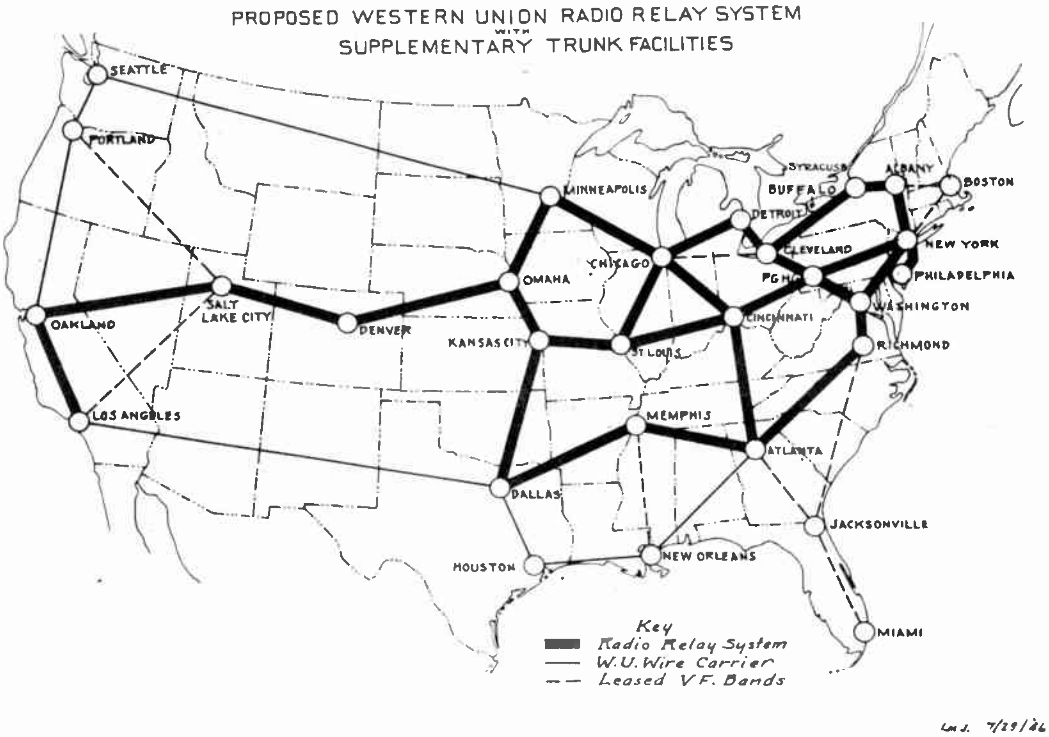
At each repeater the received signal is heterodyned to an intermediate frequency of 32 mc. and after amplification and limiting, the signal is demodulated by passing it through a discriminator. The derived output is the 1 mc. sub-carrier which then modulates the on-going transmitter. Double demodulation is used only at the receiving terminal, thus making the original input frequencies available for dissection into voice-bands, and finally into the telegraph carrier channels.



New York Terminal Station Equipment Racks with Doors Removed.



Backs of Racks with Covers Off.



Map Diagram Showing Proposed Western Union Radio Relay System and Trunks

Diversity reception is used on all sections over 15 miles in length, with antennas spaced vertically by a distance of approximately 25 ft., depending upon the carrier frequency and length of the section. This materially reduces the fading range caused by multipath transmission of the direct wave and an upper wave refracted from an atmospheric air mass boundary which sometimes forms during late night hours in the summer. The two received signals are combined at the 1 mc. sub-carrier level, where practically no phase difference occurs.

For control of the repeater stations, which are normally unattended, a service channel of communication is provided. The service channel frequency modulates the final carrier directly, and either voice or tone signals are recovered at each repeater station. An ingenious system of testing has been designed which permits the terminal attendants to determine which relay station is faulty. This system also provides an identifying tone for each repeater station. This tone is normally off, but is keyed in code pulses to indicate such conditions as operation of the gas-engine-driven emergency power supply, low building temperature, illegal entry, etc.

In November 1945, the FCC granted Western Union construction permits for a network of stations arranged to connect New York, Washington and Pittsburgh, with a second chain connecting New York and Philadelphia. Work on this system progressed satisfactorily throughout 1946, even though much delay resulted from strikes and material shortages.

Extensions of Western Union's radio operations are planned generally in the form of triangular relay systems which will replace trunk pole line facilities as soon as radio relaying becomes established on a commercial basis and existing contracts permit.

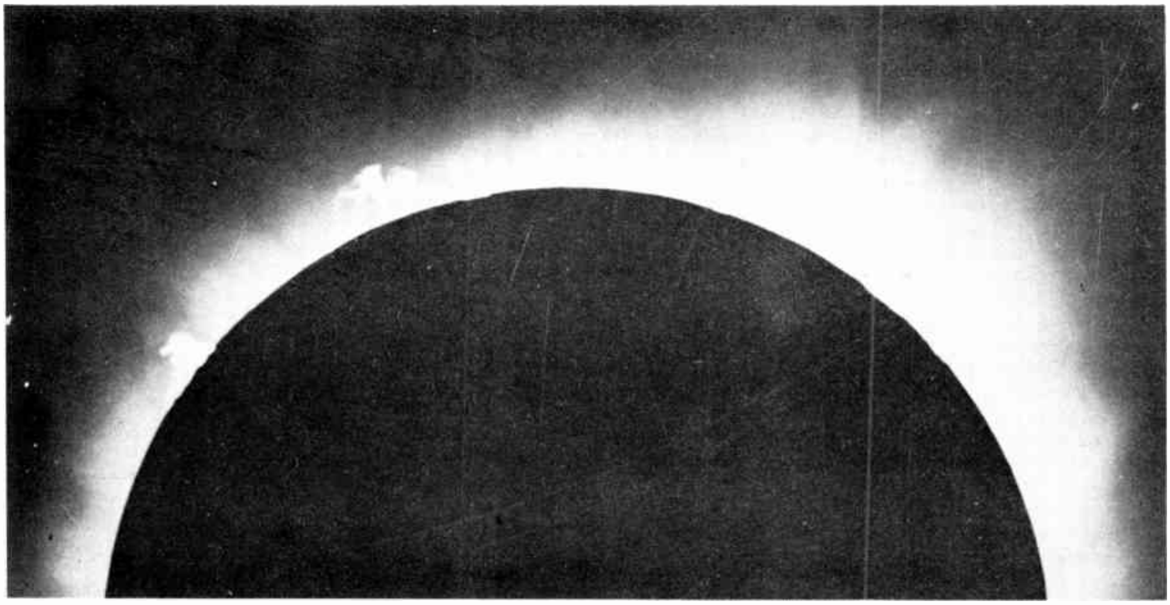
[1]A Preview of The Western Union System of Radio Beam Telegraphy, by Col. Julian Z. Millar, JOURNAL OF THE FRANKLIN INSTITUTE.

[2]A Microwave Relay Communication System, by G.G. Gerlach, RCA REVIEW, December 1946.

[3]A Microwave Relay System, by Leland E. Thompson, PROCEEDINGS OF THE IRE, December 1946.

* *

THE SOLAR CORONA



Magnetic storms and abnormal earth currents are associated with sunspots. One theory is that the storms occur when the spots are accompanied by solar flares such as appear in the sun's corona. An article on the phenomena and their effect upon telegraphy will appear in the next issue of the REVIEW.

APPLICATIONS OF ELECTRONICS IN A TELEGRAPH SYSTEM

By J. R. Hyneman

> "Electronics is that branch of science and technology which relates to the conduction of electricity through gases or in vacuo."
> --American Standard Definitions of Electrical Terms--

This definition of electronics is quoted for the purpose of keeping the author within reasonable bounds and also as a memory refresher to readers.

INTRODUCTION

The invention of the telegraph culminated in the first great electrical industry. There was expended upon its development the genius of the times as represented by scientists, skilled mechanics, and members of that new profession, electrical engineering, not to mention the ubiquitous amateur. The early sending and receiving instruments were mechanical in nature, and constant potentials interrupted at relatively slow rates were used for the transmission of messages. Tone telegraphy was with us from the earliest days, but in the absence of satisfactory amplifying devices, it could not compete in transmission properties, with direct current. It followed, therefore, that when the art or science of electronics was merely in the cradle stage, telegraphy had become very soundly based upon direct current transmission methods accommodated to sending and receiving instruments, by then developed to a high order of electrical and mechanical perfection. The entry of the new art into the field of commercial telegraphy was, therefore, delayed by this competition until after it had made considerable progress in the radio field.

SUBMARINE CABLES

The first branch of the telegraph industry to definitely adopt allegiance to the vacuum tube was that of submarine cables. The Transatlantic cables in service up to 1924 were limited in speeds to 6 to 8 cycles per second because of the very high attenuation which they presented to frequencies above this range.

A redeeming feature was that these cables could be duplexed for sending messages simultaneously in each direction, by providing at each end of the cable an artificial cable for balancing the real cable in a Wheatstone bridge circuit. At each end signals could then be received independently of the transmission from that end. The costliness of repairs in case of insulation breakdown obliged the limitation of sending voltages to 50 volts or less. Interference due to static, earth currents and induction pick-up from adjacent cables and power circuits, along with interference from imperfect duplex balances, presented a substantial residual noise level which set a lower limit for received signal strength. The receiving instruments were delicate, required frequent skilled adjustment and were subject to damage from lightning or other severe interference.

Clearly, here was a situation which was open to improvement. Accordingly, following the development of permalloy by the Western Electric Company, that company was engaged to design, in collaboration with Western Union engineers, a continuously-loaded cable, and to provide suitable terminal multiplex telegraph equipment to take advantage of the available high speed. The new cable, laid in 1924 between New York and Horta, Azores, operated at a speed of 65 cycles, its capacity being distributed among 5 channels each operating at the rate of 54 words per minute. This change from duplex manual cable code operation to simplex Baudot printer operation gave a net increase in message capacity of 300% over the best non-loaded cables.

In 1926, a second loaded cable was laid between New York and Penzance, England, via Bay Roberts, Newfoundland, where a repeater was interposed; and in 1928, a third such cable was laid between Bay Roberts and Horta.[1] The latter cable was of a type which permitted practical duplex operation, a feature impossible in the two former cables because of the peculiarities of the loading material.

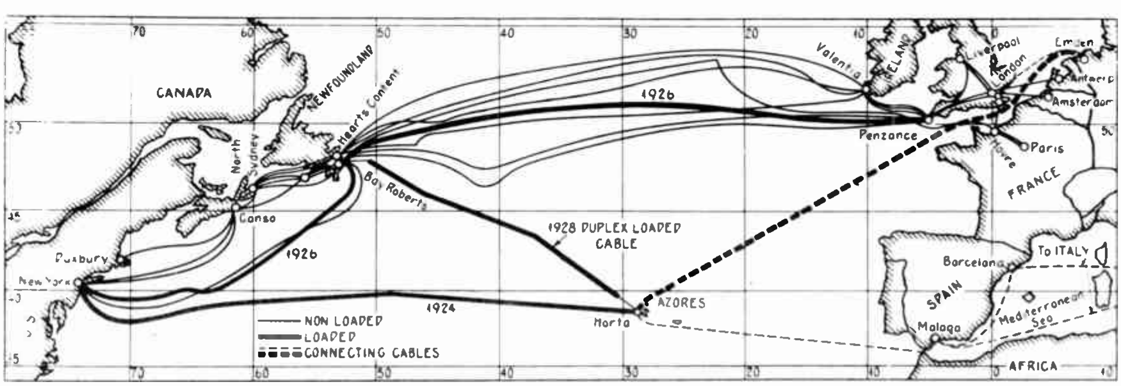


Fig.1 - Western Union Cable System in the North Atlantic, Showing Loaded Cables.

Electronic equipment[2] for these three cables was very similar and comprised principally the terminal and intermediate repeating amplifiers. Many difficulties were presented in the design of these sensitive amplifiers which must not only shape the highly distorted signal and eliminate unwanted interference, but must at the same time withstand heavy overloads and give continuous reliable and trouble-free operation. These amplifiers were required to receive a signal containing components ranging from a fraction of a cycle up to 180 cycles, the low frequency components having voltages as high as 10 volts, while the upper frequency voltages might be as low as .5 millivolt, and to variably amplify these components so as to produce a recognizable replica of the transmitted signal for the operation of a relay.

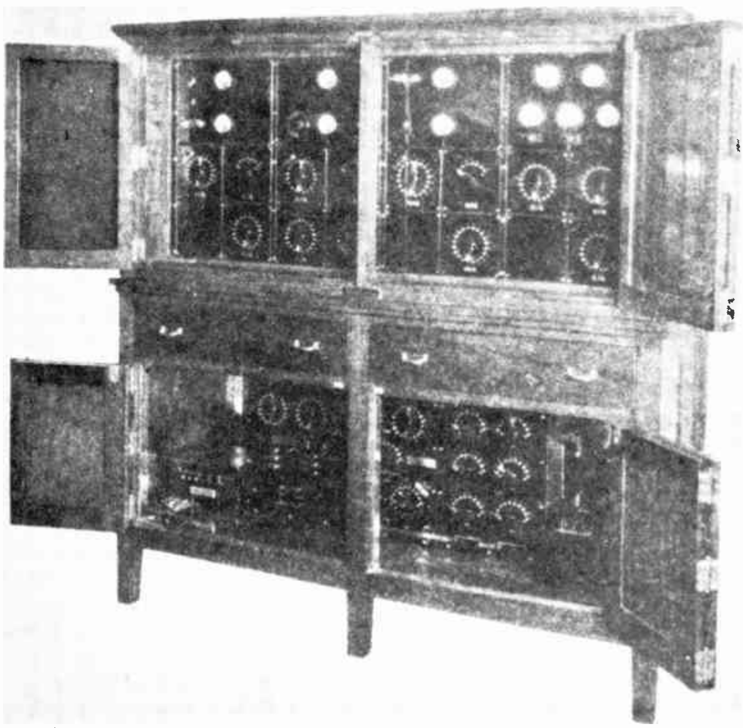


Fig.2 - External Appearance and Mounting of Loaded Cable Shaping Amplifier, (1924).

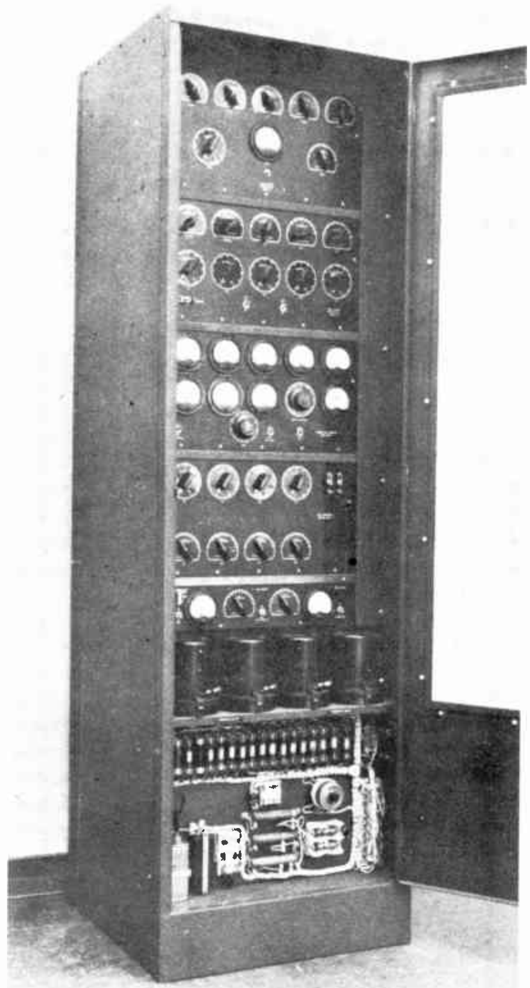


Fig.3 - Loaded Cable Shaping Amplifier,(1946).

Continued activity by Western Union cable engineers brought about many improvements in these original designs of loaded cable amplifiers, and also created a series of amplifiers adapted for operation with the slower speed non-loaded cables. In consequence of these developments, the cable code operator has gone the way of the Morse operator, and printing telegraphy reigns supreme on the Transatlantic cables. Probably the most unique technical achievement in this field was the London-New York submarine cable picture transmission system[3] which operated successfully until more essential war activities forced its close. This circuit employed loaded submarine cables for the Penzance-Bay Roberts-Hammel sections, and underground metallic cables for the shorter landline sections at each terminal. In all, 4 repeaters, each different in design, were required.

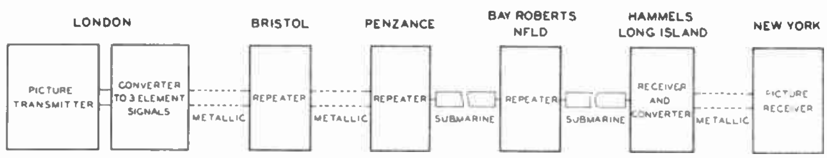


Fig.4 - Route of London-New York Submarine Cable Picture Transmission Circuit.

Probably the finest compliment which the cable engineers could receive came upon the entry of the United States into the war when they were called upon to provide terminal and repeating amplifiers and other equipment for cables in various parts of the world so that these cables could be converted to multiplex printer operation. These cables included the Army's Alaska Cable System and the Commercial Cable Company's Transatlantic cables. Equipment was also supplied to the Commercial Pacific Cable Company, and for the British Pacific cables but these long cables still employ cable code.

CARRIER CURRENT TELEGRAPHY

Progress in modes of telegraph transmission has come about in four major steps. Until about 1915, the nation's telegraph needs were served by a countrywide transmission network composed of telegraph poles each bearing as many as 60 wires or more, first of iron but later of copper, and operated principally by manual Morse methods. At this time, expanding business demanded either the installation of hundreds of thousands of miles of new wire, at a time when copper had become very expensive, or that means be found to increase the capacity of the existing wires. When the problem was placed in the hands of engineers, naturally the latter solution was undertaken.

Over many years, sporadic attempts had been made to operate high-speed printing telegraph systems both in this country and Europe. Necessity now gave earnestness to the effort, and the Western Union multiplex was developed, using the best features of several previously unsuccessful systems. Suffice it to say that through this development, and the solution of many associated problems, the multiplex, by providing from 2 to 4 duplex channels, was able to increase the capacity of a wire by as much as 800 percent over Morse methods.

The multiplex, operating over single grounded wires, provided sufficient new traffic capacity to meet the growth for several years, but again history repeated itself in a third phase. This time the demand was filled by another new-old art -- carrier current telegraphy, the first high-speed channels of which were installed in 1926. Improvements were made rapidly and new installations followed so that in 1937, although retarded by the business recession of the 30's, a carrier network covering the eastern third of the country had been established. Since 1937, growth has been rapid, so that carrier systems now span the country over trunk routes from east to west, and from north to south.

In addition to these trunk route systems, there are many installations of smaller systems designed to provide a few channels over relatively short distances to meet the requirements of seasonal business or other bottle-neck situations.

Probably carrier current methods of communication seem elementary to the present generation of communications engineers. It may be well, therefore, to point out some of its underlying features which served first to delay but later to accelerate its growth. The first wire communication circuit was an iron wire stretched along a line of poles with reliance on the earth for the return circuit. It served very well as a telegraph circuit, and for telephony too. In time, the pole line became loaded with scores of wires and distances stretched out to thousands of miles. However, by substituting copper for iron and by introducing various other measures, the grounded circuits sufficed to handle the country's telegraph business through the added expedient of increasing the line speed, or frequency. But the ground return circuits reached their limit at speeds of 60 to 80 cycles, and it became necessary, as stated, to either build more pole lines or to adopt carrier methods in operating the wires. To adopt carrier methods was a rather radical departure. The wires would not serve as they were; it was necessary to select two wires on adjacent pin positions which were alike as to size and make-up (copper, iron, cable, etc.) and were in good condition with respect to joints, sags, insulators and other factors. Any deficiencies had to be corrected, and then it was necessary to transpose the wires according to a standard pattern and, if the cable sections were long, to install loading coils at regular intervals. The numbers per mile of both transpositions and loading coils are roughly proportional to the highest frequency at which the wires are to be used. All this, in addition to providing the terminal channelizing and the intermediate repeater equipment, meant that the establishment of a new carrier system even along an existing pole line was an engineering project of some magnitude and quite expensive to carry out. Not the least of the adverse factors was the circumstance that all hands were strongly indoctrinated in the grounded circuit techniques.

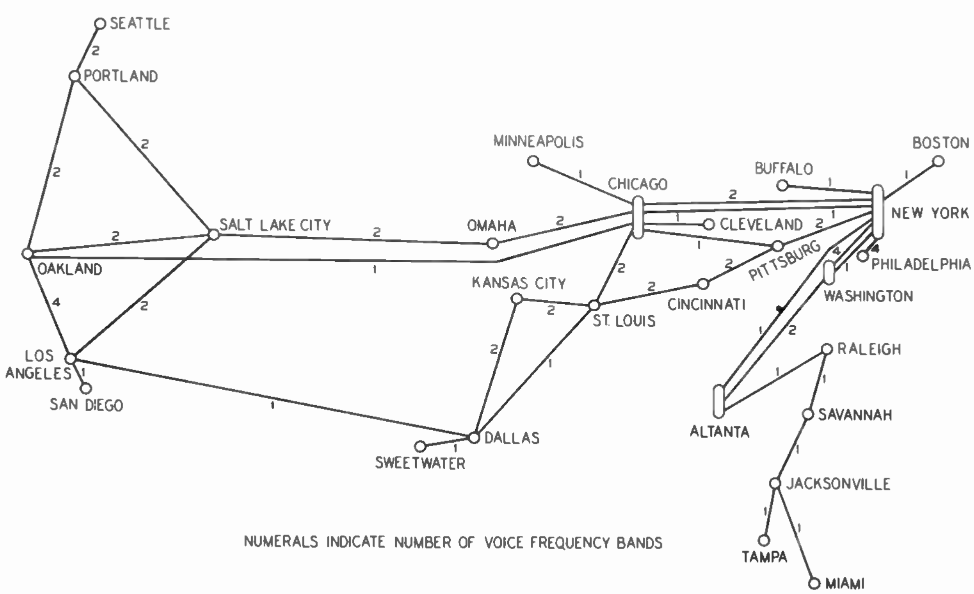


Fig.5 - Map of Western Union Trunk Carrier Routes, (1946).

Carrier circuits proved themselves in as soon as their basic characteristics were understood. These are several but, to the design engineer, two stand out. The first is the conception of flexibility of circuit design; that is, within a wide transmission band width one may accommodate in any order all varieties of service, such as telegraph, facsimile, telephone, supervisory, etc., in any desired number, speed or quality. If the band width is a limitation he can re-engineer the lines to handle wider bands. But here the second characteristic enters as a restraining influence. As already intimated, cost of the circuit increases in rough proportion to available transmission band width so that there is every incentive to design for efficiency and to avoid wastage of valuable frequency spectrum.

As is well known, the thermionic vacuum tube in its function principally as an amplifier but also as a detector, oscillator and modulator, made carrier current telegraphy possible as a reliable long distance circuit facility. Reference will be made to a few of the more prominent applications in this field. The building block from which most of Western Union's multichannel carrier systems as now installed are built is the so-called 15-A Channel Terminal.[4] This frequency-modulated channel has now virtually displaced amplitude-modulated channels in the Company's service because of its marked freedom from noise and bias troubles.

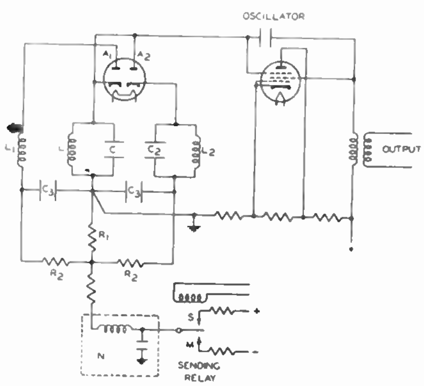


Fig.6 - Circuit Diagram for Frequency Modulated Carrier Telegraph Transmitter.

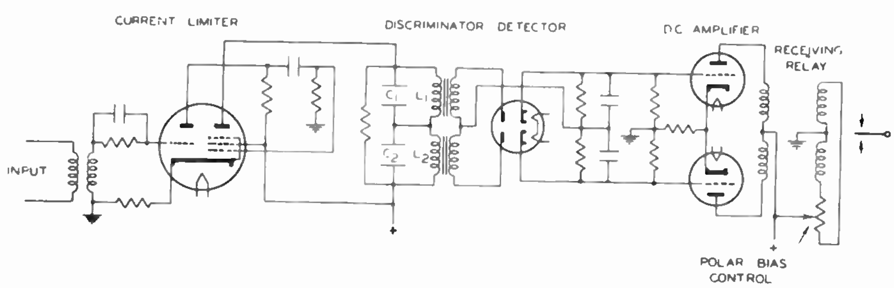


Fig.7 - Circuit Diagram for Frequency Modulated Carrier Telegraph Receiver.

The FM method of operation is to carrier telegraphy what the polar method is to D.C. telegraphy. In its present practical embodiment, it is achieved by varying the frequency of an oscillator, which is normally tuned to the center of the channel band, by ±70 cycles to produce the marking (M) and spacing (S) signals. Limiters and discriminators of more or less conventional type convert these frequency-modulated signals into polar signals for operation of the final receiving relay. This is a true frequency modulation process, since the marking, spacing and intermediate transit time frequencies all traverse the same channel filters at the sending and receiving ends, in contrast to the "two-tone" systems which in effect utilize two distinct carrier channels, one for marking and the other for spacing. The channel frequency spacings are 300 cycles, which with 70-cycle deviation, will accommodate high-speed multiplex circuits at 70 cycles. A similar FM channel, but having 150-cycle spacing with 35-cycle deviation is widely used for slower speed multiplexes and for teleprinter service.

The critical functions of the FM terminal are, of course, performed by vacuum tubes. Special mention is accorded to the use of two diodes which, when subjected to the D.C. polar telegraph signals as a bias to render them alternately conductive, connects to the oscillator the marking or spacing tuning circuits, and also to the two-stage regenerative limiter.

Except for certain services, present trends are departing from the high-speed multiplex and favor the use of individual channels from sending operator to receiving operator. A telegraph plant based upon this premise requires a greatly augmented transmission capacity and large numbers of channel terminals. Accordingly, development has been concentrated on a FM terminal with 150-cycle channel spacing, which is simplified to the greatest possible degree. Special features are the use of vacuum tubes for performing the functions of the transmitting and receiving relays, and the concentration of all testing and regulating facilities for convenient and rapid handling.

The building blocks just described are used in building up multi-channel systems of which two types known as F[5], and G[6] are principally used. Both of these systems provide two-way transmission on a single pair of wires, their salient features being briefly expressed as follows:

TABLE I

		Two-Way Telegraph Channels		Directional Band Limits Kc		Installed Mileage	
	2-Way VF Bands	300-Cycle Spacing	150-Cycle Spacing	W-E	E-W	Sys.	Chan.
F	2	18	32	.6-6.6	9.6-16.3	7384	1,101,000
G	4	36	64	17.2-30.6	.6-13.8	2351	209,400

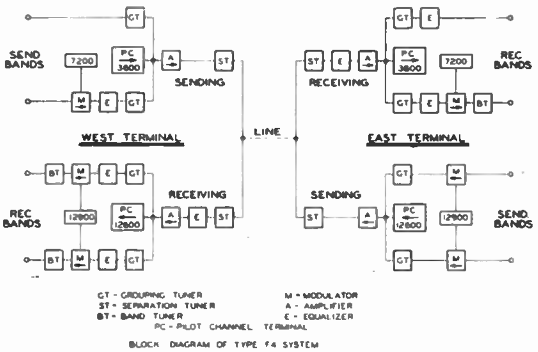


Fig.8 - Type F Carrier System, 18 Channels.

Space does not permit detailed reference to the multitude of oscillators, modulators, amplifiers, filters, equalizers and miscellaneous items which comprise these system terminals nor the slightly less multitudinous panels which comprise the repeaters which must be spaced along the routes at attenuation intervals of 40 db or so. As Table I indicates, carrier telegraph systems are now definitely big business; they are relied upon exclusively whenever new facilities are required, unless the distances are quite short or the increment of increase very small. Fortunately these developments were available to meet the wartime demands for wide-spread expansion of facilities, particularly for the long distances in the western part of the country.

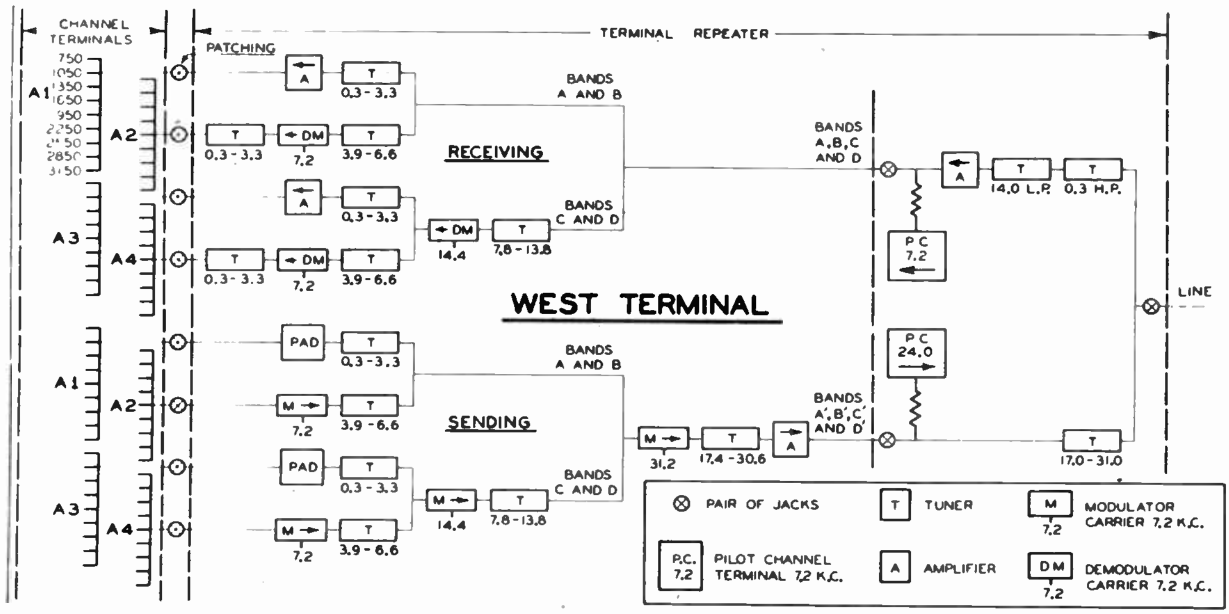
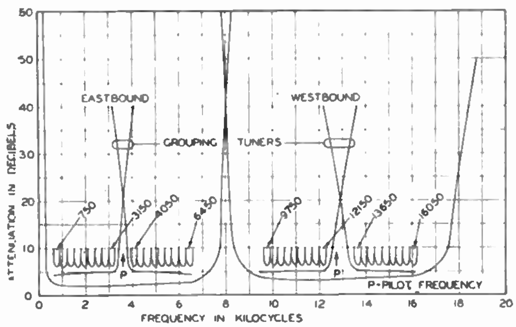


Fig.9 - Type G Carrier System, 36 Channels. West Terminal Only.

Carrier methods have also proved their utility on submarine cables. On long telegraph cables, the primary d.c. circuit is always geared to absorb the last inch of cable transmission capacity but on shorter cables whose speed is determined by the speed of longer connecting cables or other considerations, there may be some excess capacity in the frequency space directly



above the primary channel which can be devoted to carrier channels. Such channels have been applied to the 340-mile sections of cable in the Bay of St. Lawrence which serve as connecting links in the Trans-atlantic cables, and also to the 100-mile Key West-Havana cables. In the latter location, each of 3 cables handles grounded duplex multiplex circuits. The carrier equipment is being redesigned to

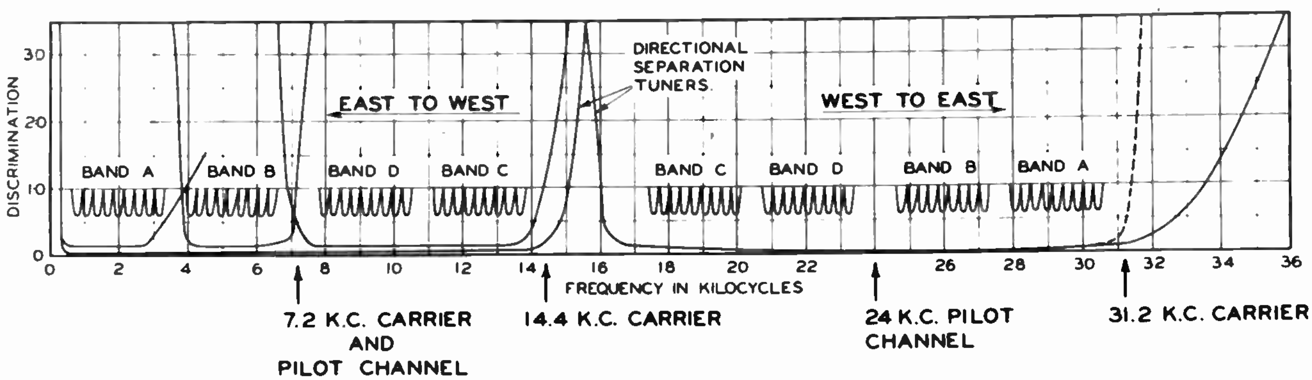
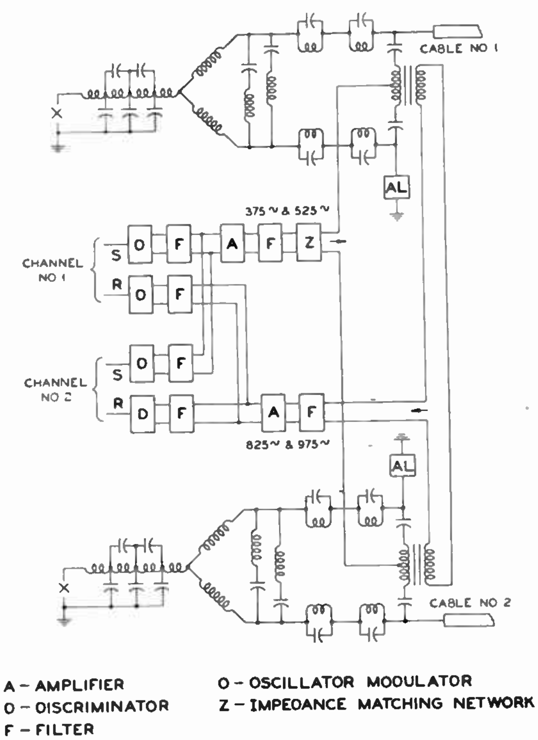


Fig.10 - Channel Allocations of Type F, 18 Channel and Type G, 36 Channel Systems.



provide 2 two-way channels operating at frequencies of 375 and 425 south bound, and 825 and 975 north bound, and which may be superimposed on any two of the three cables to provide a metallic carrier circuit.

Fig.11 - Schematic Circuit of One Terminal of Key West - Havana Cable Carrier System.

RADIO RELAY

The fourth and current phase in this onward march of telegraph transmission methods paced by advances in electronic science is the radio relay. Its system design is subject to the same general principles and yields the same general advantages as the land line carrier systems just described. Further, the same VF channel terminals may be used as the building blocks for bringing the prodigious message capacity of the micro-wave radio frequencies down to earth, so that operators can send and receive messages.

Readers are familiar with the many articles which have been published pertaining to the many military and other applications of the micro-wave radio frequencies, and the items of equipment which have been developed to render these services possible. Characteristics of the radio channels in the 4000 mc region make them attractive as transmission mediums over routes where telegraph traffic is heavy. These characteristics are, notably:

1. Beaming of the transmitted wave reduces interference, favors secrecy and permits the multiple use of the same wave length.

2. RF power requirements are very low.

3. Wide bands are available.

A series of radio relay systems connecting major cities is planned, and construction of the first links of the network is well under way.[7] The initial installations will link the cities of New York, Philadelphia, Washington and Pittsburgh, and will require the establishment of 20 radio relay stations distributed between these terminals. The adaptation of what are essentially radar techniques to these long-distance telegraph systems is the work of engineers of the Victor Division of the Radio Corporation of America. Western Union engineers have established the transmission requirements as regards the exacting quality and continuity necessary for a commercial telegraph system, and have developed the 512 channel carrier terminal which will load up the 150 kc RF band.

The 512 channel figure is figurative rather than literal for it is not at all necessary to expend the entire transmission capacity on the handling of teleprinters. Reference to the figures indicates that the 150 kc band is broken down in a succession of steps into smaller and smaller units until eventually there appears a series of 32 bands of 3000-cycles width, which in the next step are halved and are then each divided into 8 channels suitable for teleprinter operation. At any of these points, suitable terminal apparatus may be connected to accommodate facsimile or other services.

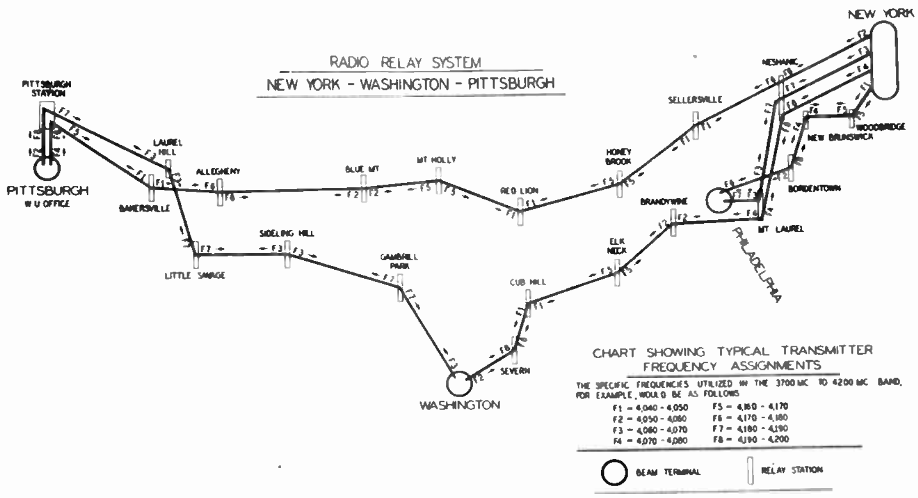


Fig.12 - Route of Radio Relay Circuits, 1946-47.

The abbreviated diagram for the 150 kc system gives only an idea of the vast number of equipment panels filled with apparatus which make up this system. Amplifiers are necessary at frequent intervals to recoup the losses occasioned by modulation, filtering, etc. An extensive frequency generation system is necessary. The modulators are all of the crystal or copper-oxide types.

As a measure of the confidence which is placed in modern thermionic tubes and other electronic devices, it can be pointed out that a telegraph signal in passing from a sending to a receiving teleprinter may traverse in the 150 kc terminals alone 20 amplifying stages. In the radio transmitter and receiver 40 more tubes are encountered, these including klystrons operating at 4000 mc. At each relay station, 23 more tubes in wide variety are traversed. Further, any channel group is dependent upon tubes serving auxiliary functions such as frequency supply, AVC, power regulation, etc., in the number of 18 at the two 150 kc terminals, 7 at the two radio terminals, 7 at each

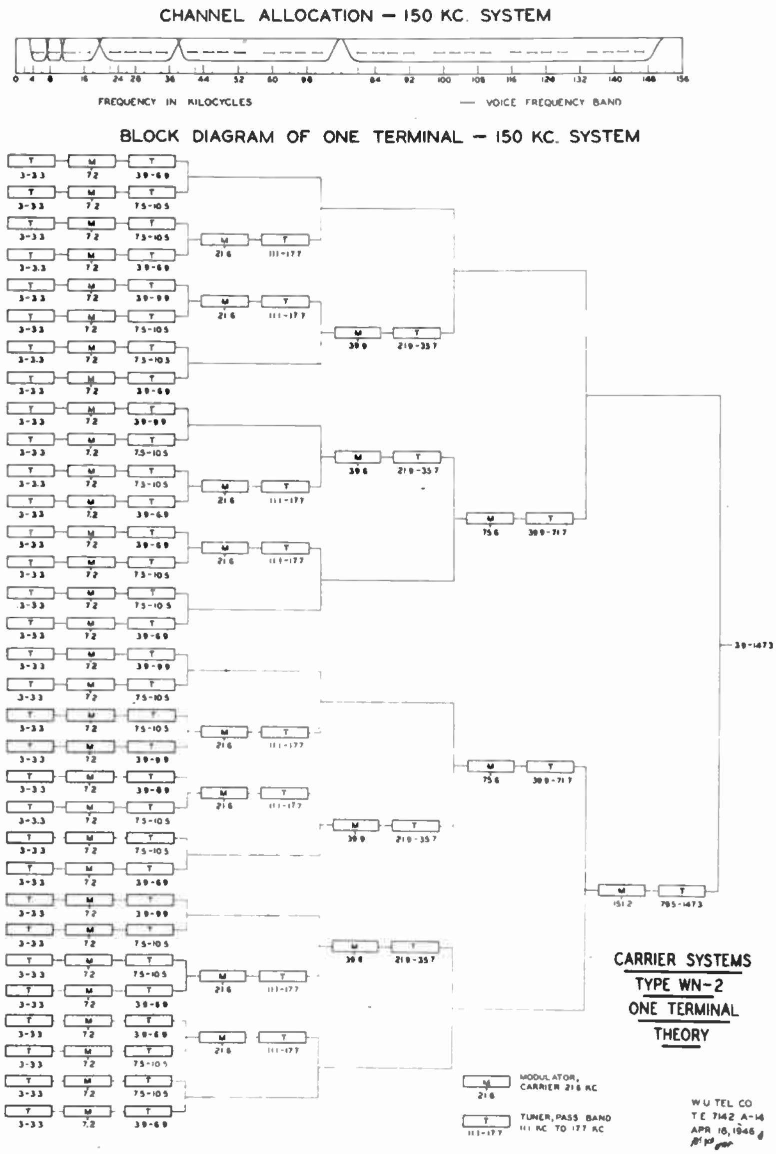


Fig.13 - 150 Kc Carrier System Terminal.

relay station. A tally indicates that for a relatively short circuit involving 10 relay stations (approximately 400 miles) the telegraph signal is entrusted with practically perfect safety to a total of 380 space paths! Of similar portent is the fact that 285 of these tubes have in their tender care the entire load of 512 telegraph channels. When a single tube failure means the interruption of 512 circuits, naturally tube reliability must be of a pretty high order. The near perfect freedom from distortion and intermodulation which is now provided in vacuum tubes will be obvious from the above figures. It is worth noting also that frequency translations occur in the number of 12 in the two 150 kc terminals, 5 at the two radio terminals and 3 at each relay station, to total 45 for the above system.

FACSIMILE

Telefax, the name given to the facsimile method developed by Western Union engineers, is handling an increasing share of the telegraph load particularly in the direct contacts with the customer.[8] Most vital of the facsimile electronic items is the photo-cell which translates the light variations as reflected from a light beam directed upon the message sheet into electrical current variations. Of equal importance is the transcribing process at the receiver where a stylus carrying signal current at a moderately high potential plays upon a moving sheet of Teledeltos paper. The stylus potential serves to transfer black particles from the carbon-coated under surface of the paper through the paper to the light-colored upper surface to produce black marks upon the paper corresponding exactly to the marks on the original message sheet as encountered by the scanning light beam.

Fig.14 - Slot Deposit Telefax.

Intermediate these two basic elements of apparatus, the transmission process is much the same as in carrier current telegraphy and the same facilities may be used. However, as facsimile has moved in to the class of practical signaling systems, it has taken many specialized forms as dictated by the service which it is called upon to provide, and has surrounded itself with a variety of auxiliary supervisory, compensating, automatic control and test equipments. Needless to say, vacuum tube elements are the basis of most of these conventional and nonconventional items.

D.C. TELEGRAPHY

While d.c. telegraph methods have relinquished the bulk of the telegraph load, these methods are still a major facility, and it should be remembered that except for facsimile subscribers' sets, the primary sending and receiving instruments of all circuits are a teleprinter keyboard and a printing magnet. The equipment is principally electromechanical in nature, but thermionic devices are frequently called upon where they will do the job better or more economically. Many of the large telegraph offices are now being completely mechanized so that manual handling of messages as they pass between local distribution circuits and main-line trunk circuits is being entirely eliminated. Interspersed among the intricate mechanisms vacuum tubes are found serving as storage and timing devices, polarity selectors, rectifiers and alarms, and for other specialized functions.

Much ingenuity has been expended in the effort to replace relays with vacuum tubes in telegraph repeaters. The inherent characteristics of the telegraph relay as regards simplicity and cost, input and output impedances, interference discrimination, and its signal regenerating performance make it a "natural" for this job. However, there has been recently developed a repeater for regenerating start-stop signals which now shows considerable promise.[9] This repeater is entirely electronic in nature, except for the receiving and transmitting relays and employs a total of 34 vacuum tubes, most of them twin types, for a two-way repeater. This repeater substitutes for the usual start-stop mechanical distributor a balanced 7-section delay network whose total propagation time is equivalent to one revolution of the usual 7-segment distributor. Receipt of an incoming signal starts a pulse traveling down the network which at each junction energizes the grid circuits of a pair of vacuum tubes to determine the proper polarity for retransmission.

Another telegraph repeater has seen limited service which is designed to repeat the signals as received without distortion, in contrast to the regenerative type.[10] It is intended for service on duplex circuits in unattended locations. Variations in duplex balance between the lines and the repeater artificial lines in consequence of weather changes produce distortions in the repeated signals but these distortions are transmitted faithfully in order that they may be partially compensated at the next attended repeater station. In this repeater, to avoid the usual problems of amplification of d.c. polar signals, the incoming signal reversals produce 180° phase reversals in a local carrier. After amplification, the carrier phase reversals are converted back to d.c. signal reversals which are then applied to the grids of a pair of transmitting tubes.

The switching systems, the Varioplex[11] and the Reperforator Switching System[12], are using an increasing number of tubes for various specialized purposes such as timing, signal storage, and for voltage sampling in monitoring and supervisory applications where the power available would not permit the use of current operated devices. In many of these applications, gas tubes are particularly serviceable. These functions are additional to the basic ones of amplifying, rectifying, etc., where tubes are used as a matter of course.

POWER SUPPLIES

Telegraph offices are commonly supplied with d.c. potentials of 110 and 160, both positive and negative. In large offices, these potentials are usually supplied by motor-generator sets, but in small offices, rectifiers of different types, including mercury arc, have long been used. However, with the advent of the hot-cathode mercury tubes and with the improvement in over-all circuit design, power supply rectifier sets in the smaller sizes have come into very wide use. Rectifiers for furnishing main-line battery supply to two or more circuits must have very low internal impedance in order to avoid intermodulation between the circuits. This requirement is ordinarily met through the choice of tubes and by proper design of the filter circuits. In the larger sizes, three and six-phase designs may be resorted to in order to elevate the ripple frequency and hence simplify the filtering and common impedance problems. Many of the larger plants embody voltage regulating means.

A considerable number of specialized rectifier designs have been developed for particular purposes. Among them are the small and cheap units which accompany customers' teleprinter installations, and the units which furnish ungrounded potentials to metallic telegraph circuits.

Since the regular and emergency power supplies in telegraph offices are always at 110 and 160 volt potentials, it is necessary to design thermionic apparatus to operate on either one or both of these two potentials. In consequence, the tubes with 25-35 volt cathode heaters are preferred and these are connected two or three in series where possible. Occasionally this limitation has been somewhat of a handicap. It is possible that eventually the practice will be adopted of furnishing the equipment bays with low voltage a.c. distribution systems for cathode heating.

MISCELLANEOUS

The applications previously outlined account for the bulk of the vacuum tube consumption in the telegraph field. However, since all communications engineers, whatever their particular specialty, are electronics conscious, vacuum tubes are put to work wherever they will do the desired job better than the alternatives. Some of these jobs are:

Back voltage rectifiers to prevent cable electrolysis.

Neon tubes as tell-tales, voltage indicators and regulators.

Gaseous tube lightning protectors.

Lineman's communicating sets.

Cable ship test and indicating instruments.

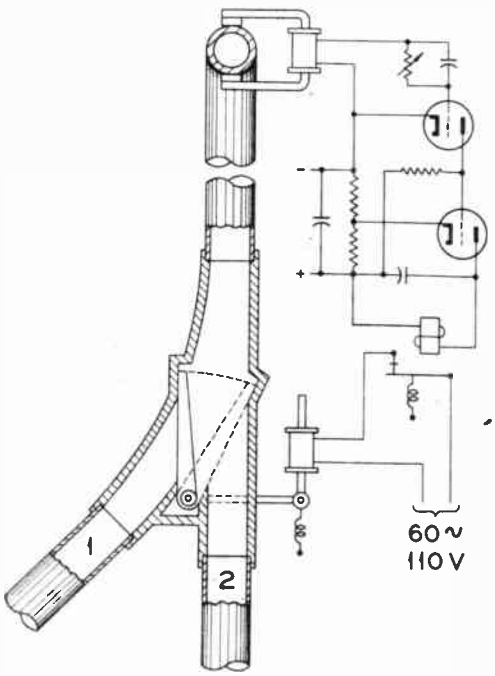


Fig.15 - Pneumatic Tube Carrier Selector System.
(Non-magnetic carriers enter branch 1. Carriers provided with a magnetic band cause operation of the gate to deflect them into branch 2.)

Submarine cable transmission measuring and testing equipment.

In carrier selectors in pneumatic tube systems.

Power interference neutralization.

Standard frequency forks.

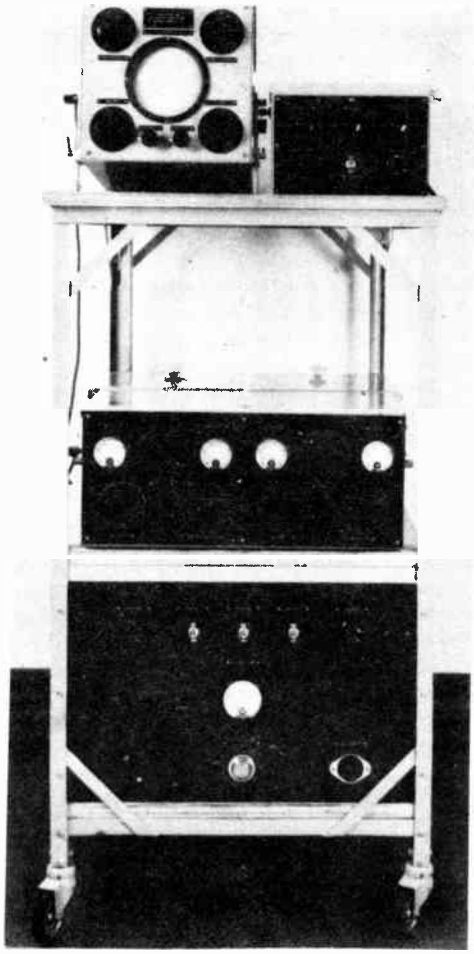


Fig.16 - Special Oscilloscope for Submarine Cable Investigations.

LABORATORY AND TEST EQUIPMENT

In the laboratories of the Telegraph Company, there is in progress a continuous process of developing new communications systems and of improving the current ones. Like any other up-to-date communications laboratory, these laboratories are well equipped with the basic items of test apparatus, but they include in addition a variety of equipment designed to perform specialized functions peculiar to the job at hand.

For field use in circuit testing, oscillators and amplifiers of appropriate frequency ranges are, of course, indispensable. This apparatus is both fixed and portable in type, occasionally it is of commercial design but more often these items must be specially designed to meet the service conditions and power supply. Lines of special sets have been designed for such purposes as testing the quality of telegraph transmission, the level and character of interference, the checking and adjusting of relays and many others.

SUMMARY

Under the limitations of a brief paper it has been necessary to omit detail, but it will be clear that in this fourth era of telegraph progress electronic apparatus has reached an order of importance perhaps second only to the line conductors themselves. The number of tubes in service has been growing at what might be called a logarithmic rate to a sort of momentary climax in the 1946-1947 period. In this period, there will be consummated a conversion and expansion program involving the mechanization of many large offices, the installation of a considerable mileage of new carrier systems and the inauguration of a radio relay system linking the cities of New York, Philadelphia, Washington and Pittsburgh. In this program electronics will have a most important part. In 1946, Western Union purchases included 30,000 tubes of one of the popular types, and smaller purchases of 60 or more other types.

Substantially all of the tubes in telegraph service are of the standard types as described in the familiar receiving tube manuals, chosen primarily on the basis of function and adaptability to the available supply potentials. Since most tubes perform a vital service 24 hours daily under a wide range of conditions such matters as life, ruggedness, overload capacity and power consumption are very important. Continued availability and insurance against obsolescence are also important considerations. Tubes designed for service in home broadcast receivers do not always meet these all-around exacting requirements, and consideration has been given to the design of a special line of tubes in what the radio industry characterizes as the "receiving" tube class. "Industrial" types are of course employed wherever they can be made to serve.

The mechanical operating equipment of telegraph offices must be precision built, and in service requires considerable maintenance by specially skilled mechanics. These costly features will encourage telegraph engineers to develop substitute equipment operating along electronic lines. New systems may be entirely electronic in nature with but a minimum of mechanical elements. Progress in this direction is being accelerated by additional factors such as the electronic mindedness of the new generation of telegraph operating and maintenance personnel, and the redesign of the power supply and distribution systems of telegraph offices to better accommodate tube requirements.

- - - - - - - -

BIBLIOGRAPHY

[1]The Newfoundland-Azores High Speed Duplex Cable, by J.W. Milnor and G.A. Randall, ELECTRICAL ENGINEERING, May 1931, p. 337.

[2]Application of Vacuum Tube Amplifiers to Submarine Telegraph Cables, by A.M. Curtis, BSTJ, July 1927, p. 425.

[3]Picture Transmission by Submarine Cable, (Patents 2,248,887; 2,281,996; 2,281,997), by J.W. Milnor, TRANSACTIONS AIEE, March 1931, p. 105.

[4]Frequency Modulated Carrier Telegraph System, by F.B. Bramhall and J.E. Boughtwood, TRANSACTIONS AIEE, Jan. 1942, p. 36.

[5]A High Speed 2-Wire, 16 kc, Telegraph Carrier System, by F.B. Bramhall, TEL. & TEL. AGE, Oct. 1942, p. 16.

[6]Patent 2,374,567, R.C. Taylor.

[7]Radio Relays for Telegraphy, by F.B. Bramhall, ELECTRICAL ENGINEERING, NOV. 1946.
A Preview of the Western Union System of Radio Beam Telegraphy, by J.Z. Millar, JOURNAL FRANKLIN INSTITUTE, June 1946, p. 397.
A Micro-Wave Relay Communication System, by G.G. Gerlach, RCA REVIEW, Dec. 1946.

[8]Facsimile Telegraphy, Some New Commercial Applications, by J.H. Hackenberg, ELECTRICAL COMMUNICATIONS, Jan. 1940, p. 240.

[9] Electronic Regeneration of Telegraph Signals, by H.F. Wilder, TRANSACTIONS AIEE, Jan. 1946, p. 34.

[10]Patent 2,341,902, W.D. Cannon, et al.

[11]Basic Principles of the Varioplex System, by P. Holcomb, TRANSACTIONS AIEE SUPPLEMENT, DEC. 1941, p. 1102.

[12]Recent Developments in Telegraph Switching, by F.E. d'Humy and H.L. Browne, TRANSACTIONS AIEE, Feb. 1940, p. 71.

THE SUPPRESSED CARRIER MODULATOR

AS A FREQUENCY TRANSLATOR

By

F.B. BRAMHALL

The classical explanations of the phenomenon of modulation are probably wholly satisfying to one trained to think and visualize as the mathematician does. Still there are many of us who would like to see in simple words a satisfying explanation of frequency translation without resort to mathematical mystery. The task is undertaken in a playful mood but yet not irreverently. Perhaps it can be done. If it can, any reasonable effort expended is justified. The current communication literature generally "tacitly" assumes an understanding of the basic principles of modulation saying, "a signal of 1000 cycles modulates a carrier of 8000 cycles and produces some useful 7000 and some disposable 9000". Many readers of these words are tempted to think that the author misused the word "tacitly", and surmise that he "tactfully" dodged the issue. A thorough appreciation of the beauty of the phenomenon, however it be presented, does get one rather deeply into the woods of mental concentration. Before we push in so deep we can't see the forest for the trees, let's have a look at the reason for our interest in modulation as a means of transplanting frequencies.

Our primary interest is, let us say, telegraph communication; telephone modulation we shall learn later takes care of itself and is quite as simple. Striving for economy in the use of line conductors, we want to stack a great many communication channels above one another and transmit them all over a single pair of wires. Analogous considerations lead to the same ambition if the transmission medium be a coaxial cable, a radio circuit, or a wave guide. Why, you may say, don't we generate them in the proper position in the first place? One good reason is the extreme and increasing difficulty and expense of building narrow channelizing filters for higher and higher frequencies. Another is the consideration of flexibility; groups of channels of the size required to serve an average community make for ease and simplicity in circuit routing and handling. Economy in constructing channelizing equipment also results by limiting the number of different types and increasing the number of units of each. In telephony, of course, we just can't generate the speech currents in a high band. Similarly, we can't receive them directly on a high band either - they just must be translated at both ends.

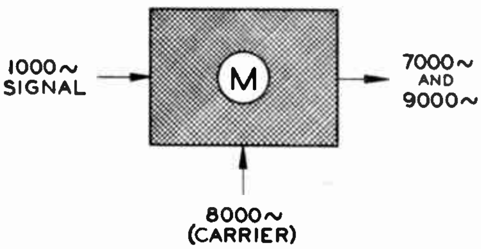


Fig. 1 - The Fact We Propose to Explain

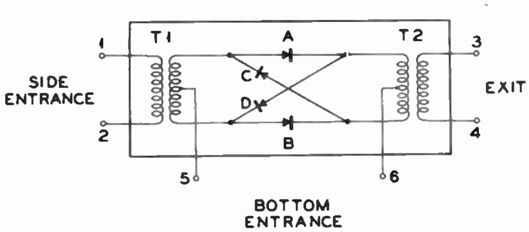


Fig. 2 - Contents of Black Box - Modulator

Now because hindsight is usually better than foresight, let us attack this translation from the back end. Without worrying about the why and the wherefore, let us look at the result of a strange technique and explain it later. We are told in the "tacitly" written literature that if we pour a signal frequency (let's call it 1000 cycles) into the side hole of the black box marked "M" (for modulator), and push another frequency up in the bottom hole of the box (say 8000 cycles) out of the exit hole comes 7000 cycles and 9000 cycles.

Let's open the box and see what makes it perform this seeming miracle. We find an innocent looking arrangement of transformers and rectifiers.

Transformers we'll presume to behave as transformers were taught to behave. Therefore, let us assume that no explanation of these is necessary. One hundred words about the rectifiers. If a huge positive potential is applied to the arrows they become negligible resistances, and will conduct tiny a-c currents, induced by a second source of potential, freely in either direction. If a huge negative potential is applied to the arrows, they flatly refuse to conduct anything; they become extremely high resistances. Does that concept offend your intelligence and contradict your preconceived notion of how a well brought up rectifier ought to behave? Well let's say it differently with Figure 3.

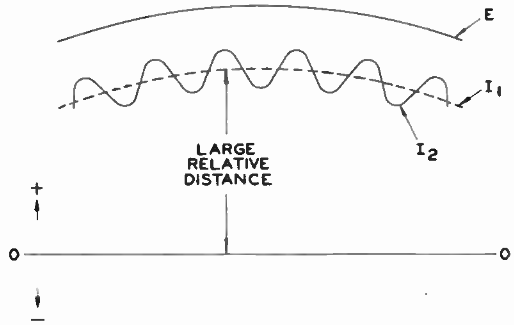


Fig. 3 - Superposed Currents.

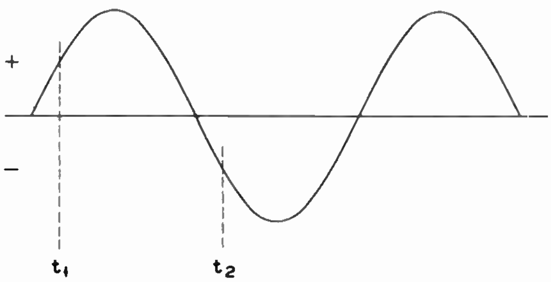


Fig. 4 - High Amplitude 8000-Cycle Carrier Applied to Terminals 5 and 6.

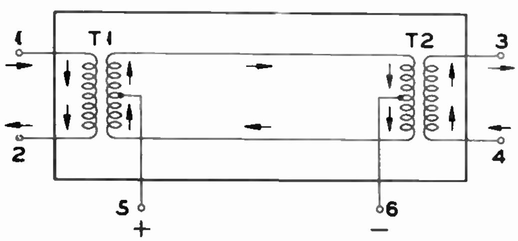


Fig. 5-A - Condition When Terminal 5 is Positive.

Let I_1 be the current produced by the huge positive potential E. No law against having that current go up and down a trifle in response to a second small potential so long as it remains a current from arrow to plate, always flowing through the rectifier in the same direction. So I_2 can be the small current flowing in response to the second potential, wholly unresisted. All right! If E is moved to the other side of 0-0 (opposite pole) no current flows from any cause. We allowed that in the first place.

OK! Now let's push a relatively large potential of 8000 into the bottom (carrier) entrance to the modulator. Let it be a nice sine wave like Figure 4, and look at time t_1 very early on the rise of this first positive half cycle. A plus voltage of considerable magnitude appears on Terminal 5 with respect to Terminal 6. So by our token rectifiers "A" and "B" are now conductors and will pass currents. We have the condition of Figure 5-A, where rectifiers "A" and "B" are substantially perfect conductors and "C" and "D" are as good as open. What happens? Well our 1000-cycle signal wave of relatively small amplitude impressed across terminals 1 and 2 sees its chance to rush right through both transformers and come out on terminals 3 and 4. The small arrows in Figure 5-A show the direction of the 1000-cycle current at time t_1. It starts, but after it has climbed only a trifle the rectifier control potential on terminals 5 and 6 (8000 cycles) has passed its first positive half cycle and started on the negative half; the potential reverses on terminals 5 and 6 rendering rectifiers "A" and "B" nonconducting. But that's all right because at time t_2 positive shows up on the arrows of "C" and "D" and these two become conductive as shown in Figure 5-B. The 1000-cycle signal still has a path to terminals 3 and 4, but the connection of the secondary of transformer T_1 to the primary of transformer T_2 has suddenly become reversed. Being not dismayed, the 1000-cycle signal decides to make the best of the situation and go through in spite of the sudden change in direction. The new path is again shown by the small arrows.

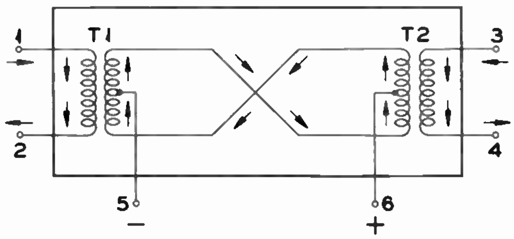
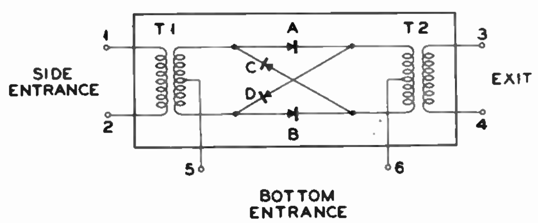


Fig. 5-B - Condition When Terminal 5 is Negative

The continual shifting of paths makes the 1000 cycles come out a bit shredded. We'll draw it out in Figure 6, one full cycle.

No two ways about it, X is what did come out but what is X? We'll persist in our original intent if possible, and insist we don't know any mathematics beyond 3rd grade, and see what we can make of X.

The first impression is that there must be some 8000 cycles because whatever it is it goes through zero at the same time the 8000 does. True it is a peculiar wave shape; looks like square topped 8000 changing in amplitude from zero to maximum.



We presume, however, from looking at the circuit of the modulator that anything which goes into it at the bottom (terminals 5 and 6) can never come out of either end because of the evident differential, or balanced nature of the arrangement. Terminals 5 and 6 connect to the mid-points of both transformers so whatever the currents that flow from 5 to 6, they split equally at these mid-points; and flow on from there in opposite directions through the transformer winding. This says they produce no magnetic flux in the transformer and can, therefore, induce no potential in the other winding. This is the fact. We look a little closer, and we notice that the two succeeding bursts (cigars) of 8000 are 100% out of phase - 180° if you must be rigorous.

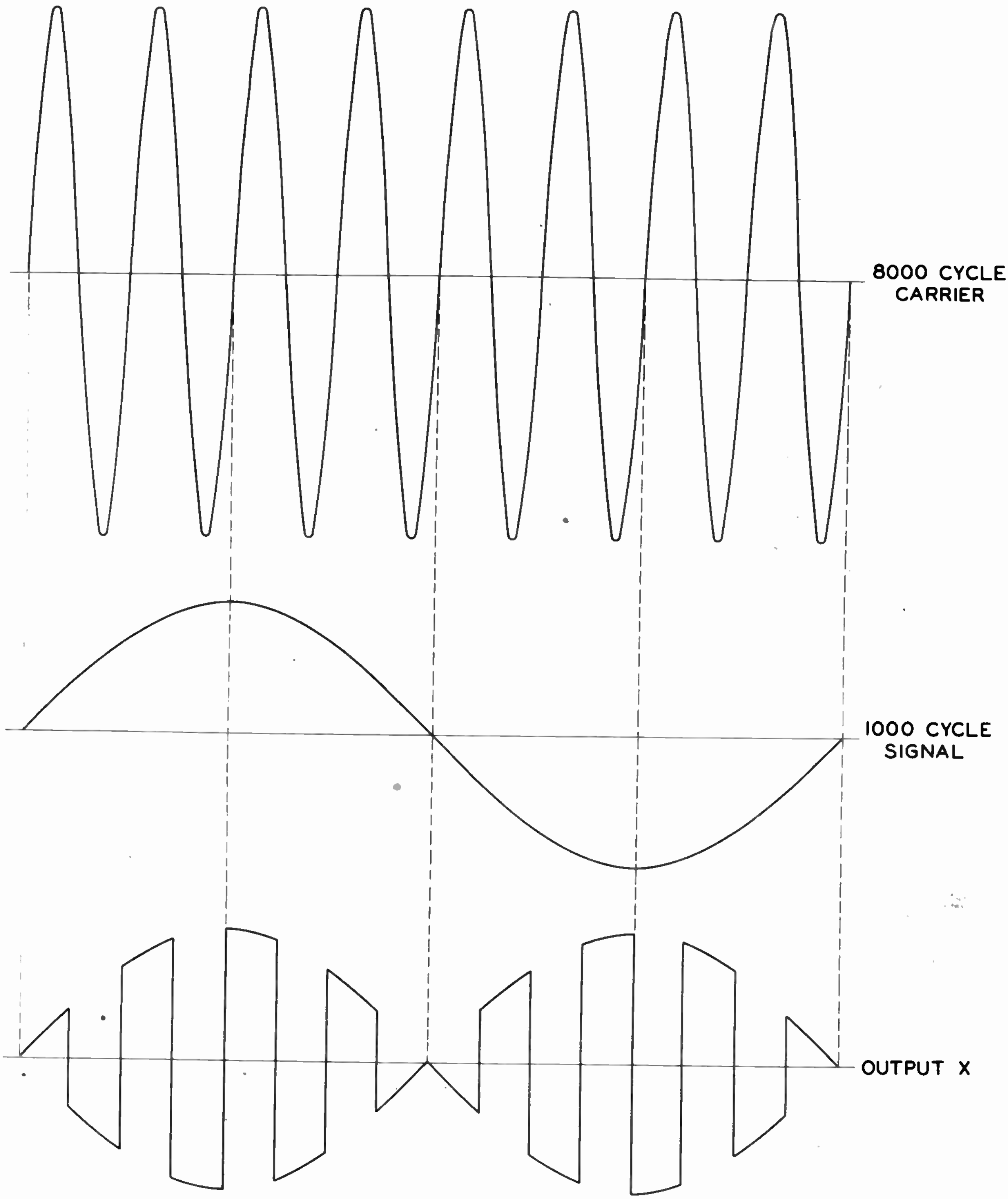


Fig. 6 - Instantaneous Switching of Signal at Carrier Rate.

Figure 7 shows how No. 2 burst would look if it weren't wrong side up. If we try to drive an 8000-cycle resonator with X of Figure 6, we find it won't go because no sooner does it start to get in motion under the influence of cigar No. 1 than it is completely discouraged by cigar No. 2 so we are forced to admit there is no detectable or measurable 8000.

The other frequency that went into the modulator to make up X was 1000. Isn't there any of that here either? We can't say offhand.

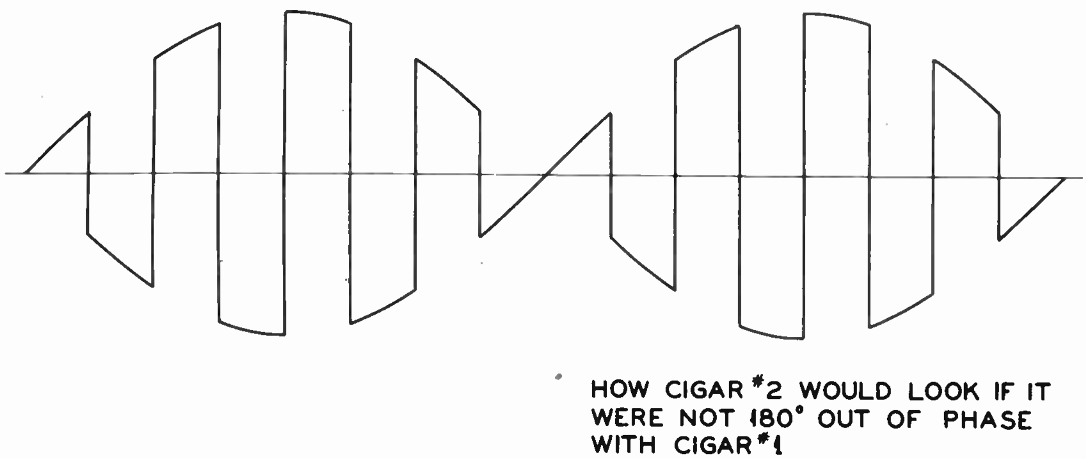


Fig. 7 - Were the Phase of Succeeding Envelopes Not Reversed.

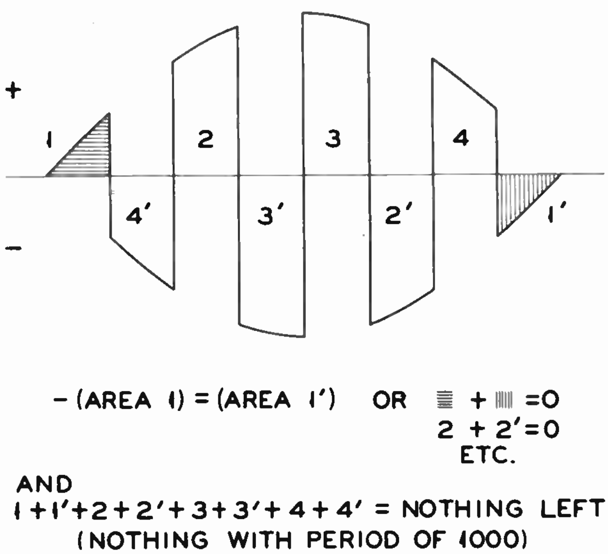


Fig. 8 - Will Not Drive a 1000-Cycle Resonator.

One test is will it keep a 1000-cycle resonator going. Is there anything in cigar No. 1 to push up, and anything in cigar No. 2 to push down with a periodicity 1000 cycles per second? Integrate all the energy above and below the line on cigar No. 1. Oh, no! We can't integrate. Well better still, cross off equal bits above and below and see what's left, Figure 8.

After we cross off equal portions this way, there is nothing left either in cigar No. 1 or cigar No. 2. Rigorous test, there's no 1000 cycles either. We're very fortunate up to now - we surely would have been in a bad way if we'd found either.

Just what is X anyhow? Well, we hope there's some 7000 and some 9000. Let's be highly unscientifical and take some 7000 and some 9000 and add them up. If the answer looks like X, we can live happily ever after, maybe. We know the answer anyhow; thanks to the mathematicians; we only want to explain it. In Figure 9, we draw a sinusoidal 9000 - (upper sideband) and 7000 (lower sideband), then just quietly add them point by point. The result is X'. It bears a fundamental resemblance to X. And I use the word "fundamental" advisedly. We might call it a sinusoidal edition of X (not so rigorous, but qualitatively correct). Now, let's inquire what is the difference, or more precisely, what does the difference represent? Well qualified authors tell us in terms of "Fouriers Series" that a square topping of a periodic wave introduces frequencies which are odd-number multiples of the fundamental frequency. For all practical purposes, the only difference between X and X' is the square topping of the former. Now odd multiples of 8000 are as follows:

3 x 8000 = 24,000   7 x 8000 = 56,000
5 x 8000 = 40,000   N x 8000 = M, thousand

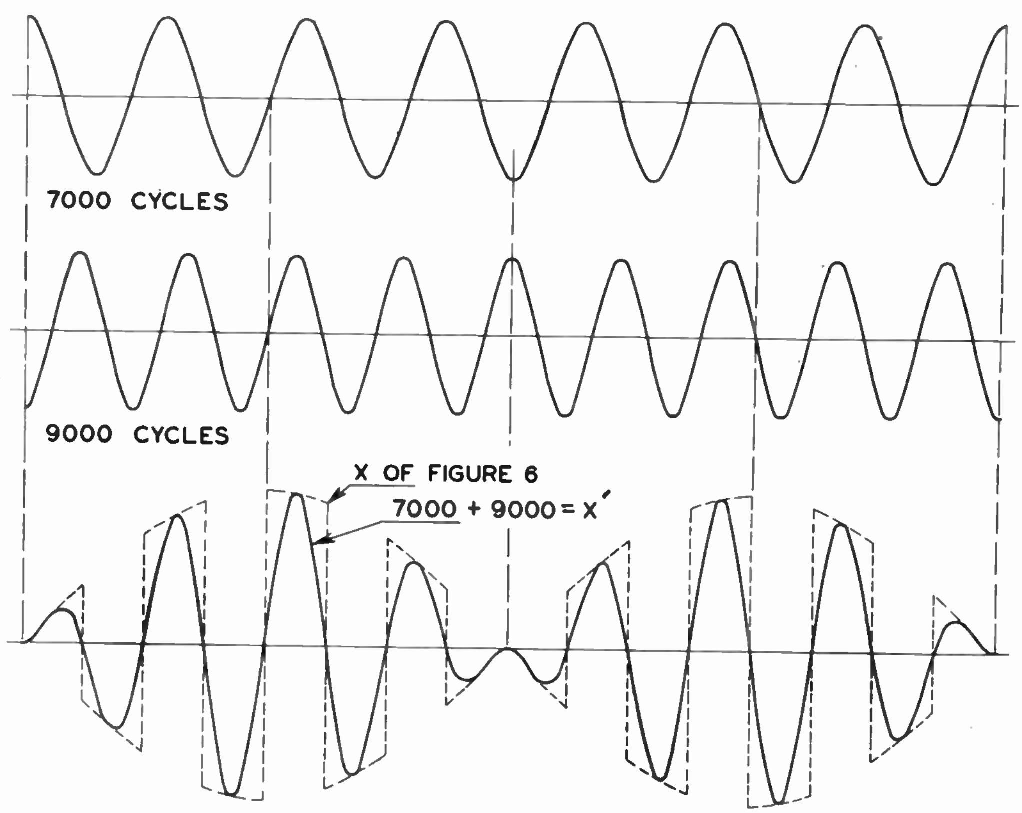


Fig. 9 - Simple Synthesis of Modulated Output Wave

Now we examine in a crude manner the wave shape to see if we can reasonably expect to find one of these frequencies, say the first, 3 x 8000. We deliberately draw a third harmonic on a wave somewhat like X', Figure 10. We examine, compare, and cross out elements of what we presume to be a 24,000-cycle ripple. It looks very much like all 3 x 8000 bucks itself out for the same reason that the 8000 itself cancelled out. Now let us retire to the solitude of a laboratory equipped with measuring apparatus. We promise to report the results in truth, give the whole truth and no befuddling embellishments. We conduct an experiment and try to find some 24,000 by measuring what part of this wave will actually come through a 24,000-cycle filter. We find none! But while hunting for 24,000, we do discover some 23,000 and some 25,000. Working now on a hunch, we look for 39,000 and 41,000 and find them both but no 40,000. So we jump at the conclusion that those things which make X have its squared appearance are removed from their true harmonic positions by a frequency which is actually the signal frequency, 1000 cycles. In other words, the first pair of unwanted products of modulation are (3 x 8000) + 1000 and (3 x 8000) - 1000.

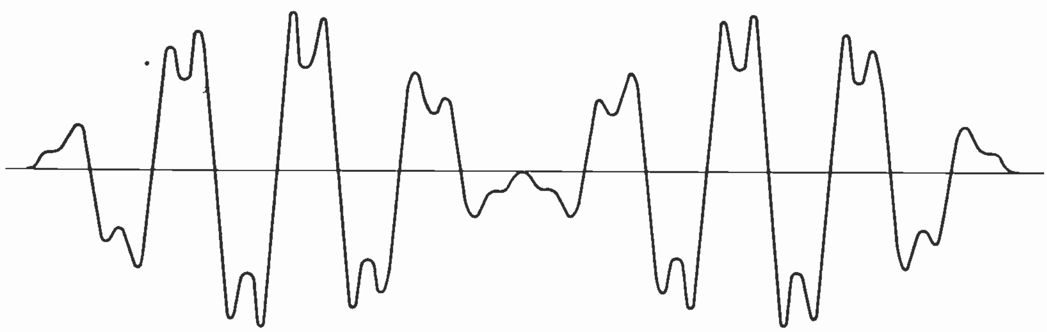


Fig. 10 - Synthesis of Improved Fidelity

All the frequencies present in X to produce the square topping are well out of range of the thing we were interested in. In other words, we set about to translate 1000 into 7000, let us say. We follow our modulator "M" by a filter "F" which rejects things above a certain number. It is only required to reject frequencies which are odd multiples of the carrier plus and minus the signal frequency. This seems a reasonable enough requirement and with only a little forethought in band layout, it is easily met.

Oh, so you've heard of the double pole, double throw reversing switch analogy for modulators! Exactly, except for certain simply stated but difficult to accomplish requirements, we may replace the four rectifiers with a double pole, double throw switch. All it need do is reverse the connections between the two transformers. The requirements are that we throw the switch 8000 times per second, and that the time when the blades are in mid-air be zero. This is a bit difficult to imagine, but remember vacuum tubes were used in modulators of this type many years ago. Remember, too, that modulators take many other forms.

Summing up now, we showed that the output of a balanced modulator contained no signal frequency and that it contained no carrier frequency. It did consist of two sidebands, the frequencies of which are the sum and the difference of the carrier and the signal frequencies. These we call first order sidebands. The spurious odd-multiple frequencies are generally called higher order sidebands. Specifically, they are sometimes identified by the numbers by which we multiply the carrier to locate them, as for instance, 3rd order, 5th order, etc. Make no mistake, there are other unwanted products of the modulation, but perhaps we need not explore them here as they will also be pretty well out of the range of useful frequencies and so disposable if good filters are used after our modulators.

Up to this point, it has been presumed that both the carrier and the signal are at steady state amplitudes, or more simply perhaps both have been going on without alteration since the beginning of time. With the signal continuously at steady state of course, we send to the receiving station no intelligence, only a knowledge of its frequency. To send intelligence as represented by the teleprinter or other code, the signal frequency is in some manner in its turn modulated. Either it is started and stopped conforming to the printing impulses, or else its frequency is moved up and down by these impulses. Let's suppose it's to be started and stopped. Very well, then this act of starting and stopping the 1000 cycles (the original signal frequency) is as legitimately called modulation as is the translation of the 1000 to 7000. But you say, yes, you knew that. It is proposed to pursue the subject only far enough to show that the original modulation, starting and stopping, of the 1000 will show up on the 7000. Let us choose to look at that and ignore the 9000 because both will behave in the same manner.

Looking at Figure 11, we use a square topped 100-cycle relay signal S_1 to start and stop our 1000-cycle channel frequency which we will call C_1 (for first carrier). We will assume we are able to start it and stop it instantaneously, which will give us our signal in new form S_2.

But our nice square topped bursts of 1000 cycles will not go through a filter. They get rounded corners - let's say they come out like S_2'. The matter of square wave envelopes going through tuners is quite beyond the intended scope of this story. Perhaps a few simple facts about the phenomenon will not be out of place, however. It turns out that if the tuner has just sufficient width to pass the first order sidebands, the

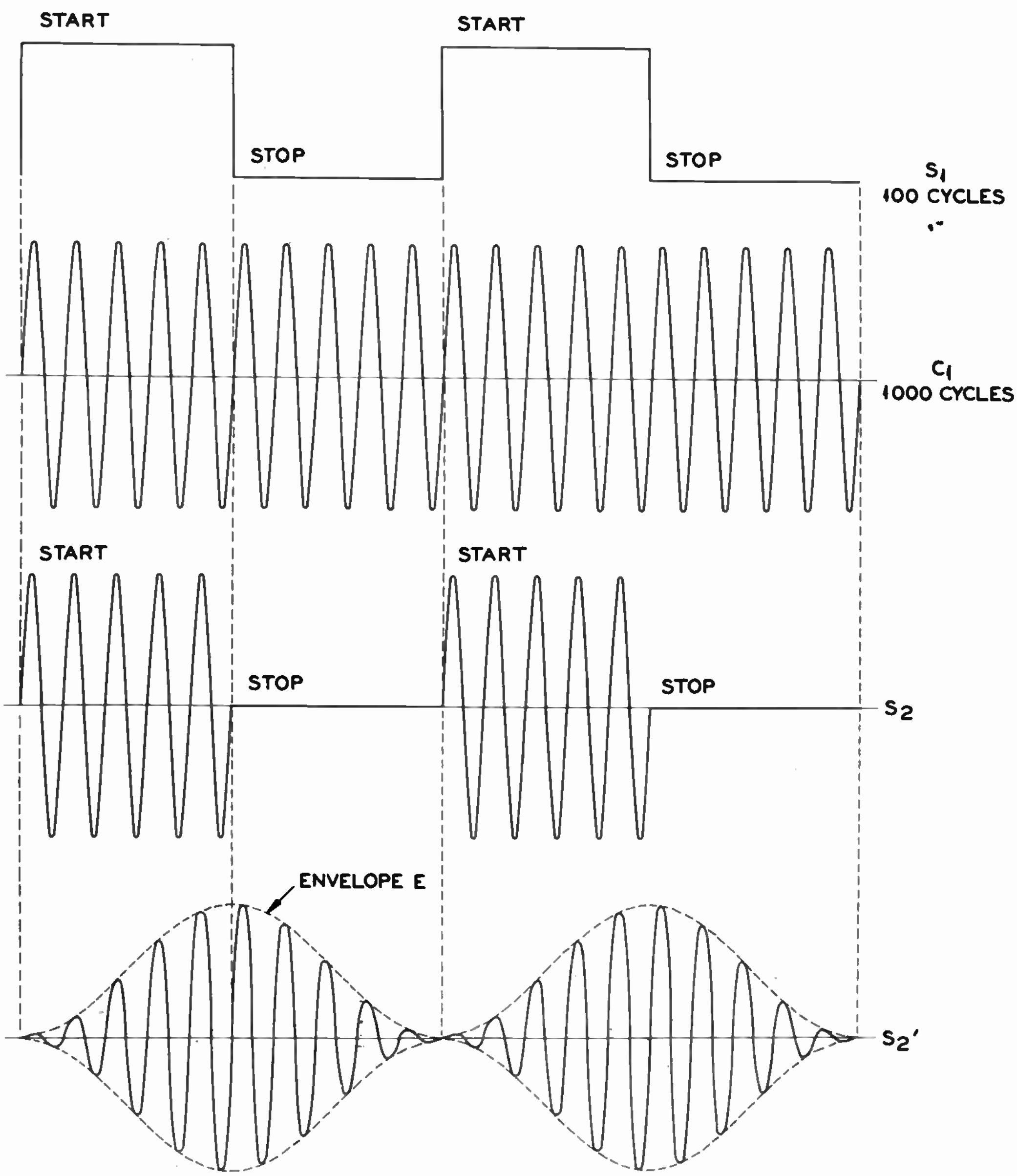


Fig. 11 - Square Topped Amplitude Modulation Through Band Filter

output wave resulting from a square topped input wave such as S_2 of Figure 11 has a sinusoidal envelope. More simply stated for the case at hand, if the telegraph channel tuner has only enough width to pass frequencies between 900 and 1100, the envelope will be that of S_2'. 900 and 1100 are, respectively, 1000 - 100 and 1000 + 100. This cigar S_2' can be shown to contain 1000 cycles at amplitude "A" plus 900 and 1100 cycles, each at amplitude "1/2 A". In Figure 12 we simply add these three frequencies in these relative amplitudes and we get S_2' to prove our point.

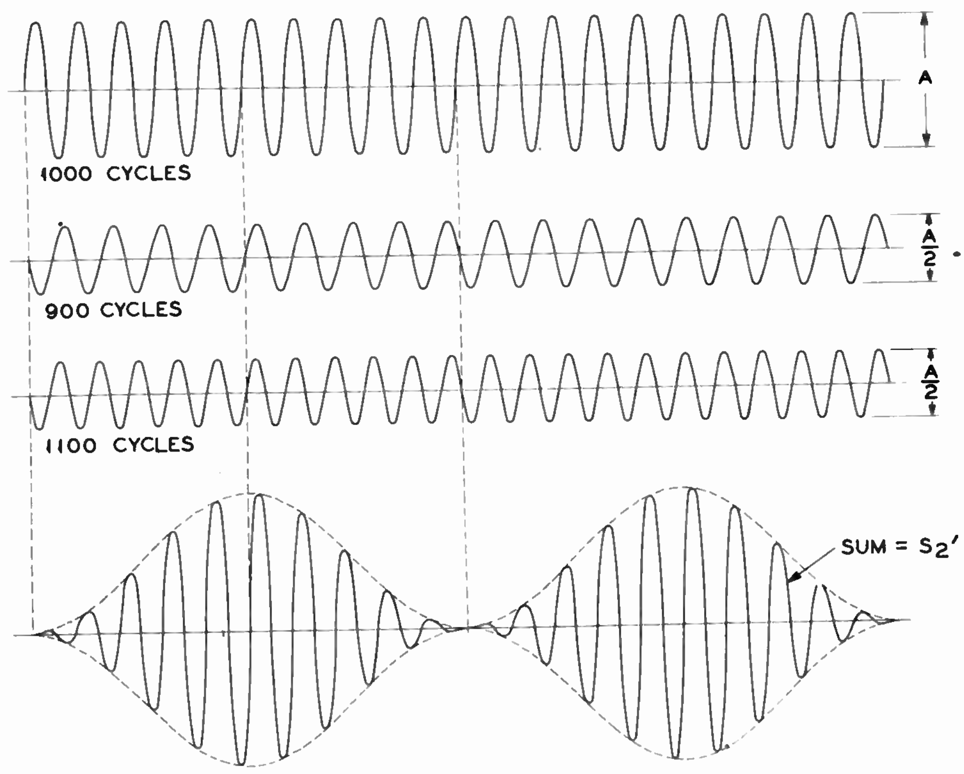


Fig. 12 - Synthesis of Figure 11 Result

All right! Let's go on with the business of translating a wave of varying amplitude. Let's take the first few cycles of one of the cigars in S_2' and enlarge them in Figure 13 so we can have a big enough picture to admit of real close inspection. We then draw our 8000-cycle carrier, C_2, to the same frequency scale - 8 cycles of C_2 in same length of time as one cycle of S_2'.

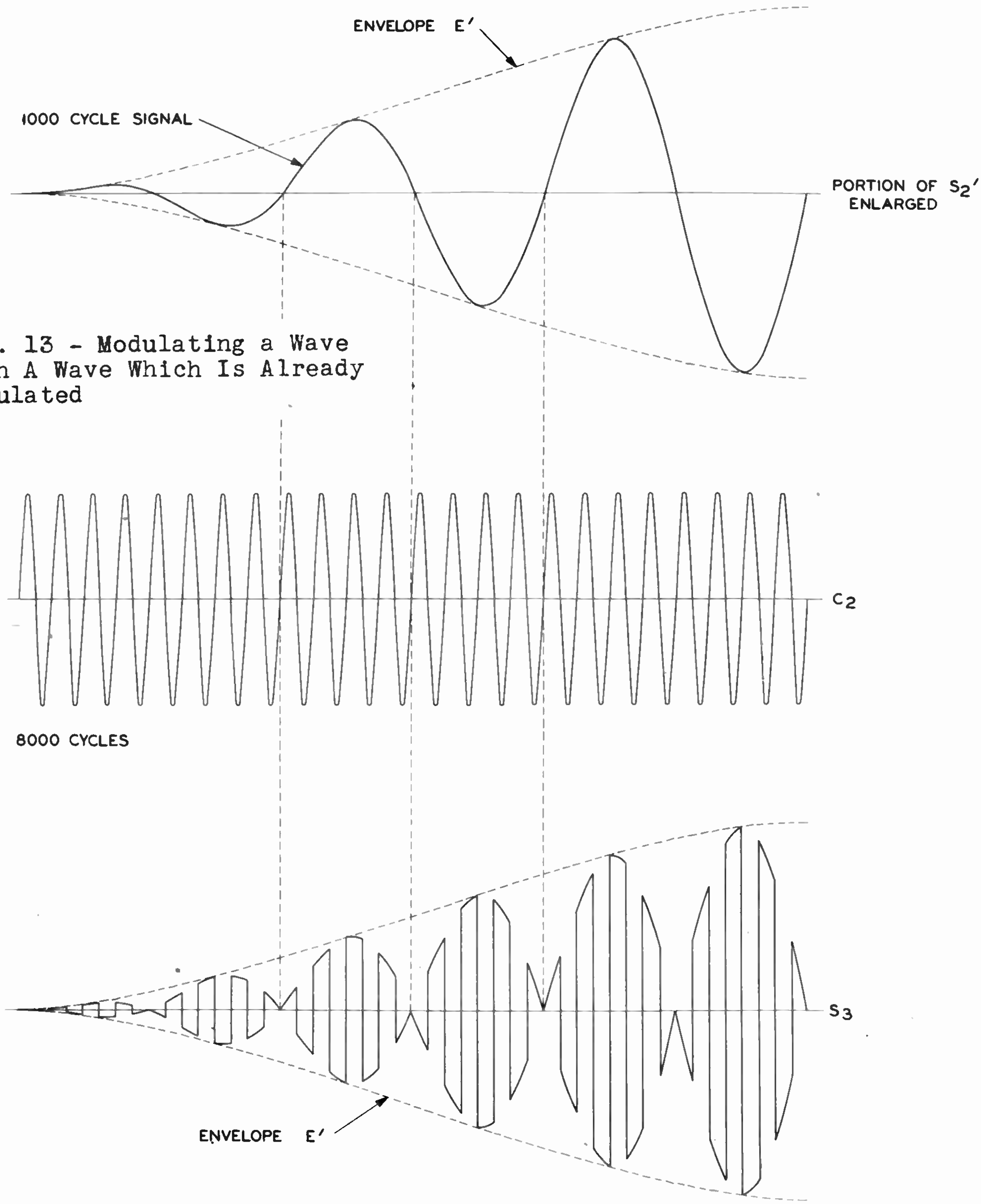


Fig. 13 - Modulating a Wave With A Wave Which Is Already Modulated

From the previous more simple example, we know we shall get the strange looking signal S_3 of Figure 13 that crosses zero at the same time as the 8000-cycle carrier, and the instantaneous amplitude the same as the instantaneous amplitude of the modulating signal S_2'.

Now using our hindsight, we don't have to guess too hard to find out what is in S_3. We know it contains 8000 + S_2' and 8000 - S_2', plus a lot of higher order sidebands. But this time the signals are continually varying in amplitude, so let's try adding 8000 + S_2' and 8000 - S_2', both of which vary in amplitude in accordance with envelope E'. We have already shown that S_2' is 1000 cycles varying in amplitude. Therefore, 8000 + S_2' equals 9000, the upper sideband U of Figure 14, and 8000 - S_2 equals 7000, the lower sideband L, both varying in amplitude. Count the cycles and see if we are right.

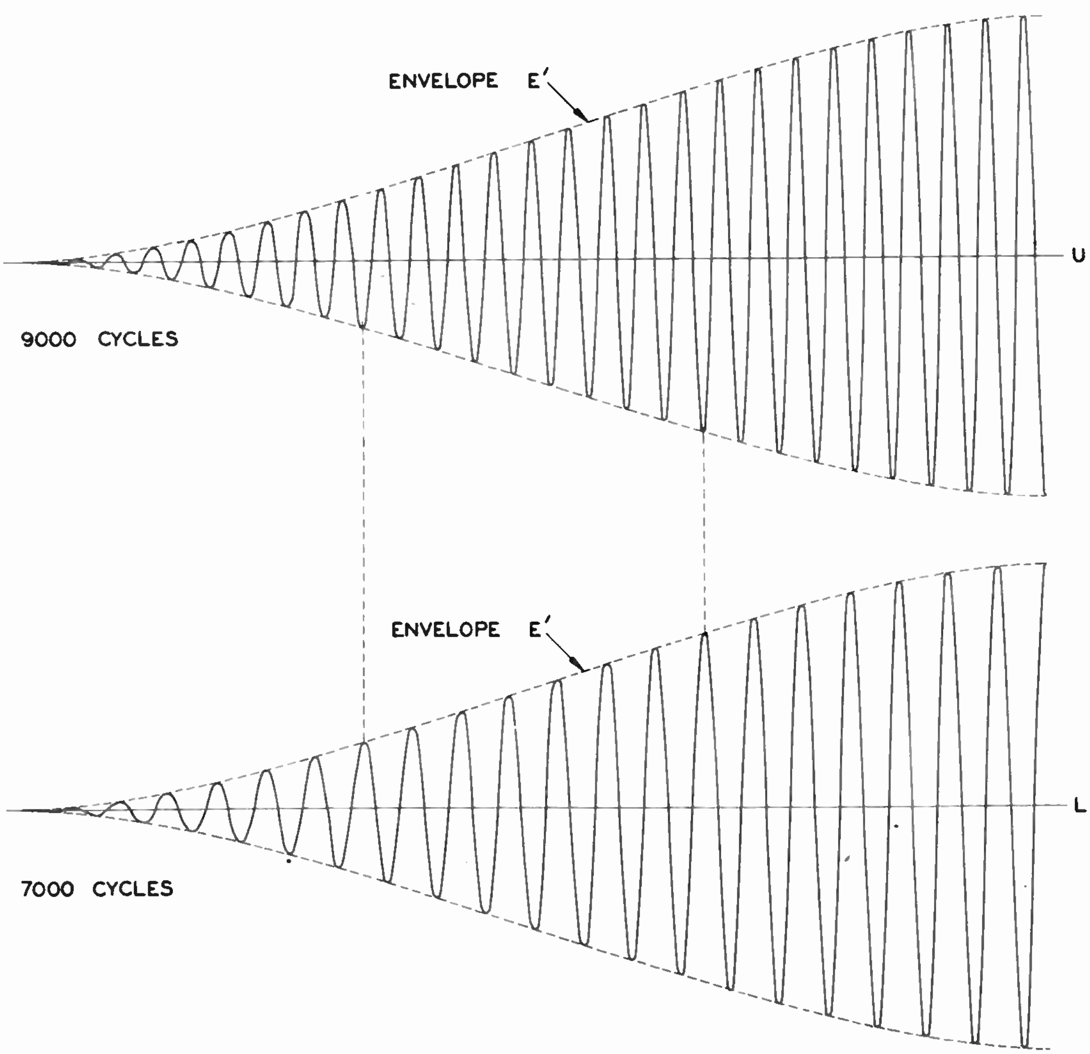


Fig. 14 - Synthesis of Figure 13 Result

Now if we add U and L, we shall again get a signal like S_3 without the square topping. Actually drawing it out is a lot of work, and I am sure you can agree that the last statement is going to be true. So if we throw away U and keep L, we have a signal with the same amplitude rise or envelope as S'_2 only it is 7000-cycle instead of 1000.

Decrease the scale of L and redraw it, and we get S_4, Figure 15, our final useful signal that goes up and down in accordance with our original envelope E, but now each burst is filled with 7000 instead of 1000. All we have said is that the process of translation goes on faithfully and reproduces any amplitude changes of the signal wave.

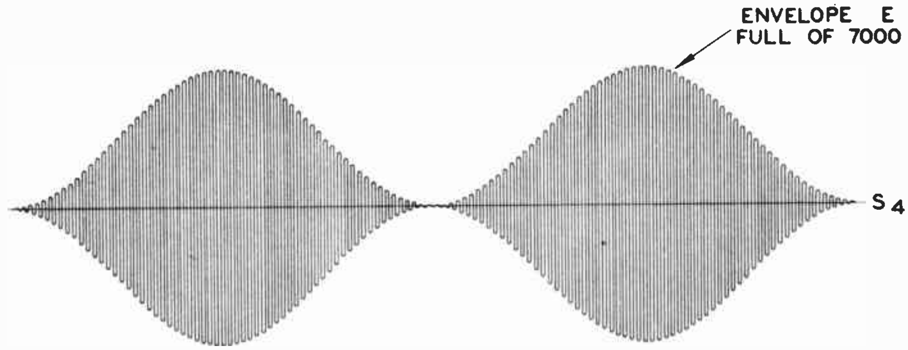


Fig. 15 - 1000-Cycle Telegraph Signal of Fig. 11 Translated with Faithful Envelope Shape to 7000 Cycles

The envelope of S_4 we note is the same as the envelope of S'_2. We know that this wave contains still something besides 7000 cycles. We suspect strongly from analogy that it takes the same things to give it this appearance that it took to make S_2' have this shape envelope. The fact is it is made up of one part 7000, one-half part 6900 and one-half part 7100. In other words, the sidebands are in the same places and have the same relative amplitudes as before we translated it from 1000 to 7000. Marvelous and delightful; no more spectrum space is required to transmit the intelligence contained in the 100-cycle telegraph signal than had we left it in its original position at 1000 cycles and we are now in a position to pile one telegraph channel top another ad infinitum.

Without much stretching of the imagination, we should be able to make one further step or deduction without bothering to draw it all out. If our signal varied in frequency instead of starting and stopping our resulting signal should vary in frequency instead of in amplitude. See Figure 16. Using a 1050-cycle mid-frequency channel, let us say our signal is frequency modulated to give a 50-cycle deviation, resulting in 1000 cycles during a mark and 1100 cycles during a space, always constant amplitude. We know the 1000-cycle marking signal will give an upper sideband of 9000 and a lower sideband of 7000 when we use an 8000-cycle carrier. It is not hard to picture an upper sideband of 9100 and a lower sideband of 6900 when we have a 1100-cycle spacing signal.

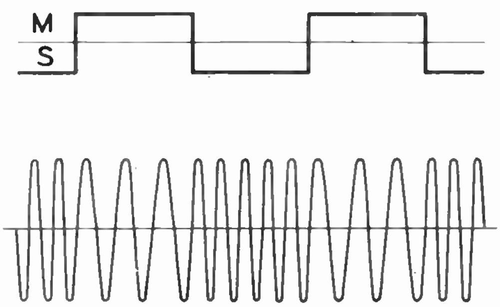


Fig. 16 - Obviously Susceptible to Analagous Translation

Presto! - - Our original signal varied 50 cycles either side of 1050 giving 1000 for mark and 1100 for space. If we take the lower sideband of our final signal, we still find it varying the same 50 cycles above and below 6950, and we get 7000 for a mark and 6900 for a space.

So we find the modulator is really a pretty convenient device for translating frequencies. It cares not what the frequency or the amplitude of the signal, it translates everything to the new position in the spectrum. Speech currents we know vary in both frequency and amplitude. The modulator as a frequency translator quite obviously may be used to stack telephone conversations one above another.

From quite analagous reasoning and diagrams we may appreciate the simplicity of translating in the opposite direction. Anything whatever that we have stepped up can be stepped back to its original position by employing the same carrier frequency to bring it back as we employed to get it up in the first place.

From what has been said, it should be obvious also that successive (tandem) stages of modulation may be employed if desired. Present day techniques keep wave form distortion to an unbelievably low level. Speech we know can be translated up and down many times and still lose none of its identifying characteristics. The engineer characterizes that property of the modulator which permits it to operate in a distortionless manner as "linearity". Today's modulation systems are as linear as are the best amplifiers.

Our avowed interest in the modulator as a frequency translator results from its ability to effect efficiency in the use of frequency spectrum. Perhaps another type of diagram, another mental image or point of view, will be helpful in bringing us to a realization of the great advantage of single sideband operation.

In Figure 17 we draw the familiar line diagrams of sideband relations. Adhering to the symbols and specific frequency locations of the amplitude modulated telegraph problem used as an example, we find C_1, with its two sidebands at 1000 cycles. In translating these three essential frequencies to a new position on the spectrum, had we not suppressed the carrier and discarded one sideband, we would have found it necessary to assign all the space from 6900 to 9100 to this lone telegraph channel. By obviating the necessity for transmitting all those frequencies shown dotted on Figure 17, we conserve nearly 2000

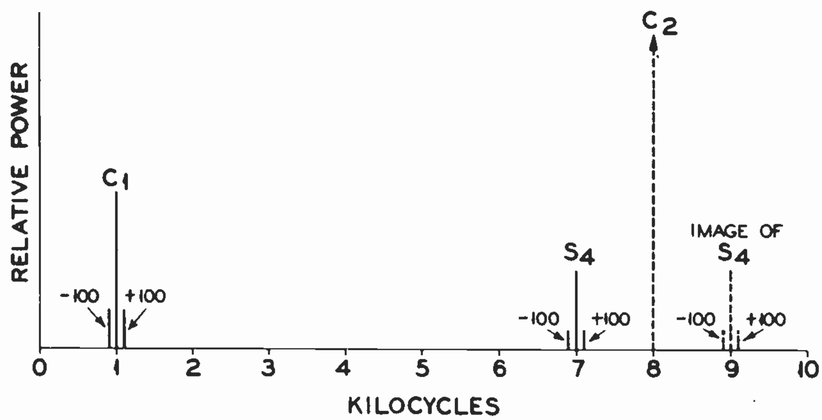


Fig. 17 - Efficiency of Spectrum Utilization

cycles of space which may be used for other similar telegraph channels. The price we pay for the privilege of throwing away the image of S_4 is only the cost of a little extra gain in an amplifier. We must double the power transmitted on the sideband we do retain because the energy was divided equally between the two. The price we pay for the privilege of throwing away the carrier C_2 is the cost of maintaining frequency accuracy of the translating carrier relative to the detranslating carrier. Obviously if one changes with respect to the other, C_1 comes back to us at the receiving terminal displaced from the original 1000 by the amount of the difference between them. No other disastrous results ensue as a result of a lack of matching but we cannot let C_1 come back so far displaced as not to fall within the narrow channel filter for which it is destined. If the modulation be speech or music, we do not want its pitch materially altered. If the telegraph be FM, an even more rigorous control must be maintained over differences between translating and detranslating carriers.

A U T H O R S

COL. J. Z. MILLAR was born in Mattoon, Ill. After graduation from the University of Illinois, in 1923, he was employed by Western Union in the Washington, D.C. office, and studied for two years as an Engineering Apprentice, later becoming Assistant Chief Operator of Telephone. Next came a three month assignment in the General Office, Traffic. In 1926 he was transferred to the Water Mill Laboratory, where he was able to take up electronics as a profession, a subject which had been of great interest to him since his amateur days before World War I, and during college. Following 15 years of vacuum tube work, specializing on short wave equipment and audio frequency apparatus, Col. Millar was called to active duty with the Signal Corps. He served as Member and Director of the Signal Corps Board in Fort Monmouth, N.J., from March 1941 to April 1944, and was then assigned as Signal Officer of the Normandy Base Section and as Signal Officer, Loire Section, European Theatre. On February 15, 1945, Col. Millar returned to Western Union and was appointed Radio Research Engineer. He is a Senior Member of the IRE.

J. R. HYNEMAN grew up in Indiana and graduated from Purdue in 1921 after a two year interruption due to World War I. He has been with Western Union since July 1920, serving first as an installer during the construction of the present Chicago office and later as night manager in the Lafayette, Indiana office during his senior year in college. He joined the staff of the Apparatus Engineer in June 1921, transferring to the Research, later Transmission Division, in 1926. Since 1926, Mr. Hyneman has specialized in patent engineering, handling a variety of work which is normally the joint responsibility of the designing engineers and the patent attorneys. Such work has covered many fields, and the article published in this issue is a natural result of the perspective gained from such a career. He is a Member of the AIEE.

F. B. BRAMHALL, a native of Pennsylvania, graduated from the Pennsylvania State College in 1919, and later did considerable graduate work in physics and mathematics at Columbia University. After a trick as "sparks", radio operator, on a tramp freighter, he came to the Engineering Department in 1920. Telegraph transmission problems engaged his attention from the beginning. He has been intimately and responsibly associated with the entire development of the Company's carrier telegraph systems. With a splendid opportunity to witness the progress of many inspiring developments, Mr. Bramhall has written a number of educational article . His writings are characterized by a free and unrestrained style which greatly contributes to an understanding of technical concepts that might otherwise remain obscure. Mr. Bramhall, now Transmission Engineer, is active in the administration of the AIEE in which society he holds the rank of Fellow. He gives freely of his energy to various other extracurricular activities.