PAPER No. 26

The Voice Frequency Carrier Telegraph System

By C. ANQUETIL
Engineer, Transmission Section, Postmaster-General's Department

Paper Presented before the Postal Electrical Society of Victoria, September 14, 1936

Reprinted from
THE ELECTRICAL ENGINEER AND MERCHANDISER
September, 1936

TAIT PUBLISHING CO.
Melbourne - - Sydney

The Voice Frequency Carrier Telegraph System

By C. Anquetil,

Engineer, Transmission Section Commonwealth Postmaster-general's Department

As the name implies, the voice frequency carrier telegraph system is a multi-channel carrier telegraph system operating on frequencies which lie within the normal commercial voice range. The system, therefore, can be superimposed on any telephone channel, physical or carrier.

Operation

The principle of operation is as follows:—For each channel a carrier frequency is generated at the sending end and transmitted to line via a sending filter circuit. At a suitable point between the generator and the filter the carrier supply is short-circuited by the contact of a sending relay operating from a local telegraph loop. Telegraph signals operate the sending relay, and its contacts correspondingly interrupt the carrier, which is therefore sent to line in spurts. At the distant end of the circuit this interrupted carrier is filtered into its own particular channel equipment, where it is amplified and detected. A receiving relay in the plate circuit of the detector tube is operated by the rectified carrier spurts, and sends telegraph signals into the local receiving telegraph loop.

The voice frequency carrier telegraph systems at present used in Australia are of the Universal type, which means that the circuits are so arranged that any standard system of telegraph operation, e.g., single or double current, duplex or simplex, will work satisfactorily into the carrier terminal. The general practice here is to run separate Send and Receive loops from the carrier terminal to the telegraph operating room, and to install any necessary repeating equipment at that point. Wherever possible the loops are operated on double current, negative for "marking" and positive for "spacing."

Brief Circuit Description

Fig. 1 shows a simplified schematic circuit of a voice frequency carrier telegraph terminal. It will be seen that associated with the sending direction is a group of sending band filters. The sending filters are commoned on the line side and connected to line through a suitable transformer. The receiving filters are similarly connected, a separate receiving line transformer being provided when four-wire working is adopted. If it is desired to operate the system two-wire, the send and receive filters are strapped together. Paralleled across the filters on the line side is a compensating network particular to the installation, which takes care of the irregularities caused by any missing filters, and also improves the characteristics of the filters at the higher frequencies.

Associated with each sending filter is a source of carrier frequency, either an alternator or an oscillator. This carrier is connected permanently, through a suitable pad, to the input of the sending filter, at which point the line is bridged by the contacts of the sending relay. The sending relay is directly controlled by telegraph signals from the telegraph operating room, and its armature correspondingly modulates the carrier, which is transmitted to line in spurts corresponding to the movements of the relay tongue. Because of the design of the detector circuit, the most satisfactory arrangement is to have carrier permanently going to line during the non-signalling periods, the first signal being actually transmitted by a cessation of carrier. The operation of a reversing key at the carrier terminal determines whether negative or positive current will be normally fed into the telegraph loop.

At the receiving end the incoming carrier frequencies are applied to the paralleled group of receiving filters, each filter selecting its own particular frequency band to the exclusion of all others, and applying it to its individual amplifier and detector. The detector incorporates in its design an automatic volume control feature, and the design of the detector is the result of a series of experiments calculated to determine the most satisfactory method of detection to ensure the best average of undistorted telegraph signals. The detector circuit will be discussed more fully in a later paragraph.

Included in the plate circuit of the detector is the receiving relay which operates on the detected spurts of carrier, and transmits "marking" and "spacing" signals to the telegraph operating room.

Frequencies

The carrier frequencies used in the voice frequency system are multiples (actually odd harmonics) of a fundamental frequency of 60 cycles per sec., and are spaced, for purposes of band width consistently with maximum exploitation of the available frequency range, at 120 cycles apart. Under this allocation the number of effective one-way carrier telegraph channels obtainable within the normal voice frequency range of a normal two-wire line is 18. It follows, therefore, that on a four-wire physical circuit or a normal carrier system amended to operate four-wire where there are, in effect, two one-way voice

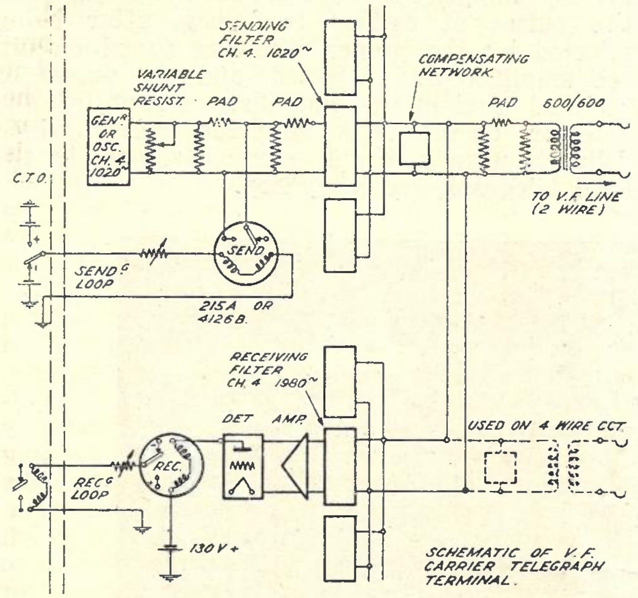

Fig. 1. Schematic of V.F. Carrier Telegraph Terminal

frequency bands, one in each direction, these 18 telegraph frequencies can be sent both ways; thus 18 duplex telegraph channels can be obtained. Should it be necessary to operate the system on an ordinary two-wire line or its equivalent (a "balanced" or "common sideband" carrier system), the number of duplex telegraph channels obtainable is reduced to half, as different frequencies must be used for sending and receiving within the single voice channel. In actual practice, it is generally taken that the number of duplex channels available on a single two-wire circuit is eight only, as it is desirable for the sake of effective filtering to drop one band of frequencies between the two groups. This leaves a spare one-way channel should it be required.

As a point of interest, the Sydney-Tamworth system is operated on a four-wire basis giving 18 duplex channels, whilst the Tasmanian emergency system (designed to provide five duplex channels) is arranged for two-wire operation so that it can be applied without discrimination to either type of carrier channel, balanced or directional, or to the physical circuit.

Frequency Allocation

To ensure a signalling speed of at least 50 Bauds, each channel has a nominal band width of 120 cycles and, commencing with a lowest carrier frequency of 420 cycles for Channel 1, the frequencies rise by 120 cycles per channel to 2,460 cycles for Channel 18, as shown in Table 1.

Table 1.—Carrier Frequencies for Telegraph Channels

Channel	Carrier Frequency	Channel	Carrier Frequency	Channel	Carrier Frequency
1	420	7	1,140	13	1,860
2	540	8	1,260	14	1,980
3	660	9	1,380	15	2,100
4	780	10	1,500	16	2,220
5	900	11	1,620	17	2,340
6	1,020	12	1,740	18	2,460

On the Melbourne-Launceston emergency five-channel system frequencies corresponding to Channels 5, 6, 7, 8, 9 of the above table will

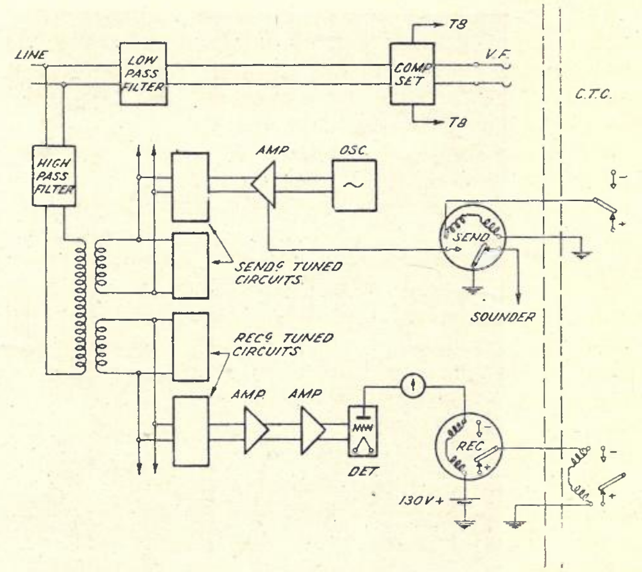

Fig. 2. Simplified Schematic of Type B Carrier Telegraph

operate Melbourne to Launceston, and those corresponding to Channels 11, 12, 13, 14, 15 in the opposite direction. Channels 3 and 4 Melbourne-Launceston and 16 and 17, Launceston-Melbourne, will be added ultimately.

Type B Carrier Telegraph System

Prior to the introduction of voice frequency carrier telegraph systems the only type of carrier telegraph used in Australia was the Type B. This system is fairly well known, but for the benefit of any who have not had the opportunity of studying it a very brief description will be included here, sufficient to allow of a comparison with the newer voice frequency system.

The Type B is a 10-channel system, and operates on carrier frequencies just above the commercial voice frequency range, these frequencies being arranged into two groups for transmission in opposite directions. At repeater stations the groups are separated by directional band filters, amplified, and passed on in the correct direction.

Table 2.—Frequencies for Type B Carrier System

Channel No.	B to A. Frequency in cycles	A to B. Frequency in cycles
1	3,330	6,500
2	3,570	6,800
3	3,810	7,110
4	4,050	7,440
5	4,290	7,800
6	4,530	8,180
7	4,770	8,590
8	5,010	9,030
9	5,250	9,500
10	5,500	10,000

The actual frequencies allotted are shown in Table 2. As these frequencies lie above the commercial voice frequency range, it will be seen that, with the aid of normal high and low pass filters having a 3,000 cycles cut-off, the B type telegraph carrier can be superimposed on a telephone circuit without interfering with the normal use of the line for telephone or composite telegraph working.

The essentials of the Type B system are as follow:—At the sending end there is a sending telegraph relay, an oscillator generating the required frequency, a single stage amplifier and a sending tuned circuit. At the receiving end is a receiving tuned circuit, a two-stage amplifier, a detector and a receiving telegraph relay. In setting up the channels the sending oscillator and tuned circuit are set to the correct frequency, and at the far end the corresponding receiving circuit is critically tuned to that frequency from the received carrier itself. Fig. 2 shows a simplified circuit of Type B terminal.

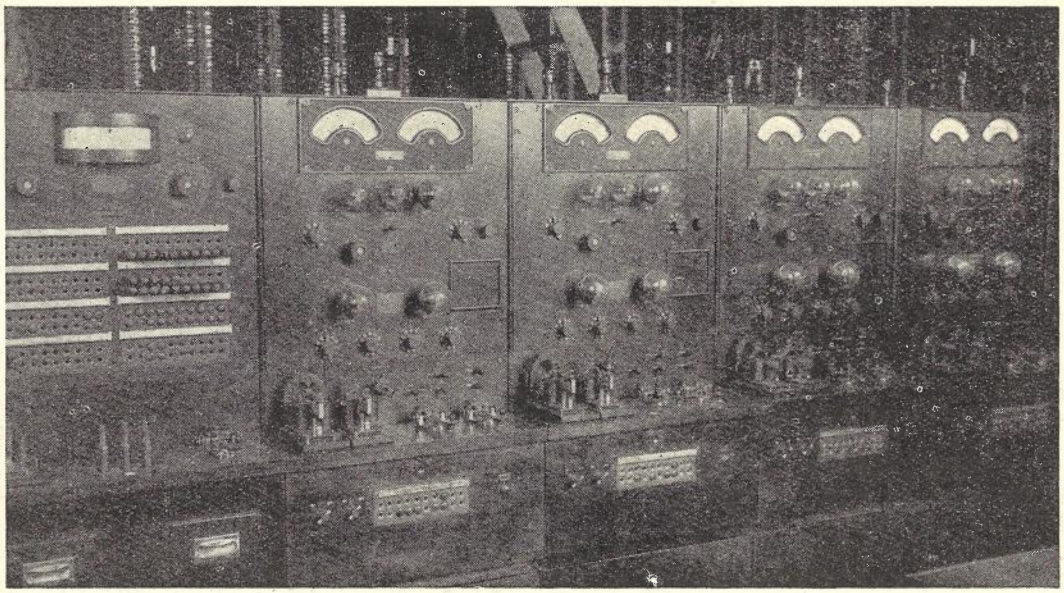

Fig. 3. Floor-pattern
Type B Carrier Equipment

Operation of Type B System

The output of the carrier oscillator is connected to the amplifier and transmitted to line via the sending tuned circuit and line transformer. The grid of the amplifier tube is intermittently grounded by the operation of the sending relay which is actuated by d.c. telegraph signals from the telegraph loop. The carrier output to line is correspondingly interrupted. At the distant end the pulses of carrier frequency, after being selected by the proper receiving tuned circuit, are amplified and detected, and the pulses of rectified current in the plate circuit of the detector operate the receiving relay, which delivers, usually, double current signals to the local telegraph receiving loop.

The Type B system uses 1-amp. tubes of the familiar types 101D and 102D. The sending oscillator and amplifier each use a 101, the receiving amplifier employs two 102's, and the detector is a 101. The send and receive sides of any one channel are mounted close together, and all five filaments burn in series controlled by a filament rheostat. The relays used are the 215 type (sending) and 209 (receiving) arranged to plug into relay sockets for ready changing when a relay is suspected of being faulty. A relay adjusting table forms part of each installation.

Type B systems are at present operating between Brisbane, Sydney, Melbourne, Adelaide and Perth, the equipment including both the earlier floor units and the more recent rack-mounted channels. With the development of the voice frequency system the advantages of the Type B carrier telegraph have been largely eclipsed, as the later system provides better facilities and does not occupy a complete carrier line. It will be seen that if a high-pass or carrier frequency circuit is available it can be more fully exploited by instal-

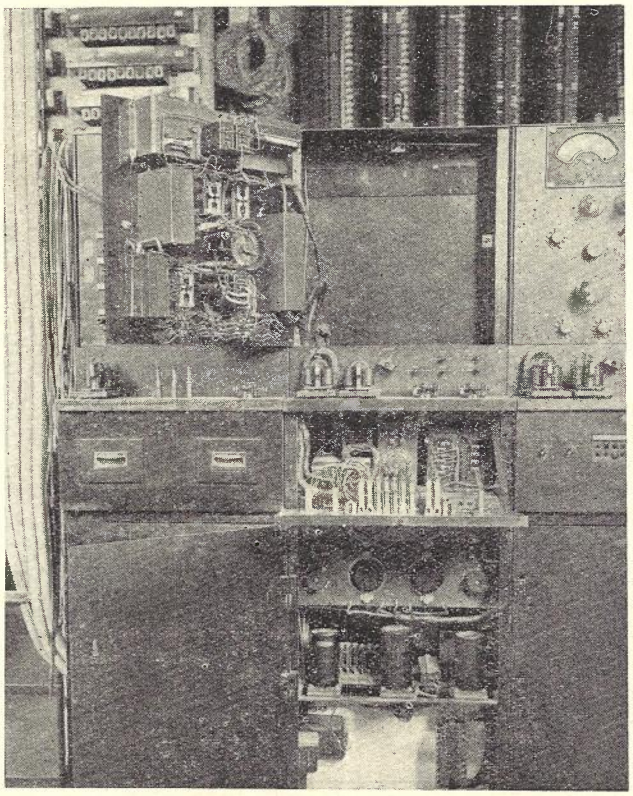

Fig. 4. Rear View of Type B Equipment

ling a three-channel carrier telephone system and using one of the three channels for four-wire voice frequency telegraph. Three-channel carriers can be operated over filters having a 5,000 cycle cut-off, thus leaving the physical circuit free for an emergency broadcast channel if required. With the Type B carrier telegraph, however, 3,000 cycles cut-off filters are necessary, limiting the physical circuit to the commercial speed band. The Type B system would have an application on a route requiring additional telegraph circuits without any accompanying telephone development. These conditions rarely exist. Figs. 3 and 4 are front and rear views of Type B floor-pattern equipment installed at Melbourne.

Advantages of Voice Frequency System

It will have been noted that both the Type B and the voice frequency carrier telegraph systems employ the same general principle of operation, in that a fixed carrier is interrupted by a sending relay, and that a distant detector or rectifier delivers the translated carrier pulses to a receiving relay. As regards design and the actual components, however, considerable advances have been made in the voice frequency system. The main changes may be summarised as under:—

1. Use of band filters instead of tuned circuits.
2. Special repeaters other than those which would be used on the voice channel are not required.
3. Use of form of automatic volume control on the detector which maintains a steady level of incoming signals.
4. Use of frequencies within the voice range instead of immediately above.
5. Use at main offices of a multi-frequency generator to supply the carrier frequencies.
6. Improved testing facilities.

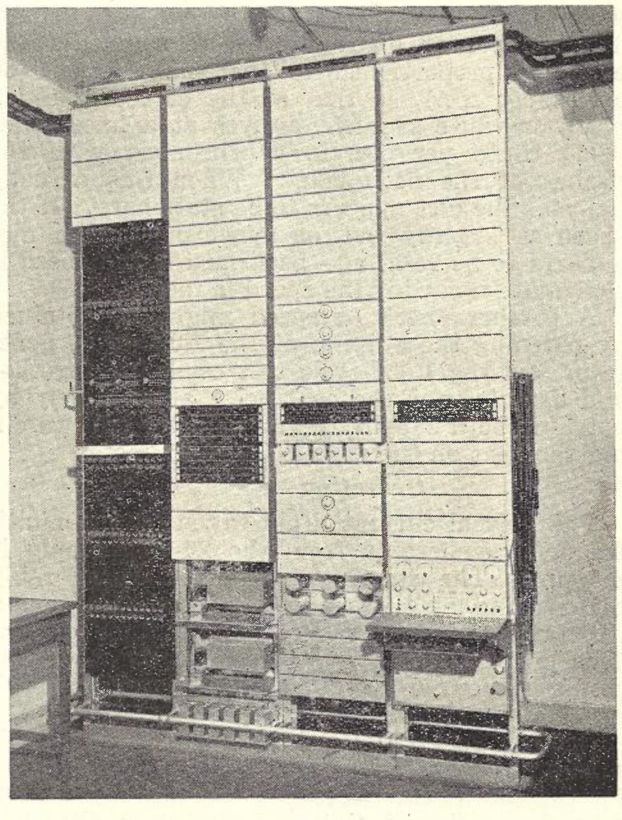

Fig. 5. Voice Frequency Carrier Telegraph Terminal

In addition to the above major alterations, the details regarding mounting and finish are varied in that the voice frequency system is mounted more compactly and on double-sided racks, and that it has the new aluminium finish instead of black. Fig. 5 shows the voice frequency carrier telegraph terminal at Melbourne.

Source of Carrier Frequencies

At large offices where a number of voice frequency carrier telegraph systems will eventually operate, the various carrier frequencies are produced by a special multi-frequency generator which is mounted on one of the supply bays associated with the equipment. This unit takes the form of an inductor alternator operating from the 24-volt d.c. supply, and having 18 sets of rotors and stators, one for each frequency. The alternator field exciting windings are all connected in series, and are energised by direct current from the 24-volt battery. The speed of the machine is 3,600 r.p.m., and is governor controlled to within the close limits of $\pm$ 0.1 per cent. by the governor contacts intermittently short-circuiting a series field resistance. Associated with the generator is a 1,020-cycle fixed frequency oscillator which is used to check the generator speed and, consequently, the carrier frequencies. The output of the oscillator is connected to a neon lamp mounted over a stroboscopic disc which is fitted to the end of the generator shaft. The number of black and white segments (34 each) is proportioned to the shaft speed (60 cycles per sec.), so that at the correct speed a black or white segment arrives at a fixed point 2,040 times per sec. in synchronism with the flashes of the neon lamp. When this actually happens the disc appears to be stationary. If the speed is slightly out of synchronism the disc appears to be rotating—backward if the speed is slow and forward if the speed is fast.

A further check of speed might be obtained by patching the outputs of the 1,020-cycle generator and the 1,020-cycle test oscillator together and listening for the beat note; alternatively by patching both supplies into a detector and watching the beat on the rectified current meter.

Operating Current

The normal current drain taken by the multi-frequency generator from the 24-volt supply is 8 amps. The starting current is considerably higher, and at the moment of switching on a resistance is included in the armature circuit. This is shorted out by a special relay when the motor gathers sufficient speed to develop a back e.m.f. of approximately 6 volts.

Battery current is fed to the motor through a 15-amp. fuse, whilst the field exciting current for the carrier alternators is fed through a 1.33-amp fuse. A rheostat is included in the field circuit to control the exciting current, and this in turn regulates the alternating current output voltages of the 18 alternator sections. Further individual adjustments are made by varying shunt resistances across the alternator outputs. The normal output voltage of each section is 1 $\pm$ 0.05 volt.

Multi-frequency generators as described above are designed for the larger offices. On smaller installations, where development beyond 18 channels is not anticipated, e.g., as at Launceston, the carrier frequencies are produced by oscillators. The oscillators are set at the correct frequencies by reference to a standard oscillator, and, as they are designed for stability of output and frequency, very little further attention is required.

The oscillators are panel-mounted, and the components, including the valves, are totally enclosed by the detachable metal cover. The rack space occupied is very small, a single oscillator being face mounted on a panel 19 in. by $3\frac{3}{8}$ in. Each oscillator employs a $\frac{1}{4}$-ampere tube, Type 4020A, the filaments of two tubes (i.e., two oscillators) being wired in series. Filament control is by ballast lamps.

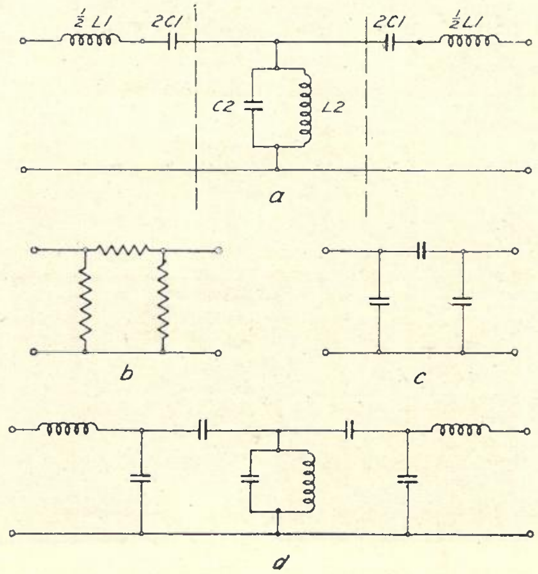

Fig. 6. Band Filters, Voice Frequency System

Band Filters

It was mentioned in an earlier paragraph that a feature of this system is that it uses band filters instead of the tuned circuits employed on Type B. The band filters follow the conventional design, but have one or two interesting features which might be mentioned here. Taking the sending filter which is the simpler of the two, the normal constant K configuration, as shown in Fig. 6, is used with certain modifications. It will be seen from the diagram that the filter is of the unbalanced type, i.e., the series elements are all included in one leg, the other side being a commoning point for the shunt components. A transformer is, therefore, interposed between the filters and the line. The sending filter consists of a single band filter section and the receiving filter of two sections.

To produce a filter at the frequencies and band widths required by this system which would give the correct impedance, would have involved considerable difficulties in manufacturing the components to their accurate values. Capacities of the order of 4.421 mf. for C_2 were indicated and, in one case, an inductance of less than a millihenry for L_2 would have been necessary. This would have involved the use of paper condensers, with the consequent difficulty of adjustment, plus higher dielectric losses and temperature variations, whilst the inductances would have been critical to such an extent that the addition or removal of one turn of wire would have caused a noticeable variation.

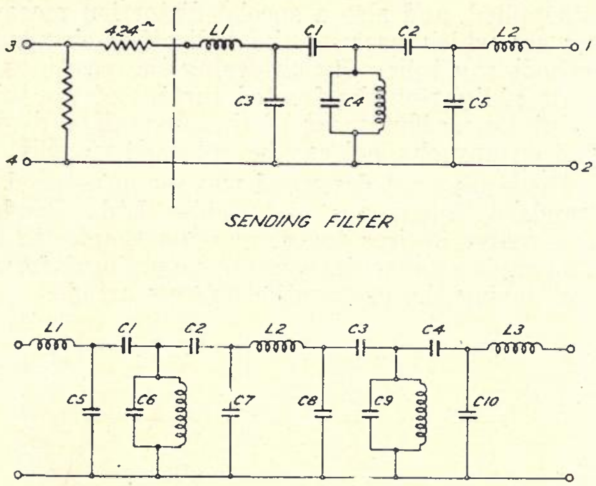

Fig. 7. Send and Receive Filters, Voice Frequency System

The difficulty was overcome by including in the filters impedance transformer sections corresponding to step-up and step-down transformers, which so raised the internal impedance of the filter that condensers of a convenient size for manufacture in mica were possible, whilst the inductances were increased to more practical sizes. This transformation was introduced at the points indicated by the vertical dotted lines. It can be shown that a step-up transformer having inductance and resistance can be simulated by a suitable network of the form shown in Fig. 6b which, for all practical purposes, becomes the condenser network of Fig. 6c. By adding these sections to the filters the desired changes of C_2 and L_2 were effected. The influence on the design is most noticeable in the additional shunt capacities (Fig. 6d†). Fig. 6 shows diagrams of the actual Send and Receive filters used on the voice frequency system.

Detector

The detector used with the voice frequency system includes an automatic volume control feature which ensures that stable telegraph signals are received, notwithstanding fairly wide variations in line attenuation. The detector circuit is shown in Fig. 8. The unit consists of a high gain amplifier valve V_1 followed by a detector V_2. The circuit is so arranged that by moving link switches the volume control feature can be cut in or out at will. On stable physical circuits, such as cables, where variations in attenuation are insufficient to require any special compensation, the circuit is arranged to function as a straight amplifier and detector. In the latter condition the links are set in position 2. The detector obtains its grid bias from a potentiometer bridged across the telegraph battery, and the amplifier bias is taken from the drop across an 8-ohm filament resistance.

In position 1 of the links the input level to the detector—subject to a small time element—actually determines the grid bias of the amplifier stage. It will be seen that the bias for both tubes is taken from the same point; hence under

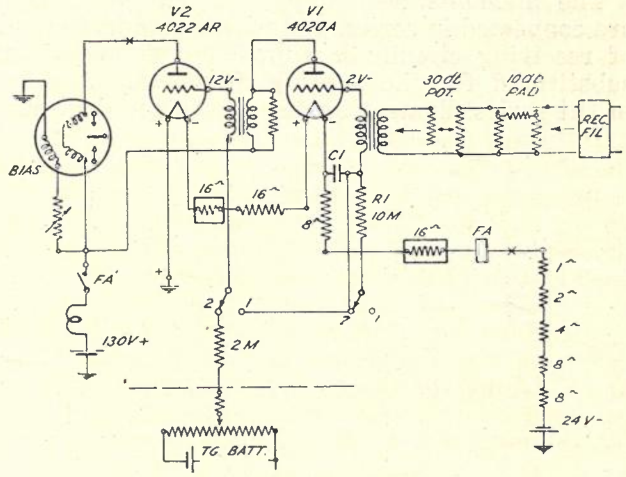

Fig. 8. Detector Circuit of Voice Frequency System

direct current conditions the normal bias on the detector will be approximately 12 volts with respect to its own filament, whilst that of the amplifier will be approximately 2 volts.

Between the common bias point and the filament circuit is a 10-megohm resistor R_1 which is bridged by the condenser C_1. A normal signal amplified by the first valve makes the grid of the detector valve slightly positive, with the result that grid current flows in the detector valve via the 10-megohm resistor 1. The flow of current through R_1 increases the negative bias of the amplifier valve V_1, and thus reduces its amplification. The negative bias of V_1 will be reduced during an interruption to the incoming carrier, provided that the interruption is of sufficient duration to allow condenser C_1 to discharge through R_1. The capacity of C_1, however, and the value of R_1 ensure that C_1 will hold its charge

†For further details see "Electrical Communication," April, 1932; also "Transmission Networks and Wave Filters," by T. E. Shea.

for a time at least equal to the time length of the maximum telegraph spacing signal. The flow of detector grid current through resistance R_1 must also affect the grid bias voltage of the detector valve V_2, but the change from its normal value is not large enough to appreciably move its operating point, so that the effect on the signals delivered is negligible.

If the attenuation of the circuit decreases, the grid bias of the amplifier valve is further increased and the gain is reduced accordingly. On the other hand, if the attenuation of the circuit increases, the grid current through R_1 is reduced, the condenser C_1 discharges slightly and the gain of the valve V_1 is increased. By this means a constant output is obtained from valve V_2 over a given working range. A three-position key also forms part of the detector circuit. This is used for testing and lining-up purposes when the automatic gain control device is employed (links in position 1). The input potentiometer has a range of 30db.

The filaments of two panels, i.e., four tubes, are connected in series, and where an odd number of receiving circuits is supplied resistances are substituted for the missing filaments. A relay in the series filament circuit serves the dual purposes of switching on the plate and relay bias potentials and providing a filament alarm. The relay bias winding is fed from the normal plate battery through a suitable resistance. The bias winding is necessary to restore the armature of the relay when rectified current is not flowing in the detector.

Testing Apparatus

The voice frequency system is supplied with the necessary meters for measuring currents in plate circuits and loops, the meters being connected to the required circuit by patching. In addition, a relay test table something similar to that used on the Type B carrier telegraph system is supplied, and also a special distortion measuring set which uses as the indicating element a cathode ray tube. By observing the positions of spots of light on the frosted surface of the tube, a definite measurement of the amount of distortion on any channel can be obtained visually.

The equipment described was manufactured by Standard Telephones and Cables Ltd., London. The writer desires to express his thanks to the company's representatives for supplying information during the preparation of this article.