WS No. 19 Mark III

CARRIER TELEPHONY

GENERAL PRINCIPLES

1. A carrier telephony system permits the transmission of several conversations simultaneously over one pair of wires. In principle it is similar to radio telephony in that it transmits speech as modulation of supersonic carrier frequencies and, at the receiving terminals, after amplification, separates the carrier channels by band pass filters and demodulates them. Each speech channel thus involves a transmitter and a selective receiver. Several transmitters and several receivers are grouped together to form a terminal but, whereas in wireless transmission each channel has its own amplifiers, in carrier technique amplifiers are common to several channels.

SINGLE SIDEBAND SUPPRESSED CARRIER SYSTEMS

2. For intelligible speech all frequencies from 300 to 2,600 c/s must be transmitted. With normal double sideband transmission the band required allowing for channel separation would be 6 kc/s.

3. On line transmission the available portion of the frequency spectrum is very limited and considerable economy can be effected by using only a single sideband. In double sideband working the carrier bears a definite phase relation to the two sidebands. The audio frequencies produced on demodulation due to the beating of the carrier with the upper and lower sidebands respectively should be in phase so that they add. If the phase is altered, selective fading will ensue. In the case of single sideband working, however, the phase of the carrier does not matter. The carrier and only one sideband are concerned. It is possible to send a sideband without carrier, thus narrowing the frequency band necessary and to generate the carrier at the receiver. Modulators used in carrier telephony are therefore designed to suppress the carrier frequency and are followed by band pass filters to remove one sideband. This system is known as a single sideband suppressed carrier system.

Choice of sidebands

4. In this country nearly all existing carrier telephone systems, including the Army 1 + 4 system, use the lower sideband throughout, but international standard practice is to use the upper sideband and later civil equipment conforms to this practice.

Spacing of channels

5. International standard spacing is 4 kc/s, which makes available a bandwidth of over 3 kc/s per channel. Army equipment employs slightly closer spacing to increase the number of channels in a given carrier frequency band.

CIRCUITS AND LINES

Number of channels and loading

6. The total number of channels which can be accommodated on one system depends on the cut-off frequency of the line. Lines for carrier working must therefore consist of overhead special carrier quad cable. They should be either non-loaded, or continuously loaded in order to give high cut-off frequency. The term loading refers to the artificial addition of inductance to the line to improve its characteristic.

Repeaters

7. Repeatered telephone circuits (*i.e.*, circuits which have valve amplifiers inserted in the line to compensate for loss) use either two wires or four wires (the latter provides one pair for transmitting in each direction) whereas the exchange line always consists of two wires only. A four-wire circuit thus requires equipment to convert from two-wire (exchange side) to four-wire (line side) and *vice versa* at termination only, whilst a two-wire circuit requires two-wire to four-wire conversion at intermediate repeaters as well (see diagram in Fig. 1). Such a conversion is normally effected on physical circuits by a hybrid transformer and balancing network.

Hybrid and balancing networks

8. The function of the hybrid and balancing network is to prevent the output of the two amplifiers of one two-wire repeater from feeding into each other and hence causing a circulating current between the two. Such a circulating current, equivalent to self-oscillation of the system, is known as "singing." The hybrid therefore converts from a two-wire to a four-wire circuit and prevents "singing" between the two pairs of the four-wire circuit. The actual method is shown in the circuit of Fig. 1 (a). If i_1 is equivalent to i_2 then they will cancel each other in the input to the GO amplifier. This will be so if the impedance of the balancing network equals that of the two-wire line. Thus half the available output of the return amplifier will proceed in the desired direction along the two-wire line to the exchange, half will be dissipated in the balancing network, and no transmission will occur between the two amplifiers.

Impedance balancing networks

9. The efficiency of such a system depends on the quality of the impedance balance provided by the balancing network. To provide a good quality balance over a very wide frequency band would require an increasingly complicated balancing network. In carrier telephony, therefore, the methods described below are used.

10. When using a two-wire circuit, different carrier frequencies are used in each direction. The lower carrier frequencies are transmitted in one direction and the higher frequencies in the other. The two directions are separated by directional filters where necessary (*i.e.* at repeaters and at channel terminals). This can be achieved by either of two methods:

(*a*) Arranging for the system to be composed of two terminals differing such that one terminal transmits the lower carrier frequencies and receives the higher frequencies, and *vice versa* for the other terminal.

(*b*) Arranging for both terminals to be similar and to use the same channel carrier frequencies. At one terminal, a much higher carrier frequency is further modulated by the group of carrier channel frequencies and, at the other end, this higher carrier frequency is demodulated and then the channel frequencies are separated and demodulated. This method is known as group modulation (see Fig. 2 (a)). If for instance it is wished to provide four

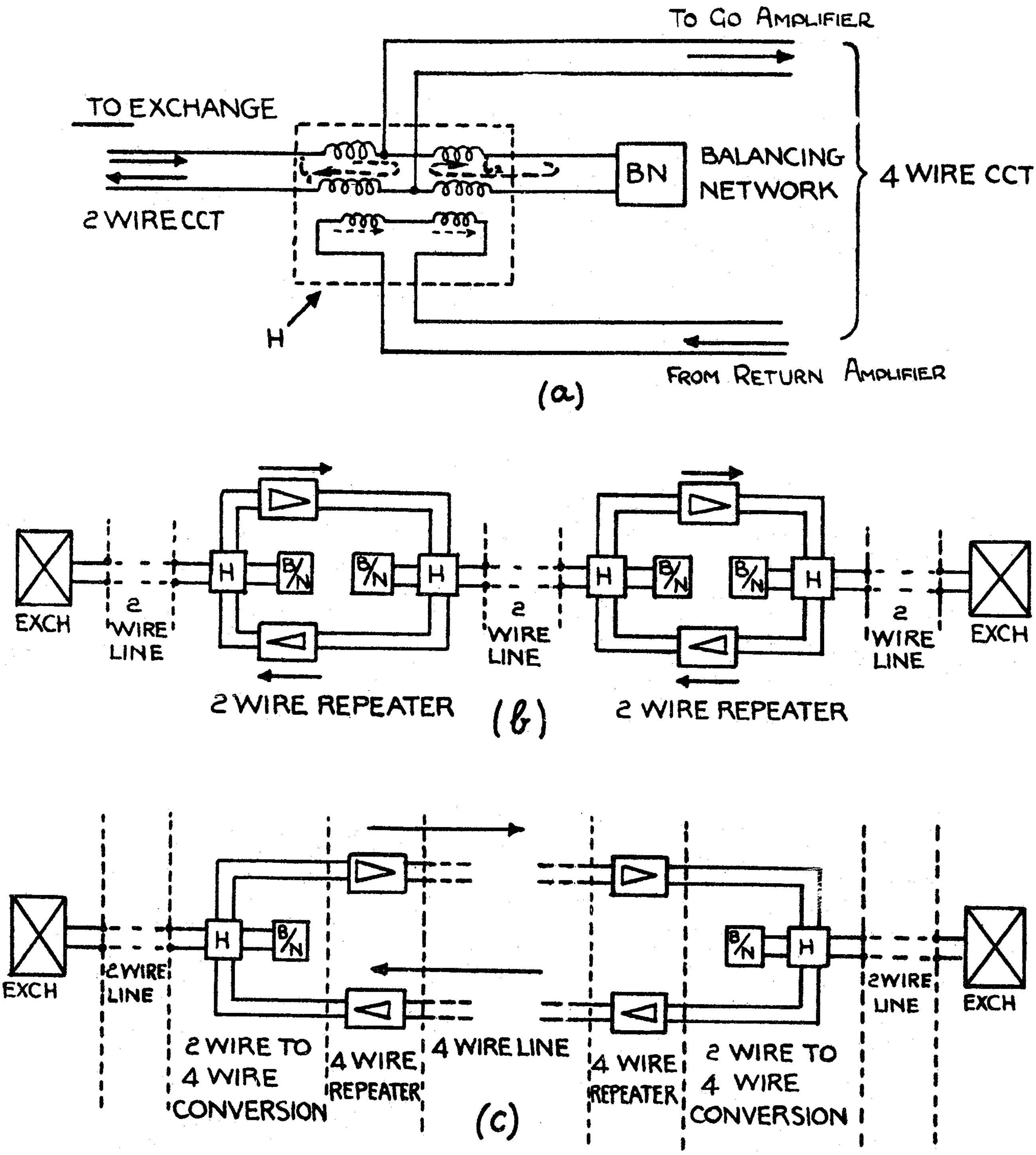

Fig. 1. (a) Two-wire to four-wire conversion (hybrid) system.
(b) Two-wire circuit.
(c) Four-wire circuit.

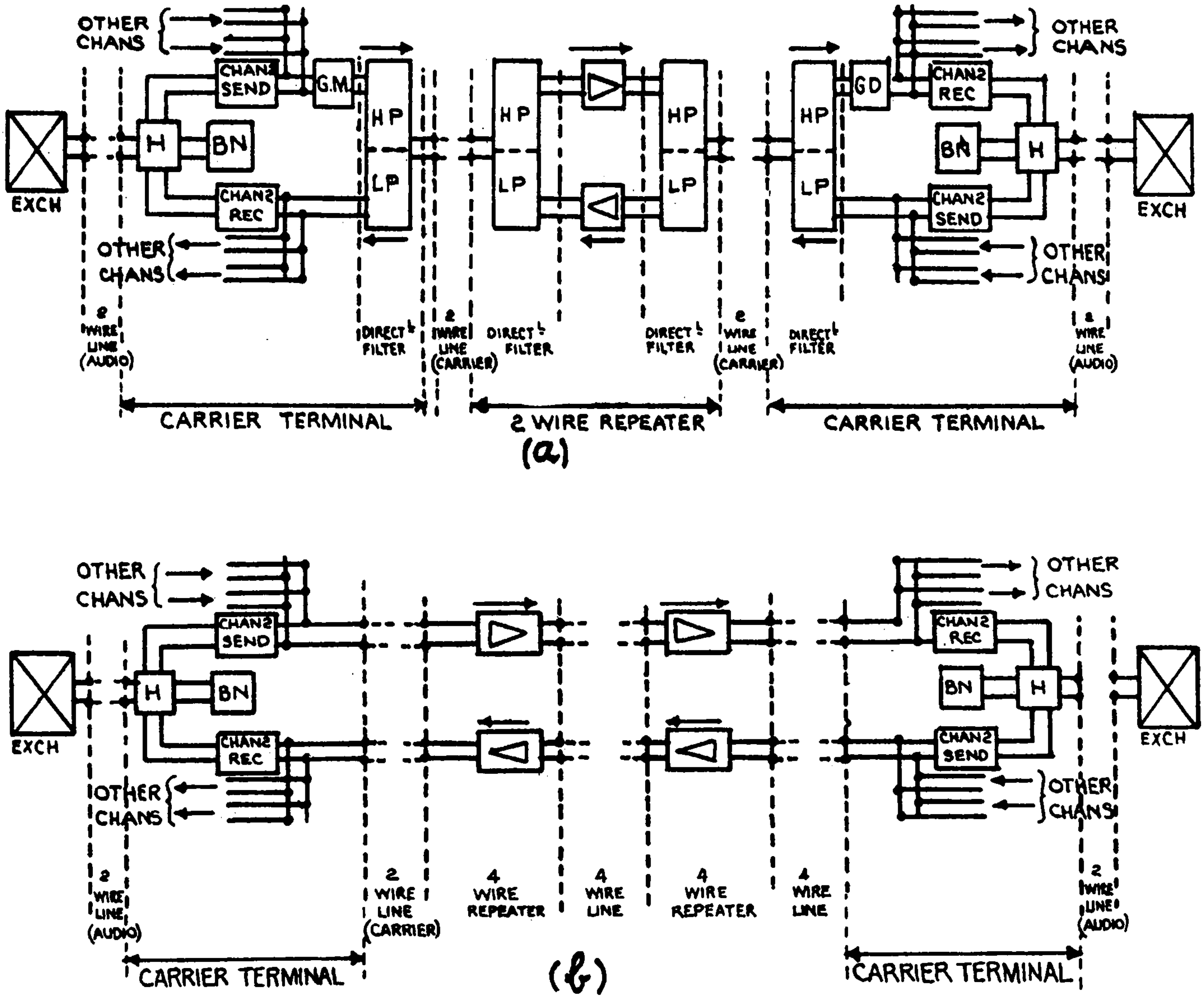

Fig. 2. (a) Two-wire carrier circuit on group modulation system.
(b) Four-wire carrier circuit.

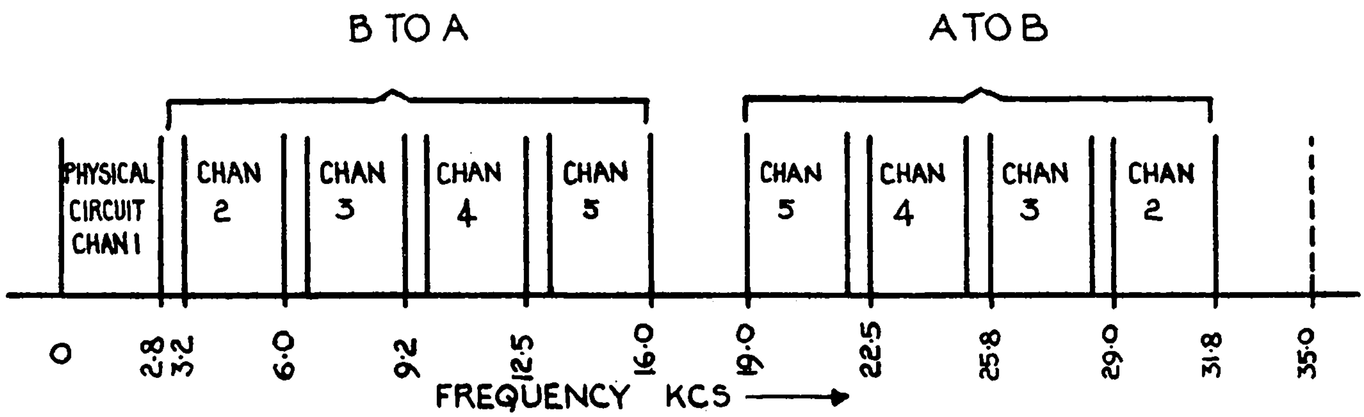

Fig. 3. Diagram of channels in frequency spectrum of Army 1 + 4 carrier system working two-wire.

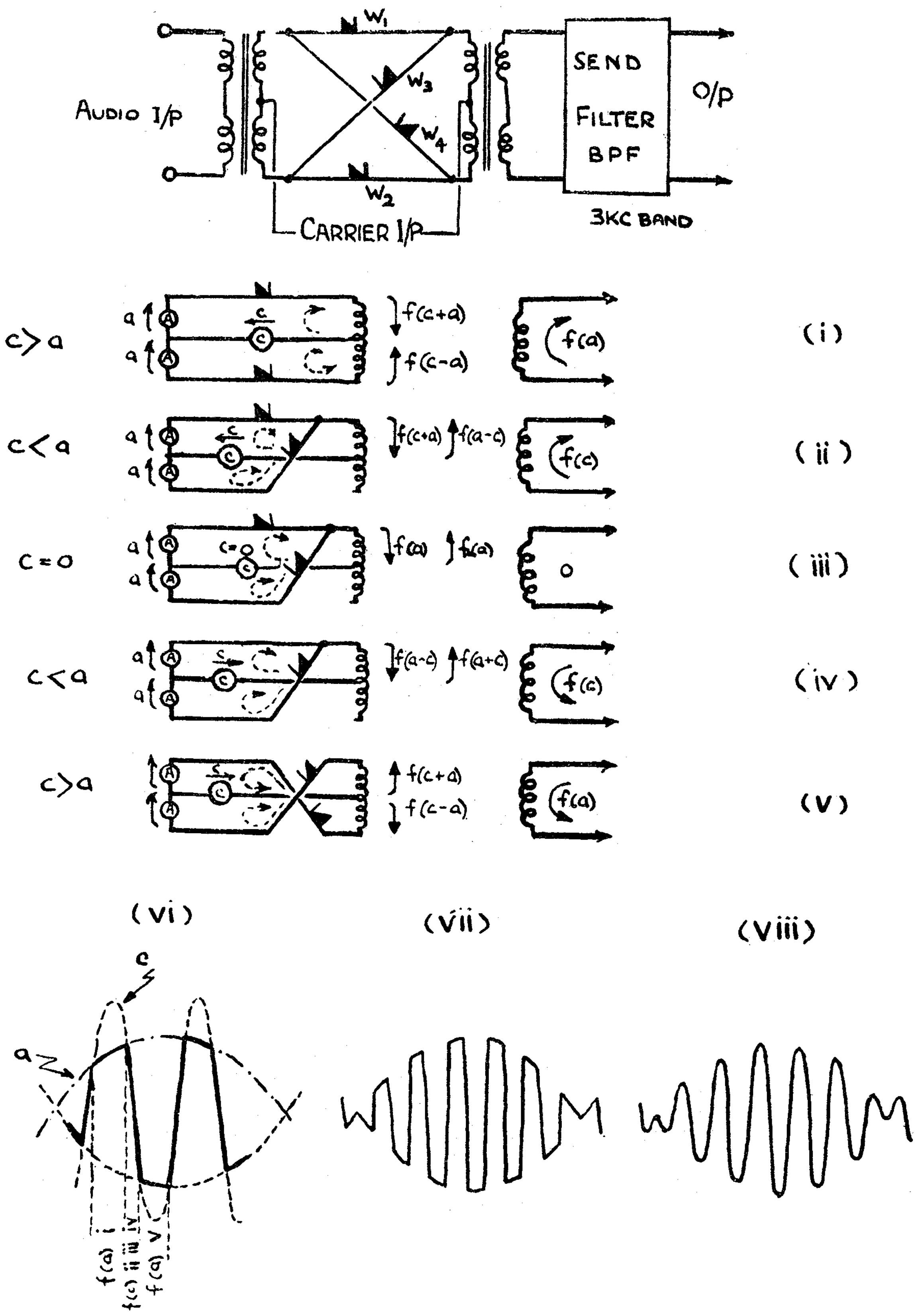

Fig. 4. Action of rectifiers in modulation.

carrier channels above the physical channel, between 3 and 4 kc/s spacing must be allowed between carrier frequencies to accommodate the speech sidebands of 3 kc/s bandwidth ; virtually eight such carrier frequencies would be required. A system such as is shown diagrammatically in Fig. 3, would provide the required spacing so giving a 3 kc/s space between 16 and 19 kc/s which would accommodate the directional filter cut-off characteristics. As is shown, the group carrier frequency is 35 kc/s and the line must have a higher cut-off than this frequency to provide two-wire working. This is the frequency spectrum of the Army 1 + 4 carrier system working a two-wire circuit.

11. When using a four-wire circuit, similar carrier frequencies are used in each direction. Directional filters are therefore not used. The two-wire to four-wire conversion is made on the audio frequency side (exchange or physical side) of each carrier channel (see Fig. 2 (b)).

Obviously for two-wire working virtually twice the number of carrier frequencies would be necessary as also for four-wire working, so that more than twice the total bandwidth would be required. Hence, for Army circuits two-wire working is normally used on open wire systems and four-wire working on cable systems. For systems giving only one carrier channel two-wire working is achieved by using the upper sideband in one direction and the lower sideband in the other.

Ringing on carrier

13. The exchange ringing current of 17 c/s cannot be transmitted over a carrier channel. The 17 c/s ringing is therefore converted to 500 c/s by the carrier terminal equipment. The 500 c/s modulates the carrier frequency in the same manner as does speech. At the receiving end the carrier is demodulated and the 500 c/s tone is detected in the signal receiver, causing 17 c/s ringing to be transmitted to the local exchange.

14. In order that the voice produced frequency of 500 c/s does not operate, the signalling receiver devices are usually incorporated to make the signalling system "voice immune." These often take the form of interrupting the 500 c/s signalling tone at frequency of interruption of 20 c/s and to construct the acceptor circuits in the signalling receiver to respond only to such an interrupted tone.

15. An alternative or additional method is to include in the signalling receiver circuit, additional acceptor circuits tuned to frequencies other than 500 c/s (*i.e.* 600 c/s or 700 c/s) and to arrange that when stimulated by voice produced frequencies they "close down" the receiver and prevent ringing (false ringing) being transmitted to the exchange. In addition the ringing tone is usually of a higher level than speech at the input of the signalling receiver, and the receiver is designed to be suitably insensitive to normal speech level.

MODULATION

16. In carrier telephony, modulators and demodulators consist almost invariably of copper oxide rectifier circuits. The most usual type of circuits used are as shown in Figs. 4 and 5. Copper oxide rectifiers have an impedance characteristic as shown in Fig. 6.

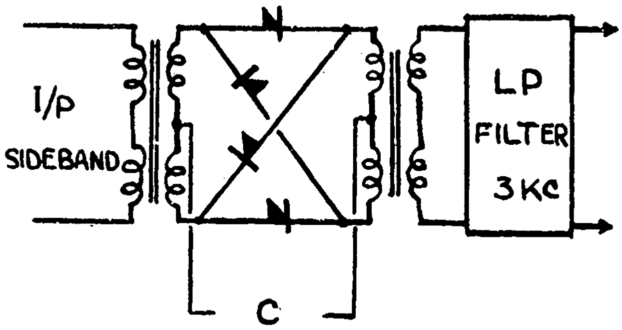

Fig. 5. Skeleton circuit showing principles of demodulation.

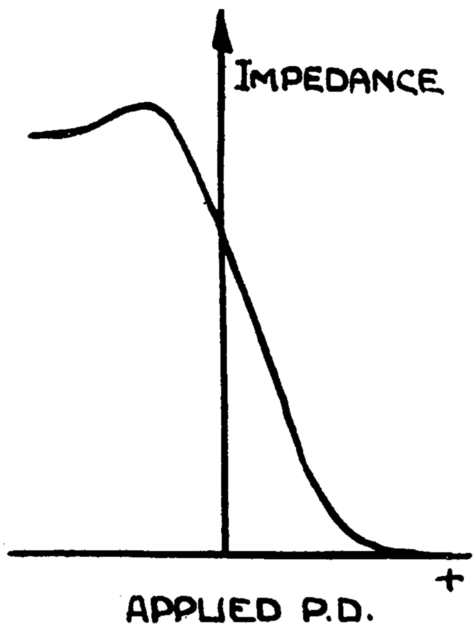

Fig. 6. Characteristic of copper oxide rectifier.

17. Thus in Fig. 4, suppose speech is being fed in at the audio input, then the carrier frequency (which is of a greater voltage amplitude than the audio input voltage) will cause W_1 and W_2 to have low impedances and W_3 and W_4 to have high impedances on the peak carrier half cycles which make A positive to B, and will cause W_3 and W_4 to be low and W_1 and W_2 to be high impedances on the reverse peaks.

18. The action can be seen by following the change of impedance of the branches of the modulator through one cycle of carrier. Fig. 4 (i to v) shows the paths of low impedance as the carrier changes from positive peak through zero to negative peak, and shows the discontinuity produced when the instantaneous carrier amplitude "C" equals the instantaneous audio amplitude "a."

19. The output varies through + f (a), + f (c), o, − f (c), − f (a), for the period of carrier cycle shown. f (a) and f (c) will be similar to the instantaneous values of a and c for the corresponding instants of time. Thus the output will be as shown in vi and vii and represents the commutation of the audio input at a carrier frequency.

20. Fig. vii represents viii very closely. The latter again represents two sidebands, the upper and the lower, of equal amplitude beating together, *i.e.* consists of the sidebands only and no carrier frequency. Thus, the products of modulation, as shown in Fig. 4 vii consist almost entirely of the two sidebands with certain harmonics ; the carrier has been suppressed.

21. In Fig. 4 the output of the modulator is passed through a band pass filter. This has a bandwidth of 3 kc/s and is designed to pass only the lower sideband ; the upper sideband and harmonic products of the rectifier action are filtered out. In effect the output of the modulator is

$$k' \sin \omega_1 t \sin \omega_2 t = \frac{1}{2} k' \left[\cos (\omega_1 - \omega_2) t - \cos (\omega_2 + \omega_1) t\right] \quad \ldots \ldots \ldots \ldots \ 1$$

where $\omega_1 = 2\pi f_1 = 2 \times \pi \times$ audio frequency
and $\omega_2 = 2\pi f_2 = 2 \times \pi \times$ carrier frequency

and the inputs were $A \sin \omega_1 t$ and $B \sin \omega_2 t$. The output of the channel $= k'' \cos (\omega_1 - \omega_2)$, *i.e.* the lower sideband only, where k′ and k″ are functions of the amplitude of the modulation.

DEMODULATION

22. An exactly similar circuit is used for demodulation and is shown in Fig. 5. The two inputs are now the lower sideband and the carrier frequency ; *i.e.* the inputs are now

$k_1 \sin (\omega_2 - \omega_1)$ instead of $A \sin \omega_1 t$
and $k_2 \sin (\omega_2 t + \phi)$ instead of $B \sin \omega_2 t$

The demodulator performs an exactly similar function to the modulator. Hence substituting in 1 above

$k_1 \sin (\omega_2 - \omega_1)t$ for $A \sin \omega_1 t$
and $k_2 \sin (\omega_2 t + \phi)$ for $B \sin \omega_2 t$

$$\text{the output} = K \sin (\omega_2 - \omega_1)t \sin (\omega_2 t + \phi)$$
$$= \frac{K}{2}\left[\cos (\omega_2 t - \omega_1 t - \omega_2 t - \phi) - \cos (\omega_2 t - \omega_1 t + \omega_2 t + \phi)\right]$$
$$= \frac{K}{2}\left[\cos (\omega_1 t + \phi) - \cos (2\omega_2 t - \omega_1 t + \phi)\right] \quad \ldots \ 2$$

where K is a function of the sideband amplitude.

23. Thus the product is the audio frequency represented by ω_1 and a term in the order of the second harmonic of carrier frequency $(2\omega_2 t - \omega_1 t + \phi)$. The phase angle ϕ has no effect. The L.P. filter suppresses the H.F. product and only the required audio frequency is produced. Were the local carrier frequency not correct we could let the error be ϕ where $\phi = \omega_3 t$ (*i.e.* f_3 is the frequency error where $2\pi f_3 = \omega_3$). It is obvious from the above, by substituting for ϕ, that the demodulation product is a frequency $f_1 + f_3$ instead of f_1. In speech such an error of audio frequency is not serious provided that f_3 is not greater than about 20 c/s.

24. It is interesting to note the effect of transmitting both sidebands. We should have to substitute $k_1 \sin \omega_1 t \sin \omega_2 t$ for $k_1 \sin (\omega_2 - \omega_1)t$ in the above. The effect of $\omega_3 t$ (frequency difference) now has marked distorting effect which cannot be tolerated.

i.e. Output $= K \sin \omega_1 t . \sin \omega_2 t . \sin (\omega_2 + \omega_3)t$

$$= \frac{K}{2}\left[\cos (\omega_2 - \omega_1)t - \cos (\omega_2 + \omega_1)t\right] \sin (\omega_2 + \omega_3)t$$
$$= \frac{K}{2}\left[\cos (\omega_1 + \omega_3)t - \cos (2\omega_2 - \omega_1 + \omega_3)t + \cos (\omega_1 - \omega_3)t - \cos (2\omega_2 + \omega_1 + \omega_3)t\right] \quad \ldots \ 3$$

25. The audio terms will now beat together at an audio beat frequency of $2\omega_3$. Thus, in double sideband suppressed carrier transmission, oscillators would have to be of exactly the same frequency, otherwise beats would be heard, whereas in single sideband transmission the frequency stability of the oscillators need not be so high.

CARRIER BALANCE

26. The effectiveness of the modulator circuit in suppressing the carrier depends on the exact equivalence of the impedance of the rectifiers, and the balance of the two halves of the transformer windings. In order to ensure that the carrier is effectively suppressed, the modulator is often in the form shown in Fig. 7. The tapping is adjusted to give the best carrier suppression.

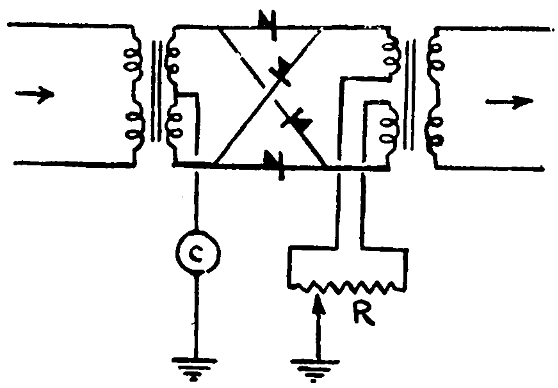

Fig. 7. Carrier leak potentiometer.

LIMITER CIRCUIT

27. The 500 c/s signalling tone is usually at a very high power level compared with speech. In order to prevent this high level overloading the send repeater, an automatic limiter is often included in the audio input to the channel. The circuit is of the form shown in Fig. 8. The rectifiers W_1 and W_2 are given a negative bias from the potentiometer across the input to the modulator and cause little attenuation. Should the level of the input be such that the peaks exceed the bias then the rectifiers conduct on each half cycle. When conducting, they represent a small impedance across the modulator input and so attenuate the signalling tone voltage. The level at which this action commences is controlled by the potentiomete supplying the bias.

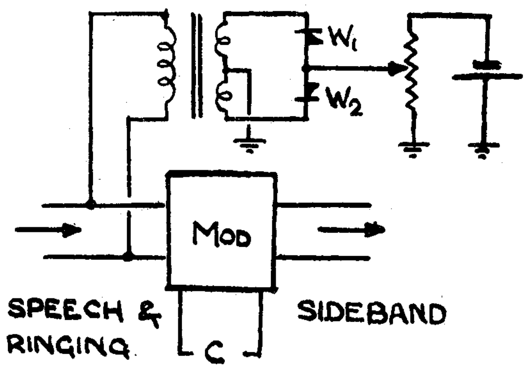

Fig. 8. Automatic limiter circuit for 500 c/s signalling tone.

OSCILLATORS

28. These are always of fixed frequency, suitably trimmed for setting up the frequency. They must be stable, since the group oscillators at each end must remain exactly in step though they may differ from their nominal frequency by 100–200 c/s. The channel oscillators can differ in frequency by 30–50 c/s, but the effect on speech becomes noticeable after about 20 c/s difference. An example of type used is shown in Fig. 9. This is the circuit of the oscillator used in the Army 1 + 4 system.

AMPLIFIERS

29. Two types of amplifiers are used in carrier telephony. The first is the line repeater, and it must be designed to give wide band amplification (*i.e.* from 3 kc/s to 30 kc/s) especially at the higher frequencies, due to the increased line attenuation there. The gain is of the order of 30–40 db. The second type is the channel amplifier and amplifies the audio output (0–3 kc/s). The gain of this amplifier need not be as high as the line amplifier (it is usually from 10 to 30 db) since its function is to replace the losses due to the channel receive filters, demodulator, etc.

PHYSICAL CIRCUITS

30. The lowest carrier frequency used is of the order of 6 kc/s. A lower sideband of 3 kc/s leaves a band of frequencies 0–3 kc/s which can be used as a physical or telegraph channel. This physical channel is divided from the carrier channels by a directional system of low pass and high pass filters. The resultant physical circuit is a

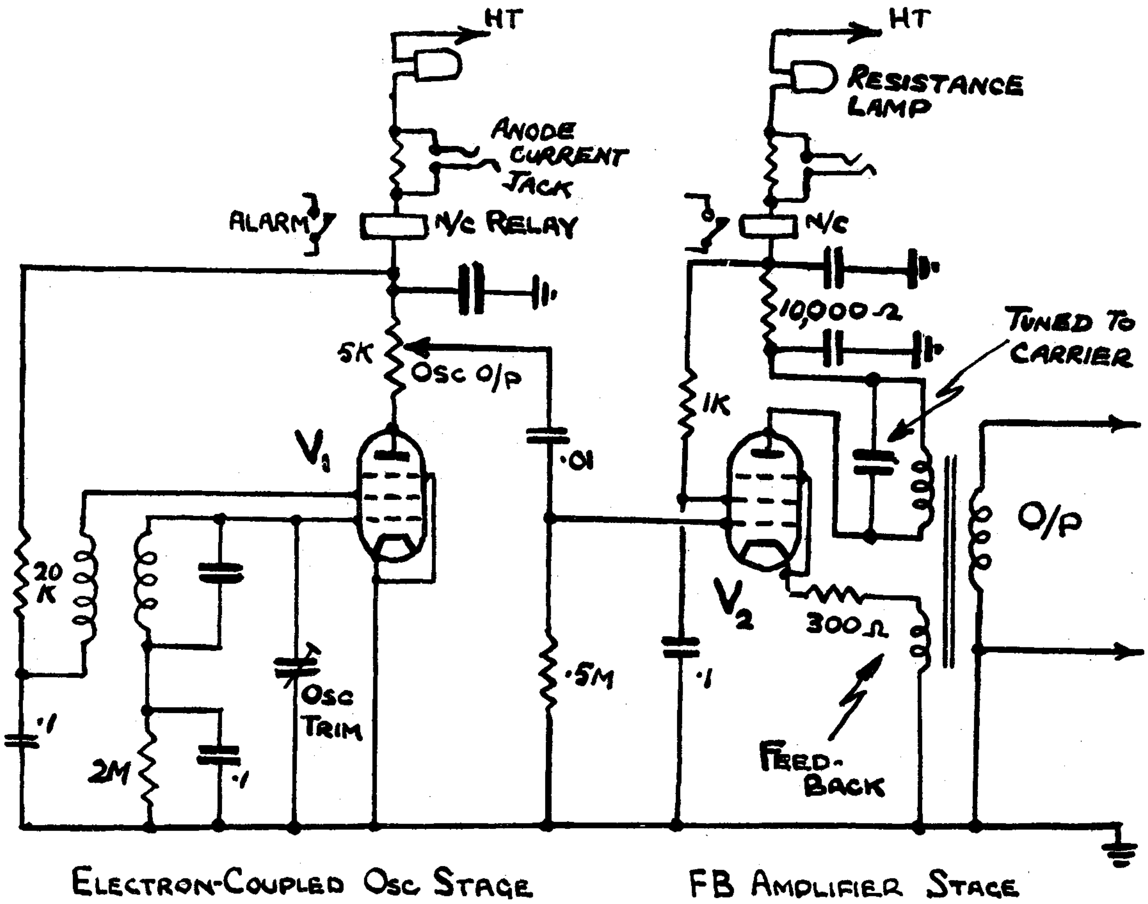

Fig. 9. Channel oscillator.

four-wire or two-wire circuit, depending upon whether the whole system is being used on a four-wire or two-wire basis, and hence requires appropriate terminations.

EQUALIZERS

31. These are networks (usually reactive) of a carefully designed form inserted in the termination of the line and are ideally such that they have a loss characteristic which is exactly the inverse of the loss characteristic of the line.

GENERAL CIRCUIT. BLOCK SCHEMATIC

32. The diagram Figs. 10 and 11 give a block schematic of one channel of a typical carrier system showing the generally adopted scheme. Fig. 10 shows the four-wire arrangement, and Fig. 11 the two-wire (group modulated) system. The terminal is arranged to send or receive the group carrier by simple changeover of connections to the Modem (Modulator-demodulator) and to the directional filter.

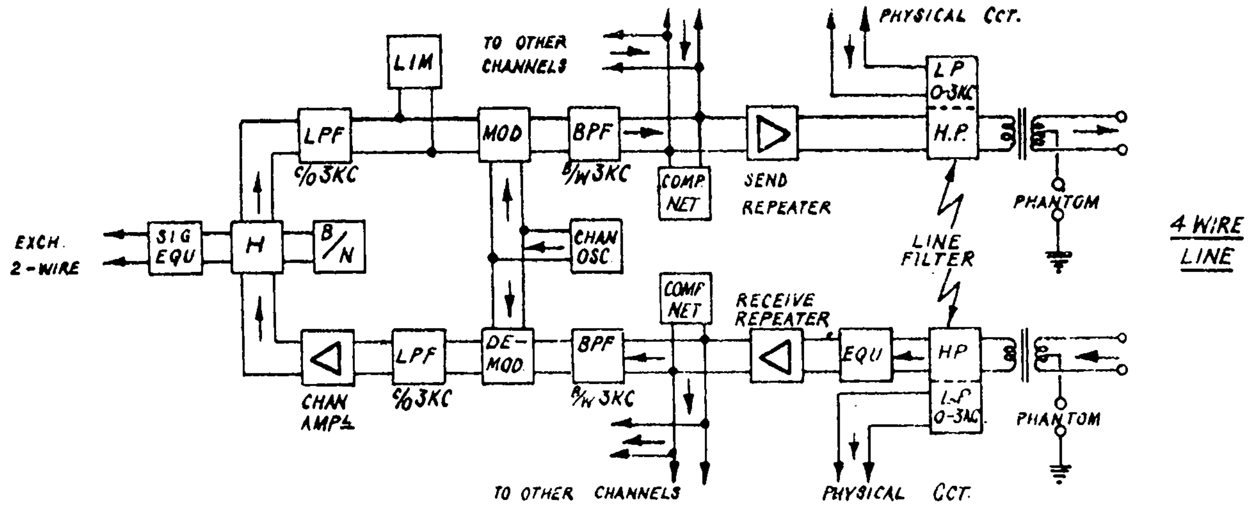

Fig. 10. Block schematic diagram of four-wire terminal.

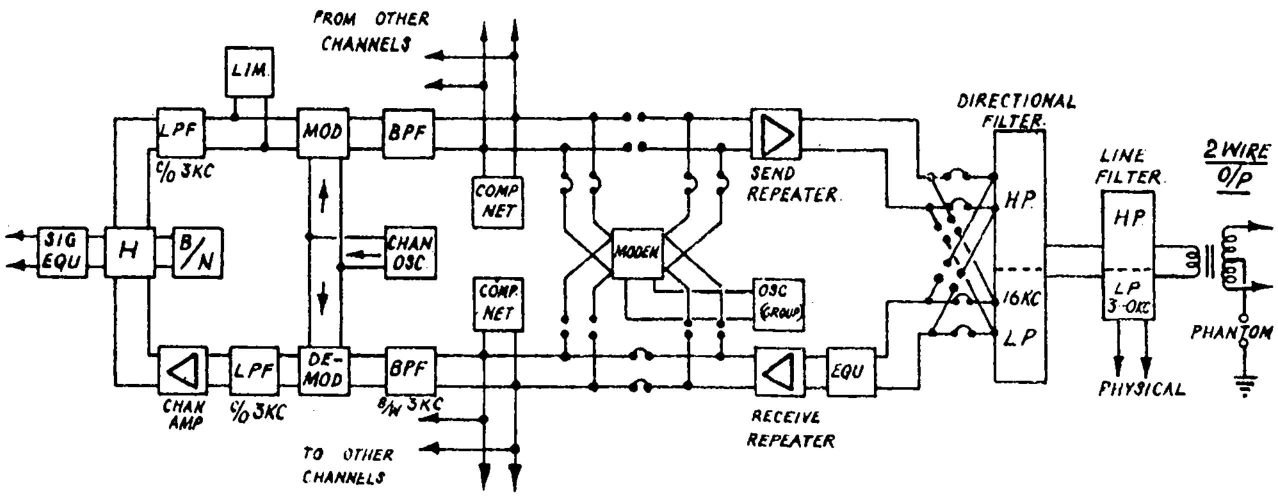

Fig. 11. Block schematic diagram of two-wire terminal.

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