WS No. 19 Mark III

FREQUENCY SHIFT SIGNALLING

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INTRODUCTION

General

1. All telegraphic codes are dependent upon variations of two primary conditions, 'Mark' and 'Space', these conditions may be represented in simple electronic terms as 'current' and 'no current'. In line telegraphy the conditions are produced by breaking the current at the transmitting end and thereby sending a series of D.C. pulses over the line. In radio telegraphy the conditions are not necessarily produced by breaking the transmission from the sender.

2. C.W. ON-OFF or 'Keyed Carrier' signalling, employs the same principles as line telegraphy, the carrier is transmitted for a mark and switched off for a space, but in carrier or radio-frequency shift (C.F.S.) signalling there is no break in transmission. In this system the two conditions of 'Mark' and 'Space' are represented by two different carrier frequencies, and both frequencies are used in the reception apparatus. The presence of an additional or spacing carrier constitutes the essential difference between carrier-frequency shift (C.F.S.) signalling and ordinary C.W. (ON-OFF or Keyed Carrier) signalling. Two audio tones can be used to modulate the carrier and this system is known as 'Tone Frequency-Shift Signalling', however, this system is not used by the Army and will not be described.

3. Frequency-shift signalling may be considered as the telegraph equivalent of frequency modulation (F.M.) speech transmission. The two resemble each other in the following respects:—

(*a*) the carrier frequency is varied (by constant amount for telegraphy) to convey the required intelligence.

(*b*) The factors governing signal/noise ratio are the same for frequency-shift signalling and for F.M.

(*c*) In both cases the signal/noise ratio can be improved by the method of reception (paras. 49-50).

It should be noted that the term 'frequency-shift' is applied only when a change in frequency from 'Mark' to 'Space' or vice versa, is continuous and is not accompanied by an abrupt change in phase; this is the case when the frequency of an oscillator is changed by varying the inductance or capacitance of the controlling tuned circuit. If the change in frequency is discontinuous as in the case when one oscillator is switched off and another is switched on, the term 'frequency exchange' is applied. The general term 'frequency change' covers both methods.

4. In carrier-frequency shift signalling, the 'frequency-shift' (the difference between the mark and the space frequencies) is normally about 850c/s although shifts of from 200-1,200c/s are sometimes used. The mark frequency is usually higher than the space frequency.

5. Comparison of C.F.S. and keyed carrier signalling.

(*a*) Fast fading.
Fast fading which is a main source of trouble in long range radio telegraph links cannot be countered effectively in keyed carrier signalling by the use of A.G.C. If the A.G.C. is rapid enough it will amplify the noise to signal level during the space period of the transmission, consequently there is a lack of positive indication of a space code, because the noise level is comparable with the signal level. With C.F.S. signalling, positive indication is continuously given, the action of the limiters compensating for any fast variations in signal level not sufficiently dealt with by the A.G.C.

(*b*) Transients, waveforms and band-width.
A C.F.S. transmitter is operated under constant load conditions, hence the output waveform is easily controlled and fewer transients are transmitted than with the ON-OFF system of keying. At the same keying speeds the band-width of a C.F.S. transmission is, in practice, less than the band-width using keyed carrier.

(*c*) Power supply
As the transmitter is radiating continuously in C.F.S. signalling, the problem of regulating the power supply is almost completely solved. For example, the absorber circuits used in the Senders S.W.B. 8 and 11 for keyed carrier signalling are unnecessary when C.F.S. signalling is used.

Stability

6. Both the transmitter and the reception set must possess a very high degree of stability for C.F.S. signalling. These conditions can be achieved without difficulty in medium and high-powered transmitters.

METHODS OF TRANSMISSION

General

7. To obtain a frequency-shift, the inductance or capacitance of the tuned circuit controlling the frequency must be changed.

This can be done by a simple keying method as shown by the series fed tuned anode oscillator in Fig. 1. On 'Space' the capacitor C2 is shunted across the tuned circuit (L1-C1) and the oscillator frequency is lowered. This basic method is very unsatisfactory, owing to the capacity of the keying contacts and the leads to them, and to the production of undesired keying transients. The keying (i.e., the changing of the reactance of the tuned circuit) is usually carried out electronically. The two basic ways of doing this, the 'Impedance-valve' and 'Reactance-valve' methods, are described in paras. 8 and 9. Although the circuits used in Army equipments may be considerably different from those shown in this E.M.E.R., they are almost all variations of one or other of these two fundamental methods.

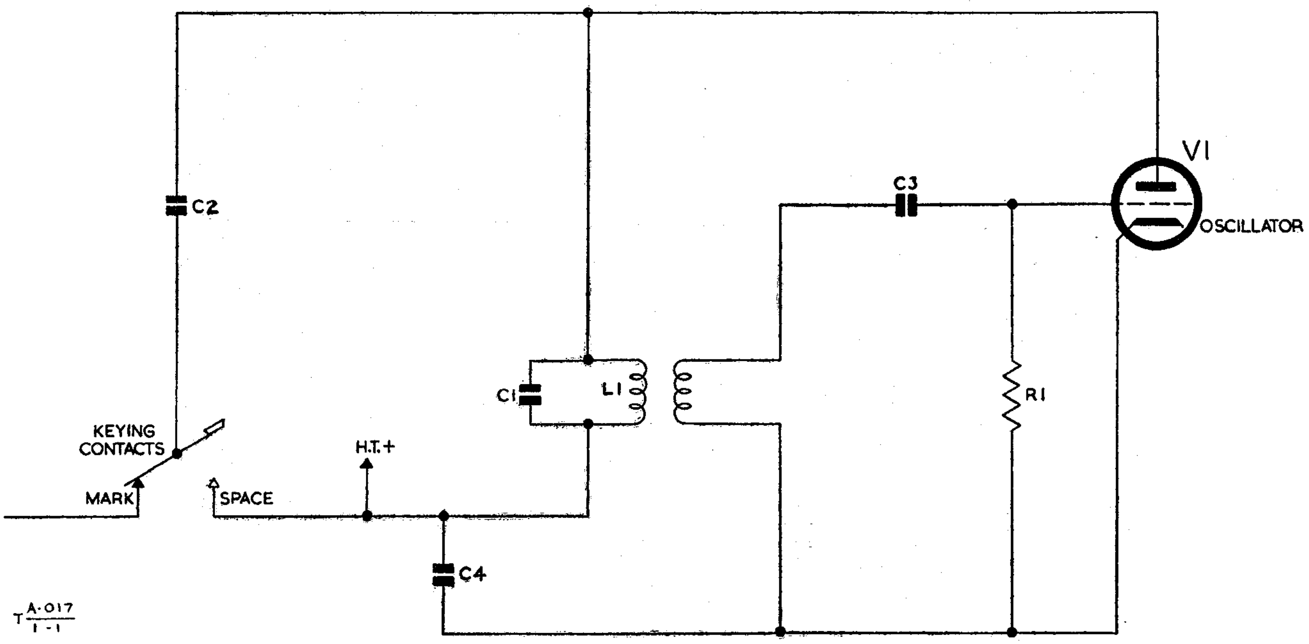


Fig. 1—Simple method of obtaining frequency-shift

Impedance-valve keying

8. In this method, shown in Fig. 2, a diode V1 is employed in place of the keying contacts which are used, instead, to bias the valve. On 'Mark' the anode is negatively biased, and the valve does not conduct, so that the capacitor C2 is not in circuit. On 'Space', the anode is biased positively, the valve conducts, and C2 is shunted across the tuned circuit L1-C1, thus lowering the oscillator frequency. Adjustment of the magnitude of the shift can be achieved in two ways either by adjustment of C2, or by alteration of the biasing voltage which controls the extent to which the valve conducts.

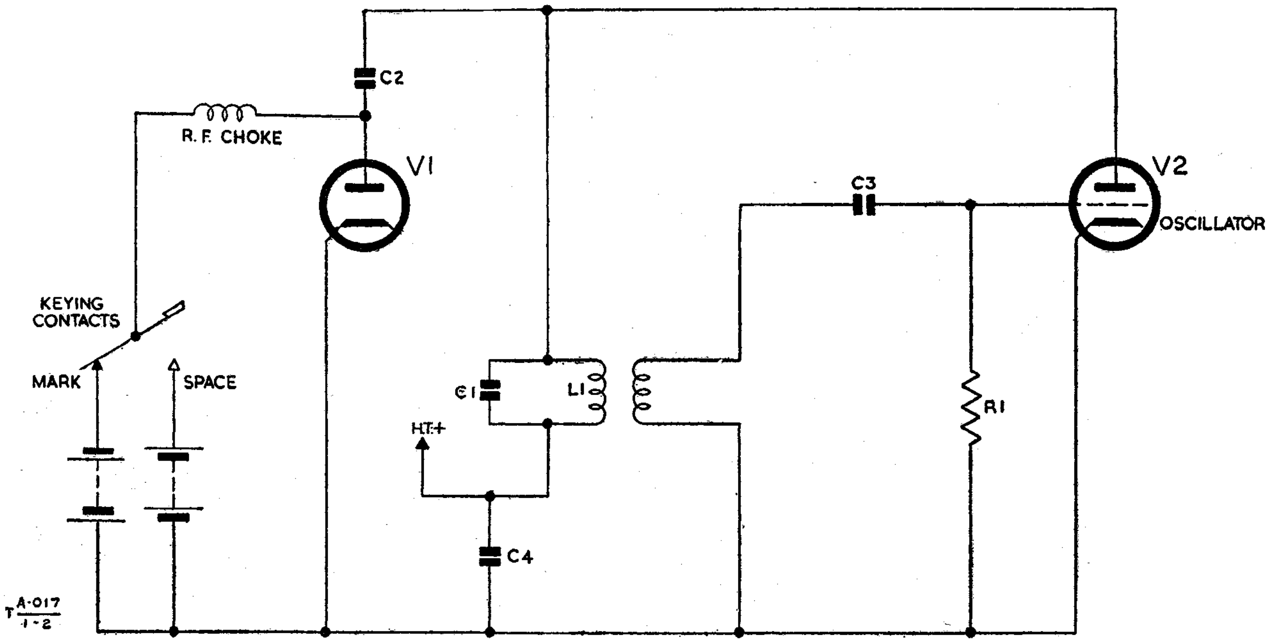


Fig. 2—Impedance-valve keying

Reactance-valve keying

9. A typical arrangement of a reactance-valve circuit is shown in Fig. 3. This is, as before, applied to a tuned anode oscillator, but the keying contacts are used to alter the bias on the control grid of the pentode V1, placed across the tuned circuit (L1-C1) of the oscillator. The grid is connected to the anode through the phase-changing network R2-C2, so that the anode current leads the anode voltage by 90°. The anode and cathode of V1 now form, effectively, the two plates of a capacitor whose capacitance can be varied by altering the grid voltage. The valve therefore behaves as a reactance in parallel with the tuned circuit, and variation of the grid bias voltage will cause a variation in the frequency of the oscillator. When the key moves over from 'Mark' to 'Space' the negative bias on the grid is reduced, the anode current increases, and the reactance, which is the ratio of anode voltage to anode current, will decrease. The effect is the same as that obtained with the impedance-valve method in which the capacitance across the tuned circuit increases, with a consequent drop in frequency.

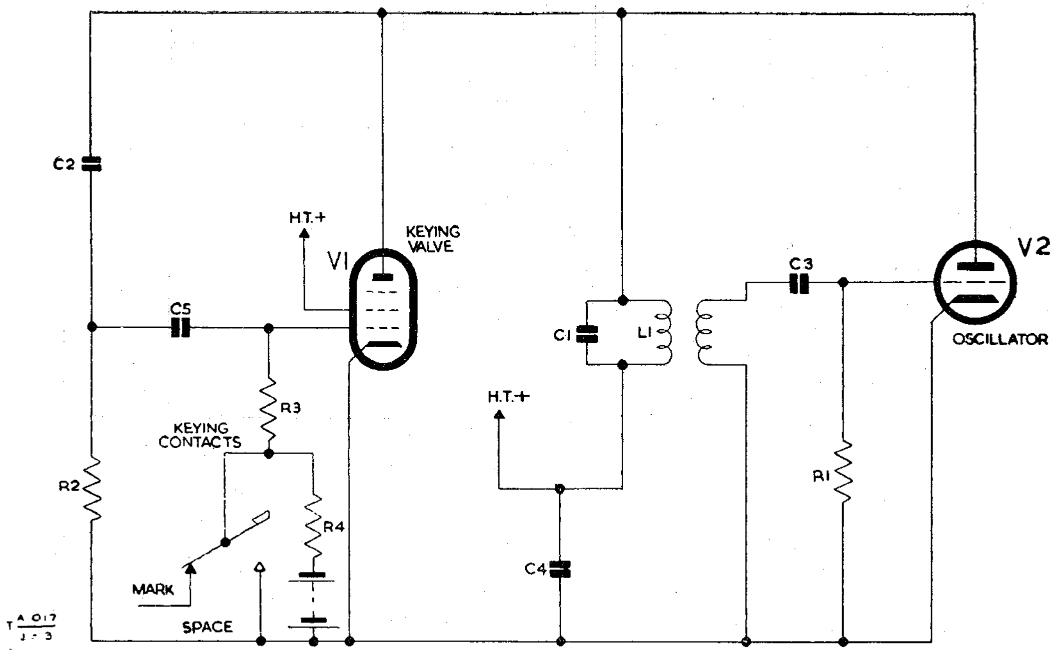


Fig. 3—Reactance-valve keying

Frequency stability in transmitters

10. The normal tolerance for small mobile transmitters, when not crystal-controlled, is of the order of ± 1 part in 20,000. This permits a drift of ± 1kc/s in a typical carrier frequency of 20Mc/s. Receivers which employ the filter method of reception (para. 22) use filters with band-widths of 700c/s, and so a transmitter with a drift of ± 1kc/s can only be used when automatic frequency-control is employed in the receiver. A.F.C. is not very satisfactory (para. 28), and crystal-control is therefore desirable when using filter reception. Paras. 12-15 detail the methods of employing crystal control in keying circuits. It should be noted, however, that modern receivers, using discriminator reception, can function satisfactorily with a drift of ± 3kc/s, without using A.F.C. (para. 38 et seq.).

Pulled-crystal excitation

11. Fig. 4 shows how either the impedance-valve or the reactance-valve method can be applied to 'pull' the frequency of an crystal oscillator. This method gives good frequency stability, and is occasionally used in mobile equipments, owing to its simplicity and light weight. Its use, especially in larger installations, is restricted, largely because of the difficulty of selecting suitable crystals. Few crystals of standard type can be pulled sufficiently and some cannot be pulled at all. Of those that can be pulled, many are found to exhibit spurious responses, and the shift is often unstable. A new type of crystal with particularly good pulling characteristics is being developed for this purpose.

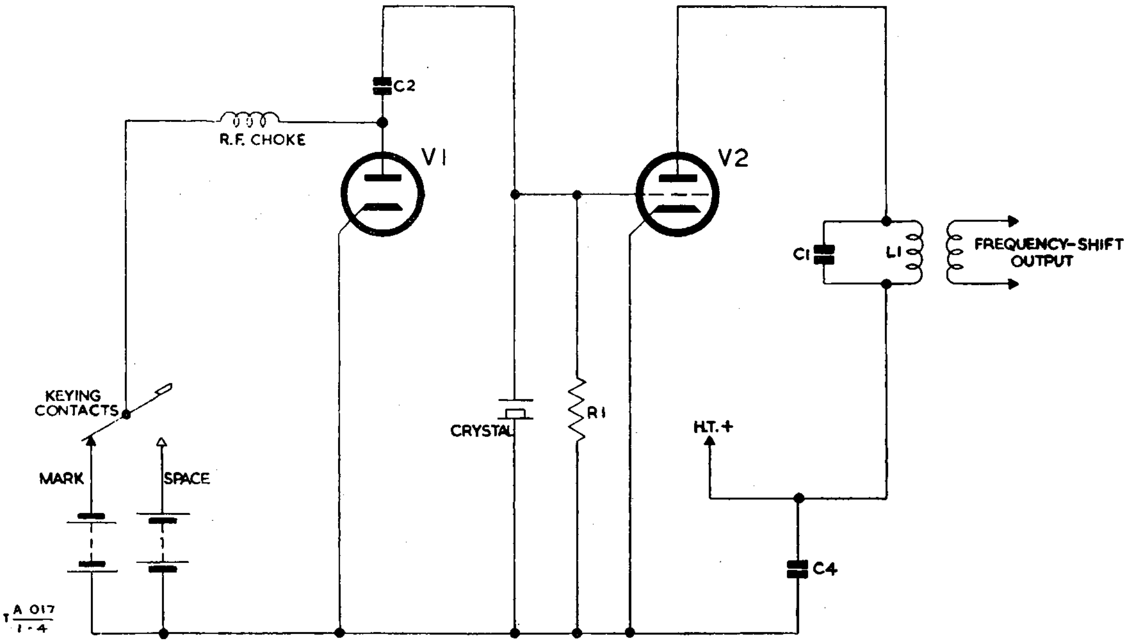


Fig. 4—Pulled-crystal exciter

Mixed-oscillators excitation

12. Although it is rather more complex than the pulled crystal method of excitation, a satisfactory method of obtaining good frequency stability is to mix the outputs of two oscillators, one of which is crystal-controlled, while the other employs a conventional L-C tuned circuit. A block diagram of the method is shown in Fig. 5. The crystal-controlled oscillator operates at a frequency 200kc/s below the desired carrier frequency. A shift is applied to the other oscillator by means of an impedance-valve or a reactance-valve, the frequency of this oscillator being 200kc/s.

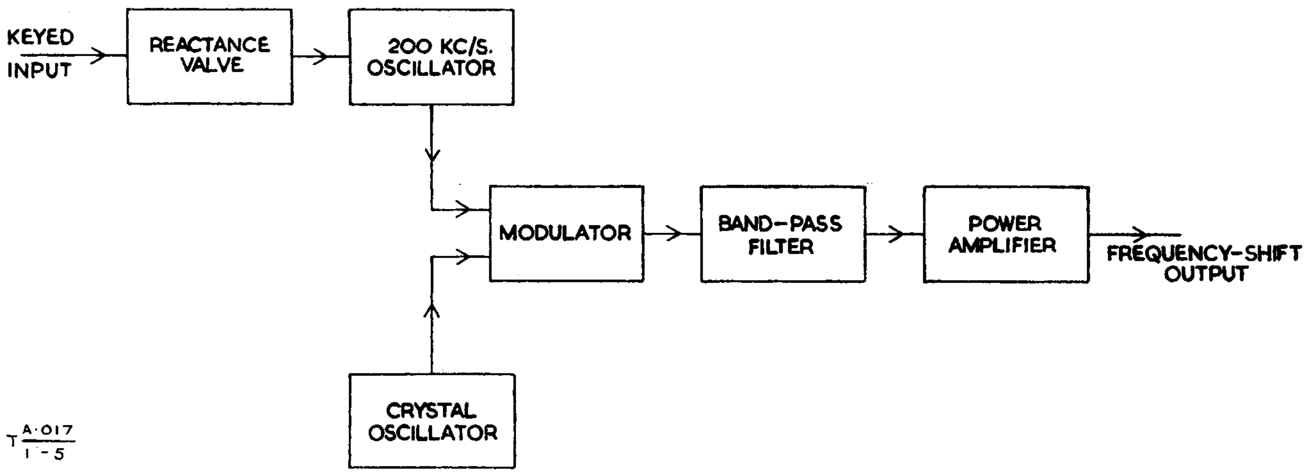


Fig. 5—Block diagram—mixed oscillators exciter

13. The modulator output will contain a number of components, one of which will be the sum of the frequencies of the two oscillators. Since this is the desired carrier frequency, a band-pass filter is employed to pass this component, which is then amplified, and all other components are blocked. When a shift is applied to the 200kc/s oscillator, it is also applied to this carrier frequency, so that the transmitter output is, therefore, the desired carrier frequency, to which a shift has been applied.

14. The drift of the crystal oscillator is negligible, and the other oscillator, with the normal tolerance of 1 part in 20,000 has a drift of ± 10c/s, so that the total drift of the transmitter is only ± 10c/s. For a normal carrier frequency of 20Mc/s, this drift is only 1% of the drift of a transmitter with no crystal control. A further advantage lies in the fact that it is easier to construct an oscillator of high stability, but without crystal control, at a frequency of 200kc/s, than at 20Mc/s. A standard crystal can be used in the crystal-controlled oscillator, since no frequency-shift is applied to it

Distortion of keying signals

15. When the keying signals from the operating teleprinter or auto-transmitter are applied to the transmitter over a long line, the waveform is often rounded in shape, as for example, in Fig. 7 (*b*), instead of resembling as nearly as possible the ideal square waveform of Fig. 7 (*a*). Further rounding of the signals may be introduced by the keying and amplification stages of the transmitter, and by various stages in the receiver, and still more distortion may take place owing to noise, selective fading, and other propagation effects. It is clearly advantageous to maintain at each stage a waveform which is as square as possible, so that the over-all distortion is kept to a minimum, and fewer misprints result.

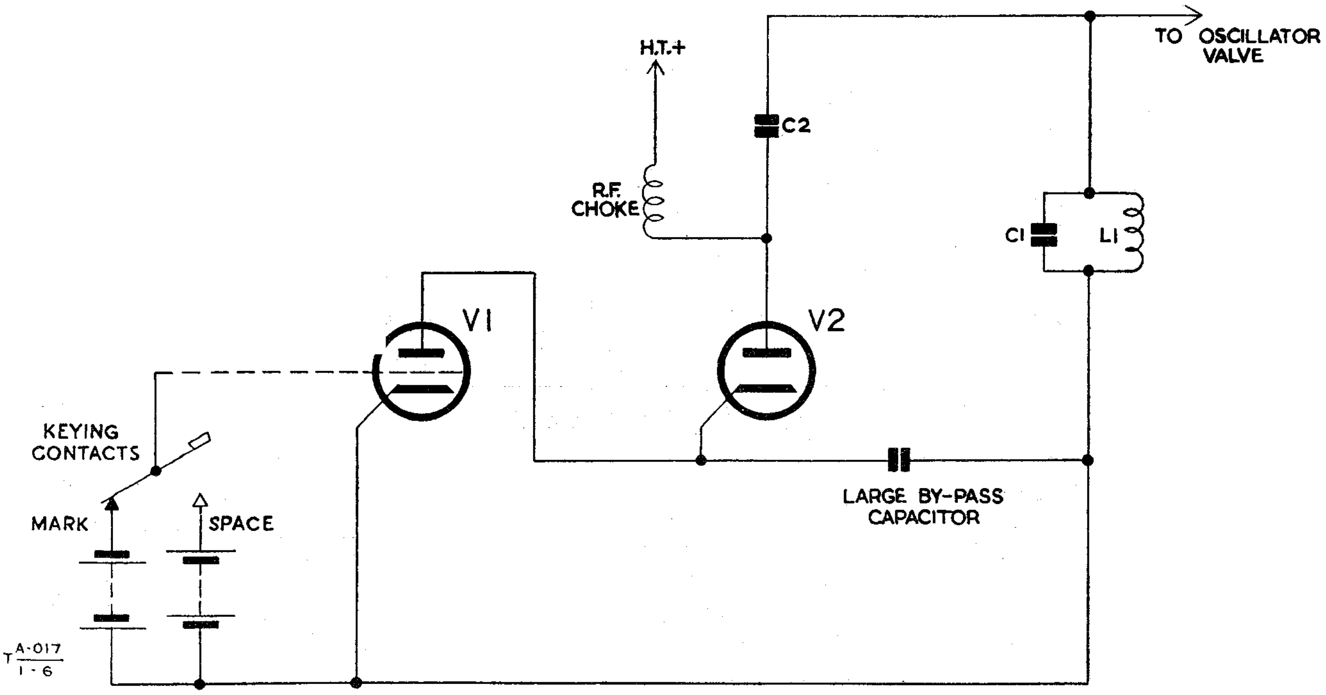


Fig. 6—Electronic relay applied to impedance-valve keying

16. In Fig. 7 (*a*) the change from mark to space is instantaneous. In practice this is not possible, but, whatever rounding of the signal is introduced before it reaches the transmitter, it is important that the change at the transmitter from mark to space should be made as rapidly as possible. When the input to the transmitter is already distorted, and has a waveform similar to that in Fig. 7 (*b*) some form of relay is needed so that the output is as undistorted as possible. To avoid the periodical adjustments which a mechanical relay requires, an electronic relay is normally used.

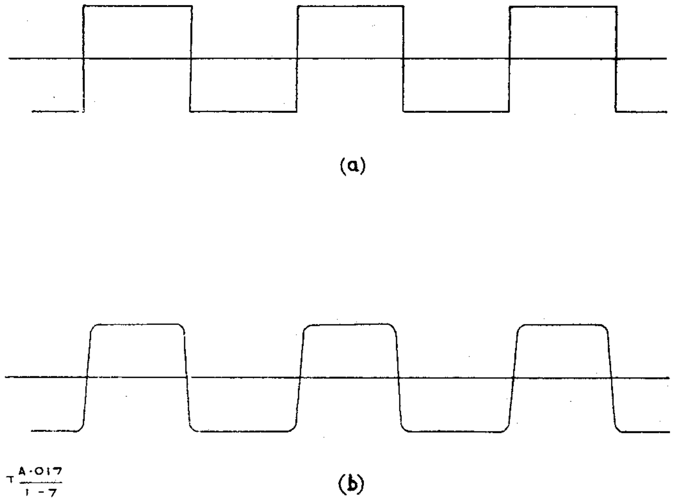


Fig. 7—Keying waveforms

Electronic relay

17. Fig. 6 shows a normal arrangement incorporating the relay with an impedance-valve. The keying signals are used to give a large bias voltage to the relay valve, so that it is driven well beyond cut-off on 'Mark', and right up to saturation on 'Space'. The relation between anode current (I_a) and grid bias voltage (V_g) for the relay valve is shown in Fig. 8. The effect of the large bias voltage is to cut off the peaks of the input signal, so that the change from zero anode current to maximum anode current takes place on the least distorted part of the input signal curve, and the time taken to change over is small, even with badly distorted signals.

18. The impedance-valve is in the anode circuit of the relay valve. The anode current of the relay valve, which has a waveform similar to the original input signal but is less distorted, and becomes the keying signal for the impedance-valve which operates in the normal way.

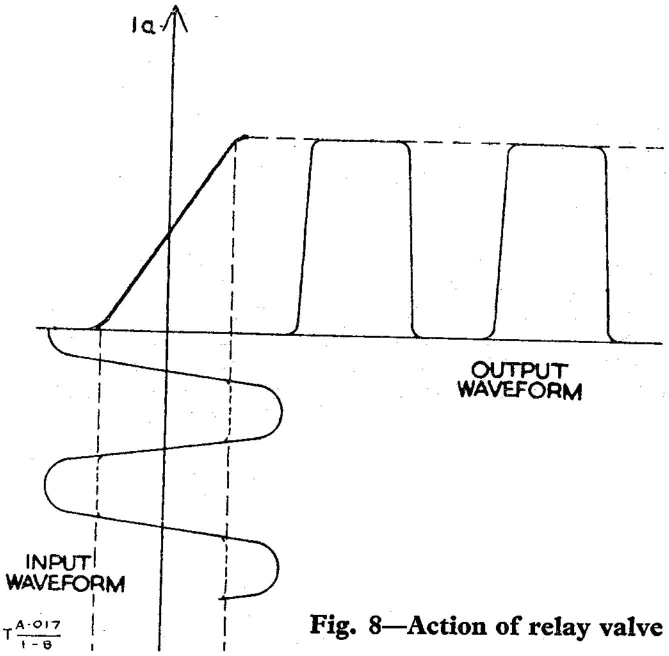


Fig. 8—Action of relay valve

Application of frequency-shift exciters

19. Any of the exciters described in this E.M.E.R. may be used in place of the existing oscillator stage of a normal transmitter to convert it to frequency-shift operation. A frequency-modulated speech transmitter may be converted to frequency-shift operation simply by applying a telegraph keying voltage in place of the audio modulating voltage. However, when frequency multiplication is employed in the later stages of the F.M. transmitter the frequency-shift is multiplied as well as the carrier frequency. Consequently a compensating voltage dividing network is normally introduced into the input circuit of the keying apparatus, in order that the multiplied shift in the transmitter will be correct.

METHODS OF RECEPTION

General

20. Two basic methods are used for the detection of frequency-shift signals. The first method uses two band-pass filters, one for the mark and the other for the space frequency. The second method employs a discriminator, as used in F.M. telephony reception. All frequency-shift receivers employ variations of these basic methods, and almost invariably use superheterodyne reception.

Filter method of reception

21. A typical filter-type receiver is shown in Fig. 9. The early stages are normal, the output from the I.F. stages being heterodyned by a second oscillator giving an output consisting of two A.F. tones. Common frequencies used are 2,950c/s and 2,100c/s, for 'Mark' and 'Space' respectively. Two band-pass filters with band-widths of about 700c/s separate the two frequencies, and feed them into the mark and space rectifiers respectively, whence they pass to a polarized relay.

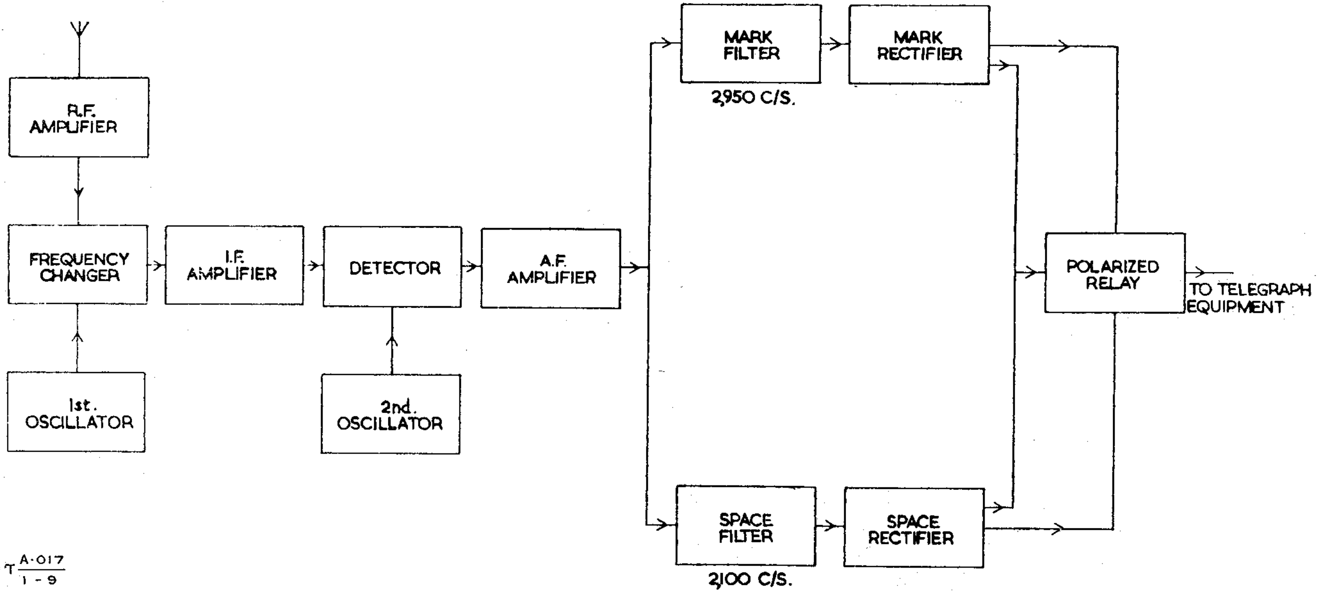


Fig. 9—Filter-type frequency-shift receiver

Frequency drift

22. The normal keying speed for radio links is 50 Bauds and at this speed the band-width of each tone signal will be approximately 150c/s. The pass-bands of the twin filters will be 1,750 to 2,450c/s and 2,600 to 3,300c/s, it follows, therefore, that the maximum permissible frequency drift is $\pm\left(\frac{700-150}{2}\right) = \pm$ 275c/s, greater drift than this will cause the mark and space tones to be clipped or cut off by their respective filters. If the frequency shift is not exactly 850c/s (2,950 − 2,100), the permissible drift is reduced by an amount equal to the departure from 850c/s, unless the filter mid-band frequencies are correspondingly adjusted. A very high degree of frequency stability is therefore essential, not only in the transmitter, but also in the 1st (R.F.) and 2nd (B.F.O.) oscillators in the receiver.

Automatic frequency-control

23. Occasionally small transmitters which are not crystal-controlled are used, and drifts of up to ± 1kc/s occur. To permit operation of a filter-type receiver when the transmitter is subject to drift of this order of magnitude, automatic frequency-control is often incorporated, and this will normally permit satisfactory operation with a drift of ± 1kc/s.

24. Fig. 10 shows a filter-type receiver with A.F.C. applied to it. The output from the A.F. amplifier is taken through two filters (F1 and F2) to a discriminator. This discriminator develops a D.C. control voltage proportional to the difference between the incoming signal frequency and the frequency to which the receiver is tuned. This control voltage is applied to a reactance-valve (see Fig. 3), which corrects the frequency of one of the oscillators, normally the second.

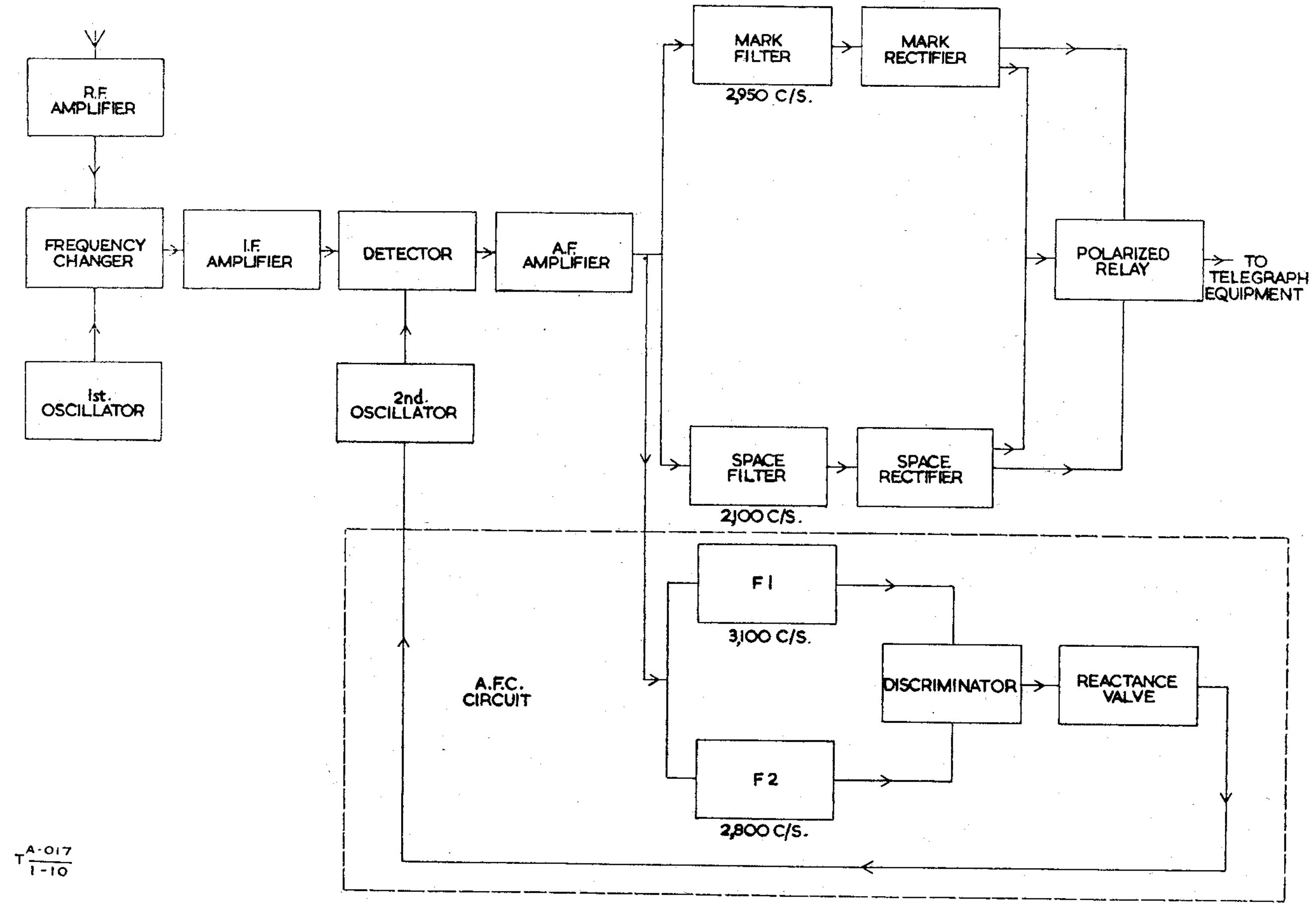


Fig. 10—Filter-type frequency-shift receiver incorporating A.F.C.

25. Teleprinters are so arranged that when no messages are passing the mark frequency is transmitted, and so the A.F.C. is made dependent upon this frequency. (The maximum time that can elapse without the mark frequency being transmitted is 100m sec.) The filters F1 and F2 have, therefore mid-band frequencies associated with the mark frequency being 150c/s higher and lower respectively. The filters and discriminator are so arranged that when an A.F. tone of 2,950c/s is fed into the filters, the control voltage is zero, and the oscillator frequency is not altered. A variation from 2,950c/s causes a control voltage of appropriate polarity and magnitude to be fed to the reactance valve, which then adjusts the frequency which returns to approximately 2,950c/s.

26. The reactance-valve does not return the mark frequency to exactly 2,950c/s, so that there is always a tuning error, on the existence of which the A.F.C. depends. If there is always some error however slight, there will always be a control voltage applied to the reactance-valve, which therefore keeps a continued check on the frequency of the second oscillator and on the drift of the system. A.F.C. is not very satisfactory, as a deep fade may allow the A.F.C. circuit to lose control, and it may not regain control when the fade has passed. If there is a strong interfering signal near the required signal, the A.F.C. circuit may lock on to the un-

wanted signal, and no messages will be received. An A.F.C. system utilizing a motor-driven capacitor is the most satisfactory as it will not lock on to an unwanted signal should a serious fade occur, and will resume control at approximately the frequency setting at which the control became ineffective.

Discriminator method of reception

27. In this method, the changes of transmitted frequency are converted into changes of amplitude and these are treated as normal D.C. telegraph signals. The two main types of discriminator used are the Round-Travis discriminator, and the Foster-Seeley discriminator. Both of these are also used in F.M. reception.

28. Before the discriminator stage, one or more limiter stages are employed to remove any variations in amplitude of the incoming signals. These stages are ordinary I.F. stages but the input signal is much greater than the grid base of the valve. The output signal is therefore of constant amplitude.

29. A low-pass filter is normally inserted in the output circuit of the discriminator to offer high attenuation to all but the low frequency telegraph signals, thereby improving the signal/noise ratio. The Foster-Seeley discriminator is the more widely used owing to its greater sensitivity, but the Round-Travis discriminator is more simple, and will be described first.

Round-Travis (amplitude) discriminator

30. This is a double tuned discriminator, the circuit diagram of which is shown in Fig. 11. The limiter valve feeds constant amplitude signals to an I.F. transformer, the two secondary windings of which are tuned to frequencies 2kc/s above and 2kc/s below the mid-point between the mark and space frequencies, by capacitors C3 and C4 respectively. The two tuned circuits are connected to diode rectifiers, the load resistors of which are connected in series to give opposing voltages. Each tuned circuit will give a voltage which will be greatest when its resonant frequency is fed to the I.F. transformer, and will decrease as the frequency moves away from the resonant frequency.

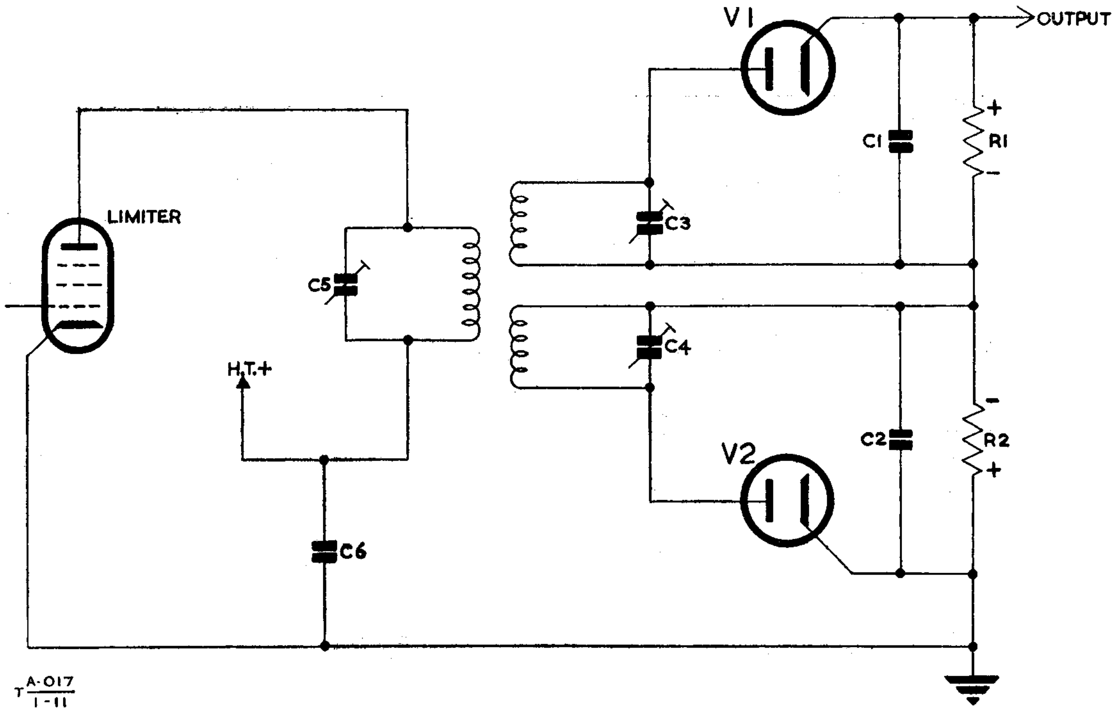


Fig. 11—Round-Travis (amplitude) discriminator

31. When the frequency is mid-way between the mark and space frequencies and therefore mid-way between the resonant frequencies, the voltages across R1 and R2 will be equal and opposite. When the frequency is increased to the mark frequency, the voltage across R1 is greater numerically than the voltage across R2, and there is a positive output. When the frequency is decreased to the space frequency, the voltage across R2 is numerically greater than the voltage across R1, and there is a negative output. A mark therefore gives a positive output, and a space gives a negative output. These output voltages are fed to a D.C. amplifier and thence to a polarized relay feeding the telegraph receiver.

Foster-Seeley (phase) discriminator

32. The circuit diagram of this type of discriminator is shown in Fig. 12, and employs an input transformer having a single centre-tapped secondary winding. It makes use of the fact that the voltages across the two halves of such a transformer are respectively 90° and 270° out of phase with the primary voltage at the frequency to which both windings are tuned (the frequency mid-way between the mark and space frequencies). In Fig. 13 the primary voltage is represented by E_1, and E_2 and E_3 represent the voltages across the upper and lower halves of the transformer. At frequencies above and below resonance the phase angle between the primary and secondary voltages are no longer 90° and 270°. Above resonance these angles decrease, and below resonance they increase in proportion to the departure from the resonant frequency.

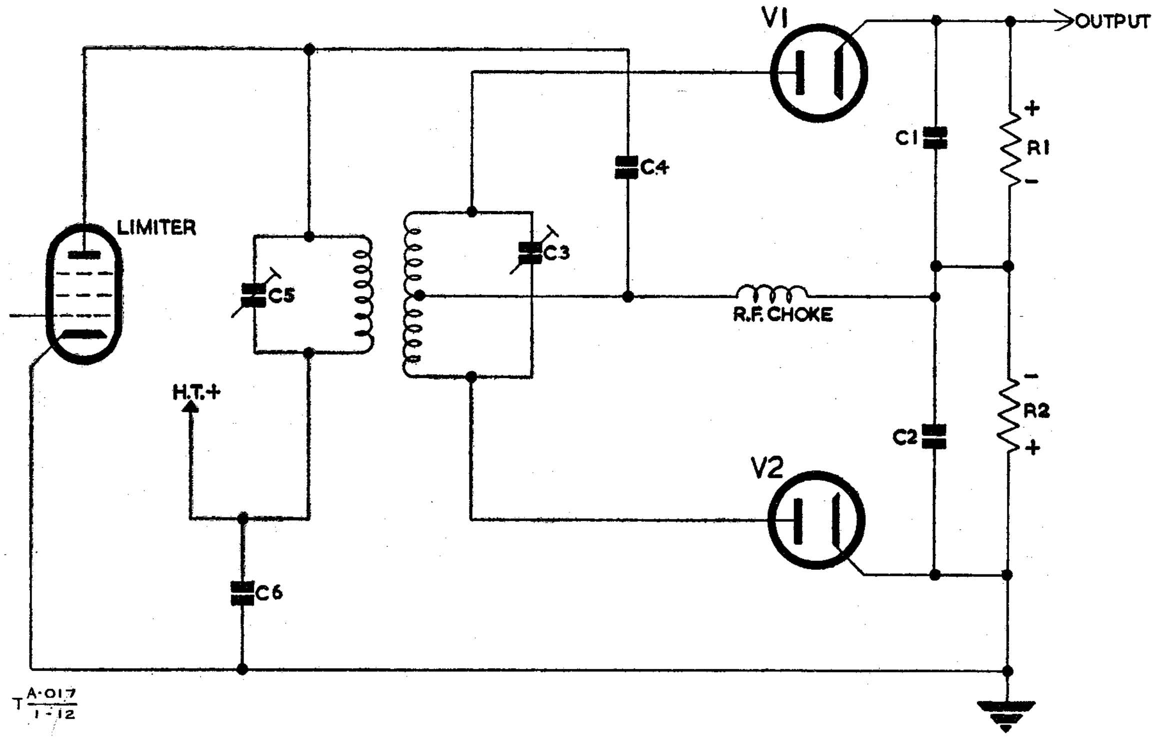
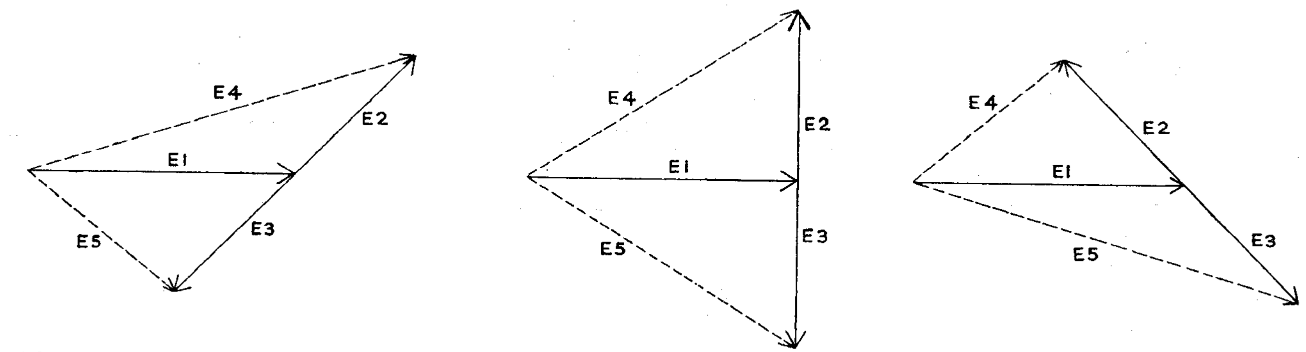


Fig. 12—Foster-Seeley (phase) discriminator



(a) ABOVE RESONANCE (b) AT RESONANCE (c) BELOW RESONANCE

Fig. 13—Vector diagrams in phase discriminator

33. The primary voltage E_1 is applied via the capacitors C4, C2 and C6 to the R.F. choke. The voltage E_4 applied to the diode V1 is, therefore, the voltage E_1 appearing across the R.F. choke, plus the voltage E_2 appearing on the upper half of the transformer secondary. The voltage E_5 applied to the diode V2 is, similarly, E_1, plus the voltage E_3, appearing on the lower half of the transformer secondary. The vector diagram showing the conditions above resonance, at resonance, and below resonance are given in Figs. 13 (*a*), 13 (*b*) and 13 (*c*) respectively.

34. The voltages E_4 and E_5 across the diodes develop corresponding voltages across the load resistors R1 and R2, these voltages being independent of phase. From Fig. 13 (*b*) it can be seen that E_4 and E_5 are equal, and hence equal voltages are developed across R1 and R2. Since these resistors are connected to give opposing voltages, the output at resonance is zero. For the mark frequency, which is above resonance, E_4 is greater than E_5 (see Fig. 13 (*a*)) and there is a positive output, as with the Round-Travis discriminator. For the space frequency which is below resonance, E_5 is greater than E_4, and the result is a negative-output. These outputs are fed, as in the Round-Travis discriminator to a polarized relay, and thence to the telegraph receiver.

Foster-Seeley discriminator using shunt-fed diodes

35. The R.F. choke in Fig. 12 can be replaced by a resistor, but then only a part of the total voltage produced by the diodes appears across the output terminals. The Foster-Seeley discriminator can be modified to employ shunt-fed diodes. This is shown in Fig. 14, and eliminates the R.F. choke.

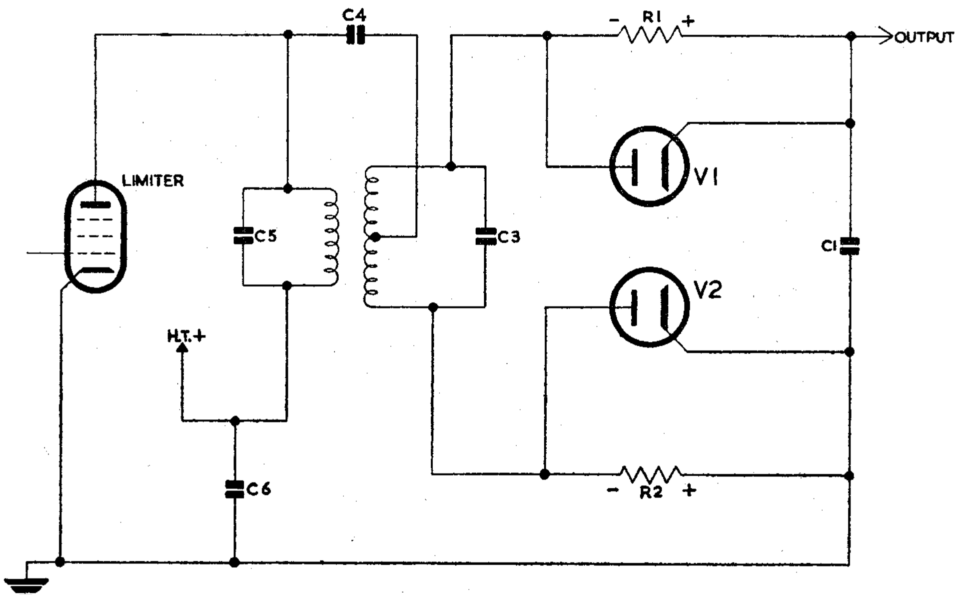


Fig. 14—Foster-Seeley discriminator using shunt-fed diodes

Drift in a discriminator-type receiver

36. Without using any correction circuits, a discriminator can accommodate a drift of ± 375c/s for an 850c/s shift. A greater drift will reduce the voltage of either 'Mark' or 'Space' to a very low level, or zero. A further increase of drift will give outputs of the same polarity on both 'Mark' and 'Space'. A.F.C. can be used to increase the drift tolerance, but as explained in para. 28, it is not very satisfactory. A D.C. bias correction circuit is, however, often used, and may be arranged to give satisfactory reception of signals with a drift of ± 3kc/s (see para. 42).

37. The output from a discriminator is, in practice, never square, but is always rounded or trapezoidal, since the input is also rounded or trapezoidal. If there is no drift, the output is symmetrical, as shown in Fig. 15 (*b*), and this, when fed to the polarized relay in the teleprinter, will produce mark and space pulses of equal time duration, as shown in Fig. 15 (*c*). There is, therefore, no effect on the input to the teleprinter when the discriminator output is trapezoidal instead of square, provided that there is no drift.

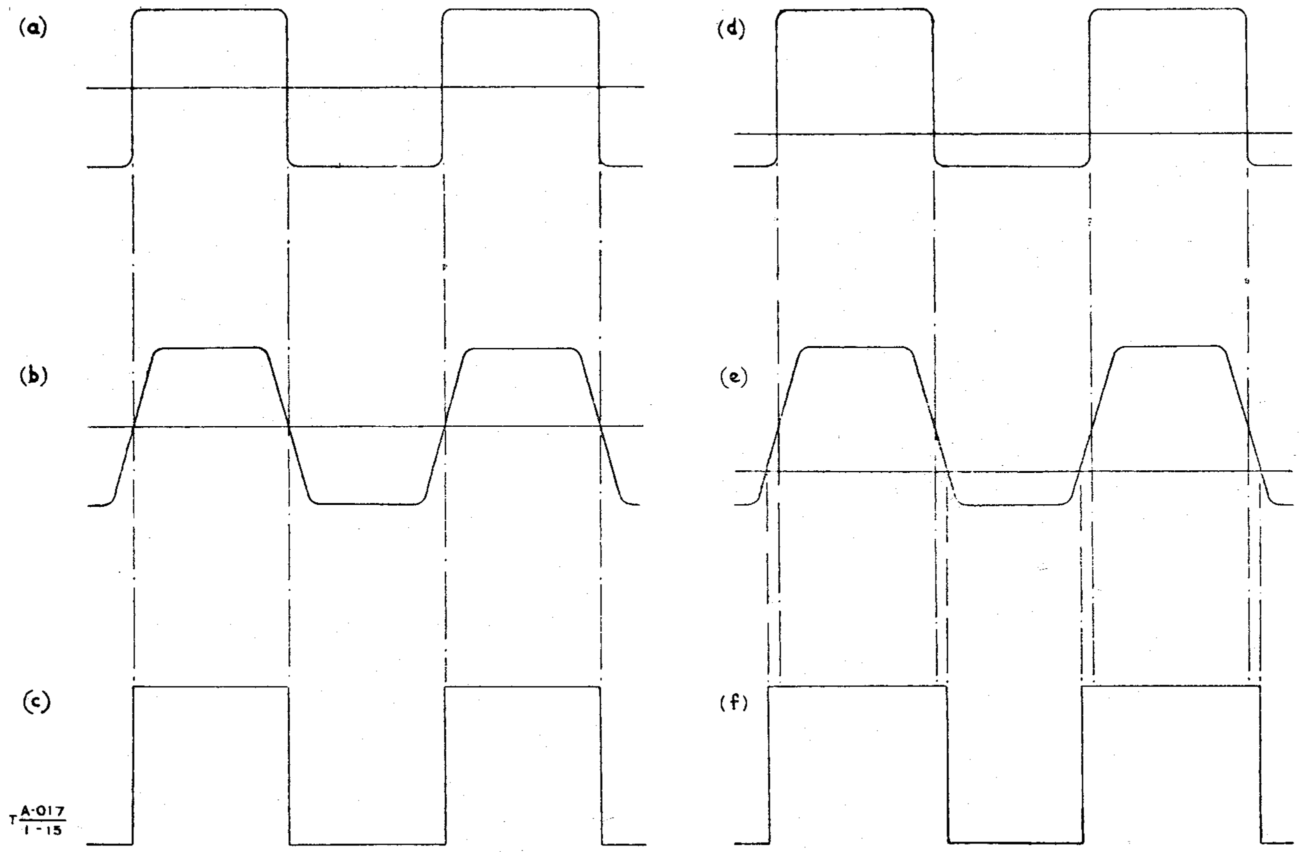


Fig. 15—Waveforms

38. The effect of a drift in a discriminator is to introduce asymmetry into the output, as the mark and space frequencies will not be symmetrically placed about the resonant frequency of the discriminator. This will give the discriminator an output waveform similar to that of Fig. 15 (*e*), which is both trapezoidal and asymmetrical. When fed to the polarized relay, this will produce mark and space pulses of unequal time duration as shown in Fig. 15 (*f*), and this will cause erratic operation of the teleprinter by causing the transitions from 'Mark' to 'Space', or vice versa, to be early or late. The production of pulses of unequal time duration is known as 'bias distortion'.

39. The output of the discriminator has a D.C. component which is the mean level about which the mark and space signals rise or fall. When the frequency drifts this mean level changes and as the circuits are set for a certain level distortion is produced. It follows therefore that in order to compensate for frequency drift the D.C. component must be removed or kept at a set level.

40. (*a*) Removal of D.C. component.
This can be accomplished by passing the output through a capacitor. However, the signal is not true A.C. but polar, and therefore requires D.C. restoration circuits after the capacitor. No D.C. restoration circuits have been designed which operate satisfactorily and without these the distortion introduced causes occasional mis-printing even with a perfectly good radio signal.

(*b*) Locking relay circuit.
This circuit employs two valves in a 'flip-flop' action, one valve conducting when a space signal is received and the other valve when a mark signal is received. With this circuit if either signal is received for a prolonged period the charge on the grid of the first valve tends to leak away and thus makes the circuit unstable. In this state it can be tripped by a random burst of interference. This can be compensated for but it is still possible for the first few signals to be lost before the circuit is operating correctly.

(*c*) D.C. bias correction circuit.
As it is impracticable to remove the D.C. component from the discriminator output and yet not introduce distortion a circuit must be included to keep the mean D.C. level constant irrespective of drift. A D.C. feedback circuit will accomplish this and a normal circuit will be described.

D.C. bias correction feedback circuit

41. This method, which is commonly used in practice, can be arranged to permit satisfactory printing with a signal drift of up to ± 3kc/s. A D.C. bias voltage is developed equal and opposite to the mean output voltage from the discriminator (i.e., the voltage causing the asymmetry), an this bias voltage is then applied in series with the discriminator output, so that it neutralizes the voltage causing the asymmetry. Using this correction circuit, the receiver can, therefore, operate satisfactorily when the mark and space frequencies are both on the same side of the resonant frequency of the discriminator.

42. Fig. 16 shows how such a bias voltage may be obtained. The output voltage from the discriminator (V1 and V2) is built up across C1 and C2 in series, and is applied through a low-pass filter to the grid of the D.C. amplifier valve V3. The output from this valve is taken to an electronic relay circuit feeding the teleprinter, and also to a bias correction circuit, V4 and V5.

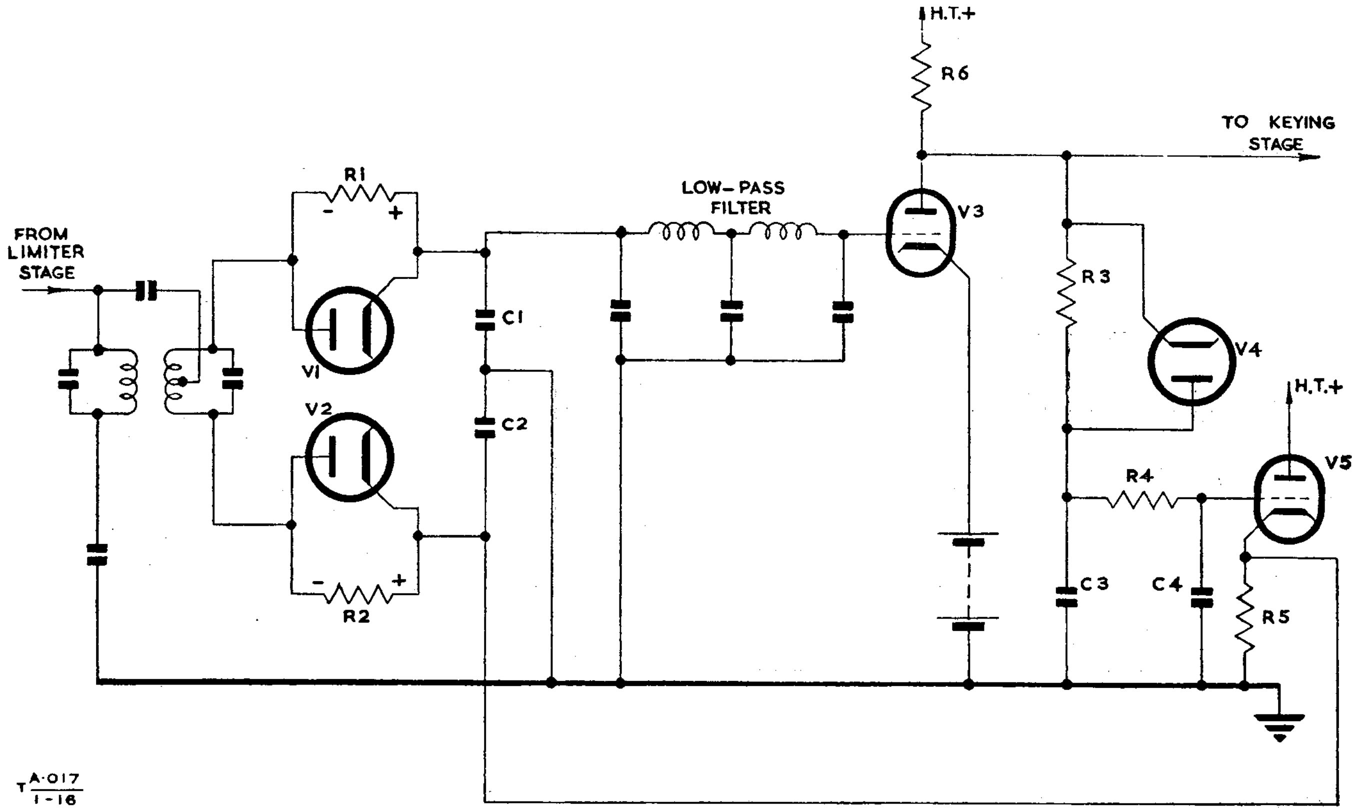


Fig. 16—D.C. bias correction circuit

43. The capacitor C3 is charged up from the H.T. supply through R3 and R6, and the voltage on C3 is passed on to the grid of V5 via R4 and C4, which form a filter to remove any keying voltage that may appear across C3. The values of C3 and C4 and R3 and R4 are of the order 4μF and 2·7MΩ respectively, so that the over-all time-constant is about 30 seconds. Since normal drift is mainly due to temperature changes, and therefore varies slowly, this time-constant is sufficiently low for the correction circuit to follow these variations, but it will not follow the fast keying variations, so that the bias developed is equal to the mean keying voltage.

44. The resistor R5 in the cathode circuit of V5 is large compared with 1/gm for this valve, and the voltage appearing on the cathode is practically the same as that applied to the grid. The voltage on the cathode of V3 is fed back as positive bias in series with the discriminator. This results in a permanent positive bias on the grid of V3, and so the cathode of V3 is also maintained at a constant positive potential, represented in Fig. 16 by the battery B. The rcuit constants are chosen so that, in the absence of drift, the D.C. voltage fed back is equal to B, so that the net voltage on the grid of V3 is simply that from the discriminator due to keying.

45. When drift occurs, the discriminator voltage is either added to, or subtracted from the voltage feedback from R5, the polarity depending on the direction of the drift. If the incoming signal drifts to a higher frequency, the discriminator output is more positive, which makes the grid of V3 more positive. This decreases the anode potential, which in turn, decreases the potential on the grid of V5, and the potential on the cathode of V5 also drops. This has the effect of reducing the bias voltage fed back to the discriminator, and the voltage on the grid of V3 is returned to its correct value.

46. The condition obtained in a teleprinter circuit when no messages are passing is 'Mark' and the largest possible duration of a space is 100m sec. The bias correction circuit must therefore be referred to the mark condition, and must not be affected by keying to 'Space' for intervals of up to 100m sec., since this would have the same effect as a drift to a lower frequency. On receipt of a spacing signal, the negative voltage on the grid of V3 causes the anode of that valve to ecome more positive, and C3 commences to charge up through R3. The increase in voltage across C3 is very small during a spacing signal owing to the large time-constant of R3-C3. On receipt of the marking signal after the spacing signal has ended, the anode of V3 becomes less positive, and the cathode of V4 also becomes less positive, so that V4 conducts and discharges any additional charge that may have accumulated on C3 during the spacing signal.

Diversity reception

47. In order to overcome the effects of fading, and to maintain the signal at as high a level as possible, diversity reception is often used in conjunction with frequency-shift signalling. Two or more receivers are used with their aerials so spaced that when the signal for one aerial fades out, the signal from another aerial is likely to be arriving at good strength. The signals arriving at the various aerials, having traversed different paths, will not be in the same phase; the difference in arrival time possibly being as much as 2 or 3m sec. Moreover, since their paths are continually varying, the phase differences between the voltages induced in the aerials will be continually changing.

48. It is therefore impossible to combine the signals when ey are still at radio frequency, or even in the I.F.stages, since the phase differences may be several times larger than the time of one cycle. After detection, however, the difference in arrival time of a given transition over the various paths is much less than 20m sec. which is the length of one telegraph code element. The various receivers are, therefore, combined after detection, and this combined output is fed through a common amplifier to the telegraph equipment. An alternative to this method of combining the signals is to use an automatic path selector, which selects the strongest signal and switches it through to a single detector.

SIGNAL/NOISE RATIO

49. The noise appearing in the output of a radio receiver consists of an irregular succession of voltages of all frequencies, and these are partly originated in the early stages of the receiver and are partly picked up by the aerial. In teleprinter reception these noise voltages can cause the printing of wrong characters.

50. Frequency-shift signalling has a great advantage over C.W. telegraphy, in the improved signal/noise ratio obtainable. Random noise appears as amplitude modulation of the signal, and in C.W. telegraphy this may distort the mark signal, and may also cause a 'Space' to be mistaken for a mark. Since the amplitude of the signal in C.W. is not always the same, a limiter stage cannot be employed to remove the random noise voltages. In frequency-shift signalling the signal has constant amplitude, and an amplitude modulating noise voltage can be almost completely cut off by means of a limiter stage. This does, therefore, give a great improvement in signal/noise ratio.

51. One method of obtaining a good signal/noise ratio, which is common to both frequency-shift and C.W. signalling is the reduction of the receiver band-width. As noise voltages are more or less evenly distributed over the frequency spectrum, a reduction in band-width will reduce the noise level. It can be shown mathematically that there is a minimum band-width below which erratic operation will result in telegraph distortion. The optimum band-width is, therefore, that for which the probability of misprinting due to telegraphic distortion is the same as the probability of misprinting due to noise and interference.

52. Although the use of reduced band-width is applicable to both C.W. and frequency-shift signalling, the signal/noise ratio possible with frequency-shift signalling is considerably greater than that possible with ordinary C.W. telegraphy, owing to the use of the limiter stage. Table 1 shows the relative signal/noise ratios possible with the various methods of signalling for the same transmitter power, allowing for the fact that the transmitter is radiating continuously in the case of frequency-shift signalling, but only for about 50% of the time with C.W. transmission.

System	*Relative db. signal/ noise ratio*
C.W.—Keyed carrier	O (reference) level
C.W. —With L.P. filter after detection	+7db.
F.S. —Filter-type detection	+7db.
F.S. —Discriminator detection with L.P. filter after discriminator	+11db.

Table 1—Comparison of signal/noise ratio

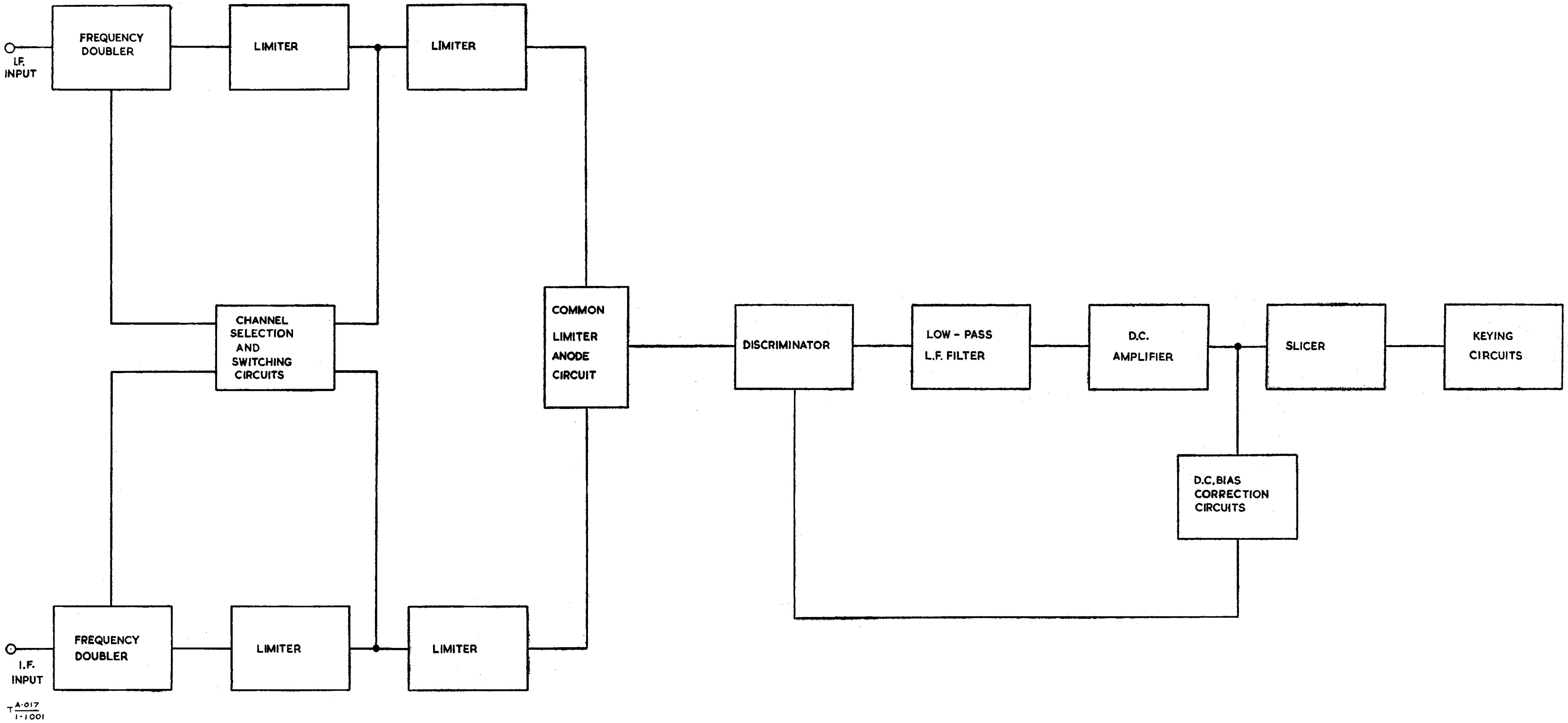


Fig. 1001—Block diagram of typical dual diversity receiver

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END