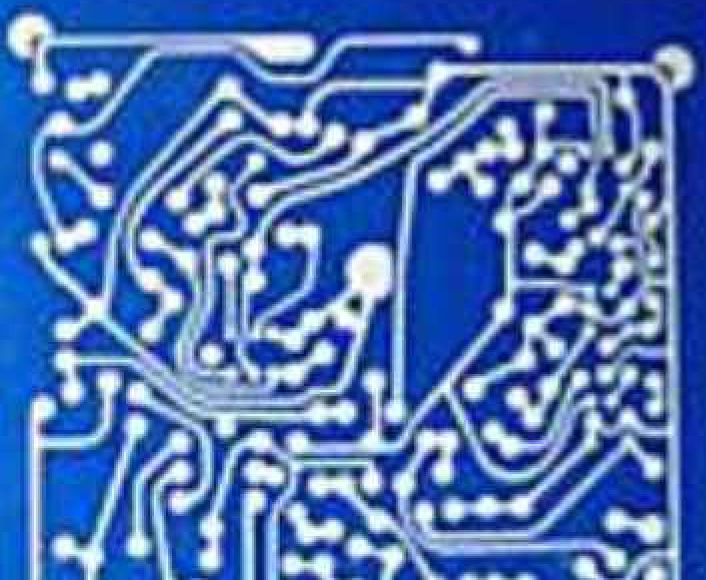
DESIGN AND CONSTRUCTION OF

TRANSISTOR SUPERHETS

R. H. Warring



Design and Construction of TRANSISTOR SUPERHETS

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LONDON
MUSEUM PRESS LIMITED

First published in Great Britain by Museum Press Limited
26 Old Brompton Road, London, S.W.7
1965

PRINTED IN GREAT BRITAIN
BY EBENEZER BAYLIS AND SON, LTD.
THE TRINITY PRESS, WORCESTER, AND LONDON
B.3851

PREFACE

THE superhet offers many technical advantages over the conventional regenerative radio receiver, although its working remains something of a mystery to many amateur constructors, setting as it does the problem of alignment. However, although the circuit *is* more complex, it is still quite easy to understand and master; also with the availability of pre-tuned i.f. transformers—or transfilters—quite satisfactory alignment can often be done aurally using normal broadcast stations.

The transistor superhet provides the smallest, neatest "package," as it were, and has largely rendered the valve receiver out of date except for the larger and more elaborate cabinet models. Since transistors require only low voltages to operate, the fully portable battery receiver offers an economy of operation not even approached by any valve receiver, with the other advantage that it can be used anywhere—and can be designed to have a performance to match.

In this book I have treated the subject from the practical angle, although the basis of transistor working and the design of the various superhet stages is well covered. The best guide, however, still remains the successful, proven circuit, so we have included a selection of such designs, a number of which are available in kit form to make amateur construction easy. In this latter respect we are particularly indebted to Messrs. Mullard Ltd. for permission to reproduce their circuit designs, and also to other manufacturers mentioned in Chapters 6 and 7 for a similar courtesy. It is, of course, only proper to mention that these circuits are for amateur use only and must not be used "professionally" without permission of the originators.

R. H. W.

CONTENTS

CHAPTER I

BASIC RADIO PRINCIPLES AND THE SUPERHET

The basis of all radio communication is the transmission of electromagnetic waves through space, the production of such waves constituting transmission and their reception or conversion at a distant point into the same intelligence as put into them constituting reception. The frequency of such waves used for broadcasting ranges from about 150,000 cycles per second (150 kilocycles/second) up to several hundred megacycles per second (1 megacycle = 1,000,000 cycles). The higher the frequency the lower the length of each wave (wavelength), and vice versa. All electromagnetic waves travel with the speed of light (186,000 miles per second) and have the common relationship that frequency multiplied by wavelength *equals* speed of transmission. Knowing the frequency it is thus possible to calculate the wavelength, and vice versa, from a simple equation, namely:

$$\text{Frequency (cycles per second)} = \text{velocity/wavelength} = \frac{300{,}000{,}000}{\text{wavelength in metres}}$$

$$\text{Wavelength} = \frac{300{,}000{,}000}{\text{frequency (cycles per second)}} = \frac{300}{\text{frequency (megacycles per second)}}$$

In addition to high-frequency or radio-frequency (r.f.) waves, considerable use is also made of low-frequency (l.f.) waves. These come within the range of sound waves which are audible to the human ear, and for that reason are also known as audio-frequency (a.f.) waves. One of the basic requirements of reception, in fact, is to extract or derive from the r.f. waves detected a corresponding signal at the much lower a.f. which can then be amplified as necessary to operate an electro-mechanical device (e.g. an earphone or loudspeaker) and so produce an audible output.

The output signal from the transmitter comprises a r.f. signal of specific frequency or wavelength (allocated to that particular station) on which the audible or a.f. programme is superimposed. This takes the form of modulating the original signal (or carrier as it is sometimes called). In the case of long, medium, and short waveband transmissions modulation is applied to the amplitude of the carrier wave, resulting in an actual transmission of the form shown in

Fig. 1. This wave still retains the original r.f. frequency of transmission but its amplitude is modulated at a.f. In practice, of course, modulation will not be the result of a single pure tone (i.e. a single modulating frequency), but a continually changing mixture of tones resulting in a complex "peaky" wave form. The depth to which this "cuts into" the original carrier is usually expressed as a percentage modulation. Thus 50 per cent modulation would be equivalent to varying the r.f. between ½ and 1½ times its normal (unmodulated) form. One hundred per cent modulation would vary the amplitude of the r.f. carrier between zero and twice its unmodulated value.

Since the frequency of the modulated current is still the same as that of the carrier the complex modulated current is still a radio-frequency signal and thus it could not be made audible directly, e.g. by passing through the speech coil of a loudspeaker. Before the

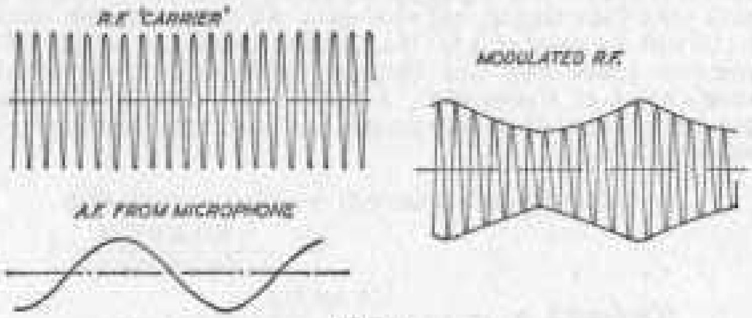


Fig. 1

audio content can be recovered as intelligence the current must be *de-modulated* in the receiver.

There is also another form known as frequency modulation. In this system the *frequency* of the transmitted r.f. signal or carrier is varied in sympathy with the audio-frequency modulating current. As the modulating current rises the frequency of the combined signal is increased, and vice versa, the *amplitude* of the signal always remaining the same (Fig. 2). Frequency modulation or f.m. has certain advantages, but needs the use of different receiver techniques. For satisfactory frequency modulation, too, it is necessary to use a much higher r.f. frequency for the carrier, so f.m. stations are always found in the v.h.f. (very high frequency) bands ranging from about 50 megacycles/second upwards.

Normal broadcast radio waves are omnidirectional, as radiated from the transmitting aerial, their actual strength at any particular point decreasing with the square of the distance of that point from the source. At any one point, therefore, during broadcast hours there will be a considerable collection of r.f. signals, differing in

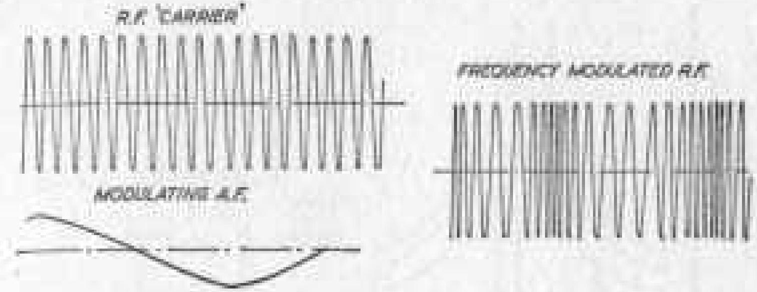


Fig. 2

strength and frequency. Each is a potential source of r.f. input to a receiver, the first necessity being to pick out or tune in to the actual signal required (or, in practice, a means of tuning in to various different frequencies independently so that a range of broadcast transmissions can be turned into separate intelligence, one at a time).

This is accomplished by means of an aerial coupled to a *tuned circuit* (Fig. 3). Technically, the latter comprises a *resonant circuit* or

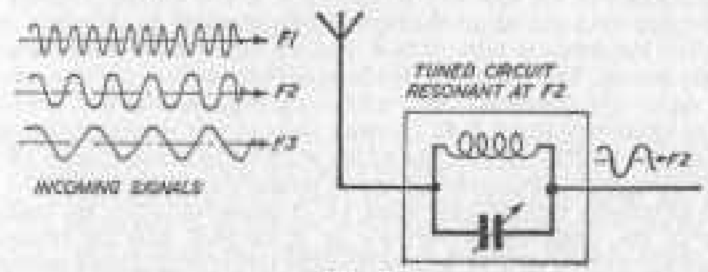


Fig. 3

one which is particularly responsive to a specific frequency, called the resonant frequency. This is readily made possible by the fact that the inductive reactance of a coil and the capacitive reactance of a capacitor are oppositely affected by frequency. Thus for a particular combination of inductance and capacity there will be one frequency for which the inductive and capacitive reactances are equal and will cancel one another. In this case the total reactance in the circuit is zero, leaving only the resistance of the components to oppose current flow.

The effect may be illustrated graphically as in Fig. 4. Assuming, for the sake of simplicity, just three r.f. signals of different frequency fed to the coil and capacitor connected in series, the response to these different signals will be as shown on the graph. The additional

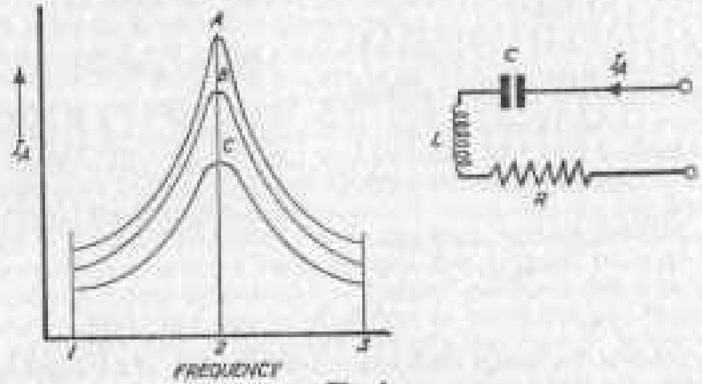


Fig. 4

component R is introduced into the circuit to represent the resistance of the circuit. Signals 1 and 3 fed into the circuit produce a relatively small current in the circuit because in addition to the resistance R the reactance of the capacitor and coil increase the effective resistance to flow by many times. The frequency of signal 2, however, corresponds to the resonant frequency of L and C (the presence of resistance does not affect the resonant frequency). In this case only R offers resistance to current flow, hence a strong current is produced in the circuit. The actual current level will depend on the strength of the signal and the actual value of R—e.g. high as at A if R is small, or progressively lower B or C—with increasingly greater resistance.

Such a resonant circuit, therefore, is effective in selecting a particular frequency corresponding to the resonant frequency of L and C, and effectively rejecting all other r.f. frequencies. Also, by making one of the components variable in value (e.g. C), the resonant frequency can be altered, thus permitting tuning to different resonant frequencies as required over a certain range. The *sharpness* of the resonance will largely depend on the value of the internal resistance R: the higher R the flatter the resonant frequency curve and thus the less the ability of the circuit to discriminate between r.f. signals of different frequencies. Thus sharpness or selectivity is an important factor in the design of tuned circuits for radio work.

Since at frequencies below about 28 megacycles/second the internal resistance is practically wholly in the coil the quality factor or Q of the tuned circuit is determined by the Q of the coil, or its ratio of reactance to resistance.

As an alternative to series connection of L and C, the parallel-resonant circuit of Fig. 5 offers certain advantages. Selectivity characteristics are similar except that where the series-resonant circuit results in minimum voltage across LC at resonance, the parallel-resonant circuit gives maximum voltage across LC at

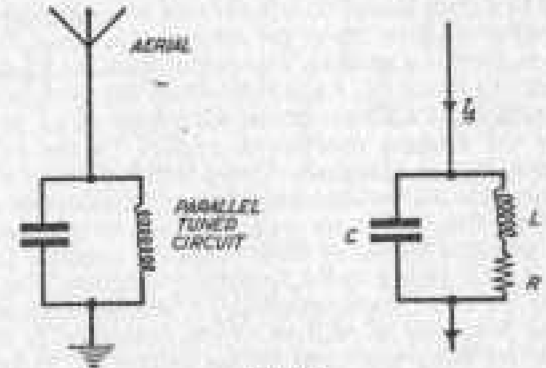


Fig. 5

resonance. In both cases, however, the required values of L and C can be calculated by the same formula. Thus to tune to any specified frequence f—

$$f = \frac{1}{2\pi\sqrt{LC}} \times 10^6$$

where f = frequency in kilocycles/second
$2\pi = 6{\cdot}28$
L = inductance in microhenries (μh)
C = capacitance in micro-microfarads ($\mu\mu f$)

Having achieved a method of selecting a particular r.f. signal in the tuned circuit it is then necessary to transfer this to a further stage as r.f. input where the a.f. modulation is extracted from the r.f. carrier. This stage is called the *detector*, the requirements being to convert the r.f. input into unidirectional current, the amplitude of which will vary at the same rate as the modulation. In effect, this demands rectification, which function can be performed by a simple diode in the circuit shown in Fig. 6. The resistance R represents the load or component (or next stage) to which detection is applied—

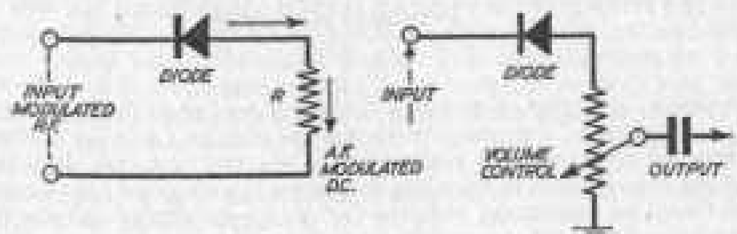
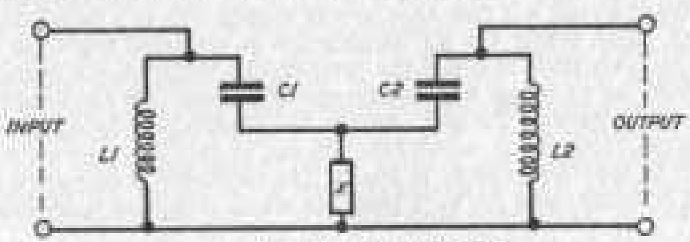


Fig. 6

which may be simply headphones in the case of a very simple circuit; or an amplifier stage to boost the detected a.f. signal for greater volume or to operate a speaker. The output from the diode consists of a mixture of a.f. and r.f., e.g. a radio-frequency component at the signal frequency and a direct-current modulated at a.f. in identical manner to the original modulation applied to the r.f. carrier. Receivers may vary in complexity from a simple detector coupled to the tuned circuit to multi-stage layouts having amplification at several different radio-frequencies as well as audio-frequencies. If the detector is preceded by one or more tuned r.f. amplifier stages it is known as a t.r.f. (tuned radio frequency) receiver. The superhet receiver, on the other hand, employs r.f. amplification at a fixed intermediate frequency as well as at the frequency of the signal itself, the latter being converted by the heterodyne process to an intermediate frequency (see page 17).

Whilst each stage in the receiver constitutes a separate unit performing a specific function, succeeding stages must obviously be coupled so that the output of one stage provides the input for the next, and so on. The circuit delivering energy is called the primary circuit and that receiving energy the secondary circuit. The energy may be practically all dissipated in the secondary circuit itself, or the secondary circuit may simply act as a medium through which the energy is transferred to a load resistance where it does work. The former is the normal arrangement in receivers.

Coupling may be accomplished by using a circuit element common to both primary and secondary circuits, e.g. a common capacitor, inductance or resistor, as shown in Fig. 7. This is known as direct



X = COMMON COMPONENT

Fig. 7

coupling, the degree of coupling becoming greater as the reactance (or resistance) of the common element is increased relative to the remaining reactances (or resistances) in the two branches. If both circuits are resonant to the same frequency, the common impedance (reactance or resistance) required for maximum energy transfer is usually quite small compared with the other reactances in the circuit.

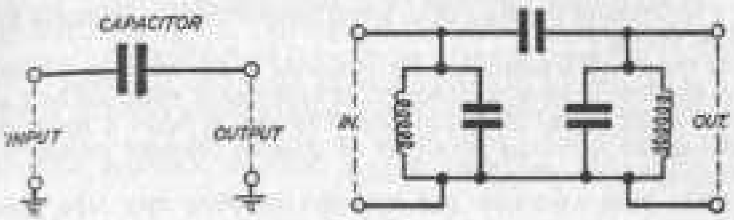


Fig. 8

Capacity coupling is shown in Fig. 8. The degree of coupling increases as the capacity of the coupling capacitor is increased (resulting in a decrease in its reactance). Again where two resonant circuits are being coupled by this means the capacity required for maximum energy transfer is quite small if the Q of the secondary circuit is at all high, e.g. typically of the order of a few microfarads only at high frequencies.

A method of coupling without physical interconnection is provided by inductive coupling (Fig. 9). Inductive coupling with a tuned-

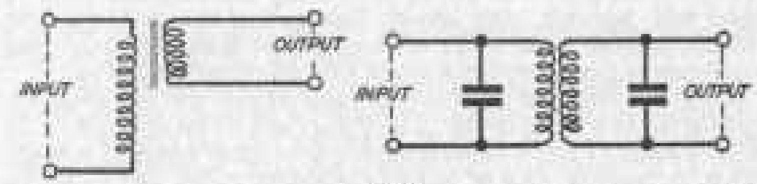


Fig. 9

secondary circuit is frequently used in receiver circuits for coupling between circuits where the tuning must be varied to respond to signals of different frequency; the coupling with tuned input is particularly useful for coupling r.f. to a resistive load. A double-tuned circuit is more useful for coupling fixed frequency stages (e.g. amplifiers).

With tight coupling the effect of inductive coupling where one (or both) coil(s) is untuned is very much the same as if the untuned coil were tapped on to the tuned circuit. Thus any resistance in the circuit to which the untuned coil is connected is coupled into the tuned circuit in proportion to the mutual inductance. In effect this tends to increase the series resistance of the tuned circuit and thus lower its Q value. These circuits may, however, be used for impedance matching by adjusting the coupling and/or the number of turns in the untuned coil.

In a similar manner, any reactance in the circuit to which the untuned coil is connected will be coupled in to the tuned circuit. Thus any variation of coupling can require readjustment of tuning in the tuned circuit.

In the case of a tuned primary connected to a tuned secondary the overall effect is more complicated, although their effect can be rendered negligible by loose coupling. This also provides a means of varying the selectivity of a pair of coupled resonant circuits by changing the coupling between them.

Since both capacitive and inductive coupling may take place accidentally owing to proximity of components in a practical circuit it may also be necessary deliberately to *prevent* coupling. Stray capacitive coupling is usually prevented by enclosing the components likely to cause this condition in a metallic container of low resistance which is connected to earth potential. Lines of force which would otherwise provide capacitive coupling with neighbouring components are then short-circuited and constrained within the can. In certain cases complete circuits may be enclosed within a grounded metal cover for the same purpose. Magnetic coupling can usually be prevented by metal plates or shields erected alongside the offending component or between two components likely to suffer from inter-reaction. In this case induced currents produce eddy currents in the shield, opposing and effectively restraining the magnetic field. A shield will, however, only absorb that part of the magnetic field which it interrupts and thus sources of radiant fields (e.g. coils) need completely enclosing within a shield for "all-round" shielding.

In the conventional regenerative radio circuit the incoming r.f. signal is fed to a tuned circuit, the output from which at resonance is fed to a detector and thence through one or more stages of amplification, as required. One or more r.f. amplifier stages may be added before the detector stage in the t.r.f. circuit. In both cases the signal is received at radio frequency by the detector, the output of which is an a.f. signal (Fig. 10).

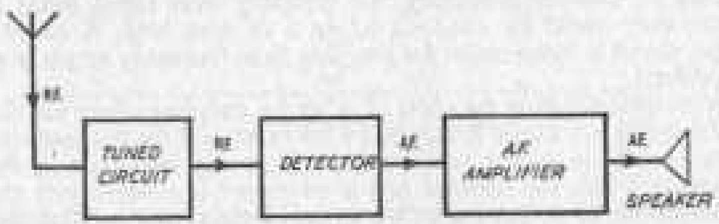


Fig. 10

The superheterodyne or superhet receiver works on a somewhat different principle. The incoming r.f. signal is picked up by a tuned circuit in the normal way but is then combined with another high-frequency in a *mixer* or *converter* stage, the output from this stage

being a "beat" frequency equal to the difference between the two or *intermediate frequency*. This signal is then amplified (by one or more stages of i.f. amplification) before being passed to the second detector stage, where the modulated i.f. is converted to a.f. and subject to further stages of amplification. The second high-frequency signal is generated within the receiver itself by the h.f. oscillator or *local oscillator*, applied to the mixer. A block diagram is shown in Fig. 11,

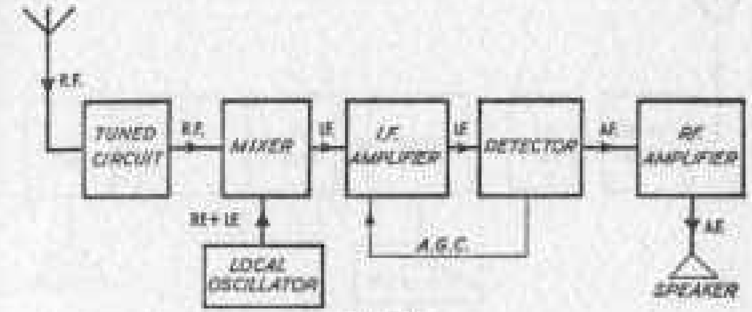


Fig. 11

where it will be noticed that r.f. amplification can again be applied after the tuned circuit, if required.

The principal advantages offered by the superhet are that the gain and selectivity obtained from the intermediate frequency amplifier do not depend on the frequency of the signal as they do with "straight" receivers. Also the intermediate frequency can be made lower than the signal frequency, resulting in higher stage gain and a narrower response curve than is possible at signal frequency. Again, too, since the i.f. amplifier is dealing with a constant frequency it can dispense with variable condensers, reducing the risk of unwanted feedback and generally making the receiver less critical in design. The main disadvantages are the higher cost of such a circuit and the necessity of achieving proper alignment.

Most commercial domestic receivers are of the superhet type because of the superior performance offered and, although rather more complex, the type is equally suited to amateur construction.

The usual intermediate frequency employed is between 450 and 475 *kc/s* (470 *kc/s* is more or less standard in this country) and the i.f. amplifier is tuned to the specific i.f. employed. This i.f. amplifier thus employs one or more stages of r.f. amplification with fixed tuning. A little thought will show that to "feed" the i.f. amplifier correctly it will be necessary to vary the local oscillator in step with the tuned circuit. Thus if the receiver is designed to tune over a range of from, say, 800 *kc/s* to 1800 *kc/s* and the intermediate frequency is 470 *kc/s*, then the oscillator frequency must range in step with the tuned circuit from 800 + 470 = 1270 *kc/s* to 1800 + 470 = 2270 *kc/s*. Equally, to produce the same i.f. frequency response the local oscillator could be set to lag by the i.f.: e.g. 800 − 470 = 330 *kc/s* to 1800 − 470 = 1330 *kc/s*. The result would be the same as far as the i.f. amplifier was concerned. In practice, however, it is more usual to establish the local oscillator frequency above the signal frequency (Fig. 12).

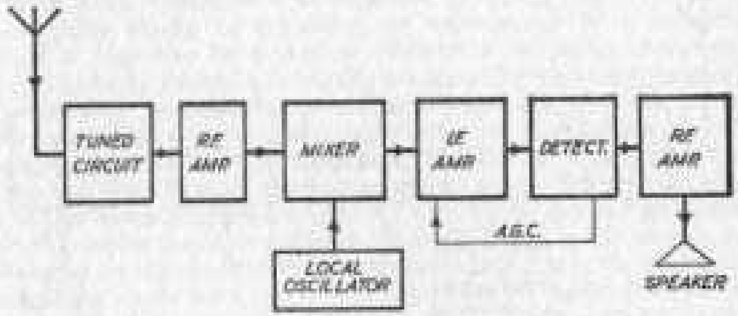


Fig. 12

The converter thus actually receives two frequencies of r.f.: the signal frequency which can be designated f_s and the local oscillator frequency f_o. The following i.f. amplifier stage is tuned to a fixed frequency of $f_o - f_s = f_i$, the intermediate frequency (or $f_s - f_o = f_i$ where the local oscillator frequency is chosen to be below the signal frequency); and it is the purpose of the converter to supply this particular i.f. as its output by a process of frequency conversion.

In fact, any h.f. oscillator frequency will cause i.f. response at two signal frequencies, one equal to f_o *minus* f_i and the other equal to f_o *plus* f_i. One will be the real signal required, e.g. the correct value of f_s for the station selected, whilst the other is an undesirable *image* signal.

To clarify this by a numerical example. Suppose the desired signal frequency is 800 *kc/s* and the intermediate frequency is 450 *kc/s*, with the local oscillator set above the input signal frequency. To produce the necessary i.f. output at 800 *kc/s* signal input the local oscillator will have to be set for 800 + 450 = 1250 *kc/s*. Exactly the same i.f. output will be produced, however, if a 1250 + 450 = 1700 *kc/s* input signal is received since the result of mixing will again be a frequency of 1700 − 450 = 1250 *kc/s*. An essential feature of satisfactory working, therefore, is good *selectivity* in order to reduce the response to image signals to negligible effects.

The signal-to-image ratio, or image ratio as it is usually called, depends on the selectivity of the r.f. tuned circuits preceeding the mixer or converter. At the same time the higher the intermediate

frequency the higher the image ratio, since raising the i.f. increases the frequency separation between signal and image and places the latter farther away from the peak of the resonance curves of the signal-frequency circuits.

CHAPTER II

TRANSISTORS

TRANSISTORS are commonly considered to be the modern alternative to the older radio valve or "tube" as it is called in America, which supposition is far from being correct. In a normal radio valve the current flows through a near vacuum, necessitating that the valve elements be enclosed within a sealed and evacuated envelope, and the flow of electrons can be controlled by inserting one or more grids between the anode and cathode. The controlling influence is modified by the number of grids present, and their connection, giving rise to distinct valve characteristics related to the number of grids, e.g. diode (no grid), triode (one grid), tetrode (two grids) and pentode (three grids). Generation of electrons depends on the heating of the cathode or filament (also called the heater) by a separate external battery, i.e. one distinct from the main source of current flow through the valve and source of potential applied to the controlling grids.

The transistor differs in many ways. Basically it is a crystal and thus current carried by it flows through a solid. It is not necessary to enclose the crystal in an evacuated container and the whole device can be made much more compact and mechanically stronger. Absence of individual components suspended in an open volume also means that the transistor, unlike the valve, is non-microphonic. A further difference is that a transistor requires no heater battery and only moderate to low functional voltages. Compared to a valve it is less subject to deterioration and failure, and is basically free from "hum". At the same time the transistor has certain inherent limitations, notably sensitivity to light and heat. The former can be overcome by enclosing the transistor in a lightproof casing. Sensitivity to temperature cannot be overcome completely, calling both for "stabilized" circuitry and limitations regarding maximum ambient temperatures for satisfactory working. This can affect assembly (soldering and mounting position), and air temperatures in use.

Electronically, too, transistors have ratings which are absolute. That is to say, if these ratings are exceeded for any reason the circuit will be prone to unreliability and early failure. This applies particularly to the newer types of transistors where the ratings are realistic. With older types rather large safety factors were commonly allowed in drawing up transistor data and such transistors could frequently be worked well beyond stated limits without damage.

Most transistors are of three-electrode junction construction

forming, in effect, a sandwich in which the central layer, known as the base, is very thin. The two outer layers comprise the emitter and the base (Fig. 13). The alloy-diffused transistor is the later type and

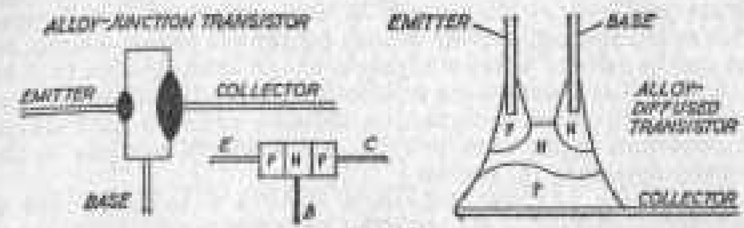


Fig. 13

has better (more stable) high-frequency performance than the alloy-junction type. Since the transistor elements themselves are invariably enclosed within a can or envelope the only identifiable features are the three leads and the type number printed on the can. The leads emerge from the bottom of the can "in-line" (typical of older types), or arranged in the form of a triangle (Fig. 14). In the former case the

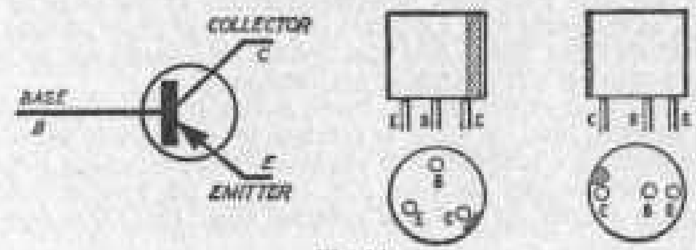


Fig. 14

collector lead is indicated by a coloured dot on the side of the can or edge of the base, and can be further identified by the fact that it is spaced more widely apart than the other two leads. In the case of triangular arrangement, the collector is again marked by a white or coloured dot near it (or on the side of the can), whilst emitter and base leads are closer together than the collector is to either. It is particularly important having identified the collector to note clearly the identification of the other two leads as they always follow the same respective positions. In other words, only the collector is marked for position, and which of the remaining two is the emitter and base can be worked out from this. The exception is the power transistor, which may have only two leads which will be marked *E* (for emitter) and *B* (for base) on the bottom. In this case the collector is electrically connected internally to the base and the collector connection is made to a tag which is held in contact with the top of the mounting base by one of the mounting nuts.

Transistors can be P–N–P or N–P–N, according to the dosing of the emitter, base, and collector materials.[1] The majority of transistors produced, in this country at least, are of the P–N–P type. This means that the positive battery supply will always connect to the emitter and the negative supply to the collector. With a N–P–N transistor these polarities are reversed. Regardless of transistor type, however, and circuit configuration, collector and base must always be connected to the same polarity, which will be opposite to the polarity applied to the emitter.

One of the principal differences between a transistor and a thermionic valve is that the transistor has a comparatively low input resistance (impedance) and is normally current driven from a high source impedance. The thermionic valve, by comparison, has a high input impedance and is voltage driven. Thus characteristics of transistors are usually expressed in terms of input current and those of valves in terms of input voltage, with the transistor regarded as a current amplifier. Electrically the output characteristics of a transistor are similar to those of a pentode valve, with a characteristic "knee" and a high output resistance. The knee voltage is usually very low with transistors, however—typically of the order of 0·2 volts, as compared with a typical knee voltage of about 30 volts for a pentode valve. This means that low supply voltages can be used with transistors whilst retaining high efficiency.

To derive input and output circuits from a three-electrode device one electrode must obviously be common to both circuits, with three such alternative configurations possible. These are usually referred to by the common electrode, e.g. common (or grounded) base, common emitter, or common collector (Fig. 15). These may be

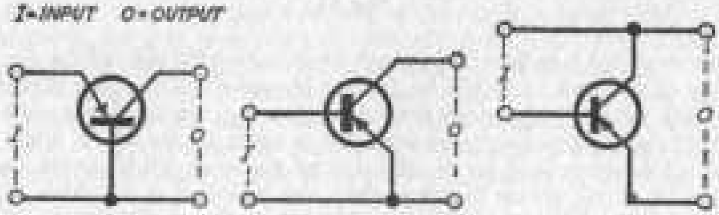


Fig. 15

compared with the three basic circuits for a triode valve—grounded grid, grounded cathode or cathode follower (Fig. 16).

[1] See *Instructions in Electricity and Magnetism* by R. H. Warring (Museum Press) for a simple explanation of transistor theory and working characteristics.

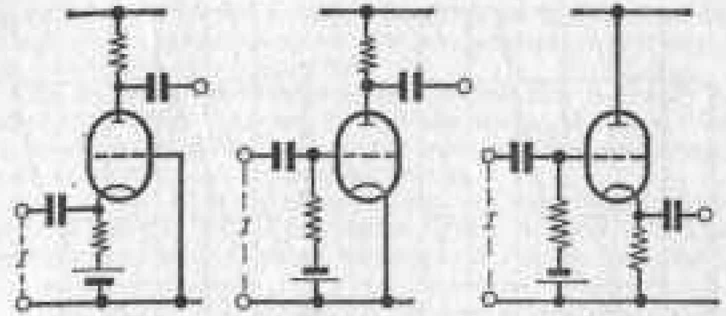


Fig. 16

Of the three transistor circuits the common emitter connection is the most widely used, since this provides both high current and voltage gain, and thus high power gain. Another advantage is that the same battery can be used to provide both forward and reverse bias. The common base configuration provides high voltage gain with a current gain of approximately unity. It is not often used at a.f. but its low input and high output impedances are useful in some circuits (e.g. for preamplifiers and with moving-coil microphones to take advantage of the low input impedance characteristic; or for feeding into valve amplifiers to take advantage of the high-output impedance characteristic). The common collector configuration has the characteristic of high input impedance and low output impedance with high current gain. It is not widely employed but may be used in "buffer" stages, or possibly to replace a transformer.

Transistor characteristics are normally specified by a series of curves or graphs covering static d.c. performance. A.c. characteristics may then be derived or calculated from these at particular working points. In more general terms, the quantity alpha (α) is defined as the current gain of the transistor working in common base configuration; and beta (β) the current gain when operated in the common emitter configuration. The value of α is always slightly less than unity, whereas values of β may range up to 100 or more.

It follows that with a common emitter circuit the current gain can be calculated as $\alpha/1-\alpha$. Also, if α is the general symbol for collector current divided by emitter current, and α' is the symbol for collector current divided by base current:

$$\alpha' = \alpha/(1-\alpha) \text{ and } \alpha = \alpha'/(1+\alpha')$$

A graph of typical input characteristics is shown in Fig. 17 for both common emitter and common base configurations. These characteristic curves show the base current I_b plotted against base

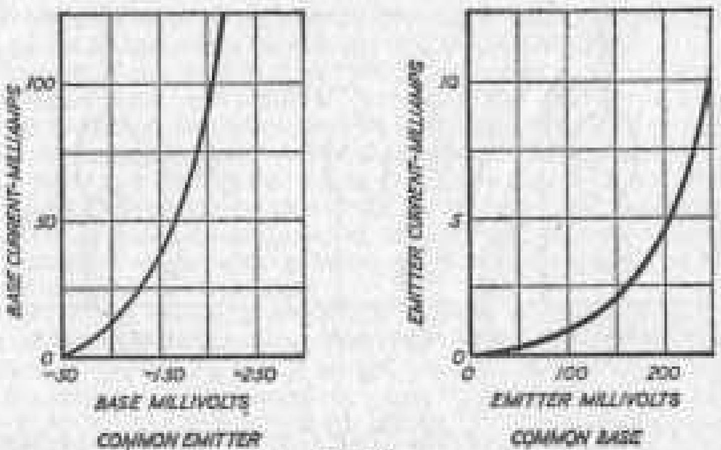


Fig. 17

voltage V_b (measured between base and emitter in a practical circuit and more correctly designated V_{be}). It will be noticed that the input characteristic is non-linear and also that the input resistance depends on the current at which it is measured. This is one reason why the transistor is normally driven from a current rather than a voltage source, using a source resistance large in comparison with the input resistance. If the source resistance (impedance) is not high enough to swamp the varying impedance of the transistor under drive, then considerable distortion will result.

The graphs of Fig. 18 show typical transfer characteristics, or the variation of collector current (I_c) with base current (I_b). For distortion-free transfer this curve should be linear. Note particularly

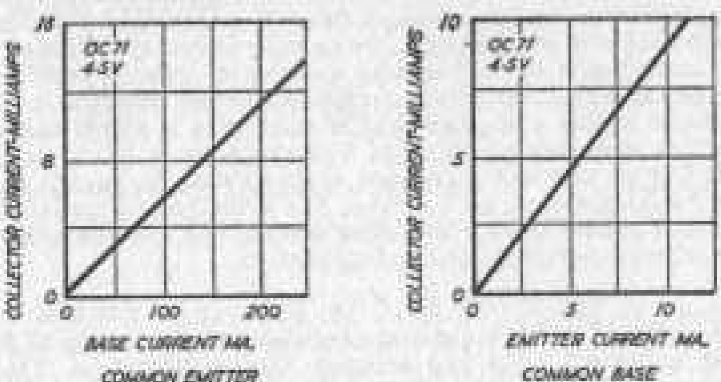


Fig. 18

the difference in current amplification produced by the two circuits —high in the case of common emitter configuration and slightly less than unity with common base.

This method of showing transfer characteristics is usually preferred to plotting I_c against V_b and determining the slope of the curve (which would be directly comparable with the mutual conductance as determined for thermionic valves).

Static output characteristics of a transistor are normally given in terms of collector current (I_c) plotted against collector voltage (V_c) for a range of base or emitter currents as in Fig. 19. In a practical

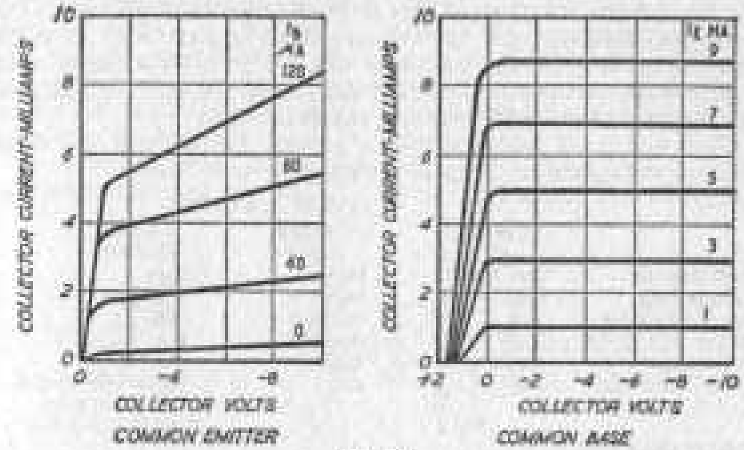


Fig. 19

circuit V_c would correspond to the voltage measured between the collector and emitter (V_{ce}). These curves show a characteristic knee, with a high output resistance above the knee voltage. In the common emitter circuit it will be noted that with zero emitter voltage (i.e. base open circuited) there is still a small flow of current which is known as the (collector) leakage current I'_{co}, the value of which increases slightly with voltage. It is, however, usually small—i.e. of the order of 100 to 200 microamps. The characteristic leakage current is even smaller in the case of the common base circuit—e.g. typically of the order of 5 microamps.

Static d.c. performance curves are mainly of use in establishing a suitable working point for the transistor. A.c. characteristics are normally rendered in terms of hybrid or *h* parameters or *z* parameters for audio-frequencies; or by *y* parameters for high-frequency transistors. A description of the method of designating these characteristics and the mathematical employment of these parameters is out of place in this present book and further works on transistor theory and performance should be studied for a complete explanation.

Mention must, however, be made of cut-off frequency which is the point at which the current amplification factor falls to 3 *dB* or 0·707 below the zero frequency (static) value. This is usually designated f_α (for common base circuit) or f'_α (for common emitter). Current amplification is, in any case, dependent on frequency and the rate of fall-off if affected both by the type of transistor and the circuit configuration. The common base configuration generally gives the better high frequency performance for a given transistor than in common emitter configuration, i.e. f_α is usually higher than f'_α. The quoted cut-off frequency is usually an arbitrary figure in the sense that although the current amplification has fallen to 0·707 times its static value the transistor will still go on working at even higher frequencies (with further reduction in current amplification and a general spread of transistor characteristics).

Comparison of performance in general terms, with the three different configurations, can be summarized as follows:

	CONFIGURATION		
	Common Base	*Common Emitter*	*Common Collector*
Current gain	less than 1	high	high
Voltage gain	high	high	less than 1
Input impedance	low	medium	high
Output impedance	high	medium	low
Power gain	medium	high	low
Cut-off frequency	high	low	varies with output load resistance, but generally low
Voltage phase shift at low frequencies	approx. zero	approx. 180°	approx. zero

In any practical circuit d.c. stabilization is particularly important because of the effect of temperature on the operating characteristics of the transistor (and thus the possible variations in collector current). Thus bias is normally applied in a manner which prevents excessive shift of the d.c. working point. Without sufficient stabilization there is the possibility of a wide spread in input and output impedances of the transistor, a risk of overloading the transistor at high ambient temperatures, and also the risk of "thermal runaway" (although the latter is usually only significant in high voltage and/or high power stages).

In the common base configuration the base can be biased with a constant emitter current by making the bias voltage (applied across the emitter and base) large in comparison with the input voltage. The two equations governing the performance are then

$$I_c = I_{co} + \alpha' I_e$$

$$I_e = \frac{\text{bias voltage} - \text{input voltage}}{\text{emitter resistance}}$$

With the common emitter circuit the transistor is biased with a constant base current since the battery voltage is large in comparison with the input voltage, but the resulting d.c. stability is poor. The corresponding performance equations are

$$I_b = \frac{\text{battery volts} - \text{input volts}}{\text{bias resistance (battery to base)}}$$

$$I_c = I'_{co} + \alpha' I_b$$

Some degree of stabilization can be introduced by using a collector-base feedback resistor, i.e. the base resistor is returned to the collector end of another resistor instead of battery, the other end of this resistor connecting to battery. With resistance-capacity coupling this resistor also supplies the d.c. feedback and no additional components are required. However, there will also be a.c. feedback unless the stage is decoupled by a capacitor from approximately the middle of the base resistor to the battery.

By far the more usual—and satisfactory—arrangement is the emitter-resistor and potential divider circuit (Fig. 20). Here the input

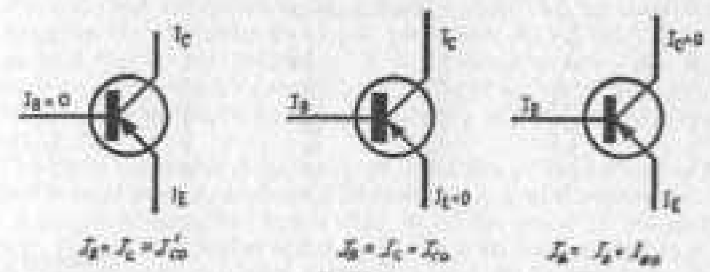


Fig. 20

voltage is determined by the value of the emitter resistor *R3*, in conjunction with the potential-divider *R1–R2* connected across the battery. Any increase in emitter current causes a large voltage drop across the emitter resistor and reduces the base-emitter voltage. The base current is thus reduced and in a manner compensating for the original change. The feedback depends on how constant the base potential can be maintained during changes in base current, and the value of *R3* (the higher the value of *R3* the better the stabilization provided). The *maximum* value of *R3* depends on how much of the battery voltage can be dropped across it. The *minimum* values of *R1* and *R2* are determined by the current which *R1–R2* can be allowed to draw from the battery; or alternatively by the amount of shunting of the incoming signal when resistance-capacity coupling is used.

In some circuits a modified form of this circuit is used with *R2* replaced by a thermistor, or paralleled by a thermistor, which is basically a device where resistance varies with temperature. Thus an n.t.c. thermistor has negative temperature coefficient (falling resistance with increase in temperature); and a p.t.c. thermistor a positive temperature coefficient (increasing resistance with increase in temperature). An n.t.c. thermistor replacing or paralleling *R*2 is the more common type used to provide better stabilization. Complete compensation over the whole temperature range cannot, however, be provided by a thermistor.

Recommended values for *R*1, *R*2, *R*3 and the collector resistor R_c for circuits employing the OC71 transistor are summarized in the table which follows. Values are given for a range of voltages from 1·5 to 12, and for two methods of coupling (i.e. resistance-capacity coupling and transformer coupling). Maximum operating temperature for these circuits would be 45° C. (113° F.).

RESISTOR VALUES IN KILOHMS

Battery Volts	Collector Current (milliamps)	*R*1	*R*2	*R*3	R_c
		R–C Coupling			
4½	0·5	18	2·7	1	3·3
6	0·5	33	3·9	1	3·3
	1·0	39	10	1	2·2
	1·5	22	10	1	1·5
9	1·0	62	10	1	3·9
	1·5	39	10	1	2·7
12	1·0	82	10	1	5·6
	1·5	56	10	1	4·7
		Transformer Coupling			*primary output transformer (ohms)*
1½	0·5	4·7	3·3	1	200
3	0·5	10	2·7	1	200
4½	3·0	10	6·8	0·47	200
6	3·0	12	4·7	0·47	200

Note: R–C coupling would not normally be used at voltages below 4½.

A basic transistor amplifier stage is shown in Fig. 21, which uses only one battery to provide the bias voltage for the transistor, the bias voltages being provided by the voltage drops across resistors *R*1 and *R*2. The values of these resistors are chosen so that the current flowing through the potential divider formed by *R*1 and *R*2 is considerably larger than the base current of the transistor; thus the base potential remains appreciably constant regardless of variations in base current. Resistor *R*3 is included in the circuit to provide stabilization—i.e. reduce the effects of transistor spreads with changes in temperature. Any increase in the emitter current produces

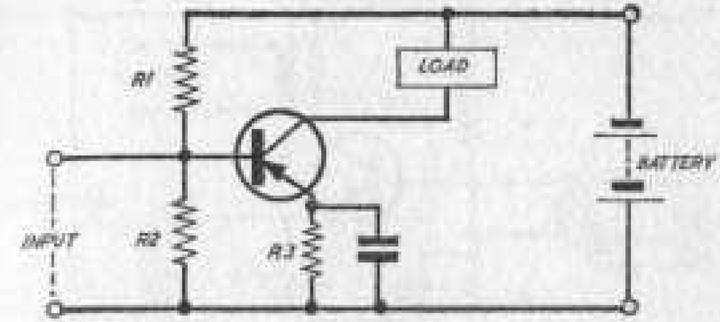


Fig. 21

a large voltage drop across *R*3, which consequently reduces the base-emitter voltage to compensate. A typical value for *R*3 is of the order of 1 kilohm. Whilst providing d.c. stabilization it is also necessary in a practical circuit to provide decoupling to reduce a.c. feedback.

The coupling capacitance for a typical stage can be considered to be connected between the input resistance R_{in} of the following stage and the source resistance of the preceding stage R_s. R_s is formed by the collector load (R_c) in parallel with the high output resistance of the transistor. In practice R_s will be approximately equal to R_c.

The input resistance is typically of the order of 1 kilohm and the collector load resistance about 5 kilohms. A typical theoretical value for a coupling capacitor would then be of the order of 0·3 microfarads. Normally a higher value would be used for improvement of tone quality—e.g. anything between 3 and 10 microfarads. This would be an electrolytic capacitor, when correct polarity is important—the negative side of the capacitor connecting to the collector of the preceding transistor and the positive side to the base of the following transistor.

Values of *R*1 and *R*2 are usually low. These, together with a high value of *R*3 produce, effectively, a common base configuration for the transistor, and consequently high stability. Stability will decrease with increasing values of *R*1 and *R*2 and decreasing value of *R*3. If *R*1 and *R*2 are made large, for example, and *R*3 small, the circuit is effectively the common emitter configuration with poor stability.

A typical Class A amplifier stage is shown in Fig. 22, involving the same elements and considerations as just described and with transformer coupling for the input and output. This is typical of a simple audio-amplifier which is used where current drain is not important, but its efficiency is relatively low (under 50 per cent). A Class B output stage, with push-pull operation, gives a much higher theoretical efficiency (75 per cent) with a low current drain.

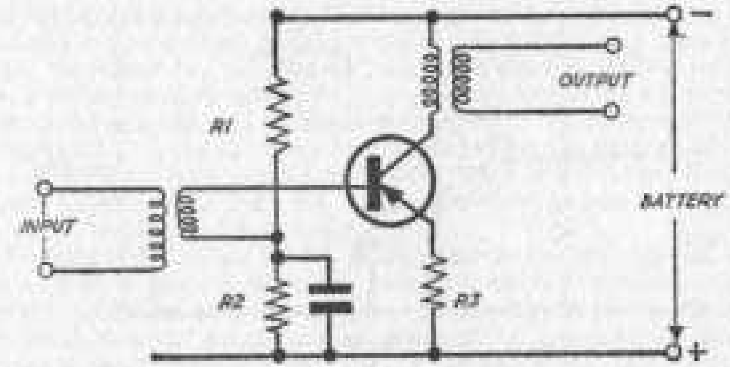


Fig. 22

It is, therefore, usually preferred for receiver circuits designed to operate off dry batteries.

A basic class B output stage is shown in Fig. 23, bias voltages being provided by *R*1 and *R*2 as before, with *R*3 added to provide d.c. stabilization. This circuit is, however, subject to "crossover" distortion if both transistors are biased exactly to cut-off, but this can usually be eliminated by adjusting the value of *R*1 (or *R*2), usually by trial and error to give a satisfactory quiescent current through the two transistors.

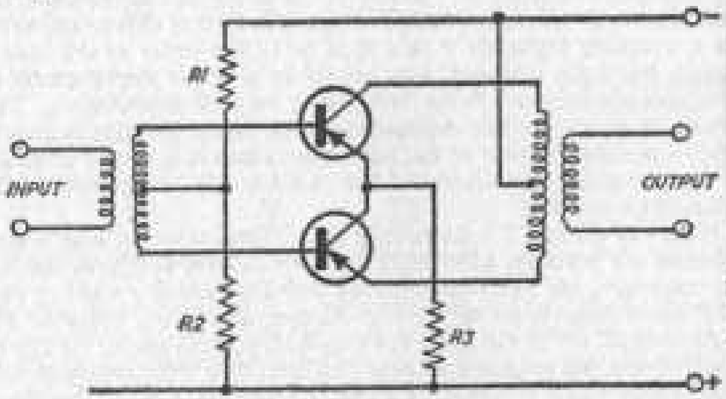


Fig. 23

The alternative circuit shown in Fig. 24 employs a single-ended rather than a transformer output, with a high impedance speaker providing the matching load. It is often preferred in receiver designs since it eliminates one transformer and performance is identical with

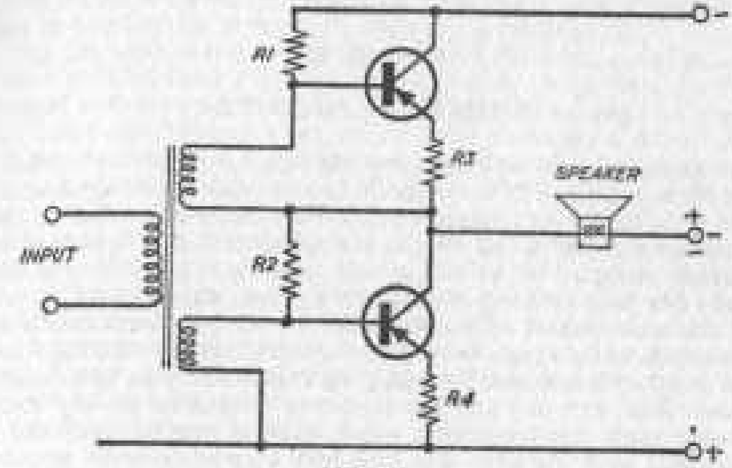


Fig. 24

that of the circuit shown in Fig. 23 provided the voltage of each half of the battery is equal to the supply voltage of the circuit of Fig. 23, i.e. normally demanding a larger (higher voltage) battery.

Basic details of other transistor circuits appropriate to the various stages of a superhet receiver are described in Chapter V.

CHAPTER III

PRINTED CIRCUITS

The printed circuit has almost entirely replaced "wired-up" circuits for all new designs of radio receivers and other electronic devices, and in particular for miniature and sub-miniature assemblies. At the same time it has given rise to the development of components specially designed for printed circuit assembly, e.g. resistors of flat wafer-like form with tags to plug into a printed circuit board instead of the conventional cylindrical resistor with wire leads emerging from each end; capacitors with two terminal leads protruding from the base; switch assemblies and gang condensers with base-tagged connections, and so on. What started as a technical novelty some twenty years ago—and one which nobody seemed particularly interested in at the time—has now both become common practice in the radio and electronics industry and set new standards and requirements for component manufacturers.

The modern printed circuit base material consists of copper foil 2, 3, or 5 thousandths of an inch thick (or in some cases thicker) bonded to a thermoset plastic base of suitable thickness—e.g. typically 1/16 in. thick for general work. The base material may be laminated or reinforced phenolic (most common in this country) or polyester reinforced with glass fibre (generally favoured in America and now coming more to the fore in this country). The type of base material is not of primary importance, provided it has the necessary electrical qualities of being a stable non-conductor and has the necessary rigidity and physical strength to act as a chassis plate. It must also be a suitable material for taking the bonded copper surface layer and be capable of being drilled or punched to accommodate component leads, etc. The main advantage of a glass fibre board over "Paxolin" or a similar material is that it is translucent and so it is possible to see the printed circuit pattern or "lands" from the other side of the board, making it easier to locate components correctly or trace connections when checking. On the other hand glass fibre boards are usually more expensive and are harder to cut. Also drills used for hole-making are readily blunted by them and need frequent replacement or resharpening.

Printed circuit stock is invariably purchased in panels which can be cut to the overall size required. One face of these panels is coated with copper foil and it is on this face that the actual circuit pattern is produced by etching. This involves transferring a drawing of the circuit on to the copper, coating all copper areas which are to remain with a suitable resist and then immersing the panel in an acid bath to etch or dissolve away the remaining unwanted copper. The

resist is then removed with a solvent, when the printed circuit panel can be prepared for component assembly by drilling, etc.

All this work is well within the scope of the amateur enthusiast, either working from a printed circuit plan or designing a suitable printed pattern equivalent to a theoretical circuit design, although the latter can become quite an involved business. Alternatively, many standard radio designs, etc., are available as kits or in component form for home assembly, including a complete printed circuit, ready drilled as necessary. This latter feature saves a lot of time and effort, and is a point of design on which the less experienced constructor is likely to go wrong. One of the basic essentials of printed circuit design, in fact, is complete familiarity with component sizes, so that mounting holes or holes for leads properly match the component to be accommodated—with each component arranged in logical order, both physically and electrically. Unlike ordinary wiring-up, printed circuit conductors cannot be crossed over each other.

The typical superhet circuit (Fig. 25) is relatively complex and

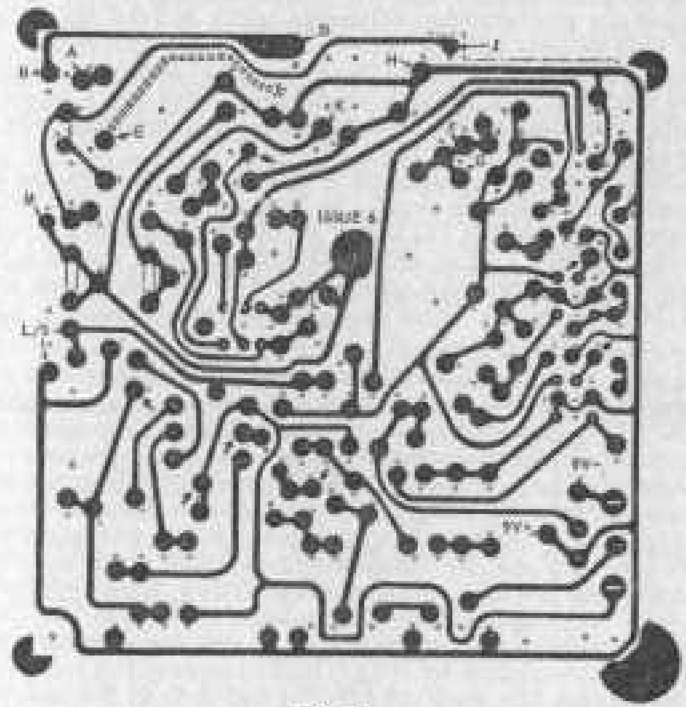


Fig. 25
Printed circuit layout of the "Realistic Seven" Receiver
(Compare with the theoretical circuit diagram, Fig. 62)

without experience in printed circuit layout can present an almost unsolvable problem as to how all the necessary conductors can be arranged on a single plane. In general, however, the layout should follow basically the same physical disposition as the theoretical circuit. Where this diagram itself includes crossing conductors it may well be of considerable help to see if it can be replanned so that these are eliminated. If this proves physically impossible, and a solution cannot be found by altering the disposition of the components, it may be necessary to terminate certain connections on the printed circuit lands and interconnect to cross other lands with an insulated jumper wire. Whilst this may be considered bad design, it is perfectly suitable for one-off or amateur construction. Bear in mind, too, that components themselves can be used for bridging over adjacent conductors.

The current-carrying capacity of conductors varies with foil thickness, but, since the current values in transistor receiver circuits are invariably low, conductor size is unlikely to be critical, although recommended minimum figures should be adhered to.

Minimum recommended conductor width is 1/16 in., with at least 1/32 in. clear spacing between adjacent conductors to reduce the possibility of accidental shorts of "bridging" between conductors when soldering. The drawing should also allow for a minimum spacing of at least 1/32 in. between the outside conductor and the edge of the printed circuit board.

Where holes have to be drilled to take component leads, the hole diameter should closely match the lead size—e.g. with a typical resistor lead of 0·028 in. (22 s.w.g.) the corresponding hole diameter should be at least 1/32 in. or No. 67 drill. Sufficient area of copper "land" should be provided around each hole for a minimum width of 1/16 in. (Fig. 26). Holes should be correctly spaced to match

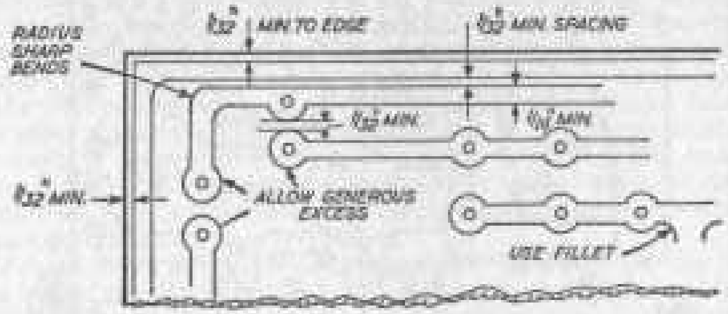


Fig. 26

component leads, allowing for a "finger bend" at each end or down the side of the component, according to whether horizontal or vertical

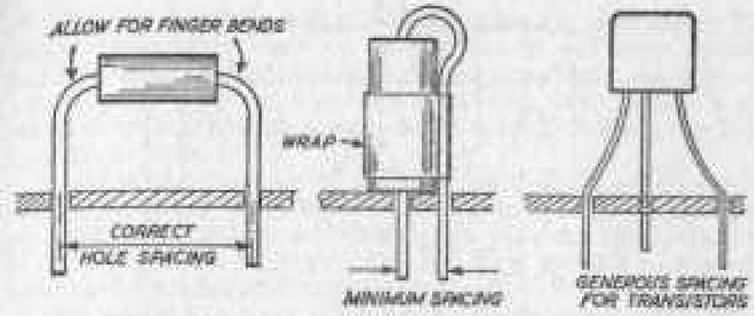


Fig. 27

assembly is to be used (Fig. 27). The former is to be preferred except where a minimum size panel is aimed at, when vertical mounting of resistors, etc., will occupy minimum base area. At no point, however, should spacing between adjacent holes be less than twice the laminate thickness (i.e. normally not less than 1/8 in. on standard laminate).

Other points to watch are that where conductors join at an acute angle they should be faired in with a generous fillet, increasing the area bonded at the joint and making the copper far less liable to be lifted. Also do not leave unnecessarily wide or large areas of copper as conductors. These may be subject to excessive heating and expansion, with the result that the copper tends to lift from the base. Either cut down the outline of such areas or relieve the surface area with slots to be etched away. This is not so important on low-voltage circuits, but on mains circuits no copper area of more than about one square inch should be left "solid".

For professional work the printed circuit design is usually prepared as a master drawing two or three times actual size—and sometimes to a very much larger scale where a complex circuit is being designed to be accommodated within minimum area. This is then photographically reduced and printed or otherwise transferred to the laminate. For amateur work an accurate tracing is usually made off an actual-size master drawing, transferred on to the laminate (copper face) with carbon paper. Simple circuits can be drawn directly on to the copper with a lead pencil. All the land areas are then carefully painted in with cellulose paint (or resist ink, as preferred) and allowed to dry. The panel is then ready for etching.

Although the majority of home-constructed superhets are built from professionally made printed circuits the technique of preparing a laminate will be described in detail for those who may prefer to start from scratch, or work to their own circuit designs.

The first step, having prepared a printed circuit drawing, is to cut the laminate to the required overall size, using a fine tooth saw. The

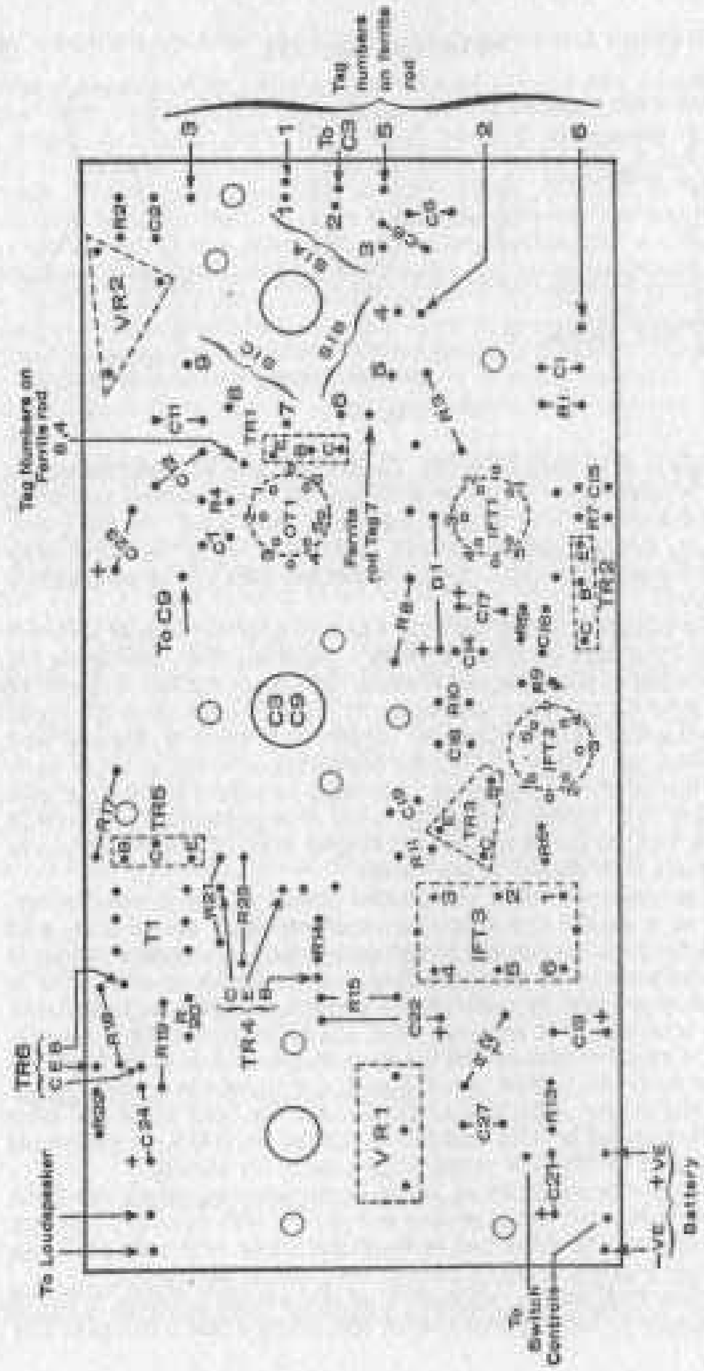


Fig. 28
Component position for the "Good Companion" Receiver

cut edges can then be smoothed with a fine flat file, as necessary. The copper surface has probably become greasy and dirty through handling, and so should now be cleaned thoroughly by washing with a detergent and rubbing dry with a clean cloth. If the copper is discoloured through corrosion, use a domestic abrasive cleaner to bring it up bright clean.

A test of cleanliness is to hold the panel under a tap, copper side up, and allow water to run on to it. If the water wets the whole area and flows smoothly over it, the surface is clean and grease free. If isolated patches of copper stay dry these are still coated with grease and need further cleaning.

Once completely clean the printed circuit pattern is drawn or traced on to the copper. Cellulose paint or resist ink should then be used to paint in all the land areas, using a ruling pen for straight lines and a small brush to fill in and complete the wider sections. The whole of the pattern may be painted on, if preferred, although the result may be somewhat more ragged. Avoid painting on too much paint or resist, as this may overrun the outlines. At the same time make sure that all the land areas are fully covered. The painted pattern should then be left to dry, which may take an hour or more with cellulose paints or 10 to 15 minutes with resist inks.

The solution normally used for etching is ferric chloride mixed with a little hydrochloric acid, or straight dilute nitric acid. The former is generally preferred since it does not "gas" as much as the acid alone, but either will be equally effective. The etching solution is poured into a suitable shallow container, such as a plastic sandwich case or tray and the laminate slid into it to immerse. Rate of etching will depend on the temperature of the etching solution and also the degree of agitation. Thus at a temperature of 50° F. a ferric chloride bath will etch the copper at a rate of about 1 thou. in 20 minutes—or nearly an hour to etch 3-thou. foil. At 70° F. the rate of etching is increased to about 10 minutes per thou., and at 100° F. is almost twice as active again. The etching rate can also be increased by gentle agitation, e.g. moving the board gently backwards and forwards in the bath, or gently rocking the container to swill the etching solution from end to end.

Etching should be allowed to proceed until all traces of copper have disappeared from the surface. The board can then be removed and rinsed under running water to remove any traces of etchant. The paint or resist ink covering the lands is then removed either with a solvent (e.g. cellulose thinners in the case of cellulose paint) or a cleaner (in the case of resist inks). After this, again wash and dry the board, when it is ready for drilling.

Three basic rules must be observed when drilling printed circuit panels:

(i) Always use a sharp drill (preferably a new drill, or one which has been resharpened prior to use).

(ii) Always drill from the copper side (i.e. copper face up).

(iii) Always use a backing of hard material underneath the laminate so that the drill point will not tear out a section of the laminate when the point breaks through.

Drilling may be done with a hand or electric drill, the latter being far less tiring to use when there are a large number of holes to be drilled, although the small size of drill required may lead to a high breakage rate unless special care is taken.

LAMINATE MATERIALS

Resin	*Binder*	*Approx. Bond Strength lb./in.*	*Moisture Absorption %*	*Suitability for Drilling and Punching*
Phenolic	Paper	6–12	0·63 to 2·0	Excellent, low drill wear
	Cotton	6–12	approx. 1·2	Excellent, low drill wear
	Nylon	5–7	0·4	Excellent, low drill wear
Epoxy	Glass fibre	6–12	0·1	Fair, high drill wear
Polyester	Glass fibre	3–5	0·2	Good, high drill wear
Silicone	Glass fibre	2–4	0·4	Fair, high drill wear
PTFE	Glass fibre	4–9	less than 0·3	Good, high drill wear

CHAPTER IV

PRINTED CIRCUIT ASSEMBLIES

ELECTRIC irons are invariably used for electronic assemblies together with resin-cored solder (i.e. the solder is in the form of a hollow wire with the core filled with a resin flux). Flame-heated irons are not satisfactory for they are usually too large and cumbersome, and also do not permit good temperature control. Equally, one should always use an electrical (cored) solder when no separate flux is required. An acid-type flux should *never* be used on electrical work as this will inevitably produce corrosion.

The basic rules for good soldering are extremely simple, although they are frequently ignored. They may be summarized as under:

(i) The iron should be of the right size and type.
(ii) The iron should be hot enough to melt the solder freely.
(iii) The tip of the iron must be kept tinned and clean.
(iv) The work surfaces to be soldered must be clean and grease-free.

The right size of iron is important for if too small it will rapidly lose heat when applied to the work, and if too large may overheat adjacent components or be awkward to apply to the work. For printed circuit assemblies a 3/16-in. bit diameter is about right for general work—not too large, but large enough to retain enough heat for more or less continuous work. It may be awkward to use when soldering up a miniature panel where the lands are close together, when a 3/32-in. or even a 1/16-in. bit may be preferred. This smaller size will, however, usually lose so much heat in completing a single joint that it has to be left to heat up again before it can be applied to the second joint.

Iron size is also specified by wattage, but this is more of a nominal rating than anything else, for irons of different make but of the same stated wattage can have a considerable difference in performance, e.g. differences in heating-up times and in bit temperature achieved (and variations in the latter can be as high as 100° C.). To avoid the possibility of overheating, an iron with a rating of more than 50 watts should never be used for printed circuit assemblies.

Iron voltage must be matched to the mains voltage available, and it is usual to operate an electric iron on the middle voltage of the range, e.g. for a 240-volt main voltage a 230/250-volt iron would be correct. An iron should never be operated on a mains voltage below the lowest figure of its rating as in such a case it will not develop its proper bit temperature.

Typically a good electric iron will achieve a saturation temperature of approximately 375° C. The time taken to reach this temperature will vary with the size and design, but very roughly should be of the order of wattage divided by four, in seconds, e.g. in the case of a 30-watt iron the bit should reach its maximum or saturation temperature in about $30/4 = 7\frac{1}{2}$ seconds. It should also take about one-third of this time (e.g. watts divided by 12) to reach a satisfactory bit temperature for soldering (250° C.), although this can readily be judged by trying the solder on the bit to see if it runs freely.

The *minimum* bit temperature required for satisfactory soldering is 40° C. above the melting point of the solder used. The melting point will vary with the composition of the solder. A 60/40 tin/lead alloy which is used for high-quality electrical work melts at 189° C. Other alloys, e.g. 50/50, 45/55, 40/60, etc.—all of which may be specified as "electrical" solders—melt at increasingly higher temperatures. The melting point of 40/60 solder, for example, is 232° C. For printed circuit assemblies especially it is always advisable to use 60/40 alloy as requiring the lowest bit temperature for satisfactory work (e.g. a minimum bit temperature of 229° C.) as this reduces the risk of damage to components through overheating.

Whether the temperature of the bit is satisfactory or not can readily be judged by the time it takes to complete a joint. This should be of the order of three to four seconds—no more. The resulting solder joint should be bright clean, with the solder completely "wetting" both surfaces of the joint. If the joint takes longer to make and/or the solder has a pasty or dull appearance, the iron is not hot enough. If the solder is reluctant to take or flow over the joint, or collects in blobs rather than spreading out, then the joint surfaces are dirty.

Before attempting assembly on components, the printed circuit panel should always be cleaned so that the lands are bright all over with no dull spots. Once cleaned, the lands should not be finger-marked by handling. An ordinary domestic powder cleaner is as good as anything for cleaning the printed-circuit lands, used wet or dry, the panel being rinsed under running water to remove any traces of abrasive after cleaning and then dried on a clean rag.

Component leads are normally tinned and therefore in a suitable state for soldering. Almost certainly, however, the tinned surface will have become dirty or partly corroded during handling and storage and it is generally recommended to clean leads immediately prior to assembly and soldering in position. A scrap of fine emery paper is excellent for this, simply wrapped around the lead and pulled along the length of the lead, taking care not to impose excess mechanical strain on the lead. Similarly with tags, etc., which can be "sanded" with a scrap of emery paper. Time taken in cleaning leads, etc., is usually time saved, for one can then be sure of a satisfactory soldered joint at the first attempt.

Where space permits, components are usually mounted horizontally, resting on the plain side of the printed circuit board as in Fig. 29. Transistors are the exception since these always require a

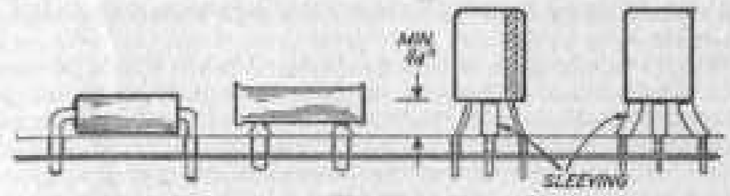


Fig. 29

reasonable length of lead to ensure that they are not damaged by heat during soldering. A *minimum* mounting height for transistors of $\frac{1}{4}$ in. above the plain face of the board is advisable, and preferably $\frac{1}{2}$ in. or more. To avoid any possibility of the exposed leads shorting they can each be covered with a length of sleeving, or alternatively just the collector (or base) covered with sleeving. This latter method saves cutting a piece of sleeving for each lead, provides almost the same degree of protection against shorting, and also serves as a ready identification for the position of the collector (or base) and thus the other two leads.

If it is necessary to crowd components more closely together, the upright mounting can be employed for resistors and capacitors, as in Fig. 30. The top lead in this case is bent to come down alongside

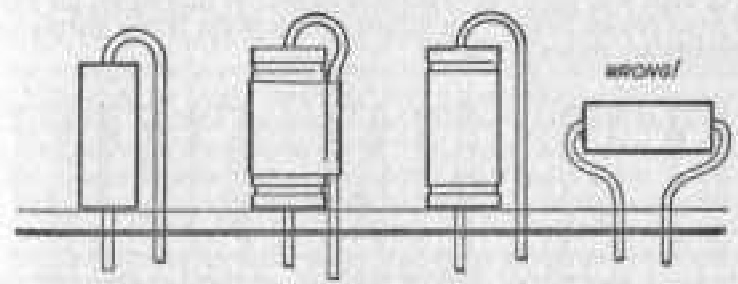


Fig. 30

the component itself. In the case of electrolytic capacitors the top lead would conventionally be the negative and is often taped to the side of the capacitor in the case of components supplied for printed circuit assemblies.

The original drawing of the printed circuit must, of course, be laid out to accommodate capacitors and resistors in either a horizontal or vertical position. It would be bad practice, for example, to mount a resistor horizontally when it was intended for vertical mounting, as determined by the corresponding holes in the printed circuit panel. In the case of professionally supplied printed circuits, too, it may be impossible to get all the components into the physical space available on the board unless the design mounting positions are adhered to.

Where leads have to be bent to shape, all bends should be done with the fingers as this places the least mechanical strain on the component itself and also enables the bend to be made reasonably close up to the end of the component. Some people advocate bending with round-nose pliers (never flat-nose pliers) as giving a tighter, neater bend, but this method can put considerable strain on the lead and even pull it out of the component. If pliers are used for bending leads, they should be used at some distance from the component, never close up where the plier jaws can "lever" against the end of the component (Fig. 31).

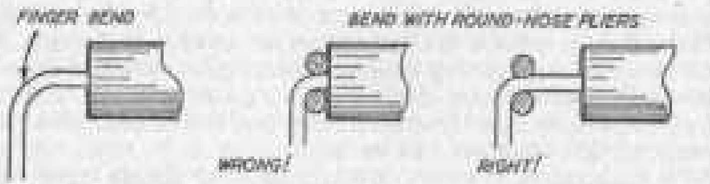


Fig. 31

Opinion also differs as to the best method of making off the ends of leads passed through the printed circuit panel. Three alternative methods are shown in Fig. 32:

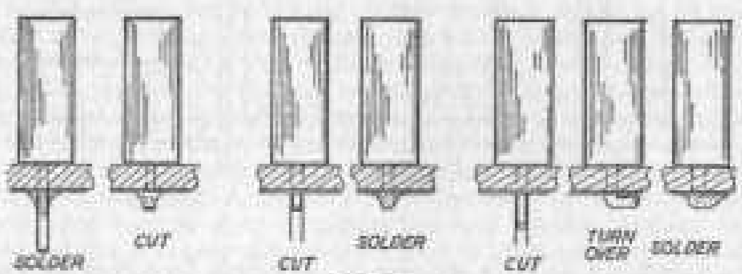


Fig. 32

(i) The leads are passed through their respective holes, the component pressed down flush with the board and the leads soldered to the lands. Excess wire is then cut off with wire-cutters.

(ii) The component is mounted as above but the leads are cut off

to stand proud of the lands by about 1/16 in. before soldering to complete the joint.

(iii) The leads are cut off and turned over once the component is located and then soldered to complete the joint.

Each of these methods has it particular application. Method (ii) is usually the cleanest for general work, but method (i) and particularly method (iii) have the advantage that the component is supported in position until the soldered joint is completed, and cannot drop out when the board is turned over for soldering. A disadvantage with method (iii) is that it makes it much more difficult to remove a component once it has been soldered in position.

Then there is the question of heat damage to consider. Provided the joint is completed quickly—i.e. within three or four seconds of application of the iron—no component is likely to suffer heat damage. This even applies to transistors which are normally rated to withstand continuous application of a soldering bit no closer than ¼ in. from the base for a period of up to 10 seconds without damage. Thus if all goes well and soldered joints are completed quickly and neatly, it is seldom necessary to worry about heat damage.

It is, however, still commonly recommended that a "heat sink" should always be used on each lead of a transistor when soldering in position. A heat sink, basically, is a mass of conducting material which will absorb heat from the iron rather than let the full heat flow up the lead. The jaws of a pair of pliers gripping the transistor lead form a convenient heat sink, or if these are not convenient to use a crocodile clip can serve the same end (especially if the jaws are filed flat to provide maximum surface contact with the lead).

The most likely cause of heat damage is re-working a joint which has not been made properly, or trying to unsolder a lead which has been wrongly positioned. This may mean leaving the iron in contact with the joint far longer than the "safe" three or four seconds, when damage can result to the component. Excessive heat applied locally in this manner will also tend to "lift" the copper land away from the base material, so that the printed circuit itself is damaged.

Removing a component which has been mounted on a printed circuit can, in fact, be a tricky process. If it is a faulty component which is to be replaced the *safest* way to go about such a job is to cut the component off, as shown in Fig. 33, leaving stub lengths of the original lead protruding from the plain side of the printed circuit panel. The new component can then be soldered in place *to*

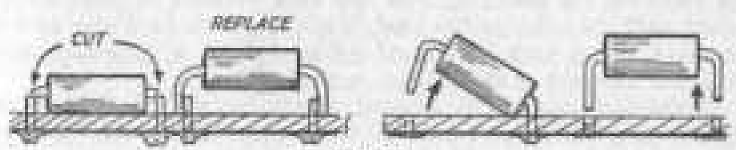


Fig. 33

these stub leads. Alternatively, having cut off the component, each lead can be removed in turn by laying the tip of the iron on the solder joint (printed circuit side) and withdrawing the lead with pliers as soon as the solder has melted. Then, before the solder has had time to set again, blow surplus solder out of the hole (Fig. 34).

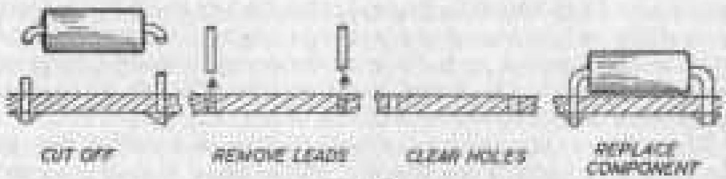


Fig. 34

To remove a component intact usually means working on one lead at a time, lifting first one end of the component and then the other. It is not always possible to be sure that the component so removed is undamaged, however. In the case of components mounted on rigid leads or tags the problem of removal is even more difficult, generally demanding working on pairs of tags at a time, and gradually levering the component upwards. This usually entails considerable risk of overheating the component, and of "lifting" the printed circuit lands if too much heat is applied to the tag side.

A trick which often helps in removing a rigidly mounted component, such as an i.f. transformer, is to heat the tags and brush off the solder with a stiff bristle wire brush of suitable size. This is repeated on each tag until the component is sufficiently loosened to be prised free. It is important, however, to avoid splashing excess solder on to other parts of the printed circuit board.

Unless obviously faulty, transistors or diodes should not be removed from a printed circuit board once assembled, as the possibility of permanent damage resulting is high. If imperative that they should be removed (e.g. if they have been connected up wrongly), a heat shunt should always be used (e.g. a pair of thin-nosed pliers gripping the lead between the transistor body and the printed circuit board).

Where the board itself is damaged—e.g. foil has come unstuck through excessive local heating—a simple repair is often effective. Loosened lands can usually be stuck back again by carefully heating the foil with the soldering iron and then pressing in place on the board until the adhesive has reset. If not, the loose land may have to be stuck down with additional adhesive—e.g. a general-purpose domestic adhesive of the modern rubber-base type.

Mechanical damage to printed circuit boards can be repaired by bridging breaks or cracks in the copper lands with "jumper" wires soldered in place. The jumper can be plain tinned copper wire, but if a longer jumper is required which passes over adjacent lands, either insulated wire should be used or the wire length fitted with insulated sleeving. All repaired areas should then be coated with clear lacquer for protection.

Where a printed circuit board is quite extensively damaged, or needs to have a number of components changed, it is usually more satisfactory in the long run to scrap the original board and start again with a new one and preferably new components, rather than to try to salvage all the original components as these may be damaged in the process of removal from the old board.

CHAPTER V

SUPERHET STAGES

THE modern radio receiver normally employs a compact tuning coil mounted on a ferrite rod, the latter forming a core which greatly increases the inductance and thus the Q of the coil. With such an aerial system it is normally possible to dispense with the use of any external aerial, except under adverse conditions, e.g. areas of very poor reception or when the receiver is being used as a car radio (where the body of the car acts as a shield cutting off the transmitter signals before they can reach the aerial). To cater for such circumstances provision can be made to plug in an external aerial to the internal system to increase aerial efficiency (or in the case of the car radio, to bring the aerial into a position outside the car where signals are present).

The medium- and long-wave broadcast bands together represent a range of frequencies from 1500 *kc/s* to 150 *kc/s*, or a tenfold difference, which is beyond the practical coverage of a single L.C. combination using a small-diameter coil with a fixed value of inductance (L) and variable capacitance (C). It is usual, therefore, to employ separate coils for medium- and long-wave reception, the latter representing an extension of the medium-wave coil which is switched into circuit by a wave-change switch.

Referring to the formula for resonant frequency (Chapter I) and rewriting in the following form:

$$\sqrt{LC} = \frac{159}{\text{frequency (kilocycles)}} = \frac{1 \cdot 88}{\text{wavelength (metres)}}$$

Where L = inductances in microhenries
C = capacitance in micro-microfarads

or:

$$\text{Resonant frequency } (kc/s) = \frac{0 \cdot 1593 \times 10^{-3}}{\sqrt{LC}}$$

Where L is in henries and C is in farads

we have to ensure suitable values of L and C in the tuned circuit so that the required frequency range is covered. In practice this means producing a coil of suitable inductance to match the normal capacity swing available from tuning condensers, which is normally from 50 to 500 picafarads (nominal), or less (e.g. a 175 to 200 picafarad swing).

Coil windings are thus designed to match (i.e. produce the corresponding inductance required relative to the core material em-

ployed). Thus whilst required inductance can be calculated direct for an air core, the Q of the coil is increased appreciably by using a ferrite rod core, which at the same time considerably modifies the winding specification. Coil windings are, therefore, specific to the size and type of core material employed on practical aerial units.

Fig. 35 shows the corresponding proportions of an air-core coil which will give inductance values matching a 450 *pF* swing when close wound in 38 s.w.g. enamelled or double-silk-covered wire, wound in the form of an auto transformer for direct coupling to the

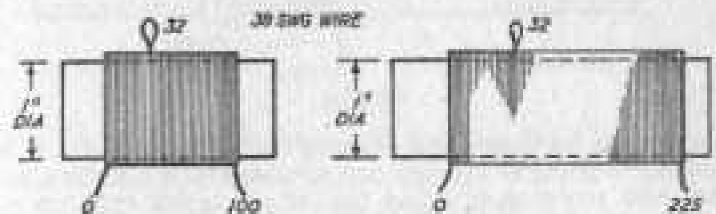


Fig. 35

next stage. The tapping point is nearest the earth end of the coil. It will be noticed that for the increased inductance required to cover the long-wave frequencies the coil length is simply extended with further turns and it would be normal practice to switch in these additional turns via a wave-change switch, as shown in the circuit diagram. The matching capacitor would be required to tune over the range 50 to 500 picofarads.

If the tuning range proves incorrect for the actual capacity range available from the variable condenser, then coil inductance can be adjusted by adding more turns, or reduced by removing turns. With auto transformer winding, however, it is necessary to add (or remove) the same *ratio* of turns at each end, so that the same balance is preserved about the tapping point. Since the tapping point comes at one-third the coil length, this means adding (or subtracting) coils in the ratio 1 : 2, e.g., 1 turn added to the earth end must be balanced by adding 2 × 1 = 2 turns to the other end.

An air-core coil of this type would not normally be used on a practical receiver because of its low overall efficiency (low Q). It would, in fact, almost certainly have to be employed in conjunction with a long external aerial to get satisfactory reception in most areas. Although a smaller diameter coil will be less efficient by itself, when mounted on a ferrite rod its inductance is considerably increased in a low resistance high Q coil capable of excellent selectivity.

Typical proportions for miniature tuning coils wound on a 5/16-in. diameter ferrite rod are shown in Fig. 36, the first being an auto-transformer type for direct coupling and the other employing

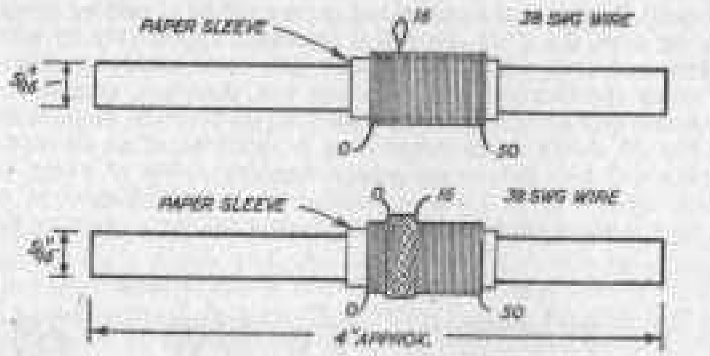


Fig. 36

separate coils for transformer coupling (inductive coupling). Either is capable of giving an excellent performance over the medium-wave band, with provision to adjust the inductance for optimum performance by sliding the coil along the ferrite rod until the best position is found.

Any attempt to extend such a coil to give long-wave coverage also is often disappointing, using simple coil-winding techniques. For satisfactory performance, in fact, it is usually necessary to wave-wind the long-wave coil. A typical design based on a 7-in. long 19/32-in. ferrite rod is shown in Fig. 37. Here the medium-wave

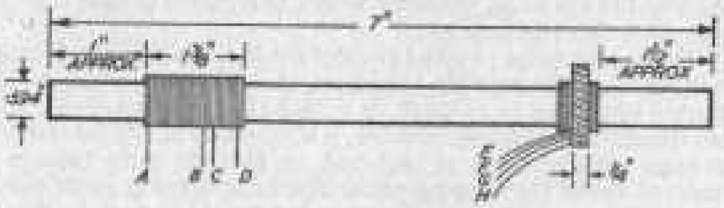


Fig. 37

coil consists of a single layer winding of 19/0·0028 (22 s.w.g.) stranded insulated wire forming 64 turns *A–B* and 6 turns *C–D*. The long-wave coil is wave-wound from 28 s.w.g. enamelled and rayon- or cotton-covered wire, forming *E–F* with 41 turns and *G–H* with 175 turns. Coil sizing and spacing is approximately as shown. Small adjustments to the coil inductance can be made by sliding the coils along the rod, as necessary. The matching tuning capacitor required for this coil is 175 *pF* maximum.

It is usually the most satisfactory solution to purchase commercially wound coils matched to a specific size and quality of ferrite rod in order to ensure maximum performance from receivers intended to have long-wave coverage. These will also be related to a

specific tuning capacitor range. A typical commercial design is shown in Fig. 38, where it will be noted that the complete unit may also provide a special coupling point for a car aerial.

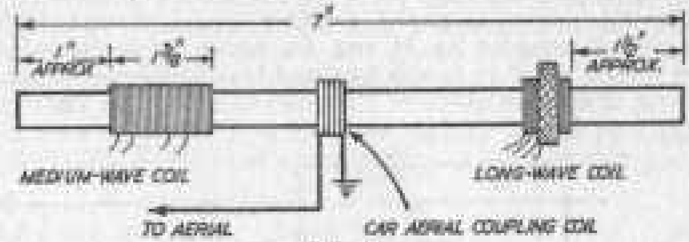


Fig. 38

Winding specifications for the coil shown in Fig. 37 are:

Medium-wave coil (single-layer winding)
AB: 64 turns 19/0·0028 covered wire
CD: 6 turns 19/0·0028 covered wire
Long-wave (wave-wound)
EF: 41 turns 0·0076 in. rayon-covered enamelled wire
GH: 175 turns 0·0076 in. rayon-covered enamelled wire

In the case of the superhet the resonant r.f. signal established in the tuned circuit is fed to the converter or mixer stage. However, an intermediate r.f. amplifier stage may be incorporated to increase the sensitivity of the receiver, improve selectivity by reducing the image frequency response, or reduce background noise. Disadvantages—apart from extra cost—are the additional alignment problems posed and also the fact that a three-gang condenser is required for tuning instead of the normal two-gang (aerial and oscillator).

R.f. amplification can be provided by a simple untuned circuit as shown in Fig. 39, which does not require the use of a three-gang

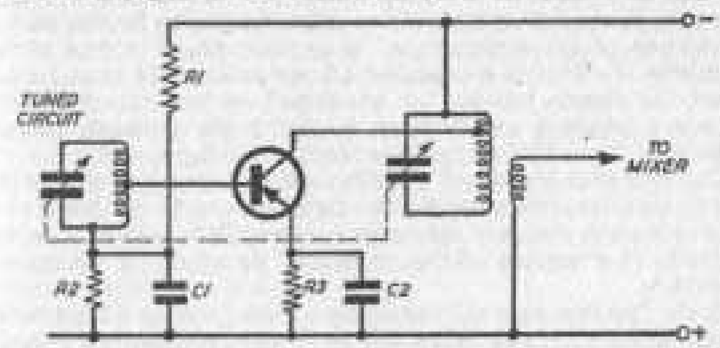


Fig. 39

condenser, although the gain is not particularly high. *R1* and *R2* provide base bias for the transistor, with *C1* and *C2* acting as bypass for r.f. Output from the amplifier is resistance-capacity coupled to the converter stage.

A typical common emitter r.f. amplifier circuit is shown in Fig. 40. Base bias is provided by *R1* and *R2*, whilst d.c. stabilization is given by *R3*, which in turn is bypassed by *C3* to prevent negative feedback at signal frequencies. *C1* is also an r.f. bypass. The output

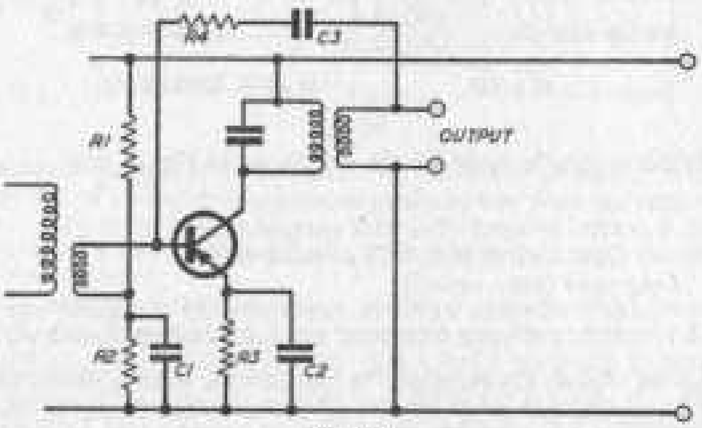


Fig. 40

is then coupled to the next stage via an r.f. transformer with a turn ratio of approximately 5 : 1. This avoids loading the tuned circuit and reducing the selectivity. Using suitable components a power gain of 20 to 25 *dB* should be obtained.

A possible failing with this type of circuit may be a tendency to oscillate owing to internal resistive and capacitive feedback. This can, however, be eliminated by applying neutralization by feeding back a proportion of the output signal in opposite phase to that of the transistor. To do this a capacitor *C3* and resistor *R4* in series are connected directly between the transistor base and output and the capacitor adjusted, as necessary, to match the feedback characteristics of the individual transistor in the working circuit.

The converter (or mixer) and the local oscillator can be tackled as two separate circuits, or the two functions can be combined in a single autodyne circuit to operate as a self-oscillating mixer. The two methods of treatment of this stage can, therefore, be considered separately.

In the first case separate transistors are used, one as a local oscillator and the other as a mixer. The problem of producing a suitable oscillator is an important one since, theoretically at least, the

frequency difference between the oscillator and radio frequency circuit must always be constant and equal to the intermediate frequency. This is achieved first by mechanical ganging of the tuning capacitors concerned but at the same time it demands stable oscillation with frequency constancy independent of temperature, changes in supply voltage, etc., and absence of "squegging" (a state of unstable oscillation where the oscillator amplitude varies in audio frequency).

In practice, perfect separation or tracking cannot be achieved. Thus instead of the ideal curve of Fig. 41 the best that one can

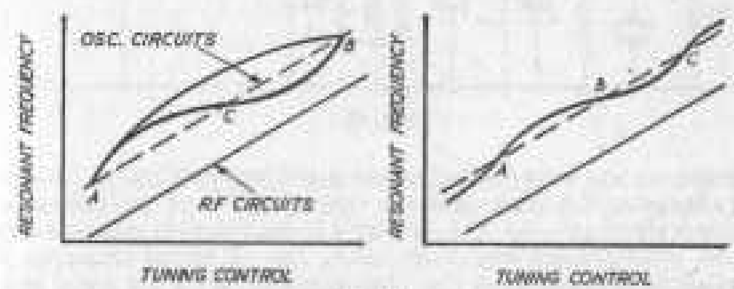


Fig. 41

normally achieve is a means of trimming or aligning the practical circuitry so that absolutely correct tracking is achieved at a number of points only along the curve. If correct alignment is produced at the two ends of the tuning range, as in *AB*, deviation over the middle of the band is likely to be large, with considerable loss of amplification and "image protection". Aligning at three points (*A*, *C*, and *B*), one in the middle and the other two near each end, considerably reduces the maximum deviation at any point. Closer alignment still (e.g. giving three absolutely correct points of tracking, *A*, *B*, *C*, as in the right-hand diagram) further reduces the deviation, especially if points *A* and *C* are selected well in from each end of the tuning range.

As a general rule the maximum deviation permissible (or tolerable) is greatest at the high frequency end, which means that for a frequency-tuning range of 3 to 1 the deviation permissible at high frequencies is about three times that at low frequencies. On this basis it would appear desirable to design for, and provide adjustment for aligning, at absolutely correct tracking over the lower-frequency range rather than the top end. Against this, however, is the fact that at the high-frequency end image protection is least, and so selectivity may suffer as a consequence.

A typical circuit employing a separate Hartley type oscillator and mixer is shown in Fig. 42. The collector is tapped about one-third of the way down the coil in order to reduce the effect of collector

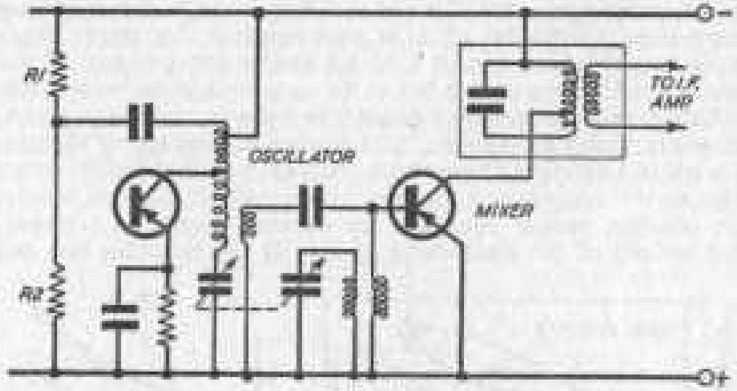


Fig. 42

capacitance and improve impedance matching, stability, and tracking characteristics. The oscillator circuit itself is of perfectly conventional form with the output coupled to the mixer via the secondary of the oscillator coil and a capacitor. The r.f. signal frequency is applied simultaneously to the mixer transistor from the aerial coil, oscillator and aerial tuning capacitors being ganged. The two signals are thus mixed in the base-emitter circuit or mixer input, with the sum and difference frequencies appearing at the collector with a gain of anything up to 15 to 20 *dB*. This difference frequency is fed to the tuned circuit comprising the primary of the first i.f. transformer, with output from the secondary to the i.f. amplifier.

Autodyne converters are often preferred in modern superhet designs since they generally have better frequency stability and, of course, can provide both local oscillation and mixing with a single transistor. In point of fact there is very little difference in performance between the two types and both can be designed for satisfactory frequency stability. Cost, therefore, is usually the main consideration in favour of a self-oscillating mixer.

In the typical self-oscillating mixer circuit shown in Fig. 43, r.f. signals from the aerial coupling coil are fed to the base of the transistor, which produces its own local oscillation by means of feedback from the collector to the emitter. Noise initiated in the collector and coil *L2* is induced in the secondary *L3* of the oscillator transformer, causing oscillation at the resonant frequency determined by the variable capacitor. This is fed back to the emitter and thus recirculated. Provided *L2* and *L3* are so arranged as to produce no phase change (in practice this means that *L2* must be connected the right way round), oscillation will be maintained, with *L3* acting as an autotransformer giving a proper match between the high-impedance tuned circuit and the low-impedance emitter circuit.

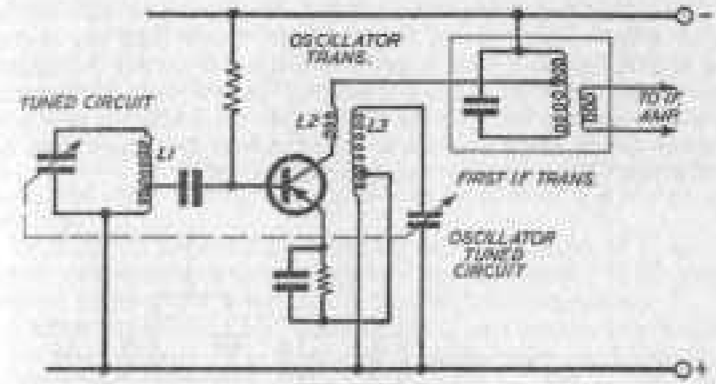


Fig. 43

The output, comprising sum and difference frequencies amplified, is taken from *L2* to the tapping point on the tuned primary of the first i.f. transformer which selects the i.f., the secondary of this transformer providing the i.f. input for the i.f. amplifier.

A variation commonly employed is shown in Fig. 44. Here the transistor is effectively operating in the common base configuration,

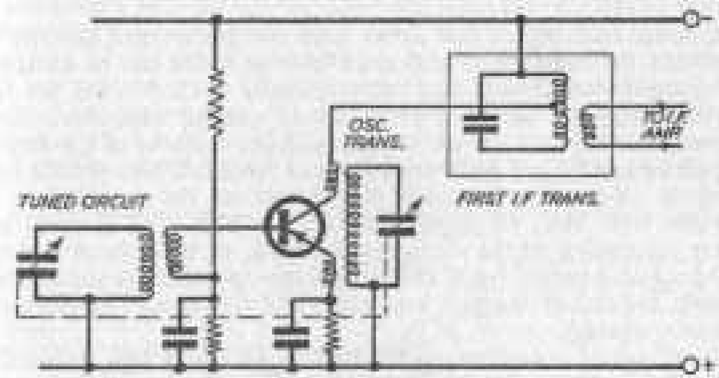


Fig. 44

and the oscillator coil has a third winding on the same core. The necessary low-impedance input in this case demands tapping the aerial coil to match (autotransformer aerial coil) or inductive coupling of the aerial via a separate coupling coil. In the practical circuit trimmers and padders will also be introduced to provide a final means of adjustment and alignment.

Yet another variation is shown in Fig. 45 where the local oscillator signal is fed to the base of the transistor rather than the emitter, and referred to as a base-injected autodyne converter (as distinct from emitter-injected circuits described previously). Performance should be directly comparable, except that the transistor in a base-injected circuit needs to have a higher cut-off frequency than one used in the corresponding emitter-injected circuit.

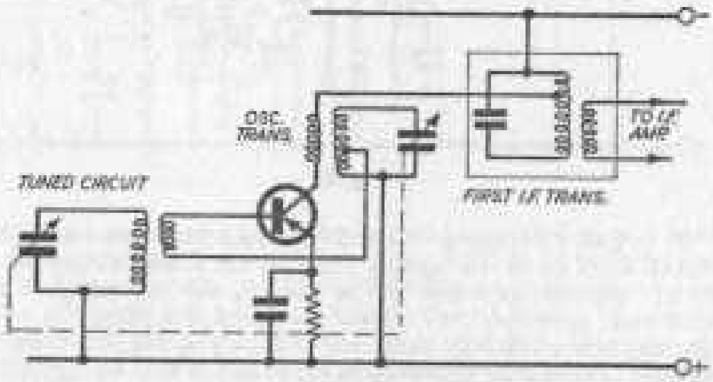


Fig. 45

Correct tracking of the aerial- and oscillator-tuned circuits to maintain the constant i.f. difference in frequencies can be obtained by using a tuning capacitor with specially shaped vanes for the oscillator circuit; or by a conventional padded capacitor. Stray capacitance between the aerial and oscillator sections of the tuning capacitor can form a path for unwanted feedback between the two sections, so a screen is usually placed between the two sections to prevent this. Stray capacitance effects can also arise between the wires connecting to the wavechange switch, so these must be kept as short as possible (or if completely incorporated on the printed circuit, the circuit elements kept short and well spaced to eliminate capacity effects).

In all cases, regardless of the type of oscillator and mixer, the first i.f. transformer receives a mixture of local oscillator frequency, signal frequency and the sum and difference of the two. It is therefore necessary to use a capacitor across the primary to produce an L.C. circuit to resonate at the i.f. This capacitor is of fixed value (matched to the inductance of the coil), when any adjustment required for alignment is provided by an iron-dust core in the coil enabling the inductance to be varied over the necessary range. Once the overall L.C. value has been adjusted to a resonant frequency corresponding to the i.f. the tuning remains fixed.

Output from this stage is an a.f. modulated high-frequency signal at the intermediate frequency, which has also been subject to a degree of amplification. Additional amplification is then provided by the i.f. amplifier, which may consist of 1, 2, or 3 stages, depending on the performance required. The common choice is two i.f. stages and the circuitry involved is usually quite straightforward. The transistor(s) may be used in either common-base or common-emitter configuration, the latter usually being preferred as providing a higher gain per stage.

A single i.f. stage would normally call for the use of a double-tuned transformer, whereas with two or three stages of i.f. amplification single-tuned transformers may be fully satisfactory.

The i.f. transformer providing the input must be correctly matched to the input impedance of the transistor, and similar conditions apply to the transformer used at the output end: i.e. this second transformer has to be matched to a high-output impedance and a low-input impedance to the next stage. Mis-matching materially reduces the gain.

In place of i.f. transformers a component known as a transfilter may be used. This, basically, is a piezo-electric solid-state device comprising, basically, a crystal clamped between two electrodes. It will then resonate at one frequency only and input and output impedance characteristics match the requirements of the i.f. transformer stage. Transfilters can, therefore, be used in place of i.f. transformers with the specific advantage that they require no tuning (their operating frequency being fixed) and if manufactured to the required i.f. frequency considerably simplify alignment problems. At the present stage of development, however, transfilters have certain limitations and the majority of superhet designs are still based on the use of tuned i.f. transformers.

A typical single-stage i.f. amplifier circuit is shown in Fig. 46

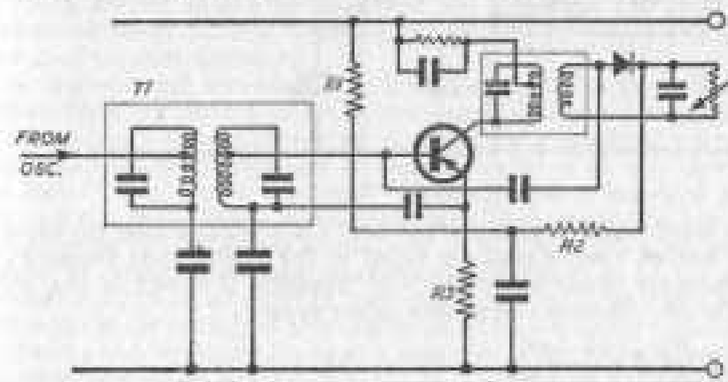


Fig. 46

employing a double-tuned transformer (*T1*). The collector current is normally stabilized by a potential divider *R1* and *R2*, and a suitable resistance in the emitter circuit. Automatic gain control (a.g.c.) may also be introduced to prevent overloading on strong signals. This is applied from the detector. Fig. 47 shows the somewhat simpler

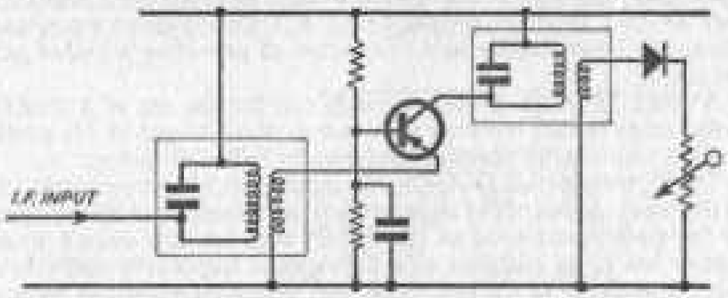


Fig. 47

circuitry possible using the transistor in common-base configuration, the other advantage here being that with common-base connection the cut-off frequency is much higher for a given transistor.

Another basic single i.f. stage is shown in Fig. 48, which is similar

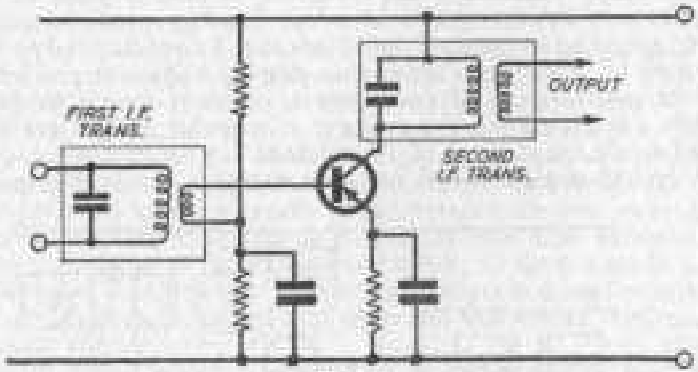


Fig. 48

to a basic audio amplifier stage with the exception that the input and output transformers are tuned to the intermediate frequency. A complete circuit using an OC45 transistor is shown in Fig. 49, where the following component values apply:

R1: 22 kilohms
R2: 4·7 kilohms
R3: 1 kilohm

R4: 3·9 kilohms
C1: 0·1 μ*F*
C2: 0·25 μ*F*
C3: 18 *pF*

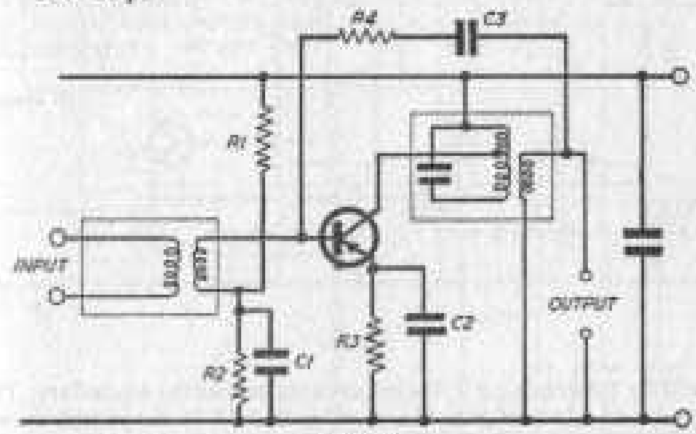


Fig. 49

A fall in gain with frequency is experienced with all transistors and thus limits, to some extent, the usefulness of transistors for h.f. The gain in a common-emitter circuit falls off more rapidly with frequency than with common-base configuration, so the cut-off frequency of the transistor chosen needs to be well above the frequency of operation. A stage gain of 25 to 35 *dB* should then be obtained with a suitable choice of transistor (e.g. OC45), there being some inevitable losses through coupling and mismatching.

It is also important at high frequencies that the internal feedback of the transistor should be small and not subject to too great a spread, although internal feedback can readily be neutralized by means of external feedback.

A conventional two-stage i.f. amplifier circuit with realistic values based on the use of OC45 transistors is shown in Fig. 50. The matching i.f. transformers are designed for a transistor output impedance of 28 kilohms and an input impedance of 800 ohms. *C1* and *C2* are bypass capacitors. Neutralization is provided by *R3* and *C3*, which form a feedback path from output to input. A.g.c. is applied from the output side of the detector. First and second i.f. transformers can be identical, but the third i.f. transformer is designed to have an unloaded *Q* of 160 with the load resistance of the secondary arranged to maintain a stability factor of four with a bandwidth of 9 *kc/s* and a stage gain of 34 *dB*. If necessary, the required stability factor of four can be restored (e.g. if the output resistance of the mixer stage rises above the design 28 kilohms

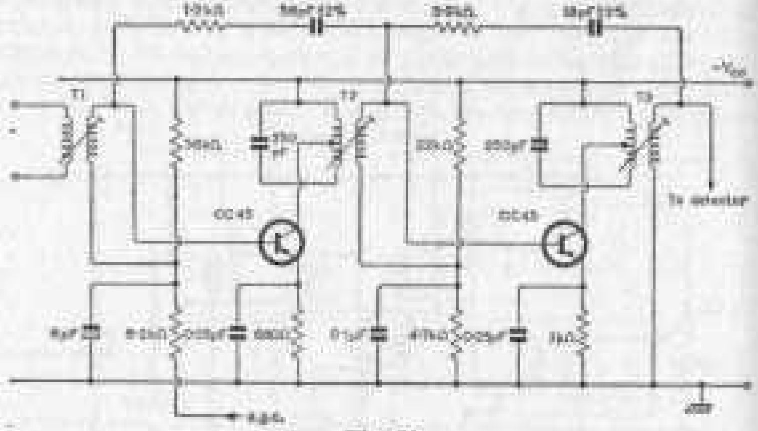


Fig. 50

match) by connecting a 750-ohm resistor across the secondary. This will result in a loss of gain of the order of 2 *dB* on the circuit shown.

A diode is normally used for the detector stage and the circuitry is quite simple and conventional—see Fig. 51. A steady voltage is developed across the variable resistance (usually shunted by a 0·01 μF capacitor), which acts as the load for the detector output and also forms the volume control, and is fed back to the first i.f.

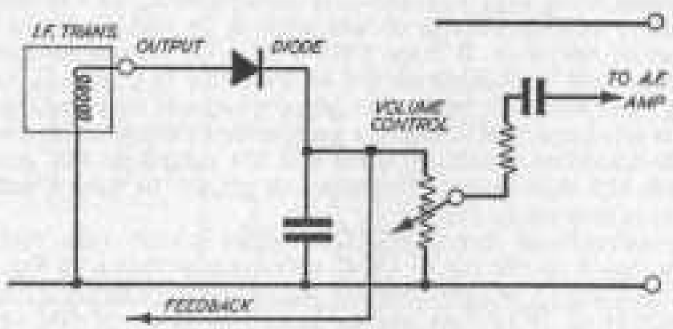


Fig. 51

transistor to give a.g.c. The small forward bias applied to the diode by the a.g.c. circuit helps maintain the input resistance of the detector constant at all signal levels. At the same time this small bias applies constant loading to the i.f. amplifier to improve efficiency of detection on small signal strengths and provide stability.

Some designers prefer to use an r.f. transistor instead of a diode for the detector, as this is capable of providing amplification as well as

demodulation. A surface-barrier transistor offers a superior performance to a conventional junction type for this particular duty. The basic circuit normally follows that shown in Fig. 52. The detector may also be made regenerative to provide further i.f. gain (e.g. for use with a single stage of i.f. amplification) by means of a feedback loop.

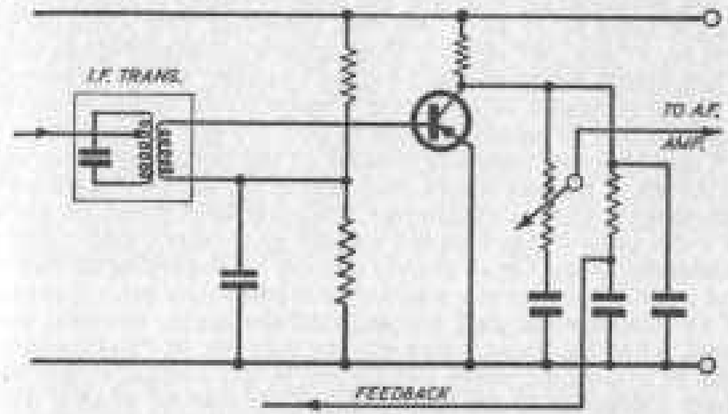


Fig. 52

The back end of the superhet circuit then consists of a driver stage and an output stage, e.g. a complete audio-amplifier end, the output of which is designed to provide the power required. This may range from an output power of 1 milliwatt or less for driving an earphone in a miniature receiver to about 500 milliwatts for driving a small speaker; or up to 5 watts or more for driving a large speaker. This in turn will influence both the choice of circuit and type of transistors employed.

An elementary a.f. amplifier stage need consist only of a minimum of components, as shown in Chapter II, Fig. 21, where the output power would be of sufficient power to operate a deaf-aid earpiece. Additional amplifier stages can be built up in this manner, directly coupled, giving a good performance from an extremely simple, straightforward circuit, as shown in Chapter II, Figs. 22–24. Effectively the overall gain is equal to the product of the betas of the number of transistors used, although three transistors is a logical limit for this type of circuit. Stabilization can be provided by feedback from the collector of the last transistor via a suitable value of resistor (e.g. of the order of 10 kilohms), with *C1* acting as a bypass to earth for a.f.

More commonly, however, a single stage of a.f. amplification is followed by a push-pull output, as in Chapter II, Fig. 23. Here the driver transistor *T1* is selected for high gain with the output load formed by the primary of a phase-splitting transformer. The two matched output transistors *T2* and *T3* then comprise a push-pull amplifier with input 180 degrees out of phase, so that each transistor, in turn, amplifies alternative halves of the signal. To provide satisfactory reproduction, a small forward bias is also usually applied to each transistor in order to eliminate "crossover" distortion.

The particular advantage of this form of output is high efficiency (of the order of 75 to 80 per cent, compared with about 50 per cent for a "straight" circuit). This means a low current drain which is particularly favourable with battery receivers. Another advantage is that it is capable of producing a much higher output power for the same type of transistors used in the "straight" configuration.

There are many variations possible on this particular theme, such as the use of a centre-tapped loudspeaker of matched impedance to eliminate the speaker transformer; designing for single-ended output to avoid using a centre-tapped speaker or speaker transformer; or eliminating transformers entirely (usually by employing an N-P-N and P-N-P transistor as a matched push-pull output pair). Retention of an interstage coupling (driving) transformer is, however, more usual, when the output stage may or may not be "single-ended," with or without a speaker transformer. A single-ended output with direct connection to the speaker is usually referred to as a transformerless output.

CHAPTER VI

PROFESSIONAL CIRCUIT DESIGNS

WHILST the superhet circuit must comprise, basically, standard stages in logical sequence, there is the choice of alternative circuits for the individual stages (with the exception of the detector stage, which is almost invariably a diode feeding a potentiometer load in the case of all-transistor receivers, although a transistor detector can be used), and considerable possible variation in detail design. The final proof of value of the complete circuit is its performance and so rather than detail a number of possible design variants this chapter describes three proven designs from authoritative sources as representative of modern all-transistor superhet circuitry.

MULLARD 6-TRANSISTOR RECEIVER

This design was developed, basically, to provide a performance equivalent to that of a four-valve portable receiver using alloy-junction transistors and a single 9-volt battery with transformerless push-pull output. The circuit is suitable for making as a medium-size portable receiver with a Ferroxcube rod aerial, or in miniature size if preferred. The standard i.f. frequency of 470 *kc/s* is used with the local oscillator frequency above the signal frequency (see page 17). One OC44 and two OC45 transistors are used in the mixer and i.f. stages. The detector is a germanium diode type OA70. The audio stages comprise one OC71 transistor driving a matched pair of OC72 transistors.

The OC44 operates as a self-oscillating mixer, with r.f. signals from the aerial coupling coil fed into the base of the OC44, leading to the generation of local oscillation feedback from the collector to the emitter. The i.f. is selected at the collector of the OC44 by the first i.f. transformer *T3*.

The i.f. amplifier comprises two OC45 common-emitter circuits operating unilateralized, with the choice of bandwidth compromising between quality and selectivity. The third i.f. transformer *T5* is connected to the OA70 diode detector, with the d.c. output fed back to the first i.f. transformer to provide automatic gain control. Double-tuned i.f. transformers are recommended for optimum performance as regards frequency response and image rejection.

The Class B transformerless output stage requires a loudspeaker with a 35-ohm speech coil to provide the correct load for an output of 200 milliwatts, with negative feedback applied to the emitter of the OC71 driver from the loudspeaker terminal.

For the aerial circuit the coil design shown in Fig. 37 (page 48) will be suitable, wound on ⅜ in.-diameter formers. Specification for the Ferroxcube rod is FX1268, with a size of 7 in. long by ⅜ in. diameter. The aerial is coupled to the frequency changer by low-impedance coils placed adjacent to the aerial coils. The long-wave coil is short-circuited by *SA1* during operation on the medium-waveband to avoid any damping effect on the medium-wave coil. During long-wave operation the medium-wave coil is left open-circuited.

All component values are shown on the circuit diagram (Fig. 53). The value of the tuning capacitance is not critical, but must be sufficient to provide the desired frequency coverage. The aerial section has a capacitance of 175 *pF* and the oscillator section a capacitance of 123 *pF*. A screen should be used between the oscillator and aerial sections of the tuning capacitor (i.e. the tuning capacitor so specified) to be sure of eliminating undesired feedback in the circuit. The possibility of feedback will be at maximum when the receiver is tuned to its highest frequency, and will also be increased when the tuning capacitor has a low value (e.g. as typically the case with a miniature tuning capacitor).

A modified version of this circuit is shown in Fig. 54, employing a damping diode across the first i.f. transformer *T3*. This retains the original feedback path for automatic gain control but the OA79 diode is included to damp the first i.f. transformer. This diode heavily loads *T3*, widening the bandwidth and allowing a much larger input signal to be handled.

A miniaturized version of the original circuit is shown in Fig. 55, again with all component values marked. Here the output is reduced to 100 milliwatts driving a 75-ohm miniature receiver. Current consumption of this circuit is reduced from 9 *mA* zero signal, 20 *mA* average, to 7*mA* and 13 *mA*, respectively. This miniaturized circuit permits of further modification by substituting a Class A output with transformer drive to the speaker, reducing the number of transistors required to five, but increasing the battery consumption.

Typical performance data (Figs. 53 and 54)

Output power: 200 milliwatts
Frequency range:
  Medium wave: 540 to 1640 *kc/s*
  Long wave: 155 to 280 *kc/s*
Battery consumption:
  Zero signal: 9—10 milliamps
  Average listening level: 20 milliamps

Component data for Mullard circuit (Figs. 53 and 54)

Medium-wave aerial coil:
  Primary 64 turns 19/0028 bunched conductors wound in single layer

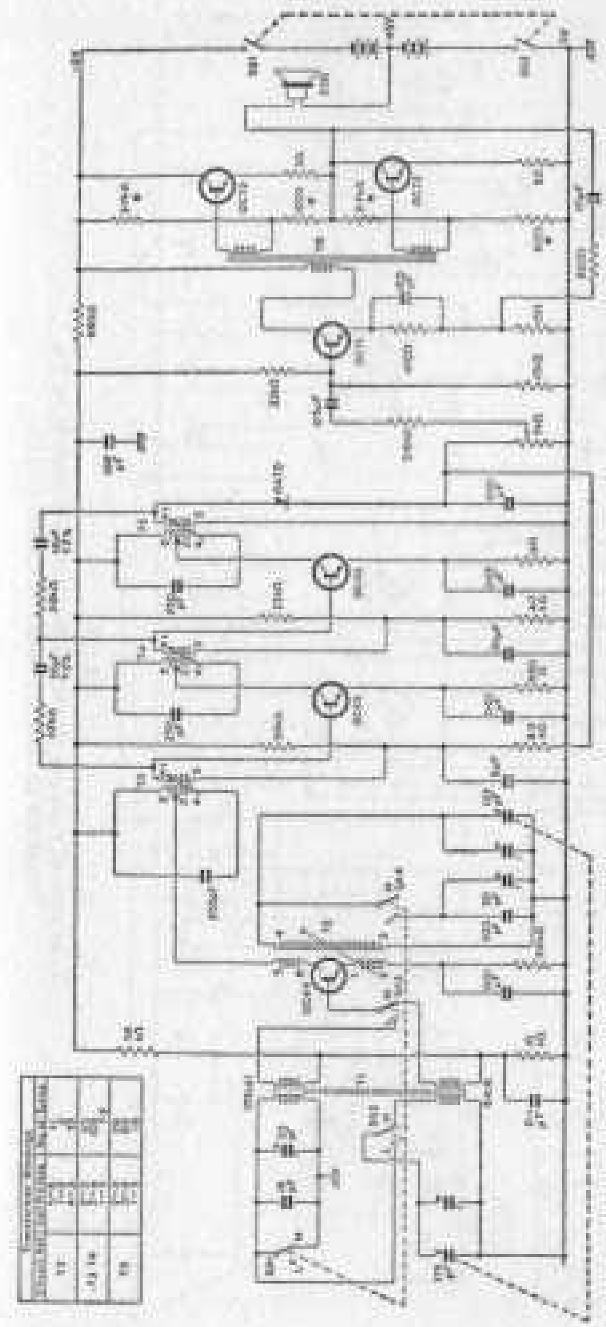


Fig. 53
Tolerance of resistors marked with an asterisk should be 5%
Tolerance of all other resistors should be 10%

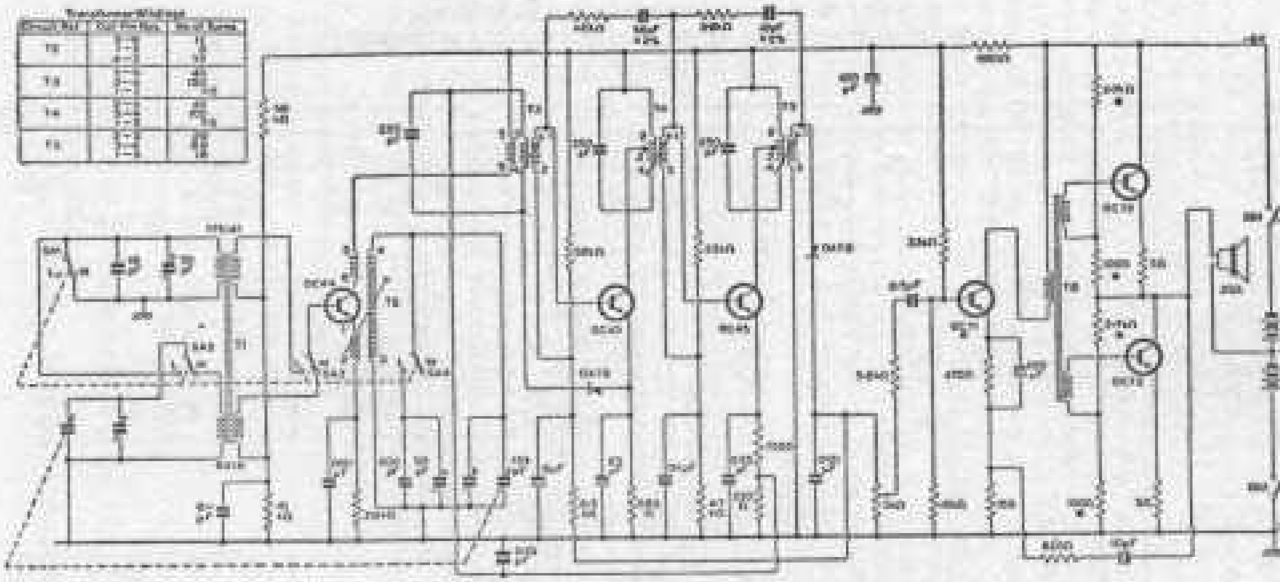


Fig. 54

Tolerance of resistors marked with an asterisk should be 5%
Tolerance of all other resistors should be 10%

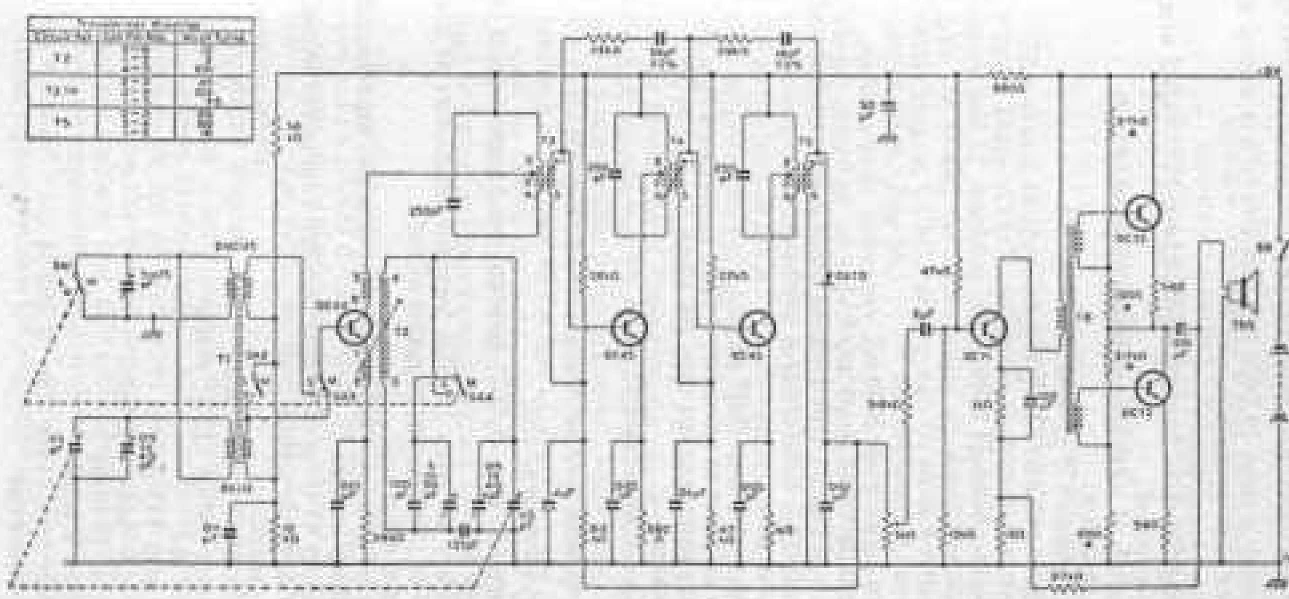


Fig. 55

Tolerance of resistors marked with an asterisk should be 5%
Tolerance of all other resistors should be 10%

Secondary 6 turns 19/0028 bunched conductors wound at low end of primary

Long-wave aerial coil:

Primary 175 turns 34 s.w.g. rayon-covered enamelled wire, wave-wound

Secondary 41 turns (continuation of primary coil)

Tuning capacitor:

Aerial section 175 *pF* max.

Oscillator section 123 *pF* max.

Oscillator coil (screened) 173 μH:

Windings—Main 73 turns

Collector 11 turns,

Emitter 2 turns

First and Second i.f. transformers:

Tuning capacitance 3000 *pF*

Ratio collector to secondary 6 : 1

Note: for circuit of Fig. 54 with damping diode a separate collector winding on the first i.f. transformer is necessary.

Third i.f. transformer:

Tuning capacitance 4000 *pF*

Ratio collector to secondary 1·85 : 1

Primary resistance less than 200 ohms

Loudspeaker:

Speech coil impedance 35 ohms

Component data for Mullard circuit (Fig. 55)

Medium-wave aerial coil:

Primary 88 turns 19/0028 bunched conductors wound in single layer

Secondary 12 turns 19/0028 bunched conductors at low end of primary nearest centre of rod

Long-wave aerial coil:

Primary 240 turns 3/0024 bunched conductors wave-wound in three sections

Secondary 45 turns of 3/0024 bunched conductors wound as fourth-pie section

Tuning capacitor:

Aerial section 115 *pF* swing

Oscillator section 115 *pF* swing

Oscillator coil:

Inductance 313 μH

Windings—Main 100 turns

Collector 13 turns

Emitter 2 turns

I.f. transformers, as for Figs. 53 and 54

Driver transformer:

Turns ratio 7 : 1

Primary—Inductance 5 *H* at 1·5 milliamps d.c.,

Resistance less than 750 ohms

Secondary resistance less than 100 ohms per winding

Loudspeaker:

Speech coil impedance 75 ohms

Mullard 6-Transistor Receiver

This circuit employs alloy-diffused transistors in the r.f. and i.f. stages. Three AF117 transistors are used for the self-oscillating mixer and i.f. amplifier stages. The detector is a germanium diode type OA70 and the audio stages consist of an LFH3 audio pack comprising an OC81D driving two OC81 transistors in a push-pull output stage. (Fig. 56.)

Aerial circuit comprises medium- and long-wave coils as previously described, mounted on a Ferroxcube rod. One section of the long-wave coil is short-circuited to earth on medium-wave operation to prevent damping of the medium-wave coil. The aerial signal is fed to the base of the AF117 self-oscillating mixer and local oscillation is provided by feedback from the collector to the emitter through transformer *T*1.

The two transformers *T*2 and *T*3 in the first two i.f. stages are double tuned. The i.f. transistors do not require neutralization. The final i.f. transformer *T*4 couples the i.f. signal to the detector stage, and a potentiometer (volume control) couples the detected signal to the audio stages which follow. Automatic gain control is provided by feedback to the base of the first i.f. transistor and a damping diode is used to extend the a.g.c. range and also to clamp the mixer collector voltage and thus eliminate instability under conditions of high collector load impedance produced by large signals.

"Weyrad" Superhet

This particular circuit has been developed for amateur construction to fit a printed circuit base 8¼ by 2¾ in. The circuit employs six transistors and a diode detector with push-pull output capable of driving a 7 × 4 in. elliptic loudspeaker (or equivalent) with alternative output stages.

A circuit diagram, including all component values, up to and including the detector stage is shown in Fig. 57. Tuning condenser is a Jackson Brothers type "OO". The front section of this has a maximum of 208 *pF* and tunes the aerial coils. The rear section (farthest from the spindle) has a maximum capacity of 176 *pF* and tunes the oscillator coil. It is particularly important that the correct values are employed for the associated fixed capacitors—the medium-wave padder being 215 *pF* and the long-wave padder 175 *pF*, with a parallel capacitor across the long-wave coil of 150 *pF*. If the gang is

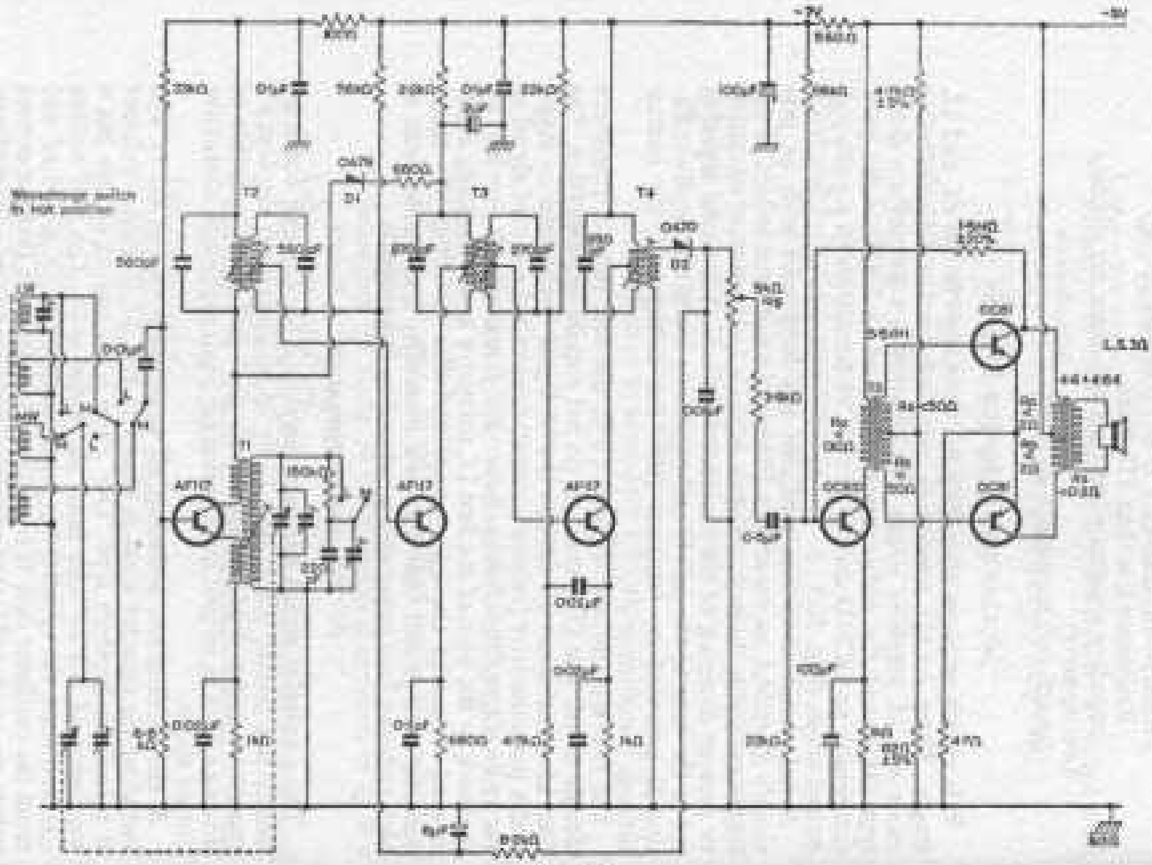


Fig. 56

All resistors ±10% except where shown otherwise

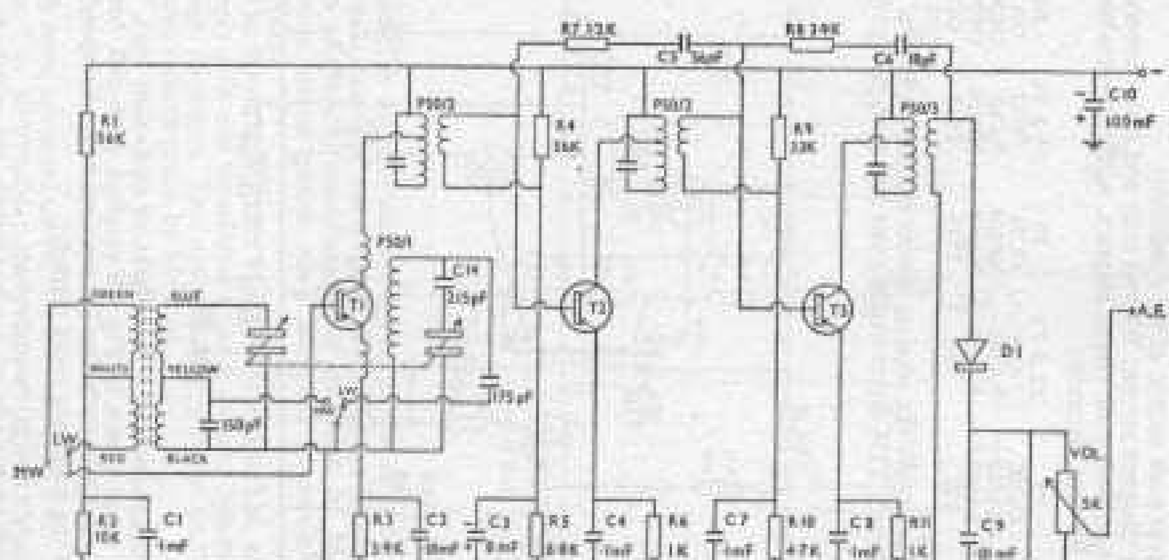


Fig. 57

not fitted with trimmers it will be necessary to connect a 3-30 *pF* Phillips type across each section of the condenser.

This circuit is designed around Weyrad coils and transformers to type number as specified on the circuit diagram. Alternative makes of transistors may be used, as under:

	T1	*T2 & T3*	*T4*	*T5 & T6*	*D1*
Mullard	OC44	OC45	OC71	OC72	OA70
Ediswan	XA102	XA101	XB103	XC101	GEX34
or	XA104	XA103	XB104	XB104	GEX34
Brimar	TS8	TS7	TS13	TS17	GD6

A.f. stages to complete the receiver circuit are shown in Fig. 58, utilizing a Weyrad LFTD4 driver transformer and push-pull output

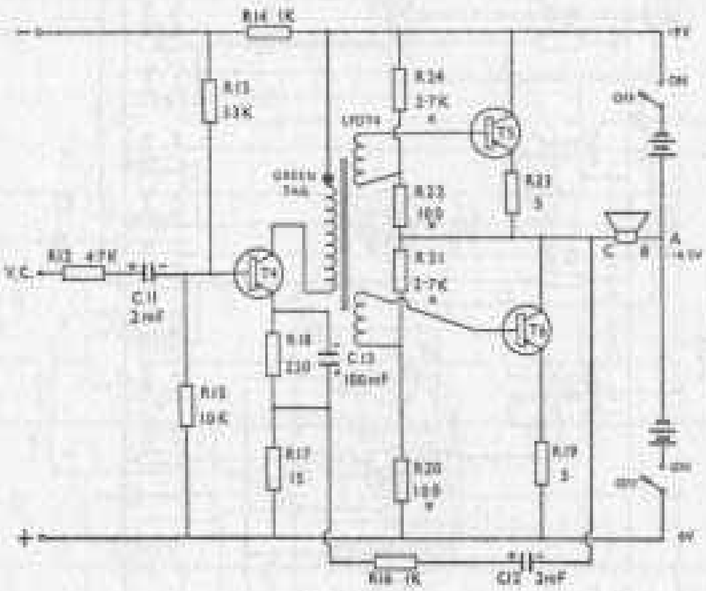


Fig. 58

to a 35-ohm loudspeaker (7×4 in. elliptic, or equivalent size). The alternative a.f. stage shown in Fig. 59 employs push-pull output with transformer output to a 3-ohm loudspeaker with corresponding modification of the transistor types, namely:

T4: Mullard OC81D, or equivalent.

T5 and *T6*: Mullard OC81 (matched pair), or equivalent.

Output with this configuration is 500 milliwatts.

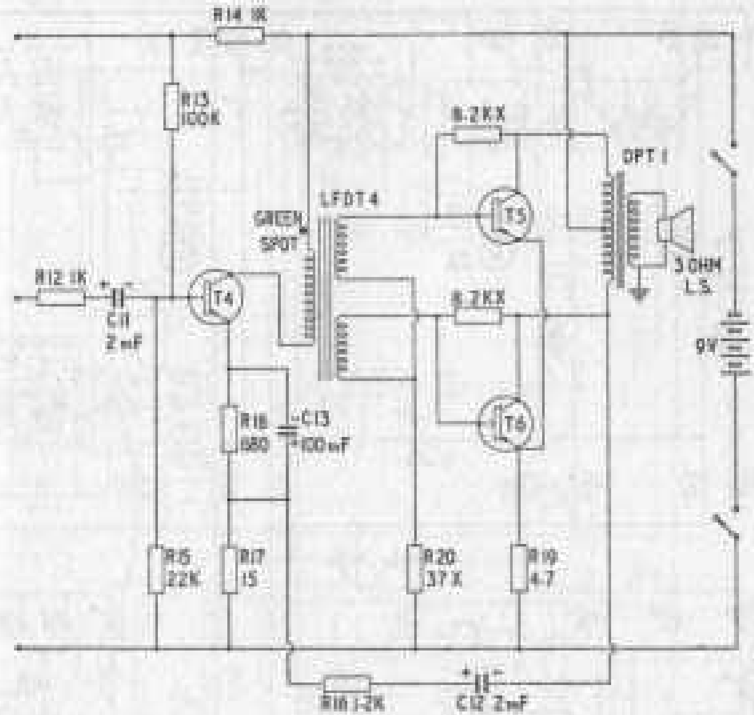


Fig. 59

Note: The Mullard circuits shown do not refer to particular commercial receivers nor are they for components (other than transistors and diode) manufactured or marketed by Mullard. Suitable printed circuit panels may, however, be available from radio suppliers.

The Weymouth Radio Manufacturing Co. Ltd. manufacture and supply coils and transformers and a finished printed circuit for the design illustrated. This design is largely based on the six-transistor circuit recommended by Mullard.

MULLARD 9-TRANSISTOR CIRCUIT

A more advanced circuit is shown in Fig. 60, which is a combined a.m./f.m. all-transistor receiver operating on a battery voltage of 9 volts (negative earth) and employing alloy-diffused r.f. and i.f. transistors. All nine transistors are used for f.m. reception and seven

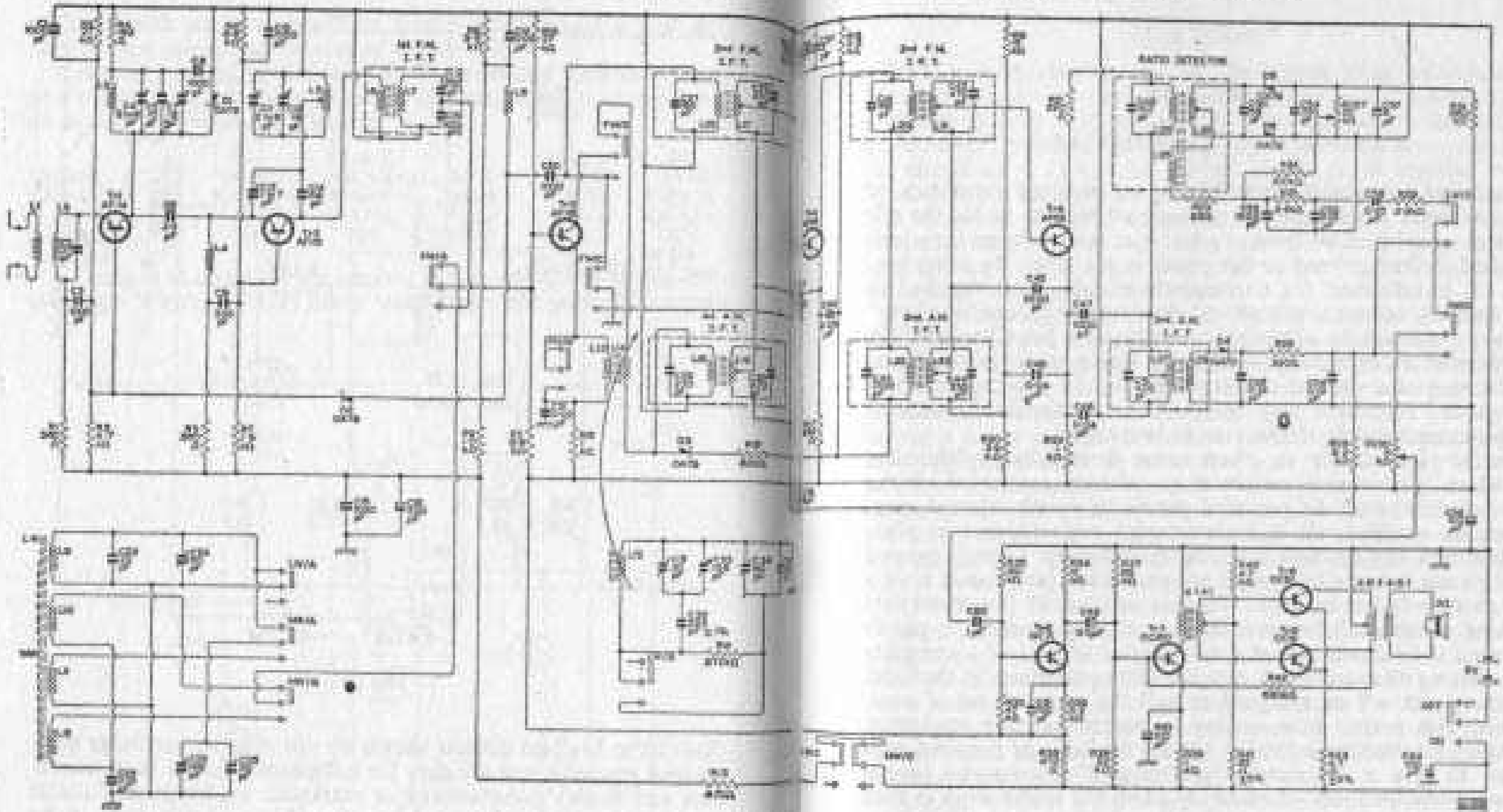


Fig. 6

for a.m. reception. This circuit has been designed to cover the medium- and long-wave bands on a.m. reception, and 87 to 101 megacycles on v.h.f.

Changeover from a.m. to f.m. reception is provided by switching the first f.m. i.f. transistor into the a.m. mixer stage, and the connection of the relevant detector to the audio stages by switches *LW/D* and *MW/D*. Switch *FM/C* short-circuits the second f.m. i.f. transformer during a.m. operation when it is connected into the collector

circuit of the mixer transistor. The audio stages are common to both a.m. and f.m. operation, the audio signal from the detector stage being fed to an OC71 a.f. preamplifier *Tr6*. The output from this is capacitively coupled to an OC81D transformer-coupled to two OC81 transistors in class B push-pull output. Audio-power output is 500 milliwatts with a low-impedance (3-ohm) loudspeaker speech coil.

CHAPTER VII

COMMERCIAL MODELS

The amateur constructor with little or no previous experience of transistor radio construction is strongly advised to tackle the all-transistor superhet in the form of a kit, or at least a design for which a finished, drilled printed circuit panel is available. By using pre-tuned i.f. transformers (or alternatively transfilters as supplied in some designs), correct assembly will then at least ensure "working" results with a minimum of trouble over alignment (see Chapter VIII). The design of an original superhet circuit, and in particular the design and drawing of a printed circuit panel, should only be attempted after gaining experience with one or more prefabricated panels, if disappointment and frustration are to be avoided.

Kits for all-transistor superhets range from fully prefabricated kits, which may include certain stages already assembled on the printed circuit panel, to prepared panels to match selected components as specified, all to be assembled and soldered in place together with any additional wiring as necessary. Usually printed circuit panels for specific designs are pre-drilled (and this is always to be preferred), but in such cases it is particularly important that matching components be used. This applies particularly to panels purchased individually rather than supplied as part of a complete kit containing all components necessary for completion. In the latter case the panel will be designed to suit the matched set of components, with correct hole spacing to match the gang condenser, etc. Also an attractive cabinet is usually available or supplied with the kit to give a completely "professional" appearance to the finished, assembled job—particularly as all the solder work is then completely hidden inside the case!

Commercial kit models available range from those which are extremely good in performance (quite as good as, and in many cases better than, finished domestic receivers), to those with distinct limitations as regards either constructional or design features, or both. As a general guide, and also because the circuits involved are instructive and useful to study, we have selected a number of the outstanding models in this field to describe. These are representative of the best of modern designs (1964) with none of the limitations of many earlier transistor circuits; ranging in size from miniature to standard portable, and from low to medium-high price. It must be stressed that this selection is not comprehensive, and that omission of any other design does not necessarily imply inferior performance, etc.

The "Capri"

This is undoubtedly one of the outstanding miniature all-transistor superhets designed for amateur construction and is available in fully prefabricated kit form complete with matching plastic case. Overall size is $4\frac{5}{8} \times 2\frac{7}{8} \times 1\frac{1}{4}$ in., the case accommodating the circuit on a $2\frac{3}{8} \times 2\frac{3}{8}$ in. printed circuit panel together with a $2\frac{1}{4}$ in. diameter loudspeaker and a PP3 9-volt battery (or equivalent). The circuit is designed to cover both medium- and long-wave reception, using a self-oscillating mixer, two i.f. stages, audio-amplifier and single-ended push-pull output stage. A germanium diode (OA90) is used as the detector.

The circuit diagram is shown in Fig. 61, which includes all small component values. The ferrite rod aerial is of the slab type, with matching coils wound on a paper sleeve. An OC44 transistor is used as a self-oscillating mixer, followed by two OC45 transistors forming the first and second i.f. amplifier stages, respectively. Diode detector output is fed to an OC81D transistor a.f. amplifier stage and thence to a push-pull output via a matched pair of OC81 transistors to a miniature loudspeaker with an 80-ohm speech coil. The circuit is conventional with an i.f. of 470 *kc/s* and basically similar to those previously described, except for the use of miniature components throughout and single-tuned i.f. coils. The gang condenser has a maximum capacity of 190 *pF* on both stages with trimmers (*C2A* and *C3A*) 3–10 *pF*. Battery connection corresponds to positive earth.

Alignment is straightforward and can be done without the use of a signal generator. Particular care must, however, be taken not to overtighten the tuning slugs in the miniature coils as these are easily jammed, resulting in permanent damage to the coil since it will be virtually impossible to remove the core without first removing the coil from the printed circuit; and similarly almost impossible to remove the coil without damage.

To align without a signal generator, the set is tuned to the mid-way point on the long-wave band and the core of *L4* adjusted to receive the Light programme. The tuning control should then be turned to come at the higher wavelength end of the medium-wave-band and the cores of *L9*, *L7*, and *L5* adjusted for maximum output. Further adjustment of volume can then be made by sliding the aerial coil along the ferrite slab and once the best position is found the sleeve should be fixed with wax or cellulose tape. The receiver should then be tuned to 300 metres approximately and trimmer *C3A* adjusted until Hilversum or Midland Region is received and then brought up to maximum volume by adjustment of *C2A*. If necessary, the alignment stages should then be repeated for the medium-wave-band until all stations are received at good signal strength.

Using a signal generator, standard alignment recommendations are:

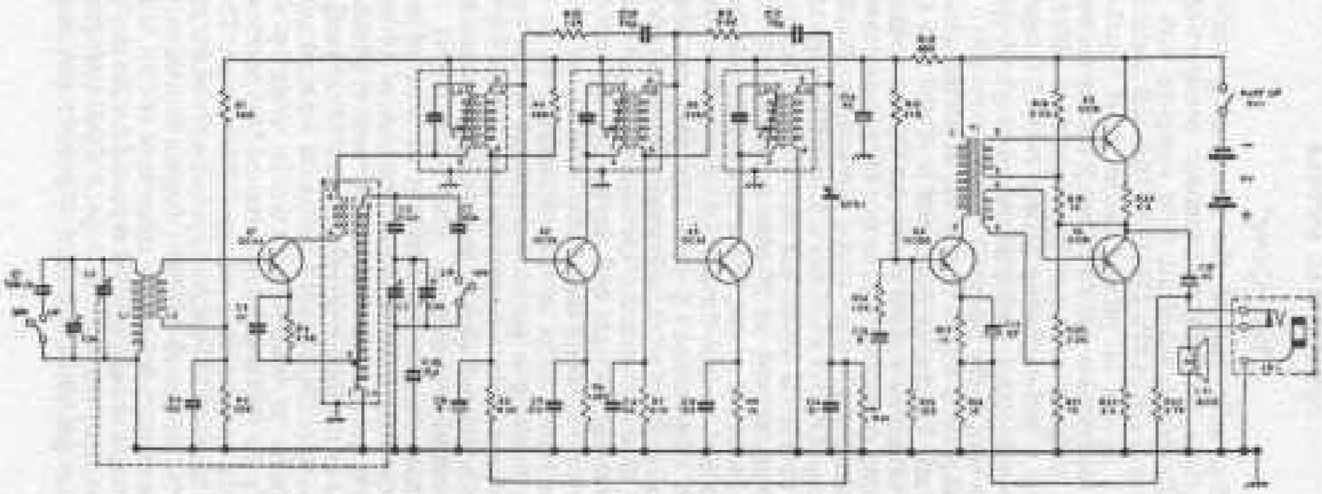


Fig. 61

Resistors

R1	56 kΩ	10%
R2	10 kΩ	10%
R3	3·9 kΩ	10%
R4	68 kΩ	10%
R5	8·2 kΩ	10%
R6	680 Ω	10%
R7	4·7 kΩ	10%
R8	22 kΩ	10%
R9	1 kΩ	10%
R10	1·2 kΩ	10%
R11	3·9 kΩ	10%
R12	680 Ω	10%
R13	47 kΩ	10%
R14	1·2 kΩ	10%
R15	10 kΩ	10%
R16	15 Ω	10%
R17	1 kΩ	10%
R18	2·2 kΩ	5%
R19	75 Ω	5%
R20	2·2 kΩ	5%
R21	75 Ω	5%
R22	2·7 kΩ	10%
R23	5·6 Ω	10%
R24	5·6 Ω	10%

Capacitor Description

C1	1350 pF 2% 125 V P'styrene
C2	190 pF } Gang { 2A 3–10pF
C3	190 pF } capacitor { 3A 3–10pF
C4	0·04 μF 20% 150 V
C5	0·01 μF 20% 150 V
C6	210 pF 2% 125 V P'styrene
C7	160 pF 2% 125 V P'styrene
C8	8 μF 6 V Electrolytic
C9	0·04 μF 20% 150 V
C10	56 pF 5%
C11	18 pF ± 1 pF
C12	0·04 μF 20% 150 V
C13	0·04 μF 20% 150 V
C14	0·01 μF 20% 150 V
C15	45 μF 10 V Electrolytic
C16	8 μF 6 V Electrolytic
C17	32 μF 6 V Electrolytic
C18	45 μF 10 V Electrolytic
C19	5 pF ± 1 pF 125 V P'styrene

Coil Description

L1, L2	Ferrite aerial
L3, L4	Oscillator coil
L5, L6	1st single tuned 1 ft.
L7, L8	2nd single tuned 1 ft.
L9, L10	3rd single tuned 1 ft.

Transistor Description

X1	OC44	Mullard	Miniature R.F.G. 3M Package
X2	OC45	Mullard	
X3	OC45	Mullard	
X4	OC81D	Mullard	Miniature L.F.H. 3M Package
X5	OC81*	Mullard	
X6	OC81*	Mullard	

*Matched pair

Transformer Description

T1 Transformer driver

Miscellaneous

LS1	Loudspeaker 2½ in. round 7,700 lines
RV1 5K	Log with single pole switch
SCR1	Diode OA90
JS1	Jack socket

At 600 *kc/s*—tune in at end of medium waveband.
At 470 *kc/s* adjust *L9*, *L7* and *L5* for maximum output.
At 600 *kc/s* adjust aerial coil position for best results.
At 1450 *kc/s* adjust *C3A* and *C2A* for maximum output.

The "Capri" is marketed in kit form by Henry's Radio Ltd., 303 Edgware Road, London, W.2; and Radio Clearances Ltd., 27 Tottenham Court Road, London, W.1.

The "Realistic Seven"

This is a seven-transistor circuit for medium- and long-wave coverage with a 350-milliwatt output powering a 4 in. diameter speaker. Battery is 9 volts with a current consumption of the order of 25 to 35 milliamps at average listening level. Cabinet size is 7 in. high by 10 in. wide by 3½ in. deep, and receiver weight, complete with battery, is approximately 3½ pounds. Particularly attractive features on the building side are ease of construction and very low total cost for a receiver of this type and performance.

A circuit diagram for the "Realistic Seven" is given in Fig. 62. An OC44 transistor is used for a self-oscillating mixer, with OC45s for the i.f. stages to a diode detector. Audio output is via an OC71D transistor amplifier stage and finally to a push-pull output utilizing a matched pair of OC81 transistors. The loudspeaker has a 25-ohm impedance to match. Negative feedback and automatic gain control are incorporated in the circuit.

Working voltages (measured negative with respect to the common line) are:

	G1	*G2*	*G3*	*G4*	*G5*	*G6*	*G7*
Emitter	1·5	0·7	0·9	0·6	1·3	4·5	0
Base	1·4	0·8	1·0	0·7	1·4	4·65	0·15
Collector ...	7	7	7	1·4	8·5	9	4·5

These voltage figures must be read as approximate.

Alignment procedure recommendations specify that the aerial and oscillator circuits must be aligned with the set in the cabinet. I.f. alignment may be carried out with the set either in or out of the cabinet. The intermediate frequency is 470 *kc/s*.

I.f. alignment

(1) Switch receiver to m.w. and close gang.

(2) Set signal generator to 470 *kc/s* and connect to base of mixer via a blocking capacitor.

(3) Align each i.f.t. for maximum output with either the output meter connected in place of the speaker or with the voltmeter connected across the speaker.

R.f. alignment

For r.f. alignment the signal generator should be loosely coupled

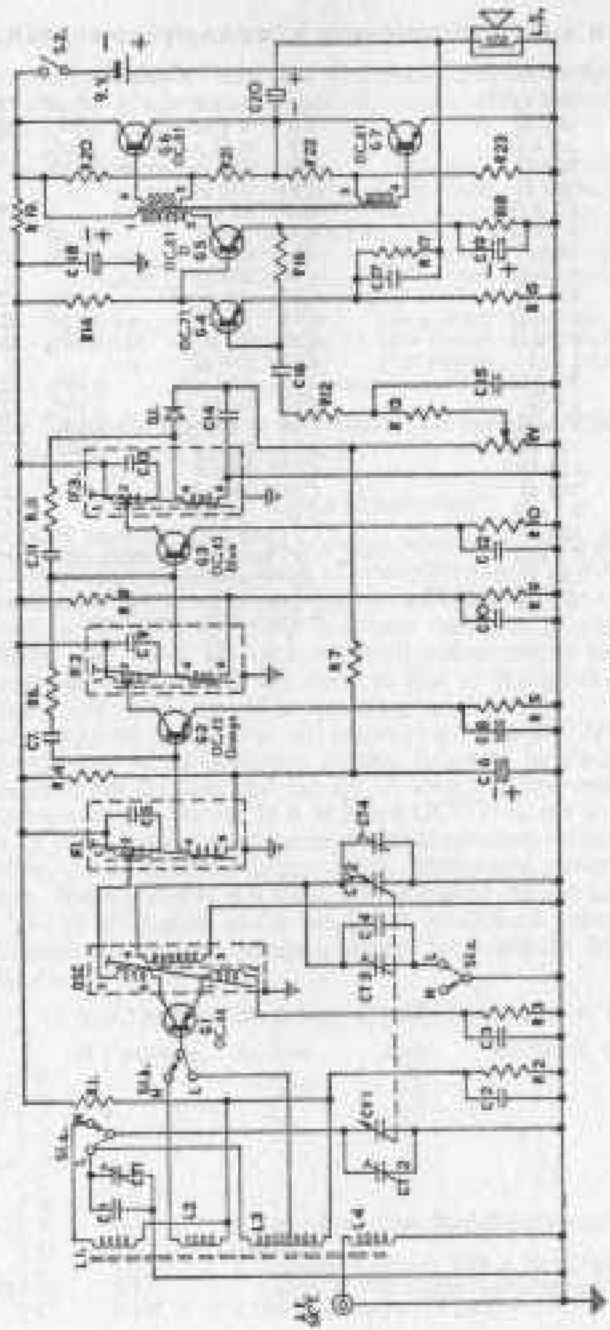


Fig. 62
(See key overleaf).

Resistors		*Capacitors*			
*R*1	39 *k* Ω	*C*1	10 *pF*	±1 *pF*	125 *V*
*R*2	10 *k* Ω	*C*2	0·1 μ*F*	±10%	125 *V*
*R*3	3·9 *k* Ω	*C*3	0·01 μ*F*	±10%	125 *V*
*R*4	56 *k* Ω	*C*4	200 or 210 *pF*	± 5%	125 *V*
*R*5	680 Ω	*C*5†	250 *pF*		
*R*6	1·2 *k* Ω	*C*6*	12 or 10 μ*F*		50 *V*
*R*7	8·2 *k* Ω	*C*7	56 *pF*	±1 *pF*	125 *V*
*R*8	22 *k* Ω	*C*8	0·1 μ*F*	±10%	125 *V*
*R*9	4·7 *k* Ω	*C*9†	250 *pF*		
*R*10	820 Ω	*C*10	0·047 μ*F*	±10%	125 *V*
*R*11	3·9 *k* Ω	*C*11	18 *pF*	±1 *pF*	125 *V*
*R*12	2·2 *k* Ω	*C*12	0·1 μ*F*	±10%	125 *V*
*R*13	1 *k* Ω	*C*13†	250 *pF*		
*R*14	8·2 *k* Ω	*C*14	0·01 μ*F*	±10%	125 *V*
*R*15	1 *k* Ω	*C*15	0·047 μ*F*	±10%	125 *V*
*R*16	33 *k* Ω	*C*16	0·022 μ*F*	±10%	125 *V*
*R*17	100 *k* Ω	*C*17	100 *pF*	±10%	125 *V*
*R*18	820 Ω	*C*18*	100μ*F*		12 *V*
*R*19	560 Ω	*C*19*	100 μ*F*		12 *V*
*R*20	2·7 *k* Ω	*C*20*	100 μ*F*		12 *V*
*R*21	100 Ω	*CT*1 and *CT*3 Trimmer 3%40 *pF*			
*R*22	2·7 *k* Ω	*CV*1 and *CV*2 Tuning capacitor			
*R*23	100 Ω	(incorporating *CT*2 and *CT*4)			
	± 10% ⅛ W rating	† Integral part of I.F. transformers			
		* Electrolytic capacitors			

to the set by a loop of insulated wire placed at a convenient distance from the set. Maximum pick up will be got with the loop at right-angles to the ferrite rod.

Operation	*Waveband*	*Generator*	*Receiver*	*Adjust for max. output*
1	m.w.	525 *kc/s*	Gang closed	Osc. coil
2	m.w.	1570 *kc/s*	Gang open	Osc. trimmer
		Repeat operations 1 *and* 2		
3	m.w.	600 *kc/s*	500 metres	m.w. aerial coil
4	m.w.	1300 *kc/s*	230 metres	m.w. aerial trimmer
		Repeat operations 3 *and* 4		
5	l.w.	155 *kc/s*	Gang closed	l.w. osc. trimmer
6	l.w.	180 *kc/s*	1670 metres	l.w. aerial coil
7	l.w.	270 *kc/s*	1110 metres	l.w. aerial trimmer
		Repeat operations 6 *and* 7		

The "Realistic Seven" is marketed in kit form by Lasky's Radio, 207 Edgware Road, London, W.2.

The "Good Companion"

This has been selected as a design which has been produced in both conventional form using i.f. transformers (Fig. 63) and with transfilters in place of i.f. transformers (Fig. 64). The two circuits shown in the accompanying diagrams make an interesting comparison. The Mark III version (1964) again reverts to i.f. transformers and is basically the same as that of the Mark I with the exception of some changes in capacitor values.

The standard circuit (Fig. 63) employs a Philco 2N1727 transistor self-oscillator in an autodyne circuit, followed by Philco 2N1728 transistors for the first and second i.f. stages, a conventional diode detector with a.f. output to a Mullard OC81D driver to a matched pair of OC81 transistors forming a transformerless output stage to a 35-ohm 5 in. diameter loudspeaker. Maximum power output is 1 watt. Battery supply is 9 volts, with a typical current consumption of 10—12 milliamps under no signal conditions rising to 20-25 milliamps at typical listening level. Intermediate frequency is 470 *kc/s*.

VOLTAGES FOR GOOD COMPANION MARK II

		All Conditions	*Medium*	*Long*	*No Signal*	*Strong Signal*
TR1	E		0·9	1·1		
	B		1·05	1·3		
	C		5·3	4·9		
TR2	E				0·9	0·05
	B				1·1 *V*	0·2 *V*
	C				3·6 *V*	7·3 *V*
TR3	E	1·0 *V*				
	B	1·2 *V*				
	C	7·1 *V*				
TR4	E	1·2 *V*				
	B	1·3 *V*				
	C	8·2 *V*				

Except where states the following conditions were observed:

1. Voltages measures with a 20 kilohms per volt meter (10-volt range) for battery positive.
2. Battery voltage (on load) 8·6 *V*.

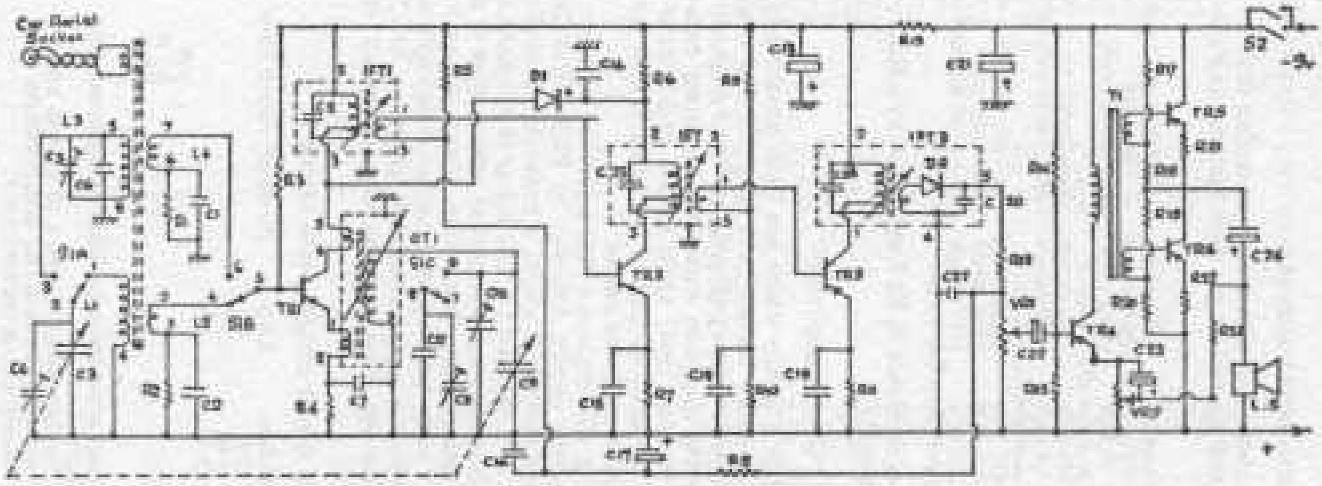


Fig. 63

R1 12 kΩ
R2 8·2 kΩ
R3 47 kΩ
R4 1·8 kΩ
R5 47 kΩ
R6 1·2 kΩ
R7 680 Ω
R8 8·2 kΩ
R9 15 kΩ
R10 47 kΩ

R11 1 kΩ
R12 2·2 kΩ
R13 560 Ω
R14 33 kΩ
R15 10 kΩ
R16 Not used
R17 2·7 kΩ
R18 100 Ω
R19 2·7 kΩ
R20 100 Ω

R21 3·3 Ω
R22 3·3 Ω
R23 3·3 kΩ
VR1 10 kΩ
VR2 500 Ω
C1 0·05 μF
C2 0·05 μF
C3 Gang
C4 Trimmer
C5 3–30 pF

C6 100 pF
C7 0·01 μF
C8 IFT1
C9 Gang
C10 Trimmer
C11 3–30 pF
C12 330 pF
C13 100 μF
C14 0·05 μF
C15 0·05 μF

C16 0·05 μF
C17 8 μF
C18 0·05 μF
C19 0·05 μF
C20 IFT3
C21 100 μF
C22 30 μF
C23 50 μF
C24 100 μF
C25 IFT2

C26 IFT3
C27 0·05 μF
Ferrite rod JB128/1
OT1 JB285
IFT1 JB282
IFT2 JB139
IFT3 JB139
T1 TD3
S1 JB3

Speaker 35 Ω High Flux
S2 On/Off Ganged with VR1
Printed Panel TypeS 12

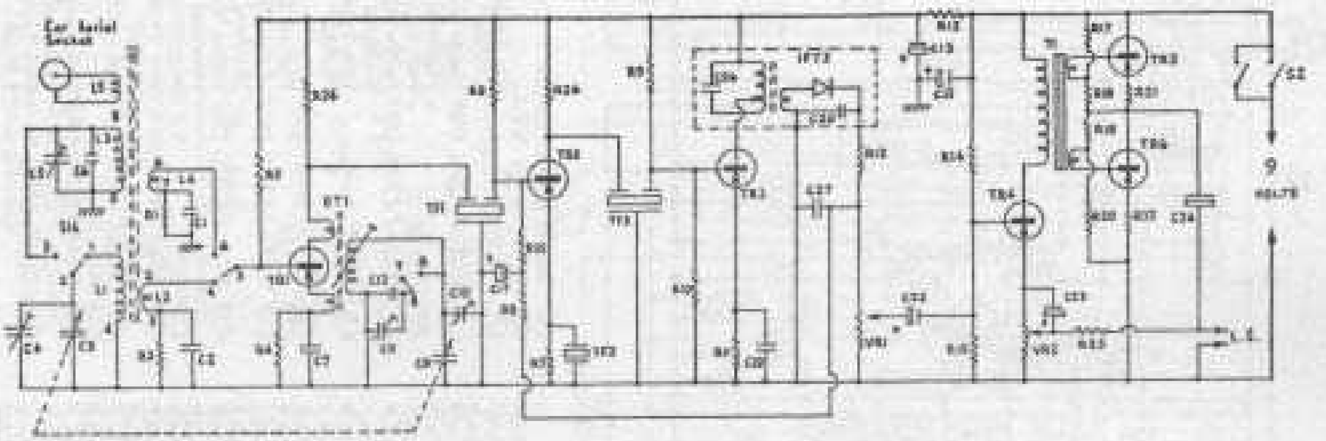


Fig. 64

R1 12 kΩ
R2 8·2 kΩ
R3 39 kΩ
R4 1·8 kΩ
R5 39 kΩ
R7 680 Ω
R8 3·9 kΩ
R9 22 kΩ
R10 4·7 kΩ
R11 1 kΩ

R12 560 Ω
R13 560 Ω
R14 33 kΩ
R15 10 kΩ
R17 2·7 kΩ
R18 100 Ω
R19 2·7 kΩ
R20 100 Ω
R21 3·3 Ω
R22 3·3 Ω

R23 3·3 kΩ
R24 3·9 kΩ
R25 3·9 kΩ
R26 2·7 kΩ
C1 0·05 μF
C2 0·05 μF
C3 Tuning gang
C4 Trimmer on C3

C5 Trimmer 3–30 pF
C6 100 pF
C7 0·01 μF
C9 Tuning gang
C10 Trimmer on C9
C11 Trimmer 3–30 pF

C12 330 pF
C13 100 μF
C17 8–10 μF
C19 0·05 μF
C20 in IFT3
C21 100 μF
C22 10–30 μF
C23 50 μF
C24 100 μF
C26 in IFT3

C27 0·01 μF
T1 TD3
OT1 JB285
IFT3 JB139
TF1 T002D
TF2 TF01D
TF3 T002D
Aerial JB128/1

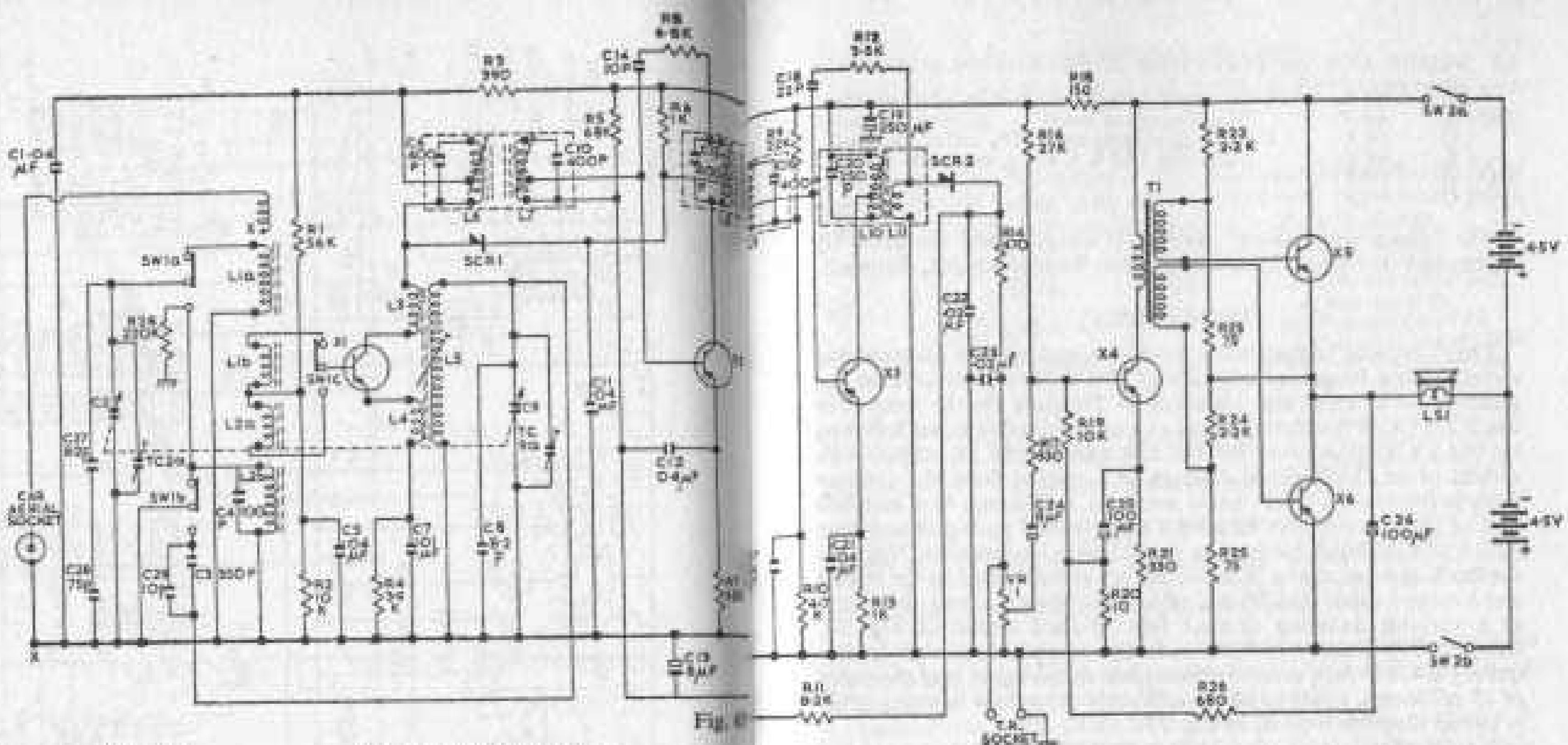


Fig. 4

Resistors

*R*1	56 *k* Ω	±10%	Erie Type 8AP
*R*2	10 *k* Ω	±10%	Erie Type 8AP
*R*3	390 Ω	±10%	Erie Type 8AP
*R*4	3·9 *k* Ω	±10%	Erie Type 8AP
*R*5	68 *k* Ω	±10%	Erie Type 8AP
*R*6	1 *k* Ω	±10%	Erie Type 8AP
*R*7	680 Ω	±10%	Erie Type 8AP
*R*8	6·8 *k* Ω	±10%	Erie Type 8AP
*R*9	22 *k* Ω	±10%	Erie Type 8AP
*R*10	4·7 *k* Ω	±10%	Erie Type 8AP
*R*11	8·2 *k* Ω	±10%	Erie Type 8AP
*R*12	3·3 *k* Ω	±10%	Erie Type 8AP
*R*13	1 *k* Ω	±10%	Erie Type 8AP
*R*14	470 Ω	±10%	Erie Type 8AP
*R*16	27 *k* Ω	±10%	Erie Type 8AP
*R*17	330 Ω	±10%	Erie Type 8AP
*R*18	150 Ω	±10%	Erie Type 8AP
*R*19	10 *k* Ω	±10%	Erie Type 8AP
*R*20	10 Ω	±10%	Erie Type 8AP
*R*21	330 Ω	±10%	Erie Type 8AP
*R*22	2·2 *k* Ω	±5%	Erie Type 8AP
*R*23	75 Ω	±5%	Erie Type 8AP
*R*24	2·2 *k* Ω	±5%	Erie Type 8AP
*R*25	75 Ω	±5%	Erie Type 8AP
*R*26	680 Ω	±10%	Erie Type 8AP
*R*28	220 *k* Ω	±20%	Erie Type 7AD

Capacitors

*C*1	0·04 μ*F* ±20% 150*V*	Hunts Min Moldseal
*C*2	Part of gang condenser	
*C*3	350 *pF* ±1%	S.R.C.
*C*4	100 *pF* ±2%	Erie Type N750BP
*C*5	0·04 μ*F* ±20% 150*V*	Hunts Min Moldseal
*C*6	400 *pF*	Part of *L*6
*C*7	0·01 μ*F* ±20% 150*V*	Hunts Min Moldseal
*C*8	8·2 *pF* ±10%	Erie Type P100BP
*C*9	Part of gang condenser	
*C*10	400 *pF*	Part of *L*7
*C*11	0·04 μ*F* ±20% 150*V*	Hunts Min Moldseal
*C*12	0·04 μ*F* ±20% 150*V*	Hunts Min Moldseal
*C*13	8 μ*F*	6 *V* Electrolytic
*C*14	10 *pF* ±5%	Erie Type P100BP
*C*15	400 *pF*	Part of *L*8
*C*16	400 *pF*	Part of *L*9
*C*17	0·04 μ*F* ±20% 150*V*	Hunts Min Moldseal
*C*18	22 *pF* ±5%	Erie Type NP0BP
*C*19	250 μ*F*	12 *V* Electrolytic
*C*20	250 *pF*	Part of *L*10
*C*21	0·04 μ*F* ±20% 150*V*	Hunts Min Moldseal
*C*22	0·02 μ*F* ±20% 150*V*	Hunts Min Moldseal
*C*23	0·02 μ*F* ±20% 150*V*	Hunts Min Moldseal
*C*24	8 μ*F*	6 *V* Electrolytic
*C*25	100 μ*F*	12 *V* Electrolytic
*C*26	100 μ*F*	12 *V* Electrolytic
*C*27	8·2 *pF* ±10%	Erie Type P100BP
*C*28	75 *pF* ±10%	Erie Type N750BD
*C*29	10 *pF* ±10%	Suflex Type HS10/D

Transistors

*X*1	Transistor OC44	(Mullard) Yellow
*X*2	Transistor OC45	(Mullard) Orange
*X*3	Transistor OC45	(Mullard) Blue
*X*4	Transistor OC81D	(Mullard)
*X*5	Transistor OC81	(Mullard)*
*X*6	Transistor OC81	(Mullard)*

*Matched pair

*TC*2*a* Trimmer condenser Part of gang

*TC*9*a* Trimmer condenser Part of gang

Semi-Conductors

*SCR*1 Diode OA79 (Mullard)
*SCR*2 Diode OA70 (Mullard)

*T*1 Transformer (printed circuit mounting)

Coils

*L*1, *L*2 } Ferrite rod aerial assembly
*L*3, *L*4, *L*5 } Oscillator coil
*L*6, *L*7 } Double-tuned I.F.T.
*L*8, *L*9 } Double-tuned I.F.T.
*L*10, *L*11 } Single-tuned I.F.T.

Miscellaneous

*LS*1 Loudspeaker 25 Ω imp.
*VR*1 Potentiometer 5 *k* Ω semi-log
*SW*1 Switch 3 pole 2-way wave/change
*SW*2 On/Off switch. Part of *VR*1

TR5	E	4·3 *V*
	B	4·4 *V*
	C	8·6 *V*
TR5	E	0·0 *V*
	B	0·1 *V*
	C	4·3 *V*

3. No signal in/put, switched to m.w. at low frequency end of travel.
4. All measurements are ±10% except for those concerning TRs 4, 5, and 6, which are ±20%.

The "Good Companion" receiver is designed and marketed by Electronics (Croydon) Ltd., 266 London Road, Croydon, Surrey.

THE "CONTESSA"

The "Contessa" incorporates a conventional modern six-transistor circuit with a frequency coverage of 530 *kc/s* to 1620 *kc/s* on the medium-wave band, and 160 *kc/s* to 270 *kc/s* on the long-wave band. An OC44 transistor is used as a self-oscillating mixer followed by two OC45 transistors for the first and second i.f. stages, with output to an OA70 diode detector. A.f. output from the detector stage is fed to an OC81D audio amplifier and thence to a matched pair of OC81 transistors forming a single-ended push-pull amplifier with transformerless connection to a 25-ohm loudspeaker. Negative feedback and automatic gain control are incorporated in the circuit and a second diode (OA79) is used to assist the a.g.c. and also to act as a variable damping element (see Mullard circuit of Fig. 57, Chapter VI). Battery is 9 volts, centre-tapped. Intermediate frequency is 470 *kc/s*. Current consumption on no signal is of the order of 15 milliamps, rising to 25–30 milliamps at average listening level. A circuit diagram is given in Fig. 65.

A particular feature of this kit is that all components used are specifically designed for printed circuit assembly, making for very easy assembly. Performance is of the highest order and alignment is seldom a particular problem using double-tuned i.f. transformers for the first and second i.f. stages.

The "Contessa" is marketed in kit form by Radio Clearances Ltd., 27 Tottenham Court Road, London, W.1.

THE "SKYROVER"

The "Skyrover" is a seven-transistor six-waveband receiver designed to cover 520–1670 *kc/s* in the medium-wave band; 31–94 metres in the short-wave band; and also the 25-metre, 19-metre, 16-metre, and 13-metre short-wave bands. A circuit diagram is given in Fig. 66, the transistor line-up being AF116 oscillator; AF115 mixer, OC81D audio-amplifier and a matched pair of OC81 transistor for Class B push-pull output via an output transformer to a 35-ohm 5 in. diameter loudspeaker. Power output is 500 milliwatts. Battery supply is 4·5 volts, with a current consumption of 20 milliamps at no signal, rising to 45 milliamps at 50 milliwatt output and 120 milliamps at 500 milliwatts output. An OA90 diode

is used as a detector and a second OA79 diode for automatic gain control damping.

Alignment Data

R.f. alignment: Set cursor to gang max. marker (left-hand end of scale) with the tuning gang set for maximum capacitance. Inject signal at telescopic antenna lead through a 20 *pF* capacitor.

Range	*Frequency*	*Cursor Position*	*Adjust*
BC	600 *kc/s*	Pad	BC Osc. coil (*L6–8*) and antenna coil (*L3*)
	1500 *kc/s*	Trim	BC Osc. trimmer (*C42*) and antenna trimmer (*C5*)
SW	3·5 Mc/s	Pad	SW Osc. coil (*L9–10*) and antenna coil (*L2*)
	9 Mc/s	Trim	SW Osc. trimmer (*C36*) and antenna trimmer (*C2*)
BS1 (25 m)	11·6 Mc/s	Calibration pip	BS1 Osc. trimmer (*C46*) and antenna trimmer (*C8*)
BS2 (19 m)	15·1 Mc/s	Calibration pip	BS2 Osc. trimmer (*C48*) and antenna trimmer (*C9*)
BS3 (16 m)	17·7 Mc/s	Calibration pip	BS3 Osc. trimmer (*C49*) and antenna trimmer (*C10*)
BS4 (13 m)	*21·2 Mc/s	Calibration pip	BS4 Osc. trimmer (*C50*) and antenna trimmer (*C11*)

*Note: Oscillator tuned below carrier frequency on this band.

Output meter: Connect a 35-ohm output meter in place of internal loudspeaker, or a 20,000-ohm voltmeter, set to a low a.c. voltage range, across the internal loudspeaker terminals.

Audio check: Inject a 1 *kc/s* signal across the volume control with the control set for maximum volume. An input of 10 *mV* should give an output of 50 *mW*, or 1·3 volts measures on the 10-volt range of a Model 8 Avometer (see Service Note 2).

I.f. alignment: Switch receiver to BC with the volume control set for maximum volume and the tuning gang capacitor set for minimum capacitance. Inject a 470 *kc/s* signal, 30 per cent amplitude modulated, through a 0·1 *μF* blocking capacitor connected across the antenna section (*C6*) of the tuning gang capacitor.

Peak IFT3, IFT3, IFT1 in that order for maximum output.

Service Notes

Fault-finding may be carried out in the usual way, but the following points should be particularly noted:

(1) Apart from total current consumption, no other current measurements should be attempted; check current by calculation from measured voltage-drop across resistors.

(2) When a signal generator is used for circuit checking, use the direct output and inject via a d.c. blocking capacitor. A 0·1 *μF* capacitor should be used when checking the i.f. circuits and the signal injected at the aerial section of the gang or VT2 or VT3 base

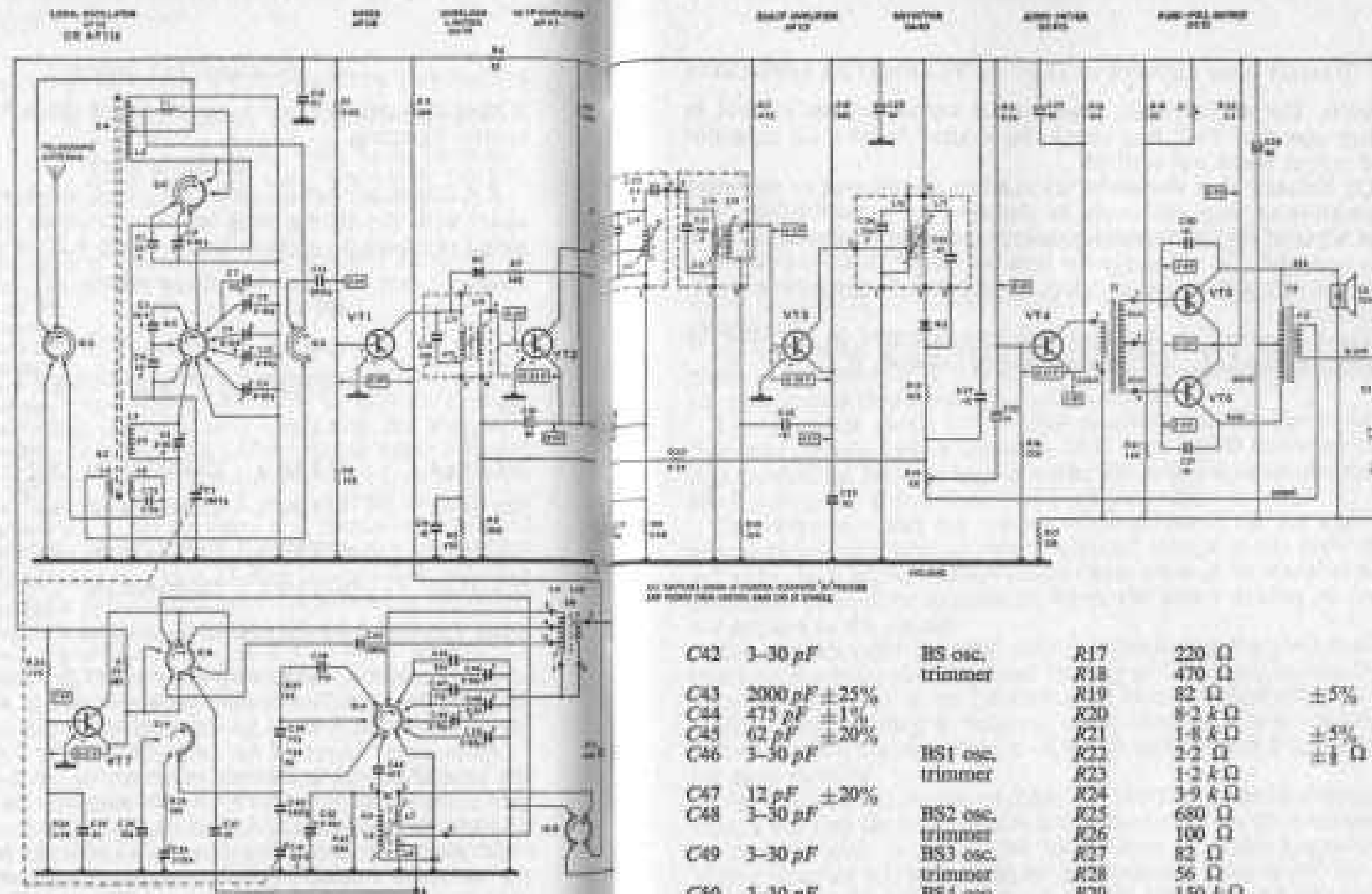


Fig. 66

Capacitors

C1	20 pF ±10%		
C2*	3–40 pF		SW antenna trimmer
C3	39·5 pF ±2·5%		
C4	60 pF ±2·5%		
C5*	3–40 pF		BC antenna trimmer
C6†	388·5 pF		Part tuning gang
C7	110 pF ±10%		125 V wkg.
C8*	4–80 pF		BS1 antenna
C9*	8–120 pF		BS2 antenna
C10*	4–80 pF		BS3 antenna
C11*	4–80 pF		BS4 antenna
C12	0·1 μF +50–20%		
C13	3000 pF ±20%		
C14	700 pF ±5%		30 V wkg.
C15	0·01 μF +50–20%		
C16	80 μF	electrolytic	6·4 V wkg.
C17	80 μF	electrolytic	6·4 V wkg.
C18	0·01 μF ±20%		
C19	700 pF ±5%		30 V wkg.
C20	8·2 pF ±½ pF		
C21	700 pF ±5%		30 V wkg.
C22	0·01 μF ±20%		
C23	0·02 μF +50–20%		
C24	700 pF ±5%		30 V wkg.
C25	80 μF	electrolytic	6·4 V wkg.
C26	0·01 μF +80–20%		....
C27	0·01 μF ±20%		
C28	10 μF	electrolytic	16 V wkg.
C29	80 μF	electrolytic	6·4 V wkg.
C30	0·01 μF +80–20%		
C31	0·01 μF +80–20%		
C32	80 μF	electrolytic	6·4 V wkg.
C33	470 pF ±20%		
C34	0·01 μF +50–20%		
C35	30 pF ±10%		
C36	3–30 pF		SW osc. trimmer
C37	0·01 μF +50–20%		
C38	34 pF ±2·5%		
C39	42 pF ±2·5%		
C40	2400 pF ±2·5%		
C41†	323·8 pF		Part tuning gang
C42	3–30 pF		BS osc. trimmer
C43	2000 pF ±25%		
C44	475 pF ±1%		
C45	62 pF ±20%		
C46	3–30 pF		BS1 osc. trimmer
C47	12 pF ±20%		
C48	3–30 pF		BS2 osc. trimmer
C49	3–30 pF		BS3 osc. trimmer
C50	3–30 pF		BS4 osc. trimmer
C51	0·047 μF ±20%		400 V wkg.

* 6-way trimmer bank: Part No. Z90856.

† Tuning gang: Part No. Y90822.

Resistors

All ±10%, ¼ W unless otherwise stated.

R1	6·8 kΩ	
R2	33 kΩ	
R3	680 Ω	
R4	82 Ω	
R5	470 Ω	
R6	56 kΩ	
R7	680 Ω	
R8	680 Ω	
R9	2·2 kΩ	
R10	22 kΩ	
R11	4·7 kΩ	
R12	680 Ω	
R13	470 Ω	
R14	5 kΩ	Log. Pot.
R15	8·2 kΩ	
R16	22 kΩ	
R17	220 Ω	
R18	470 Ω	
R19	82 Ω	±5%
R20	8·2 kΩ	
R21	1·8 kΩ	±5%
R22	2·2 Ω	±¼ Ω
R23	1·2 kΩ	
R24	3·9 kΩ	
R25	680 Ω	
R26	100 Ω	
R27	82 Ω	
R28	56 Ω	
R29	150 kΩ	

Inductors

L1	Band spread antenna shunt coil	Y90860
L2	SW antenna coil	Ferrite rod assy. Y90866
L3	BC antenna coil	(Ferrite rod assy.)
L4	BC base coil	(Ferrite rod assy.)
L5	Telescopic antenna coupling coil	(Ferrite rod assy.)
L6–8	BC osc. coil	Y90858
L9–10	SW osc. coil	Y90839
L11–12	IFT1	X90894
L13	IFT2 (pri.)	X90895
L14–15	IFT2 (sec.)	X90896
L16–17	IFT3	X90897
T1	Driver transformer	Y90746
T2	Output transformer	Y90854

Miscellaneous

Volume control (see R14)	Y90815/1
On/Off switch (S2)	(Y90815/1)
Wavechange switch (S1A-D)	X90673
Telescopic antenna	N90852
Thermistor X1	YA1040

circuits. For audio check, inject signal across volume control in which case the "live" lead should be blocked by an 8 μF capacitor and output meter not earthed.

(3) Extreme care should be taken when unsoldering or soldering transistors as they can easily be damaged by excessive heat. The lead wires of the replacement transistor must not be shorter than the one removed. Do not apply the iron for longer than necessary and grip the wire with a pair of pliers, to reduce heat conduction to the transistor.

The "Skyrover" is designed and manufactured in kit form by Lasky's Radio Ltd., 207 Edgware Road, London, W.2.

CHAPTER VIII

TESTING AND ALIGNMENT TECHNIQUES

BASIC equipment for the checking or testing of transistor circuits comprises:

(i) A universal meter capable of reading voltages up to 15 volts, ohms and current up to 500 milliamps; or, separately, a voltmeter, ohmmeter, and (less essential) a milliammeter.

The universal meter for voltage measurement (or the separate voltmeter) should have a resistance of at least 20,000 ohms per volts and, preferably, have a range of scales for accurate measurement of small voltages, e.g. 0–5, 0–10 and 0–15 (or 0–25).

The universal meter for resistance measurement (or the separate ohmmeter) should have an output terminal voltage of not more than 1·5 volts, as a higher voltage could cause damage to transistors or miniature electrolytic capacitors when the meter probes or leads are applied to the circuit.

The milliammeter is useful only for measuring the total current drain on the battery, the normal reading of which may range from about 10 milliamps up to 100 milliamps or more, depending on the circuit design. Failing a range of scales (such as is provided by a universal meter), a single range of 0–100 milliamps will be suitable for most circuits.

(ii) A signal generator capable of producing audio-frequency signals and also the intermediate and radio-frequencies it is necessary to explore, with provision for modulation at audio-frequencies. Where separate a.f. and r.f. signal generators are employed the a.f. generator should have an impedance of the order of 600 ohms, which can be fed directly into the top of the volume control of the receiver through a 0·1 μF capacitor; or to the base of a transistor through a 10-kilohm resistor and a 1-μF isolating capacitor.

The r.f. generator should be of low impedance (of the order of 60 ohms output impedance) and, in general, can be fed into the base of the i.f. transistor or mixer transistor via a 0·5-μF capacitor.

ALIGNMENT

Where no signal generator is available, alignment must be carried out using broadcast stations as the source of signals. If an output meter with an impedance of around 25 ohms is available this should be connected in place of the loudspeaker; or alternatively a high-resistance voltmeter capable of reading 0–2 or 0–5 volts a.c. can be connected across the speech coil to give a visual indication of output signal strength. If neither type of meter is available, the output signal strength must be judged aurally.

(1) Aerial and oscillator trimmers should be set to approximately the mid-point of their travel and the tuning control then set to the correct position for a local station, preferably in the middle of the m.w. band. Turn volume control to a maximum. Adjust the oscillator core to bring the station to the correct point on the tuning scale.

(2) Turn the receiver so that it is oriented in the direction which gives *minimum* signal strength. Adjust i.f. transformer cores for maximum output. (Note: if necessary, reduce the volume via the volume control to a minimum audible signal before adjustment as it is easier to judge an increase in strength of a weak signal aurally than an increase in strength of a strong signal. A meter will give a more positive indication regardless of the original signal strength, but at high signal levels the true output may be modified by the effect of a.g.c. action).

(3) Tune to the high-frequency end of the m.w. band, e.g. Radio Luxembourg on 208 metres, and adjust the oscillator trimmed to bring the station into tune consistent with the scale calibration. If this proves difficult or impossible, try adjusting first with the aerial trimmer followed by the oscillator trimmer.

(4) Tune to the low-frequency end of the m.w. band, e.g. to a station around 500 metres such as the Third Programme (464 metres). It should be possible to adjust for maximum signal by sliding the aerial coil along the ferrite rod. If not, it may be necessary to adjust the oscillator trimmer to get agreement with the scale calibration.

(5) Steps 3 and 4 must then be repeated until an optimum adjustment is realized where adjustment of one end has no effect on the other.

(6) Tuning on the long-wave band is not likely to be critical and it is usually only necessary to set the tuning condenser to the calibrated position and adjust the position of the long-wave aerial coil on the ferrite rod to bring in the station at maximum strength (or adjust the long-wave aerial trimmer, if fitted).

The technique may vary slightly with different designs of receivers and where specific instructions are given with circuits these should be followed. Alignment instructions for the "Contessa" circuit, for example, using broadcast stations instead of a signal generator are as follows (refer to Fig. 65 for circuit component identification):

(1) Tune to a strong local station by means of the gang condenser. Turn volume control to a maximum.

(2) Orientate the printed board and aerial for minimum audible output.

(3) Adjust *L10* for maximum output.

(4) Adjust *L8*, *L9* for maximum output.

(5) Adjust *L6*, *L7* for maximum output.

(6) Tune by means of the gang condenser to a station whose frequency is in the region 540–650 *kc/s*. Orientate as above for minimum audible output. (This is to prevent the a.g.c. action masking the effects of adjustment.) Adjust *L5* for maximum output.

(7) Tune to a station in the region of 1300–1640 *kc/s*. Re-orientate if necessary. Adjust *TC9a* for maximum output.

(8) Repeat operations 6 and 7 to ensure correct coverage.

(9) Hold tuning dial and set calibration corresponding to wavelength of station selected for operation 6. Adjust *L1a* for maximum output.

(10) Hold tuning dial and set calibration corresponding to wavelength of station selected for operation 7. Adjust *TC2a* for maximum output.

(11) Repeat operations 9 and 10 to ensure maximum tracking.

(12) Switch to long-wave band and tune to a local station. Adjust *L2b* for maximum output.

Where a signal generator is available, the i.f. stages and signal circuit are aligned separately, in both cases using an output power meter or a.c. voltmeter connected across the speech coil (speaker terminals). Before attempting alignment the volume control should be set to a minimum in order to use the lowest signal from the signal generator consistent with a reasonable output, e.g. 50 milliwatts or 1 volt across the speech coil. This avoids a.g.c. action.

For aligning the i.f. stages the signal is set at the i.f. (normally 470 *kc/s*) and usually applied to the base two i.f. transistors and mixer, in turn, working backwards (i.e. starting with the second i.f. transistor). The corresponding i.f. transformer cores are adjusted to maximum output, in turn. The signal is injected using a 0·5 μF capacitor and an 820-ohm resistor in series with the generator output lead and never applied directly. Alternatively the whole of the alignment may be carried out with a radiating loop output from the signal generator, as described for aligning the signal circuit (see later).

Having peaked the i.f. transformers, the circuit is switched to medium wave, the generator set to a typical low frequency (e.g. 540 *kc/s*) and the oscillator trimmer adjusted for maximum output.

The tuning capacitor is then set to minimum capacity and the signal generator to a high frequency (typically 1640 *kc/s*) and the second (mixer) gang trimmer adjusted for maximum capacity. These two stages are then repeated, as necessary, for optimum results.

For alignment of the signal circuits no direct connection is made but the output or live terminal of the signal generator is connected to a loop of wire consisting of two or three turns approximately 7 to 9 in. in diameter with a series resistor in circuit of 430 or 390 ohms. The loop should be situated about 24 in. from the receiver ferrite rod (Fig. 67). Normal procedure is then:

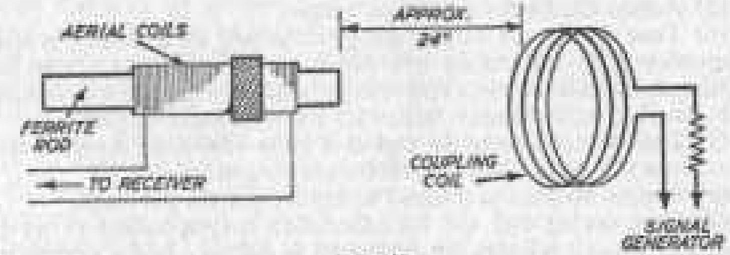


Fig. 67

(1) Set signal generator to a low m.w. frequency (e.g. 600 *kc/s*) and tune gang condenser to the corresponding position on the scale. Adjust aerial coil position or aerial trimmed for maximum output.

(2) Repeat with the signal generator set to a high m.w. frequency (e.g. 1400 *kc/s* and adjust gang condenser trimmer for maximum output.

(3) Repeat operations 1 and 2 as necessary.

(4) Switch to long wave, set generator to a typical frequency in about the middle of the l.w. band (e.g. 220 *kc/s*) and adjust the long-wave aerial coil position or trimmed for maximum output.

As a further example of low optimum alignment requirements may be specific to a circuit design recommended alignment procedure for the "Good Companion" receiver is as follows (see Fig. 63 for circuit component details):

(1) Equipment required:
Output meter (connect across speaker).
Signal generator.
Radiating loop, made from ordinary plastic-covered wire 6 ft. long. Wind into a 6 in. loop, 4 turns, connect a series resistor of 390 ohms. Connect the other end of the series resistor to the live terminal of the signal generator. Situate the loop 2 ft. from the ferrite rod.
(2) Set radio to m.w., gang closed, volume fully up.
(3) Set signal generator to 470 *kc/s*.
(4) Adjust cores of IFT1, 2, 3 for maximum output, repeat until no further improvement can be obtained.
(5) Set as in 2. Adjust signal generator for an output at 540 *kc/s*.
(6) Adjust the core of OT1 for maximum output.
(7) Set *L*1 for maximum output.
(8) Set tuning gang for minimum capacity.
(9) Set signal generator for 1640 *kc/s*.
(10) Adjust *C*10 for maximum output.
(11) Adjust *C*4 for maximum output.
(12) Repeat 5–11 until no further improvement can be made.
(13) Switch to l.w.

(14) With gang closed feed in a signal at 160 *kc/s*.
(15) Adjust *C*11 for maximum output.
(16) Adjust *L*3 for maximum output.
(17) Set gang fully open, feed in signal at 280 *kc/s*.
(18) Adjust *C*5 for maximum output.
(19) Repeat 14–18 until no further improvement can be obtained.

Checking Circuits

Normally the most satisfactory check for a newly assembled circuit is to make absolutely sure that all components have been correctly assembled and connected, paying particular attention to the positioning of the leads of transistors, and also checking the battery is connected with the correct polarity. A careful visual check should also be made of the printed circuit to see that it has not been damaged and that excess or loose solder is not bridging any of the conductors. These checks should be made before switching on to try the circuit for the first time. Unless there is a wrong connection, or a component is faulty or has been damaged in assembly, a "commercial" circuit will invariably work.

The current drain of the receiver can be checked by inserting a 0–100 milliammeter in one of the battery leads, taking care to preserve the correct polarity (Fig. 68). With the set switched on under quiescent or no-signal condition—i.e. not tuned to a station—

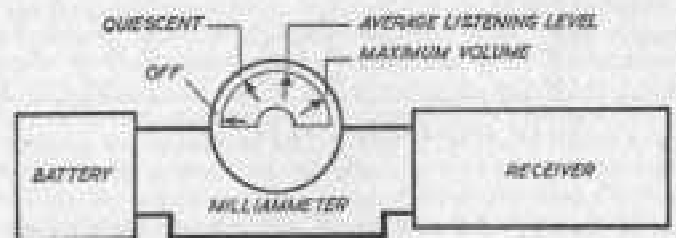


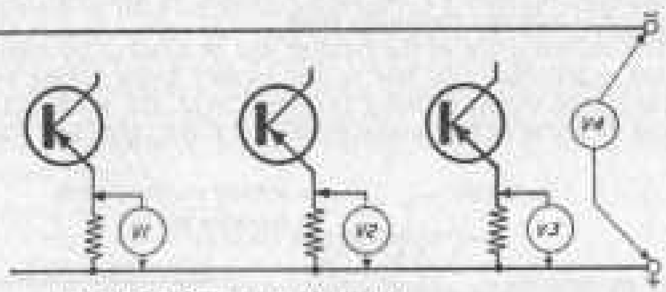
Fig. 68

the current drain should agree more or less with the quoted figure for the circuit design (see Chapter VII). Lacking such data, a figure of about 10 to 20 milliamps is fairly typical for a six-transistor superhet. No exact figure can be given since the current drain will vary slightly with ambient temperature.

Leaving the milliammeter connected and tuning to a station the current drain will be found to rise, reaching a maximum with maximum position of the volume control. The figure for average listening level can be checked against that given for the circuit, although this reading has little meaning. It is a function of the circuit design—some circuits having a higher current drain than others (see Chapter II)—and of the setting of the volume control. The no-signal current drain is significant only if it is excessively high —indicating the presence of a short-circuit inside the receiver; or excessively low—indicating the presence of a high-resistance fault in the receiver circuit.

A similar check to the above can be made with an ohmmeter, disconnecting the battery and simply using the meter to measure the total d.c. resistance of the circuit when applied to the battery leads. If this reading is noted for a new circuit it can be compared with later readings when fault finding, when a marked drop in resistance would indicate a short and a marked increase a high-resistance internal fault.

The most useful d.c. check which can be made on the complete circuit is to use a voltmeter to measure the d.c. voltage across the emitter resistor of each transistor in turn. This should be within 20 per cent either way of voltage figures for the circuit. Any variation in voltage outside this limit will indicate a fault at that particular



VOLTAGE CHECKS AT V1, V2, V3, V4

Fig. 69

stage. In the case of a new circuit which works satisfactorily but for which no check voltages are given, it may be useful to measure the above d.c. voltages and keep them as a record and guide for future servicing requirements. Note, however, that the polarity of transistor receivers are not necessarily the same (most are positive earth or "common," but some are negative earth).

Another most useful voltage check is the voltage across the battery terminals with the set switched on. This "load" voltage will indicate the condition of the battery. If less than about five-sixths of the nominal voltage of the battery, the battery can be reckoned as needing replacement. In making a battery voltage check it is important that this be done under load and after the receiver has been switched on for a minute or so at least. A nearly flat battery may show a high voltage reading under load immediately after it is

switched on, but the voltage will then fall quite markedly after a while. In the case of a centre-tapped battery, both halves of the battery should be checked for "load" voltage separately.

The d.c. voltage check across the emitter resistor of each transistor (or equivalent check point as specified on the circuit diagram) provides an almost complete check on the d.c. conditions and will show up such faults as component failures or open-circuit joints, and also the stage at which the fault is present by the wrong voltage reading at that stage. The fault can then be expected to be confined to components in this stage, which can be checked individually if the fault is not apparent (e.g. a broken printed circuit, short-circuit between lands, dry-soldered joint, etc.). If individual resistors need checking, it is best to isolate the component(s) for test by unsoldering the connection at one end. If this is not readily possible or desirable—e.g. there may be a number of components to test in the stage—the stage transistor (and the stage) can be isolated by unsoldering the base lead of the transistor. A heat sink should be used in order to avoid heat damage to the transistor and *only* the base lead should be removed from the circuit.

Capacitor faults will not show up on a d.c. check, unless the capacitor is short-circuited. In this case the fault will disappear (as far as d.c. voltage measurements are concerned) as soon as the faulty capacitor is disconnected. By-pass capacitors can be checked for open-circuit faults by temporarily shunting with a 0·5 μF capacitor. If this produces an increase in volume with the set switched on, the original capacitor is either faulty or of wrong value. The time-honoured method of "fault-finding" with valve radios by shunting various sections and components on a "trial-and-error" basis with a capacitor should *not*, however, be applied to transistor circuits. This can cause permanent damage to transistors.

Normally the transistors are unlikely to be found faulty in a non-working circuit, unless they have been subject to a severe overload caused by, for example, (i) changing components with the receiver switched on; (ii) connecting the battery the wrong way round; (iii) injecting a high voltage accidentally into the circuit. A transistor fault may, however, occur in a new circuit owing to heat damage during mounting. If a transistor fault occurs after a period of use, and cannot be traced to the above accidental causes, all the adjacent components are also suspect and should be checked before replacing the transistor with a new one.

The a.c. working of the receiver can only be checked satisfactorily by signal injection. Standard procedure is to feed an audio-frequency into the audio section of the receiver, starting from the output stage and working backwards towards the detector. If all the audio stages work satisfactorily the i.f. stages are similarly tested with the signal generator set to the intermediate frequency modulated with an audio-frequency. Finally the radio-frequency stages can be tested

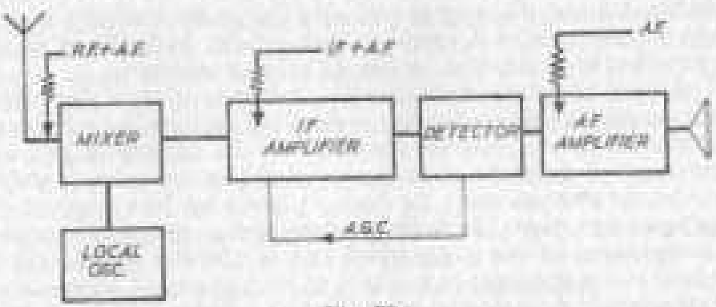


Fig. 70

by injecting a radio-frequency signal modulated with an audio-frequency.

In other words, to test the a.c. working of the complete receiver an appropriate signal is injected at each stage in turn, starting with the last stage and working back to the front end. The faulty stage will show up as the first one which does not produce any increase in the audio-frequency output, or yields no final output at all. The necessary signal is usually best injected into the base of the appropriate transistor (i.e. that particular stage transistor), via a suitable resistor in series to ensure current drive. A suitable value of resistor is 10 kilohms. Having found the faulty stage it is then necessary to check the components involved, in turn, in order to determine the source of the fault, e.g. it could be nothing more than a faulty coupling capacitor.

The checking of circuits in this manner depends upon an ability to "read" the printed circuit in terms of the actual physical connections of the components, determined by studying the theoretical or circuit diagram in conjunction with the physical assembly. Initially this may prove a somewhat tedious process, particularly on miniature receivers due to the crowded assembly, but is basically a straightforward technique which can readily be mastered with practice. A haphazard approach to fault-finding is seldom productive, and may in fact even lead to additional damage. As a further guide, some typical faults, causes and cures are described under separate headings.

Receiver is "dead" when switched on. In the case of a newly completed receiver this could be due to incorrect connections, so a check of the circuit should be made. In the case of a receiver which has previously been working satisfactorily, likely causes are:

(i) Battery completely dead—check "on load" voltage.
(ii) Open circuit joint.
(iii) Component failure.

In the case of (ii) or (iii) the fault may be d.c. or a.c., and the appropriate stage and faulty component can be isolated by the standard methods of testing previously described.

There is also the possibility that the on-off switch may be faulty.

Receiver operates intermittently. The usual cause is a dry joint or an intermittent connection. It is often difficult to reproduce the fault exactly when required for testing although if it can be established how it can be initiated—e.g. by pressing on a certain point of the set or panel—the source can usually be traced without much further trouble. Other possible causes are faulty battery connections or even a battery with an intermittent internal disconnection; or a faulty on-off switch.

Receiver fades after a short period of reception. Almost invariably this is due to a low battery. After being on load for a short period the battery voltage drops right off. The only cure is to change the battery.

Note: a sign of a failing battery is distortion of the signal received. If distortion is present with a new battery, however, this is due to circuit limitations (see pages 29 and 100). Distortion can also result from faulty alignment.

Low sensitivity. If this occurs with a new set of established design, the most likely cause is incorrect alignment of the i.f. stages, or a fault on the aerial or oscillator tuning circuits. The latter may also occur in use, such as a broken ferrite rod, poor aerial connections, an aerial coil which has become displaced on the rod, bent vanes on a tuning capacitor. If the loss of sensitivity is restricted to a part of the tuning range, the aerial circuit and the ganged condenser are immediately suspect. If these check out as all right, the self-oscillating mixer stage should be checked.

In most circuits the oscillator provides part of the working bias for the r.f. transistor. The voltage measurement across the emitter resistor of the mixer transistor should be compared with the design figure with the receiver switched on normally and then with the oscillator coil damped by temporarily connecting a 1 μF capacitor across the oscillator tuned circuit. If the oscillator is working correctly there will be a difference between the two voltage readings. Note: When connecting *or* disconnecting a temporary component into the circuit for test purposes, *the receiver should always be switched off.* Failure to follow such a precaution can result in permanent damage to transistors.

Receiver tunes in one station only over whole range. The fault in this case is most likely to be in the self-oscillating mixer stage, which should be checked through.

Receiver howls or oscillates. This is caused by i.f. instability and is most likely to be due to a defective coupling capacitor, a defective neutralizing component on the transistor, or even a faulty i.f. transistor.

Receiver "growls" (low-frequency instability). This is a fault restricted to the audio stages and is most likely to be caused by a faulty audio decoupling capacitor.

High background noise level. This is usually due to a poor or faulty transistor, in which case it will often be associated with low gain. The cause is a high-leakage current in one (or more) transistor(s). This may be an initial fault of the transistor (i.e. a sub-standard component), or have been caused by heat damage to the transistor when soldering into the circuit. The only cure in such a case is to find and replace the faulty transistor.

Lack of volume. On a new circuit this is almost certainly due to incorrect alignment. For optimum results it is necessary to follow the alignment technique specified for a particular circuit as this may differ in detail with different circuit designs. Concentrating on improvement in gain when aligning, however, can lead to loss of other desirable characteristics, e.g. an increase in distortion and loss of response. Alignment must concentrate on establishing an optimum adjustment between *all* desired characteristics.

Lack of volume will also result from a poor transistor (see above), or low battery voltage. In the latter case loss of volume will be accompanied by increasing distortion.

Distortion. If the set has previously been working satisfactorily but distortion subsequently sets in, the cause is almost certainly a falling battery voltage. The battery voltage should be checked on load, and the battery replaced if the voltage has fallen below five-sixths of its nominal new voltage, i.e. a 9-volt battery should be replaced when its on load voltage fails below $5/6 \times 9 = 7{\cdot}5$ volts.

Distortion in a new set will probably be caused by a mismatch in gain, where the circuit employs a push-pull output. In other words the two transistors employed in the push-pull circuit are not a matched pair. In such a case both transistors will have to be replaced by a matched pair. Note that this also applies in the case where one of the output transistors develops a fault—i.e. both transistors would have to be replaced with a matched pair.

Circuit faults which can cause distortion include (i) a faulty audio-coupling capacitor and (ii) a fault in the automatic gain control producing overloading of the audio stages. In case (ii) the fault will show up on strong signals only.

Distortion can also be produced by a design fault, e.g. crossover distortion due to incorrect values of the bias resistors on the output stage. In this case the fault may be rectified by finding a more suitable value for one of the resistors by trial and error (see Chapter II).

Transistor faults. Transistor faults are relatively uncommon, but the more usual causes and effects are:

(i) Heat damage during assembly—which can lead to a high-leakage current, loss of gain, and a noisy receiver. In extreme cases the transistor may be destroyed and not work at all.

(ii) An open-circuited junction caused by a heavy overload, in which case the transistor will not work at all.

(iii) A short-circuited junction caused by a high-voltage surge. This is a fault which can readily be induced by working on a circuit with the current switched on, and in particular by removing or replacing components in the circuit with the current switched on.

A faulty transistor in any stage will normally lead to low sensitivity and gain. A faulty transistor in the i.f. stages will lead to howling. A faulty transistor in the audio stage will lead to distortion.

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