9

A.M. Receivers

9.1. Introduction

A radio transmitter transmits or radiates a modulated carrier voltage. This modulated carrier is picked up by the antenna of the radio receiver. This signal sò received is very weak. Hence generally this signal is first amplified in an R.F. (Radio Frequency) amplifier stage of the radio receiver. Further since the signal is accompanied by lots of unwanted signals (noise) at adjacent frequencies, it must be selected and the noise be rejected. Finally the R.F. carrier must be demodulated to get back the original modulating signal. Also since the detected signal (audio in the case of broadcast receiver) is usually weak, it has got to be amplified is one or more stages of audio amplifiers.

Thus the following are the main functions of a radio receiver :

(*i*) intercept the electromagnetic waves in the receiving antenna to produce the desired R.F. modulated carrier
(*ii*) select the desired signal and reject the unwanted signals
(*iii*) amplify the R.F. signal
(*iv*) detect the RF carrier to get back the original modulation frequency voltage
(*v*) amplify the modulation frequency voltage.

Thus a radio receiver is an electronic equipment which picks up the desired signal, rejects the unwanted signal, amplifies the desired signal, demodulates the carrier to get back the original modulation frequency signal.

9.2. Classification of Radio Receivers

Radio receivers are generally classified according to the type of traffic they are designed to handle. Accordingly they may be classified as :

(*i*) *A.M. (Amplitude Modulation) Broadcast Receivers.* These are meant for listening to broadcast of speech or music radiated from amplitude modulation broadcast transmitter operating on long wave, medium wave (broadcast band) or short wave bands.

(*ii*) *F.M. (Frequency Modulation) Boadcast Receivers.* These are used for receiving broadcast programmes from F.M. broadcast transmitters operating in VHF or in UHF bands.

(*iii*) *T.V. (Television) Receiver.* These receivers are used for receiving television broadcast in VHF or in UHF bands.

(*iv*) *Communication Receivers.* These are superheterodyne receivers used for reception of code (telegraph) and shortwave telephone signals and include circuit refinements such as I.F. beating oscillator for code reception, noise limiters or noise suppressors, band spread for fine tuning, crystal filter for high and adjustable selectivity, sensitivity control, volume expander, interchannel noise suppressor, tuning indicator etc. These communication receivers are, therefore, more costly and complicated and their operation involves some technical knowledge and skill as possessed by radio operators.

(*v*) *Code Receivers.* These are, in general, simple superheterodyne receivers with the addition of I.F. beating oscillator to produce audio beat note with I.F. signal. Other code receivers are meant for receiving code signals, *i.e.* radio telegraph signals and consist of an oscillating detector with amplifier stages.

(*vi*) *Radar Receivers.* These are receivers used for receiving Radar (Radio detection and ranging) signals.

9.3. Salient Feature of Broadcast Receivers

Broadcast receivers, both of amplitude modulation and frequency modulation types, are meant for use in home mostly for entertainment purpose. Accordingly these broadcast receivers must have the following features :

(*a*) *Simplicity of Operation.* These receivers are required to be handled by listeners who have little technical knowledge and hence simplicity of operation is essential. Simplest broadcast receiver, therefore has only three controls namely (*i*) band switch for selecting the band of frequencies, (*ii*) tuning control for tuning to the desired station and (*iii*) volume control for adjusting the volume or level of the reproduced sound programme. In more sophisticated broadcast receivers, in addition to the above three basic controls, there are also provided the tone control, tuning indicator and sometimes band spread control.

(*b*) *Good Fidelity.* Since these broadcast receivers are primarily designed for entertainment purpose these should have good electrical fidelity, *i.e.* a reasonably large and uniform frequency response over almost the entire audio frequency band. In A.M. broadcast, the maximum audio modulating frequency is 5 kHz. Hence a receiver with good fidelity must reproduce all these frequency terms. In F.M. broadcast, on the other hand, maximum modulation frequency allowed is 15 kHz. Hence F.M. broadcast receivers are designed to reproduce faithfully the entire audio frequency band upto 15 kHz. F.M. broadcast thus permits better fidelity.

(*c*) *Good Selectivity.* By selectivity of a radio receiver is meant its ability to discriminate the desired signal from unwanted signal at other frequencies, notably the side bands of adjacent channels in the frequency spectrum.

(*d*) *Average Sensitivity.* Broadcast receivers should have reasonably high sensitivity so that it may have good response to the desired signal of medium and low strengths but should not have excessively high sensitivity otherwise it will pick up all the undesired electrical disturbances produced in the vicinity.

(*e*) *Adaptability to different types of aerials.* A broadcast receiver should be designed to operate satisfactorily with any type of aerial.

9.4. Basic Functions A.M. Receivers

A radio receiver in its most elementary form performs the following four essential functions :

(*i*) *Reception.* This consists in receiving or picking up energy from the various electromagnetic waves radiated by the radio transmitter. This function is performed by the receiving antenna. When electromagnetic waves strike the antenna, a voltage of the wave frequency is induced in the antenna.

(*ii*) *Selection.* This consists in selecting or responding to desired radio wave with the exclusion of all others. Thus at any instant of time, a large number of electromagnetic waveform of different radio stations at different frequencies are intercepted by the antenna and each of these induces a voltage in the antenna. The selector circuit or tuner in the form of a parallel tuned circuit responds to the desired signal only and rejects all other signals.

(*iii*) *Detection or Demodulation.* The desired signal in the form of a modulated carrier voltage is detected in a detector circuit to recover the original modulating voltage.

(*iv*) *Reproduction.* This consists in feeding the detected signal to a loudspeaker or headphones to reproduce the sound waves giving the original programme.

9.5. Straight Receivers

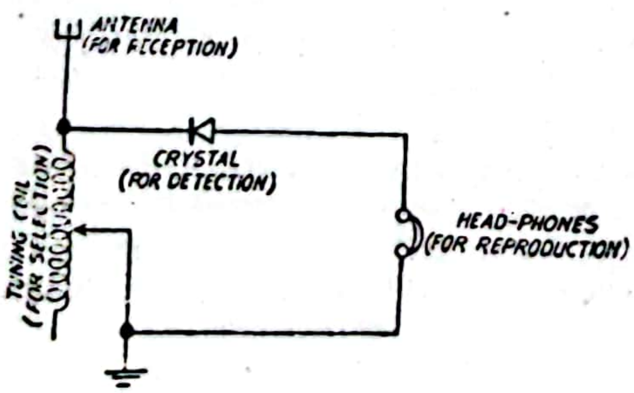


Fig. 9.1. Schematic diagram of simple crystal receiver.

Based on the technique of operation, radio receivers may be put into two categories (*i*) Straight receivers, *i.e.* receivers which operate in straight forward manner without frequency conversion, (*ii*) Super-heterodyne receivers in which incoming R.F. signal is converted to standard Intermediate Frequency (I.F.) before detection takes place. This is done with the help of a frequency converter. Straight receivers were extensively used earlier but are not used these days. However, a study of straight receiver is included here in brief as the same is useful in understanding the principle of operation of receivers.

Simple Crystal Receiver. Fig. 9.1 gives the schematic diagram of a simple crystal receiver using only one crystal diode as the detector. The circuit performs all the four basic functions mentioned in section 9.4.

This simple receiver circuit of Fig. 9.1 has drawbacks of poor sensitivity and poor selectivity. These drawbacks may be overcome by first amplifying the signal is one or more tuned R.F. amplifier stages tuned to the signal frequency and then feeding the signal to the detector. Such receivers are referred to as Tuned Radio Frequency (abbreviated as TRF) receivers.

TRF Receivers. As mentioned above a TRF receiver is a straight receiver in which the incoming signal is first amplified in one or more tuned R.F. amplifier stage. This increases the magnitude of the signal and hence improves the sensitivity of the receiver. The amplifier signal is then fed to the detector to reobtain the original modulation frequency signal. The modulation frequency is further amplified in one or more stages of audio frequency amplifiers before being fed to the loudspeaker. Fig. 9.2 gives the block diagram of a typical TRF receiver.

TRF receiver with one or two tuned R.F. amplifier stages has enough sensitivity and selectivity but if too many such stages are used, the circuit becomes too selective and may lower the fidelity of the receiver. Another limitation of TRF receiver is that the selectivity of the receiver varies considerably with the frequency of the received signal. Selectivity decreases as the carrier frequency increases.

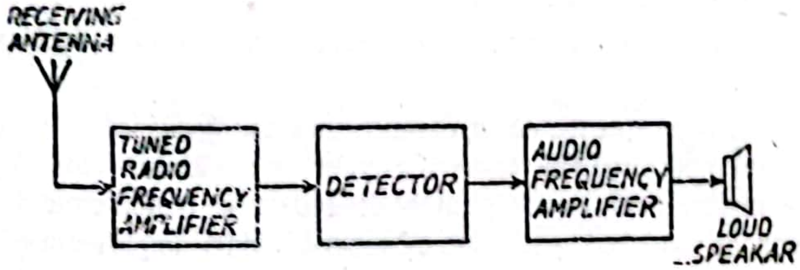


Fig. 9.2. Block diagram of TRF receiver.

Straight receivers of the TRF type (using electron tubes) were once popularly used because of their low cost. But because of the limitations mentioned above, these were superseded by superheterodyne receivers. Since middle thirties, all commercially manufactured broadcast and communication receivers are of superheterodyne type.

9.6. Principle of Superheterodyne Receiver

To heterodyne means to mix. Heterodyne reception stands for the radio reception after converting the modulated carrier voltage into similarly modulated voltage at a different carrier frequency. Thus the heterodyning process involves a simple change or translation of carrier frequency. This change in carrier frequency is achieved by heterodyning or mixing the modulated carrier voltage with a locally generated high frequency voltage in a non-linear device to obtain at the output a similarly modulated carrier voltage at the difference carrier frequency, called the *intermediate frequency*.

Superheterodyne reception is a form of heterodyne reception in which frequency conversion takes place one or more times before the modulated carrier voltage is fed to the detector to recover the original modulation frequency voltage. In practice, however, the name superheterodyne is applied to receivers in which only one frequency conversion takes place before detection. The receiver in which frequency conversion takes place twice before detection is called a *double superheterodyne receiver* or a *triple detection receiver*.

In a simple superheterodyne receiver, the modulated carrier voltage of frequency f_c is fed to a nonlinear device called the *frequency mixer* (or simply mixer) to which is also fed the voltage of frequency f_o generated in a *local oscillator* and at the output we get voltages of sum and difference frequencies ($mf_c - nf_o$) where m and n are integers. A tuned circuit in the output of the mixer stage tuned to the difference frequency ($f_c - f_o$) picks up this difference frequency component constituting the intermediate frequency (abbreviated as I.F.).

This I.F. voltage is modulated exactly similar to the incoming modulated carrier voltage. There results only a translation or change in the carrier frequency from f_c to f_i. This intermediate frequency f_i is fixed for a receiver.

The constant difference frequency f_i is maintained between the local oscillator frequency and the RF signal frequency, usually through use of capacitance tuning wherein the capacitors in the R.F. tuned circuit and local oscillator are ganged together and operated in unison through use of a single control knob.

The IF amplifier is a two or three stage tuned amplifier tuned to the intermediate frequency and provides most of the gain and hence the sensitivity of the receiver. It also fixes the 3-dB bandwidth (typically 10 kHz) of the receiver. The IF amplifier, being fixed frequency amplifier, has fairly uniform selectivity and sensitivity and the entire superhet receiver has almost constant selectivity and sensitivity throughout the carrier frequency band. In this respect it is superior to TRF receiver in which both the selectivity and sensitivity change greatly with the carrier frequency. Further the RF amplifier stage in superhet receiver rejects the *image frequency.*

Because of the various merits of superhet receivers over TRF receivers, these superhet receivers are most popularly used in almost all radio receiver applications such AM broadcast receivers, AM communication receivers, FM receivers, SSB receivers, TV receiver, Radar receiver etc.

9.7. Constituent Stages of a Superheterodyne Receiver

Fig. 9.3 gives the block diagram of a superheterodyne receiver. Functions of different stages are briefly given below :

Antenna or Aerial. It intercepts the electromagnetic waves. Voltages induced in the antenna are communicated to the receiver input circuit by means of a feeder wire or lead-in wire. A parallel tuned circuit at the input of the receiver responds only to voltage at the desired carrier frequency and rejects voltages at all other frequencies. The voltage so picked up is fed to the input of the RF amplifier stage.

R.F. Amplifier. This stage is generally a tuned voltage (small-signal) amplifier tuned to the desired carrier frequency. The chief functions of RF amplifier stage are :

(*i*) To amplify the input signal voltage to a suitably high level before feeding it to the frequency mixer which contributes large noise. Thus signal/noise ratio is improved.

(*ii*) To provide discrimination or selectivity against image frequency signal and intermediate frequency signal.

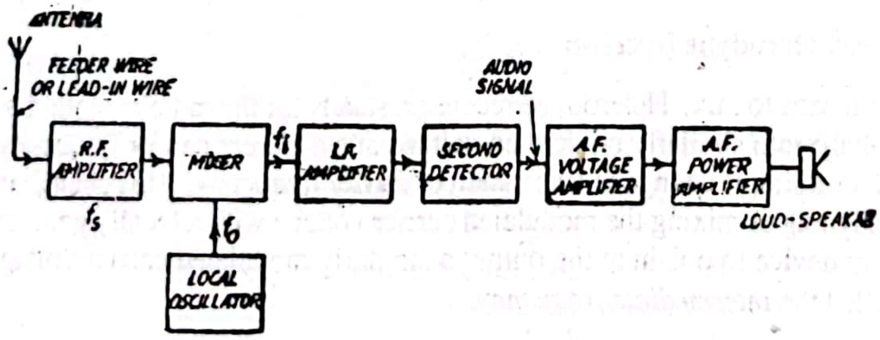


Fig. 9.3. Block diagram of superheterodyne receiver.

Frequency Converter Stage. This consists of a local oscillator and frequency mixer. To the frequency mixer are fed both the local oscillator voltage as well as signal voltage. The mixer, being a non-linear device, produces at its output the various intermodulation terms. The difference frequency voltage is picked up by the tuned circuit in the output circuit of the mixer. This difference frequency is called the intermediate frequency, the value of which is constant for a receiver. For all-wave receivers, typical value of intermediate frequency is 465 kHz or 456 kHz. Sometimes two separate transistors are used as local oscillator and frequency mixer but more often only one transistor functions both as local oscillator and frequency mixer. Such a transistor is then referred to as a frequency converter transistor. Thus with the help of frequency converter stage, RF signal of any carrier frequency is converted into similarly modulated fixed frequency IF signal.

I.F. Amplifier Stage. It consists of two or more stages of fixed frequency voltage amplifier having a 3dB bandwidth of 10 kHz for AM broadcast. This IF amplifier provides most of the receiver amplification and selectivity.

Second Detector. Output of the last IF amplifier stage is fed to this second detector which is generally linear diode detector. Output of this detector is the original modulation frequency voltage. For satisfactory operation of this detector, *i.e.* for linear detection, it is necessary that the carrier voltage fed to it be at least 1 volt. Hence the preceding amplifier stages must be designed to provide enough gain so as to feed a carrier of at least one volt to the detector for the weakest signal desired to be received by the receiver.

Audio Frequency Amplifier. Audio frequency output from second detector is fed to the a.f. amplifier which provides additional amplification. Usually one stage of audio voltage amplifier is used followed by one or more stages of audio power amplifier.

Loudspeaker. Amplified audio output voltage of audio power amplifier is fed to loudspeaker through impedance matching transformer. The loudspeaker reproduces the original programme.

9.8. Characteristics of Ideal Receiving Aerials

The receiving aerial intercepts electromagnetic waves. The voltage induced in the receiving aerial is fed to the receiver input circuit through the antenna coupling circuit.

An ideal receiving aerial has the following characteristics :

(*i*) It receives efficiently all the desired signals without wave band switching.

(*ii*) For broadcast reception, it normally has omni-directional chracteristics on long, medium and short wave ranges. Directional aerials are generally required for VHF and UHF receptions and also in communication receivers operating on short waves.

(*iii*) It has small variation of the resistance and reactance components of its terminal impedance with change of signal frequency.

(*iv*) it should minimize fading. Thus for long and medium waves, only the direct ray should be selected whereas for short waves, the aerial should be located for optimum reception of the ionospheric wave.

(*v*) It should minimize interference effects from house wiring etc. It may be achieved by placing the aerial out of the interference zone and connecting it to the receiver by shielded cable.

(*vi*) It should be resistant to corrosion or damage by weather and should be easy to install.

(*vii*) For broadcast receivers, the aerial should be cheap and good-looking.

9.9. Types of Receiving Aerials

The receiving aerial may be extremely varied in shapes and sizes ranging from a single long wire to a series of closed loops or a wire mesh or even just a small opening in a metal sheet.

The receiving aerials for use on medium and short waves may be classified as below :

(*a*) *Indoor Aerials*
(*i*) Frame Aerials
(*ii*) Mesh Aerials
(*iii*) Ferrites Rod Aerials
(*iv*) Metallic Rod Aerials

(*b*) *Outdoor Aerials*
(*i*) Vertical Aerials
(*ii*) Inverted-*L* Aerials
(*iii*) *T*-Aerials
(*iv*) Dipole Aerials.

An indoor aerial has relatively poor pick up and its terminal impedance, *i.e.*, the impedance between the aerial and ground looking into the aerial from the receiver, has large capacitive and resistive components. However indoor aerial are more handy and occupy less space and hence they are popularly used in preference to outdoor aerials in domestic receivers.

Outdoor aerials, in general, provide better pick-up and may be designed for terminal impedance which does not vary excessively with frequency. However, outdoor aerials occupy more space, and are costly. Hence outdoor aerials are no longer popularly used. They are principally used in communication receivers or in table model broadcast receivers particularly when excellent performance is desired.

Terminal Impedance of Receiving Aerial. If the terminal impedance of an aerial is known over the tuning frequency range, then for the purpose of design of the aerial coupling circuit, the aerial may be replaced by a generator having internal impedance equal to the terminal impedance of the aerial and open circuit voltage equal to the effective pick-up voltage of the aerial. The aerial coupling network may then be designed for either maximum signal voltage transfer or for maximum signal/noise ratio. The maximum signal transfer requires the aerial and the receiver input impedances to be matched and this is generally attempted in broadcast receivers operating on long, medium and short wave ranges. In communication receivers and UHF receivers, good signal/noise ratio should be the aim and this is not normally achieved by matching the aerial to the receiver. Further, at ultra high frequency, it may not be always possible to secure optimum signal/noise ratio because of sensitivity and selectivity considerations.

The choice and design of aerial coupling network becomes cumbersome primarily because the type of aerial which may be used with the receiver is unknown.

9.10. The Vertical Aerial

As for as reception is concerned, two important aspects of the aerial are : (*i*) its voltage pick up and (*ii*) its terminal impedance..

The vertical aerial may be regarded as a network of series inductive and shunt capacitive arms distributed along its length with a generator in series with each inductive arm as shown in Fig. 9.4.

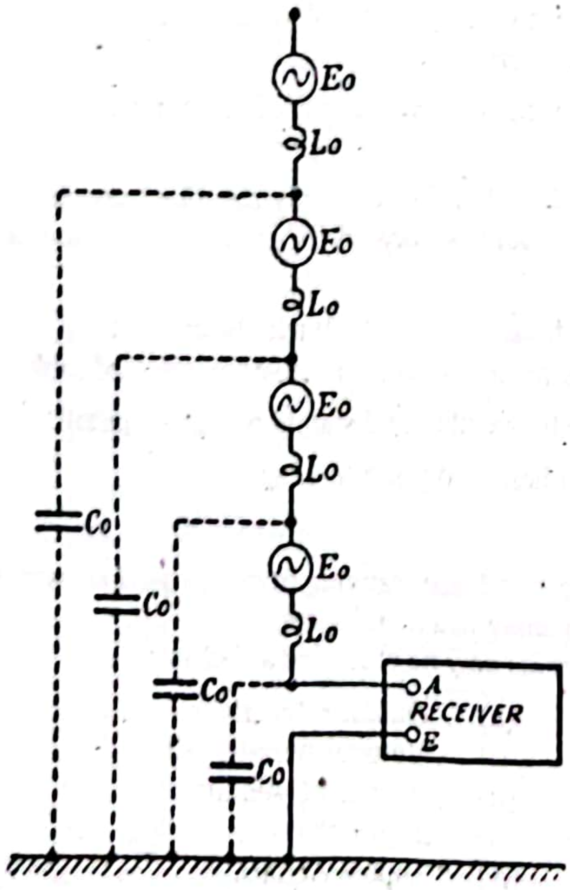


Fig. 9.4. Equivalent generator circuit for a vertical aerial.

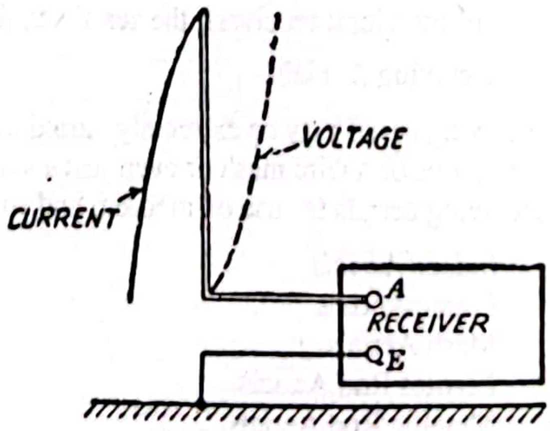


Fig. 9.5. Distribution of current and voltage in a vertical aerial.

Owing to the open circuit top, the voltages induced in each section cannot be equally effective in driving a current through the receiver impedance. It is clear that the voltage generated at the top has no complete circuit and it cannot, therefore, contribute anything to the output. The second generator, on the other hand, sends to the base only a small current because of the high reactance return path provided by the capacitance

C_o. The third generator works more efficiently than the second while the bottom most generator works most efficiently.

The current distribution along the entire length of the vertical aerial is thus as shown in Fig. 9.5. Standing waves of voltage and current are produced along the aerial. The voltage maximum occurs at the top of the aerial and the voltage minimum occurs at the base. The current maximum occurs at the base and the current minimum occurs at the top. The shape of the standing waves is sinusoidal but if the height of the aerial is much less than $\lambda/4$, the shape may be taken as almost triangular. Hence the equivalent generated voltage is the average voltage of the whole length of aerial, *i.e.*, equal to $Vh/2$, where V is the voltage pick-up per unit length and h is the total height of the aerial. It is, however, more common to associate the 1/2 with h than with V and $h/2$ is designated as the effective height of the aerial. Thus if we have a vertical aerial 2 metres high in a field of strength 10 μV/ metre, the generated voltage is $\frac{1}{2} \times 2 \times 100 = 100\ \mu V$. In this calculation, we have assumed that the incident electromagnetic field is uniformly distributed from the earth upwards. Changes in earth conductivity and the presence of earthed conductors near the aerial distort and weaken the field. The effective height of low aerial is, therefore, usually less than $h/2$.

The analysis of aerial terminal impedance may be made by treating the aerial as open circuited transmission line. Neglecting the end effects, it may be shown that the inductance and capacitance per unit length of a vertical wire close to the earth are given by the following relations :

$$L_o = 2\left[\ln\frac{h}{r} - 1\right] \times 10^{-3}\ \mu\text{H/cm} \quad \text{...(9.1)}$$

$$C_o = \frac{10^{-6}}{1.8\,[\ln(h/r) - 1]}\ \mu\text{F/cm} \quad \text{...(9.2)}$$

where h = length of the aerial in cm
r = radius of wire in cm.

The characteristic impedance of the aerial acting as a transmission line is :

$$Z_o = \sqrt{\frac{R_o + j\omega L_o}{G_o + j\omega C_o}} \quad \text{...(9.3)}$$

where R_o and L_o are respectively the resistance and inductance per unit length.
and G_o and C_o are respectively the leakage conductance and capacity per unit length.

Generally $\omega L_o \gg R_o$ and $\omega C_o \gg G_o$ so that,

$$Z_o = \sqrt{\frac{L_o}{C_o}} = 60\,(\ln h/r - 1) \quad \text{...(9.4)}$$

$$= 138\,[\log_{10} h/r - 0.435] \quad \text{...(9.5)}$$

where C_o is in μ F/cm and L_o is in μ H/cm.

Applying the using transmission line procedure, the terminal impedance Z_{oo} of the aerial is given by

$$Z_{oo} = Z_o \coth\sqrt{(R_o + j\omega L_o)(G_o + j\omega C_o)} \times h \quad \text{...(9.6)}$$

$$= Z_o \coth(\alpha + j\beta)\,h \quad \text{...(9.7)}$$

where α = attenuation constant of the aerial

$$= \sqrt{\frac{1}{2}\left[\sqrt{(R_o^2 + \omega^2 L_o^2)(G_o^2 + \omega^2 C_o^2)} + (G_o R_o - \omega^2 L_o C_o)\right]} \quad \text{...(9.8)}$$

and β = phase constant of the aerial

$$= \sqrt{\frac{1}{2}\left[\sqrt{(R_o^2 + \omega^2 L_o^2)(G_o^2 + \omega^2 C_o^2)} - (G_o R_o - \omega^2 L_o C_o)\right]} \quad \ldots(9.9)$$

We may rearrange α as follows :

$$\alpha = \sqrt{\frac{1}{2}\omega^2 L_o C_o \left[\left(1 + \frac{R_o^2}{\omega^2 L^2}\right)^{1/2} \left(1 + \frac{G_o^2}{\omega^2 C_{o^2}}\right)^{1/2} - \left(1 - \frac{G_o R_o}{\omega^2 L_o C_o}\right)\right]} \quad \ldots(9.10)$$

when $\omega_o L_o \gg R_o$ and $\omega_o C_o \gg G_o$, we have

$$\alpha = \sqrt{\frac{1}{2}\omega^2 L_o C_o \left[\left(1 + \frac{R_o^2}{2\,\omega^2 L_o^2}\right)\left(1 + \frac{G_o^2}{2\,\omega^2 C_o^2}\right) - 1\right]} \quad \ldots(9.11)$$

$$= \frac{1}{2} R_o \sqrt{\frac{C_o}{L_o}} + \frac{1}{2} G_o \sqrt{\frac{L_o}{C_o}} \quad \ldots(9.12)$$

Similarly it may be shown that,

$$\text{phase constant } \beta = \omega \sqrt{L_o C_o} \quad \ldots(9.13)$$

The velocity of propagation of wave along the wire is,

$$v = f \lambda \text{ metres/sec.} \quad \ldots(9.14)$$

where f = frequency in hertz

and λ = wavelength in metres $= \dfrac{2\pi}{\beta}$ ...(9.15)

Hence

$$v = \frac{2\pi f}{\beta} = \frac{\omega}{\beta} = \frac{1}{\sqrt{L_o C_o}} \quad \ldots(9.16)$$

Actual velocity of propagation v is dependent on α, because from Eqs. (9.8) and (9.9),

$$2\alpha^2 - 2\beta^2 = 2(G_o R_o - \omega^2 L_o C_o)$$

or

$$\beta = \sqrt{\alpha^2 + \omega^2 L_o C_o - G_o R_o} \quad \ldots(9.17)$$

Hence

$$v = \frac{\omega}{\beta} = \frac{\omega}{\sqrt{\alpha^2 + \omega^2 L_o C_o - G_o R_o}} \quad \ldots(9.18)$$

From Eq. (9.18) we find that as α increases, β increases and velocity of propagation v falls.

For most types of aerials and open wire feeders, v is very nearly the velocity of light, *i.e.* 3×10^8 metres/second but in coaxial feeders and twisted wires, it tends to be appreciably low.

Analysis considering the radiation resistance. The voltages and currents induced in the aerials by the incident electromagnetic waves themselves produce electrostatic and electro-magnetic wave in space. Hence the resistance term in the above formulae must include the effect of the radiation resistance.

The resistance component of the terminal impedance depends on the following factors : (*i*) Series resistance and shunt conductance of the aerial, (*ii*) the radiation resistance of the aerial and (*iii*) earth losses due to the circulation currents in the imperfectly conducting earth at the base of the aerial. Out of these components, those contributed by the series resistance and shunt conductance may usually be neglected except in the case of badly erected aerials and indoor aerials running close to earthed conductors. The earth losses depend on the site and are difficult to estimate. Only the radiation resistance component may be calculated assuming a perfect earth. Accordingly it is difficult to assess the total resistance component of terminal impedance.

A quarter wave resonant aerial above a perfectly conducting earth has terminal impedance which is non-reactive and equal to radiation resistance, *i.e.* 36.6 ohms. For given height of aerial, as the frequency is increased, the radiation resistance varies approximately as the square of the signal frequency upto $h = 0.4\,\lambda$, reaches a maximum of 108 ohms at $h = 0.45\,\lambda$, falls to 100 Ω at 0.5 λ and then falls to about 46 Ω at $h = 0.675\,\lambda$. To simplify analysis, we may assume that the radiation resistance is 40 Ω at $h_o = \lambda_2 / 4.2$, where h_o is the physical height of the aerial and that the radiation resistance is directly proportional to the frequency upto $h_o = \lambda / 2$. The errors introduced by the simplification are not excessive.

Combining Eqs. (9.7) and (9.13), we get

$$Z_{ao} = Z_o \coth [\alpha h_o + j\,\omega \sqrt{L_o C_o}\, h] \qquad \text{...(9.19)}$$

But
$$\sqrt{L_o C_o} = \frac{1}{v} - \frac{1}{f\lambda} \qquad \text{...(9.20)}$$

Hence from Eq. (9.19), we get

$$Z_{ao} = Z_o \coth \left(\alpha h_o + j \frac{2\pi h_o}{\lambda}\right) \qquad \text{...(9.21)}$$

But
$$\frac{2\pi h_o}{\lambda} = \frac{2\pi}{4} \cdot \frac{\lambda_o}{4} = \frac{\pi}{2} \cdot \frac{\lambda_o}{\lambda} = \frac{\pi}{2} \cdot \frac{f}{f_o} \qquad \text{...(9.22)}$$

Hence from Eq. (9.2), we get

$$Z_{ao} = Z_o \coth \left[\alpha h_o + j \frac{\pi}{2} \cdot \frac{f}{f_o}\right] \qquad \text{...(9.23)}$$

For the quarter wave resonant condition $f/f_o = 1$, Eq. (9.23) yields,

$$Z_{ao} = Z_o \coth \left[\alpha h_o + j \frac{\pi}{2}\right] \qquad \text{...(9.24)}$$

or
$$Z_{ao} = Z_o \tanh (\alpha h_o) \qquad \text{...(9.25)}$$

For a given aerial, Z_o is fixed. Also for quarter wave resonant condition, Z_{ao} = radiation resistance = 40 Ω.

Hence
$$\frac{40}{Z_o} = \tanh (\alpha h_o)$$

In most cases, Z_o is considerably larger than 40 Ω so that the ratio $40/Z_o$ is small. Hence $\tanh (\alpha h_o)$ is small and almost equal to αh_o.

Hence
$$\alpha h_o = \frac{40}{Z_o} \qquad \text{...(9.26)}$$

Z_o being fixed for a given aerial, the quantity αh_o is also fixed. Hence for any incident frequency f in MHz, Eq. (9.23) becomes,

$$Z_{ao} = Z_o \coth [A + j B] \qquad \ldots(9.27)$$

where $$A = \alpha h_o \qquad \ldots(9.28a)$$

and $$B = \frac{\pi}{2} \cdot \frac{f}{f_o} \qquad \ldots(9.28b)$$

But $$\coth (A + j \beta) = \frac{\cosh (A + jB)}{\sinh (A + jB)} = \frac{\cosh (A + jB) \cdot \sinh (A - jB)}{\sinh (A + jB) \cdot \sinh (A - jB)}$$

$$= \frac{\sinh 2A - \sinh j2B}{\cosh 2A - \cosh j2B}$$

$$= \frac{\sinh 2A - j \sin 2B}{\cosh 2A - \cos 2B} \qquad \ldots(9.29)$$

Hence $$Z_{ao} = R_{ao} + j X_{ao} = Z_o \left[\frac{\sinh 2A}{\cosh 2A - \cos 2B} - j \frac{\sin 2B}{\cosh 2A - \cos 2B} \right] \qquad \ldots(9.30)$$

Taking for illustration an aerial of No. 12 SWG copper wire. 10 metres in length, the value of $A = \alpha h_0 = (40/Z_0) = 0.084$ and and $f_0 = (300/4.2 \times 10) = 7.14$ MHz. For this value of A, Fig. 9.6 gives the curves showing the variation of R_{ao}/Z_0 and X_{ao}/Z_0 with the frequency ratio f/f_0. The curve for the frequency ratio from 2 to 3 assumes that the radiation resistance falls back again to 40 Ω at 3/4 λ_0 so that the value of R_{ao} is slightly lower than would occur in practice.

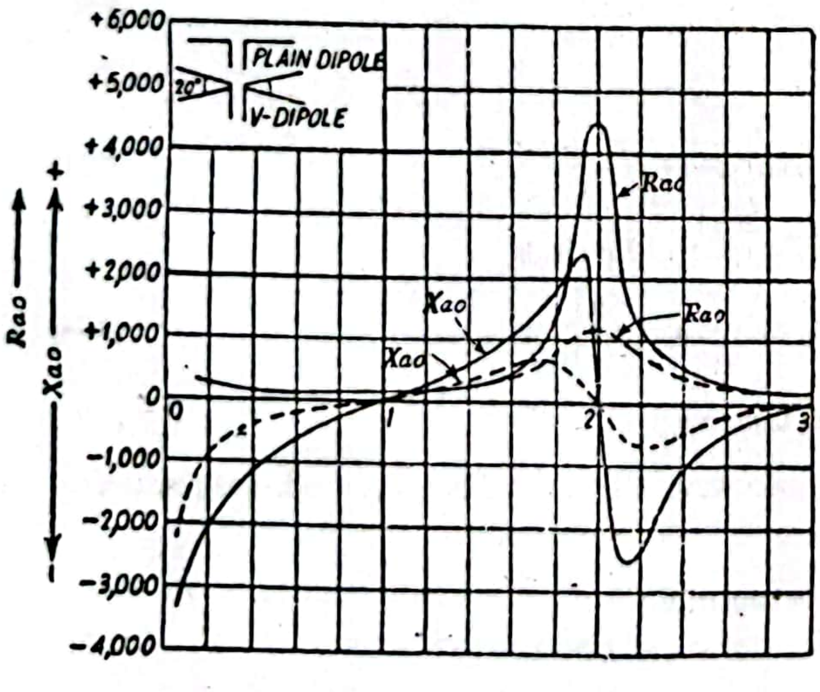


Fig. 9.6. Variation of R_{ao} and X_{ao} with frequency ratio f/f_0 for a vertical aerial.

(i) It may be seen from the curves in Fig. 9.6 that in the frequency range from 0 to f_0, X_{ao} is negative, *i.e.* capacitive and the value of effective capacitance C_{ao} increases as the frequency increases. For $f/f_0 < 0.5$, *i.e.* for $h_0 < \lambda/8$, the terminal capacitance C_{ao} approximately equals the electrostatic capacitance C_t $(= C_o h_o)$. According over the long and medium waves, most aerials may be replaced by a generator having an internal impedance consisting of a resistance in series with the electrostatic capacitance C_t of the aerial.

(ii) At $f/f_0 = 1$, the reactance X_{ao} is zero and the aerial has purely resistive impedance. At this frequency, the aerial may be regarded as a series resonant circuit. R_{ao} remains almost constant in the frequency around f_0.

(iii) For $f/f_0 > 1$ and < 2, $\sin 2B$ is negative so that X_{ao} is positive and hence inductive. X_{ao} increases with frequency, reaches a maximum and returns to zero value at $f/f_0 = 2$. The resistance component R_{ao} remains constant upto about $f = 1.4 f_0$ and then increases rapidly reaching a maximum value at $f = 2f_0$

(iv) At $f = 2f_0$, $X_{ao} = 0$ and R_{ao} is maximum and large. Thus the antenna behaves as a parallel resonant circuit.

(v) For $f/f_0 > 2$ and < 3, the aerial is again capacitive. R_{a0} reduces sharply and again assumes a low and constant value at f/f_0 greater than about 2.6.

For $f/f_0 > 3$ and < 4, the terminal impedance is again inductive and the curve is similar to that in the frequency range f/f_0 from 1 to 2.

A vertical aerial greater than $\lambda/4$ is seldom used for reception so that the curve for f/f_0 from 0 to 1 alone is of importance.

We see that this aerial of length 10 metres will function satisfactorily over long and medium wave ranges because for the highest received frequency of 1550 kHz, $f/f_0 = 0.21$ and upto this frequency the terminal capacitance is almost equal to the electrostatic capacitance C_r. However this aerial is not satisfactory over the short wave range since this range includes the $\lambda/4$ resonance condition. The performance of the tuned circuit is then materially effected because of the large change of the resistance and reactance components of the aerial terminal impedance. There is thus need to keep the aerial resonance outside the desired frequency range.

9.11. The Inverted-L-Aerial

An inverted-L aerial is formed by adding a horizontal top to a vertical aerial. This horizontal top influences both the total induced voltage in the aerial and the terminal impedance. Addition of the horizontal top amounts to adding a capacitance from the top of the vertical section of the aerial to the earth. With vertically polarised incident wave, although no voltage is induced in the horizontal top, the capacitance of the horizontal top to earth makes the voltage induced in each section of the vertical axial more effective. This results because of the following two reasons : (*i*) the top section generator now finds a return path to earth through the capacitance C_1 of the horizontal top section, (*ii*) succeeding generators in the vertical section operate more efficiency because of the added capacitance. Accordingly the average effective voltage becomes greater than $0.5\ Vh$, *i.e.* the effective height of the vertical section increases by the addition of the horizontal top. If the length of the horizontal top in an inverted-L aerial equals the height of the vertical section, then the effective height of the vertical section increases from $0.5\ h$ to $0.6\ h$.

If the incident wave has a horizontal component of electric field vector, then this component induces voltage in the horizontal part. This tends to cause fading and distortion particularly at the edge of the medium waves service area.

The terminal impedance of the inverted aerial may be found by considering the vertical and the horizontal sections separately. The horizontal section may be considered as a transmission line parallel to the earth, open circuited at the far end. The vertical section may be treated as another transmission line terminated at the upper end by the terminal impedance of the horizontal section.

The characteristic impedance of the horizontal section is given by.

$$Z_{oh} = 60\left(\ln\frac{2l}{r} - 1\right) = 60\left[\ln\frac{l}{r} + l_n^2 - 1\right] \qquad \ldots(9.31)$$

If $l \gg r, l_n^2 \ll \ln l/r$. Hence in Eq. (9.31), l_n^2 may be neglected in comparison with ln l/r.

Hence Eq. (9.31) may be put as,

$$Z_{oh} = 60\ [\ln l/r - 1] \qquad \ldots(9.32)$$

Comparison of Eq. (9.32) with Eq. (9.4) shows that the characteristic impedance Z_{oh} of the horizontal top is almost equal to the characteristic impedance Z_{ov} of the vertical section, provided that the vertical and the horizontal sections have the same radius and equal length, *i.e.* $h = l$.

The terminal impedance or the input impedance Z_h of the horizontal section is given by,

$$Z_h = Z_{oh}\ .\ \coth(\alpha_h + j\beta_h)\,l \qquad \ldots(9.33)$$

$$= Z_{oh}\ .\ \coth\gamma_h l \qquad \ldots(9.34)$$

where l = length of the horizontal section,

α_h = attenuation constant of the horizontal section,

β_h = phase constant of the horizontal section,

and γ_h = propagation constant of the horizontal section.

$\gamma_h = \alpha_h + j\beta_h$

The vertical section is terminated by this impedance Z_h. Then as per transmission line theory, the terminal impedance Z_{ao} of the vertical section is given by,

$$Z_{ao} = Z_{ov}\left[\frac{Z_h \cosh \gamma_v^h + Z_{ov} \sinh \gamma_v^h}{Z_h \sinh \; Z_{ov} \cosh \gamma_v^h}\right] \quad ...(9.35)$$

where h = height of the vertical section,

Z_{ov} =characteristic impedance of the vertical section

and γ_v = the propagation constant of the vertical section.

$$\text{If } \alpha h \ll \beta h, \text{ then } Z_h \approx Z_{oh} \coth(j\beta_h l) = -j Z_{oh} \cot(\beta_h l) \quad ...(9.36)$$

Further if $\alpha_v \ll \beta_v$, then

$$\cosh(\gamma_v h) \approx \cosh(j\beta_v h) \approx \cos\beta_v h$$

and

$$\sinh(\gamma_v h) \approx \sinh(j\beta_v h) \approx j\sin\beta_v h$$

Hence Eq. (9.35) may be put as,

$$jX_{ao} = Z_{ov}\left[\frac{-jZ_{oh}\cot(\beta_{hl})\cos(\beta_h) + jZ_{ov}\sin(\beta_v h)}{Z_{oh}\cot(\beta_h l)\sin(\beta_v h) + Z_{ov}\cos(\beta_v h)}\right] \quad ...(9.37)$$

From Eq. (9.37) we find that the condition for aerial resonance, *i.e.* $X_{a_0} = 0$ is as below :

$$-jZ_{oh}\cot(\beta_h l)\cos(\beta_v h) + jZ_o v\sin(\beta_v h) = o$$

$$\tan(\beta_h l)\tan(\beta_v h) = \frac{Z_{oh}}{Z_{ov}} \quad ...(9.38)$$

If we assume $L_{oh} = L_{ov}$ and $C_{oh} = C_{ov}$

then $Z_{oh} = Z_{ov}$ and $\beta_h = \beta_v = \beta$ say ...(9.39)

Hence Eq. (9.38) yields,

$$\tan(\beta l)\tan(\beta h) = 1 \quad ...(9.40)$$

or

$$\sin\beta l \sin\beta h = \cos\beta l \cos\beta h$$

or

$$\cos\beta(h+1) = 0 \quad ...(9.41)$$

or

$$\beta(h+l) = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2} \text{ etc.}$$

or

$$(h+1) = \frac{\lambda_0}{4}, \frac{3\lambda_0}{4}, \frac{5\lambda_0}{4} \text{ etc.} \quad ...(9.42)$$

Thus resonance is obtained when $(h+l) = \lambda_0/4,\ 3\lambda_0/4$ etc.

Similarly putting $Z_{oh'} = Z_{oe}$, Eq. (9.37) for terminal reactance reduces to the following form :

$$X_{oa} = -Z_o \left[\frac{\cos\beta l \cos\beta h - \sin\beta h \sin\beta l}{\cos\beta l \sin\beta h + \cos\beta h \sin\beta l}\right]$$

or

$$X_{oo} = -Z_o \cot\beta(h+l) \qquad ...(9.43)$$

From Eq. (9.19), on neglecting α, we get

$$X_{ao} = Z_o \coth[j\omega\sqrt{L_o C_o}\, h_o]$$

$$= Z_o \cot[\omega\sqrt{L_o C_o}\, h_o]$$

$$= Z_o \cot(\beta h) \qquad ...(9.44)$$

On comparing Eq. (9.47) for vertical aerial with Eq. (9.43) for inverted-*L* aerial we see that the inverted-*L* aerial well clear of earth has practically the same terminal impedance characteristics as a vertical aerial of height equal to the total length of the inverted-*L* aerial.

9.12. The T-Aerial

The *T*-aerial is similar to inverted-*L* aerial in its operation. The split horizontal section acts as a capacitance to earth, increasing the effective height of the aerial. The terminal impedance is calculated in the same manner as that for inverted-*L* aerial. However, the impedance offered by the horizontal sections to the vertical section in the case of *T*-aerial consists of the impedance of the two horizontal sections in parallel and is, therefore, given by,

$$Z_h = \frac{Z_{h1} \cdot Z_{h2}}{Z_{h1} + Z_{h2}} \qquad ...(9.45)$$

where Z_{h1} and Z_{h2} are the terminal impedances or the input impedances of the two horizontal sections. Generally $Z_{h1} = Z_{h2}$ so that

$$Z_h = \frac{Z_{h1}}{2}$$

Further if the *T*-top uses wire of the same diameter as the vertical section and is not very close to earth, then Z_h is given by,

$$Z_h = \frac{Z_{h1}}{2} = \frac{Z_{oe}}{2}\coth(\alpha_e + j\beta_e)\cdot\frac{l}{2} \qquad ...(9.46)$$

where l is the total length of the *T*-top.

The balanced horizontal top means that there will be cancellation of a horizontally polarised wave arriving at right angles to the aerial top. From all other directions the horizontal polarised wave will provide less pick up than that from an inverted-*L* aerial.

9.13. The Dipole Aerial

The dipole (or doublet) aerial consists of two equal lengths of open ended wires connected at their near ends to a feeder balanced to earth. The two wires are in the same plane and are at 180° with each other. Such an aerial is very suitable for short wave reception. It has the advantage that, if erected horizontally, the aerial itself is balanced to earth, so that the local interference effects tend to conceal out. Further short wave communication uses ionospheric propagation and the radio wave arriving from the ionosphere has an appreciable horizontally polarised component of electric vector. This horizontal component induces the desired voltage in the horizontal dipole. If the aerial is placed in a horizontal plane, the reception diagram in azimuth is a figure of eight with maximum reception in the two directions perpendicular to the diode.

A vertically erected dipole has no directional effect in azimuth and is unbalanced to earth so that the local interference voltages are not cancelled out to the same degree.

The terminal impedance of a dipole aerial can be calculated by the method employed for the vertical aerial. Let us assume that we have a horizontal dipole aerial, split at the centre to form two wires, each of length l metres and radius r metres.

Then the fundamental wavelength = 4.2 l metres
and the fundamental frequency = (300 / 4.2 l) MHz

This fundamental frequency should be chosen to lie in almost the centre of the short wave band extending from 6 to 15 MHz.

The capacitance per unit length between each wire of the dipole when the dipole is at least $\lambda / 2$ from the earth (so that the image effect can be neglected) is given by,

$$C = \frac{1}{3.6\,[\ln^{l/r} - 1]}\ \mu\mu\ \text{F/cm} \qquad \ldots(9.47)$$

The characteristic impedances is given by,

$$Z_0 = 120\,[\ln^{l/r} - 1] \qquad \ldots(9.48)$$

The radiation resistance of a $\lambda/2$ dipole split at the centre is twice that of the vertical $\lambda / 4$ aerial *i.e.* 73.2 Ω. Let us assume that the terminal impedance under these conditions is 80 Ω.

Then $$80 = Z_o \coth\left[\alpha l_o + j\frac{\pi}{2}\right] = Z_o \tanh(\alpha l_o) \qquad \ldots(9.49)$$

where l_o is the physical length of each section of the dipole.

Hence $$\tanh(\alpha l_o) = \frac{80}{Z_0}. \qquad \ldots(9.50)$$

For typical values of Z_o, the ratio $80/Z_o$ is very small, of the order of 0.1 or less.

Hence $$\alpha l_o \approx \frac{80}{Z_o} = A \text{ say} \qquad \ldots(9.51)$$

Hence the expression for the terminal impedance may be put as,

$$Z_{ao} = Z_o \coth\left(l_o + j\,\alpha\frac{\pi}{2}\cdot\frac{f}{f_o}\right) = Z_o \coth(A + j\,B) \qquad \ldots(9.52)$$

where $$A = \alpha l_o = \frac{80}{Z_o} \qquad \ldots(9.53\,a)$$

and $$B = \frac{\pi}{2}\cdot\frac{f}{f_o} \qquad \ldots(9.53\,b)$$

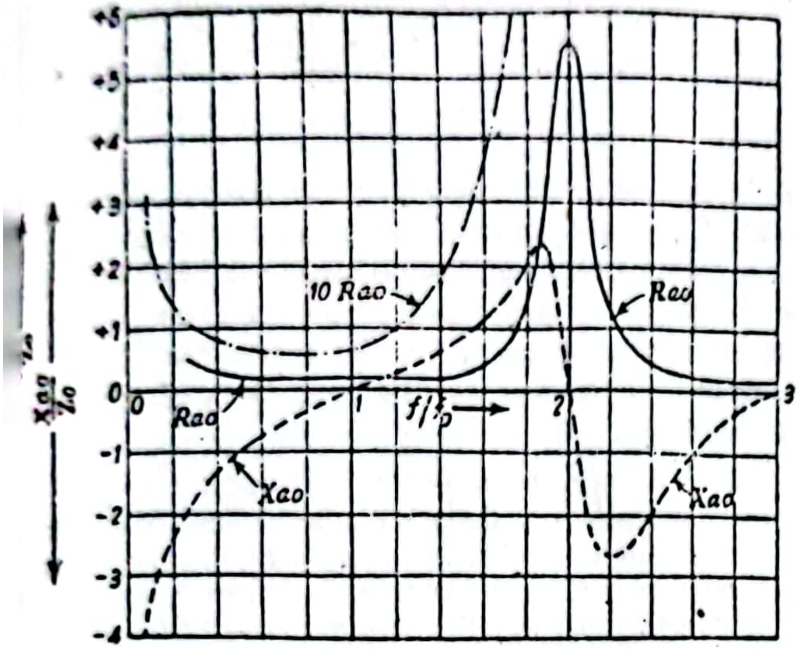
Having calculated the values of A and B from Eqs. (9.53), Eq. (9.30) then enables us to calculate the values of terminal resistance R_{ao} and the terminal reactance X_{ao}.

As an illustration, consider the horizontal dipole to be formed of two wires each 12 S.W.G. Copper wire 6 metres in length.

The fundamental wavelength $\lambda_0 = 4.2 \times 6 = 25.2$ metres. The fundamental frequency $f_o = 300/25.2 =$ 11.82 MHz. This frequency lies almost at the centre of the short waveband extending from 6 to 15 MHz.

$$Z_o = 120\,[\ln^{l/r} - 1] = 120\left[\frac{6}{\ln^{0.00132} - 1}\right] = 891\ \Omega$$

$$A = \alpha l_o = \frac{80}{Z_o} = \frac{80}{891} = 0.09$$



...g. 9.7. Variation of R_{ao} and X_{ao} of a plain dipole (solid curves) ...nd V-dipole (dotted curves) having a quarter wave radiation resistance of 80 ohms.

Fig. 9.7 gives the curves for R_{ao} and X_{ao} (solid curves) plotted against frequency ratio f/f_0 for the value of A = 0.09 and f_0 = 11.82 MHz. For f_o = 11.82 MHz, the short wave range of 5 to 15 MHz corresponds to approximately f/f_0 = 0.5 to 1.3. Study of Fig. 9.7 shows that over this frequency range, variation of terminal impedance is considerable. This variation of terminal impedance can be reduced if the characteristic impedance of the aerial is reduced. A decrease in Z_0 has no effect at $f/f_0 = 1$ since the terminal impedance is determined by the radiation resistance alone but it has a large effect at $f/f_0 = 2$.

At $f/f_0 = 2$, each section of the dipole acts as a $\lambda/2$ aerial and when αl_o is small, we have

$$Z_{ao}(\lambda/2) = Z_o \coth(\alpha l_o) \approx \frac{Z_o}{\alpha l_o} \quad \text{...(9.54)}$$

But

$$Z_{ao}(\lambda/4) = Z_o \tanh(\alpha l_o) \approx \alpha l_o \quad \text{...(9.55)}$$

Hence

$$Z_{ao}(\lambda/2) = \frac{Z_o^2}{Z_{ao}(\lambda/4)} \quad \text{...(9.56)}$$

From Eq. (9.56) we see that a small reduction in characteristic impedance Z_0 reduces considerably the ...rminal impedance Z_{ao}. Thus for example, halving Z_0 reduces $Z_{ao}(\lambda/2)$ to one-fourth of its original value. ...eduction of Z_0 can be achieved by making each half of the dipole into a V-aerial as shown in Fig. 9.7.

The capacitance for the V-dipole aerial per cm length is a function of ratio l/r, and angle θ between the ...arms. For $\theta = 20°$, the V-dipole with all other details the same as for simple dipole has $Z_0 = 515\,\Omega$.

Hence

$$A = \alpha l_o = \frac{80}{Z_o} = 8\frac{o}{515} = 0.1555,$$

Hence

$$Z_{ao} = R_{ao} + jX_{ao} = 515\left[0.1555 + j\frac{\pi}{2} \cdot \frac{f}{f_o}\right]$$

$$R_{ao} + jX_{ao} = 515\,[A + jB]$$

where

$$A = 0.1555 \text{ and } B = \frac{\pi}{2} \cdot \frac{f}{f_o}.$$

Eq. (9.30) may then be used for calculating the values of terminal resistance R_{ao} and terminal reactance X_{ao}. The dotted curves in Fig. 9.7 give the variation of R_{ao} and X_{ao} for the V-dipole plotted against the frequency ratio f/f_o. It may be seen that the V-dipole has less variation in the terminal impedance in comparison with the simple dipole.

The curves in Fig. 9.7 assume that the radiation resistance R_r is directly proportional to frequency upto $f/f_o = 2$. This assumption is not true and hence the values of R_{ao} are not strictly correct, although they form a useful basis of the design of aerial-to-receiver coupling network. The correct values tend to be higher for f/f_o <1 and to be lower for f/f_o from 1 to 1.8.

9.14. Ferrite Rod Aerial

This is in the form of two sections of coil wound on a high permeability ferrite rod of circular cross-section and length typically about a quarter metre. The aerial is housed within the receiver itself and is used for reception of medium wave signals. The ferrite rod is kept horizontal and is usually mounted at the centre and in several cases it is capable of being oriented slightly in azimuth. This aerial has maximum pick up when the rod is normal to the direction of propagation of electromagnetic waves and its axis coincides with the magnetic vector. Accordingly it is ideally suited for receiving medium wave signal travelling along the ground with electric vector vertical and magnetic vector horizontal.

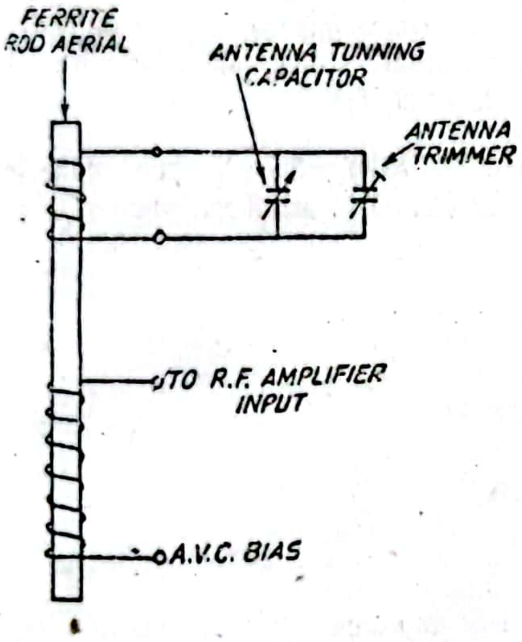


Fig. 9.8. Ferrite rod aerial and its coupling circuit.

The magnetic vector of the incident e.m. waves produces magnetic flux through the ferrite core. Since the permeability of the ferrite core is very high, there results a very heavy concentration of magnetic flux through the core. This time varying magnetic flux threads through the two sections of the coil and induces relatively high voltages. One section of the coil is tuned to the signal frequency f_s with the help of one section of the ganged tuning condenser kept in shunt with it. The voltage developed across the other section is fed to the input of the R.F. amplifier, Fig. 9.8 gives the circuit arrangement.

9.15. R.F. Amplifier

It is a small signal tuned amplifier with tuned circuits both in the input circuit and the output circuit. Both the tuned circuits are tuned to the desired carrier frequency. Accordingly the tuned circuits select the desired carrier frequency and reject all unwanted frequencies including the image frequency. Thus RF amplifier provides image signal rejection. The gain provided by the RF amplifier results in improved signal/noise ratio in the output of the receiver. The signal gets raised to a high level with the help of the RF amplifier before it is fed to the frequency mixer stage which contributes most of the noise generated in the receiver. If the signal is fed directly to the frequency mixer, the signal/noise ratio at the output of the mixer stage is poor and any amount of subsequent amplification does not improve S/N ratio. It may be noted that any transistor contributes more noise power when used as a frequency mixer than when used as an amplifier. We may thus summarise the advantages resulting from the use of RF amplifier.

Main Advantages of RF Amplifier stage

1. Greater gain; better sensitivity
2. Improved signal/noise ratio
3. Improved rejection of adjacent unwanted signals *i.e.* better selectivity
4. Improved image signal rejection.

Additional Advantages of RF Amplifier Stage

These are more specialized or relatively less important advantages.

1. Prevention of re-radiation of the local oscillator voltage through the antenna.
2. Improved coupling of the receiver to the antenna (at VHF and higher frequencies)
3. Prevention of spurious frequencies from entering the mixer and heterodyning to produce interfering frequency equal to IF.

Circuit of RF Amplifier. Fig. 9.9 gives the circuit of one stage of RF amplifier using an *npn* RF transistor. It is a small signal amplifier using parallel tuned circuit as the load impedance. This parallel tuned circuit is tuned to the signal frequency f_s. The output from the receiving antenna is transformer coupled to the base of this transistor. The secondary of the input tuned circuit is tuned to the signal frequency f_s with the help of a section of the ganged tuning capacitor. The variable air capacitors (tuning capacitors) in the input circuit and the output circuit of the RF amplifier stage are ganged together. In addition, small trimmer capacitors are connected in shunt with these tuning capacitor sections for the purpose of RF alignment. Self bias is provided with the help of resistors R_1 and R_2 and R_e-C_z assembly. A decoupling network consisting of resistor R_b and capacitor C_b is placed in the collector supply lead.

Amplified RF signal developed across the collector tuned circuit is coupled through a step down transformer to the input of the frequency mixer. This step down transformer provides the impedance match between the high impedance of the RF amplifier collector circuit and the low impedance of the base-to-emitter circuit of the following stage. The collector is connected to a suitable point on the primary of the output transformer so that the load impedance to the collector is optimum.

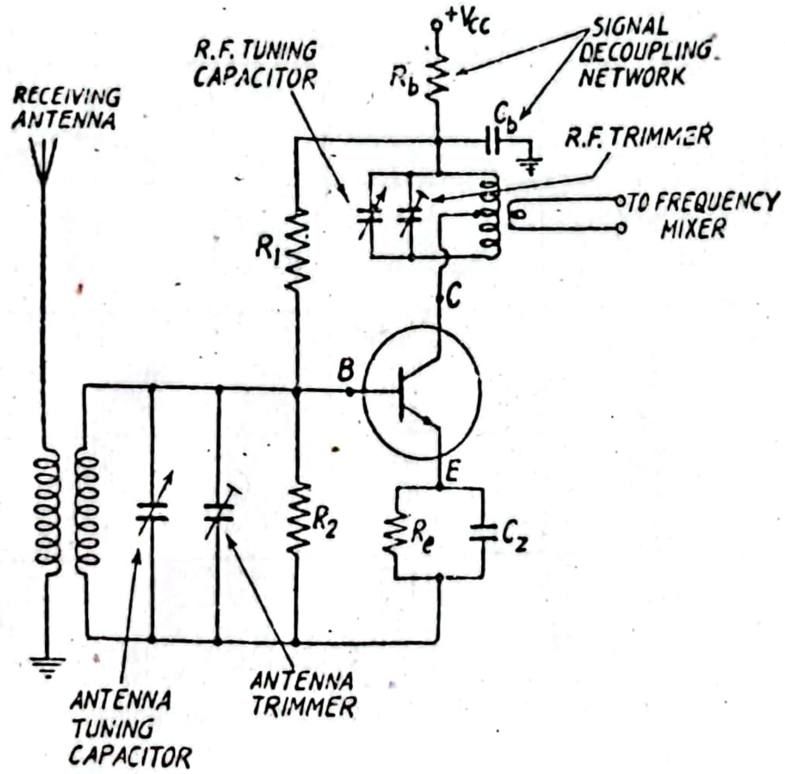


Fig. 9.9. Circuit of R.F. amplifier stage.

Sensitivity of Receiver. It is the ability of the receiver to amplify weak signals. Mathematically, the sensitivity of a radio receiver is defined as the carrier voltage which must be applied to the receiver input terminals to get the standard output power at the output terminals. In AM receiver, the carrier input so used is modulated to a depth of 30% by a 400 Hz sinusoidal voltage and the carrier voltage is applied from a standard signal generator to the receiver input through a standard coupling network called the *dummy antenna*. The standard output is 50 milliwatts with the loudspeaker replaced by a load resistance of equal value.

Sensitivity of a radio receiver is expressed in micro volts (or millivolts) or in dBs below 1 volt. The sensitivity may be measured at various carrier frequencies in a given band. Thus in broadcast band (medium wave band), the sensitivity may be measured at various carrier frequencies in the band extending from 600 kHz to 1600 kHz say at frequency intervals of 100 kHz. The sensitivity (in μV) may then be plotted against carrier frequencies to give the sensitivity curve for the receiver. Fig. 9.10 shows one such sensitivity curve.

It may be seen from this curve that the sensitivity varies over the tuning band. The sensitivity has typically minimum value (mathematically) near the two ends of the frequency band, say at 650 kHz and 1550 kHz and also at some frequency in the centre of the band, say 1050 kHz. Such a behaviour results from the procedure followed in the alignment of the receiver. The sensitivity curve seems to closely follow the tracking error curve. During R.F. alignment (to be discussed later), tracking error (difference between the desired IF and the actual difference frequency $f_o - f_s$ V) is adjusted to be zero close to the two ends of the band resulting in maximum response *i.e.* minimum mathematical sensitivity (in μV) at these two frequencies. The tracking error is positive in a part of the band and negative in the remaining part of the band. This automatically results in yet another frequency at which the tracking error is zero. This frequency lies in almost the centre of the band. The sensitivity curve of Fig 9.10 accordingly closely follows the tracking error curve and has, in general the shape shown in Fig 9.10.

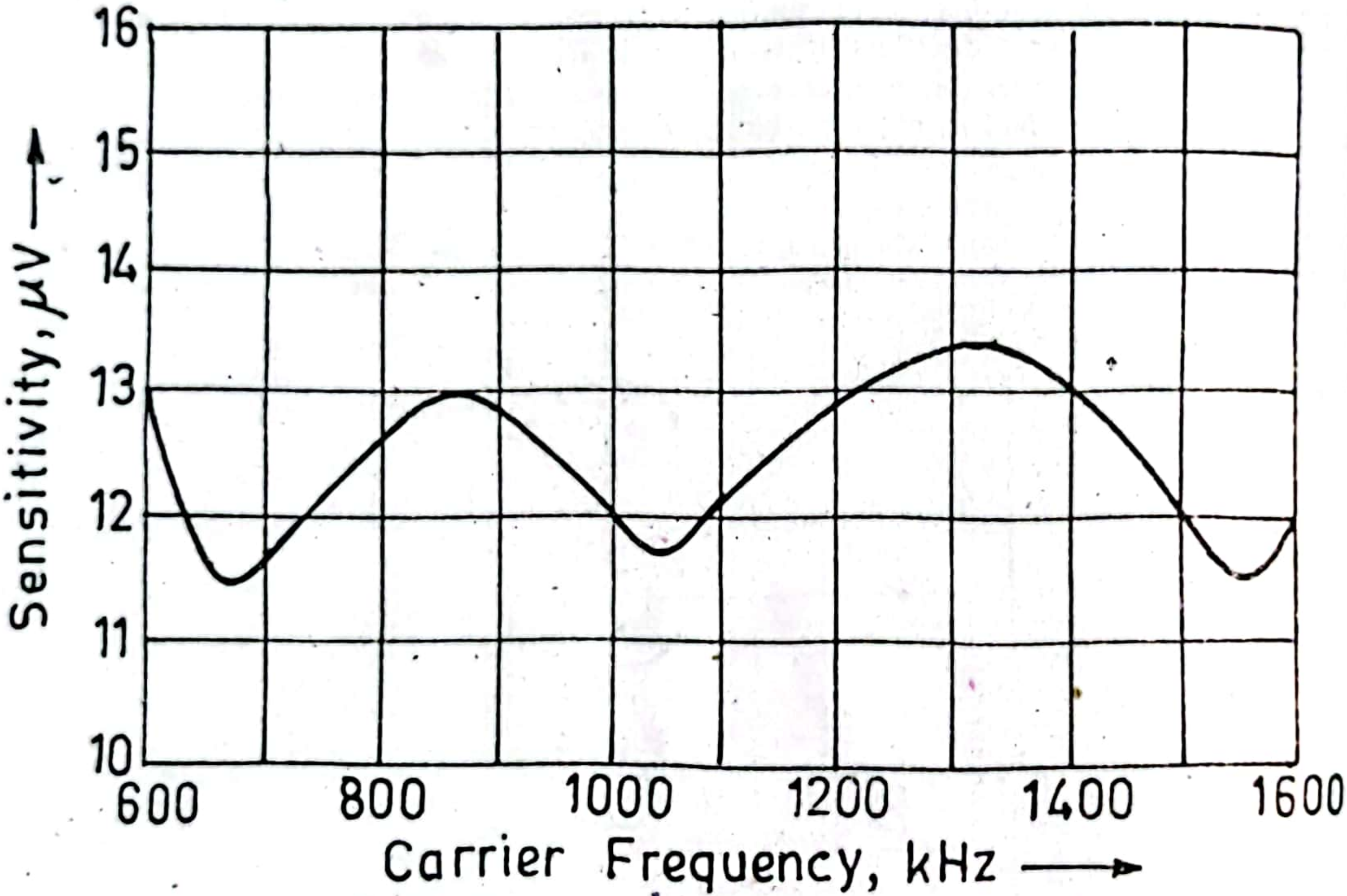


Fig 9.10. Sensitivity curve of a broadcast receiver.

In communication receiver, the S/N ratio is more important than the maximum output power. Hence for such receivers, often the sensitivity is expressed as the signal power required to produce a minimum acceptable output signal with a minimum acceptable S/N ratio. Hence in such a case, the main input power is quoted in dB below 1 mW or dBm. Thus a receiver may have sensitivity of say-80 dBm at say 1 MHz with 400 Hz modulation signal and 30% modulation. Then such a signal applied to the input terminals of the receiver through a dummy antenna produces an output of 50 mW with S/N ratio of at least 20 dB.

Selectivity. By selectivity of a radio receiver is meant its ability to reject adjacent signal. Selectivity is generally expressed as a curve plotting V/V_o in dBs against frequency detuning as shown in Fig. 9.11. Here V_o is the input carrier voltage at the desired frequency (with standard modulation of 30% at 400 Hz) needed to produce standard output power of 50 mW while V is the input carrier voltage (with standard modulation) at an adjacent carrier frequency needed to produce the same standard output (50 mW). The frequency detuning may be plotted in multiples of say 5 kHz on either side of the desired carrier frequency. Throughout these measurements, the receiver is kept tuned to the desired carrier frequency. As the input carrier frequency departs from the desired value, the output of the receiver drops and the input carrier frequency at this departed frequency is required to be increased to get the same standard modulation frequency output of 50 mW. A curve is drawn joining all the points at various departed carrier frequencies. Study of this selectivity curve of Fig. 9.11 shows that at departure of −15 kHz (*i.e.* input carrier frequency 15 kHz below the desired carrier frequency), the unwanted carrier frequency is required to be 60 dB greater than the desired carrier to get the same output. Fig. 9.11 gives the selectivity curve for a given receiver for a given desired carrier frequency. The selectivity of a receiver varies with variation of desired carrier frequency, if ordinary tuned circuits are used in IF amplifiers. Selectivity deteriorates *i.e.* the selectivity curve becomes more flat as the carrier frequency is raised. In general, the selectivity is determined primarily by the response of the IF amplifier while the responses of the mixer and the RF amplifier may play minor role. The selectivity of a receiver determines the 3 dB bandwidth of the receiver and hence determines the adjacent channel rejection of the receiver.

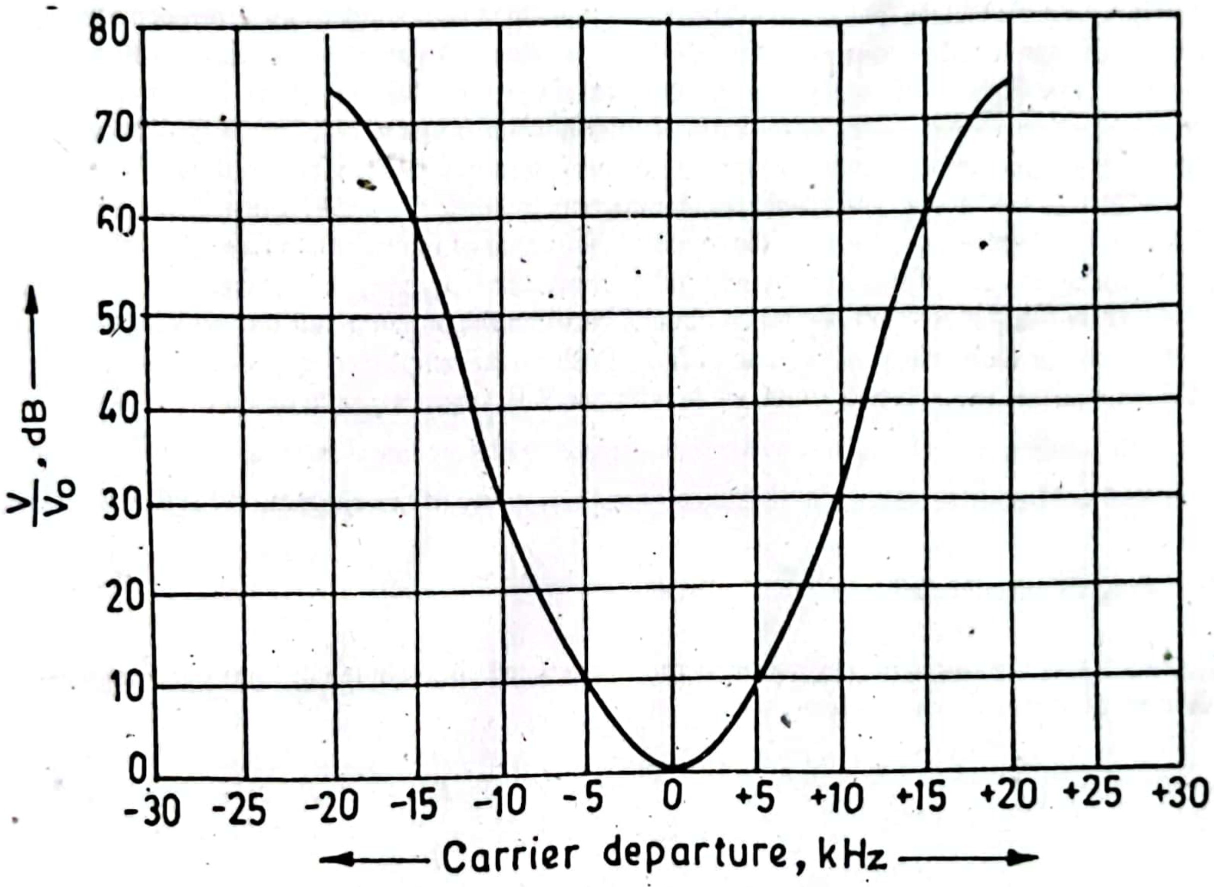


Fig 9.11. Selectivity curve of a typical radio receiver.

The value of IF also influences the selectivity curve. Other thing remaining the same, as the IF is increased 3 dB bandwidth increases and the selectivity curve becomes more flat. It is from this consideration that the IF is kept small so as to just accommodate a bandwidth of 10 kHz.

9.16. Image Signal Rejection

By image signal is meant a signal of frequency f_s' which is above the local oscillator frequency f_o by the same amount as the desired signal frequency f_s is below or *vice versa*. In medium and short wave receivers, the desired signal frequency f_s is kept below the local oscillator frequency f_o by an amount f_i (intermediate frequency). Hence the image signal frequency f_s' must be above the local oscillator frequency f_o by the same amount f_i.

Thus $$f_i = f_o - f_s \qquad ...(9.57)$$

and $$f_s' = f_o + f_i = f_s + 2f_i \qquad ...(9.58)$$

Thus the image frequency f_s' is above the desired signal frequency f_s by twice the intermediate frequency.

If this image signal can manage to reach the mixer input, then it combines with the local oscillator voltage to produce a difference frequency which again is exactly equal to the intermediate frequency and which after passing through I.F. amplifier, detector and audio amplifier appears in the receiver output in a manner exactly similar to the desired signal frequency. Image signal is undesirable and can be eliminated by providing adequate image signal selectivity between the antenna and the converter input. Any tuned circuit, tuned to the desired signal frequency, offers to the image signal discrimination per circuit of 30 to 40 dB depending on the signal frequency and the intermediate frequency. For satisfactory image discrimination, it is necessary that image signal voltage reaching the converter input be at least 30 dB below the desired signal voltage. But it is possible that the image signal at receiver input may be considerably stronger than the desired signal. Accordingly the tuned circuits placed between the antenna and the converter input must provide discrimination of at least 50 to 60 dB against image signal relative to the desired signal. It may be readily seen that image signal selectivity increases as the ratio of intermediate frequency to signal frequency increases. Accordingly for providing maximum image signal selectivity, intermediate frequency should be kept as large as possible. In all-wave receivers, typical value of intermediate frequency is 465 kHz or 456 kHz. For receivers used exclusively for short waves, it is possible to use higher value of intermediate frequency of the order of 2 MHz or so. For same value of signal frequency and intermediate frequency, higher image signal selectivity can be achieved by using more than one tuned circuits between the antenna and the converter input. This requires use of one or more stages of R.F. amplifier. With no RF amplifier only one tuned circuit exists between the antenna and the converter input, while with one R.F. stage two such tuned circuit appear.

If ω_o is the desired signal frequency to which the tuned circuits are tuned and if ω is any other frequency close to the resonant frequency ω_o, then the image signal selectivity of discrimination is given by,

$$\text{Image signal selectivity} = \left[\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega}\right]^n \cdot Q_o^n \qquad ...(9.59)$$

where Q_o is the "Q" or the *circuit magnification factor* of the tuned circuit at the desired signal frequency and n is the number of identical tuned circuits.

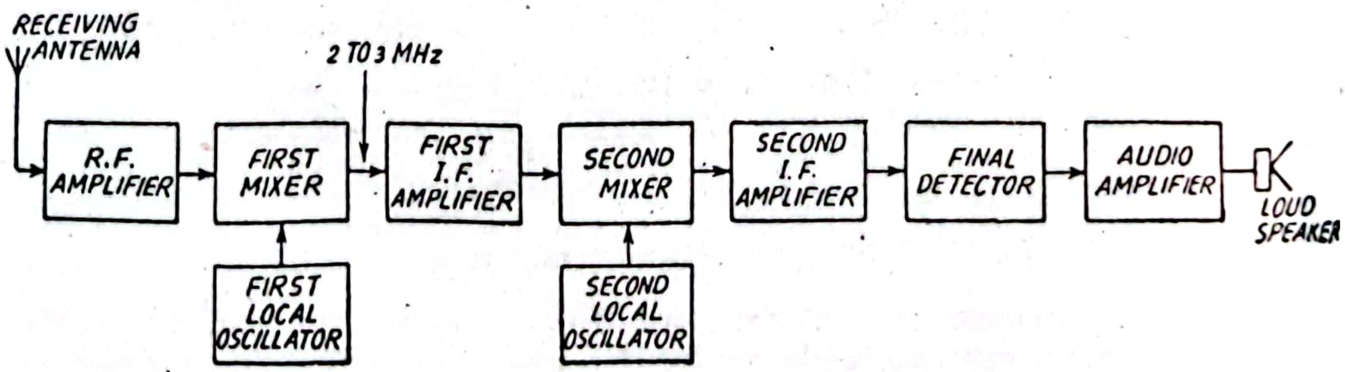


Fig 9.12. Block diagram of double-superheterodyne receiver.

From the point of view of good image signal selectivity, it is desirable to use as large an intermediate frequency as possible. But as intermediate frequency is increased, adjacent channel selectivity falls. Choice of intermediate frequency is thus a compromise between these conflicting requirements. Value of intermediate frequency equal to 465 kHz has been selected from this consideration. In case an excellent image signal selectivity as well as an excellent adjacent channel selectivity is desired, it is required to use a *double* superheterodyne receiver also called a *triple detection receiver*, in which case the desired signal is reduced by first frequency converter to first intermediate frequency of high value of the order of 2 to 3 MHz. This provides high image signal selectivity. Second frequency converter then heterodynes the first intermediate frequency signal to second intermediate frequency signal of suitably low value to provide adequate adjacent channel selectivity. Fig 9.12 gives the block diagram of triple detection receiver or double superheterodyne receiver. The name double superheterodyne receiver is given to this receiver because frequency heterodyning is done twice. Further counting each frequency conversion as basically a detection process, in all three detectors are used in this receiver and hence the name triple detection receiver is given to this receiver. This receiver, no doubt, is complicated and costly. Hence this triple detection receiver is not used as broadcast receiver but is used only as communication receiver.

9.17. Frequency Mixers and Frequency Converters

In a frequency mixer, shown diagrammatically in Fig. 9.13, the RF signal voltage of frequency f_s and local oscillator voltage of frequency f_o are applied at its input. The frequency mixer uses a device which presents non-linear dynamic characteristic. Hence the two input voltages beat together or heterodyne within the mixer to produce output current having components of frequency f_s, f_o, $mf_o \pm nf_s$, where n and m are integers. Out of all these terms, one of interest in the component of difference frequency $(f_o - f_s)$. This component may be readily selected by using a tuned circuit in the output circuit tuned to this difference frequency, called the *intermediate frequency*. Every RF signal irrespective of its frequency is reduced to this standard intermediate frequency. Accordingly it is necessary that the local oscillator frequency f_o be made to vary in such a way as to maintain the difference frequency $(f_o - f_s)$ always equal to the intermediate frequency f_i (= 465 kHz).

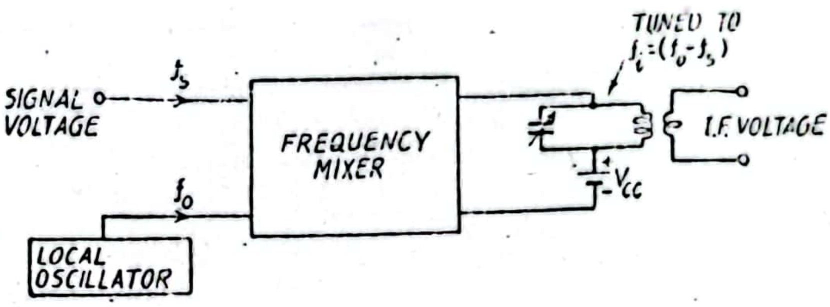


Fig. 9.13. Sehematic diagram of frequency mixer.

Several methods of frequency conversion in superheterodyne receivers are in use. In each method the collector current of the frequency mixer transistor is made to vary at a combination frequency of the signal frequency and the oscillator frequency, producing the desired intermediate frequency voltage across the tuned load. Although this basic principle of operation is the same for all types of frequency converters, the difference lies in whether a separate local oscillator is used as in a frequency mixer or the same device serves both as mixer and local oscillator.

Frequency Mixer. Fig. 9.14 shows the circuit of a frequency mixer using two transistors, transistor T_1 as the frequency mixer while transistor T_2 as the local oscillator. Transistor T_1 is so biased that the operation takes place over the non-linear region of its characteristic curve. This non-linear operation results in collector current components of frequencies $(mf_o \pm nf_s)$ in addition to components of local oscillator frequency f_o and signal frequency f_s. The tuned circuit in the collector circuit picks up the desired frequency term $(f_o - f_s)$ being tuned to this frequency.

The RF signal of frequency f_s obtained either from the receiving antenna or from the RF amplifier is fed to the base of the mixer transistor T_1 operated in *CE* configuration. The output from the local oscillator using transistor T_2 is fed to the emitter of the mixer transistor T_1. The resulting collector current is thus influenced by both the signal voltage v_s and the local oscillator voltage v_o. Because of non-linearity of characteristics of transistor T_1, this collector current contains the desired component of difference frequency $(f_o - f_s)$. This difference frequency $(f_o - f_s)$, constitutes the intermediate frequency. The desired intermediate frequency voltage gets developed across the parallel tuned circuit of transistor T_1. Capacitor C_2 feeds the oscillator voltage to the mixer but disallows the low resistance of the oscillator coil L_1 from shunting the stabilizer resistance R_2. No bypass capacitor is connected across the stabilizing resistor R_2 otherwise the oscillator voltage fed at emitter of T_2 gets grounded. Typical values of components are also indicated in the circuit.

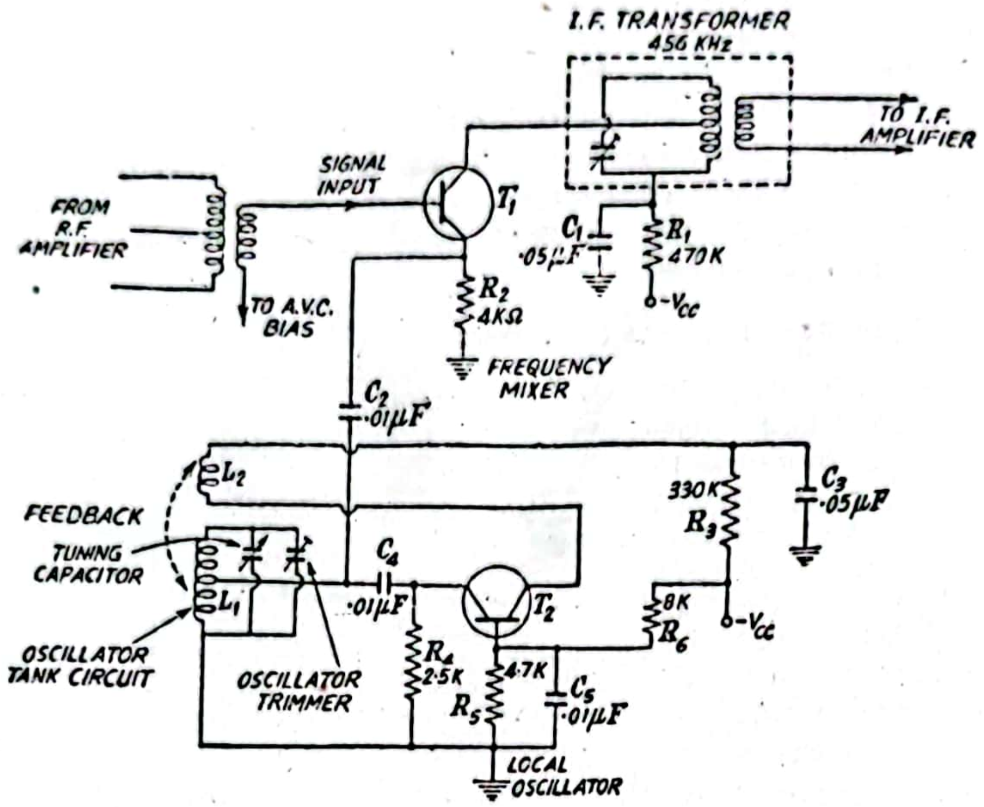


Fig. 9.14. Frequency mixer and oscillator stages using transistors.

The tuned circuit constitutes the primary of the I.F. transformer whose secondary is left untuned. The I.F. voltage developed across the secondary is fed to the I.F. amplifier. The I.F. transformer, being a step-down transformer, provides a current gain and also impedance match between the high impedance collector circuit and the low impedance input circuit of the first I.F. amplifier.

Frequency Converter Using Transistor. A frequency converter uses a transistor which serves both as frequency mixer and local oscillator. Fig. 9.15 gives the basic circuit. The RF voltage from the receiving antenna or from the RF amplifier is fed to the base of transistor T_1 while the local oscillator voltage gets fed to the emitter of the same transistor. Coil L_1 and L_2 constitute the oscillator coils. Coil L_2 is tuned with the help of a tuning capacitor and trimmer and is inductively coupled to coil L_1. Thus there results a positive feedback from coil L_1 to L_2, resulting in desired oscillations. Coil L_2 along with the tuning capacitor and trimmer determine the frequency of local oscillator. Transistor T_1 acts as the internal amplifier for the feedback oscillator. The resulting local oscillator voltage causes the collector current to have component of local oscillator frequency f_o. The collector current is also controlled by the RF voltage of frequency f_s applied at the base. Further the transistor is so biased that the operation is over the non-linear region of its characteristics. Hence the resulting collector current contains a d.c. component plus components of frequencies $f_s, f_o, (mf_o \pm nf_s)$, where m and n are integers. The parallel tuned circuit in the collector circuit constituting the load is tuned to the desired difference frequency $(f_o - f_s)$ and this frequency constitutes the intermediate frequency f_i. This tuned circuit thus develops across it voltage of intermediate frequency f_i only and rejects all other frequency components. This tuned circuit constitutes the primary of the I.F. transformer whose secondary is left untuned. The I.F. voltage developed across the secondary is fed to the I.F. amplifier. The I.F. transformer is a step-down transformer. This provides current gain and also impedance match between the high impedance of the collector circuit and the low impedance of the I.F. amplifier input circuit.

The stabilizing resistor R_1 is not shunted by a bypass capacitor otherwise the oscillator voltage across tuned circuit coil L_2 finds an a.c. short circuit through this bypass capacitor. Resistors R_1 and R_2 form a potential divider across the supply voltage V_{cc} and provide the necessary emitter bias. Typical component values are also shown in the circuit.

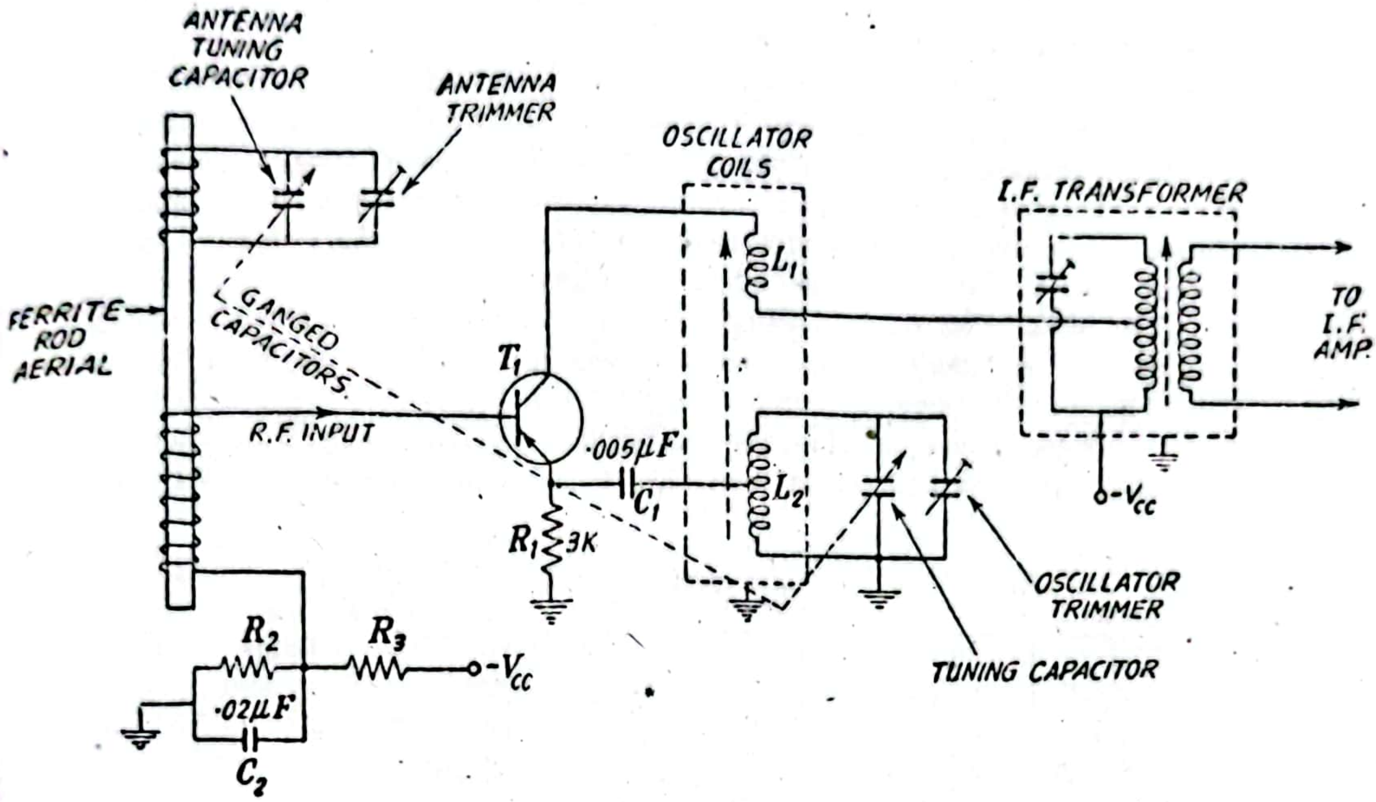


Fig. 9.15. Frequency converter using transistors.

Frequency converter circuit is most popularly used in all cheaper type of broadcast receivers since this circuit needs only one transistor. Further in these receivers, no R.F. amplifier is used. Hence, in the circuit of Fig. 9.15, the R.F. voltage from the ferrite rod aerial is fed directly to the converter input.

9.18. Tracking and Alignment of Receiver for Single Dial Tuning

Every superheterodyne receiver contains one local oscillator circuit tuned to oscillator frequency $f_o (= f_s + f_i)$ and one or more tuned circuits tuned to the signal frequency f_s. The number of R.F. tuned circuits equals $(n + 1)$, where n equals the number of R.F. amplifier stages. Thus if one R.F. amplifier stage is used, there results two R.F. tuned circuits. For expeditious and simple tuning of the receiver all these tuned circuits namely the R.F. tuned circuits and the oscillator tuned circuit must be tuned by movement of a single dial. Such a single dial tuning requires that the rotors of all these tuning capacitors be mounted on the same shaft, *i.e.* the tuning capacitors be ganged. Satisfactory single dial tuning requires that on tuning to a signal frequency f_s, all R.F. tuned circuit must be tuned exactly to the desired signal frequency f_s while the oscillator tuned circuit must be tuned exactly to the corresponding oscillator frequency f_o $(= f_s + f_i)$. So far as tuning of signal frequency tuned circuit is concerned, this can be readily achieved in capacitance tuning arrangement by using identical fixed coil and identical tuning capacitors with their rotors mounted on the same shaft in position correspondence. Residual errors may be corrected by adjustments of L and C of individual tuning circuit. This marginal adjustment is called *R.F. circuit alignment*.

Procedure for R.F. Alignment. The alignment of R.F. circuits consists in the following steps :

(*i*) Feeding at the receiver input, a signal of frequency at the high frequency end of the tuning dial, tuning the receiver to this signal frequency and adjusting the R.F. circuit trimmers to get maximum power in the receiver output.

(*ii*) Repeating the above procedure for a signal frequency at the low frequency end of the tuning band.