RADIO AMATEUR EXAM
GENERAL CLASS

By **4S7VJ**

CHAPTER-6
TRANSMISSION LINES AND ANTENNAS

6.1 Transmission line

There are three separate parts are involved in an antenna system;

1. The radiator (antenna)
2. Transmission line (Feed line)
3. Coupling arrangement (antenna tuner)

The place where RF power is generated is very frequently not the place where it is to be utilized. The antenna to radiate well, should be high above the ground and should be keep clear of trees and other obstacles that might absorb energy, but the transmitter itself is most conveniently installed indoor where it is readily accessible. The transmission line used to connect the antenna to the TX or Rx with a minimum of loss due to resistance or radiation. By the use of transmission lines or feeders, the power of the TX can be carried appreciable distance without much loss due to conductor resistance, insulator losses or radiation.

Types of Transmission line

There are three main types of transmission lines.

(1) The **single wire feed** arranged so that there is a true traveling wave on it.
(2) The **parallel wire line** with two conductors carrying equal but oppositely directed current and voltages, is balanced with respect to earth.
(3) The **coaxial** or concentric line in which the outer conductor enclosed the inner conductor.

6.1.1 Single wire feeder

Single wire feeders are inefficient and now seldom used since it is impossible to prevent them acting to some extent as radiators, and the return path which is via the ground, introduced further losses. The feeder wire itself also acting as the antenna.

6.1.2 Parallel wire line

This is called as a balanced line or open wire line. There are two types, two open parallel wires separated by insulating spreaders, and the other type is twin-lead, in which the wires are embedded in solid formed insulation. The field is confined to the immediate vicinity of the conductor and there is negligible radiation (losses), if proper precautions are taken. Line losses results from Ohmic resistance, radiation from the line and deficiencies in the insulation. Large conductors, closely spaced in terms of wavelength, and using a minimum of insulation, make the best balanced line. Balanced lines are best in straight runs. If bends are unavoidable, the angle should be as obtuse (between 90° and 180°) as possible. Care should be prevent one wire from coming closer to metal object than the other. Wire spacing should be less than 1/20 of wavelength.

Properly build open-wire line can operate with very low loss in VHF and even UHF installations. A total line loss under 2dB per 100ft at 432MHz is readily obtained. A similar 144MHz setup (2 meter band) could have a line loss under 1dB per 100ft.

6.1.3 Coaxial line

Coaxial or concentric line made out of two cylindrical conductors having a common axis. The space between two conductors is filled with an insulating material; may be a solid or air. In the coaxial line the current passes along the center conductor and returns along the inside of the sheath or braid. Due to skin effect at high frequencies the current do not penetrate more than a few micro meters into the metal; hence with any practical thickness of the sheath there is no current on the outside. The fields are thus held inside the cable and cannot radiate.

6.1.4 Characteristic Impedance

If the transmission line were infinitely long and free from losses a signal applied to the input end would travel on for ever, energy being drawn away from the source of signal just as if a resistance had been connected instead of the infinite line. This resistance is known as the **Characteristic Impedance** of the line and usually denoted by the symbol "Zo". If we replace the line with pure resistance of Zo the generator will not be aware of any change. There is still no reflection, all the power applied to the input end of the line is absorbed in the terminating resistance, and the line is said to be matched.

A transmission line can be considered as a long ladder network of series inductances and shunt capacitances, corresponding to the inductance of the wires and the capacitance between them. It differs from conventional L-C circuits in that these properties are uniformly distributed along the line. If the inductance and capacitance for **any particular length** are L and C then the characteristic impedance Zo given by:

$$Zo = \sqrt{(L/C)} \text{ Ohms}$$

(If "L" in Henrys and "C" in Farads then "Zo" is in Ohms and also "L" in micro Henrys and "C" in micro Farads then "Zo" is in Ohms.)

N.B.:-

Almost every book says the value of "L" and "C" are the inductance and capacitance for a **unit length** of the coaxial cable but it is not true, any length is suitable, and also there is no difference between straight cable or coiled form according to my practical experience.

Characteristic impedance of a parallel wire line:-

Suppose the radius of the cross section of each wire is "r" and the distance between two axis's is "s" then the characteristic impedance:

$$Zo = 276 \log(s/r) \text{ Ohms}$$

Characteristic impedance of a coaxial line:-

Suppose the diameters of outer conductor and inner conductor respectively "D" and "d" then the characteristic impedance of an **air core** coaxial line:-

$$Zo = 138 \log(D/d) \text{ Ohms}$$

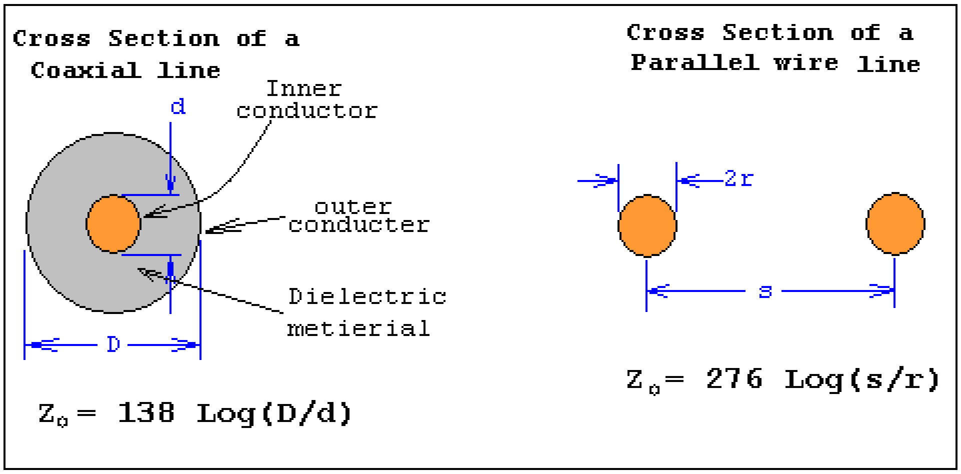

Fig 6.1

6.1.4.1 How to Measure the Characteristic Impedance

Capacitance "C"

First you take a coaxial cable having several meters long. Keep both ends open. Measure the capacitance between centre conductor and the braid with using a capacitance meter(digital multimeter) or DIP meter. (Fig. 6.2)

Inductance "L"

Then short circuit one end of the cable, and measure the inductance between the centre conductor and the braid of the other end by using an inductance meter (digital multimeter) or with a DIP-meter. (Fig. 6.2)

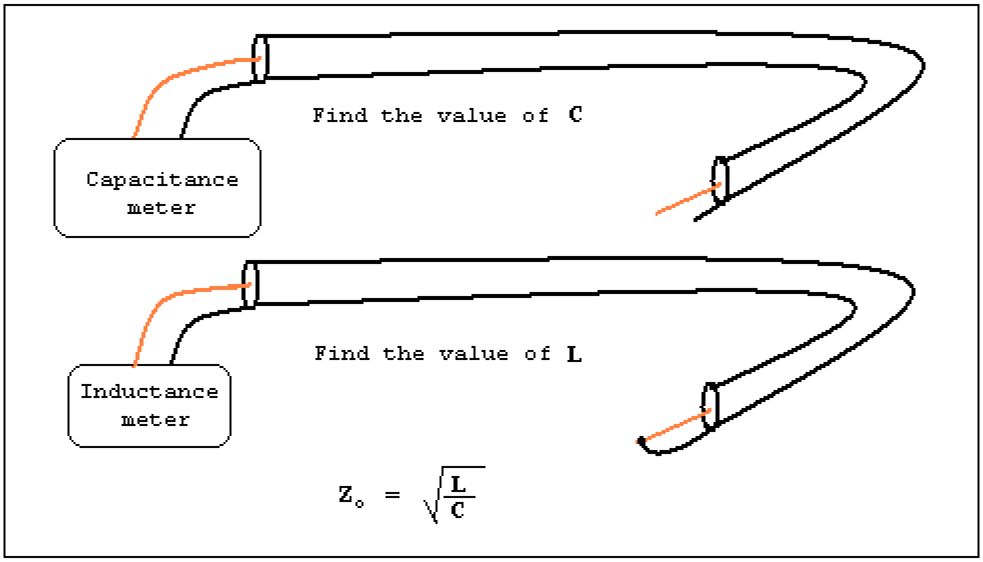

Fig 6.2

6.1.5 Velocity Factor

When the medium between the conductors of a transmission line is air, the traveling waves will propagate along it at the same speed as waves in free space. If a dielectric material is introduced between the conductors for insulation or support purposes, the waves will be slowed down.

The ratio of the **velocity of the waves on the line to the velocity in free space** is known as the velocity factor. It is approximately 0.66 for solid polythene cables. For open wire lines, it is between 0.8 and 0.95, while open wire lines with spacers at intervals may reach 0.98. It is important to make proper allowances for this factor in some feeder applications. For example **if velocity factor is 2/3 (or 0.66) then quarter wave line would be physically 1/6 wavelength long. (2/3 x 1/4 = 1/6)**

6.1.6 Standing waves

When a transmission line terminated by a resistance equal in value to its characteristics impedance, there is no reflection and the line carries a pure traveling wave. When the line is not correctly terminated, the voltage to current ratio is not the same for the load as for the line and the power fed along the line cannot all be absorbed to the load, some of it is reflected in the form of a secondary traveling wave, which must return along the line. These two waves, forward and reflected, interact all along the line to setup a **standing wave.**

6.1.7 Standing Wave Ratio – SWR

For get the maximum efficiency of a transmission line the characteristic impedance of the line (Zo) should be equal to the characteristic impedance of the antenna (Z).

Standing wave ratio or **SWR** is a figure which can be measure the amount of mismatch of the antenna system. This is always equal or greater than 1. **SWR = 1 for a perfectly matched antenna system.**

SWR = Zo/Z or **Z/Zo** (which ever is greater)

Example:

A transmission line having a characteristic impedance of 50 Ω and terminating to an antenna having 40Ω radiation resistance. What is the SWR of the antenna system?

Solution:

Zo = 50Ω and Z = 40Ω
SWR = Z/Zo
= 50/40
= **1.25**

If the line is not perfectly match, there is a standing wave along the transmission line. Therefore the voltage and the current is varying according to the standing wave. Then the ratio between the maximum and minimum value of current or voltage is equal to the SWR. Refer the diagram (Fig.6.3)

SWR = Imax/Imin
= Vmax/Vmin

If the transmission line is perfectly matched to the antenna, the voltage or current through the line is constant and **SWR = 1**

Example:

The maximum and minimum voltages along a transmission line are 180 and 100 respectively. What is the SWR of the system.

Solution:

SWR = Vmax/Vmin , Vmax = 180v, Vmin = 100v
= 180/100 = **1.8**

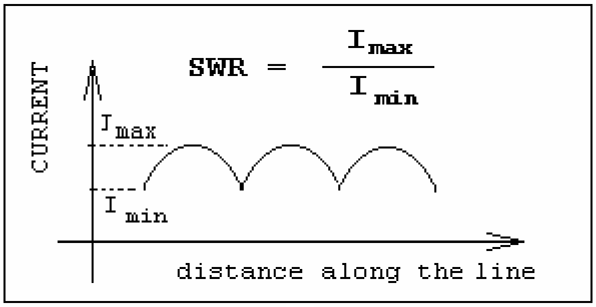

Fig 6.3

Measure the SWR according to the above explanation is not practicable because no way to measure these values.

6.1.7.1 **SWR METER**

This is a simple instrument use for measure SWR of a transmission line. Every shack should have one SWR meter. It can be the first indicator of antenna trouble. Fig 6.4 shows the circuit diagram for a simple SWR meter. (Refer paragraph 7.2.1 in the chapter-7 for calibration detail)

There is a special type of SWR meter use for visually handicaps. In this instrument generates an audio tone, the frequency of the tone is varying according to the SWR.

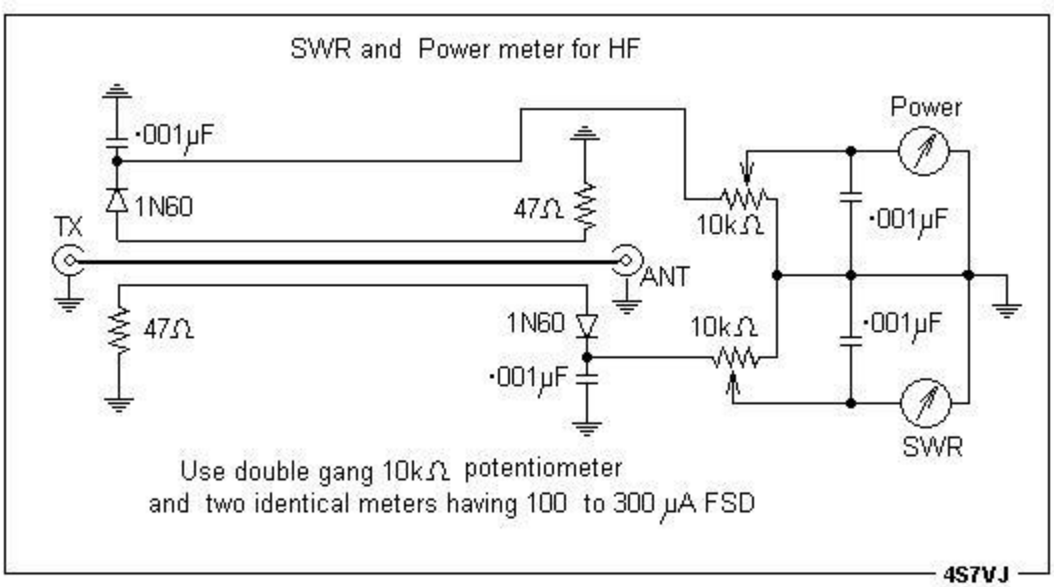

Fig. 6.4

6.1.8 Reflection Coefficient

The ratio of the voltage in the reflected wave to the voltage in the incident wave (forward voltage) is defined as the **reflection Coefficient.** This coefficient is designated by the Greek letter rho **(ρ)**

$\rho = V_r / V_f$ V_r = reflected voltage
V_f = forward voltage

$\rho = \sqrt{(P_r / P_f)}$ P_r = reflected power
P_f = forward power

For perfectly matched transmission line,

$\rho = 0$ because $V_r = 0$ or $P_r = 0$

For completely mismatched transmission line,
$\rho = 1$ because $V_r = V_f$ or $P_r = P_f$

6.1.9 Relationship between SWR and reflection coefficient

$$\text{SWR} = \frac{1 + \rho}{1 - \rho}$$

$$\rho = \frac{\text{SWR} - 1}{\text{SWR} + 1}$$

6.1.10 Relationship between SWR and voltage

We can rearrange the above formula with the forward and reflected voltages as follows:

$$\text{SWR} = \frac{V_f + V_r}{V_f - V_r}$$

6.1.11 Relationship between SWR and power

If the forward power and reflected power are respectively P_f and P_r then we can rearrange the above formula as follows:

$$\text{SWR} = \sqrt{[(P_f + P_r)/(P_f - P_r)]}$$

6.2 ANTENNAS (Aerials)

Introduction

The radio signal passes from one station to another station as a wave propagating in the atmosphere, but in order to achieve this it is necessary to have at the sending end something which will take the power from the transmitter and launch it as a wave, and at the other end extract energy from the wave to feed the receiver. This is an antenna (aerial) and, because the fundamental action of an antenna is reversible, similar antennas can be used at both ends. The antenna then is a means of converting power flowing in wires to energy flowing in a wave in space, or is simply considered as a coupling transformer between the wires and free space.

Dipole

The most simple and commonly used word in antenna work is **Dipole** or **simple dipole.** Basically a dipole is simply which has two poles or terminals into which radiation-producing current flow. Dipole is used as a reference antenna for antenna experiments.

6.2.1 Properties of Antennas

There are some important properties of antennas as follows:

1. Resonant
2. Radiation
3. polarization
4. Directivity
5. Gain
6. Radiation resistance

6.2.1.1 Resonance of an Antenna

When the SWR of an antenna is 1 (or 1:1) then the antenna is perfectly matched, in other word the total RF power out put is converts to electro magnetic wave or we can say the antenna is resonating for the particular frequency. Normally this is happens for the multiple of half wave lengths of the antenna.

6.2.1.2 Radiation

Whenever a wire carries an alternating current the electromagnetic wave travel away into the space with the velocity of light. It is called the radiation of the electromagnetic energy or RF (radio frequency) energy. We normally use the antenna as the radiator or radiating element. The amount of radiation is proportional to the current flowing into the antenna.

6.2.1.3 Polarization

There are two inseparable fields associated with the transmitted signal,

1. An electric field due to voltage changes,
2. A magnetic field due to the current changes,

and these always remain at right angles to one another and to the direction of propagation as the wave proceeds. The lines of forces in the electric field run in the plane of the transmitting antenna. By convention the **direction of the lines of forces of the electric field defines as the direction of polarization** or the plane of polarization of the radio wave.

Thus **horizontal antennas propagates horizontal polarized waves and vertical antennas propagates vertical polarized waves.**

For the maximum performance RX antenna also should be in the same polarization plane. When the TX antenna is horizontal, RX antenna also should be in the horizontal plane.

Circular Polarization

For long distance propagation through ionospheric layers, due to reflection, refraction and diffraction a degree of cross polarization may be introduced which results in signals arriving at the receiving antenna with both horizontal and vertical components presents. This signal called as **circularly polarized.** Varying of the plane of the receiving antenna is not giving any deference for circular polarized signal.

6.2.1.4 Directivity

The radiation field which surrounds the antenna is not uniformly strong in all directions. It is strongest in directions at right angles to the current flow in the antenna element and falls in intensity to zero along the axis of the element; in other words its exhibits directivity in its radiation pattern, the energy being concentrated in some directions at the expense of others. Later it will be explained how directivity may be increased by using number of elements. These are called beam antennas.

6.2.1.5 Antenna Gain

If one antenna system can be made to concentrate more radiation in a certain direction than another antenna (reference antenna), for the same total power supplied, then it is said to exhibit **gain** over the second antenna in that direction. In other words, more power would have to be supplied to the reference antenna to give the same radiated signal in the direction under the consideration.

Gain can be expressed either as a ratio of the power required to be supplied to each antenna to give equal signals at a distant point, or as the ratio of the signals received at that point from the two antennas when they are driven with the same power input. Gain is usually expressed in **decibels.**

6.2.1.6 Radiation resistance or antenna impedance

When power is delivered from the transmitter into the antenna, some small part will be lost as heat, since the material of which the antenna is made will have a finite resistance, albeit small, and a current flowing in it will dissipate some power. The bulk of the power will usually be radiated and, since power can only be consumed by a resistance, it is convenient to consider the radiated power as dissipated in an imaginary resistance which is called the ***radiation resistance*** of the antenna.

Using ordinary relationships of circuits, if the current flow is ***I*** into the radiation resistance ***R*** then the power of ***I x I x R*** watts is being radiated. ($W = I^2R$)

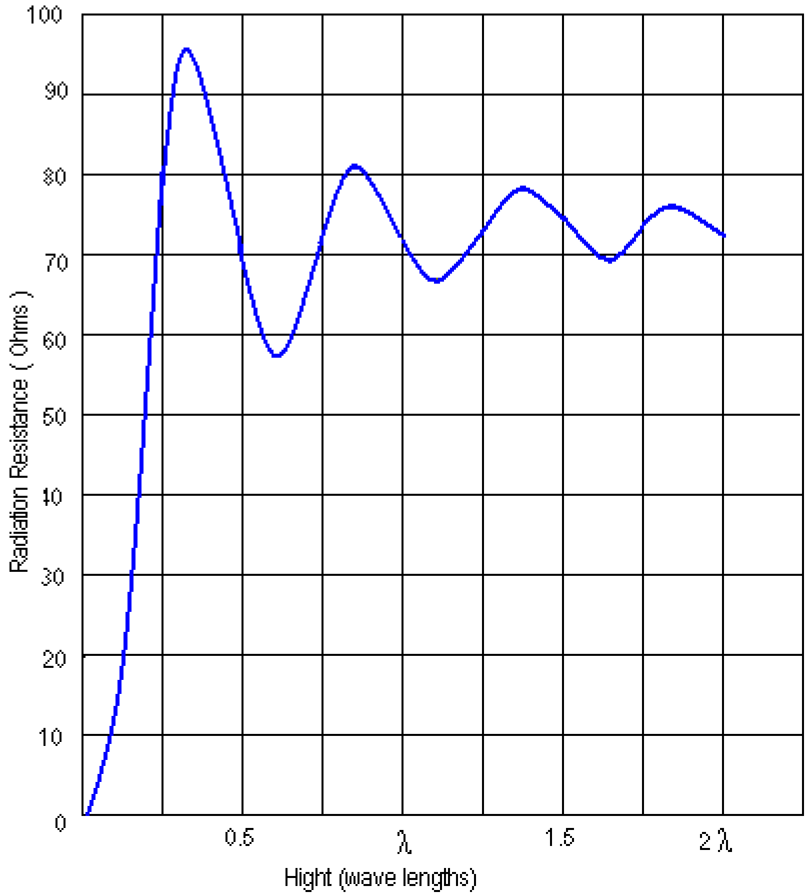

Fig 6.5

The radiation resistance of an antenna is varying with the height above the ground. Fig 6.5 shows the pattern of variation for simple dipole. It is approaching to 72 Ohms.

6.2.1.7 **Free Space Wave Length**

The relation between the wave length and frequency is very simple. The product of wave length and frequency is equal to the speed of electro magnetic wave (radio signal).

$$v = f \times \lambda$$

Where, v = speed, f = frequency, λ = wave length, speed and wave length are depend on the medium which the wave is traveling. We can assume that the wave is traveling through air (atmosphere) and free space. Speed of radio waves (same as speed of light) in the free space and the air are almost same. It is 299,792,458 m/s (299.792458 Mm/s) in free space. If we take the frequency in MHz and wave length in meters, then speed is in Mega meters, so we can write the above formula as

$$\mathbf{299.792458}\ (\text{Mm/s}) = \mathbf{f}\ (\text{MHz}) \times \boldsymbol{\lambda}\ (\text{m})$$

or

$$\text{MHz} \times \text{meter} = 299.792458$$

Approximately we can consider this as

$$\mathbf{MHz \times meter = 300}$$

6.2.2 Types of Antennas

There are various types of antennas for using with HF, VHF, UHF, and other bands and also with receivers and transmitters. The following list included several types.

1. Long wire (harmonic)
2. Dipole
3. Vertical antenna
4. Whip
5. Loop
6. Quad
7. Yagi
8. Quagi
9. Parabolic
10. Receiving antenna

All types of above, can be divided into three categories as

1. Omni directional antenna
2. By directional
3. Directional or unidirectional antenna

And also for another three categories as

1. Horizontal polarization
2. Vertical polarization
3. Circular polarization

6.2.2.1 Long wire Antenna (harmonic antenna)

An antenna will be resonant so long as its length is some integral multiple of a half wave-length. When the length of the antenna is more than one wave-length it is called a long-wire antenna, or a harmonic antenna.

This is not a good type of antenna because there are considerable losses and antenna gain is low and SWR is high. But very easy to install. Normally this type is using with an ATU (antenna tuning unit) for reduce the SWR, otherwise the final stage of the TX will be damage by overheating. The efficiency of this antenna is very low.

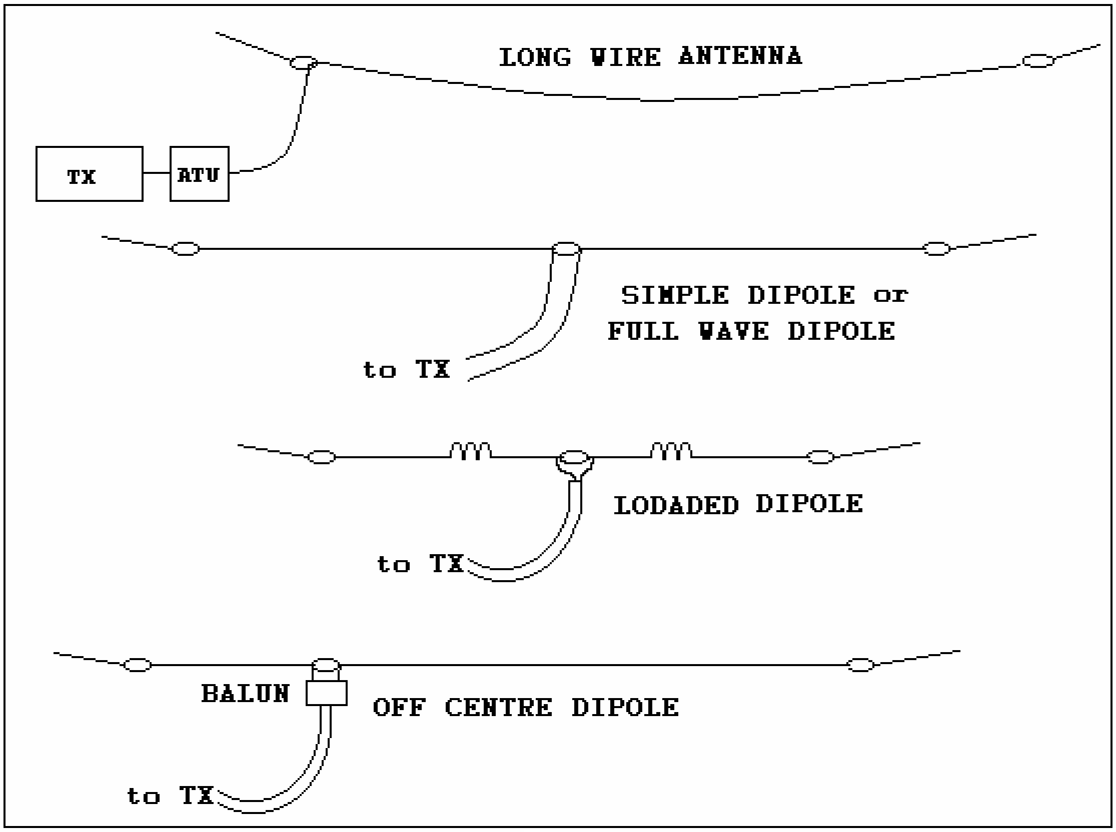

Fig 6.6

6.2.2.2 **Dipole antenna**

As mentioned earlier the dipole is the most simple useful antenna which has two poles. The length of the dipole is depend on the operating frequency or resonance frequency of the dipole. There are several types of dipoles as follows:

1. Simple dipole
2. Full wave dipole
3. Short dipole (loaded dipole)
4. Off center dipole

6.2.2.2.1 **Simple dipole**

If the length is equal to the electrical half-wave length it is called as **simple dipole** or **half wave dipole** and it is normally use as a reference antenna for antenna experiments.

Approximate length **= 467/f** feet,
or
length **= 142/f** meters (f = frequency in MHz)

Theoretical Length = **λ/2**, (150/f meters). this is the half wave length in free space for the particular frequency. The actual length is shorter than the half wave length. It is depend on the diameter of the wire, shorter length for higher diameters.

6.2.2.2.2 Full-wave dipole

The length of this is a full wave length **(λ)** or double the size of the simple dipole.

6.2.2.2.3 Short dipole or Loaded Dipole

A short dipole is less than half wave length. Its needs to be tuned to resonance by the adding of inductance because of mismatch. It should be tune for lowest SWR. This type is very much useful for a location having limited space. Only disadvantage is the narrow bandwidth.

6.2.2.2.4 Off-center dipole

For this dipole feeder wire is not connected to the center or in other words two sides are not equal in lengths. This is a multi-band antenna. The feeder wire connected to the antenna through a matching transformer called as **BALUN** (balance to unbalance transformer).

6.2.2.3 Vertical Antenna

Vertically polarized RF wave propagating from vertical antenna. Radiating element is in vertical, for most of vertical antennas. Fig 6.7 shows various types of vertical antennas. Fig 6.7(a) shows Marconi antenna; quarter wave vertical radiator installed on ground with insulation and it is connected to the center conductor of the coaxial feeder and braid is connected to the ground.

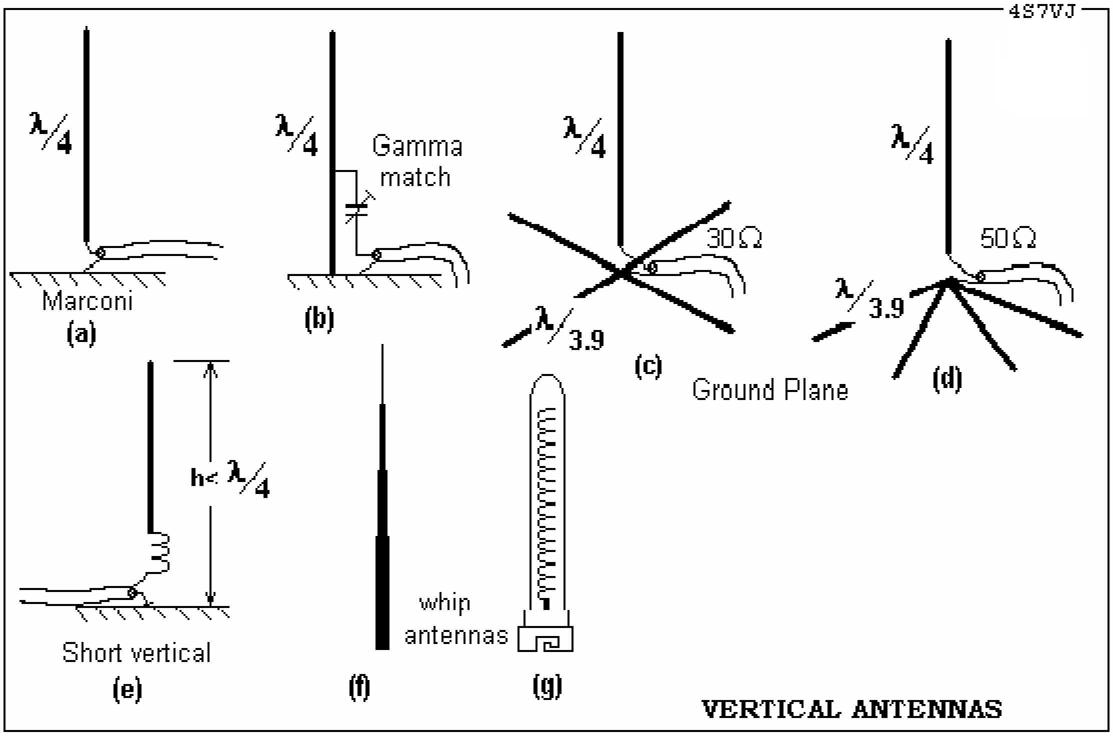

Fig. 6.7

Fig6.6(b) shows grounded quarter wave radiator connected to the coaxial feeder with Gamma match. It is very much protection against lighting because the whole antenna system is grounded. (d.c. ground antenna)

For the Gamma match system, the braid is connected to the ground and center cable connected to some point in the radiator element through a trimmer condenser and adjust the trimmer for the lowest SWR; and also adjust position of the connecting point on the radiator element.

(c)and (d) show λ/4 **Ground plane** antenna having four radials slightly longer than the radiator **(λ/3.9)**. When they are horizontal, feed point impedance is approximately 30**Ω**. If those radials slanted 45° to the horizontal the feed point impedance increase up to 50**Ω**. Instead of being actually grounded, a quarter wave antenna can work against a simulated ground (four radials) called a **ground plane**.

Fig 6.7(e) shows a **short vertical** antenna. The radiator is connected to an inductor (loading coil) at the bottom. This is very useful for low frequency bands (40m or 80m); and also for mobile operations.

Fig 6.7(f) and (g) are **Whip antennas**. Fig 6.7(f) is a telescopic type it is normally use for receivers (radio & TV). Fig 6.7(g) is a **rubber flex whip antenna**; normally use with hand held vhf TRX. The coiled antenna element is covered by a insulated rubber cover.

6.2.2.4 Loop Antenna

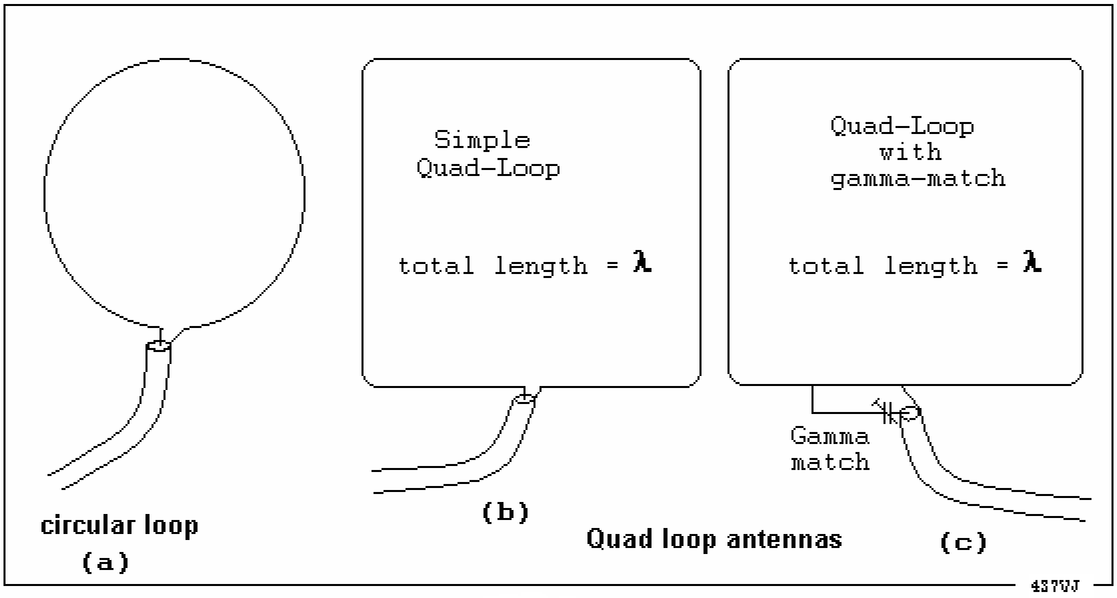

Fig 6.8

6.2.2.4.1 Circular Loop

This is the most simple loop-antenna. A conductor (tube) having a full wave length bend as a circle and two ends connected to the feeder wire. Due to practical difficulties this is suitable only, for vhf and uhf. (Fig6.8-a)

6.2.2.4.2 Quad Loop

A conductor having a full wave length, bend as a square and two ends connected to the feeder wire. (Fig 6.8-b)

If it is attach with a gamma match system and adjusted properly (SWR=1) it will be very much efficient broad band antenna. (Fig 6.8-c)

6.2.2.4.3 Delta Loop

If the same Quad loop antenna bent as a triangle it is called **Delta-Loop** antenna.(Fig 6.9-a)

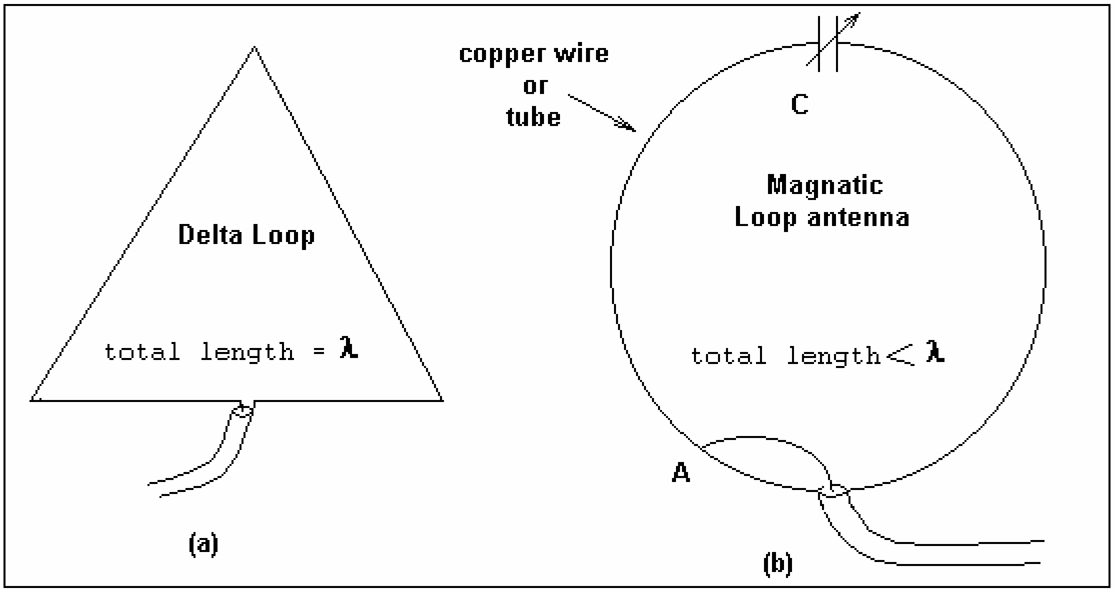

Fig 6.9

6.2.2.4.4 Magnetic Loop antenna

The construction of this is appearing in the diagram (Fig 6.9-b). An open loop constructed by a copper wire or a copper tube, and both open ends at the top are connected to a variable capacitor "C". Inner conductor of the coaxial cable connected at the point "A"; braid is connected at the mid-point of the conductor at the bottom. Position "A" is the deciding factor for the characteristic impedance of the feeder.

The ideal small transmitting antenna would have performance equal to a large antenna. This small loop-antenna can approach that performance except for a reduction in band-width. This is very narrow band, but that effect can be overcome by re-tuning the capacitor "C" for resonance. High voltage develop at the capacitor (few kV). At the resonance SWR = 1. About one meter diameter loop antenna can be use for whole HF band with varying the capacitor. This capacitor is a high quality high voltage type.

6.2.2.5 Quad or Cubical-Quad antenna

This is a directional antenna with a high gain, made with two or more number of Quad-Loops, arrange with a specific dimension.

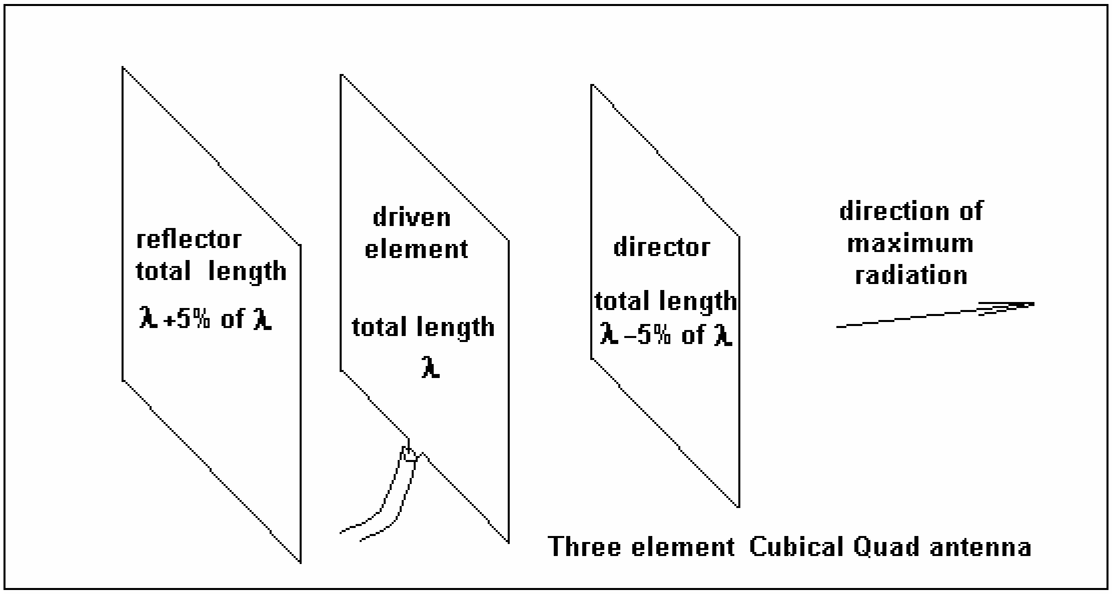

Fig 6.10

Quads have been popular with amateurs during the past few decades because of their light weight, relatively high gain and small turning radius ,and their unique ability to provide good DX performance even when mounted close to the ground. Fig 6.10 shows **three element quad.** The total length of the driven element is full wave length. Reflector is 5% greater than the driven element and director is 5% smaller. All three elements can be mount on an aluminum pipe called boom. If the feeder wire connected through the Gamma-match system, the performance is improving (SWR=1).

6.2.2.6 Yagi Antenna

This is a popular type of directional antenna. The simplest Yagi antenna is one with just two elements as indicated in the Fig 6.11. Fig 6.11(a) is having the reflector and the driven element and 6.11(b) is with the driven element and a director. Fig 6.11(c) is a three element Yagi antenna has a driven element (λ/2 long) the reflector (5% longer than the driven element) and a director (5% shorter than the driven element). The feeder line is connected to the driven element. For improve the performance we must install an impedance matching system in between the driven element and the feeder wire. Fig 6.11(d) is a five element Yagi antenna. If we increase the number of elements according to the proper dimensions; the directional property is increasing. That means, antenna gain for that particular direction is increasing.

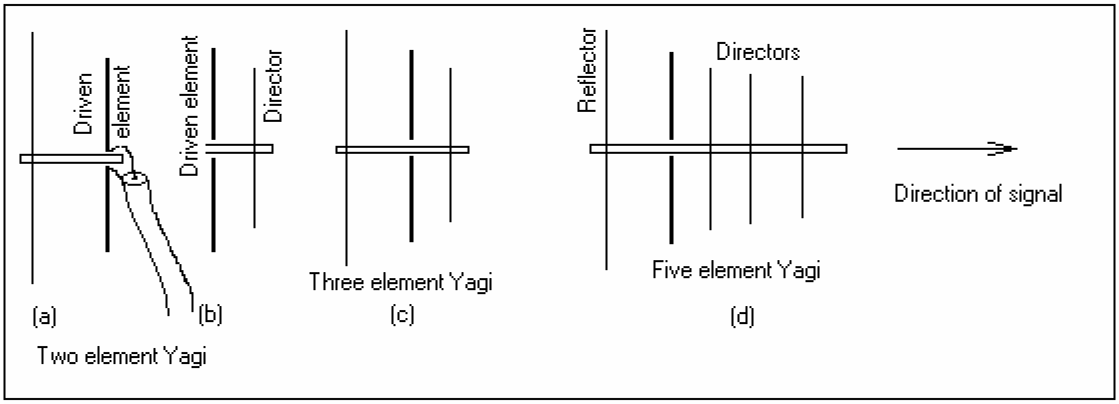

Fig. 6.11

6.2.2.7 Quagi Antenna

This is a combination of a Quad and a Yagi. Normally reflector and driven element are like a Cubical Quad and all directors like Yagi.

6.2.2.8 Parabolic Antenna

This is a dipole antenna installed at the focal point of a parabolic reflector. It is highly directional and very high gain along the axis of the parabolic reflector. This type called as micro wave antenna because this type use only for frequencies higher than UHF. (micro wave)

6.2.2.9 Receiving Antennas

Any type of antenna is possible to use with a receiver; but if it is mismatch with the receiver, the only problem is the strength of the input signal to the RX become weak; there will be no damage or power loss like transmitters. Most popular receiving antennas are

1. Ferrite rod antenna
2. Telescopic antenna
3. Loop antenna
4. Long wire antenna