BASIC RADIO THEORY

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Basic Radio Theory

Basic Radio Theory

1. Alternating current (AC) provides a more efficient means of conveying electrical energy than direct current (DC). With alternating current the electrons flow for half the total time in one direction, and for the other half of the total time in the opposite direction. The pattern of the change of direction of the current flow is **sinusoidal.**

2. It is not possible to produce an AC current flow from a battery. Low frequency AC may be produced by using alternators. The much higher frequencies required for radio and radar equipment are produced using oscillators, which electronically produce alternating current.

FIGURE 1-1
Simple AC Circuit

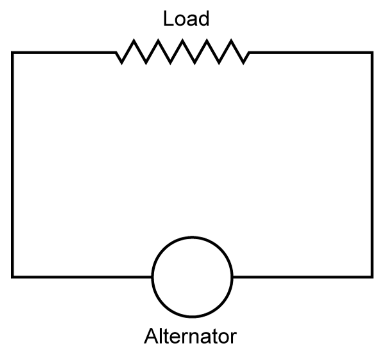
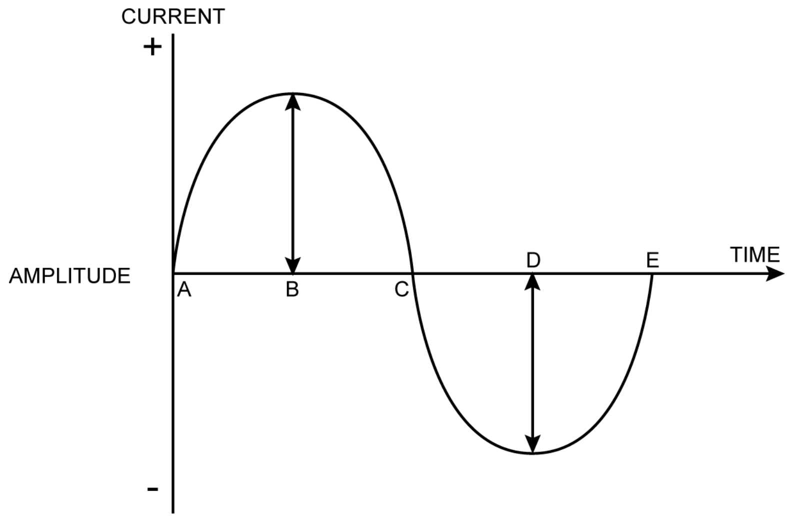


FIGURE 1-2
Current Flow in a Simple AC Circuit



3. In Figure 1-1 the battery in a DC circuit has been replaced by an alternator. Figure 1-2 shows the sinusoidal variation of current flow. Note that at times **A, C** and **E** no current flows, whilst at times **B** and **D** the current flow is at maximum, but in opposite directions. Note also that the **amplitude** of the wave is measured at its maximum value, at times **B** and **D**.

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4. Time **A** to **E** at Figure 1-2 represents one complete cycle. The term **frequency** is used to denote the number of cycles occurring in one second. With the UK National Grid system the time taken for each cycle is one-fiftieth of a second, giving a frequency of 50 **cycles per second**, or 50 **Hertz** (50 Hz). Aircraft AC supply frequency is normally 400 Hz. The frequencies used for radio wave transmissions are very much higher than 50 Hz. In order to simplify matters the units shown below are used.

1,000 Hz	=	1×10^3 Hz	=	1 Kilohertz (1KHz)
1,000,000 Hz	=	1×10^6 Hz	=	1 Megahertz (1 MHz)
1,000,000,000 Hz	=	1×10^9 Hz	=	1 Gigahertz (1 GHz)

5. If a wire (or **antenna**) is supplied with alternating current, some of the power is radiated into space as electromagnetic energy. A similar wire (antenna), parallel to the first, will have a small alternating current induced in it as the radiated electromagnetic energy passes over it. The characteristics of the induced AC will be identical to those supplied to the transmitting wire. This is the basis of all radio transmitting and receiving systems.

6. As the frequency increases the time taken to complete each cycle decreases accordingly. Consequently it is necessary to simplify the units of time, as shown below.

$\frac{1}{1,000}$ second	=	1×10^{-3}	=	1 millisecond (1 m sec)

$$\frac{1}{1,000,000}\text{ second} \quad = \quad 1 \times 10^{-6} \quad = \quad 1 \text{ microsecond } (1\ \mu \text{ sec})$$

7. The frequencies used for radio and radar systems are delineated into convenient **bands**, each frequency band having, to a degree, its own unique characteristics, as will be seen shortly. Figure 1-3 shows the frequency bands which need concern us.

FIGURE 1-3
Frequency Bands

Band	Frequency Range
VLF Very Low Frequency	3 –30 KHz
LF Low Frequency	30 – 300 KHz
MF Medium Frequency	300 KHz – 3 MHz
HF High Frequency	3 – 30 MHz
VHF Very High Frequency	30 – 300 MHz
UHF Ultra High Frequency	300 MHz – 3 GHz
SHF Super High Frequency	3 – 30 GHz
EHF Extremely High Frequency	30 – 300 GHz

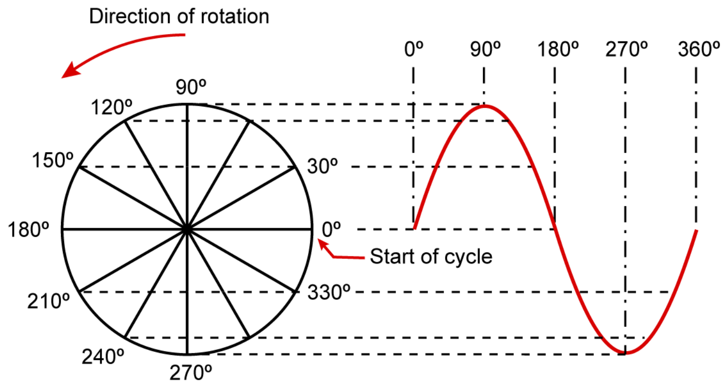
Phase Notation

8. When considering alternating current flow, or an electromagnetic force field, it is convenient to denote a particular point on the sine waveform using **phase notation**. Sine waves are constructed as shown at Figure 1-4, by tracing the progress of a given point on the circumference of a circle, the radius of which determines the amplitude of the wave. The 0° phase point always lies on the zero amplitude line at the start of the positive half of the sine wave.

9. Considering the construction it is easy to visualise phase notation. Of course the time taken for one complete 360° cycle (the horizontal axis of the graph) is dependent upon the frequency considered, the time being in fact 1/F seconds.

10. Phase notation is important since several of the equipments subsequently studied employ **phase comparison** techniques in order to determine aircraft position.

FIGURE 1-4
Construction of a Sine Wave



Phase Comparison

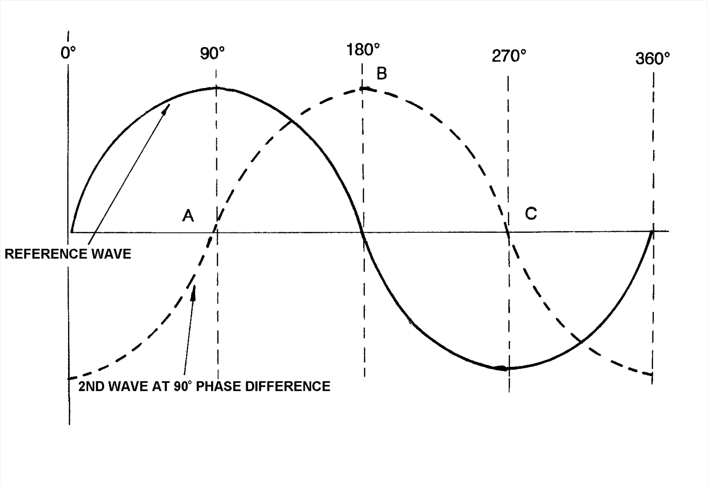
11. It is necessary to adopt a **precise** approach to the construction of a diagram showing a fixed phase difference between two sine waves. Of course, if the phase difference is to remain fixed, **the sine waves must be of exactly the same frequency.**

EXAMPLE

Draw a diagram to illustrate two sine waves which are of the same amplitude but 90° apart.

SOLUTION

First draw one of the sine waves as a reference waveform, the solid sine wave shown below.



In this case the phase difference is 90° and so the second waveform starts at the 90° phase point of the reference waveform, (point A) in the preceeding diagram. Similarly when the reference wave is at the 180° phase point the second waveform will be at its (180 – 90) 90° phase point, (position B) in the diagram. When the reference wave is at is 270° phase point the second waveform will be at its (270 – 90) 180° phase point, (position C) in the diagram and so on.

12. Figure 1-5 and Figure 1-6 show two further examples of phase comparison diagrams.

FIGURE 1-5
Two Sine Waves, 135° Phase Difference

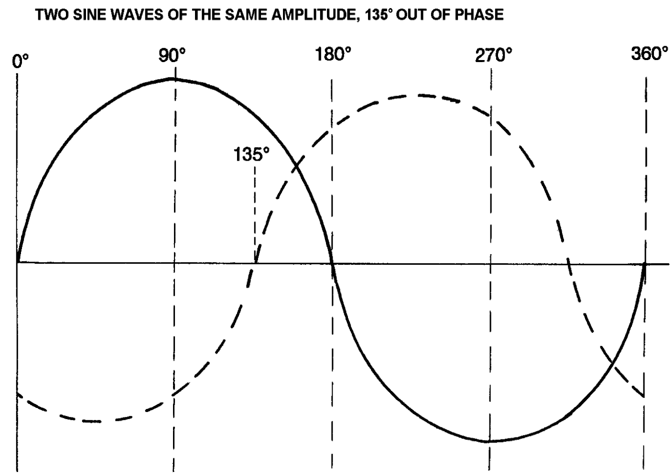
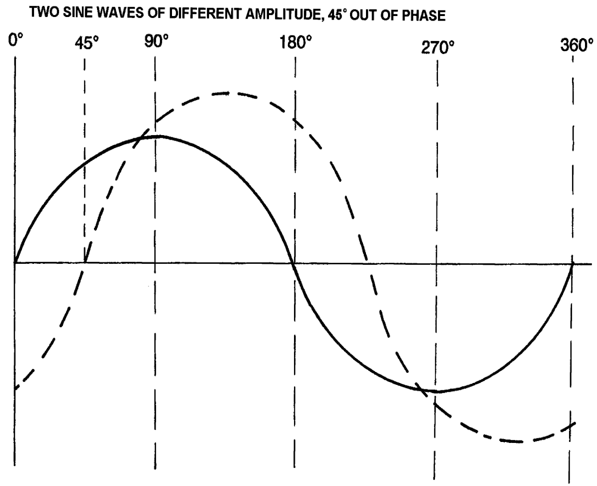


FIGURE 1-6
Two Sine Waves, 45° Phase Difference



Wavelength

13. Once an electromagnetic wave has left the transmitting aerial it is assumed to travel at the speed of light (C), which is:

300,000,000 metres per second

or

3×10^8 m/sec

14. The wave will travel a given distance in the small but finite time taken to transmit one complete cycle of energy, and this distance is known as the **wavelength** (λ). The higher the frequency the shorter the length of time required to transmit one complete cycle, and consequently the shorter the wavelength.

The relationship between frequency and wavelength is given by the formula:

$$F = \frac{C}{\lambda}$$

or

$$\lambda = \frac{C}{F}$$

where

F is the frequency in hertz

λ is the wavelength in metres

C is the speed of propagation, 3×10^8 m/sec

EXAMPLE 1-2

EXAMPLE

Given a wavelength of 30 metres, determine the frequency.

SOLUTION

$$F = \frac{C}{\lambda} \qquad \text{or} \qquad F = \frac{C}{\lambda}$$

$$F = \frac{300{,}000{,}000 \text{ m/sec}}{30 \text{ m}} \qquad \text{or} \qquad F = \frac{3 \times 10^8 \text{ m/sec}}{30 \text{ m}}$$

$$F = 10{,}000{,}000 \text{ Hz} \qquad \text{or} \qquad F = 1 \times 10^7 \text{ Hz}$$

$$F = 10 \text{ Mhz} \qquad\qquad F = 10 \text{ Mhz}$$

EXAMPLE 1-3

EXAMPLE

Given a wavelength of 35 kilometres, calculate the frequency.

SOLUTION

$$F = \frac{C}{\lambda} \quad \text{or} \quad F = \frac{C}{\lambda}$$

$$F = \frac{300{,}000{,}000 \text{ m/sec}}{35{,}000 \text{ m}} \quad \text{or} \quad F = \frac{3 \times 10^8 \text{ m/sec}}{35 \times 10^3 \text{ m}}$$

$$F = 8571 \text{ Hz} \quad \text{or} \quad F = 0.08571 \times 10^5 \text{ Hz}$$

$$F = 8.571 \text{ Khz} \quad \text{or} \quad F = 8.571 \text{ Khz}$$

EXAMPLE 1-4

EXAMPLE

Given a wavelength of 4.5 cm, calculate the frequency.

SOLUTION

$F = \frac{C}{\lambda}$ or $F = \frac{C}{\lambda}$

$F = \frac{300{,}000{,}000 \text{ m/sec}}{0.045 \text{ m}}$ or $F = \frac{3 \times 10^{8} \text{ m/sec}}{4.5 \times 10^{-2} \text{ m}}$

$F = 6{,}666{,}666{,}666$ Hz or $F = 0.667 \times 10^{10}$ Hz

$F = 6.67$ Ghz or $F = 6.67$ Ghz

EXAMPLE 1-5

EXAMPLE

Given a frequency of 15 KHz, calculate the wavelength.

SOLUTION

$$\lambda = \frac{C}{F} \qquad \text{or} \qquad \lambda = \frac{C}{F}$$

$$\lambda = \frac{300{,}000{,}000 \text{ m/sec}}{15{,}000 \text{ Hz}} \qquad \text{or} \qquad \lambda = \frac{3 \times 10^8 \text{ m/sec}}{15 \times 10^3 \text{ Hz}}$$

$$\lambda = 20{,}000 \text{ m} \qquad \text{or} \qquad \lambda = 0.2 \times 10^5 \text{ m}$$

$$\lambda = 20 \text{ km} \qquad \text{or} \qquad \lambda = 20 \text{ km}$$

EXAMPLE 1-6

EXAMPLE

Given a frequency of 9.7 GHz, calculate the wavelength.

SOLUTION

$$\lambda = \frac{C}{F} \quad \text{or} \quad \lambda = \frac{C}{F}$$

$$\lambda = \frac{300{,}000{,}000 \text{ m/sec}}{9{,}700{,}000{,}000 \text{ Hz}} \quad \text{or} \quad \lambda = \frac{3 \times 10^8 \text{ m/sec}}{9.7 \times 10^9 \text{ Hz}}$$

$$\lambda = 0.031 \text{ m} \quad \text{or} \quad \lambda = 3.1 \times 10^{-2} \text{ m}$$

$$\lambda = 3.1 \text{ cm} \quad \text{or} \quad \lambda = 3.1 \text{ cm}$$

15. Figure 1-7 reproduces the table of radio frequency bands previously shown at Figure 1-3 but now includes the wavelengths pertinent to the various frequencies shown.

FIGURE 1-7
Frequency Bands and Associated Wavelengths

Band	Frequency Range	Wavelength Range	Wavelength Denomination
VLF Very Low Frequency	3 – 30 KHz	100 km – 10 km	Myriametric
LF Low Frequency	30 – 300 KHz	10 km – 1 km	Kilometric
MF Medium Frequency	300 KHz – 3 MHz	1 km – 100 m	Hectometric
HF High Frequency	3 –30 MHz	100 m – 10 m	Decametric
VHF Very High Frequency	30 – 300 MHz	10 m – 1 m	Metric
UHF Ultra High Frequency	300 MHz – 3 GHz	1 m – 10 cm	Decimetric
SHF Super High Frequency	3 – 30 GHz	10 cm – 1 cm	Centimetric (Microwave)
EHF Extremely High Frequency	30 – 300 GHz	1 cm – 1 mm	Millimetric

Radio Wave Emission

16. If an alternating current at a suitable frequency is fed to a transmitting element (**aerial** or **antenna**) of the required dimensions, the current flow through the aerial will result in an **electromagnetic force field** being radiated from the aerial. The **lower the frequency** the **larger the aerial** required for efficient transmission (and reception).

17. A suitable frequency for radio transmission is obtained by means of a radio frequency **oscillator.** This is then amplified and fed to the transmitting aerial via a modulator, which superimposes the signal to be transmitted upon the radio frequency (more of which later).

Oscillators

18. The most common oscillators are circuits, which produce a simple sinusoid at a particular frequency. They may be fixed in frequency (FIXED TUNE) or variable. Mechanical tuning can be used to vary frequency fairly slowly. Electronic tuning will allow very rapid variation of frequency and fine control. (VCO = Voltage Controlled Oscillator).

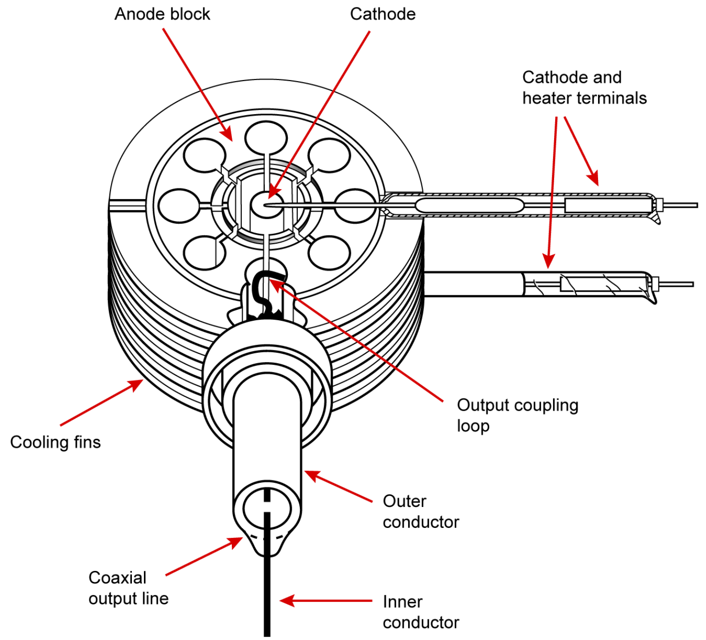
The Magnetron

19. Magnetrons are cross-field oscillators. Electrons, emitted from a central cathode, move out radially under the influence of an electrical (E) field towards the anode block. The E field is associated with a high voltage applied between anode and cathode. A powerful permanent magnet is used to supply a strong magnetic field at right angles to the electric field. Under the influence of these crossed-fields, electrons travel in curved paths in the space between cathode and anode. The anode block is made of copper and contains a number of resonant cavities.

20. The rotating cloud of electrons is made to move in synchronism with a radio wave travelling round the anode block structure. The Magnetron is an amplifier with total feedback; the output is connected directly to the input. This feedback results in oscillation and a pick-up loop in one of the cavities delivers the signal to an output coaxial line or waveguide.

21. Pulse outputs of several MW and CW outputs of a few KW are common. **Magnetrons are often used as the master oscillator in pulse radars.** Output frequency is determined by the shape and size of the resonant cavities. Figure 1-8 shows the general construction of a magnetron.

FIGURE 1-8
Schematic of a Magnetron



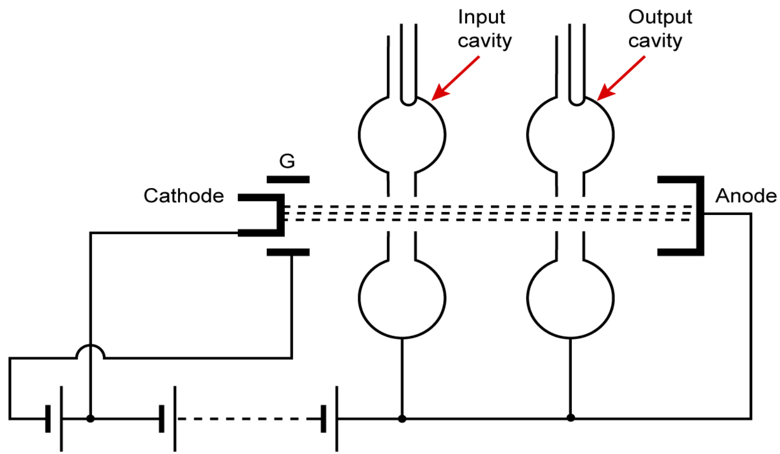
The Klystron Amplifier

22. Figure 1-9 is a schematic diagram of a very simple klystron amplifier. A powerful electron beam passes between an electron gun on the left and a collecting electrode on the right. The beam passes through hollow cavities which are tuned to support electro-magnetic fields alternating at the signal frequency. An input signal enters the input cavity along a waveguide or coaxial cable and creates an alternating field pattern in the cavity. This field disturbs the uniform electron beam creating ripples or concentrations of electrons which increase in intensity as they move along the beam. As they pass through the output cavity, the ripples on the electron beam induce alternating fields, which are stronger replicas of those fed to the input cavity.

23. In practice there are usually a number of intermediate cavities (multi-cavity klystron). These result in a larger gain and wider bandwidth than would be possible using just two cavities. A number of coils carrying direct current surround the valve in order to stop the electron beam from spreading. A longitudinal magnetic field exerts a focusing effect.

24. CW power outputs of several KW are readily available and pulse outputs of several MW. It is important to notice that in a pulse radar application the input to the klystron may be a continuous wave. The pulses are created by turning the amplifier on and off, which ensures a coherent pulse stream. Klystron amplifiers are entirely unsuitable for use as RF amplifiers in radar receivers as they are far too noisy for this application.

FIGURE 1-9
Schematic of a Twin Cavity Klystron



The Reflex Klystron Oscillator

25. A two-cavity klystron amplifier can be made to oscillate by connecting the output cavity to the input cavity in the correct manner. The reflex klystron oscillator features only one cavity but this cavity is used twice. A stream of electrons from the cathode passes through the cavity and is then turned back by the reflector electrode which is maintained at a negative potential. The stream passes through the cavity a second time. It is necessary to adjust the reflector voltage in order to achieve oscillation. The alternating signal in the cavity is extracted along a coaxial cable or waveguide. No magnetic focusing field is required.

26. A low power CW output is available from the reflex klystron, typically a few tens of mW. It can be used as a low power transmitter but is more commonly found in the role of the **local oscillator in a microwave superheat receiver.**

Quartz Crystal Controlled Circuits

27. The basic requirements for a VHF aeromobile band ground transmitter are that the equipment is capable of radiating an amplitude modulated signal (see later) of high stability containing low noise levels and that it is capable of being controlled remotely via telephone lines.

28. Frequency control is by quartz crystal. A number of crystalline substances have the ability to transform mechanical strain into an electrical charge and vice versa. This property is known as the piezoelectric effect.

29. If a small plate or bar of such material is placed between two conducting electrodes it will be mechanically strained when the electrodes are connected to a voltage. Conversely, if the crystal is compressed between two electrodes a voltage will develop across those electrodes, thus piezoelectric crystals can be used to transform electrical to mechanical energy and vice versa. This effect is frequently used in inexpensive microphones, gramophone pick-ups, and in some headphones and loudspeakers. For these purposes crystals of Rochelle salt are used. Crystalline plates also exhibit a mechanical resonance of frequencies ranging from a few thousand to many millions of cycles, the frequency depending on the material of the crystal, the angle at which the plate was cut from the crystal and the physical dimensions of the plate. Due to the piezoelectric effect the plates also exhibit an electrical resonance and act as a very accurate, and highly efficient, tuned circuit. **Such crystals are used in radio equipment in high-stability oscillator circuits and in highly selective filters.**

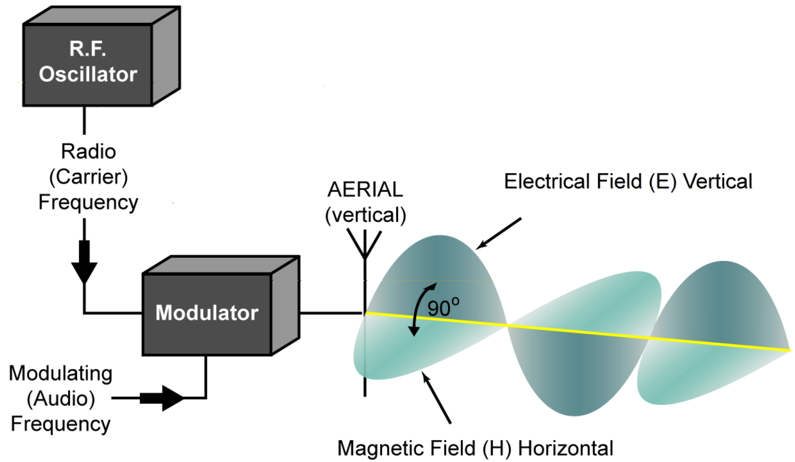
30. In ground transmitters a quartz crystal is used as the frequency determining element, controlling the oscillator circuit. Until recently it has not been possible to manufacture a crystal that will resonate in the 110 MHz to 136 MHz aeromobile band and even now these crystals are fragile and expensive. A crystal on a sub-multiple of the required frequency is therefore often used, followed by circuits designed to multiply the oscillator frequency to the final operating frequency. In early days, crystal frequencies of 5 MHz to 7 MHz were used requiring multiplication factors of 18 or 24 times, but more recently, improved techniques in cutting and mounting have produced much higher frequencies, requiring far less frequency multiplication. The crystal multiplier chain is followed by amplification stages which generate the necessary output power.

Radio Transmitters

31. A simplified block diagram of a radio transmitter, and the electromagnetic field emanating from the aerial, is shown at Figure 1-10.

32. As the name suggests, an electromagnetic force field consists of two distinct elements, the **electric field** (the E field) and the **magnetic field** (the H field). These two force fields exist in planes which are at right angles to each other and which are mutually at right angles to the direction of travel of the radio wave. The amplitude of each force field increases and collapses at the same rate as the alternating current, which is producing the radiated signal.

FIGURE 1-10
Simplified Block Diagram of a Radio Transmitter



Skin Effect

33. The current, which flows to support the H field in an aerial, would exist only on the surface of a perfect conductor. In the case of a practical conductor, the value of current is high at the surface and falls exponentially as distance within the conductor increases. For a good conductor, such as copper, the current value falls very rapidly confining the current, in effect, to a thin skin at the surface. This is the effect known as SKIN EFFECT. Note that skin depth decreases as frequency increases. For copper, skin depth is approximately 1 micron, at a frequency of 3 GHz.

Polarisation

34. The term **polarisation** describes the plane of oscillation of the **electrical field** of an electromagnetic wave. At Figure 1-10 the electrical field of the electromagnetic wave lies in the **vertical plane** and the radio wave is said to be **vertically polarised**. The electromagnetic wave shown at Figure 1-10 is transmitted from a vertical antenna and, being vertically polarised, requires a vertical antenna at the receiver to ensure efficient reception. Similarly, a signal transmitted by a horizontal aerial would be horizontally polarised (the electrical part of the electromagnetic field would oscillate in the horizontal plane), and the receiver aerial would need to be horizontal for optimum reception.

35. In general, a vertically polarised signal will achieve better ranges at frequencies up to and including VHF, however horizontally polarised signals will achieve better ranges at UHF and above.

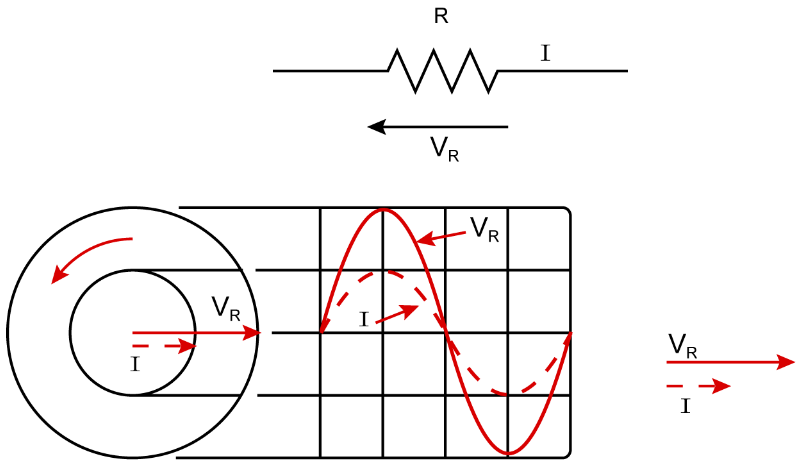
Radio Wave Reception

Electrical Resonant Circuits

36. The first stage of most radio receivers comprises of some sort of electrical resonant circuit, the workings of which will need to be understood by the student. The following paragraphs describe how such a circuit is constructed and its method of operation.

Pure Resistive Circuit

FIGURE 1-11
Phase Diagrams for Pure Resistance



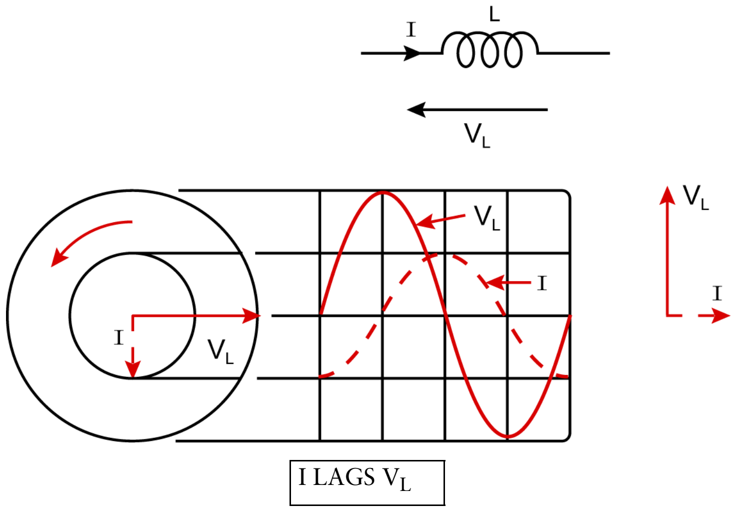
37. An ac flows through a resistance of R ohms, see Figure 1-11. From ohms law we know that V_R = IR. Thus for a pure resistance, the potential difference across it, V_R, is IN PHASE with the current flow through it.

$\boxed{\text{I IN PHASE with } V_R}$

Pure Inductive Circuit

38. Figure 1-12 shows the curve for a sinusoidal current (I), which is flowing through a coil of inductance L henrys. It can be shown that the current lags the applied voltage by 90°.

FIGURE 1-12
Phase Diagram for Pure Inductance



Inductive Reactance. In a pure resistance the ratio of voltage to current gives the resistance R. In a pure inductance the ratio of voltage to current is:

$$\frac{V_L}{I} = 2\pi FL$$

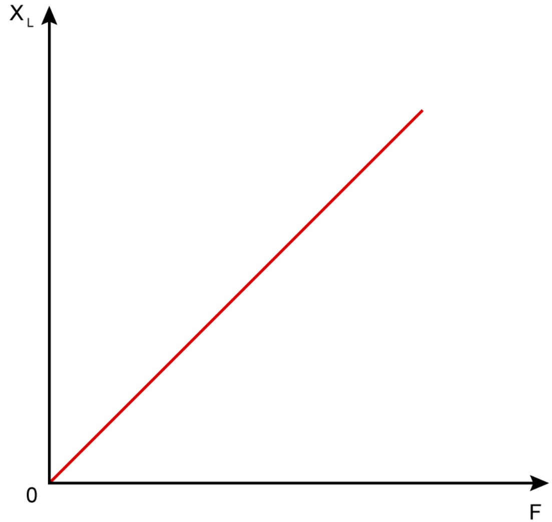
$\frac{V_L}{I}$ is called the INDUCTIVE REACTANCE, X_L, and is measured in ohms

Reactance/Frequency Graph. Figure 1-13 is the reactance – frequency graph for an inductor.

$$X_L = 2\pi FL$$

$$\boxed{X_L \alpha F}$$

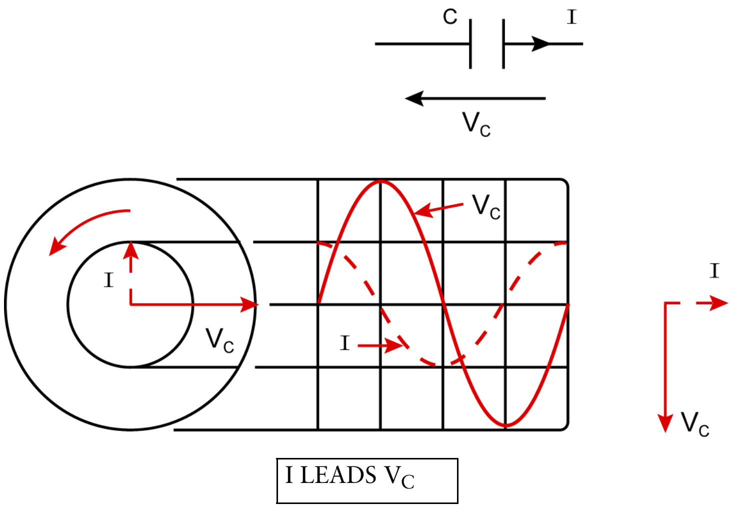
FIGURE 1-13
Effect of Frequency on Inductive Reactance



Pure Capacitive Circuit

39. Figure 1-14 shows the curve for a voltage (V_C) developed across a pure capacitor of capacitance C farads. It can be shown that the current leads the applied voltage by 90°.

FIGURE 1-14
Phase Diagram for Pure Capacitance



NOTE:

Students may find the word 'CIVIL' a useful aid memoir in that in a capacitor current leads voltage, in an inductor voltage leads current.

Capacitive Reactance. In a pure capacitance the ratio of voltage to current is:

$$\frac{V_C}{I} = \frac{1}{2\pi FC}$$

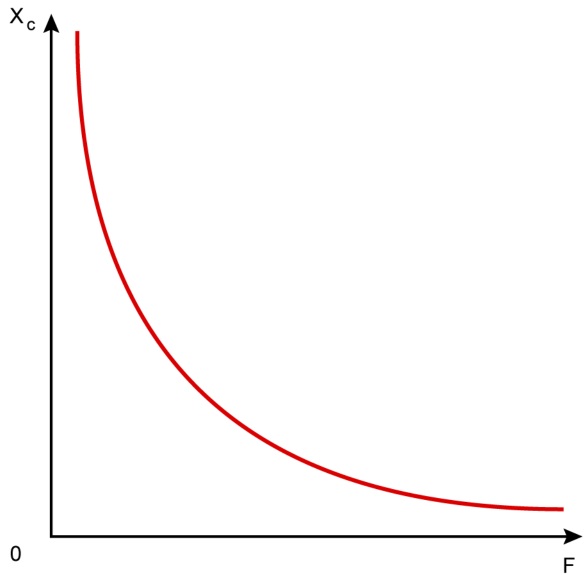
$\frac{V_C}{I}$ is called the CAPACITIVE REACTANCE, X_C, and is measured in ohms

Reactance-Frequency Graph. Figure 1-15 is the reactance frequency graph for a capacitor.

$$X_C = \frac{1}{2\pi FC}$$

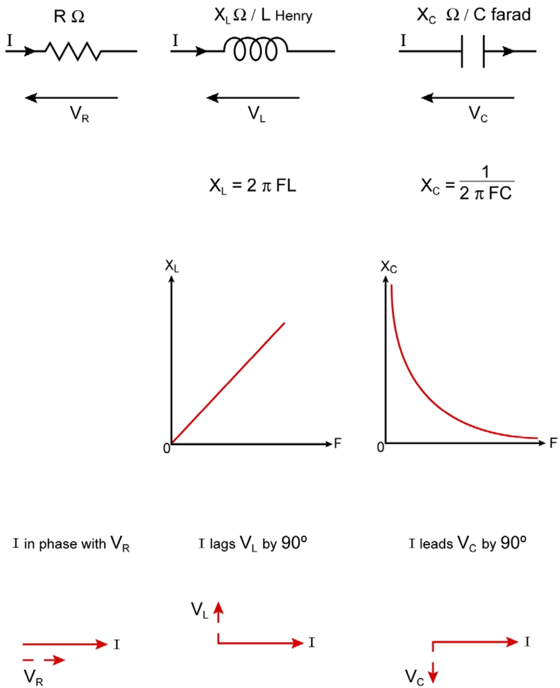
$$\boxed{X_C \alpha \frac{1}{F}}$$

FIGURE 1-15
Effect of Frequency on Capacitive Reactance



Summary

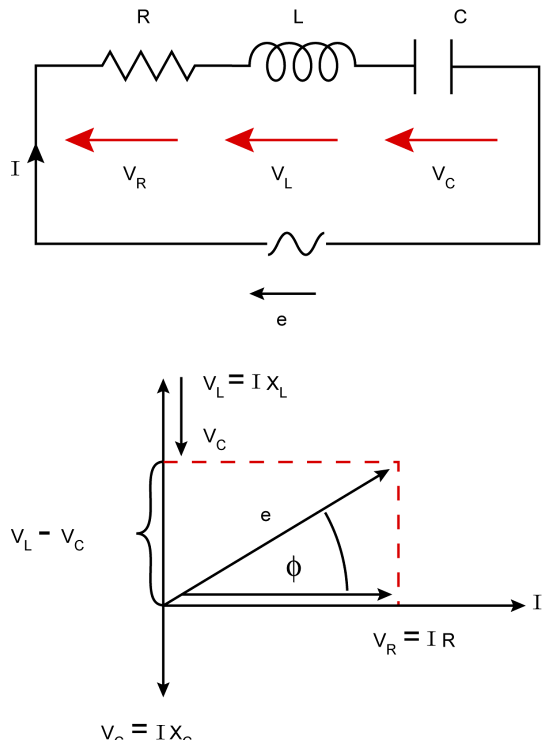
FIGURE 1-16
Summary of Pure Resistive, Capacitive and Inductive Circuits



Series Circuit

40. A coil, of self inductance L henrys and resistance R ohms, is connected to a capacitor of C farads. An emf of e volts and of variable frequency is connected to the circuit. Figure 1-17 shows the circuit details.

FIGURE 1-17
Series LCR Circuit and Phase Diagram



41. A phase diagram for the circuit is also shown in Figure 1-17. In this the potential difference (pd) across L is taken as greater than that across C and therefore the applied voltage leads the input current by the phase angle, ϕ.

Impedance

42. $\frac{E}{I}$ is called the IMPEDANCE, Z of the circuit and is measured in ohms.

$$Z = \sqrt{R^2 + (X_L \sim X_C)^2}$$

Resonance

43. When $V_L = V_C, \phi = 0$ i.e., the input current is IN PHASE with the applied voltage. In this special condition, the circuit is said to be at RESONANCE.

As $V_L = V_C$ then $I X_L = I X_C$ i.e. $X_L = X_C$

Z is a minimum and is equal to R (from above equation).

Resonant Frequency

44. The frequency at which $X_L = X_C$ may be determined as follows:

$$X_L = X_C$$

$$2\pi FL = \frac{1}{2\pi FC}$$

This value of frequency is denoted by F_O.

$$\boxed{F_O = \frac{1}{2\pi\sqrt{LC}}}$$

Response Curve

45. At frequencies other than the resonant frequency, V_L is not equal to V_C and the impedance of the circuit is higher than that at resonance, see Figure 1-18. For an applied voltage of constant amplitude, the current (rms value, I) varies as the frequency of the supply changes, see Figure 1-19. The curve shown in Figure 1-19 is called a **RESPONSE CURVE.**

FIGURE 1-18
Variation of Impedance with Frequency

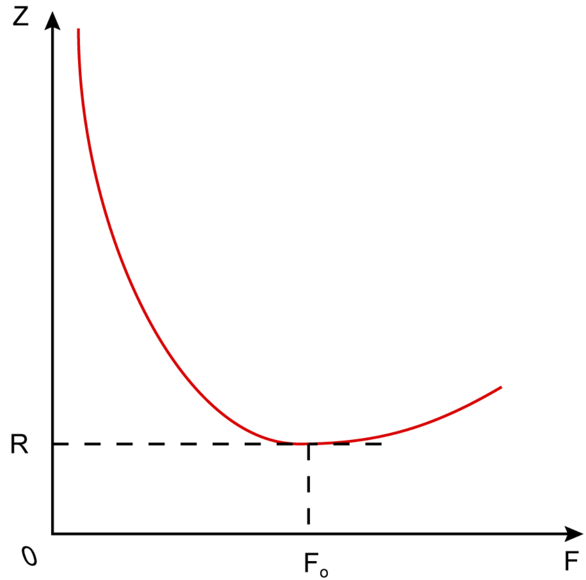
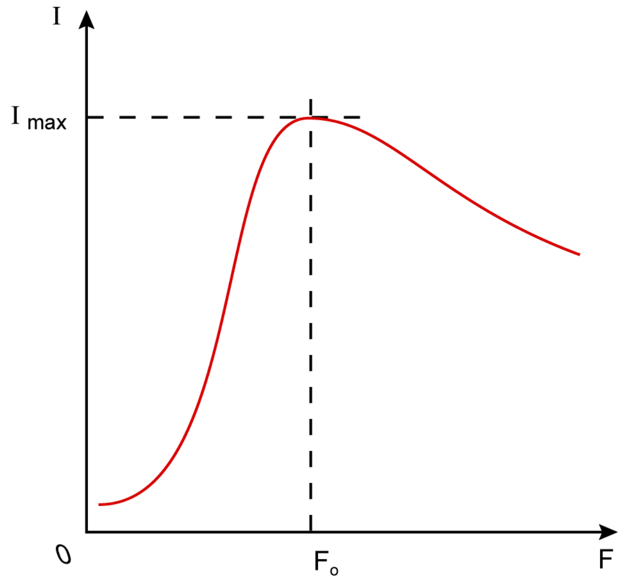


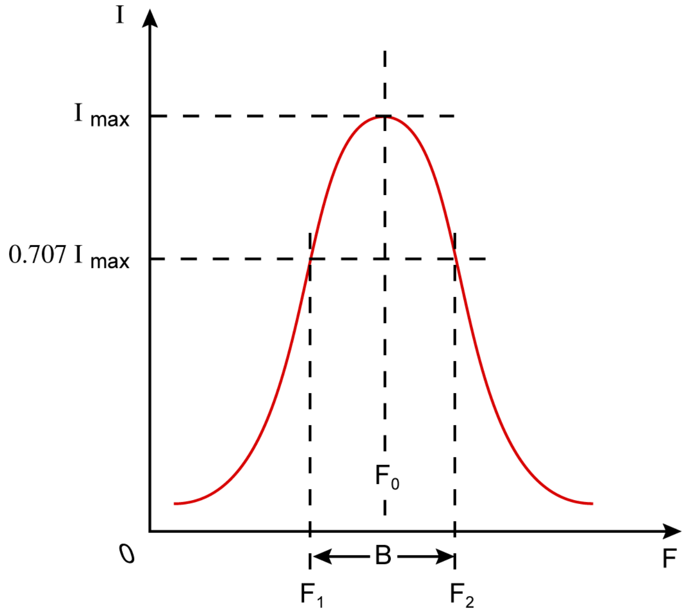
FIGURE 1-19
Variation of Current with Frequency



Bandwidth

46. The BANDWIDTH, B, of the circuit is the difference between the two frequencies either side of resonance at which the **current** has fallen to 0.707* of its maximum value, see Figure 1-20.

FIGURE 1-20
Bandwidth in a Series LCR Circuit



The bandwidth, $B = F_2 - F_1$

NOTE:

$$\frac{1}{\sqrt{2}} = 0.707$$

Selectivity

47. The sharpness of the response curve over a range of frequencies near resonance indicates the SELECTIVITY of the circuit. Selectivity is the ability of a tuned circuit to respond strongly to its resonant frequency and to give a poor response to other frequencies either side of resonance. A sharp response curve indicates high selectivity; poor selectivity is indicated by a flat response curve. For good selectivity, a circuit should have a low value of R and a high L\C ratio.

FIGURE 1-21
Narrow Bandwidth/Good Selectivity

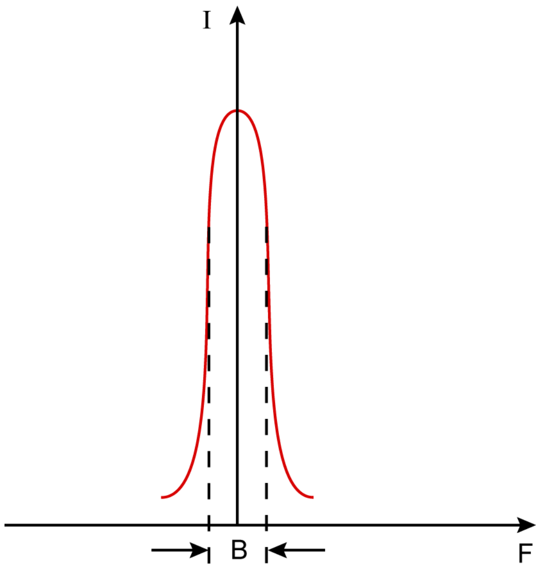
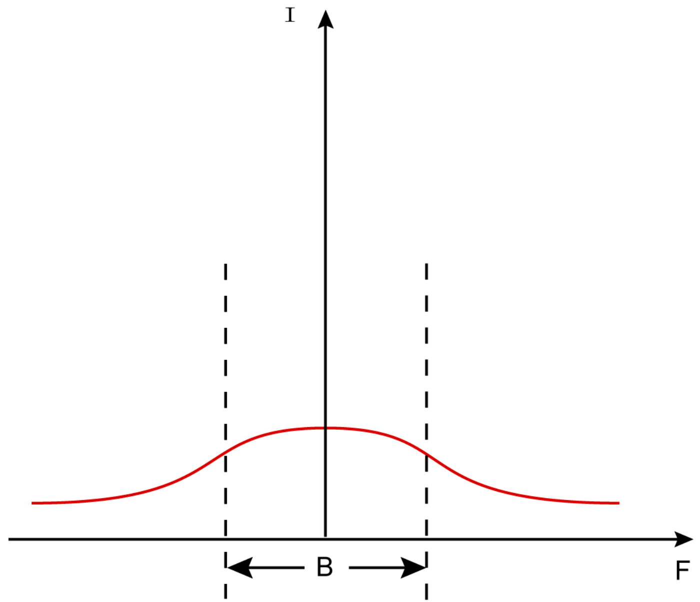


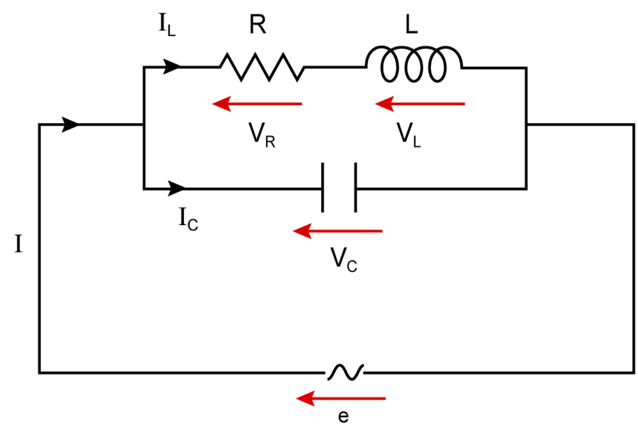
FIGURE 1-22
Wide Bandwidth/
Poor Selectivity



Parallel Circuit

48. A coil, of self-inductance L henrys and resistance R ohms, is connected across a capacitor of C farads. An emf of e volt and of variable frequency is connected to the circuit, see Figure 1-23. This type of parallel ac circuit is very common in radio equipments and has many important applications.

FIGURE 1-23
Parallel LCR Circuit



49. The pd across the coil, the phasor sum of V_R and V_L, is equal to the pd across the capacitor, V_C. The supply current is the vector sum of I_L and I_C. A phase diagram for the circuit is shown in Figure 1-24. For the condition shown, the supply current LAGS the applied voltage by a phase angle of ϕ degrees and the circuit is therefore INDUCTIVE ($I_L > I_C$).

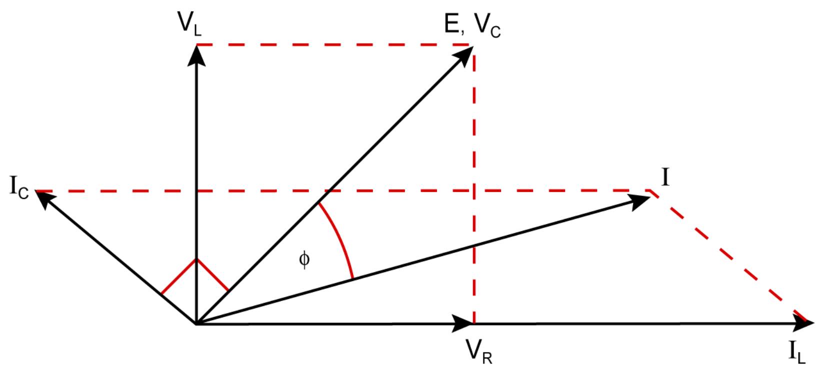


FIGURE 1-24
Phase Diagram for a Parallel LCR Circuit

50. For a certain value of frequency, I is in phase with E, i.e. the circuit is at RESONANCE. Once again it can be shown that the value of the Resonant Frequency (F_O) is given by:

$$\boxed{F_O = \frac{1}{2\pi\sqrt{LC}}}$$

51. At resonance, the impedance of a parallel circuit is a maximum and the supply current is a minimum. This circuit arrangement is called a REJECTOR circuit.

Selectivity

52. This is defined in the same way as for a series tuned circuit; namely, the ability of the circuit to respond strongly to the required signal, which is at the resonant frequency, and to give a poor response to all other signals. At resonance, the supply current is a minimum and the impedance is maximum. If the circuit is mis-tuned either side of resonance, e.g. by altering the value of C, the supply current increases and the impedance decreases, see Figure 1-25 and Figure 1-26.

FIGURE 1-25
Variation in Current with Frequency

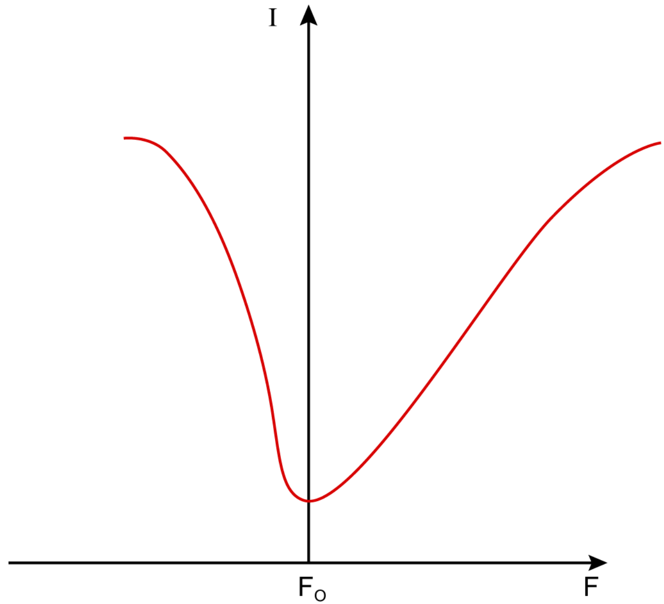
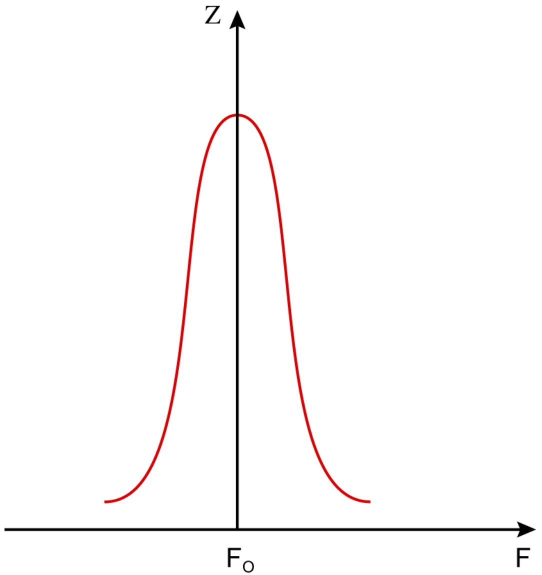


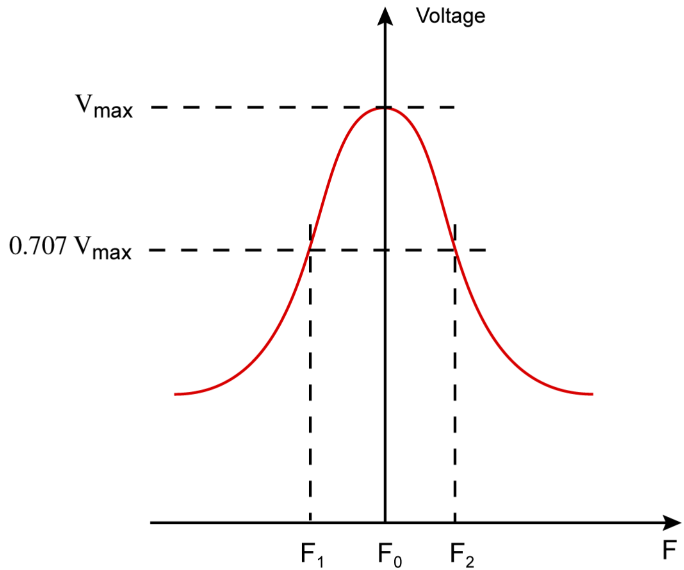
FIGURE 1-26
Variation in Impedance with Frequency



Bandwidth

53. Parallel circuits reject signals near to the resonant frequency. The BANDWIDTH of the circuit is the difference between the two frequencies, either side of resonance, at which the **voltage** has fallen to 0.707 of its maximum value. See Figure 1-27.

FIGURE 1-27
Bandwidth in a Parallel LCR Circuit



Bandwidth $B = F_2 - F_1$

In some circuits a wide bandwidth is required and one way to achieve this is to connect a resistor across the parallel circuit.

Demodulation

54. Having been filtered by the resonant circuit at the front end of a radio receiver the incoming signal is then amplified before undergoing a process called **demodulation**. Demodulation is the point at which the intelligence/information is separated from the carrier wave and therefore made available to the recipient.

Fading

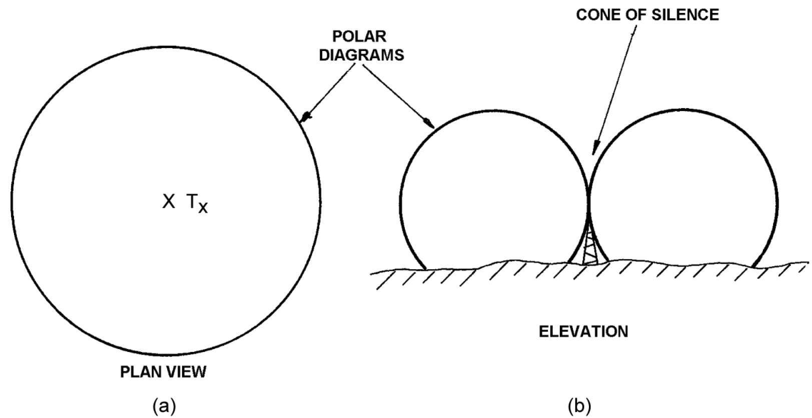
55. Occasionally radio reception suffers from the effects of fading. This is caused by the radio wave travelling by two alternative routes (e.g. surface wave and skywave) before meeting at the receiving aerial. If the two signals arrive in phase they will reinforce each other, if they arrive in anti-phase they will cancel out; if therefore, in the above example, the ionosphere is fluctuating in intensity and height the path length taken by a skywave will vary continuously, leading to fading in and out of the signal.

Polar Diagrams

56. A transmitter polar diagram is simply a pictorial presentation of the strength of the electromagnetic energy field in all directions from the transmitter aerial.

57. Figure 1-28 shows the polar diagrams in plan and side view associated with a single vertical antenna. Figure 1-28 (a) shows that the aerial is propagating radio waves omni-directionally in the horizontal plane, that is to say that at any point around the circumference of the circle, the transmitted signal strength is the same. Notice at Figure 1-28(b) that the vertical antenna is not transmitting vertically upwards. This gives rise to the cone of silence which occurs overhead, for example, VOR transmitters. Appreciate that transmitter polar diagrams do not define the limit of coverage of the transmitted signal, but rather points of equal signal strength.

FIGURE 1-28
Transmitter Polar Diagrams - Single Vertical Antenna



58. It is equally convenient to produce polar diagrams for receiver aerial arrays. Now the situation is reversed in that a signal of a given strength which is transmitted from any point on the polar diagram will induce a current of constant amplitude to flow in the receiver aerial.

59. By modifying the antenna configuration it is possible to adjust the shape of the polar diagram. The ILS transmitters give polar diagrams which are lobe shaped, whereas VOR transmitters produce a polar diagram which is known as a limacon, and which is in fact made to rotate, but more of this later in this section.

The Ionosphere

60. The ionosphere exists in the upper atmosphere above the mesospheric layer. The gaseous composition of the ionosphere is such that ultra-violet rays from the sun cause electrons to become separated from their parent atoms. The atoms which are consequently left with a **positive** charge are known as **ions**. The ionosphere is most intense, that is to say it contains the greatest concentrations of ions, during the daylight hours. During the night the displaced electrons tend to re-combine with their parent atoms, resulting in some degree of de-ionisation.

61. The areas of ionised gases tend to exist in distinctive layers, known as the **D**, **E** and **F** layers.

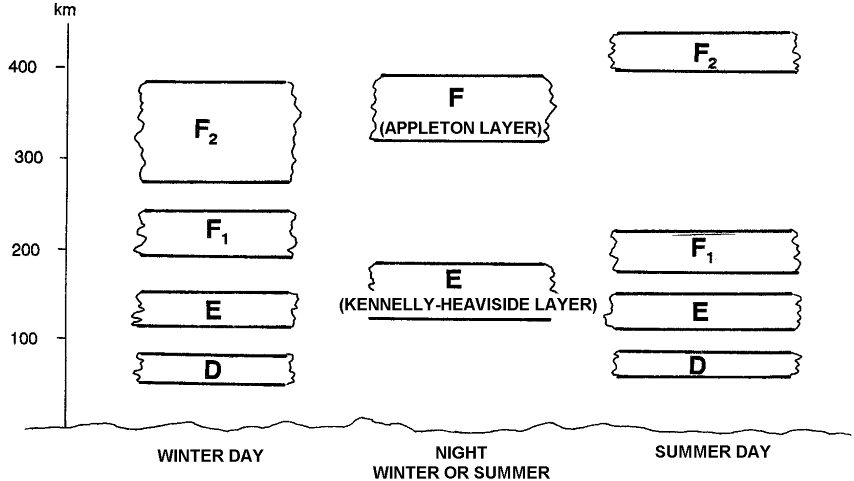
62. During the daylight hours it is normal for four distinct layers to become established, **D**, **E** **F1** and **F2**, see Figure 1-29. The height and thickness (depth) of these layers will depend upon such factors as latitude, time of the year and sun spot activity. Ionisation intensity **increases** with **increase** in height and therefore the **F** layer(s) tend to be stronger than the lower layers.

63. During the hours of darkness the four layers tend to merge into only two distinctive layers, the **E** and the **F** layers, again see Figure 1-29.

64. It is important to appreciate that, at night, the ionospheric layers are generally speaking **higher**, and are **less intensely ionised** than during the day.

65. The significance of the ionosphere is that radio waves, on entering a layer of ionised gases, will tend to both **bend** and **weaken**.

FIGURE 1-29
The Ionospheric Layers



66. The average heights of the various ionospheric layers are as follows:

(a) D Layer 75 km.

(b) E Layer 125 km.

(c) F Layer 225 km.

Attenuation

67. As any radio wave travels away from the transmitter it becomes weaker, or is **attenuated**, due to some or all of the reasons discussed below.

Range from the Transmitter

68. Assume that an electromagnetic radio wave is being transmitted in all directions, that is to say it is being transmitted **omni-directionally**. The energy is contained within a spherical wave front in this case, and as the distance from the transmitter increases the area of the wave front also increases. Consequently as the range from the transmitter increases the **field strength** of the signal decreases. Field strength is inversely proportional to the square of the range and it can be proved that, to double the range of a transmission the transmitter power must be quadrupled.

Surface Attenuation

69. If a radio wave is constrained to travel close to the Earth's surface, the wave will attenuate by virtue of its contact with the surface. Two important facts are worthy of note. Firstly, the rate of surface attenuation is likely to be three times greater over land than it is over sea. Secondly, the rate of surface attenuation **increases** as the frequency of signal **increases**.

Ionospheric Attenuation

70. As a radio wave travels through any of the ionospheric layers it will be weakened by the positively charged ions. In the extreme case a radio signal may be totally attenuated within an intensely ionised layer. The rate of ionospheric attenuation **decreases** as the transmitted frequency **increases**.

Atmospheric Attenuation

71. A radio wave travelling through unpolluted and unsaturated air would not suffer any attenuation due to the medium through which its travelling. However the atmosphere contains solid particle pollutants and water in both liquid and solid form, and these particles, droplets and ice crystals will **reflect** and **scatter** radio waves at sufficiently high frequencies.

72. The purist might say that the signal is not in fact attenuated, merely redirected in an unwanted direction. The fact remains that, if the signal is scattered, it may never reach the receiver at a given range, and is therefore of no use.

73. When considering **atmospheric signal scatter** it should be appreciated that the particles, droplets or ice crystals must be of **significant size** when compared to the **wavelength of the transmitted signal.** Radio signals in the **EHF** band may suffer considerable attenuation under these conditions.

Refraction

74. It is normal to assume that radio waves travel in straight lines, that is to say along great circle paths. Any departure from such a straight line path is said to exist as a result of **refraction** of the radio wave.

75. The principal causes of refraction are discussed below.

Ionospheric Refraction

76. Radio waves tend to bend, or refract, as they travel through any of the ionospheric layers. The rate at which this refraction occurs **decreases** as the frequency of the radio signal **increases**.

Coastal Refraction

77. It was previously convenient to accept that radio waves travel at a constant speed. In fact radio waves travelling close to the Earth's surface will travel slightly faster over the sea than over the land. In consequence any radio wave crossing a coastline at other than 90° will bend slightly towards the land mass and this phenomenon is termed **coastal refraction.** Again, the degree of refraction **decreases** as the frequency of the radio signal **increases**.

Diffraction

78. In the low frequency and medium frequency bands radio waves tend to refract to an extent such that they remain in contact with the Earth's surface, despite the curvature of the Earth. There are several theories as to why this occurs, suffice to say that is a very useful phenomenon since it increases the surface range of these frequencies.

Atmospheric Refraction

79. Atmospheric refraction sometimes occurs in certain meteorological conditions, and produces a situation known as **ducting.** This is discussed in detail at a later stage.

Propagation Paths

80. Six of the possible paths which may be taken by a radio wave are discussed below.

The Direct Wave

81. This is the simplest case, and is **normally** the only possible path for radio waves in the **VHF band or above.** This is because, at VHF and above, a signal which remains close to the ground (a surface wave) will be totally attenuated over a very short distance. Conversely, at these frequencies a signal which is beamed at the ionosphere would not be sufficiently refracted to return to the Earth (as a sky wave).

82. The curvature of the Earth is the factor which limits the **maximum theoretical range** of any direct wave, see Figure 1-30.

83. Subject to the power transmitted, the higher the transmitter and/or the receiver the greater the direct wave range.

84. The maximum theoretical range of a direct wave signal is given by the formula:

$$\text{MAX RANGE (NMS)} = 1.25(\sqrt{H_1} + \sqrt{H_2})$$

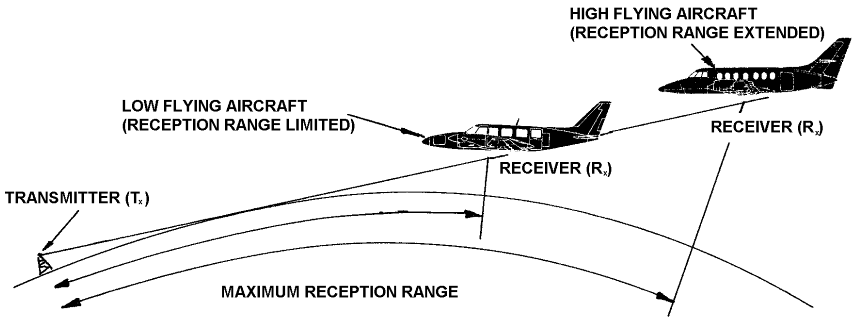
where

H1 is the height of the transmitter in feet, amsl

H2 is the height of the receiver in feet, amsl

85. Obviously the presence of **intervening high ground** will invalidate the above formula.

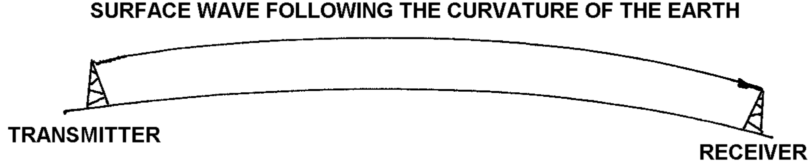
FIGURE 1-30
The Direct Wave



The Surface Wave

86. Fortunately, the maximum range from a transmitter at which radio signals can be received is not always limited to the direct wave range. At frequencies in the LF and MF bands diffraction has the effect of altering the direction of travel of the radio wave such that some will more or less follow the Earth's curvature. Thus in the LF and MF frequency bands, **surface wave** (**or ground wave**) propagation is possible, see Figure 1-31.

FIGURE 1-31
The Surface Wave



87. At the relatively low frequencies concerned, the amount of attenuation suffered by the radio wave as it travels across the surface is not too great, and the problem of surface attenuation can be overcome if transmitters of sufficient power are used. Also, at lower frequencies the amount of diffraction increases, so increasing the reception range at the surface.

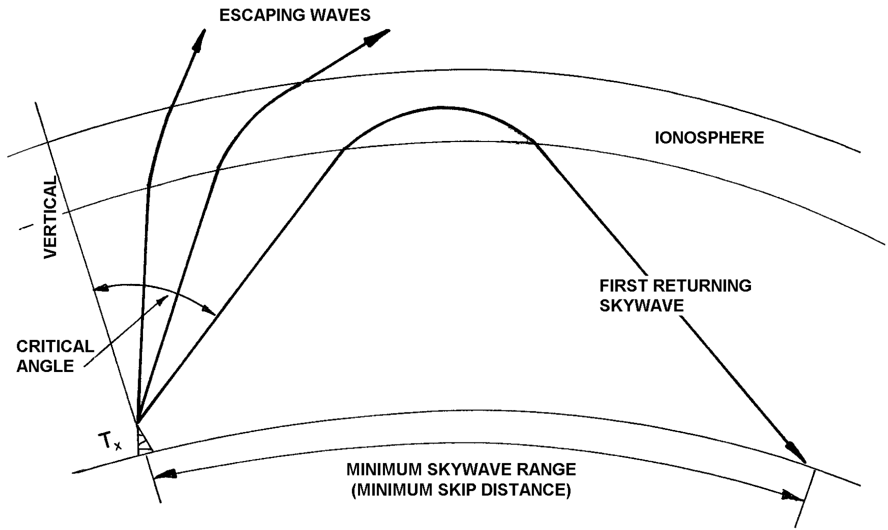
88. Remember that the rate of attenuation of a surface wave is approximately three times greater over the land than it is over the sea. Consequently maximum surface wave ranges of 1000 nms are achievable over the sea, but only 300 nms over the land.

The Sky Wave

89. So far we have considered the normal propagation paths for radio waves in the VHF band and above (**direct waves**) and the LF and MF bands (**surface waves**). The obvious gap in the middle is the HF band, and it is within this band that the refractive properties of the ionospheric layers may be usefully employed.

90. If a radio wave of a suitable frequency within the HF band is directed towards the ionosphere it will **refract** within the ionosphere. As the angle between the vertical and the outgoing radio wave increases, the radio wave will eventually bend sufficiently within the ionosphere to return to the Earth's surface. When this happens, the angle between the vertical and the radio wave is termed the **critical angle**, and the returning wave is termed the **first returning sky wave**, see Figure 1-32.

FIGURE 1-32
The Sky Wave

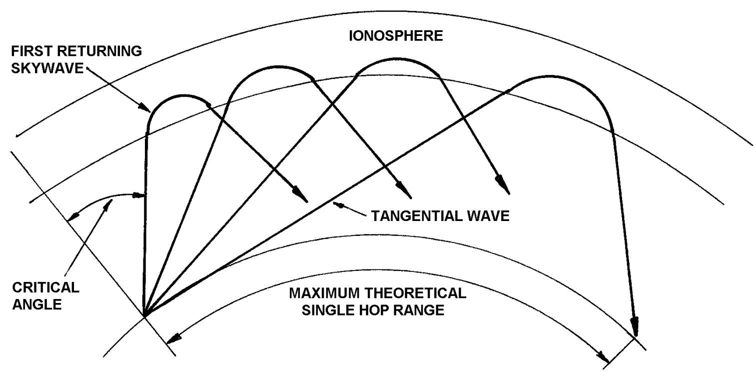


91. The critical angle will depend upon the frequency of the transmitted signal, as well as the state of ionisation of the ionosphere. As the frequency is **increased** the rate of refraction **decreases**, and therefore, the critical angle **increases**. This is because the radio wave must travel further within the ionospheric layer in order for there to be sufficient refraction to produce a returning sky wave.

92. If the signal enters the ionosphere at angles in excess of the critical angle, sky waves will continue to return to the Earth's surface, subject to transmitter power, until the angle coincides with the **Earth's tangential wave** shown at Figure 1-33.

93. Please note that at Figure 1-32 and Figure 1-33 the signal is shown **refracting within** the ionosphere, and **not bouncing off** the bottom of the ionosphere.

FIGURE 1-33
Earth Tangential Waves

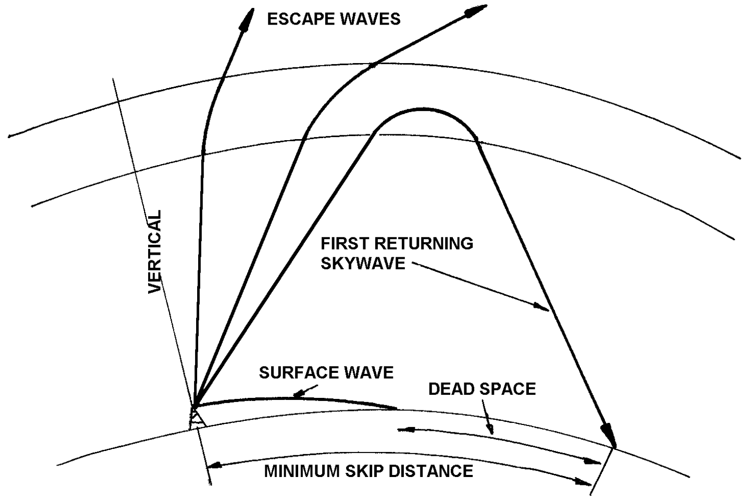


94. In all of these diagrams it is convenient to show only one ionospheric layer, however the **height** of the ionosphere is significant. For example, in the case of the tangential wave the theoretical skip distance is 1300 nm from an 'E' layer refraction and 2500 nm from the 'F' layer.

95. Because the signals used lie within the HF band, the rate of surface attenuation is fairly high and therefore surface wave ranges will rarely exceed 100 nm. It is quite possible that the first returning sky wave will not arrive at the Earth's surface below a range, which is well in excess of 100 nm. There will therefore be an area within which no signal will be received, and this is termed the **dead space**, see Figure 1-34. The distance between the transmitter and the point at which any sky wave returns to the surface of the Earth is termed the **skip distance**.

96. The distance between the transmitter and the point at which the **first returning sky wave** returns to the surface of the Earth is termed the **minimum skip distance**, and defines the far end of the dead space, as shown at Figure 1-34.

FIGURE 1-34
The Dead Space and Minimum Skip Distance



97. The preceding diagrams have shown only **single hop sky waves.** Providing that the signal has sufficient power there is no reason why it should not make the return journey to the Earth's surface via the ionosphere two or even three times. This is known as **multi-hop propagation.**

98. The final problem for your consideration in terms of sky wave propagation is the diurnally changing state of the ionosphere. Obviously there is no point in using a frequency such that the receiver lies within the **dead space.** Conversely the range between transmitter and receiver should ideally be only slightly in excess of the **minimum sky wave range**, so that the strongest possible signal is received.

99. In an ideal world the perfect situation would be for the distance between the transmitter and the receiver to be exactly the same as the skip distance for the first returning sky wave (the minimum skip distance). The frequency which would have to be transmitted in order to achieve this, for a given transmitter-receiver distance set of ionospheric conditions, is termed the **optimum frequency**. Since it is not possible to predict precisely the state of the ionosphere, the **maximum usable frequency** is used rather than the **optimum frequency**. The maximum usable frequency will be slightly lower than the optimum frequency and will therefore give a slightly shorter minimum skip distance. This ensures that slight variations in ionospheric intensity or height will not cause the receiver to lie within the dead space.

100. Figure 1-35 shows the ideal situation with the maximum usable frequency for a low and intensely ionised layer during the day. Figure 1-36 shows the situation with the same frequency at night, when the ionosphere is higher and is partially de-ionised. The receiver now lies within the dead space, and a new maximum usable frequency is required, as shown at Figure 1-37.

FIGURE 1-35
Day Time Sky
Wave Propogation

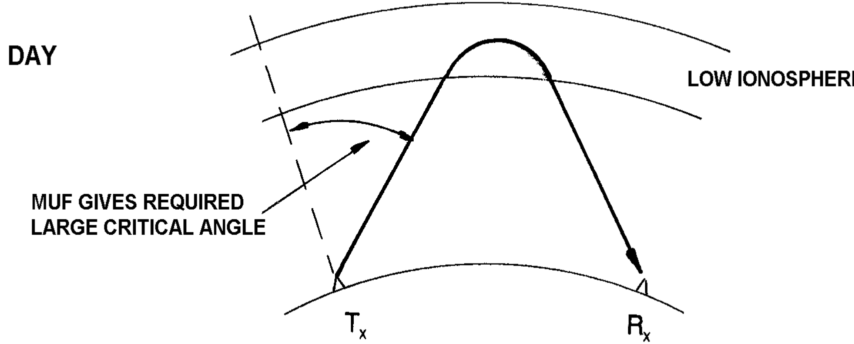


FIGURE 1-36
Night Time Sky
Wave Propogation
- same Frequency

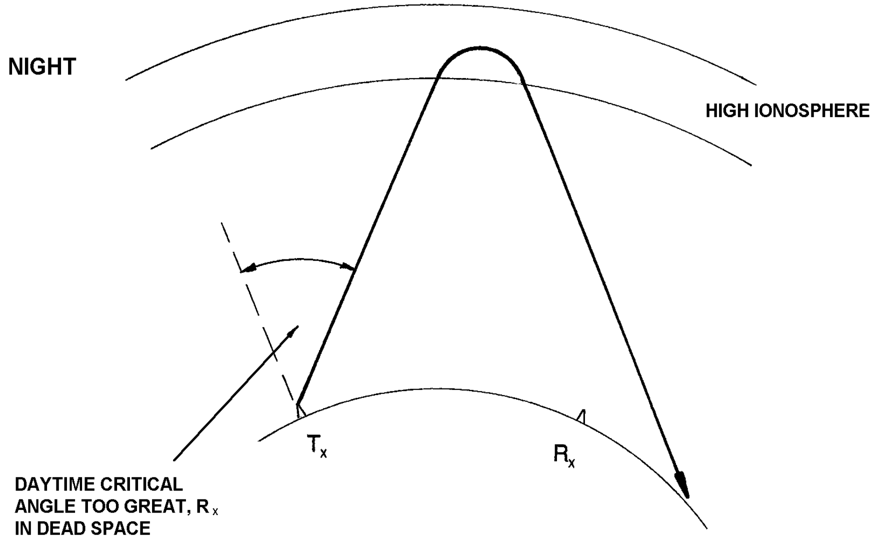
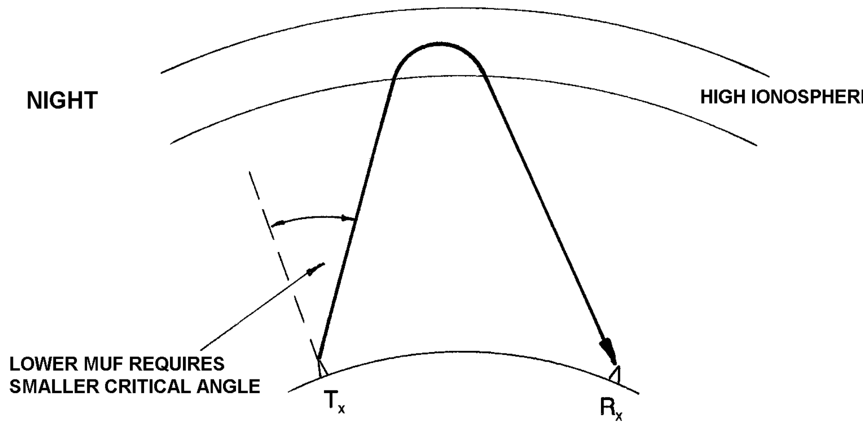


FIGURE 1-37
Night Time Sky Wave Propogation with New Max Usable Frequency



101. The maximum usable frequency required by night will be approximately **half the daytime maximum usable frequency.** This lower frequency will have a smaller critical angle, to overcome the geometry of the higher ionosphere. Additionally the lower frequency will refract at a similar rate, despite the partial de-ionisation of the layer. Finally and fortunately, the less intense level of ionisation will mean that the signal will not be unduly attenuated, despite the lower frequency, which is being used.

102. In the LF and MF bands sky waves do not generally exist by day, since the lower frequency signals are totally attenuated within the ionosphere. By night it is normal for some sky waves to survive, since the ionosphere is now somewhat **weaker.** This poses the problem of **sky wave interference** by night in such equipments as ADF.

Propagation at VLF

103. By now you should be absolutely familiar with the following general statements concerning propagation paths:

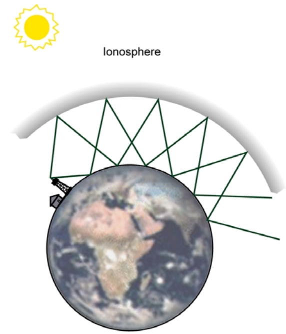
(a) **LF** and **MF** signals are propagated as **surface** (**ground**) waves. Within these bands sky waves are not normally present by day, and their presence by night reduces useful equipment range due to **night effect**.

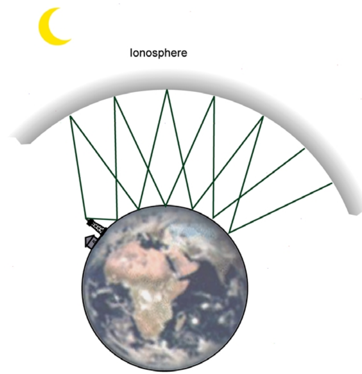
(b) **HF** signals are propagated principally as **sky waves**, which are present both by day and by night.

(c) At **VHF and above**, signal range is limited to **line of sight**, since the propagation path is **direct wave** only.

104. At VLF the wavelength is obviously much longer than at VHF or UHF and now a process which is similar to ducting (see below) occurs between the surface of the Earth and the underside of the lowest layer of the ionosphere, which may now be considered as a reflecting surface. The name which now seems to be accepted for this type of propagation path is the **conduit wave**. As with VHF ducting the VLF signals travel great distances with little attenuation and consequently ranges of more than 11,000 nm can be achieved with transmitter power outputs in the region of ten kilowatts. The principle of conduit wave propagation is shown at Figure 1-38.

FIGURE 1-38
Conduit Wave Propogation





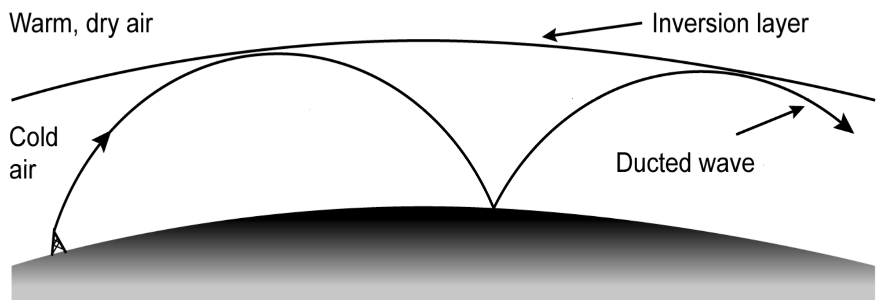
The Ducted Wave

105. The four propagation paths which have now been discussed, namely direct waves, surface waves, sky waves and conduit waves are all predictable and therefore useful. The fifth option, **ducting,** is unpredictable and ducted waves cannot therefore be usefully employed.

106. Under certain meteorological conditions, radio waves in the VHF, UHF and SHF bands, which normally travel only in straight lines, may behave in a way which is at first sight similar to sky waves.

107. The meteorological conditions required for duct propagation are **a marked temperature inversion and a rapid decrease in humidity with height**. Figure 1-39 shows ducting which, in this case, is occurring between the surface and a low-level inversion. The signal is effectively **trapped** under the inversion and may travel hundreds of miles with little attenuation. In this way, when high pressure systems prevail, interference may be heard from distant **VHF** communications stations which are far beyond the normal direct wave range.

FIGURE 1-39
The Ducted Wave



108. Ducting may also occur above the surface of the Earth, between two inversion layers.

109. Whilst ducting cannot be used to advantage, it can seriously affect receipt of signals and will cause unexpected station interference. For example, a VOR or VHF communication transmission may be trapped beneath an inversion layer so that it cannot be received by aircraft flying above the layer. Similarly, transmission which would normally be limited to short surface ranges because of their direct wave propagation may travel distances well in excess of 1000 nm.

Tropospheric Scatter

110. Small random irregularities or fluctuations in the refractive index of the atmosphere can cause a scatter of radio waves in the frequency band 200 MHz to 10 GHz. Provided that sufficient transmitter power is available, the signal will be scattered towards the receiver from a volume of atmosphere approximately 3 to 8 km above the Earth's surface. Tropospheric scatter offers extended over-the-horizon range for high power communication systems operating from the upper VHF band through to the SHF band. The maximum range achieved in this manner is considered to be in the region of 400 nm. This propagation phenomenon is akin to dust scattering a beam of sunlight in a dark room or hallway.

111. The advent of satellite communication systems has more or less halted research into the development of communications systems relying on tropospheric scatter for better than line-of-sight range at VHF and above, however the development of military **over the horizon radars** using tropospheric scatter continuous.

112. Having discussed radio frequency bands and propagation paths in this section, it is perhaps appropriate at this stage to produce a table of the radio and radar systems which you will subsequently study, showing the frequency range and frequency band in which each of these equipments operate, see Figure 1-40.

FIGURE 1-40
Individual Equipment Operating Frequencies and Frequency Bands

System	Frequency Range	Frequency Band
Decca	70 to 130 KHz	LF
Loran C	100 KHz	LF
ADF	190 to 1750 KHz	LF/MF

HF Communications	2 to 25 MHz	HF
ILS Markers	75 MHz	VHF
ILS Localiser	108.1 to 111.95 MHz	VHF
VOR	108.0 to 117.95 MHz	VHF
VHF Communications	118 to 136 MHz	VHF
ILS Glidepath	329.15 to 335.0 MHz	UHF
DME	960 to 1213 MHz	UHF
SSR	1030 and 1090 MHz	UHF
GPS	1575.42 MHz (L1) 1227.6 MHz (L2)	UHF UHF
Satcom (Inmarsat)	1500 to 1600 MHz (Aircraft to Satellite) 4000 to 6000 MHz (Satellite to Ground)	UHF SHF
Radio Altimeter	4200 to 4400 MHz	SHF
Weather Radar	9375 MHz	SHF
MLS	5031 to 5091 MHz	SHF
ATC Surveillance Radars	600 to 1300 MHz	UHF
ATC Ground Manoeuvre Radars	10 to 16 GHz	SHF

Modulation Techniques

113. The preceding section covered the various propagation options for transmitting electromagnetic radio waves from one point to another. It is now necessary to consider the various techniques which may be employed to superimpose **intelligence** on to the basic radio wave. When this is done the radio wave is termed the **carrier wave**, and the **intelligence** is said to be **modulated** on to it.

114. One way of modulating a carrier wave to convey intelligence is to vary the **amplitude** of the carrier wave in sympathy with the modulating wave form which is at a lower frequency (the intelligence). This technique is known as **amplitude modulation**.

115. Another way of modulating a carrier wave to carry intelligence is to vary the **frequency** of the carrier wave in sympathy with the modulating intelligence. This technique, logically, is known as **frequency modulation**.

116. The third modulation technique which is considered is **pulse modulation**.

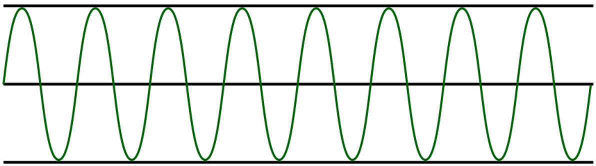
Amplitude Modulation

117. For convenience the various sub-divisions of Amplitude Modulation (AM) are coded, and the particular codes which are pertinent to this syllabus are discussed below.

Unmodulated Carrier Wave

118. As the name suggests, unmodulated (or continuous) carrier wave is simply a radio wave which is transmitted as a constant amplitude and a constant frequency, and therefore carries no intelligence. In other words the wave is **unmodulated.** This type of signal is ideal for direction finding equipment such as the ADF, although it is obviously necessary to superimpose a morse identifier onto the wave from time to time, so that the operator knows which transmitter he is tuned into. The designation normally given to this type of signal is **NON**. An unmodulated carrier wave is illustrated at Figure 1-41.

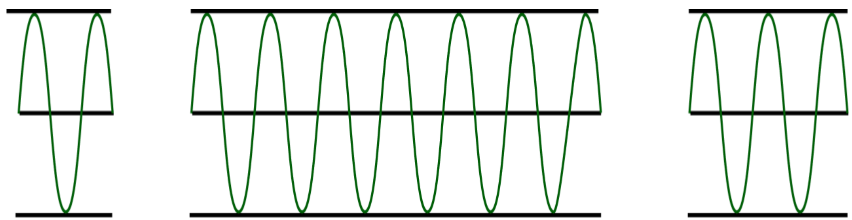
FIGURE 1-41
Unmodulated Carrier Wave



Keyed Carrier Wave

119. Keyed (or interrupted) carrier wave is the simplest form of modulation. Here the radio signal is not continuously transmitted but is switched on and off at desired intervals, see Figure 1-42. The primary use of keying is to convey intelligence using the morse code. The designation given to this type of signal is **A1A**. It is principally employed on long range NDBs, the advantage being that all of the power is contained in the carrier wave, and none in the modulating wave, since there isn't one. Range for a given transmitter power output is therefore enhanced, however the disadvantage is that a BFO (Beat Frequency Oscillator - see later) must be incorporated into the receiver to make the morse audible.

FIGURE 1-42
Keyed Carrier Wave



Simple Amplitude Modulation

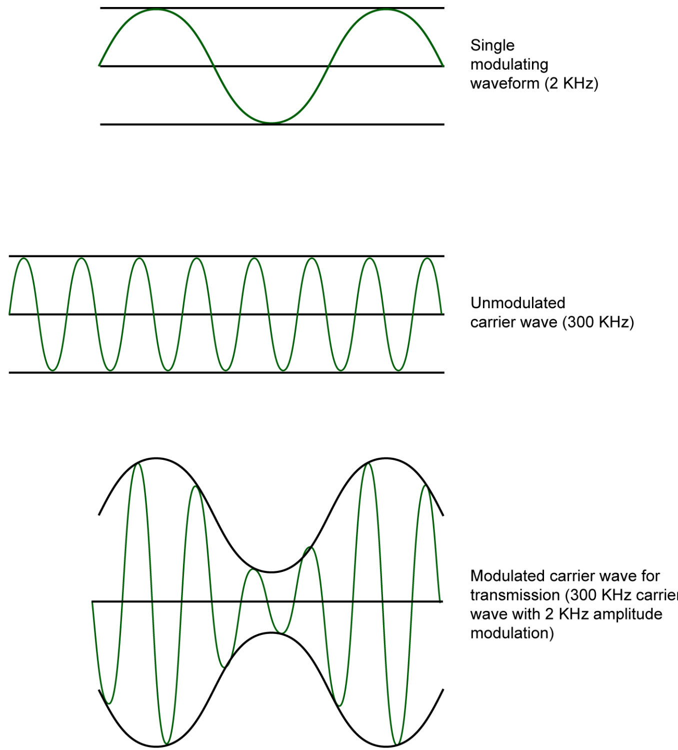
120. Now to, as it were, real amplitude modulation where the amplitude of the carrier wave consistently varies in sympathy with the intelligence wave form. The significance of **simple amplitude** modulation is that **the modulating wave form is constant in amplitude and constant in frequency**, see Figure 1-43. The intelligence normally used for this type of transmission would be a simple steady audio frequency tone.

121. By keying either the modulating signal, or the modulated carrier wave itself, the audio tone can be used to convey simple morse idents.

122. If you check any short range NDB in the COMS section of the Aeronautical Information Publication you'll find that it is given as **NONA2A**. The NON is the continuous carrier wave, which occurs between the ident sequences, and which gives the ADF receiver a nice steady signal for direction finding. The A2A which is tacked onto the end is the NDB identifier, which in this case is achieved by keyed amplitude modulation, using a steady audio tone.

123. The designation given this type of transmission is either **A2A** with an NDB (where it is keyed to achieve station identification) or **A8W** in ILS (where the depth of modulation is made to vary across the transmitted lobes).

FIGURE 1-43
Simple Amplitude Modulation



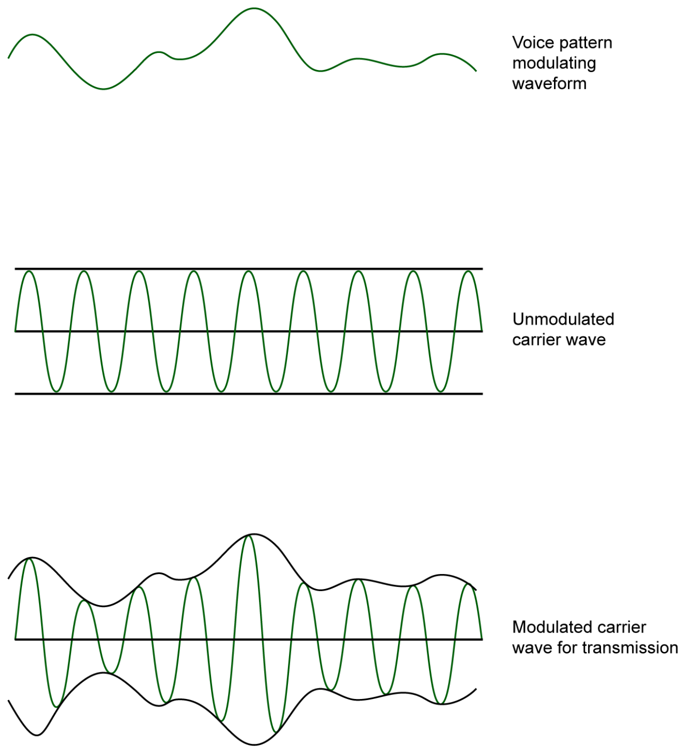
Complex Amplitude Modulation

124. The modulating waveform in the previous paragraph was simple in nature, that is to say constant in amplitude and in frequency. The human voice produces a complex waveform which is often modulated on to a carrier wave as intelligence.

125. The human voice produces a complex modulating waveform in that it is varying in both amplitude (a shout as against a whisper) and in frequency (a groan as against a scream). You may well be either groaning or screaming right now, if you have a microphone and an oscilloscope handy you can prove the complexity of the wave form! Voice modulation is shown schematically at Figure 1-44.

126. This type of signal is designated **A3E** when used in VHF communications, and **J3E** when used in HF communications (normally on single sided band networks).

FIGURE 1-44
Complex Amplitude Modulation



Depth of Modulation

127. Before proceeding on to frequency and pulse modulation techniques it is necessary to consider briefly **depth of modulation** as it applies to both simple and complex amplitude modulated signals. Quite simply, the depth of modulation is the ratio of the amplitude of the modulating waveform to the amplitude of the carrier wave prior to modulation, expressed as a percentage, or:

$$\text{Depth of Modulation \%} = \frac{\text{Amplitude of the Modulating Waveform} \times 100}{\text{Amplitude of the Carrier Wave (before Modulation)}}$$

An alternative formula for determining the depth of modulation is:

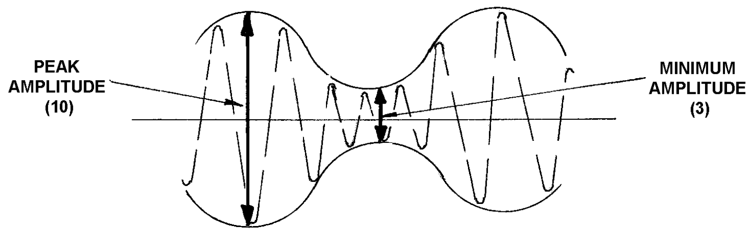
$$\text{Depth of Modulation \%} = \frac{\text{Maximum Amplitude} - \text{Minimum Amplitude} \times 100}{\text{Maximum Amplitude} + \text{Minimum Amplitude}}$$

128. Figure 1-45 shows a simple amplitude modulated carrier wave. The carrier wave (as always with amplitude modulation) is varying in amplitude in sympathy with the modulating wave. In this case maximum amplitude of the modulated carrier wave is 10 volts and the minimum amplitude of the modulated carrier wave is 3 volts. Using the second formula:

$$\text{Depth of Modulation \%} = \frac{10 - 3}{10 + 3} \times 100 = \frac{7}{13} \times 100 = 54\ \%$$

129. Since it is the power contained in the carrier wave at its **lowest amplitude** which governs the range of the signal, it is normal to reduce the percentage depth of modulation when extreme range reception is required.

FIGURE 1-45
Depth of Modulation

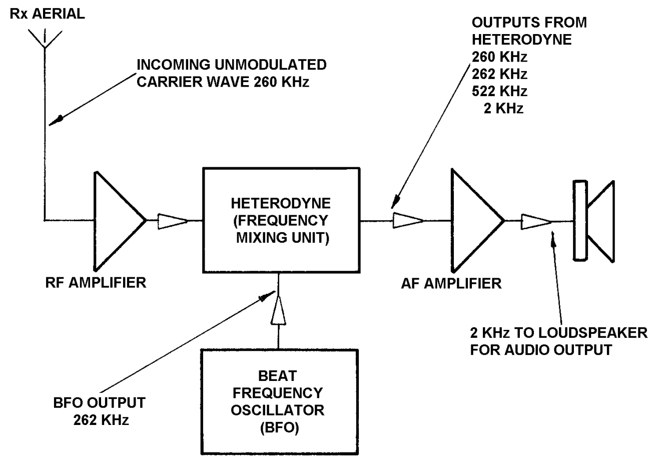


The Beat Frequency Oscillator (BFO)

130. An amplitude modulated signal is **demodulated** in a conventional receiver without any difficulty since the amplitude of the carrier wave is varying in sympathy with the intelligence waveform. With a **NON** or **A1A** (see earlier text) signal the amplitude of the carrier wave remains constant and therefore it is impossible to achieve an audible output from a receiver using conventional demodulation techniques.

131. Figure 1-46 shows how the receiver is modified when the BFO function is selected. The BFO is made to generate an alternating current, the frequency of which differs from the incoming carrier wave frequency by, typically, 2 KHz. The incoming signal and the BFO-generated signal are both fed to the heterodyne unit which **mixes** the two to give four output frequencies. The output of the heterodyne unit comprises the two input frequencies, the sum of the two input frequencies, and the **difference** frequency. It is only the difference frequency (2 KHz) which is audible, and this is fed to the loudspeaker, producing the audio tone. The difference frequency is known as the **Beat Frequency**.

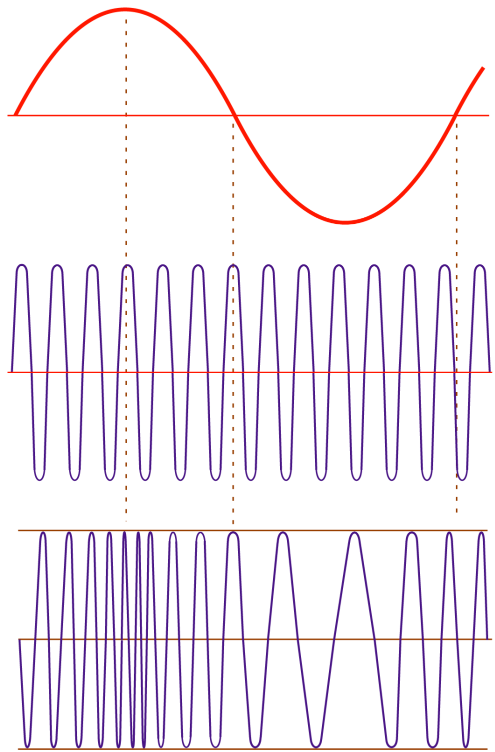
FIGURE 1-46
The Beat Frequency Oscillator



Frequency Modulation

132. When pure frequency modulation (FM) techniques are employed the **amplitude** of the carrier wave normally remains constant, however the **frequency** of the carrier wave is made to vary in sympathy with the modulating wave form (the intelligence), see Figure 1-47. The **amplitude** of the modulating waveform is represented by the **amount** by which the frequency of the carrier wave changes and the **frequency** of the modulating waveform by the **rate of change** of the carrier wave frequency.

FIGURE 1-47
Frequency Modulation



133. With VOR the carrier wave is both amplitude and frequency modulated. The designation given to this type of signal (as it applies to VOR) is **A9W.**

AM Versus FM

134. Comparing the technique of frequency modulation with amplitude modulation, **frequency modulation (FM) transmitters are simpler than AM transmitters,** the necessary modulating power is relatively lower and the reception is practically static-free. This last benefit is due to the fact that the VHF band is practically free from static, and where it is present, it is normally an amplitude-oriented disturbance. Of the disadvantages, **FM receivers are more complex** and the modulated transmission calls for a much wider frequency band to cover its multi-sidebands (see later). This is why FM broadcasters operate in the VHF band; the congestion in lower frequency bands would not permit accommodation of the necessary bandwidth. Being in the VHF band, as a side benefit they can cover a complete range of human audio frequencies (up to 15 KHz) and thus provide high fidelity reception whereas in the MF band they would have to be content with staying inside the limit of a spread of 10 KHz.

VHF Communications

135. VHF Communication Systems operate in the frequency range 118-136.975 MHz and use the frequency modulation technique for superimposing the intelligence onto the Carrier Wave. A breakdown of the VHF Communication Band is shown in Figure 1-48:

FIGURE 1-48
VHF Communication Frequency Band

Block Allotment Of Frequencies (MHz)	World-Wide Utilisation	Remarks
118 to 121.4 Inclusive.	International and National Aeronautical Mobile Services	Specific international allotments will be determined in the light of regional agreement.
121.5	Emergency Frequency.	In order to provide a guard band for the protection of the aeronautical emergency frequency, the nearest assignable frequencies on either side of 121.5 MHz are 121.4 MHz and 121.6 MHz, except that by regional agreement it may be decided that the nearest assignable frequencies are 121.3 MHz and 121.7 MHz.
121.6 to 121.975 Inclusive.	International and National aerodrome surface communications.	Reserved for ground movement, pre-flight checking, air traffic services clearances, and associated operations.
122 to 123.05 Inclusive.	National Aeronautical Mobile Services.	Reserved for national allotments
123.1	Auxiliary Frequency SAR.	

Block Allotment Of Frequencies (MHz)	World-Wide Utilisation	Remarks
123.15 to 123.675	National Aeronautical Mobile Services.	Reserved for national allotments
123.7 to 129.675 Inclusive.	International and National Aeronautical Mobile Services.	Specific international allotments will be determined in the light of regional agreement.
129.7 to 130.875 Inclusive.	National Aeronautical Mobile Services.	Reserved for national allotments.
130.9 to 136.875 Inclusive.	International and National Aeronautical Mobile Services.	Specific international allotments will be determined in the light of regional agreement.
136.9 to 136.975 Inclusive.	International and National Aeronautical Mobile Services.	Reserved for VHF Air-Ground Data Link Communications.

136. The ICAO Special Communications/Operations Divisional meeting (Montreal/April 1995) decided that, in order to increase channel capacity, the VHF communications band should be split from 25 to 8.33 KHz channel spacing. It was noted that this measure was a short term improvement for regions experiencing severe VHF frequency spectrum congestion, in anticipation of the development and implementation of the future digital VHF radio system.

European Implementation

137. As detailed above, the mandatory carriage of 8.33 KHz capable radios was required for operation above FL 245 in the ICAO EUR Region with effect from 1 January 1999. However, as a result of current fitment rates, Eurocontrol took the decision in July 1998 to delay operational implementation of 8.33 KHz channel spacing until **7 October 1999**.

138. The States that will initially implement 8.33 KHz channel spacing are Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland and the United Kingdom (known as 8.33 States).

139. Although the initial 8.33 States do not comprise all the States in the ICAO EUR Region, the mandatory carriage above FL 245 applies to the whole of the ICAO EUR Region.

140. Parallel operation of 25 and 8.33 KHz spaced VHF channels for the same airspace sector will not be achievable. Accordingly, from 7 October 1999, the flight plans of all aircraft not equipped with radios compatible with the new channel spacing, requiring the provision of an Air Traffic Service as GAT in the airspace designated for 8.33 KHz channel spacing, will be rejected.

141. Aircraft VHF radio equipment used in the ICAO EUR Region will still require to be capable of tuning to 25 KHz spaced channels and, additionally, to receive in an environment which uses off-set carrier systems (CLIMAX operation). Airspace users should take into account that these offset carrier systems may continue to be used throughout Europe for many years.

UK Implementation

142. The UK, although an 8.33 kHz participating state, will not implement 8.33 kHz channel spacing until **June 2000** due to related technical dependencies. Therefore, the UK will file a difference with ICAO to the effect that the UK has no requirement for the carriage of 8.33 kHz radios prior to June 2000. However, all non 8.33 kHz equipped aircraft intending to fly through UK airspace above FL 245 are to comply with the flight planning requirements detailed in the relevant AIC in order to prevent rejection of flight plans by IFPS.

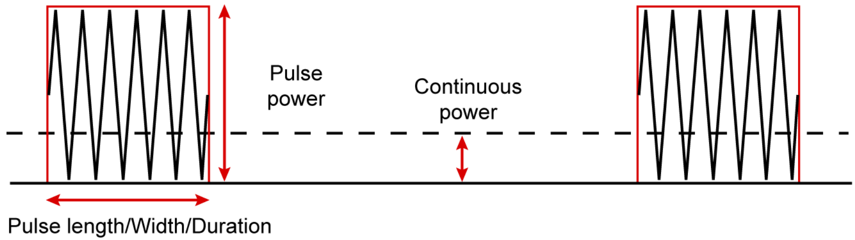
French Implementation

143. Notification had been given that France had intended to introduce 8.33 kHz channel spacing above FL 195. However, a decision has now been taken by France that initial implementation will be above FL 245 with effect from 7 October 1999.

Pulse Modulation

144. Pulse modulation is similar in principle to keyed carrier wave (A1A). The difference is that the pulses used in typical radar systems are of very short duration, typically one microsecond, whilst the period between pulses is **relatively** very long, typically one millisecond. The designation given to pulse modulation is **PON**.

FIGURE 1-49
Radar Terminology



145. The terms in Figure 1-49 should be understood by the student. The continuous power of a radar can be considered to be the average power taking into account the time interval between the pulses, the pulse width and the pulse power (i.e. it allows for the 'duty cycle' of the transmitter).

Pulse Coded Modulation

146. In some equipments (e.g. SSR) the time interval between the individual pulses of a transmitted pulse sequence is made to vary in accordance with a pre-determined code. This allows additional information to be passed between a Tx and Rx, or Rx and Tx, and is called Pulse Coded Modulation.

Multiplex Modulation

147. When two types of modulation are used together, typically AM and FM, the carrier wave is able to carry two separate sets of information. This technique is called Multiplex Modulation.

Modulation Designators

148. We can now summarise the modulation designators as they apply to some of the equipments which we will study in the Radio Navigation section:

A3E	Amplitude modulated double side-band radiotelephony (VHF communications)
J3E	Amplitude modulated single side-band radiotelephony (HF communications).
NONA1A	Unmodulated carrier wave (NON) periodically interrupted by keyed carrier wave (A1A) to give the Morse identifier (long range NDBs).
NONA2A	Unmodulated carrier wave (NON) with a simple keyed amplitude modulation periodically superimposed to give the Morse identifier (short wave NDBs)
PON	Pulse (radars)
A8W	Simple amplitude modulation, however the depth of the modulation is made to vary (ILS).
A9W	Composite amplitude/frequency modulation (VOR).
NOX.G1D	Microwave Landing System

Bandwidth

149. We tend to assume that if the published frequency of a transmitter is, for example 123.2 MHz, that the frequency transmitted is 123.2 MHz and only 123.2 MHz. This is not in fact the case.

150. With a little thought it should be obvious that a frequency modulated signal must necessarily cover a band of frequencies, this band being termed the **bandwidth** of the transmitter. For perfect reproduction of the **intelligence** the radio receiver must have the same bandwidth. That is to say that the receiver must possess the ability to accept the same band of frequencies as that transmitted. The upper and lower limits of the frequency band are equally spaced above and below the published spot frequency (except in single side band systems).

151. With FM signals the bandwidth is quite **broad**, and consequently the number of channels which can be fitted into any given part of the radio frequency spectrum, without risk of overlap and consequent interference, is somewhat limited.

152. With amplitude modulation it would appear at first sight that only one frequency is transmitted. Unfortunately life is never that simple. The example of simple amplitude modulation illustrated at Figure 1-43 shows a 300 KHz carrier wave modulated with a 2 KHz audible tone. The range of frequencies actually transmitted in this case would be 298 KHz to 302 KHz, giving a bandwidth of 4 KHz.

153. The **bandwidth** of any **amplitude modulated** signal is twice the value of the highest frequency of the modulating waveform. The range of frequencies actually transmitted is the basic carrier wave frequency **plus** and **minus** the highest frequency of the modulating waveform.

154. **The bandwidth of an amplitude modulated signal will be narrower than the bandwidth of a frequency modulated signal conveying the same intelligence.** Despite this narrow bandwidth the situation still arises whereby certain parts of the radio frequency spectrum, particularly the HF band, have become congested, and that as a result of this, interference from stations on adjacent channels often occurs. The greater the bandwidth transmitted, and therefore required of the receiver, the greater the scope for interference. Speech transmission using amplitude modulation requires a 3 KHz modulating waveform, whilst music requires about 15 KHz. In order to alleviate this problem single side band (SSB) systems are now widely used.

Single Side Band Transmission

155. With amplitude modulated signals we have established that the frequencies actually transmitted are equi-spaced about the carrier wave frequency. The **intelligence** is contained in two bands of frequencies, one above the carrier wave spot frequency, the **upper side band** (**USB**), and one below the carrier wave spot frequency, the **lower side band** (**LSB**). **The same information is conveyed in the USB as in the LSB**, and it is therefore possible to suppress one or the other without losing any of the intelligence. The effect of this is to halve the bandwidth, enabling closer channel spacing without risk of interference. Furthermore, because the side bands absorb at least 25% of the transmitter power, suppressing one of the side bands leaves more of the total transmitter power available for transmission of the carrier wave – significantly increasing the range at which the transmitted signal can be received.

156. In summary, the advantage of SSB transmission are that:

(a) It occupies less of the available radio spectrum (the bandwidth is halved).

(b) Interference from other transmissions is less likely (a better signal to noise ratio).

(c) Greater range is achieved for a given power (the same power is concentrated into the narrower bandwidth).

Interference

157. Radio interference may arise from several sources. Such interference is generally termed **noise**. It should be noted that interference generated in the atmosphere is correctly known as **static**, whereas interference generated by man-made equipment is correctly termed **noise**. **Station interference** was briefly discussed in the preceding paragraphs. This can occur when stations are operating on adjacent channels and bandwidth overlap exists. Equally station interference can occur when two stations operate on the same frequency, and the geographic spacing between them is insufficient (see ADF and VOR).

Static

158. The vast amounts of energy contained within thunderstorm cells cause the storm clouds to emit high levels of electromagnetic energy. These emissions are particularly troublesome in the VLF, LF, MF and to a degree the HF bands.

159. In the HF band, static may additionally result from ionospheric disturbances such as are caused by sun spot activity. Generally, below VHF, the lower the frequency the greater the problem. For a given location, ionospheric static will be more troublesome in summer than in winter and will be more troublesome at low latitudes than at high latitudes. Ionospheric disturbances will pose more of a problem at night than during the day, since at night sky waves spend more time within the ionised layers.

160. Precipitation static occurs, for example, when rain at a given electrical potential strikes an aircraft at a different electrical potential. On impact a current will flow between the airframe and the water droplet; dust and sand in the atmosphere can produce the same effect. Whenever a current flows it produces a magnetic field which is termed **precipitation static**. Precipitation static, including that caused by snow, is particularly troublesome within the LF and MF bands.

Noise

161. **Electrical noise** is primarily caused by **sparking**, which readily occurs at generator and electric motor commutators, at relays, and at poor electrical connections. As we probably all know from experience, this noise can seriously interfere with radio reception.

162. **Electronic noise** is troublesome at VHF frequencies and above. When alternating current electron flow occurs at these very high frequencies within the equipment circuitry, the wiring itself tends to **emit** electro-magnetic energy. In order to prevent these emissions from causing interference it is necessary to **screen** sensitive areas of the equipment.

Q Code and Radio Bearings

163. The Q code was introduced as a shorthand to assist wireless telegraphy (Morse) operators. With the advent of voice communications networks (telephony), wireless operators disappeared from flight decks and with them much of the Q code. Some Q notations still survive, and four of them which are particularly pertinent to this part of the syllabus are listed below.

(a) **QDM**. The **magnetic great circle** bearing of the **station from the aircraft**. Sometimes defined as being the great circle heading to fly to the station in still-air conditions.

(b) **QDR**. The **magnetic great circle** bearing of the **aircraft from the station.** The term **radial** is often used as an alternative to QDR.

(c) **QTE.** The **true great circle bearing** of the **aircraft from the station.**

(d) **QUJ.** The **true great circle bearing** of the **station from the aircraft.**

Aerials

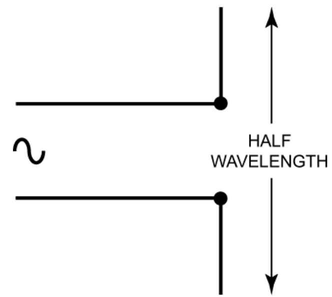
164. Alternating current flowing in a conductor is associated with a combination of electric and magnetic fields. The fields vary in time with the frequency of the alternating current and electromagnetic waves radiate away carrying energy supplied by the transmitter. A transmitting aerial is simply a conductor supplied with alternating current.

165. If the radiated electromagnetic wave is intercepted by a passive conductor, an alternating current is generated in the conductor. This conductor is acting as a receiving aerial. The receiver which it feeds is designed to detect the current, amplify it and convert it into a form appropriate to the desired display.

Half Wave Dipole

166. The half wave dipole is probably the most common practical aerial. It is a straight conducting rod, approximately half a wavelength long. Alternating current is fed to the aerial along a transmission line, which is usually connected at the centre of the rod.

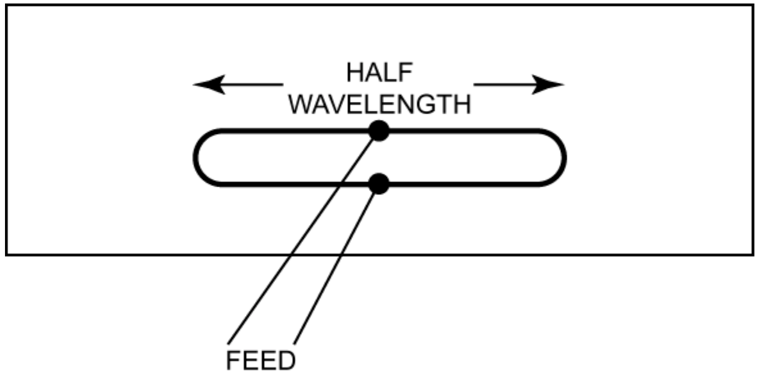
FIGURE 1-50
Half Wave Dipole Aerial



Slot Aerials

167. A half-wave slot cut in a sheet of metal behaves very like a half-wave dipole. The slot aerial in Figure 1-51 has a radiation pattern exactly like that of a vertical dipole. Slot aerials are polarised at right angles to the slots, whereas rod aerials are polarised parallel to the rods.

FIGURE 1-51
Half Wave Slot Aerial

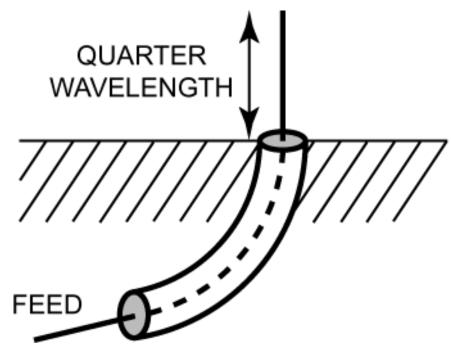


168. Some types of aircraft suppressed aerial are based on the slot. In these aerials, the slot is cut in the aircraft skin. Half-wave slots cut in the wall of a waveguide, feature in the design of certain microwave aerials.

Quarter Wave Unipole

169. The physical length of a half-wave dipole depends on design frequency and, at low frequencies, it may be excessive. The quarter-wave unipole consists of a single conductor a quarter of a wavelength long mounted at right angles to a conducting surface. This conducting surface acts as a reflector and creates the image of the unipole leading to a performance very like that of the half-wave dipole. Obviously radiation is only present in the space above the conducting surface but in this space the radiation pattern is identical to that of the dipole. The radiation resistance of the unipole is about half that of the dipole.

FIGURE 1-52
Quarter Wave Unipole Aerial



Parasites

170. The half-wave dipole is not particularly directional. A simple modification, which improves the directional qualities of a dipole, involves the use of parasitic radiating elements. Parasites are conducting rods placed near to the energised (driven) dipole. The signal transmitted from the dipole induces currents in the parasites, which reradiate the energy received. By adjusting the lengths and spacings of the parasites relative to the dipole, constructive interference can be encouraged in one direction and destructive interference in others. A parasite, longer than a half wavelength placed near to a dipole enhances the radiation in the direction of the dipole. Such a parasite is called a reflector. A short parasite tends to enhance the radiation in the direction of the parasite and such a parasite is therefore called a director.

The Yagi Array

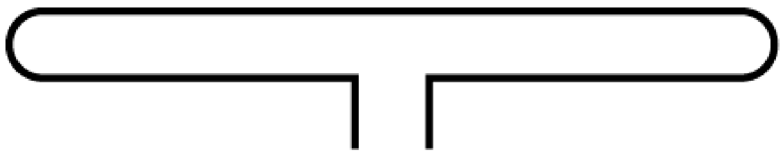
FIGURE 1-53
The Yagi Array

171. The Yagi aerial array is formed from a driven dipole, a reflector and a number of directors. The polar diagram is similar in all planes and beamwidths of a few tens of degrees are available.

The Folded Dipole

172. An effect of the parasite elements is to reduce the radiation resistance of the driven dipole. This can cause serious mismatch problems and an increase in system losses. For these reasons, the folded dipole, shown in Figure 1-54, is often used as the driver in a Yagi array. It has a higher radiation resistance which, when reduced by the effect of the parasites, offers a reasonable match to the feeder.

FIGURE 1-54
The Folded Dipole



Radar Aerials

173. The basic function of a radar aerial is to act as a coupling device or transducer between free-space propagation, and guided-wave (transmission line) propagation. When the radar transmits, the function of the antenna is to concentrate the radiated energy into a beam of the desired shape, which points in the desired direction in space. On receive, the aerial collects the energy contained in the signal and delivers it to receiver.

174. Fundamentally radar aerials do not differ at all from aerials used for communications at other frequency bands. The most important practical difference between radar aerials and most communications aerials, is the requirement to be able to direct a narrow beam of energy in any direction at will. The narrow beam property is often achieved by focussing the transmitted energy by means of a specially designed reflector, in much the same way as a searchlight beam is formed, or by utilising an array configuration in which it is arranged that the radiation from a number of individual elements adds up in one direction only. Scanning of the beam may be achieved by mechanical or electronic means.

175. The shape of the beam is a function of the aerial shape. The aerial may be designed to produce a narrow-beam pattern with a uniform beamwidth in all planes; this is usually called a pencil beam. Other applications may require a beam which is narrow in azimuth, but much wider in elevation, or vice-versa. Such a beam is called a fan beam, and is achieved by using an aerial with an aperture which is wide in the dimension requiring the narrow beam, and narrow in the other direction.

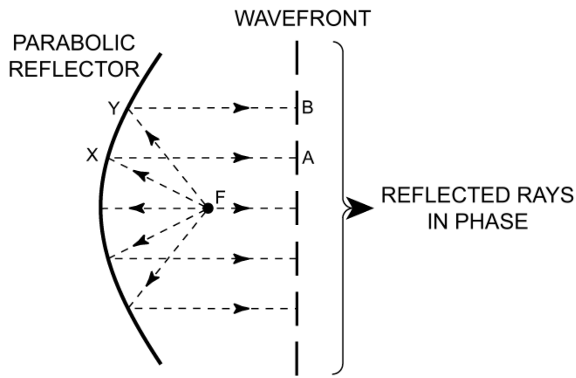
Sidelobes

176. An unavoidable feature of radar aerials is the existence in the radiation pattern of small subsidiary beams, known as sidelobes, which are generated in directions other than that of the main beam. The existence of sidelobes is usually undesirable since they represent wasted power and can give rise to spurious echoes.

Parabolic Antennas

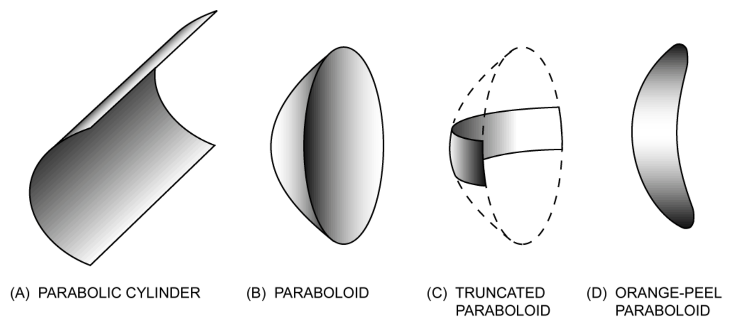
177. The paraboloid or parabolic dish is widely used as a reflector because of two basic geometrical properties. These are illustrated in Figure 1-55 for a simple parabola. Firstly, all the rays from a fixed point (called the focal point, F) to the parabola, are reflected as parallel rays. Secondly, in Figure 1-55, the path lengths FXA, FYB, etc. are all equal. Thus the reflected wave is made up of parallel rays which are all in phase. Notice that this does not imply that the beam will not diverge. In fact, except in the region very near to the antenna, the beam **will** diverge. The significant effect of a parabolic reflector is that it converts a point source of energy at the focus into a plane wavefront of uniform phase.

FIGURE 1-55
Properties of the Parabola



178. The beam shape may be modified by cutting away parts of the paraboloid and making an 'orange-peel' (Figure 1-56(d)) or a 'truncated' 'paraboloid' reflector (Figure 1-56 (c)). Notice that the beam is narrower in the plane in which the reflector aperture is greater. Another common configuration is the parabolic cylinder shown in Figure 1-56 (a), and the parabolic 'cheese' reflector which is a narrow parabolic cylinder enclosed on either side by flat plates.

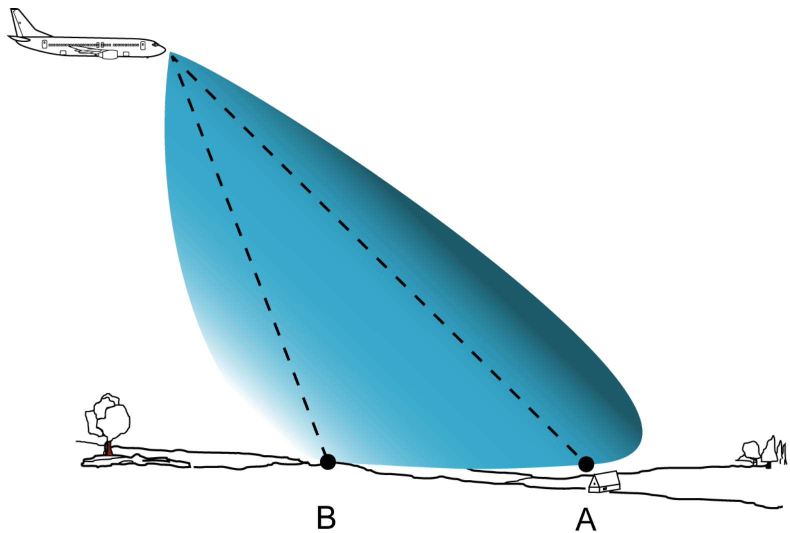
FIGURE 1-56
Types of Parabolic Reflector



Cosecant Squared Aerial

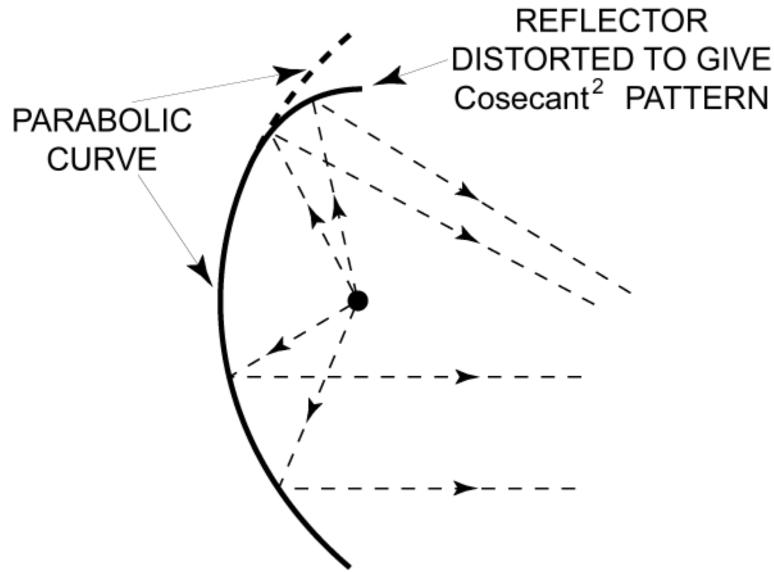
179. The shape of the vertical radiation pattern required from a radar aerial, depends on the function of the radar. Special beam shapes can be produced by appropriately configured aerials. For example the cosecant squared reflector, widely used in airborne mapping radars, produces a beam which is narrow in azimuth but wide in elevation, in order to provide equal strength returns from similar ground targets at different ranges (Figure 1-57).

FIGURE 1-57
Cosecant Squared
Radiation Pattern



180. This specialised type of pattern is often produced by distorting the upper portion of a parabolic reflector, so that more energy is directed at the longer range targets than towards those at short range (Figure 1-58).

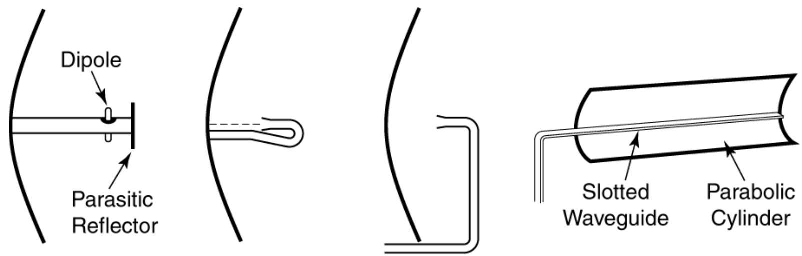
FIGURE 1-58
Cosecant Squared Reflector



Feeds for Parabolic Reflectors

181. Parabolic Reflectors are usually energised by an elementary aerial placed at the focal point, or in the case of a parabolic cylinder, a line of such aerials placed along the axis. The feed element often consists of a dipole or a waveguide horn, or for the parabolic cylinder a length of slotted waveguide. Typical arrangements are shown at Figure 1-59.

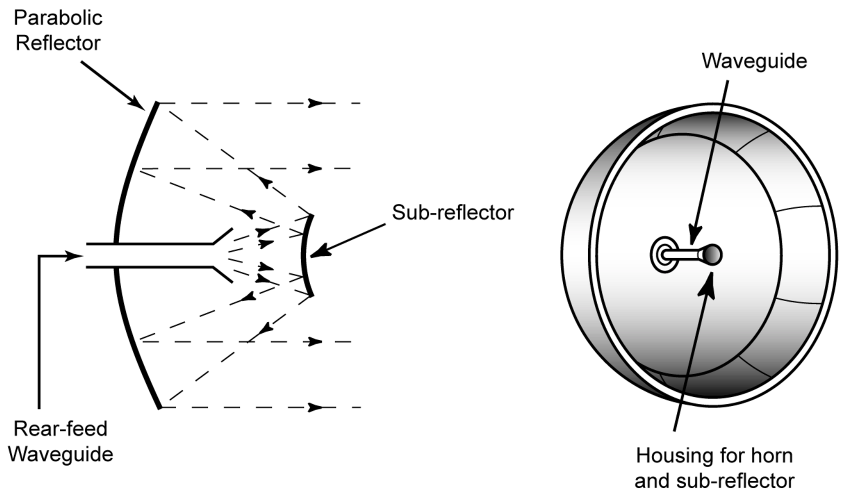
FIGURE 1-59
Feeds for Parabolic Reflectors



The Cassegrain Aerial

182. The aerial shown at Figure 1-60 is developed from a principle used to reduce the length of optical telescopes, and is known as the Cassegrain Aerial.

FIGURE 1-60
The Cassegrain Aerial

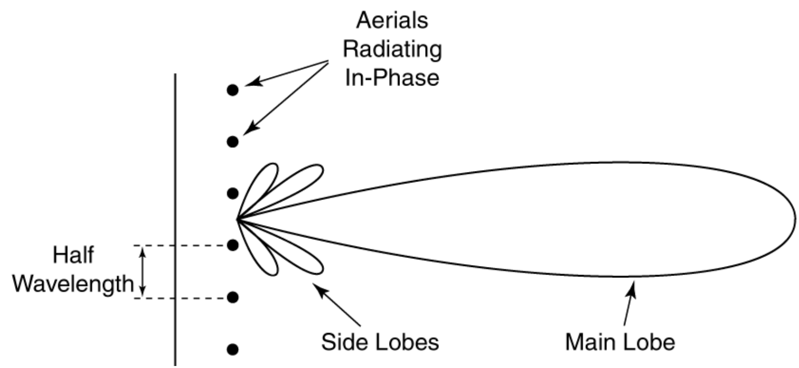


183. A parabolic reflector is fed from the rear by a waveguide horn. The waveguide energy is reflected from a small convex sub-reflector into the main parabolic reflector. This 'double-focussing' results in a beam considerable narrower than would be achieved from a conventional aerial of similar dimensions. As well as the advantages of smaller size and simpler mounting, the rear feed means that a shorter waveguide run between aerial and radar is required, and waveguide losses are thus reduced. The Cassegrain configuration is often used in low-noise applications where a low-noise amplifier may conveniently be mounted directly behind the main reflector, making the waveguide run as short as possible.

Slotted Waveguide Arrays

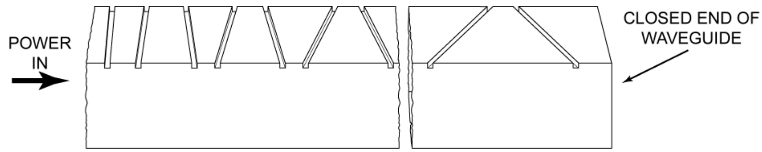
184. It has already been shown that when a number of aerials are spaced half a wavelength apart and fed in phase, the energy radiated from the aerials adds in some directions and cancels in others depending on the phase relationships involved. This type of aerial array is the linear broadside array, which gives a beam at right angles to the line of the constituent aerials (Figure 1-61).

FIGURE 1-61
The Broadside Array



185. A similar effect may be achieved by means of a series of half wavelength slots cut in the wall of a length of waveguide, and so arranged that each slot radiates equal amounts of in phase energy. Such a device constitutes a microwave broadside array. Typically the slots would be cut in the narrow dimension of the waveguide as shown at Figure 1-62.

FIGURE 1-62
Inclined Slot Waveguide Array



Instrument Landing System Aerial Radiation Patterns

186. The Instrument Landing System (ILS) is a runway approach aid which provides the pilot with accurate guidance both in azimuth and elevation during an approach in bad weather.

ILS Ground Equipment

187. The ground installation consists of:

(a) A localiser transmitter which defines the extended centreline of the instrument runway, and indicates any deviation from this centreline.

(b) A glidepath transmitter which defines a safe descent slope (normally three degrees), and again indicates any deviation from this safe approach.

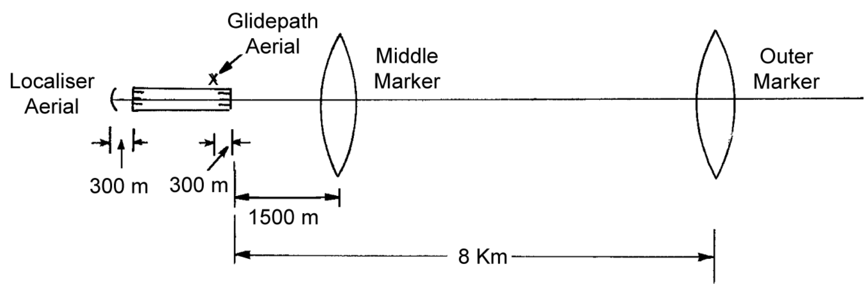
(c) Normally two (occasionally three) marker beacon transmitters for a typical installation. That is to say that with many installations the inner marker is omitted, leaving only the middle and outer markers.

The primary purpose of the markers is to define specified ranges from the runway threshold.

Localiser Transmitter

188. A localiser antenna array is approximately 25 metres wide and four metres high, and is normally situated some 300 metres beyond the upwind end of the instrument runway, see Figure 1-63.

FIGURE 1-63
ILS Aerial Locations

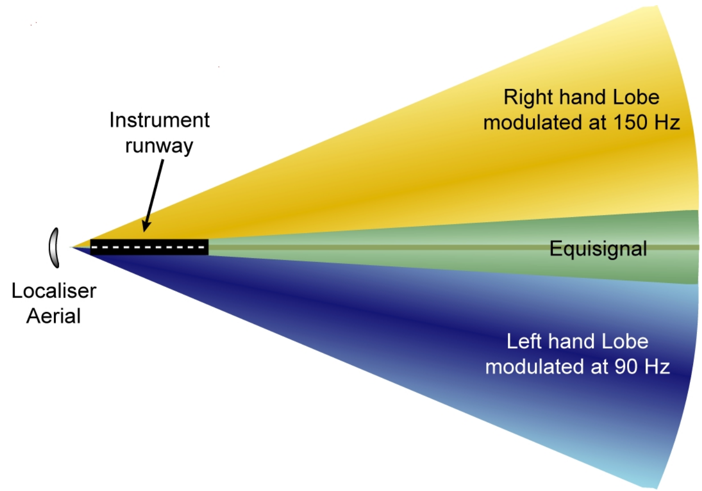


189. Should it not be possible to locate the localiser aerial on the extended centreline, it may be located to one side of the runway, giving what is known as an **offset** ILS. In this case, the QDM of the localiser centreline will differ from the runway centreline QDM by a few degrees.

Localiser Radiation Pattern

190. The localiser transmits two overlapping lobes of electro-magnetic energy (designated A8W) on the same VHF carrier wave frequency. The centre of the overlap area, **the equisignal**, defines the ILS QDM, see Figure 1-64.

FIGURE 1-64
ILS Localiser
Radiation Pattern



191. The lobe on the pilot's left during the approach is amplitude modulated at 90 Hz, whilst the right lobe is amplitude modulated at 150 Hz. The depth of modulation of both the lobes is made to vary, being greatest at the centre and least at the sides of the lobes. The airborne localiser receiver compares the depth of modulation of the 150 Hz and 90 Hz waves. When they are of equal depth the localiser needle will be centralised.

192. When the depth of modulation is uneven the localiser needle is deflected in the appropriate direction. The greater the difference in modulation depths, the greater the displacement of the localiser needle from the centre of the instrument.

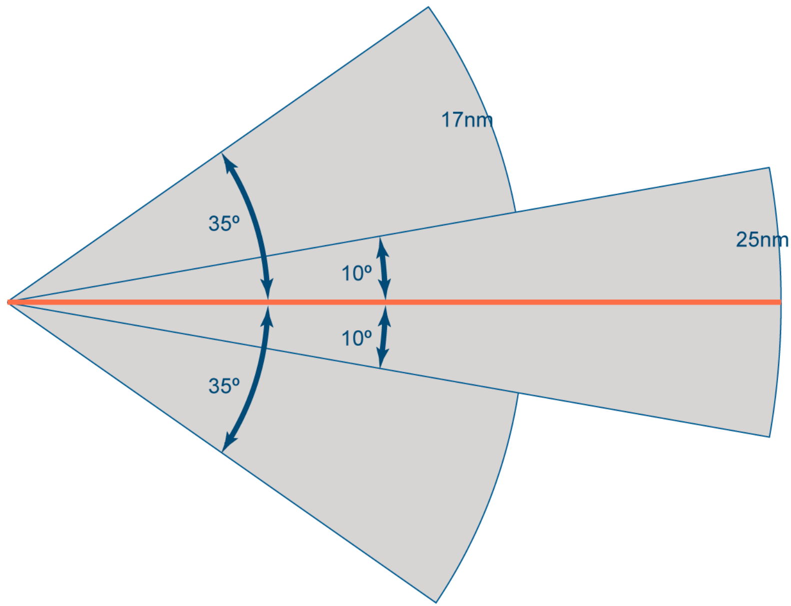
193. In the United Kingdom ILS localisers which are associated with normal glidepath transmitters provide coverage from the centre of the localiser antenna to distances of:

(a) 25 nm within plus or minus 10° of the equisignal (centre) line.

(b) 17 nm between 10° and 35° from the equisignal (centre) line.

As illustrated at Figure 1-65.

FIGURE 1-65
ILS Localiser Coverage



194. In the United Kingdom ILS localisers which are associated with steep angle glidepath transmitters provide coverage from the centre of the localiser antenna to distances of:

(a) 18 nm within plus or minus 10° of the equisignal (centre) line.

(b) 10 nm between 10° and 35° from the equisignal (centre) line.

195. As far as the above coverage areas are concerned, a **normal** glidepath transmitter should be considered to be one which produces a glidepath angle of approximately three degrees above the horizontal, and a **steep** glidepath should be considered to be one which defines an angle from the horizontal of 4° or more.

196. Pilots are warned that use of the localiser outside these areas, even on the approach side, can lead to **False Course** and **Reverse Sense** indications being received. Such use should not be attempted. In particular it must be noted that there is no provision for localiser **Back Beams** to be used in the United Kingdom, and any indications from them must be ignored.

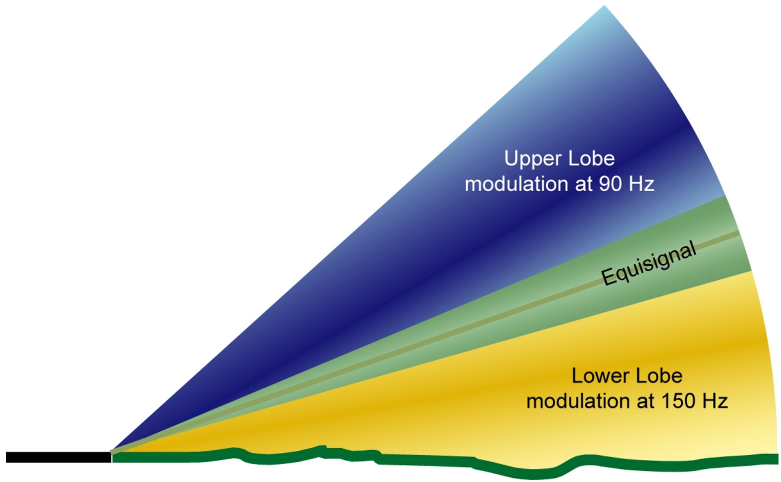
Glidepath Transmitter

197. There are two glidepath aerials which are both mounted on a mast approximately ten metres tall, which is displaced some 150 metres from the runway centreline and 300 metres upwind of the threshold markings.

Glidepath Radiation Pattern

198. As with the localiser, the glidepath transmitter emits two overlapping lobes of electro-magnetic energy (designated A8W) on the same carrier wave frequency. The frequency range used to glidepath transmissions lies in the UHF band, and in this case the lobes overlap in the vertical plane. Again the lobes are continuously amplitude modulated at 90 Hz and 150 Hz. Figure 1-66 shows the idealised radiation pattern with the equisignal defining the glidepath at a typical value of 3° above the horizontal plane passing through the touchdown zone.

FIGURE 1-66
ILS Glidepath Radiation Pattern



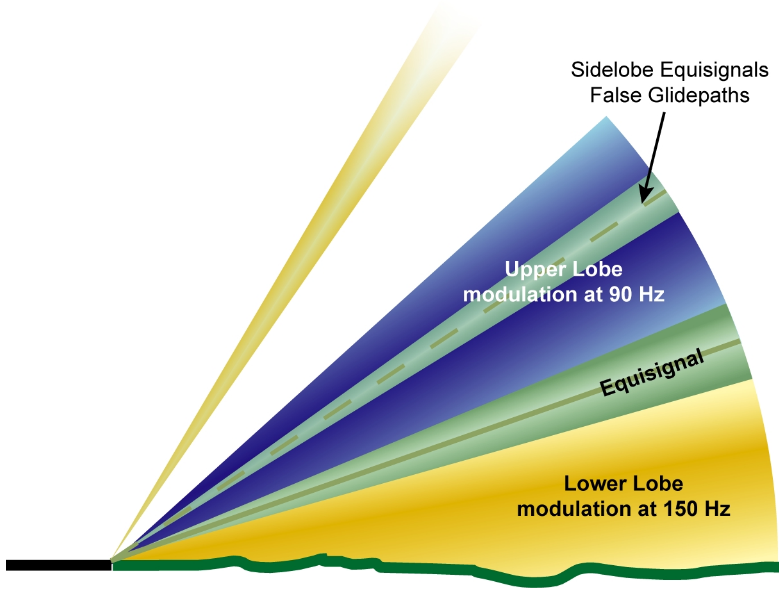
199. Since the lower (150 Hz) lobe lies adjacent to the surface ground-reflected waves result, giving side lobes (Figure 1-67). These side lobes may produce additional equisignals and consequently false glidepaths. Fortunately, these false glidepaths will be situated above the main glidepath and cannot therefore result in an aircraft flying dangerously low during the approach should the false glidepath be inadvertently followed. Indications that the aircraft is flying a false glidepath are listed below:

(a) During a normal ILS procedure, the aircraft captures the glidepath from below. This being the case, the true glidepath (being the lowest) will be the first one to be intercepted. The Civil Aviation Authority has issued a warning to pilots emphasising that special care must be taken at certain airfields around the world where procedures are published involving capture of the glidepath from above.

(b) The first (lowest) false glidepath will give a descent slope which is inclined at least 6° to the horizontal for a normal 3° glidepath, or 5° to the horizontal for a 2.5° glidepath. This will result in a rate of descent of at least twice the expected value.

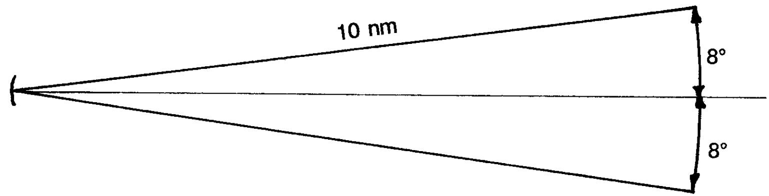
(c) The approach plate used by the pilot during an ILS approach shows check heights and altitudes at the marker beacons, and locator beacons (see later) if appropriate. If a false glidepath has been captured, a check of the altimeter will verify this. A typical check height over the outer marker would be 1500 feet (QFE), whereas on the first false glidepath the altimeter would read 3000 feet (QFE) or above.

FIGURE 1-67
ILS False Glidepaths



200. Glidepath coverage in azimuth (for United Kingdom installations) is provided through an arc of 8° on either side of the localiser centreline out to a range of 10 nm from the threshold, as illustrated at Figure 1-68.

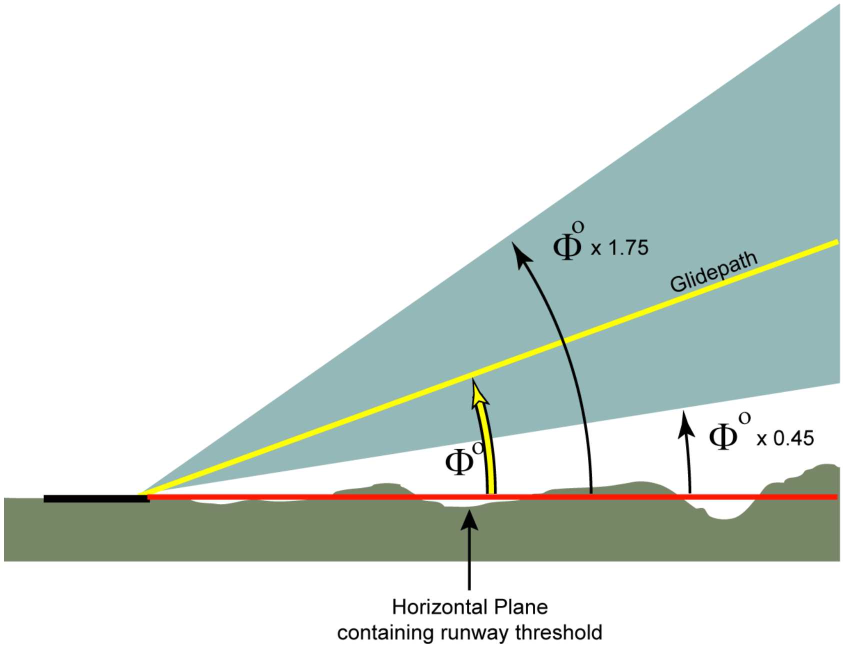
FIGURE 1-68
ILS Glidepath Coverage - Horizontal Plane



201. For glidepath transmitters which produce a steep glidepath, the coverage is reduced to a range of 8 nm from the threshold, again through an arc of 8° on either side of the localiser centreline.

202. Glidepath coverage in elevation is provided through an arc of 1.35° above the horizontal to 5.25° above the horizontal. These figures apply to a standard 3° glidepath installation, and are based on the formulae which state that glidepath coverage (in elevation) is provided through an arc (measured from the horizontal) of between **glidepath angle x 0.45** and **glidepath angle x 1.75**, as illustrated at Figure 1-69.

FIGURE 1-69
ILS Glidepath Coverage - Vertical Plane



203. Pilots are warned that use of the glidepath outside these limits can lead to intermittent and incorrect indications being received. In particular, use of the glidepath at very shallow approach angles, (that is below 1500 feet aal at 10 nm range), should only be attempted when the promulgated glidepath intercept procedure **requires** such use.

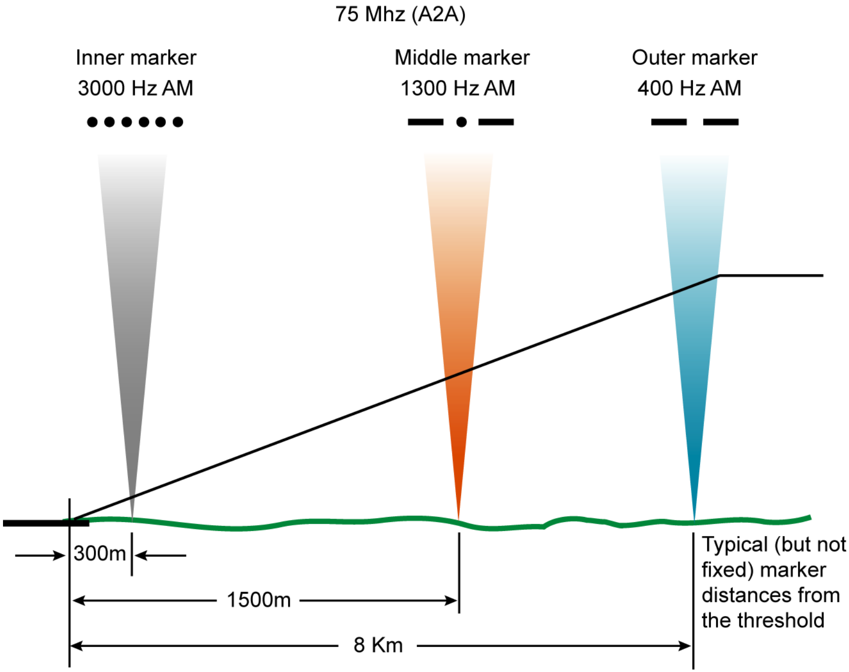
204. The glidepath indication **must** be ignored if the approach angle is so shallow as to put the aircraft at a height of 1000 feet or below at a range from touchdown of 10 nm or more.

205. Certain glidepaths in the United Kingdom do not exhibit correct deflection sensitivity to one side of the localiser course line. This effect is caused by terrain or other problems and can lead to inadequate **fly up** indications being received. When this situation exists a warning will be promulgated by NOTAM and subsequently appear in the appropriate columns of the COM2 section of the UK AIP.

Marker Beacons

206. Marker beacons radiate **fan-shaped** patterns of energy vertically upwards. Figure 1-70 shows an installation using three marker beacons, although the inner marker is not often used these days. All market beacons transmit on a set frequency of 75 MHz. Notice from Figure 1-63 and Figure 1-70 that there is no interference between adjacent beacons because of the narrow extent of the radiation patterns **along** the glidepath.

FIGURE 1-70
ILS Marker Beacon Radiation Patterns



207. The marker beacon transmissions are amplitude modulated with dots and/or dashes at given tones. As the aircraft flies through the radiation pattern associated with a given marker beacon, the pilot will receive both aural and visual indications as described at Figure 1-71.

FIGURE 1-71
Marker Beacon - Aural and Visual Indications

Outer Marker	Aural:	Low Pitch (400 Hz) Dashes
	Visual:	A Blue light flashing in synchronisation with the audible dashes at the rate of two per second.
Middle Marker	Aural:	Medium pitch (1300 Hz) alternate dots and dashes.
	Visual:	An amber light flashing in synchronisation with the audible dots and dashes at the rate of three characters per second.
Inner Marker	Aural:	High Pitch (3000 Hz) dots.
	Visual:	A White light flashing in synchronisation with the audible dots at the rate of six per second.

Airways Fan Markers or Z Markers

208. Marker beacons are still sometimes found straddling airway centrelines to denote reporting points. As with the ILS marker beacons, the airways fan markers radiate a fan-shaped pattern on a fixed carrier wave frequency of 75 MHz, however the power transmitted by an airways marker is considerably greater to facilitate high altitude reception. The aural identifier is a single Morse letter of high pitch tone (3000 Hz) which activates the white (inner marker) light on the aircraft marker beacon panel.

VOR Aerial Radiation Patterns

209. VHF Omni-directional Radio Range (VOR) is a system which gives accurate bearings with reference to ground-based stations using the principle of Phase Comparison between two waveforms.

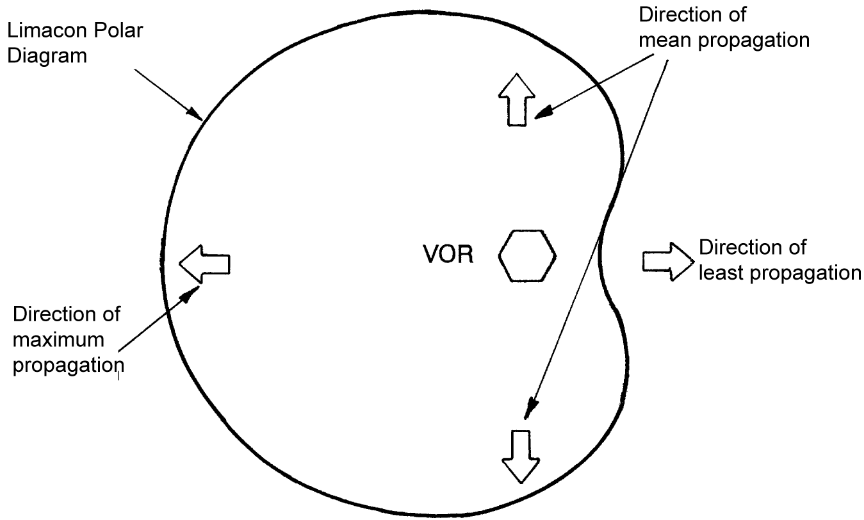
Principle of Operation

210. VOR stations transmit a carrier wave which is modulated in a manner previously described as **A9W** in the section entitled Modulation Techniques. This is to say that the single carrier wave is both **frequency** and **amplitude** modulated at the same time.

211. By **frequency** modulating the carrier wave with a simple 30 Hz waveform, the **reference** signal is achieved. This signal is so named since all airborne receivers at a given range from the station will receive a reference signal which is at the same phase, regardless of the aircraft bearing from the station.

212. The VOR station transmits in all directions (omnidirectionally), however the signal strength varies depending on the bearing from the station at a given point in time. The polar diagram for the VOR transmitter, which is known as a **limacon**, is illustrated at Figure 1-72.

FIGURE 1-72
Limacon Polar Diagram



213. The limacon itself is rotated at the rate of 30 revolutions per second and this has the effect of **amplitude** modulating the carrier wave arriving at an airborne receiver. The phase of the amplitude modulated signal will depend upon the bearing of the airborne receiver from the ground station. The amplitude modulated is therefore known as the **variphase** signal.

Doppler VOR

214. Conventional VOR transmitter aerials should be sited on flat terrain to minimise site errors. If such a site is not available, a complex aerial system may be employed to transmit the VOR signal. This type of station is know as a **Doppler VOR** (DVOR) beacon and produces a signal which is reasonably free of site errors even when the transmitter is sited in hilly terrain.

215. The way in which the bearing signal is produced is quite different from conventional VOR, the received signals are indistinguishable from each other and the airborne receiver will operate on either with equal facility. In Doppler VOR the reference signal is **amplitude** modulated at 30 Hz, whilst the bearing signal is **frequency** modulated at 30 Hz. Because this is the reverse of a conventional VOR, the bearing (or variable) modulation is made to **lead** the reference signal by a phase angle equal to the aircraft's magnetic bearing **from** the VOR ground station.

216. The Doppler VOR transmitter comprises a circle of about 50 antennae surrounding a single omni-directional antenna. The latter transmits the AM reference signal, whilst the circle of antennae are sequentially energised in an anti-clockwise direction at 30 revolutions per second (30 Hz). From any given direction, it will appear as though the transmitter is advancing and retreating at 30 Hz – in other words there will be a Doppler shift. The phase relationship between the doppler shift and the steady reference signal is arranged to be zero when received on a bearing of 000° (M) from the transmitter. Since both signals have the same modulating frequency (30 Hz), at 180° (M) from the VOR the phase difference will be 180°, at 270° (M) it will be 270° and so on.

Self Assessed Exercise No. 1

QUESTIONS:

QUESTION 1.

The HF frequency band covers frequencies between:

QUESTION 2.

The wavelength corresponding to a frequency of 339 Khz is:

QUESTION 3.

The wavelength corresponding to a frequency of 9875 Mhz is:

QUESTION 4.

The frequency which corresponds to a wavelength of 2.4 metres is:

QUESTION 5.

Study the diagram of two radio waves at Figure 207 in the Reference Book. The signal with the larger amplitude has a phase difference of _________ from the other signal.

QUESTION 6.

When an RF signal is radiated from a vertical antenna, the H field will be in the _______ plane, the E field will be in the _________ plane, and the receiver antenna should be in the _______ plane:

a) vertical horizontal horizontal

b) horizontal vertical vertical

c) vertical horizontal vertical

d) horizontal vertical horizontal

QUESTION 7.

The main advantage of using a crystal controlled oscillator in radio equipment is:

QUESTION 8.

In a basic radio transmitter, the purpose of the modulator is to:

QUESTION 9.

With reference to SKIN EFFECT in a radio antenna, the SKIN DEPTH __________ with an increase in frequency.

QUESTION 10.

The distance between the transmitter and the first returning skywave is known as the:

QUESTION 11.

In a pure capacitive circuit the voltage ________ the current by 90°

QUESTION 12.

A frequency of 4Ghz will have a wavelength of __________ which is in the _______ band.

QUESTION 13.

The bandwidth of a series LCR circuit is defined as the difference between the two frequencies either side of resonance at which the _________ has fallen to 0.707 of its maximum value.

QUESTION 14.

Atmospheric ducting is most likely to occur close to the surface of the Earth when:

a) there is a marked inversion and no change of humidity within the inversion

b) there is a marked inversion and a marked increase in humidity with height

c) there is a marked inversion and a marked decrease in humidity with height

d) there is a deep layer of stratus cloud over the sea

QUESTION 15.

The average height of the D layer in the Ionosphere is:

QUESTION 16.

As the frequency of an HF transmission is increased, the dead space will:

a) decrease

b) increase, due only to the increase in minimum skip distance

c) decrease, due to the decreasing skywave range and the increasing surface wave range

d) increase, due to both increasing minimum skip distance and to decreasing surface wave range

QUESTION 17.

The F layer of the Ionosphere is called the ___________ layer.

QUESTION 18.

VHF communication is given the designator __________ and uses ___________ modulation.

QUESTION 19.

What are the two effects of the Ionospheric layers in relation to a radio wave.

QUESTION 20.

Capacitive reactance X_c varies ________ .

a) directly with frequency

b) inversely with frequency

c) is not dependent upon frequency

d) with the applied voltage

QUESTION 21.

The advantage of single-sideband (SSB) over double-sideband (DSB) communications is;

QUESTION 22.

The frequency of HF transmission which produces a minimum skip distance which is exactly the same as the distance between the transmitter and receiver is called the ___________ .

QUESTION 23.

At what frequency does tropospheric scatter occur.

QUESTION 24.

When conveying the same intelligence using both AM and FM techniques, which method would require a wider bandwidth receiver.

QUESTION 25.

Which frequency bands are particularly susceptible to static interference?

QUESTION 26.

The true great circle bearing of an aircraft from the station is given the Q code designator _________ .

QUESTION 27.

The length of a slot aerial, in terms of wavelength, is generally:

QUESTION 28.

What is the key feature of a parabolic radar reflector.

QUESTION 29.

What frequency band does ILS equipment occupy.

QUESTION 30.

The polar diagram for a VOR transmitter is called a _______ .

ANSWERS:

ANSWER 1.

3-30Mhz

ANSWER 2.

The wavelength corresponding to a frequency of 339 Khz is:

885 metres

$$\lambda = \frac{3 \times 10^8}{339 \times 10^3}$$

ANSWER 3.

$$\lambda = \frac{3 \text{ x } 10^8}{9875 \text{ x } 10^6}$$

$= 3.03$ cm

ANSWER 4.

125 Mhz

$$F = \frac{c}{\lambda}$$

$$= \frac{3 \times 10^8}{2.4}$$

ANSWER 5.

The waveform with the dashed line is lagging behind the solid waveform by 45°

See Figure 208 in the Reference Book

ANSWER 6.

b) horizontal vertical vertical

ANSWER 7.

The generated frequency is very stable

ANSWER 8.

The modulator superimposes the modulating signal onto the carrier signal.

ANSWER 9.

Decreases - skin depth is inversely proportional to frequency.

ANSWER 10.

Minimum skip distance

ANSWER 11.

Lags

ANSWER 12.

7.5 cm, SHF

ANSWER 13.

Current

ANSWER 14.

there is a marked inversion and a marked decrease in humidity with height.

ANSWER 15.

75 km

ANSWER 16.

increase, due to both increasing minimum skip distance and to decreasing surface wave range

ANSWER 17.

Appleton

ANSWER 18.

A3E, double-sideband amplitude modulation

ANSWER 19.

They cause bending of the wave (refraction) and attenuation of the signal.

ANSWER 20.

$$X_c = \frac{1}{2\pi FC}$$

ANSWER 21.

The bandwidth is halved together with an improvement in signal-to-noise ratio.

ANSWER 22.

Optimum frequency

ANSWER 23.

VHF and above

ANSWER 24.

Frequency Modulation requires a wider bandwidth than Amplitude Modulation when conveying the same intelligence.

ANSWER 25.

The lower frequency bands (i.e. VLF, LF and MF) are prone to static.

ANSWER 26.

QTE

ANSWER 27.

a half-wavelength long

ANSWER 28.

A parabolic reflector converts a point source of energy into a plane wavefront of uniform phase.

FIGURE 207

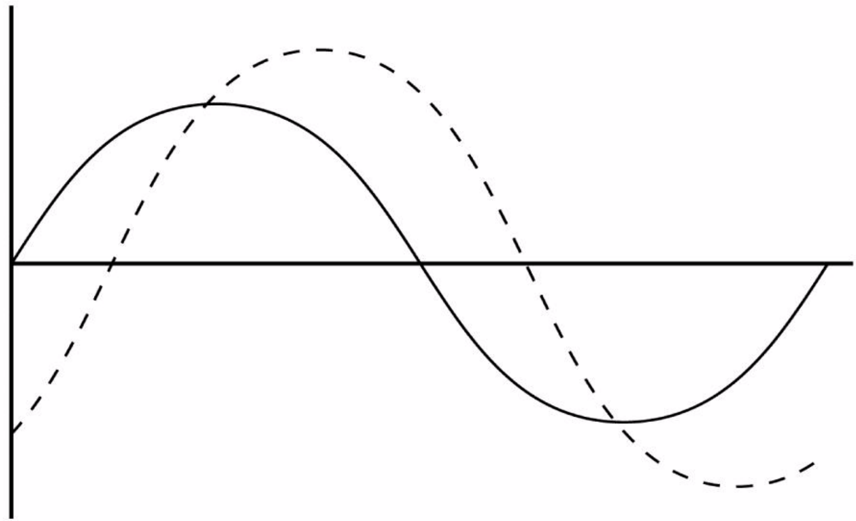


FIGURE 208