Defence School of
Aeronautical Engineering

Aerosystems Engineer & Management Training School

Academic Principles Organisation

FT4

AVIONICS PART 2 PHASE 3
Radar

BOOK 2
Microwave Techniques
Waveguides & Radar Scanners

WARNING

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RADAR MICROWAVE TECHNIQUES & SCANNERS

OBJECTIVES

T.O.s – 42.1, 42.2, 42.3, 42.13

E.O. **S92-01** Describe Aircraft Radar Fundamentals

S92-02 Describe Aircraft Radar Systems

S92-01-02 Describe RADAR Microwave production

S92-01-03 Describe RADAR waveguides

S92-02-05 Describe the electrical aspects of airborne radar scanners to LRU level.

CONTENTS :

RESONANT CAVITY MICROWAVE OSCILLATORS

Microwave Introduction

1. During the Introduction to Radar it was stated that typically the Microwave region for radar in the EM spectrum extends from the Upper UHF through SHF to the Lower EHF band, which roughly covers the NATO bands F–K across the 3 - 35 GHz range.

2. However there are several major problems when operating at microwave frequencies. As a result of these problems conventional electronic circuits and components such transistors do not work, and therefore the amplifier and oscillator devices used in aircraft radar equipment would not work either. So a range of these devices based on different principles were required.

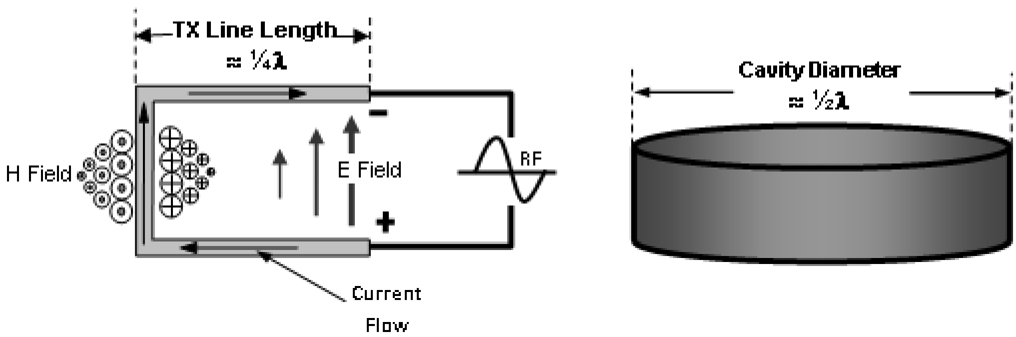
The Resonant Cavity

3. An RF transmission line terminated in a short circuit behaves like a parallel tuned circuit at a distance one quarter of a wavelength (0.25λ) from the termination.

4. The Lecher Bar oscillator (Figure 1a) is a device that uses this principle, but at microwave frequencies the losses were still too great. However by placing an infinite number of Lecher Bars in parallel to each other so that they form a hollow can or cavity, this creates a parallel tuned circuit for a highly effective low loss oscillator without the use of any discrete components.

5. This device is known as a Resonant Cavity (Figure 1b), whose internal diameter is approximately half the wavelength of its resonant frequency (0.5λ). Because frequency is dependent upon size the resonant cavity has a very narrow bandwidth (B/W).

6. At centimetric wavelengths the cavity dimensions are small enough to form an integral part of an oscillator or amplifier.



(a) Resonating Lecher Bar Oscillator (b) Resonant Cavity

Figure 1 - Lecher Bar and Resonant Cavity

Worked Example for the Resonant Frequency of a Cavity

7.

Recall: c = f x λ.

Where: (c) = Speed of Light, (f) = Frequency & (λ) = Wave Length.

Given: Speed of Light (c) = 300×10^6 m/sec.

Given: Cavity Internal Diameter (λ÷2) = 30mm (0.03m).

Question: Calculate the resonant frequency (f_o) of the cavity.

Answer: Wave Length (λ) = 2x λ÷2

= 2 x 30mm (0.03m).

Wave Length (λ) = 60mm (0.06m).

As c = f x λ then f = c ÷ λ

Therefore f = 300×10^6 m/sec (c) ÷ 60 x 10^{-3} (0.06m) (λ)

<u>Resonant Frequency (f_o) = 5 GHz</u>.

8. The instantaneous value of the E fields the H fields and the associated wall currents in a Resonant Cavity can be seen in figure 2.

a. **E fields** are **maximum** at cavity **centre** and minimum (zero) at cavity sidewalls and relates to the capacitance of a tuned circuit.

b. **H fields** are **maximum** at cavity **sidewalls** and minimum (zero) at cavity centre and relates to the inductance of a tuned circuit.

c. The associated **wall currents** are induced by the alternating H field, they **flow** on the **inside** of the cavity **only**.

d. The E and H fields are 90° out of phase and change sinusoidally in both amplitude and direction on alternate half cycles. Therefore when the E field is maximum the H field is minimum and vice versa.

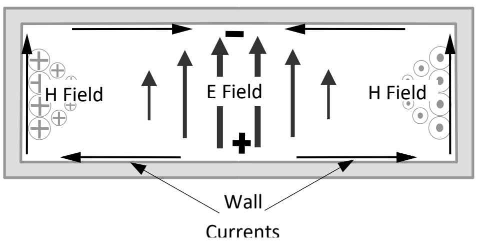


Figure 2 – Oscillating Cavity E & H Fields and Wall Currents

Resonant Cavity Shapes

9. The shape of resonant cavities vary with their function, the three commonest being:

a. Cylindrical – used in Magnetrons (later in the phase), refer Fig 3a.

b. Rectangular – used in some test equipment, refer Fig 3b.

c. Rhumbatron - used in Klystrons (later in the phase), refer Fig 3c.

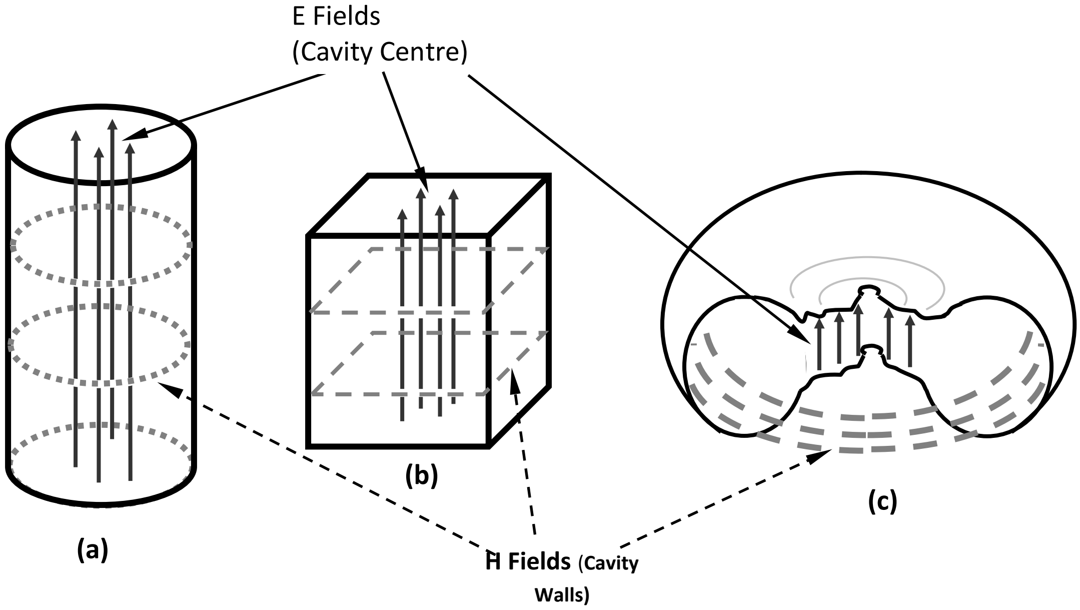


Figure 3 – Common Cavity Shapes and Fields

10. Regardless of the cavity shape the relationship between E field, H field and the associated wall currents that flow on the **inside** of the cavity remains the same.

Resonant Cavity Coupling

11. Resonant cavities are designed to operate with other circuits or as part of other microwave devices. In order to inject or extract energy from a cavity some method of transferring or coupling to and from an external circuit has to be provided. The three most common methods are:

a. Loop Coupling with the H (magnetic) field, refer Fig 4a.

b. Probe Coupling with the E (electric) field, refer Fig 4b.

c. Slot Coupling with the Wall Currents, refer Fig 4c.

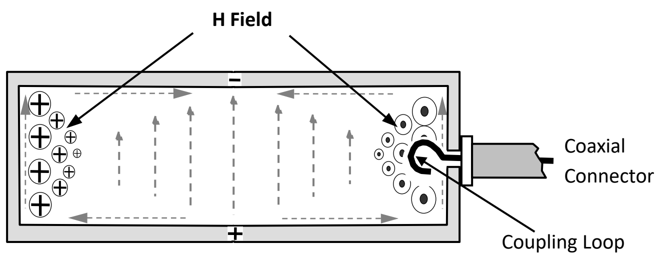


Figure 4a - Loop Coupling with the H (magnetic) field

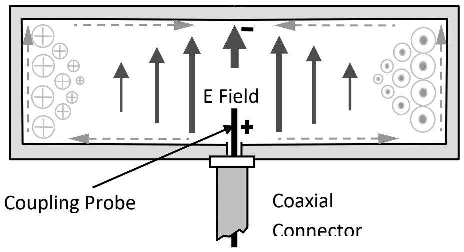


Figure 4b
Probe Coupling with the E (electric) field

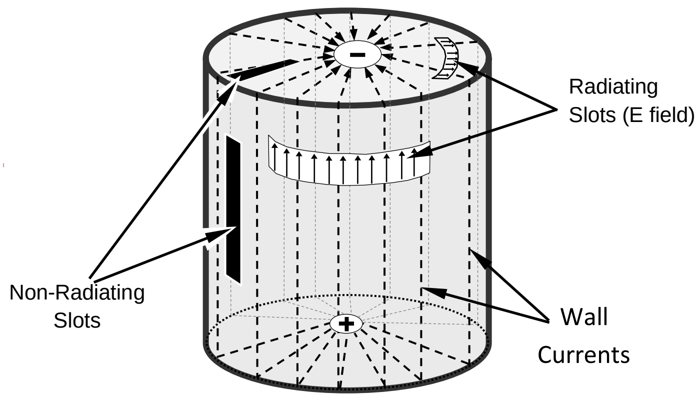


Figure 4c
Slot Coupling with the Wall Currents

Microwave Oscillator and Amplifier Devices

12. The working principles of conventional amplifying devices is that the input to the device controls or modulates the amount of current flowing through the device and thus any sinusoidal input voltage will generally produce an amplified sinusoidal output. This process is called amplitude modulation and works well at VHF and below but not at frequencies above about 400MHz.

13. A range of microwave amplifier and oscillator devices used in aircraft radar equipment were developed that were based on a different modulation technique called velocity modulation.

Velocity Modulation

14. The principle behind velocity modulation is that of varying the velocity (speed) of the electrons that make up the current in the device, rather than varying their numbers. Velocity modulation can be achieved by means of passing an electron beam through an oscillating resonant cavity or a slow wave structure. This results in electron bunches (virtual or real) being formed within the device. Using suitable circuitry it is possible to use the electron bunch formations to produce an amplified microwave output or microwave oscillator output.

15. The following microwave amplifiers and oscillators are thermionic devices (valves), that produce a beam of electrons which are then velocity modulated:

a. Cavity Magnetron

b. Travelling Wave Tube (TWT)

16. Semi-Conductors microwave oscillators such as Gunn Diodes are used in lower power applications and receivers.

Cavity Magnetron (Refer Fig 5)

17. The function and characteristics of the Cavity Magnetron.

   a. Used as high power microwave RF oscillator (it is not an amplifier).

   b. Only used in radar transmitters.

   c. Frequency Range – from 3GHz to 10GHz (f_o depends on cavity size).

   d. Heat changes the size of the cavities causing its o/p frequency to drift.

   e. Narrow B/W – uses resonant cavities.

   f. Power o/p – few watts up to Megawatts pulsed or tens of watts CW.

   g. Uses resonant cavities – usually 8 or more linked (even numbers).

   h. Very noisy internally due to electron impacts that produces lots of heat.

   i. Requires cooling.

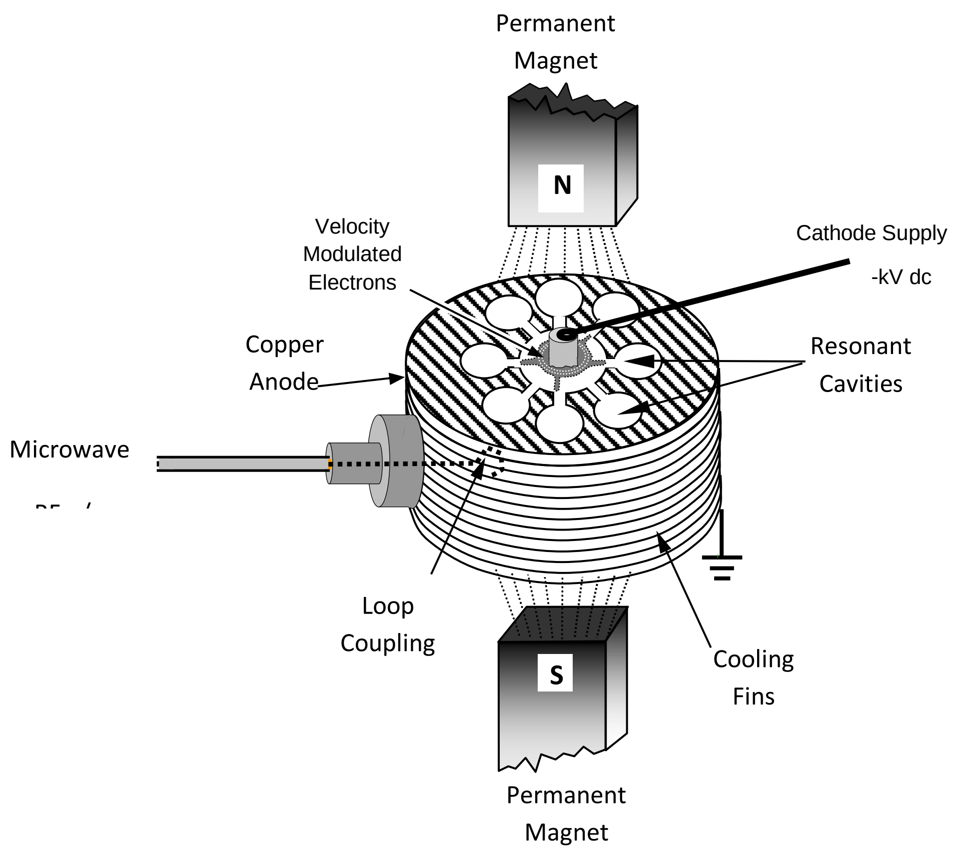


Figure 5 – Cavity Magnetron

Travelling Wave Tube (TWT) (Refer Fig 6)

18. The function and characteristics of Travelling Wave Tubes (TWT) for airborne applications:

- a. Used as a high gain microwave amplifier.
- b. Used in radar transmitters and receivers.
- c. Frequency Range – broad, from 3GHz to 12GHz.
- d. Wide B/W – (not restricted by resonant cavity size).
- e. Power o/p – few mW up to 10's KW pulsed or 1KW CW.
- f. Does **NOT** use resonant cavities – uses a Slow Wave Structure.
- g. Low internal noise – few internal impacts.

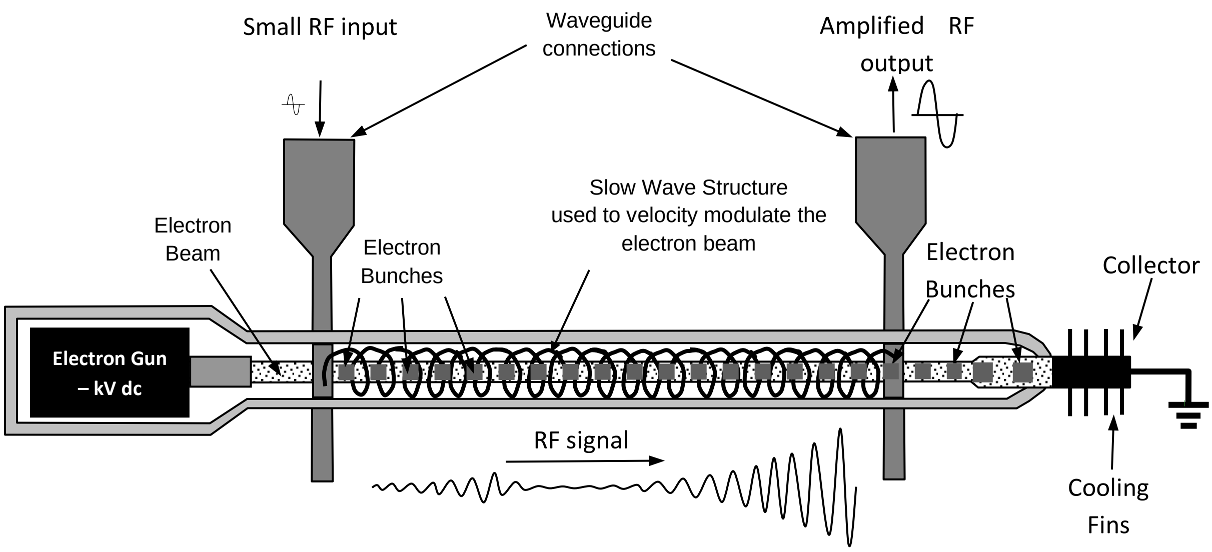


Figure 6 - Travelling Wave Tube (TWT)

Gunn Diode with Varactor Tuned Cavity (refer Fig 7)

19. Some modern radar RX local oscillators use Gunn diodes located in a resonant cavity. To provide the necessary LO frequency range it is electronically tuned by the receivers Automatic Frequency Control (AFC) that varies the voltage to a Varactor diode mounted alongside the Gunn diode.

20. The function and characteristics of a Gunn diode local oscillator.

   a. Semi-conductor device used as low power microwave oscillator.

   b. Used in radar receivers as an electronically tuneable local oscillator.

   c. Frequency Range – 8GHz to 100GHz (f_o depends on power required),

   d. Narrow B/W – uses a resonant cavity.

   e. Power o/p – from 100 mW to 1.5W.

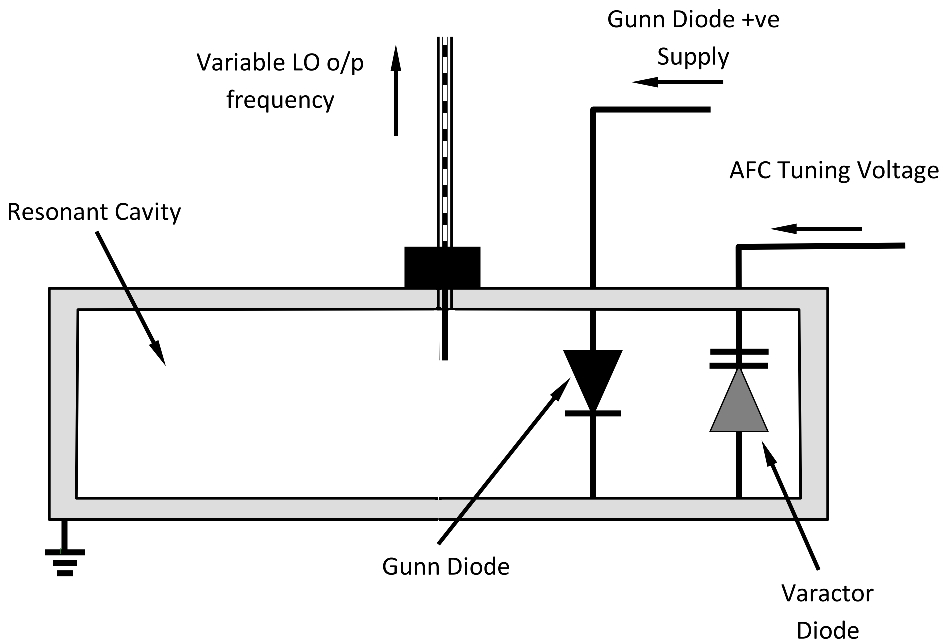


Figure 7 – Gunn Diode with Varactor Tuned Cavity

Summary of Microwave Devices

21. Table 1 below, summarises some of the functions and disadvantages of the listed microwave devices.

Device	Function	Disadvantages
Cavity Magnetron	Used only in transmitters as: High power microwave oscillators (not amplifiers).	Narrow bandwidth (Resonant cavity device). High degree of heat generated, therefore cooling required. Frequency drifts may need AFC
Travelling Wave Tube (TWT)	Used in both transmitters and receivers as: High gain, wide bandwidth, low noise amplifiers.	Physical size.
Gunn Diode with Varactor Tuned Resonant Cavity	Used only in receivers as: Low noise electronically tuneable microwave local oscillators.	Narrow bandwidth (Resonant cavity device).

Table 1 – Summary of Microwave Devices

22. The requirement for the latest radars is to have a fast frequency changing capability and this means that resonant cavity based devices are not practical. These modern radars use phased locked loop technology to achieve the necessary frequency flexibility.

WAVEGUIDES

23. To efficiently transfer RF electromagnetic energy from transmitter to aerial and from the aerial back to the receiver required the development of various types of transmission line systems that would have to deal with increasing RF frequencies and their associated losses and power limitations.

24. Refer figure 8, which shows some of the typical types of RF transmission line systems in use.

a. Open wire twin

b. line feeder – up to 200MHz

c. Coaxial Cable - up to 3GHz

d. Waveguides - 3GHz to 35GHz

e. Microwave Printed Circuit (MPC) or Flat Strip - 3GHz to 100GHz

f. Flexible & semi-rigid microwave cable (Gore Cable) – 0Hz to 67GHz

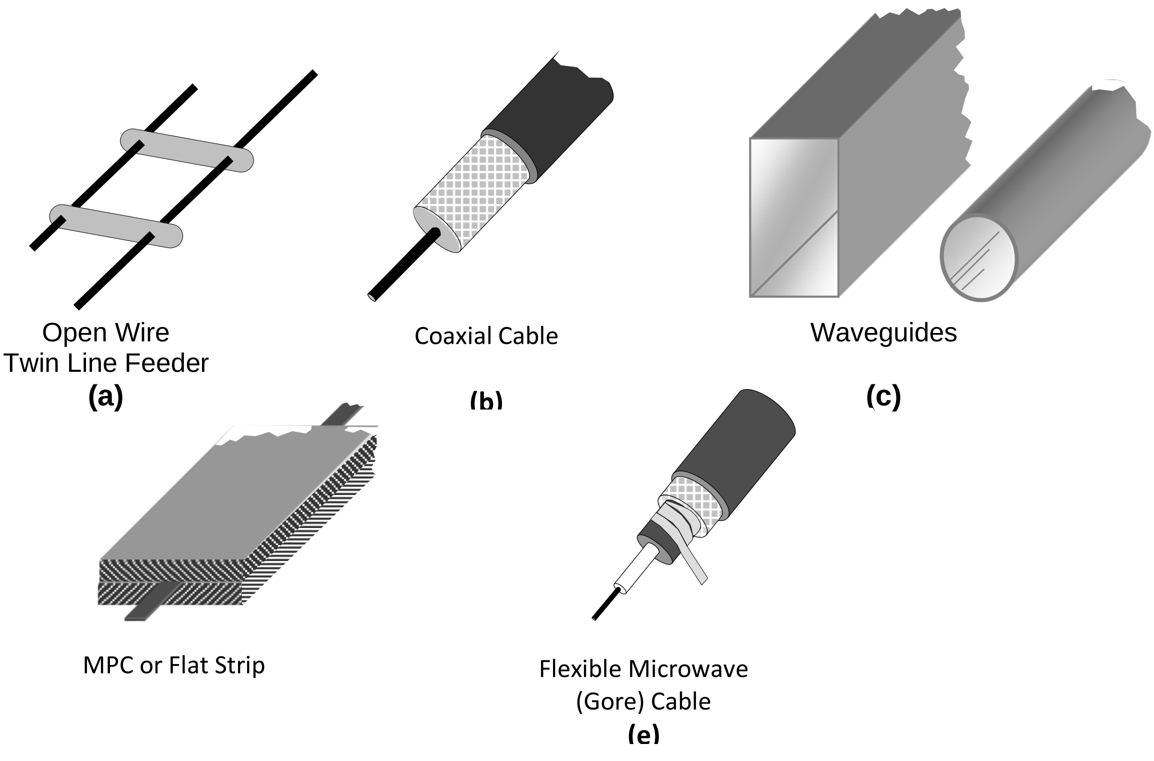


Figure 8 - Transmission Line Systems

25. Most airborne radar systems operate at frequencies between 3GHz - 35GHz and for the efficient transmission of electromagnetic energy at these frequencies waveguides are commonly used. However at lower powers within receiver's microstrip waveguides (MPC or Flat Strip) are used and at higher frequencies Flexible & Semi-Rigid Microwave Cable (Gore Cable) is increasingly used.

Waveguide Construction and Features

26. Waveguides for airborne radar are generally made from pieces of aluminium tubing usually with a flange joint at either end to allow waveguide sections to be joined together.

27. Most waveguides for airborne radar are rectangular in section.

28. Circular waveguides are used for specific purposes such as the rotating joints for scanners.

29. Waveguides are very efficient in transmitting microwaves due to low losses i.e. waveguide walls have a large surface area resulting in little resistive loss also as all the energy is inside an enclosed tube there is no loss through unwanted radiation.

30. The dimensions of rectangular waveguides are related to the frequency (broad side) and power (narrow side) to be transmitted. In general lower frequency waveguides are larger and can handle greater power than smaller higher frequency waveguides.

31. It is important that any damaged waveguide should be replaced as this will affect the dimensions of the waveguide and hence the propagation of the EM wave. There is also a possibility that standing waves will be produced, which could result in arcing between the waveguide walls.

32. Wall currents flowing in the waveguides generate heat, which represents the major source of energy loss. To help in reducing these losses, waveguides are often coated internally with a good conductor such as silver or cadmium. Also care is taken to provide good sealing of the joints, which will keep the air in the waveguides free from dirt and moisture and prevent the formation of high resistance surface oxides (corrosion).

Waveguide Coupling

33. Waveguides have a lot in common with Resonant Cavities and in order to inject or extract energy from a waveguide the same three methods of coupling to and from an external circuit are used:

a. Loop Coupling with the H (magnetic) field through the narrow side, refer Fig 4a.

b. Probe Coupling with the E (electric) field through the broad side, refer Fig 4b.

c. Slot Coupling with the Wall Currents on the broad or narrow sides, refer Fig 4c.

Waveguide System Components

Introduction

34. Unlike coaxial cables, waveguides are not just long pieces of rectangular or circular aluminium tubing used for efficiently transferring microwave energy. Basic waveguides can be adapted in various ways to provide a wide range of different components (refer Fig 9) and functions, which add to its efficiency and usefulness. A number of typical components are covered briefly in the following notes.

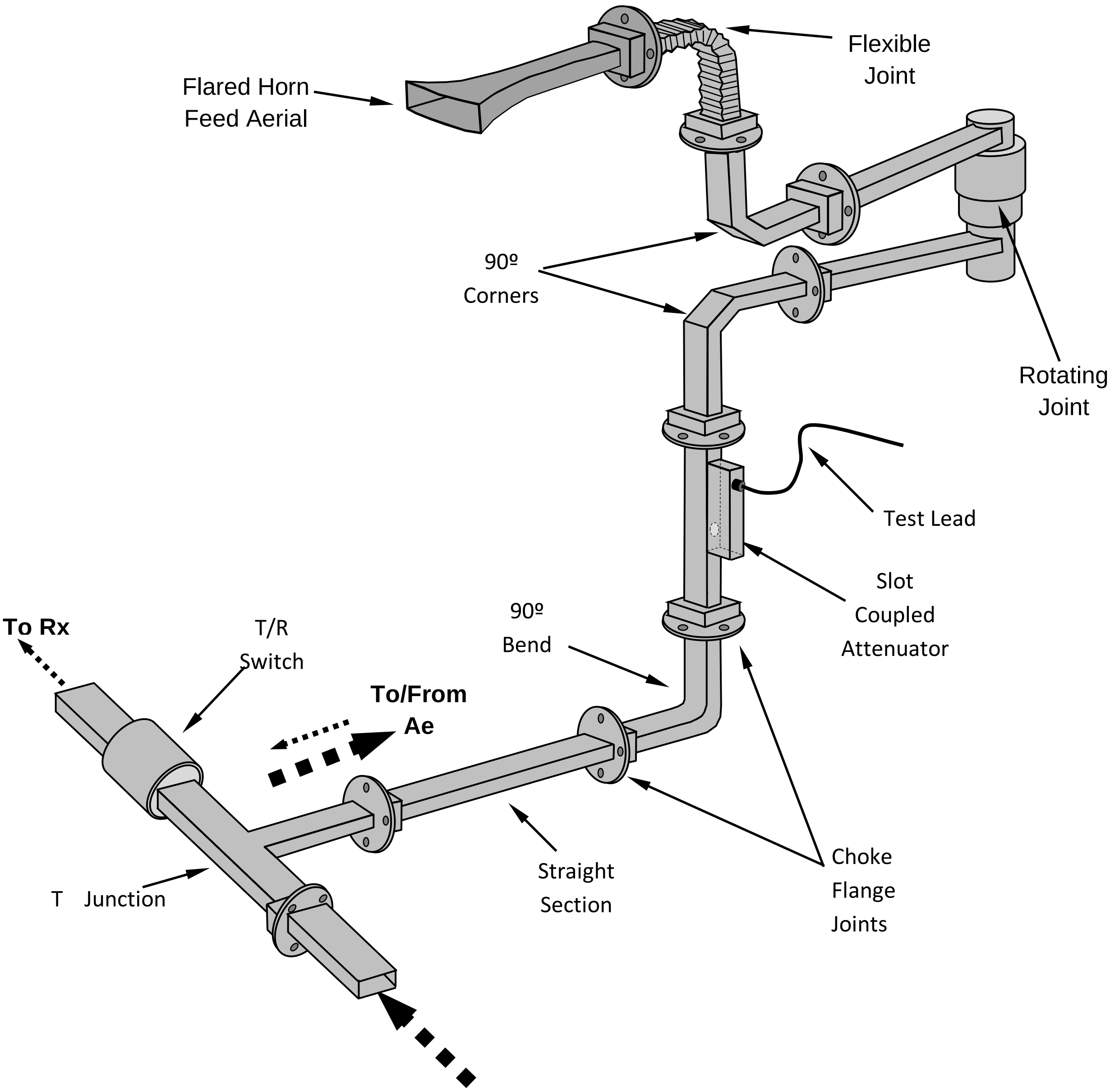


Figure 9 – Basic Radar Waveguide System

Typical Waveguide Components

35. The purpose of each of the waveguide components listed below as shown in figure 9 and/or figures 10, 12 & 13:

a. **90° Bend**. Used in preference to a 90° Corner, as the narrow or broad side dimension remains constant.

b. **90° Corner.** Used where space is limited as it takes up less room than a 90° Bend.

c. **Straight Sections**. Connecting pieces.

d. **Flexible Sections**. These allow limited movement to make the fitting of some components easier they are also used to prevent damage to fixed sections of waveguides from the vibrations produced by rotating scanners.

e. **Dummy Load** (refer figure 10). Used to absorb microwave energy without reflections. During the servicing and testing of air radar equipment, safety precautions do not usually permit power to be radiated from the aerial and a suitable "dummy load" is connected in its place.

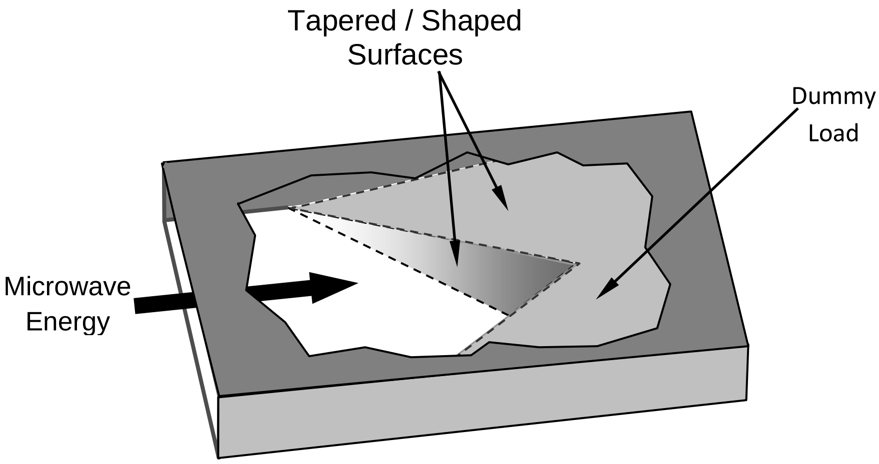


Figure 10 - Dummy Load

f. **Flared Horn Feed Aerial.** Flaring the end of the waveguide into a horn provides the aerial with a good match to the atmosphere, allowing more energy to be radiated from the waveguide.

g. **Slot Feed Aerial** (refer figure 11). Can provide beam shaping and electronic beam steering by varying the microwave energy at the slots.

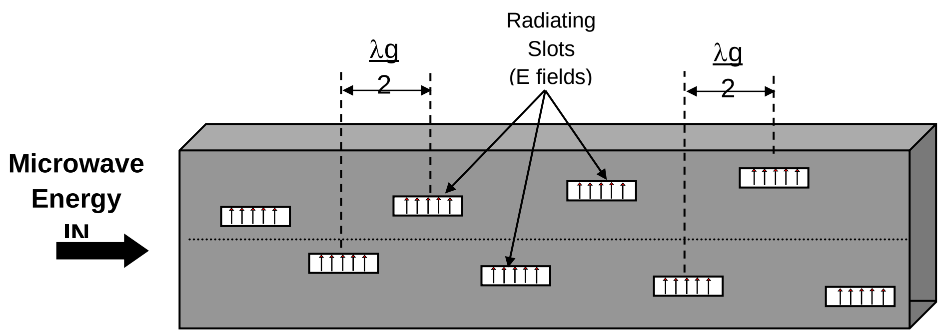


Figure 11 - Slot Feed Aerial

h. **Slot Coupled Attenuator** (refer figure 12). Used to sample the transmitted energy, in order to check frequency, power and PRF. The shape and position of the coupling slot determines the amount of coupling.

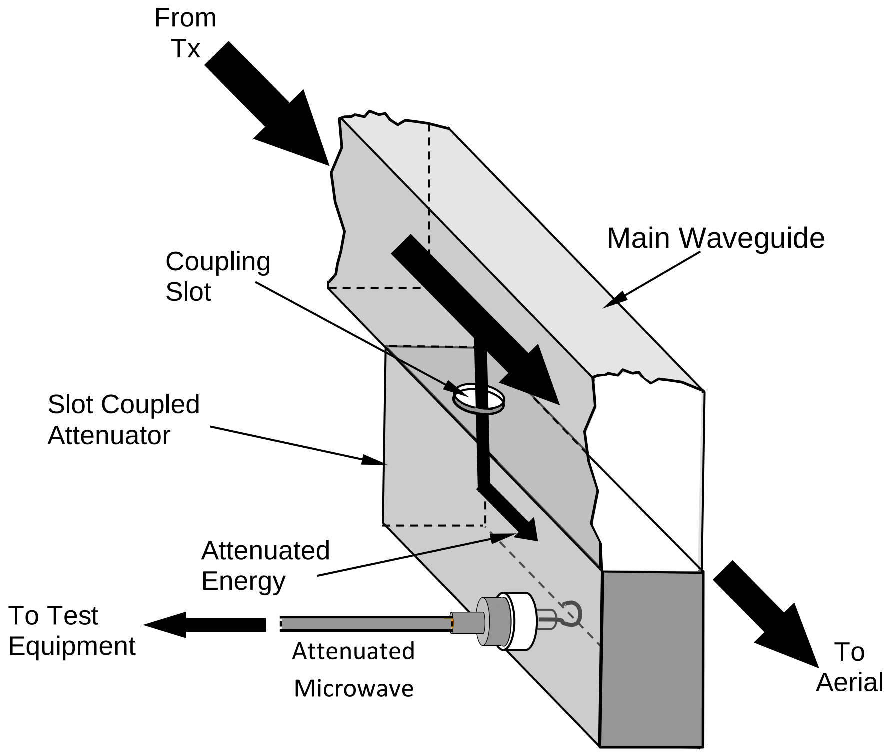


Figure 12 - Slot Coupled Attenuator

i. **Rotating Joints.** These are used to connect fixed sections of waveguides to rotating scanners.

j. **Choke Flange Joints.** Provide one means of connecting lengths of waveguide and waveguide components with minimal losses or problems?

Waveguide Joints

36. When sections of waveguide are bolted together very small gaps can be left at these "flange" joints. This is due to manufacturer's tolerances or wear and tear and is a potential cause of mismatch with standing wave reflections, arcing and energy loss through radiation leakage.

Choke Flange Joints

37. Refer figures 9 & 14. One type of joint commonly used is the choke flange joint. These joints utilise the properties of "Quarter Wave (0.25λ) shorting stubs" that avoid with the need for making highly accurate flanges that are perfectly flat and at right angles to the waveguide.

Quarter Wave (0.25λ) Shorting Stubs Properties

38. **Short Circuit Transmission Lines**. Refer figure 13. If a transmission line is terminated in a short circuit (s/c) examination of the current and voltage standing waves shows that the impedance of the line varies along its length, alternating at 0.25λ wave length intervals between open circuit (o/c) conditions with the current min and voltage max and short circuit (s/c) conditions with the current max and voltage min.

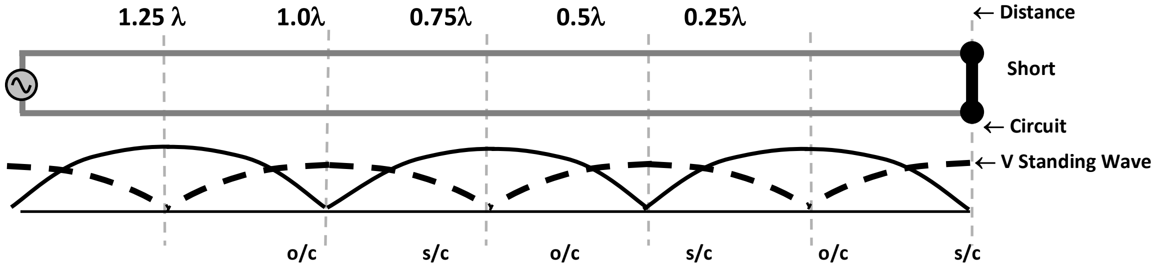


Figure 13 - Short Circuit Transmission Line Effects

39. Summary of Quarter wave (0.25λ) shorting stubs properties.

a. A **s/c** reflected over an **EVEN** number of 0.25λ wavelengths **= s/c** (e.g. at 0.5λ, 1.0λ, 1.5λ etc)

b. A **s/c** reflected over an **ODD** number of 0.25λ wavelengths = **o/c** (e.g. at 0.75λ, 1.25λ, 1.75λ etc)

Operation of a Choke Flange Joint

40. Refer figure 13. The short circuit (s/c) at "A" is reflected over 0.5λ, an **EVEN** number of 0.25λ wavelengths (AB and BC) to form a short circuit at "C". This s/c electrically completes the waveguide wall at the joint preventing any radiation leakage.

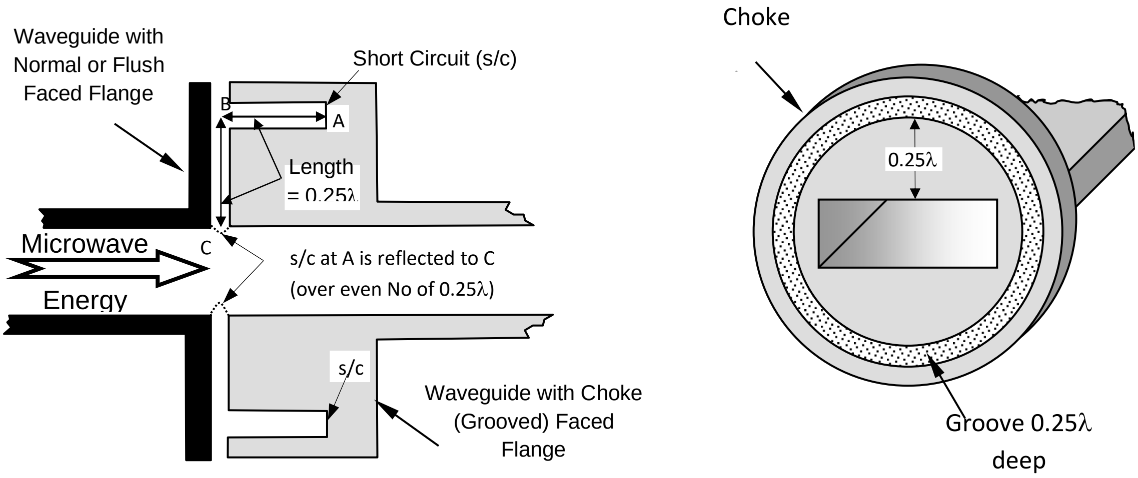


Figure 14 – Choke Flange Joint

41. .25λ wave shorting stubs properties are also used in the construction of. rotating joints and some types of flexible waveguide sections

Radar Aerials

42. The transmitting aerial of radar systems are primarily used to focus and shape the energy in the radar beam into a suitable form for scanning targets.

43. The receiving aerial of radar systems is primarily used to efficiently collect the EM energy in a returning echo.

44. Most radar systems (primary and secondary) use the same aerial for both transmitting and receiving.

45. Typical of radar systems that use separate TX/RX aerials are Radar Altimeters and Doppler Navigation Radars.

Aerial Parameters

46. Three of the main parameters used to measure the effectiveness of directional radar aerials in propagating a beam of energy are:

a. Beamwidth

b. Gain

c. Polarisation

47. **Beamwidth** is the narrowness of the beam (refer figure 15).

a. This corresponds to the point where the field strength has been reduced to 0.707 of its maximum value or at the point in the beam where the power has fallen to half of its maximum value (i.e. fallen by 3db).

b. In order to measure the beamwidth accurately, a plot of the field strength is often made in Cartesian form as shown in figure 15.

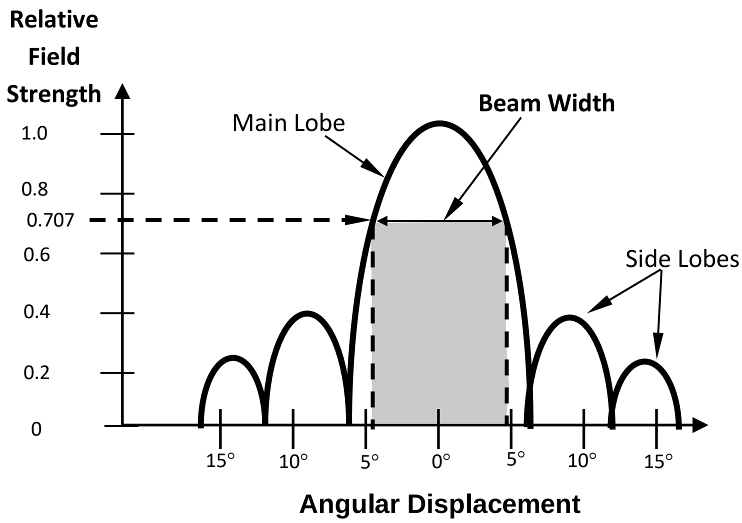
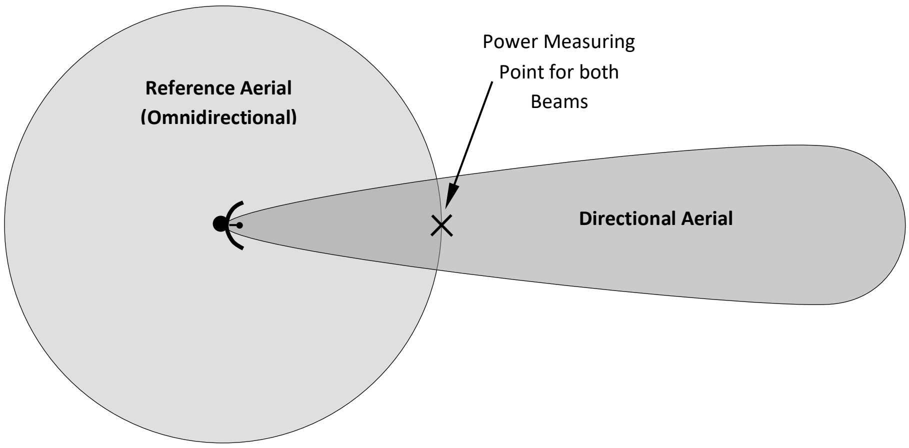


Figure 15 - Aerial Beamwidth

48. **Gain**: - ability of an aerial system to concentrate energy in the beam. (Refer figure 16)

a. Gain is measured by comparing the energy received from an omni-directional aerial to that of a directional aerial at a reference point.

b. Gain = power radiated by a directional aerial / power radiated by an omni-directional aerial



$$\text{Aerial Gain} = \frac{\text{Power radiated from a directional aerial}}{\text{Power radiated from a reference aerial}}$$

Figure 16 – Aerial Gain

49. **Polarisation** the direction of the plane in the beam that contains the electrical field “E” vector relative to the earth.

a. Vertical Polarisation (refer figure 17a)

b. Horizontal Polarisation (refer figure 17b)

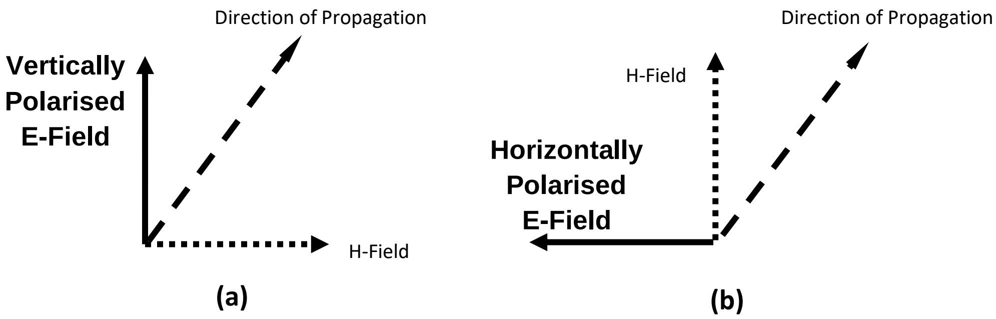


Figure 17 – Aerial Polarisation

Aerial Beam Shapes

50. Radar systems use a variety of beam shapes with different characteristics depending upon their function, some of the more common types beam shapes are listed below (refer figure 18):

a. Pencil Beam

b. Fan Beam

c. Cosecant Squared (cosec^2) Beam

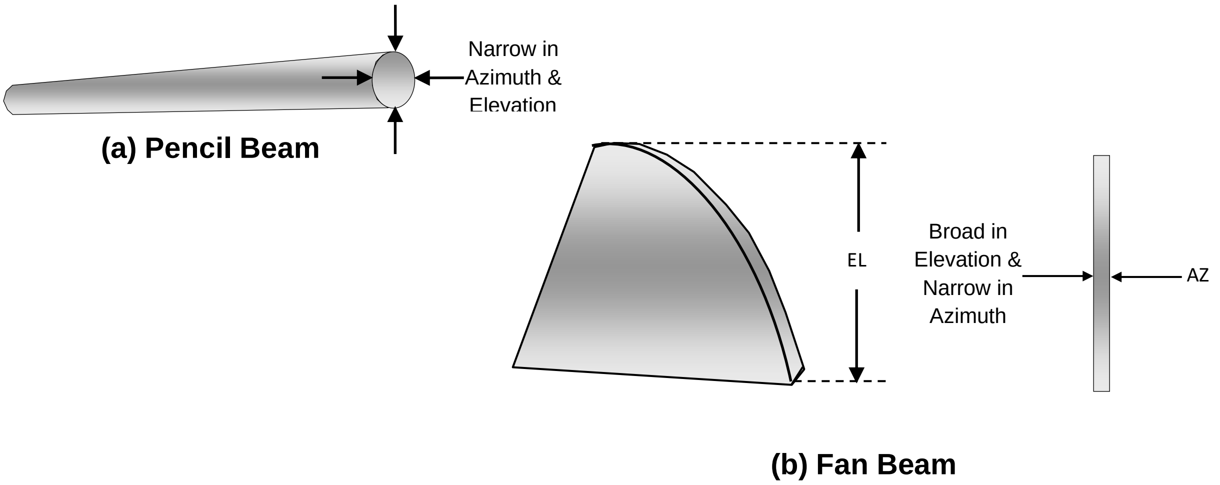


Figure 18 a & b – Pencil & Fan Beam Shapes

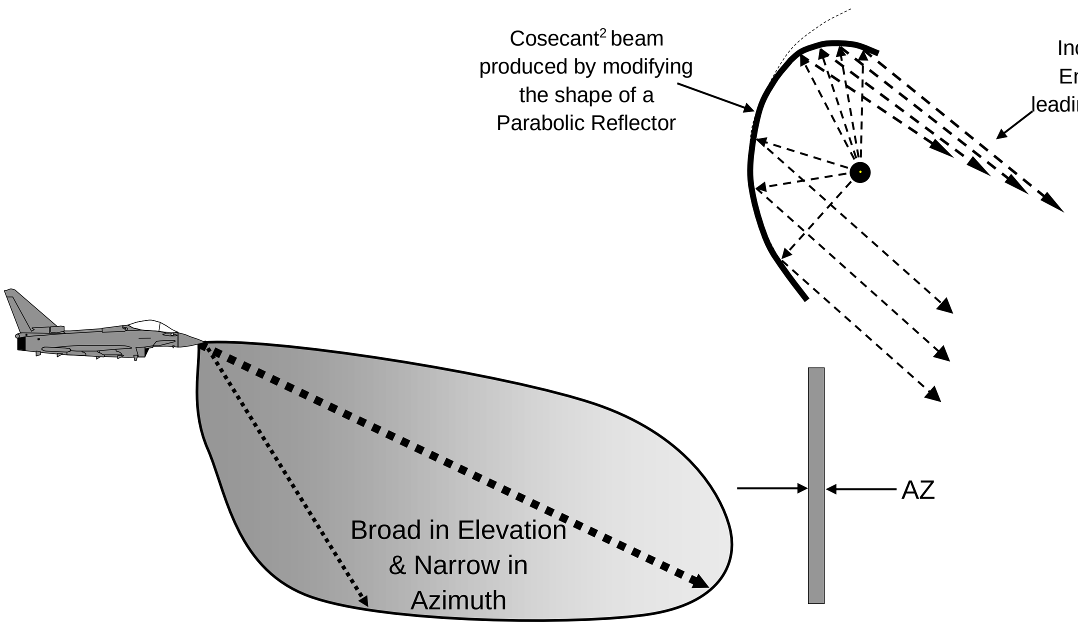


Figure 18c – Cosec^2 Beam

Summary of Beam Shapes

51. Refer table 2 for a summary of the beam shapes described in figure 20 in terms of:

a. Typical Radar Function

b. Beam characteristics

c. Type of Information obtained

Beam Shape	Typical Radar Function	Beam Characteristics	Information Obtained
Pencil Beam	Airborne Interception (AI). Weather & Collision Warning. Terrain Following Radar (TFR).	Narrow in Azimuth and Narrow in Elevation	Accurate target AZ & EL information in a small volume of space
Fan Beam	Long Range Search Radar	Narrow in Azimuth and Broad in Elevation	Accurate target AZ information in a large volume of space
Cosec^2	Ground Mapping Radar (GMR)	Narrow in Azimuth and Broad in Elevation	Improved display due to modified energy distribution giving constant amplitude returns throughout the beam footprint

Table 2 – Summary of Beam Shapes

Radar aerial reflectors and arrays

52. A variety of aerial reflectors or arrays are used in producing the necessary radar beam shapes, which include:

a. Parabolic Reflectors (old but still in use)

b. Slotted Arrays (modern and used widely)

c. Active Arrays (very modern)

Parabolic Reflector

53. Refer figure 19. Modified versions of this type of reflector can form the three types of beam shape in table 2.

a. From the Pencil beam that is a parallel beam of microwave energy (narrow in AZ and EL) to the Fan beam (narrow in AZ and wide EL)

b. Parabolic Reflector are mechanically steered using electric or hydraulic motors

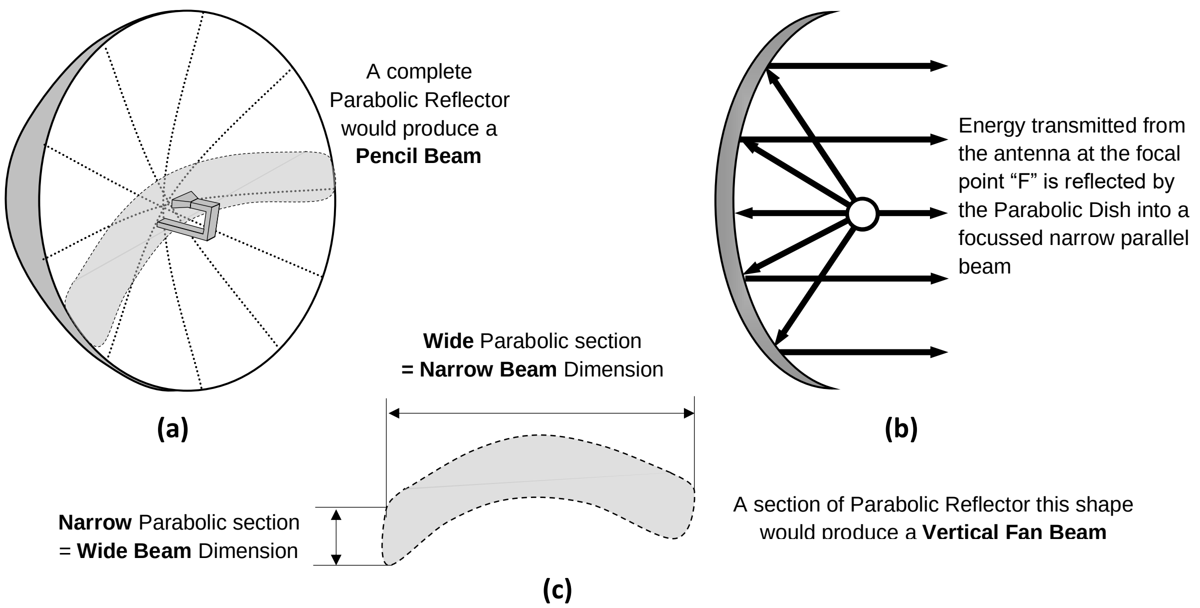
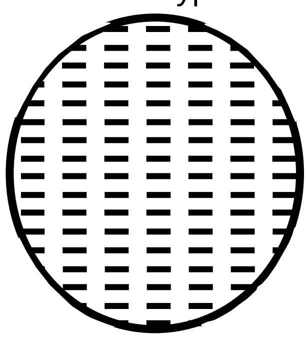


Figure 19 - Parabolic Reflectors

Slotted Arrays

54. Refer figure 20. The two common types of slotted aerial arrays are known as Planar and Phased arrays.



By varying the RF energy radiated from each slot.

It can electronically change beam shape and direction as required.

Figure 20 – Slotted Arrays

55. **Planar Array.** (Refer figure 20).

a. This type of antenna radiates energy from a large number of elements that are in the same plane. The elements are usually small slots (like slot aerials) cut into the surface of a flat dish.

b. The beam shape is produced by electronically controlling the timing or phase of energy fed to each slot, which then combines forming the required radiation pattern.

c. Great agility in changing beam shape

d. They can produce very small sidelobes.

e. When scanned by other radars only return a small echo (compared to parabolic types).

f. The dish is mechanically steered using electric or hydraulic motors.

g. This is the simplest and cheapest method especially for 180°-sector scanning.

56. **Phased Arrays.** (Refer figure 20). These types of aerial systems have a lot in common with planar arrays, the main difference being in how the beam is steered.

a. This type of antenna radiates energy from a large number of elements that are in the same plane. The elements are usually small slots (like slot aerials) cut into the surface of a flat dish.

b. The beam shape is produced by electronically controlling the timing or phase of energy fed to each slot, which then combines forming the required radiation pattern.

c. Great agility in changing beam shape

d. They can produce very small sidelobes.

e. When scanned by other radars only return a small echo (compared to parabolic types).

f. The beam is electronically steered by varying the phase of energy fed to the slots; no mechanical movement of the dish is required, leading to greatly improved reliability.

g. Great agility in scanning methods and changing beam direction, which is almost instantaneous as the dish does not have to move.

57. Because Phased Arrays use electronic control of the radar beam this makes it possible for single phased array radars to act as multiple radars for carrying out a number of different radar tasks at the same time, each with its own beam shape and scan pattern.

Active Arrays

58. Refer figure 21. The most advanced types of Phased Arrays are known as Active Arrays or Active Electronically Steered Array (AESA).

a. Instead of a single transmitter and receiver the AESA uses a large number (1000's) of active miniature "transmitter-receiver (TxRx)" elements. These Tx/Rx elements are fixed directly to the front of the dish and are individually controlled by the radar systems computer.

b. The use of AESA's can lead to lower losses (i.e. no waveguides) and an increase in radiated power with improved reliability.

c. Because the AESA does not have just a single transmitter or receiver, the loss or damage of a small number of TR elements will not severely handicap its operation.

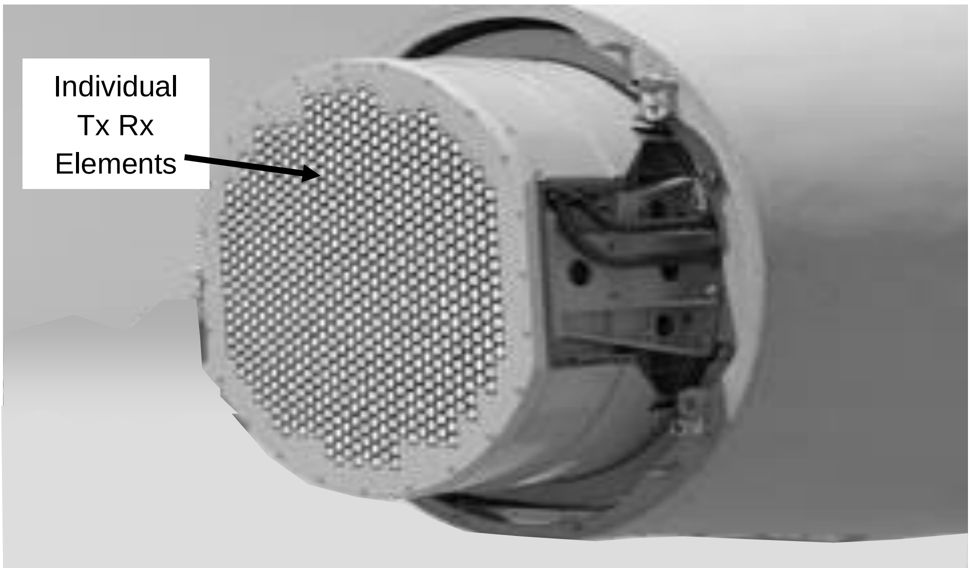


Figure 21 – AESA Radar (MIG-35)

TRANSMITTER AND RECEIVER (T/R) SWITCHING

Introduction

59. Why do some radar systems need T/R switching?

a. Most airborne pulse modulated radar systems use a common directional aerial for both transmitting (TX) and receiving (RX).

b. As the aerial cannot both transmit and receive at the same time, therefore common aerial systems need a T/R switch to automatically connect the aerial to the TX and RX as required (refer figure 22).

i. When transmitting the **T/R sw** protects the receiver by preventing the high power pulses passing to the receiver.

ii. When receiving, the **T/R sw** prevents the very low power echo pulses passing to the transmitter.

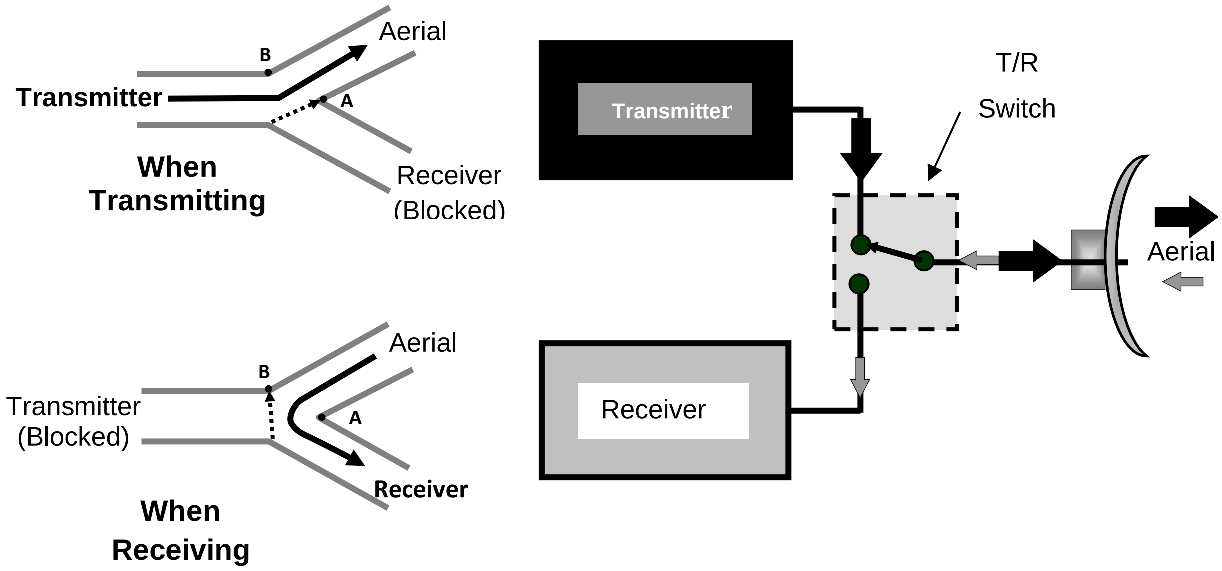


Figure 22 – T/R Switching Principle

60. Although mechanical switches operate too slowly to be of use in a practical radar system, there are however many different types of T/R switching systems that use a variety of devices and techniques such as:

a. T/R cells and Transmitter Blocking (TB) cells using waveguide and 0.25λ wave shorting stubs properties (high power, RX break through).

b. Microwave semi-conductor devices such as PIN diodes (small, low power)

c. Ferrite devices (high power, long life and broad bandwidth but are bulky due to their permanent magnets)

61. Ferrite devices have a bending effect on microwaves that come in contact with it, this can be seen in the 'Ferrite three-port circulator', which can be used in T/R switching (refer figure 23)

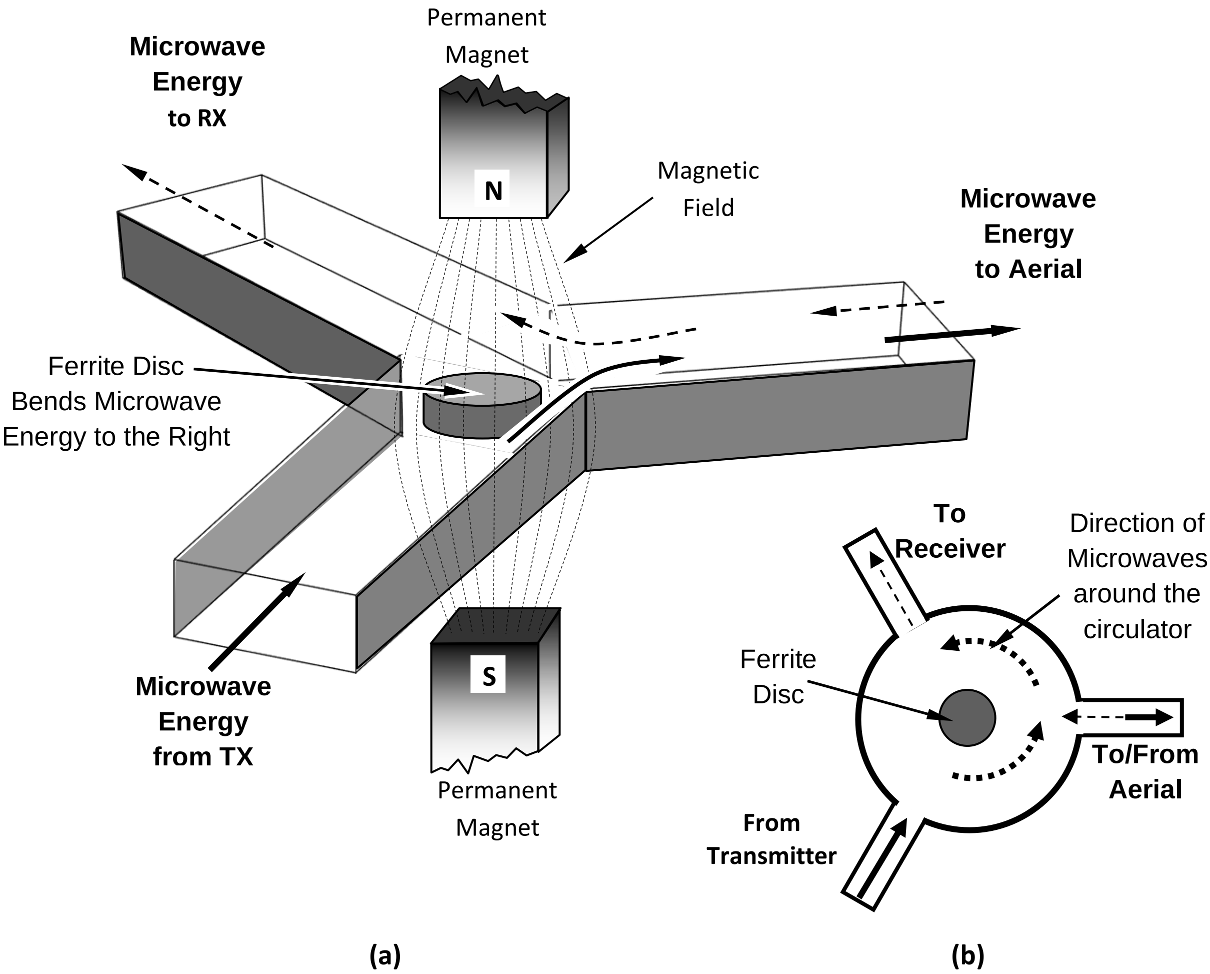


Figure 23 – Ferrite Three-Port Circulator

62. For increased isolation and protection one ferrite three-port circulator can be fed into another three-port circulator (refer figure 24). This in effect makes them into a four-port device with one port feeding a dummy load to absorb any stray energy and preventing mismatching and standing waves.

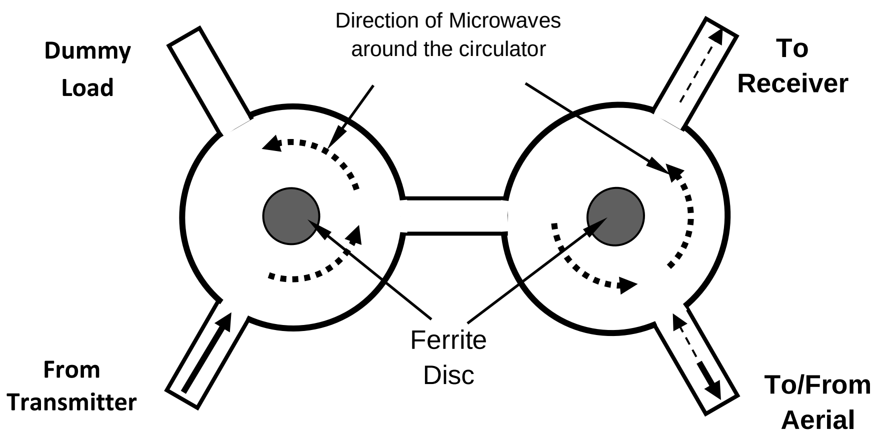


Figure 24 – Two Three-port circulators used as a T/R Switch