Radartutorial

Book 3: "Antennae Techniques"

Preamble:

The name antenna has its seeds in the work of the Italian inventor Guglielmo Marconi. During his experiments with the electromagnetic waves he used a woodenly tent pole along which was carried a radiating wire. This tent pole means in Italian language **l'antenna**. The common use of this term in the description of the experiments of Marconi led to the popular name "antenna" for this component part of transmitter sites.

An antenna transmits or receives electromagnetic waves. It is a transducer to convert electromagnetic waves into high-frequency electrical currents and vice versa. The mechanical sizes of the antenna are fractions of the used wavelength. There are antennas with more than hundred meters length using frequencies in long-wave range, and antennas with a length of few millimeters for microwave ranges. This book deals specifically with antennae used in radar installations.

Table of Contents:

Learning objectives:

The learning objectives serve as a preview of the information you are expected to learn in the chapter. This chapter provides the basis for understanding the specific radar antennae. Upon completion of this chapter, the student will be able to:

- describe antenna directivity and power gain characteristics;
- describe the focusing action of a basic parabolic antenna;
- describe the basic radiation patterns of the most common parabolic reflectors;
- describe the basic characteristics of horn radiators;
- describe the monopulse antennae concept.

Functions of an Antenna

The antenna is one of the most critical parts of a radar system. It performs the following essential functions:

- It transfers the transmitter energy to signals in space with the required distribution and efficiency. This process is applied in an identical way on reception.
- It ensures that the signal has the required pattern in space. Generally this has to be sufficiently narrow in azimuth to provide the required azimuth resolution and
- It has to provide the required frequency of target position updates. In the case of a mechanically scanned antenna this equates to the revolution rate. A high revolution rate can be a significant mechanical problem given that a radar antenna in certain frequency bands can have a reflector with immense dimensions and can weigh several tons.
- It must measure the pointing direction with a high degree of accuracy.

The antenna structure must maintain the operating characteristics under all environmental conditions. Radom's are generally used where relatively severe environmental conditions are experienced.

The basic performance of radar can be shown to be proportional to the product of the antenna area or aperture and the mean transmitted power. Investment in the antenna therefore brings direct results in terms of system performance.

Taking into account these functions and the required efficiency of a radar antenna, two arrangements are generally applied:

- the parabolic dish antenna and
- the array antenna.

Antenna Characteristics

Antenna Gain

Independent of the use of a given antenna for transmitting or receiving, an important characteristic of this antenna is the antenna gain.

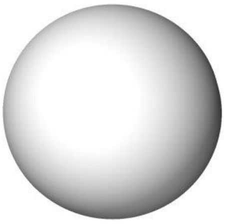


Figure 1: An isotropic radiator has got a ball-shaped radiation

Some antenna sources radiate energy equally in all directions. Radiation of this type is known as *isotropic radiation*. We all know the Sun radiates energy in all directions. The energy radiated from the Sun measured at any fixed distance and from any angle will be approximately the same. Assume that a measuring device is moved around the Sun and stopped at the points indicated in the figure to make a measurement of the amount of radiation. At any point around the circle, the distance from the measuring device to the Sun is the same. The measured radiation will also be the same. The Sun is therefore considered an isotropic radiator.

All other antennae have a gain opposite the isotropic radiator. Some antennas are highly directional; that is, more energy is propagated in certain directions than in others. The ratio between the amounts of energy propagated in these directions compared to the energy that would be propagated if the antenna were not directional is known as its gain. When a transmitting antenna with a certain gain is used as a receiving antenna, it will also have the same gain for receiving.

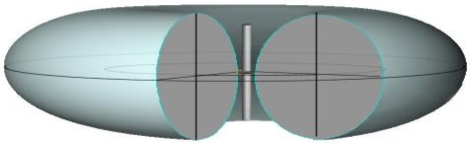


Figure 2: The dipole antennas emission diagram is a slightly flattened torus

Antenna Pattern

Most radiators emit (radiate) stronger radiation in one direction than in another. A radiator such as this is referred to as anisotropic. However, a standard method allows the positions around a source to be marked so that one radiation pattern can easily be compared with another.

The energy radiated from an antenna forms a field having a definite radiation pattern. A radiation pattern is a way of plotting the radiated energy from an antenna. This energy is measured at various angles at a constant distance from the antenna. The shape of this pattern depends on the type of antenna used.

To plot this pattern, two different types of graphs, rectangular-and polar-coordinate graphs are used. The polar-coordinated graph has proved to be of great use in studying radiation patterns. In the polar-coordinate graph, points are located by projection along a rotating axis (radius) to an intersection with one of several concentric, equally-spaced circles. The polar-coordinate graph of the measured radiation is shown in Figure 3.

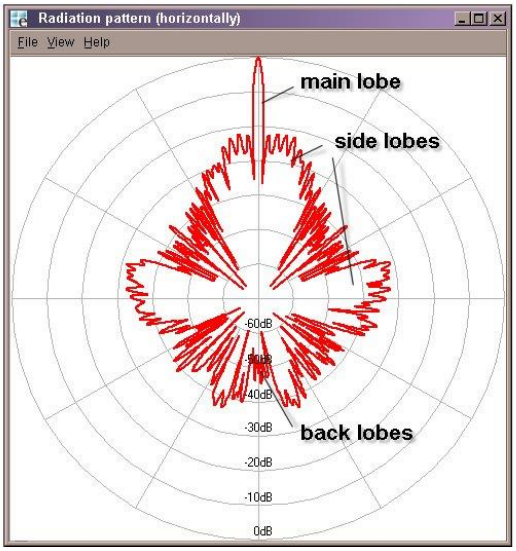


Figure 3: Antenna pattern in a polar-coordinate graph

- The *main beam* (or *main lobe*) is the region around the direction of maximum radiation (usually the region that is within 3 dB of the peak of the main beam). The main beam in Figure 3 is northbound.
- The *sidelobes* are smaller beams that are away from the main beam. These sidelobes are usually radiation in undesired directions which can never be completely eliminated. The *sidelobe level* is an important parameter used to characterize radiation patterns.
- One sidelobe is called *backlobe*. This is the portion of radiation pattern that is directed opposing the main beam direction.

The graph in Figure 4 shows the rectangular-coordinated graph for the same source. In the rectangular-coordinate graph, points are located by projection from a pair of stationary, perpendicular axes. The horizontal axis on the rectangular-coordinate graph corresponds to the circles on the polar-coordinate graph. The vertical axis on the rectangular-coordinate graph corresponds to the rotating axis (radius) on the polar-coordinate graph. The measurement scales in the graphs can have linear as well as logarithmic steps.

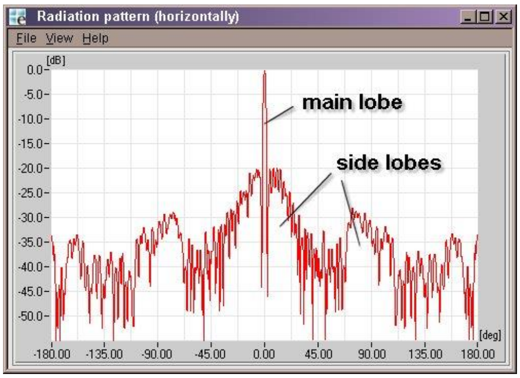


Figure 4: The same antenna pattern in a rectangular-coordinate graph

From a plotted antenna pattern you can measure some important characteristics of an antenna:

- the *front-to-back ratio,* the ratio of power gain between the front and rear of a directional antenna (in Figure 4 the value of the sidelobe in 180 degrees: 34 Decibels)
- the *side lobe ratio*, the maximum value of the sidelobes away from the main beam. (in Figure 4 the value of the sidelobe in e.g. +6 degrees: 20 Decibels)

For the analysis of an antenna pattern the following simplifications are used:

Beam Width

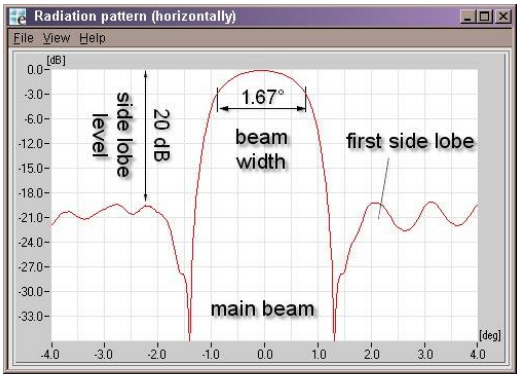


Figure 5: Antenna pattern in a rectangular-coordinate graph with narrower scale

The angular range of the antenna pattern in which at least half of the maximum power is still emitted is described as a "*beam with*". Bordering points of this major lobe are therefore the points at which the field strength has fallen in the room around 3 dB regarding the maximum field strength. This angle is then described as beam width or aperture angle or half power (-3 dB) angle - with notation Θ (also φ). The beamwidth Θ is exactly the angle between the 2 black marked power levels in Figure 5. The angle Θ can be determined in the horizontal plane (with notation Θ_{AZ}) as well as in the vertical plane (with notation Θ_{EL}).

Aperture

An isotropic radiator disperses all energy at a surface of a sphere. The power has a defined density in a given distance. A directive antenna concentrates the energy in a smaller area. The power density is higher than by an isotropic radiator. The density can be expressed as power per area unit too. The received power can be compared with a related surface. This area is called *effective aperture.*

The effective aperture of an antenna A_e is the surface presented to the radiated or received signal therefore. It is a key parameter, which governs the performance of the antenna. The antenna gain is related to the effective area by the following relationship:

$$G = \frac{4\pi \cdot A_e}{\lambda^2}; \quad A_e = K_a \cdot A \qquad (1)$$

Where:
λ = wavelength
A_e= effective antenna aperture
A = physical area of the antenna
K_a= antenna aperture efficiency

The aperture efficiency depends on the distribution of the illumination across the aperture. If this is linear then K_a= 1. This high efficiency is offset by the relatively high level of sidelobes obtained with linear illumination. Therefore, antennas with more practical levels of sidelobes have an antenna aperture efficiency less than one ($A_e < A$).

Major and Minor Lobes

The pattern shown in the upper figures has radiation concentrated in several lobes. The radiation intensity in one lobe is considerably stronger than in the other. The strongest lobe is called *major lobe*; the others are (minor) *side lobes*. Since the complex radiation patterns associated with arrays frequently contain several lobes of varying intensity, you should learn to use appropriate terminology. In general, major lobes are those in which the greatest amount of radiation occurs. Side or minor lobes are those in which the radiation intensity is least.

Front-to-back Ratio

The *front-to-back ratio* is the ratio of power gain between the front and rear of a directional antenna. In most cases there is a distinctive back lobe in the antenna pattern diagram. Sometimes you'll doesn't find a lobe exactly opposite to the main beam. In this case, the front-to-back ratio refers to the largest side lobe in the area of ±10 to ±30 degrees around the opposite direction of the main beam. A high front-to-back ratio is desirable because this means that a minimum amount of energy is radiated in the undesired direction.

Polarization

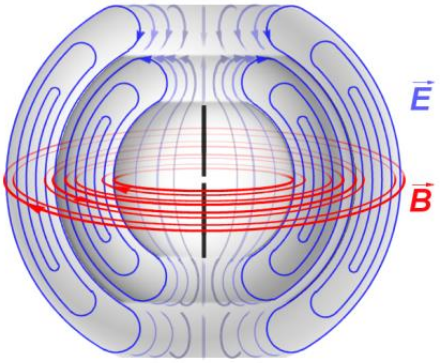


Figure 6: electric field (blue) and magnetic field (red) of a vertical mounted (polarized) dipole

The radiation field of an antenna is composed of electric and magnetic lines of force. These lines of force are always at right angles to each other. The electric field determines the direction of polarization of the wave. When a single-wire antenna is used to extract energy from a passing radio wave, maximum pickup will result when the antenna is oriented in the same direction as the electric field.

The oscillations of the electric field may be oriented in a single direction (linear polarization), or the oscillation direction of the electric field may rotate as the wave travels (circular or elliptical polarization).

Linear Polarization

Vertically and horizontally mounted receiving antennas are designed to receive vertically and horizontally polarized waves, respectively. Therefore, changes in polarization cause changes in the received signal level due to the inability of the antenna to receive polarization changes.

Two planes of polarization are used mainly:

- In a vertically polarized wave, the electric lines of force lie in a vertical direction.
- In a horizontally polarized wave, the electric lines of force lie in a horizontal direction.

The linear polarization can obviously take all planes but besides the horizontal plane and vertical plane only the positions.

When a single-wire antenna is used to extract energy from a passing radio wave, maximum pickup will result when the antenna is oriented in the same direction as the electric field. Thus a vertical antenna is used for the efficient reception of vertically polarized waves, and a horizontal antenna is used for the reception of horizontally polarized waves.

Circular Polarization

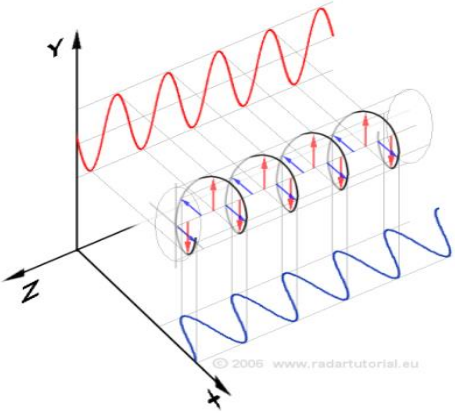


Figure 7: Rising of circular polarization

Circular polarization has the electric lines of force rotating through 360 degrees with every cycle of rf energy. Circular polarization arises by two 90° phase shift income signals and also by plane polarized antennae moving 90° simultaneously. The electric field was chosen as the reference field since the intensity of the wave is usually measured in terms of the electric field intensity (volts, millivolts, or microvolts per meter). In some cases the orientation of the electric field does not remain constant. Instead, the field rotates as the wave travels through space. Under these conditions both horizontal and vertical components of the field exist and the wave is said to have an elliptical polarization.

Circular polarization can be right-handed or left-handed. A circularly polarized wave is reflected by a spherical raindrop in the opposite sense of the transmission. On reception, the antenna rejects waves of the opposite sense of circular polarization thereby minimizing the detection of rain. The reflection from the target will have significant components in the original polarization sense because unlike rain, aircraft are not spherical. The strength of the target signal is therefore enhanced relative to rain.

For maximum absorption of energy from the electromagnetic fields, the receiving antenna must be located in the same plane of polarization. If a wrongly polarized antenna is used, then considerable losses arise, in practice between 20 and 30 dB.

At the appearance of strong weather-clutter the air traffic controllers prefer to switch on the circular polarization. In this case the hiding effect of the targets by the weather-clutter will be decreased.

Half-wave Antenna

A half-wave antenna (referred to as a dipole, Hertz, or doublet) consists of two lengths of wire rod, or tubing, each 1/4 wavelength long at a certain frequency. It is the basic unit from which many complex antennas are constructed. For a dipole, the current is maximum at the center and minimum at the ends. Voltage is minimum at the center and maximum at the ends.

Energy may also be fed to the half-wave antenna by dividing the antenna at its center and connecting the transmission line from the final transmitter output stage to the two center ends of the halved antenna. Since the antenna is now being fed at the center (a point of low voltage and high current), this type of feed is known as the center-feed or current-feed method. The point of feed is important in determining the type of transmission line to be used.

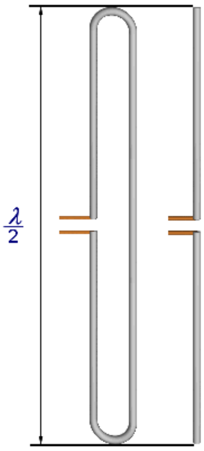


Figure 8: Folded dipole and half-wave dipole

Standing waves of current and voltage similarly arise as when a parallel oscillating circuit. However, opposite the isotropic radiator with the gain of exact 1, the half-wave antenna already has an gain of about 1.5 while the maximum radiation comes from it in a direction perpendicular to the antenna axis.

The half-wave dipole also has arisen from a simple oscillating circuit. We simply imagine that the condenser plates of the oscillating circuit are apart bent a little. The capacity is reduced now, but the condenser remains to be a condenser with that. When a getting the condenser plates apart further the lines of force of the electrical field have to cover a bigger and bigger way. The form of the condenser cannot be recognized any more. The lines of force of the electrical field go over into the free space. A half-wave dipole has arisen which is now being fed at the center.

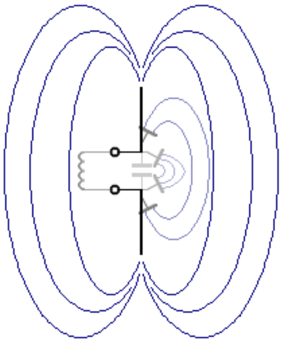


Figure 9: Rise of an antenna dipole from a dispersed oscillating circuit

Parabolic Antennae

The parabolic dish antenna is the form most frequently used in the radar engineering of installed antenna types of. Figure 11 illustrates the parabolic antenna. A dish antenna consists of one circular parabolic reflector and a point source situated in the focal point of this reflector. This point source is called „primary feed” or „feed”.

The circular parabolic (paraboloid) reflector is constructed of metal, usually a frame covered by metal mesh at the inner side. The width of the slots of the metal mesh has to be less than λ / 10. This metal covering forms the reflector acting as a mirror for the radar energy.

Figure 10: Parabolic antenna of the Weather radar *Meteor* manufactured by Gematronik

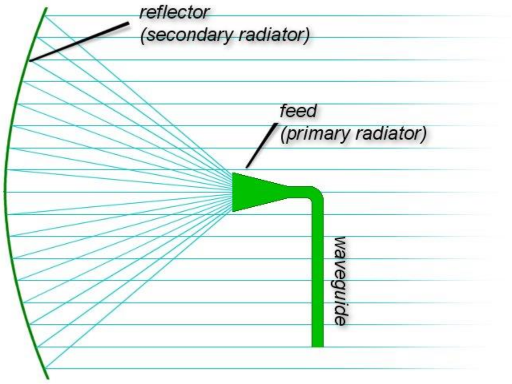


Figure 11: Principle of a parabolic reflector

According to the laws of optics and analytical geometry, for this type of reflector all reflected rays will be parallel to the axis of the paraboloid which gives us ideally one single reflected ray parallel to the main axis with no sidelobes. The field leaves this feed horn with a spherical wave front. As each part of the wave front reaches the reflecting surface, it is shifted 180 degrees in phase and sent outward at angles that cause all parts of the field to travel in parallel paths.

This is an idealized radar antenna and produces a pencil beam. If the reflector has an elliptical shape, then it will produce a fan beam. Surveillance radars use two different curvatures in the horizontal and vertical planes to achieve the required pencil beam in azimuth and the classical cosecant squared fan beam in elevation.

This ideal case shown in Figure 11 figure doesn't happen in the practice. The real parabolic antennas pattern has a conical form because of irregularities in the production. This main lobe may vary in angular width from one or two degrees in some radar sets to 15 to 20 degrees in other radars.

The radiation pattern of a parabolic antenna contains a major lobe, which is directed along the axis of propagation, and several small minor lobes. Very narrow beams are possible with this type of reflector as shown in Figure 3 and 4 in a previous chapter.

The gain G of an antenna with parabolic reflector can be determined as follows:

$$G \approx \frac{160^2}{\Theta_{Az} \cdot \Theta_{El}} \qquad (2)$$

Where:
Θ_{Az} = beamwidth in azimuth angle
Θ_{El} = beamwidth in elevation angle

This is an approximate formula but gives a good indication for most purposes while noting that gain will be modified by the illumination function.

Fan-Beam Antenna

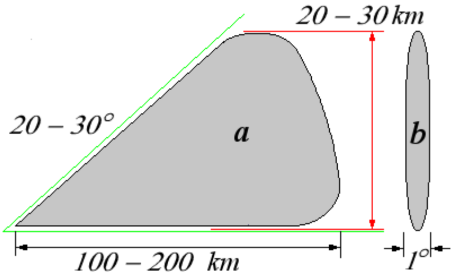


Figure 12: Fan-beam antennae pattern

a) lateral view b) frontal view

A fan-beam antenna is a directional antenna producing a main beam having a narrow beamwidth in one dimension and a wider beamwidth in the other dimension. This pattern can be obtained by illuminating an asymmetrical section of the paraboloid, e.g. by a truncated paraboloid reflector. Since the reflector is narrow in the vertical plane and wide in the horizontal, it produces a beam that is wide in the vertical plane and narrow in the horizontal.

This type of antenna system is generally used in height-finding equipment (if the reflector is rotated 90 degrees). Since the reflector is narrow in the horizontal plane and wide in the vertical, it produces a beam that is wide in the horizontal plane and narrow in the vertical. In shape, the beam of height-finding radar is a horizontal fan beam pattern as shown in Figure 14. The hornfeed isn't mounted in the middle of the antenna but more sideward's like as a commercial satellite receiver's dish antenna. This kind of feeding is known as an *offset antenna*.

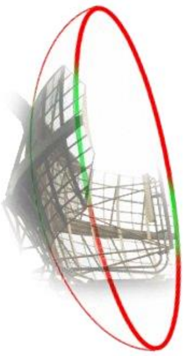


Figure 13: A truncated paraboloid reflector forming a fan beam

Offset Antenna

One problem associated with feedhorns is the shadow introduced by the feedhorn if it is in the path of the beam. The shadow is a dead spot directly in front of the feedhorn. Normally the feed horn constitutes an obstruction for the rays coming from the reflector at a parabolic antenna.

To solve this problem the feedhorn can be offset from center. In an offset feed, the feed is outside the path of the wave so there is no pattern deterioration due to aperture blocking. The horn faces upwards relative to the axis of the parabola and the lower half of the parabola is removed. The net effect is that the parabola is shallower with a larger focal length. The feed horn is therefore situated further from the reflector and requires greater directivity to avoid spill over of energy. This design therefore requires larger horns and is generally more difficult and expensive to construct.

Figure 14: Typical antenna of a height-finder using an offset antenna forming a fan beam

Antennae with Cosecant Squared Pattern

Antennae with cosecant squared pattern are special designed for air-surveillance radar sets. These permit an adapted distribution of the radiation in the beam and causing a more ideal space scanning.

The cosecant squared pattern is a means of achieving more uniform signal strength at the input of the receiver as a target moves with a constant height within the beam.

There are a couple of variation possibilities, to get a cosecant squared pattern in practice:

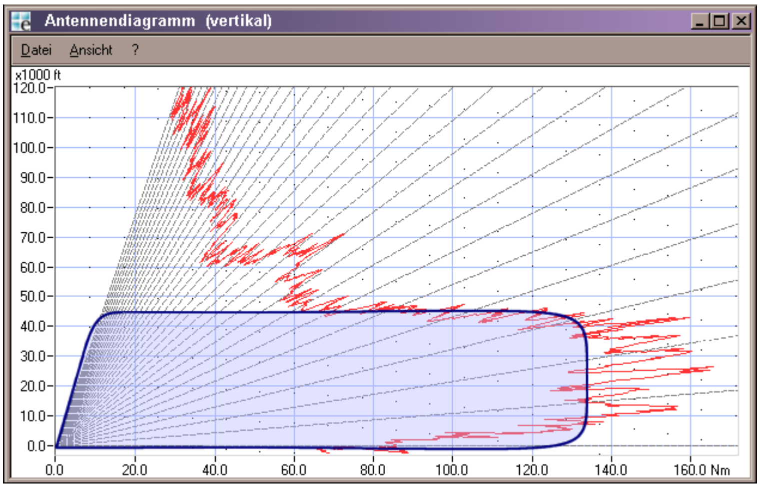


Figure 15: Vertical projection of the radiation pattern of an antenna with cosecant squared characteristic, the blue graph shows the theoretically form, the red graph e measured one in practice

- deformation of a parabolic reflector
- a stacked beam by more horns feeding a parabolic reflector

In the practice a cosecant squared pattern can be achieved by a deformation of a parabolic reflector. A radiator is in the focal point of a parabolic reflector and produces a relatively sharply bundled radiation lobe since the rays leave the reflector parallel in the ideal case.

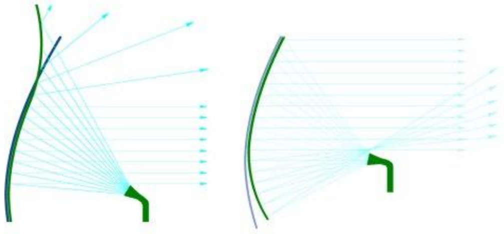


Figure 16: Different deformations to achieve a cosecant squared pattern

To get the cosecant squared pattern, a part of the radiated energy must be turned up. A possibility consists in lower bending of the top of the reflector. The part of the rays which falls to the less bent area (in the top) is reflected up now. A possible method analogously for this one is, to bend the lower part of the reflector more intense.

The lobe of the radiator is weaker to the margin too therefore the margins of the reflector are hit weaker as the center. By the fact that the rays turned up don't have a large power density, the maximum range in the higher elevation is limited with that.

Inverse Cosecant Squared Pattern

Surface Movement Radars and Vessel Traffic Systems use antennas designed to provide inverse Cosecant squared coverage and direct energy preferentially towards the surface giving constant gain for targets on the surface.

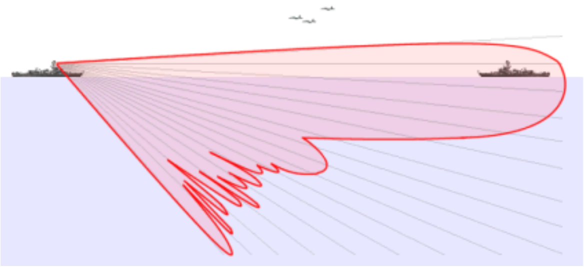


Figure 17: Inverse cosecant squared coverage diagram

The coverage diagram shows the antenna pattern of a vessel radar with an inverse cosecant squared antenna patter. The antenna is designed to preferentially radiate below 0° (the horizon line) to provide constant detection for targets approaching on sea surface.

Stacked Beam Cosecant Squared Antenna

A cosecant squared pattern can be achieved by two or more horns feeding a parabolic reflector.

Every feed horn already emits directionally. If one distributes the transmit power unevenly on the single radiating elements, then the antenna pattern approaches a cosecant squared pattern.

At use of several receiving channels a height allocation also can be carried out. The targets can be assigned to beams with defined elevation there.

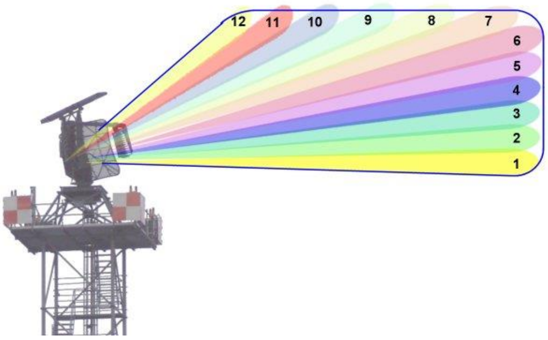


Figure 18: Principle of a stacked beam Cosecant squared antenna

The cosecant squared pattern isn't restricted to parabolic reflectors. This can be realized also with other kind of antennae. At an antenna array with Yagi- antennae the pattern is achieved by interference of the direct wave with this at the earth's surface reflected quotas.

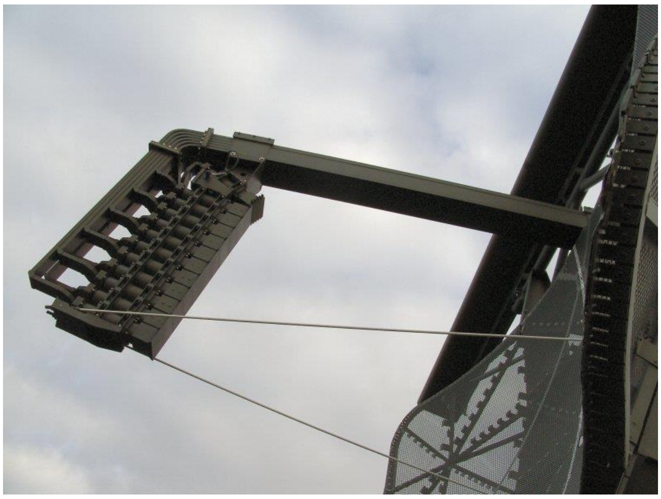


Figure 19: An arrangement of twelve feed horns at the antenna of the radar set ASR 910 achieves a stacked beam cosecant squared pattern

Proof

The term “Cosecant” sounds very much like a mathematical triangular function. This is right! It is equal to the reciprocal value of the sine function. However, what does this term have to do with our antenna?

The height H and the range R define the elevation angle ε ...

We remember what is written there on the previous page:

“The cosecant squared pattern is a means of achieving a uniform signal strength at the input of the receiver as a target moves with a constant height within the beam.”

If we convert the formula according to the range and using the trigonometric relation mentioned above already appears the term „Cosecant” – furthermore...

What there still was with the *“...uniform signal strength...”*

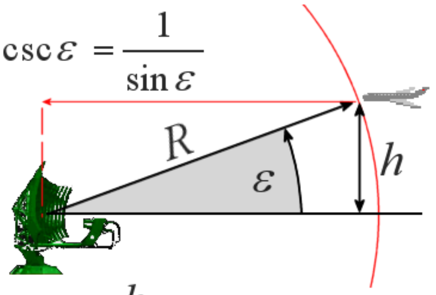
We can derive this connection from the radar equation:

If the echo has a uniform signal strength at the input of the receiver than the range is dependent on the square of the antenna gain in the fourth power linearly.

We can shorten the powers arithmetically...

We replace the range by the formula with the upper “Cosecant”-formula now. According to definition mentioned above the height also shall be constant. That means, we can shorten the height too without changing the dependence.

So we get the mathematical describing of an antenna with a “cosecant squared pattern”!



$$\csc\varepsilon = \frac{1}{\sin\varepsilon}$$

$$R = \frac{h}{\sin\varepsilon} = h\cdot\csc\varepsilon$$

$$P_E \sim \frac{G^2}{R^4} \qquad \Big|\; P_E = \text{const}$$

$$G^2 \sim R^4$$

$$G \sim R^2$$

$$G \sim (\cancel{h}\cdot\csc\varepsilon)^2 \qquad \Big|\; h = \text{const}$$

$$\boxed{G \sim \csc^2\varepsilon}$$

Phased Array Antenna

Principle of Operation

A phased array antenna is composed of lots of radiating elements each with a phase shifter. Beams are formed by shifting the phase of the signal emitted from each radiating element, to provide constructive/destructive interference so as to steer the beams in the desired direction.

In Figure 20 (upper case), both radiating elements are fed with the same phase. The signal is amplified by constructive interference in the main direction. The beam sharpness is improved by the destructive interference.

In Figure 20 (lower case), the signal is emitted by the lower radiating element with a phase shift of 10 degrees earlier than of the upper radiating element. Because of this the main direction of the emitted sum-signal is moved upwards.

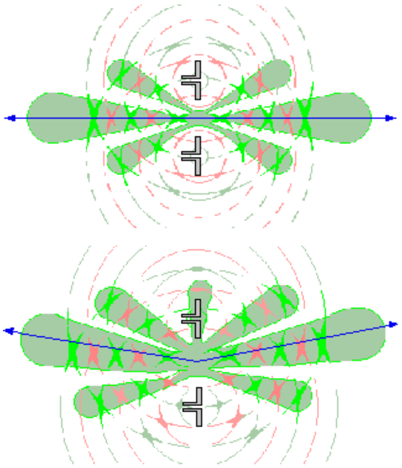


Figure 20: electronic beam-deflection, upper case: Boresight, lower case: Deflected

(Note: Radiating elements have been used without reflector in the figure. Therefore the back lobe of the shown antenna diagrams is just as large as the main lobe.)

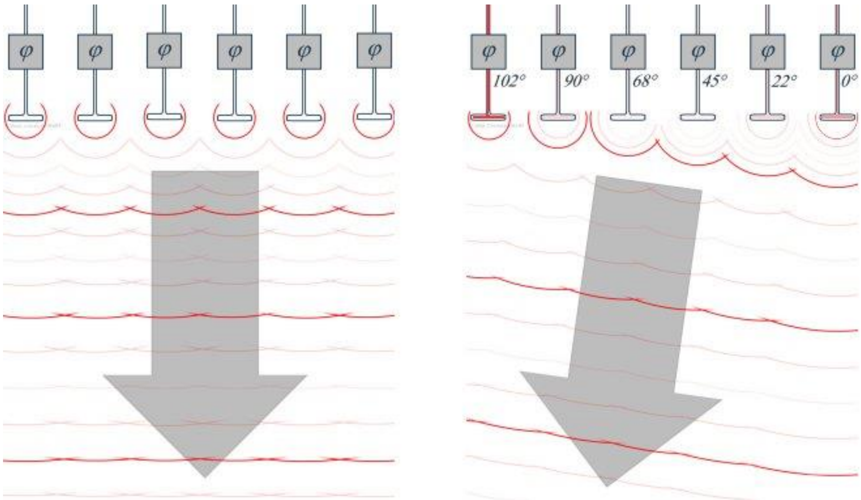


Figure 21: electronic beam-deflection by a phased array, left: Boresight, right: Deflection

The main beam always points in the direction of the increasing phase shift. Well, if the signal to be radiated is delivered through an electronic phase shifter giving a continuous phase shift now, the beam direction will be electronically adjustable. However, this cannot be extended unlimitedly. The highest value, which can be achieved for the Field of View (FOV) of a phased array antenna, is 120° (60° left and 60° right). With the sine theorem the necessary phase moving can be calculated.

Arbitrary antenna constructions can be used as a spotlight in an antenna field. For a phased array antenna is decisive that the single radiating elements are steered for with a regular phase moving and the main direction of the beam therefore is changed. E.g. the antenna of the German air-defense radar RRP-117 consists of 1584 radiating elements.

Linear Array

These antennae consist of lines whose elements are steered about a common phase shifter. A number of vertically about each other mounted linear arrays form a flat antenna.

Examples given:

- Precision approach radar PAR-80 (horizontally electronic beam deflection)
- Air-defense radar RRP-117 (vertically electronic beam deflection)
- Large Vertical Aperture (LVA) Antenna (fixed beam direction)

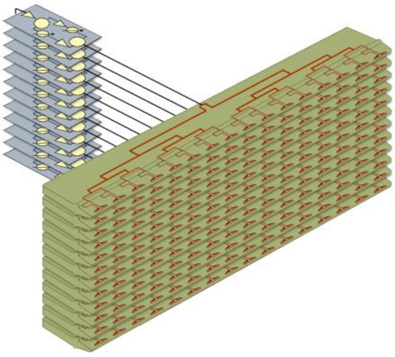


Figure 22: linear array of a phased-array antenna, each row of radiating element needs an own phase shifter

This kind of the phased-array antenna is commonly used, if the beam-deflection is required in a single plane only because a turn of the complete antenna is anyway carried out.

Planar Array

These antenna arrays completely consist of singles radiating elements and each of it gets an own computer-controlled phase shifter. The elements are ordered in a matrix array. The planar arrangement of all elements forms the complete phased-array antenna.

- Advantage: Ray deflection in two planes possible
- Disadvantage: complicated arrangement and more electronically controlled phase shifter needed
  - Examples given: AN-FPS-85 and Thomson Master-A

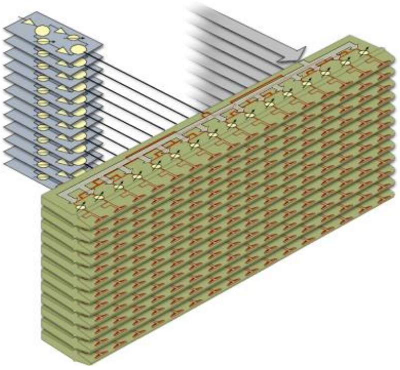


Figure 23: Planar array of a phased-array antenna, each radiating element needs an own phase shifter

The processor arranging the beam deflection needs high processing power. The phase shifters are controlled via a serial bus-system often. Additional own controlled attenuator one per radiating element can compose various beam shapes. If the radar set is mounted at a moving platform, the processor must take in account for beam deflection calculating the pitch and roll of the platform too.

Frequency Scanning Array

Frequency scanning is a special case of the phased array antenna where the main beam steering occurs by the frequency scanning of the exciter. The beam steering is a function of the transmitted frequency. This type of antenna is called a frequency scanning array. The normal arrangement is to feed the different radiating elements from one folded waveguide. The frequency scanning array is a special case of serial feeding type of a phased array antenna and is based on a particular property of wave propagation in waveguides. The phase difference between two radiating elements is n·360° at the normal frequency.

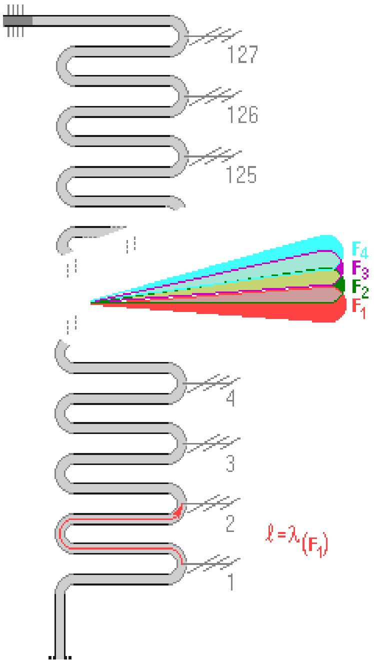


Figure 24: Frequency scanning array

By changing the frequency, changes the angle Θ_S between the axis of the main beam and the normal on the array antenna. Height information is generated using the following philosophy:

- If the transmitted frequency rises then the beam travels up the face of the antenna;
- If the transmitted frequency falls then the beam travels down the face of the antenna.

As frequency is varied, the beam axis will change, and scanning can be accomplished in elevation. The radar set is designed so that it keeps track of the frequencies as they are transmitted and then detects and converts the returned frequencies into 3D display data.

Note that frequency scanning reduces the value of using frequency change as a means of achieving other valuable effects (benefits of pulse compression).

Phase Shifter

Phase shifters switching different detour lines are faster than regulators. In the picture a 4 bits-switching phase shifter which is used in a radar unit is shown. Different detour lines are switched to the signal way. It is created therefore 16 different phase angles between 0° and 337.5° in steps with a distance of 22.5°.

The inductivities (the thin meander wires as lowpass filters) also can be recognized in the switching voltage supplies for the altogether 24 pin diodes.

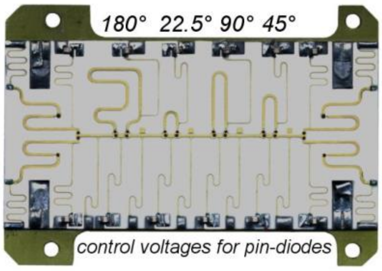


Figure 25: Circuit board with a phase shifter wiring with switched detour lines

Since this phase shifter module works both for the transmitting way and for the reception way, branching between these two paths are attached with pin diode switches on the ceramic strap at the entrance and exit of the module.

The same data word must be used for the reception time and for the transmitting moment. It is easy to understand: This one radiator, transmitting the latest phase shift, first receives the echo-signal. Its phase shifter must have the largest detour line for diagram forming in a decided direction. The same detour line is needed for a summation of the received energy and the video-pulse.

The phase shifter routes the microwave signal that is supplied to each radiating element through cables of varying length. The cables delay the wave, thereby shifting the relative phase of the output. The illustration shows the three basic delays each phase shifter can introduce. The switches are fast pin diode switches. A central computer calculates the proper phase delay for each of the radiating elements and switches in the appropriate combination of phase-shifters pathways.

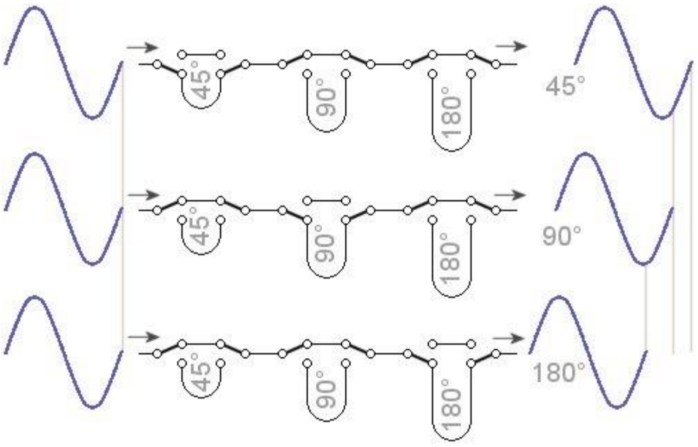


Figure 26: Wiring of the phase shifters delay lines

Monopulse Antennae

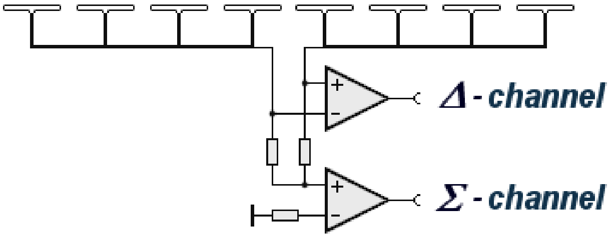


Figure 27: Principle of monopulse antennae

Under this concept antennae are combined which are built up as an antenna array and which get a special method in the feeding: The single antenna elements aren't always together switched in phase! For different purposes various sums and differences can be formed from the received energy.

In primary radar sets using a monopulse antenna all antenna elements are fed in phase and the radiation patterns are summarized. Certain groups are only summarized in the reception time and their sums or differences feed own receive channels. All signals are then compared as a video processor function and their difference is used to estimate the azimuth of the target more exactly. Therefore it can operate at a much lower rate of hits per scan.

In secondary radar sets using a monopulse antenna a pulse group is transmitted on the sum channel and an additional pulse in the difference channel. Well, the monopulse antenna is used *for side lobe suppression* there.

These two examples point: A monopulse antenna isn't an own basic antenna model. A monopulse antenna can be constructed as a group of logarithmic periodical antennae, a collection of simple dipole radiators or patch antenna fields.

Monopulse Concept

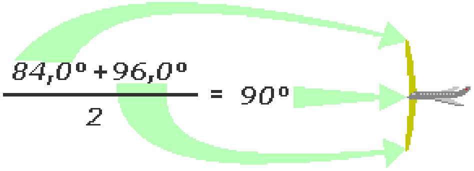


Figure 28: estimating of the angular position at classic radar sets with high hit rate

Monopulse radars find their origin in tracking systems. Since the late 1970s, the principle of monopulse has been adapted to suit PSR and SSR systems and is in common operational use world-wide today.

A target will be seen by radar from the moment it enters the main antenna beam or from the moment it is illuminated by the transmitted radar antenna beam. Search radar always makes an error in the determination of the direction of the target because it makes the assumption that the target is situated in the direction of the axis of the main beam of the antenna. This error is of the order of the beam width of the main antenna beam.

A crude way of determining angular position of a target is to move the antenna past the target direction and note the pointing direction that gives the maximum echo amplitude.

Unfortunately, the estimated azimuth position will be effected by thermal noise errors and target fluctuation errors (scintillation). The target fluctuation error is due to the cross-section changing of the target during the time-on-target of the antenna which gives a distortion of the envelope of the reflected pulse train.

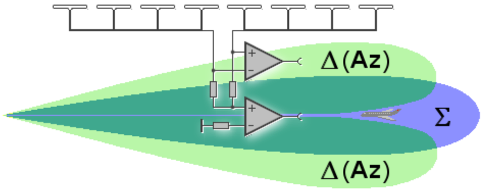


Figure 29: using a monopulse antenna the radar data processor can calculate the targets position into the beam

One received echo is sufficiently!

Monopulse gives much better target azimuth measurements than the estimating of the angular position shown in Figure 29. It can operate at a much lower interrogation rate to benefit others in the environment. Monopulse systems usually contain enhanced processing to give better quality target code information. A single pulse is sufficiently for monopulse bearing measurement (hence the use of the term monopulse).

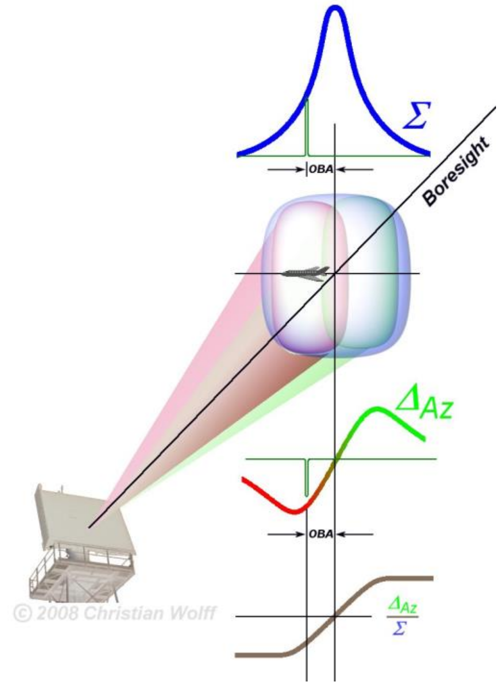


Figure 30: Principle of a monopulse system

The elements in linear antenna array are divided into two halves. These two separate antennae arrays are placed symmetrically in the focal plane on each side of the axis of the radar antenna (this often called boresight axis). In transmission (Tx) mode, both antennae arrays will be fed in phase and the radiation pattern is represented by the ice blue area, which is called the Σ or Sum –diagram, as shown in the Figure 30 as blue graph and blue pattern.

In reception (Rx) mode an additional receiving way is possible. From the received signals of both separate antenna arrays, it is possible to calculate Σ (like the transmitted Sum -diagram) and the difference Δ_{Az}, the so called Delta azimuth-diagram. The antenna pattern is given by the red and green area on the same figure. Both signals are then compared as a reply processor function and their difference is used to estimate the azimuth of the target more exactly.

The angle between the axis of the antenna (boresight axis) and the direction of the target is also known as OBA-value (Off-Boresight Angle).

The elevation angle is also measured at 3D radars as a third coordinate. Well, the procedure is used twice now. Here the antenna is derived in addition in an upper half and a lower half. The second difference channel (Δ_{El}) is called „Delta Elevation” now.

The Monopulse antenna is divided up into four quadrants now:

The following signals are formed from the received signals of these four quadrants:

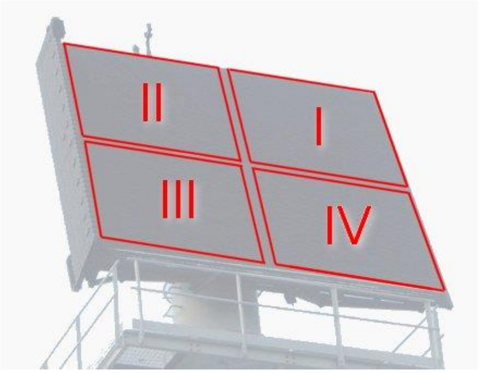


Figure 31: The antenna is divided into four quadrants

- Sum - signal Σ [(I + II + III + IV)]
- Difference - signal Δ_{Az} [(I + IV) - (II + III)]
- Difference - signal Δ_{El} [(I + II) - (III + IV)]

The

- Auxiliary Signal Ω

also shall to complete the picture be mentioned, although this one isn't tied to the monopulse antenna. This channel to the compensation of side lobes always has practically its own small antenna and has a very wide antenna diagram and also serves for the reconnaissance of active jamming.

All these signals need an own receiver channel. Well, modern 3D- radar sets have at least four parallel receiver- channels.

Conical Scan

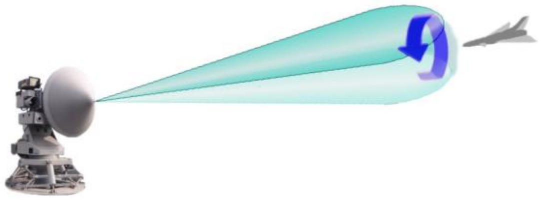


Figure 30: At conical scan the antenna traces a cone pattern around its central axis. Used in tracking radars conical scan with target azimuth and elevation being taken from the mechanical position of the antenna.

Some older tracking radar uses the conical scanning principle.

You can generate a conical scan pattern, as shown in figure 1, by using a rotating feed driven by a motor in the housing at the rear of the dish. The axis of the radar lobe is made to sweep out a cone in space; the apex of this cone is, of course, at the radar transmitter antenna or reflector.

At any given distance from the antenna, the path of the lobe axis is a circle. Within the useful range of the beam, the inner edge of the lobe always overlaps the axis of scan. Now assume that we use a conically scanned beam for target tracking. If the target is on the scan axis, the strength of the reflected signals remains constant (or changes gradually as the range changes). But if the target is slightly off the axis, the amplitude of the reflected signals will change at the scan rate. For example, if the target is to the left of the scan axis, as shown in the Figure 31 the reflected signals will be of maximum strength as the lobe sweeps through the left part of its cone; the signals will quickly decrease to a minimum as the lobe sweeps through the right part. Information on the instantaneous position of the beam, relative to the scan axis, and on the strength of the reflected signals is fed to a computer. Such a computer in the radar system is referred to as the angle-tracking or angle-servo circuit (also angle-error detector). If the target moves off the scan axis, the computer instantly determines the direction and amount of antenna movement required to continue tracking. The computer output is used to control servomechanisms that move the antenna. In this way, the target is tracked accurately and automatically.

Commonly used conical scan pattern include Conical Scan on Receive Only (abbreviated to COSRO) in which a conical scan pattern is used while the radar is in receive mode only.

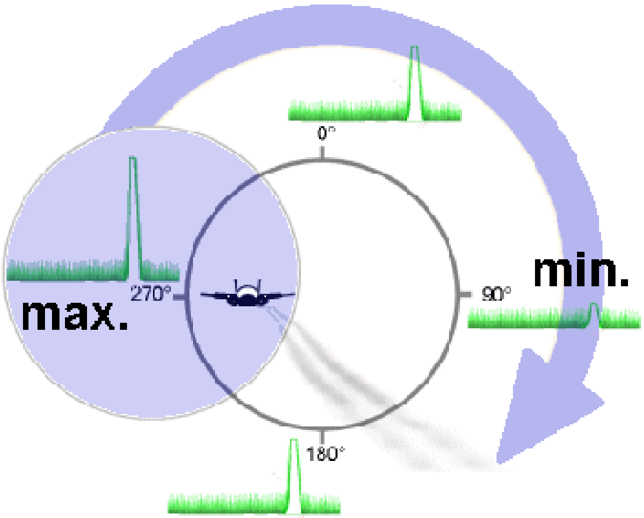


Figure 31: Principle of conical scan: if the target isn't in the boresight direction, then a maximum of backscattered power will be received in direction of the eccentric moving. The antenna must follow in this direction now.