Q2 (a) Derive all forms of radar-range equation and compare them.

Answer Page Number 6-7 of Textbook – I

Q2 (b) Discuss the major accomplishments of radar after World War II.

Answer Page Number 19 of Textbook – I

Q3 (a) A radar has a bandwidth B = 50 kHz and an average time between false alarms of 10 minutes.
(i) What is the probability of false alarm?
(ii) If the pulse repetition frequency (prf) were 1000 Hz and if the first 15 nmi of range were gated out (receiver is turned off) because of the use of a long pulse, what would be the new probability of false alarm? (Assume the false-alarm time has to remain constant.)
(iii) Is the difference between (i) and (ii) significant?
(iv) What is the pulse width that results in a minimum range of 15 nmi?

Answer Page Number 98 of Text Book – I

Q3 (b) The unambiguous range of radar is 200Km. It has a bandwidth of 1MHz.
Find the required
(i) pulse repetition interval **(ii) pulse repetition frequency**
(iii) range resolution **(iv) pulse width**

Answer
(i) PRT=1/PRF=2R/v=2X200X10^3/3X10^8=1.333 ms
(ii) PRF=1/PRT=1/1.333X10^{-3}=750 Hz
(iii) Range resolution=v/2B=3X10^8/2X1X10^6=150m
(iv) Pulse Width=2(range resolution)/v=2x150/3x10^8=1micro Sec.

Q4 Write a short note on the following:
(i) N-pulse Delay Line canceller
(ii) Doppler frequency shift
(iii) Blind speed in MTI radar
(iv) High-prf Pulse Doppler Radar

Answer
(i) Page Number 118 –119 of Textbook – I
(ii) Page Number 105 of Textbook – I
(iii) Page Number 113 - 115of Textbook – I
(iv) Page Number 172 – 173 of Textbook - I

Q5 (a) What is meant by automatic Detection and explain its four basic aspects.

Answer

In the automatic detection (sometimes called adaptive detection) algorithm in [1], the detection cells surrounding the cell under test for the presence of a target are used to estimate the background clutter power. The threshold is made proportional to this clutter power estimate and under ideal conditions the resulting false alarm probability is independent of the clutter power and is constant from cell to cell. One notices however, that the target location is not known with certainty and the potential target location cannot be taken as fixed as was done .Indeed it is clear that target echoes can interfere with, or bias, the clutter power estimate. We consider a threshold control scheme based on a priori target information concerning the p and q cells to compensate for this bias. We call this mode of threshold control, threshold compensation. A procedure for doing this was earlier considered in but it was not for a random target location model. The detection probability can be returned to a reasonable value from its degraded value due to clutter power estimate bias. However, they do not comment on the effect on false alarm probability of their procedure. We have found control of the false alarm probability to be very sensitive. To calculate the detection and false alarm probability we generalize a method presented to include the case of integration of an arbitrary number of pulses after square-law detection.

Q5 (b) Define matched filter and give its frequency response function.

Answer Page Number 276 - 277 of Textbook – I

Q6 (a) Derive the surface clutter radar equation.

Answer

Since the clutter signal is not a steady signal, it fluctuates with time and space; therefore it is better to consider the clutter signal as being a random sequence and to study its statistical properties are beyond the scope of this research.

In designing surface clutter models, Wetzel L.B (1990) has developed different models based on the grazing angle which can be effective to model sea clutter.

Figure 3.3, depicts radar illuminating the surface at a grazing angle ψ, it is assumed the width of area A_c is determined by the azimuth beam width θ_B

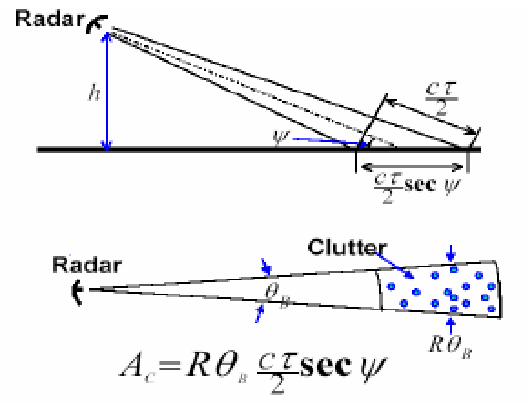


Figure 3.3. Geometry of radar clutter. Top: Elevation view showing the extent of the surface illuminated by the radar pulse, Bottom: Plan view showing clutter resolution cell consisting of individual independent scatterers.

Low Grazing Angle ψ, depicts a radar illuminating the surface at a small grazing angle **ψ.** For low grazing angles the range is determined by the radar pulse width τ. The cell width is determined by the azimuth beam width θ_B the range R. Utilizing the simple radar equation, the received echo power P_r is

$$P_r = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4} \qquad (8)$$

where P_t = transmitter power, W

G = antenna gain

A_e = antenna effective aperture m^2

R = range, m

σ = radar cross section of the scatterer, m^2

To model target echoes (rather than clutter), we let $P_r = S$ (received target signal power) and $\sigma = \sigma_v$ (target cross section). The signal power returned from target power is then

$$S = \frac{P_t G A_e \sigma_t}{(4\pi)^2 R^4} \qquad (9)$$

When the echo is from clutter, the cross section σ becomes $\sigma_c = \sigma_0 A_c$, where the area A_c of the radar resolution cell is

$$A_c = R\,\theta_B\,(c\,\tau/2)\sec\psi \qquad (10)$$

The smallest area A_c, of the sea surface within which individual targets can no longer be individually observed is termed resolution cell.

With θ_B = two way azimuth beamwidth, c = velocity of propagation, τ = pulse width and ψ = grazing angle (defined with respect to surface tangent). The Area A_c in range resolution, is ($c\,\tau / 2$), where the factor of 2 in the denominator represents for the two way propagation of radar. With these premises and definitions, the radar equation for the surface clutter each signal power C is

$$C = \frac{P_t G A_e [\theta_B (c\,\tau/2)\sec\psi}{(4\Pi)^2 R^3} \qquad (11)$$

When the echo from the surface clutter is large compared to receiver noise, the signal-to-clutter ratio is

$$\frac{S}{C} = \frac{\sigma_t}{\sigma_0 R\,\theta_B\,(c\,\tau/2)\sec\psi} \qquad (12)$$

If the maximum range, R_{max}, corresponds to the minimum discernible signal-to-clutter ratio (S/C_{min}), then the radar equation for the detection of target in clutter at low grazing angle is

$$R_{max} = \frac{\sigma_t}{(S/C)_{min}\, \sigma^0\, \theta_B\, (c\tau/2)\sec\psi} \qquad (13)$$

Notice the range appears as the first power rather than the fourth power as in the usual noise-dominated radar equation, which results in greater variation of the maximum range of a clutter dominated radar. When there is uncertainty in the range, statistical representations are useful.

The characteristics of clutter echoes are normally given in statistical terms. It is often described either by the mean (average) value of σ_0 or the median (the value exceeded 50 percent of the time). For a Rayleigh pdf, the difference between the mean and median is small (a few percent), but for non-Rayleigh distributions, the mean and the median can be quite different.

Q6 (b) (i) Why does the image show rain and there is no rain in the area?
(ii) What are the limitations of Doppler Weather radars in rainfall measurements?

Answer
(i) Most likely the radar station is in the clean air mode and is echoing off of buildings, trees, and other local obstructions. In the clean air mode, the radar is very sensitive and can pick up a flock of birds or even jet airplanes
(ii) Radar observations are very effective tool for detecting tracking and monitoring their growth, decay and movement of weather system and issuing reliable forecast and warnings for severe weather events which can cause huge loss of life and property. These observations also provide rainfall distribution due the weather systems within effective range around the radar. However, the use radar observations shall be used with much care as these are influenced by propagation through the atmosphere, earth curvature, blockage of radar beam by permanent structures, bright band occurrence, radar resolution etc. which may lead to erroneous conclusions. Some of the factors are explained below:
(a) Propagation effect -The atmosphere around the earth is non-uniform. There is gradual decrease in refractivity with height which causes the radar waves to bend down wards. The bending depends on gradient refractivity instead of its absolute value. When the bending of radar waves due decrease in refractivity is equal to the earth curvature, the wave will travel parallel to the earth's surface. Such an atmosphere is called standard atmosphere and the bending is called normal. The standard atmospheric conditions are not always present. Therefore, the bending depending on refractivity gradient is some times grater or less than the normal.

When the downward banding of the radar waves is stronger than normal this condition is called supper refraction. Under supper refraction conditions radar receives returns from ground which gives false indication of precipitation echoes. It also causes over estimation of cloud heights. In case the radar waves are not bent down ward as much as usual (normal reflection), under extreme conditions may bent upward. This condition is called sub refraction. This decreases the radar detection range. Under such condition radar under estimates the echo heights.

(b) Radar resolution problem -The radar beam width and thus the sampling volume increases with range. Therefore, radar resolution at long distances is poorer. This leads to distorted echoes at long ranges non-detection of multi trip echoes, tornado signatures. Two approaching echoes may appear as one and the receding echoes may appear to merge in one.

(c) Attenuation due to rain -The attenuation of radar waves (especially for short wavelengths 5 cm or less) by rain at close distances may obscure precipitating echo at long ranges. The stronger echoes at long distances may appear weak. Also, the precipitation area observed by radar may be less than actual.

(d) Partial beam filling -In case the radar beam is not completely filled by hydrometeors, the echo will be displayed as if it is from entire beam. As such the values displayed will not be true representative of the sampling volume.

(e) Bright band -In clouds, the precipitation particles are in the form of ice/snow above the freezing level and liquid water below it. When ice / snow particles fall through the freezing level, they start melting gradually and get coated with water but retain their large surface area. Thus, to the radar melting snow will look like large drops. As the water coated ice particles fall further and melt, their size decreases. Further, the reflectivity from ice is less than that from water for particles of the same size because the dielectric constant for ice is less than the water. Therefore, the radar observes slightly higher reflectivity below freezing level. Differential fall velocity of solid and liquid particle, aggregation and coalescence of particles play role in increase of reflectivity in this layer.

The identification is of practical importance in rainfall estimation. Attenuation and reflectivity values from a bright band are high. Radar estimates of precipitation are required to be corrected if the radar beam cuts the bright band.

(f) Beam blockage -If the beam is obstructed by man made or natural objects (building, trees, hills etc), the radar will not be able to probe beyond the range of obstruction. If the beam is partially blocked, observations will not true representative of the area. As we probe with distance, the bin volume increases with range. A small obstruction which completely blocks a range bin very close to the radar causes no data beyond that obstruction for the rest of the range in that particular elevation. Therefore, the data in respect of these bins is needs correction before processing it for computation of rainfall estimates.

Q7 (a) Explain the working of phased array antenn(a)

Answer Page Number 560 – 562 of Textbook - I

Q7 (b) Is it possible to discriminate details smaller than the angular resolution? If yes, how?

Answer

It is NOT possible to discriminate details smaller than the radar resolution cell, but, in presence of relative (tangential) motion between radar and target, this angular resolution is NOT necessary the same as the physical aperture of the antenna beam.

The improvement can be achieved using a technique called "synthetic aperture". If proper coherent processing of the echoes is provided, observing the target from different points can be considered like "sampling" different points of a "virtual antenna" as long as the distance traveled by the radar during the observation time.

The same effect can be understood by thinking at a radar (supposed operating in continuos wave for simplicity) moving wrt a point target at about 90 deg from its velocity vector. The echo will have a positive Doppler shift when the target is at <90 deg (closing) and negative Doppler shift when target is at >90 deg (receding).

Analysing the target Doppler history, it is then possible to localise the target with a resolution better than the antenna beam aperture.

Independently from the approach used to model this effect, the conclusion is that, for a so-called "stripmap" (i.e., side-looking with no antenna steering) synthetic aperture radar (SAR) the resolution (in m) is independent from the target range and is proportional to the antenna dimensions. For an antenna of lenght L, the resolution is L/2.

This because a smaller antenna provides a larger beam, which allows longer illumination times and then a larger "synthetic antenna", thus improving the angular resolution. Increasing the target range also produces an increasing of the synthetic antenna aperture and then an improvement of angular resolution, compensating for the degradation due to the increased distance.

Even if the principle is simple, practical implementation of this technique is very complex. The correlation to be performed on each individual pixel requires huge computing resources, and several disturbing effects need to be accounted for and compensated. Anyway, several systems of this kind are currently operational on both airborne and space platforms.

Q8 (b) What are Radar displays? Explain their principle of Operation with examples and sketches.

Answer

The A-scope display, shown in the figure, presents only the range to the target and the relative strength of the echo. Such a display is normally used in weapons control radar systems. The bearing and elevation angles are presented as dial or digital readouts that correspond to the actual physical position of the antenna. The A-scope normally uses an electrostatic-deflection crt. The sweep is produced by applying a sawtooth voltage to the horizontal deflection plates. The electrical length (time duration) of the sawtooth voltage determines the total amount of range displayed on the crt face.

B-scope displays were common in airborne and fire-control radars in the 1950s and 60s, which were mechanically or electronically scanned from side to side, and sometimes up and down as well. The center of the bearing usually is movable through hand wheels in fire-control radars. The antenna turntable then is turned into the new direction. The screens middle is defined as the main reception direction of the antenna normally. The bearing area is covered through an electro-mechanical or electronic beam steering.

The used designation “B-scope” is ambiguous sometimes. The term refers to two completely different types of scopes. In radar devices without measurement of the azimuth angle, the term “B-scope” is also used (e.g.: Ground Penetration Radars). The abscissa is a time coded scale then, and shows a history of the pulse periods.
The PPI-scope shown in this figure, is by far the most used radar display. It is a polar coordinate display of the area surrounding the radar platform. Own position is represented as the origin of the sweep, which is normally located in the center of the scope, but may be offset from the center on some sets. The ppi uses a radial sweep pivoting about the center of the presentation. The sweep rotates on the display just as fast as the radar antenna. This results in a map-like picture of the area covered by the radar beam. A long-persistence screen is used so that the targets remain visible until the sweep passes again.

Q9 (a) What are the various factors which determine the accuracy of tracking radar?

Answer

The angular accuracy of tracking radar will be effected by such factors as the properties of the radar antenna and pedestal, the method by which the angular position of the antenna is measured, the quality of ,phase the stability of the electronic circuits, the noise level of the receiver, the antenna beamwidth, atmospheric fluctuations, and the reflection characteristics of the target. These factors can degrade the tracking accuracy by causing the antenna beam to fluctuate in a random manner about the true target path. These noiselike fluctuations are sometimes called tracking noise, or jitter.
simple radar target such as a smooth sphere cause degradation of the angular tracking accuracy. The radar cross section of a sphere is independent of the aspect at which it is viewed; consequently, its echo will not fluctuate with time. The same is true, in general, of a radar beacon if its antenna pattern is omnidirectional. However, most radar targets are of a more complex nature than the sphere. Tlle amplitude of the echo signal from a complex target may vary over wide limits as the aspect changes with respect to the radar. In addition, the effective center of radar reflection may also change. Both of these effects-amplitude fluctuations and wandering of the radar center of reflection-as well as the limitation imposed by receiver noise can limit the tracking accuracy. These effects are discussed below.
Amplitude fluctuations. cornplex target such as an aircraft or a ship may be considered as a nuniber of independent scattering elements. The echo signal can be represented as the vector addition of the contributions from the individual scatterers. If the target aspect changes with respect to the radar-as might occur because of motion of the target, or turbulence in the case of aircraft targets-the relative phase and amplitude relationships of the contributions from the individual scatterers also change. Consequently, the vector sum, and therefore the amplitude, change with changing target aspect.
Amplitude fluctuations of the echo signal are important in the design of the lobeswitching radar and the conical-scan radar but are of little consequence to the monopulse tracker. Both the conical-scan tracker and the lobe-switching tracker require a finite time to obtain a measuremerlt of the angle error. This time corresponds in the conical-scan tracker to at least one revolutiorl of the antenna beam. With lobe switching, the minimum time is that necessary to obtain echoes at the four successive angular positions. In either

case four pulserepetition periods are required to make a measurement; in practice, many more than four are often used. If the target cross section were to vary during this observation time, the change might he erroneoilsly interpreted as an angular-error signal. The monopulse radar, on the other ttand. detern~ines the-angular error on-the-.basis of a single pulse. Its accuracy will therefore riot be affected by changes in amplitude with time.

To reduce the effect of amplitude noise on tracking, the conical-scan frequency should be chosen to correspond to a low value of amplitude noise. If considerable amplitude fluctuation noise were to appear at the conical-scan or lobe-switching frequencies, it could not be readily eliminated with filters or AGC. A typical scan frequency might be of the order of 30 Hz. Higher frequencies might also be used since target amplitude noise generally decreases with increasing frequency. However, this may not always be true. Propeller-driven aircraft produce modulation components at the blade frequency and harmonics thereof and can cause a substantial increase in the spectral energy density at certain frequencies. It has been found experimentally that the tracking accuracy of radars operating with pulse repetition frequencies from 1000 to 4000 Hz and a lobing or scan rate one-quarter of the prf are not limited by echo amplitude fluctuations.[29]

The percentage modulation of the echo signal due to cross-section amplitude fluctuations is independent of range if AGC is used. Consequently, the angular error as a result of amplitude fluctuations will also be independent of range.

Angle fluctuations.[29,30] Changes in the target aspect with respect to the radar can cause the apparent center of radar reflections to wander from one point to another. (The apparent center of radar reflection is the direction of the antenna when the error signal is zero.) In general, the apparent center of reflection might not correspond to the target center. In fact, it need not be confined to the physical extent of the target and may be off the target a significant fraction of the time. The random wandering of the apparent radar reflecting center gives rise to noisy or jittered angle tracking. This form of tracking noise is called *angle noise*, *angle scintillations*, *angle fluctuations*, or *target glint*. The angular fluctuations produced by small targets at long range may be of little consequence in most instances. However, at short range or with relatively large targets (as might be seen by a radar seeker on a homing missile), angular fluctuations may be the chief factor limiting tracking accuracy. Angle fluctuations affect all tracking radars whether conical-scan, sequential-lobing, or monopulse.

Consider a rather simplified model of a complex radar target consisting of two independent isotropic scatterers separated by an angular distance θ_D, as measured from the radar. Although such a target may be fictitious and used for reasons of mathematical simplicity, it might approximate a target such as a small fighter aircraft with wing-tip tanks or two aircraft targets flying in formation and located within the same radar resolution cell. It is also a close approximation to the low-angle tracking problem in which the radar sees the target plus its image reflected from the surface. The qualitative effects of target glint may be assessed from this model. The relative amplitude of the two scatterers is assumed to be a, and the relative phase difference is α. Differences in phase might be due to differences in range or to reflecting properties. The ratio a is defined as a number less than unity. The angular error $\Delta\theta$ as measured from the larger of the two targets is[31]

$$\frac{\Delta\theta}{\theta_D} = \frac{a^2 + a\cos\alpha}{1 + a^2 + 2a\cos\alpha} \tag{5.2}$$

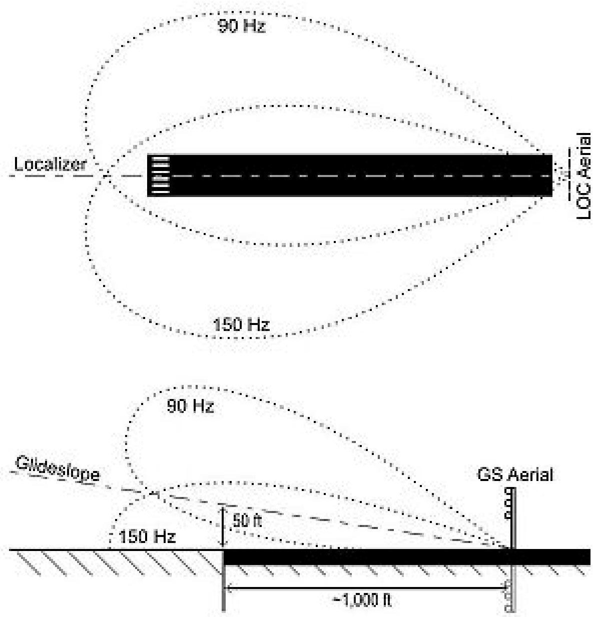
This is plotted in Fig. 5.13. The position of the larger of the two scatterers corresponds to $\Delta\theta/\theta_D = 0$, while the smaller-scatterer position is at $\Delta\theta/\theta_D = +1$. Positive values of $\Delta\theta$ correspond to an apparent radar center which lies between the two scatterers; negative values lie outside the target. When the echo signals from both scatterers are in phase ($\alpha = 0$), the error reduces to $a/(a+1)$, which corresponds to the so-called "center of gravity" of the two scatterers (not to be confused with the mechanical center of gravity).

Angle fluctuations are due to random changes in the relative distance from radar to the scatterers, that is, varying values of α. These changes may result from turbulence in the aircraft

Q9 (b) What is an instrument landing system? Explain how elevation guidance is provided in this system. Give the configuration of localizer antenna also.

Answer

An ILS consists of two independent sub-systems, one providing lateral guidance (localizer), the other vertical guidance (glide slope or glide path) to aircraft approaching a runway. Aircraft guidance is provided by the ILS receivers in the aircraft by performing a modulation depth comparison.



The emission patterns of the localizer and glideslope signals. Note that the glide slope beams are partly formed by the reflection of the glideslope aerial in the ground plane.

A localizer (LOC, or LLZ until ICAO designated LOC as the official acronym) antenna array is normally located beyond the departure end of the runway and generally consists of several pairs of directional antennas. Two signals are transmitted on one out of 40 ILS channels between the carrier frequency range 108.10 MHz and 111.95 MHz (with the 100 kHz first decimal digit always odd, so 108.10, 108.15, 108.30, and so on are LOC frequencies but 108.20, 108.25, 108.40, and so on are not). One is modulated at 90 Hz, the other at 150 Hz and these are transmitted from separate but co-located antennas. Each antenna transmits a narrow beam, one slightly to the left of the runway centerline, the other to the right.

The localizer receiver on the aircraft measures the difference in the depth of modulation (DDM) of the 90 Hz and 150 Hz signals. For the localizer, the depth of modulation for each of the modulating frequencies is 20 percent. The difference between the two signals varies depending on the position of the approaching aircraft from the centerline.

If there is a predominance of either 90 Hz or 150 Hz modulation, the aircraft is off the centerline. In the cockpit, the needle on the horizontal situation indicator (HSI, the instrument part of the ILS), or course deviation indicator (CDI), will show that the aircraft needs to fly left or right to correct the error to fly down the center of the runway.

If the DDM is zero, the aircraft is on the centerline of the localizer coinciding with th physical runway centerline.

A glide slope (GS) or glide path (GP) antenna array is sited to one side of the runway touchdown zone. The GP signal is transmitted on a carrier frequency between 328.6 and 335.4 MHz using a technique similar to that of the localizer. The centerline of the glide slope signal is arranged to define a glide slope of approximately 3° above horizontal (ground level). The beam is 1.4° deep; 0.7° below the glideslope centerline and 0.7° above the glideslope centerline.

These signals are displayed on an indicator in the instrument panel. This instrument is generally called the omni-bearing indicator or *nav indicator*. The pilot controls the aircraft so that the indications on the instrument (i.e., the course deviation indicator) remain centered on the display. This ensures the aircraft is following the ILS centreline (i.e., it provides lateral guidance). Vertical guidance, shown on the instrument by the glideslope indicator, aids the pilot in reaching the runway at the proper touchdown point. Many aircraft possess the ability to route signals into the autopilot, allowing the approach to be flown automatically by the autopilot.

Text Books

1. Introduction to Radar Systems, Merrill I. Skolnik, 3e, TMH, 2001

2. Electronic and Radio Engineering, F.E. Terman, McGraw Hill Publications.