**Some Problems with answers**

Set 1

(i) In a pulsed radar, transmitter-pulse is 1 µs and the duplexers recovery time is 0.5 µs.

(a) What is the minimum distance at which the target can be detected by the radar?

(b) What is the minimum distance (in nmi) between two equal-size targets in order to be completely resolved by the radar.

(ii) What is the Doppler Effect? How are the echoes from approaching target separated from the receding target? What will be the Doppler frequency shift due to a receding target with velocity of 100ms-1 for a radar with carrier frequency of 1 GHz?

(iii) A pulsed radar has a duty cycle of .016. If the pulsed repeating period (PRP) is 380 μs and the carrier frequency is 2 GHz.

(a) Pulse width? (b) Pulse Repetition Frequency? Minimum range, in meters, of this radar?

(c) If radar is operating at a PRF of 326.09 s -1, what is the maximum unambiguous

1. A certain airborne pulsed radar has peak power Pt = 10KW, and uses two PRFs, fr1 = 10KHz and fr2 = 30KHz . What are the required pulse widths for each PRF so that the average transmitted power is constant and is equal to 150 Watts? Compute the pulse energy in each case.

Answers:

(i) (a) The target cannot be detected if the echo round trip time is ≤1.5 µs. This gives an equivalent range of 225m.

(b) The range resolution for 1 microsecond is 150 m =resolution 0.08099 nmi

(ii) When radar transmission is incident on a target in relative motion with respect to the radars, the echo frequency is different that the transmit frequency. This phenomenon is known as the Doppler Effect. The echo from the targets approaching to the radar is at higher frequency that the transmit frequency; whereas the receding show echo frequency lesser than that of the transmit frequency. The Doppler frequency shift will be 666.67 Hz. ( 2X 100/ 0.3)

(iii) (a) PRP X Duty Cycle = Pulse Width = 6.08 μs. (b) PRF= 1/ PRP = 2.6315 kHz, Minimum range= cτ/2=30,00,00,000 X(6.08 X 10-6/2)= 912m (c) Pulse Repetition period = 1/PRF= 326.09 460 km.

(iv) PW = Pav / (PpeakX PRF). Therefore, PW1=150/(103 X 103)= 1.5 μs, similarly for PRF of 30 KHz,the pulse width (PW) is 0.5 μs

**Set-2**

1. A C-band radar with the following parameters: Peak power G = 45dBm, operating frequency f0=5.6 GHz, antenna gain G=45dB, effective temperature Te=290 K, pulse width τ= 0.2μs. The radar threshold is (SNR) min = 20 dB. Assume target cross section σ=0.1 m2. Compute the maximum range. (make convenient assumptions)
2. An airport surveillance radar operating at a frequency of 2.9 GHz (S-Band).Its maximum range is 60 nmi for the detection of target with a radar cross section of 10,000 m2(σ=10,000 m2). Its antenna is 5m wide and 2.7 m high (size is 5 X 2.7 m2), antenna aperture efficiency ρa of 0.7 and minimum detectable signal Smin equal to 10-9 W. What will be it’s peak power?
3. Compute the power aperture product for an 10 GHz, X-band radar with the following parameters: signal-to-noise ratio SNR=15dB; losses L=8dB ; effective noise temperature Te= 900 degree Kelvin; search volume Ω=20 ; scan time TSC=2.5 seconds; noise figure F=5 dB . Assume a –10dB m2 target cross section, and range R=250 km. Also, compute the peak transmitted power corresponding to 30% duty factor, if the antenna gain is 45 dB.
   1. The atmospheric attenuation can be included in the radar equation as another loss term. Consider X-band radar whose detection range at 20 km includes a 0.25 dB/km atmospheric loss. Calculate the corresponding detection range with no atmospheric attenuation.
   2. Let the maximum unambiguous range for low PRF radar be Rmax. (a) Calculate the SNR at ½ Rmax and ¾ Rmax. (b) If a target with σ=10 m2 exists at ½ Rmax, what should the target RCS be at ¾ Rmax, so that the radar has the same signal strength from both targets.
4. A Milli-Meter Wave (MMW) radar has the following specifications: operating frequency f0=94GHz , PRF fr=15 KHz , pulse width τ=0.05µs, peak power Pt=10W , noise figure F=5 dB , circular antenna with diameter D=0.254 m, antenna gain G=30 dB , target RCS σ=1m2, system losses L=8dB, radar scan time TSC=3s, radar angular coverage 2000 and atmospheric attenuation 3 dB/km. Compute the following: (a) wavelength (b) range resolution ; (c) bandwidth ; (d) the SNR as a function of range; (e) the range for which SNR=15dB ; (f) antenna beam width; (g) antenna scan rate; (h) time on target; (i) the effective maximum range when atmospheric attenuation is considered.
5. An X-band airborne radar transmitter and an air-to-air missile receiver act as a bistatic radar system. The transmitter guides the missile toward its target by continuously illuminating the target with a CW signal. The transmitter has the following specifications: peak power Pt=4KW; antenna gain Gt=25dB; operating frequency f0=9.5GHz . The missile receiver has the following characteristics: aperture Ar=0.01m2; bandwidth B=750Hz; noise figure F=7dB ; and losses Lr=2dB . Assume that the bistatic RCS is σB=3m2. Assume Rr=35 km, Rt=17km ; . Compute the SNR at the missile.
6. Consider a low PRF C-band radar operating at f0=5000 MHz . The antenna has a circular aperture with radius 2m. The peak power is Pt=1MW and the pulse width is τ=2μs . The PRF is fr=250 Hz, and the effective temperature is T0=600K . Assume radar losses L=15 dB and target RCS σ=10m2. (a) Calculate the radar’s unambiguous range; (b) calculate the range R0 that corresponds to SNR=0dB; (c) calculate the SNR at R=0.75R0.
7. Non-contact level based measurement system is installed on a cylindrical petroleum reservoir. This system is expected to measure liquid level from 1ft (≈ 0.3m) to 30 ft (≈ 9m). The measurement must be done with the resolution of 0.5 ft.
8. What is the bandwidth of the RF system?
9. Design a transmit wave pattern. What is the period of frequency Chirp?
10. Can the accuracy of the measurement be increased keeping the resolution same?
11. If an FMCW radar altimeter operating in “X band maritime navigation frequencies” (9.3-9.5 GHz). Design the waveform if the system is expected to use vertical velocity as well as the height at which the radar is flying? Give measurement range of height and the vertical velocity. If the system in complete frequency band will the echoes result in OFF-band transmission?

If the altimeter antenna tilts by an angle of 10 degrees, what is the error in the height measurement (Make convenient but realistic assumptions?)

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**Answers**

(i) **Parameter computations:**

Wavelength @ 5.6 GHz= 3X108/5.6X 109= 0.05357 m= -12.7 dB(meter)

Optimum Bandwidth at 0.2 μs pulsewidth = 5 MHz

**Assumptions:**

We assume that the noise Figure is 0dB (=1) ideal amplifier.

also the signal with strength equal to noise will be detected. Therefore Smin= kTB



This calculationwith a reasonable approximation becomes much easier in dB.

Rmax= 0.25 (45+90-25.4-10-33+107)=43.4 dB(meter)=21.877 km

(ii) Parameter computations:



Rmax= 111120 m = 50.45 dB(meter)

**Assumption**: Minimum detectable signal is received from Rmax.



Rearranging the terms we have Transmitted peak power is 22.950 kW.

This calculation is much easier in dB

Pt(dB)=-90+33+201.6 -80.90-40+19.7=43.4= 21.877 kW

1. We need to derive the equation for the relation between SNR and power aperture product



Assumption: There is only one pulse per beam spot while scanning. We have

*Tsc= TPRF X No. of beam spots*= (Ώ/dθdϕ) Where dθ and dϕ are the beam-widths in orthogonal direct ions. We also know that Gain (G=4π/ dθdϕ) and B=(1/τ). The expression becomes…



Re-arranging and substituting, we have



Computing in dB terms

Power Aperture Product= 11+215.9-199.08+8+5+15-14.5-4+10= 47.32dBWm2=53951.03 Wm2.

Now, we compute Peak Transmitted power

Antenna gain 45 dB=31622.77 Hence the area (Ae)will be = 31622.77 X (0.03)2/ 4 π=2.26 m2

Pav= 53951.03/2.26=23.821 kW, with 30% duty, we have Pt=79.403 kW

1. With the loss of 0.25 db/ km, we have round trip loss of 2 X 20 X 0.25=10 dB

For radar with no atmospheric losses an advantage of 10 dB is available.

This will improve the range by 2.5 dB ( a factor of 1.778)

Hence the range will be 35.56 km.

(b)The SNR at

½ Rmax will be 16 times (12 dB)

¾ R max will be 3.16 ( 5 dB) times higher.

By taking the target at the range of 1.5 times, the signal becomes weaker by 5.0625 times. Hence the target RCS should be5.0625 times bigger (i.e 50.625 m2)

(iv)

1. Wavelength= 3.125 mm
2. Range Resolution= 7.5 m. ( with pulse width of 0.05 ms = 7.5 km)
3. Bandwidth = 1/τ= 20 MHz (20 kHz)
4. Following expression



But this is represented better in dB terms.

SNR (dB) = 70-50-33-9+140-8-5-4R (km,dB)-120-3R (km)

=-15 -4R(dB,km)- 3 R (km) …. = 45 -4R (db(km)-3 R(km)

1. Range at which SNR =15 dB is 0 dB(km)≈ 0.183 km. (3.22km)
2. Beam width= 70 X0.003125/0.254=0.86 degrees
3. Scan rate 200/3 =66.67 degrees per second
4. Target is assumed to be a point target. Time on target= 0.86/200s= 4.3ms.
5. We assume that 1 dB SNR is required for detection. Therefore, therefore maximum range is

2 dB(km)= 1.6 km. ( 3dB SNR, 42/7= 6 (dBkm)= 4 km.)

This problem becomes interesting if we take the pulse width to be 0.05 ms (resolution does not play role)

(v)



Solving in dB terms,

SNR=36+25-20+5-33-90-84.6+175= 13.64

(vi)

1. Unambiguous range=1/ fr=4 ms=> 600 km.

(b)



Assuming that noise figure is 0dB,

In dB terms, SNR= 60+92.84-24.43+10-33+144-15= 234.6 – 4 R (dB(m)) = 707.9 km.

This is higher than unambiguous range

1. At 0.75 R0, the SNR will be5 dB.
2. 0.5 ft Resolution will require bandwidth of 1 GHz.

Design any suitable chirp. E.g. 1 second period will have fb=6.67 Hz per meter

Yes accuracy can be in creased by having a good SNR.

1. This is a discussion type question, needs thinking and assumptions. Multiple correct answers.

Try yourself

* 1. Numerical problems

1. The transmitter of the MST radar transmits peak power of 2 MW with a pulse width of 1 µs. The modulator ON off ratio is 80 dB and the Duplexer isolation is 70 dB. Will this system require a blanking switch? If yes, what should be isolation?

If the expected minimum Doppler frequency is 1 Hz, what should be the phase noise specifications? Will such condition relax the isolation requirements? How?

This is case of inadequate data (sorry)

Conditions for Pulsed radar operation:

1. **During the transmit time,** the receiver should not saturate

I have not given the saturation power level for receiver. Assume it to be 0 dBm= 1mW.

For this value: the calculation is as follows:

2 MW = 93dBm {= 10 log 2 (MW/1mW)}

Power to the receiver🡺 93-70dB (duplex-isolation) = 23dBm

This is higher than 0dBm.

Therefore the Blanking switch will be required.

The Blanking Switch isolation> 23 db

**During the transmit time**: The transmitter (DC leakage) will be = 93-80dB (On-Off ratio)-70 = -57 dBm

The minimum signal / receiver sensitivity is not given. We assume that it is -110 dBm

This signal is lower by 53 dB (=-57- (-110))

The DC leakage should not have phase-noise such that it skirts the signal with Doppler.

Therefore the phase noise specifications of the carrier transmission= <-53 dBc @ 1Hz.

( dBc = dB below carrier)

If the carrier has higher specifications, say “-70dBc @1 Hz”

Then the isolation and ON-OFF ratio could be relaxed by 17 dB.

1. A fuel tank level measurement system is an FMCW radar operating in X band with a transmitter power of 1 watts. The receiver uses direct down conversion mixer diode with 1 the local oscillator power requirement of 1 mW. Can this radar be operated in mono-static mode with suitable circulator? If yes, what should be isolation of this circulator?

In FMCW radar, when operated in mono-static mode, circulator leakage can be used as a local oscillator power. Therefore, circular isolation should be Ptx(dB)-PLo(dB)= 30-0=30 dB.

Fig. 3.3 (a) Continuous Wave Radar:

Mono-static configuration

Fig. 3.3 (b) Continuous Wave Radar:

Bi-static configuration

RF Generator

Amplifier Filter

Receiver Processor

Directional Coupler

Circulator

Directional Coupler

Mixer

Mixer

Amplifier Filter

Receiver Processor

RF Generator

Circulator Leakage

1. An atmospheric radars operates with Tx-pulse width of 1μs, and antenna beam width of 0.1 rad. (in both orthogonal directions) The clear-air target volume reflectivity is = 10-16m2.m-3. What is the radar cross section at a range of 20 km?

We compute pulse volume for clear air target= (cτ/2) X (πr2dϕdθ/4) OR (cτ/2) X (r2dϕdθ)

σ = Vol X η= (150 X π X 22X106)/ 4 X 10-16= 4.71 X 10-8 m2

1. Derive the frequency transfer function for 5 stage Decimating type of CIC filter and plot the frequency response.

(Assume arbitrary data)