**MID Semester Examination (EE602: 2020-1)**

Date 8.10.2020 **Timings: 1330-1615 (hard-limit 1730 Hrs**) Maximum marks = 25

**Note:** Assume data if necessary and WRITE the assumption.

Calculations in dB and engineering approximations are encouraged.

Improper explanation, wrong or no units, late submission shall lead to reduces credits

**Q1** (7 marks)

1. A radar receiving system consists of super-heterodyne receiver (Rx) followed by a detector. The receiver (Rx) has noise figure (NF) of 3 dB has a sensitivity of -110 dBm (minimum input at which the signal is detected). Signal detection requires minimum signal to Noise ratio (SNR) of 5 dB at Rx output). What is the value of the noise power at the input of the receiver (in watts)? What is the bandwidth of the receiver? (Boltzmann constant= 1.38 ×10-23 J K-1) (1+1=2 Marks)
2. The transmitter power of radar is increased from ‘P’ dBW to ‘P+8’ dBW. What is the percentage increase in the maximum range? (1 Mark)
3. (a) A target (aircraft) is travelling radially towards the radar with a relative velocity of 100 knots. The radar transmits continuous wave energy at a wavelength (λ) of 5 cm. What will the Doppler shift observed by the radar? What will the Doppler shift be if the target alters its course (changes direction) by 600? (1 Knot= 1 nautical mile hr-1 = 1.852km.hr-1) (1+1=2 Marks)
4. Write a mathematical condition/ relation between angular time frequency (ω) and the wave number (k= 2π/λ) for fast wave structure/ interaction. Name one example of the device.

What is the mathematical condition in terms of ω and k for the travelling wave tube (TWT) type device? Whether TWT is slow wave structure? (1+1=2 Marks)

**Q2** (5 marks)

A pulsed radar operating at 15GHz performs areal scan covering a solid angle Ω =2sr (Steradian). This scan is performed by sequentially acquiring echoes from multiple beam-spots positioned appropriately. The radar beam-widths in orthogonal directions are dθ and dϕ. The radar acquires the echoes from three (n=3) pulses (repeating with period TPRF) for each beam spot. Assume that the total number of beam spots to be Ω/dθdϕ; Total scan time (time required for all beam spots) is TSC=3 seconds

1. Compute the power aperture product (Average transmitted power **Paverage**× effective antenna area, **Ae**) for following parameters: signal-to-noise ratio SNR=10dB; cable losses L=9dB and noise figure F=4 dB. Target cross section of 11dB m2 and range R=150 km. (Boltzmann constant= 1.38 X 10-23 m2 kg s-2 K-1) (easier to calculate in dB). (3 Marks)
2. Also, compute the peak transmitted power corresponding to 10% duty factor, if the effective antenna area is 5 dBm2. (2 Marks)

**Q3** (6 Marks)

A pulsed Doppler radar operating at 15GHz uses 3 pulse repetition frequencies (PRFs), namely 10kHz, 15 kHz and 20 kHz. It detects 3 targets, A, B, and C. The receiver performs complex (in-phase and quadrature) sampling followed by DFT computations for approaching as well as receding Doppler velocity measurements.

(a)Find the unambiguous range and unambiguous velocity for each of the PRF? (1 X 3 =3)

(b) Find the correct range and velocity of each of the targets A, B, C. (1 X 3 = 3)

The range-Doppler data for three PRFs corresponding to A, B, C is given in following table.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | PRF 10 kHz | | PRF 15 kHz | | PRF 20 kHz | |
|  | **Range** | **Velocity** | **Range** | **Velocity** | **Range** | **Velocity** |
| Target A | 9km | -20ms-1 | 9km | -20ms-1 | 1.5km | -20ms-1 |
| Target B | 4 km | 30ms-1 | 4 km | 30ms-1 | 4 km | 30ms-1 |
| Target C | 5km | +20ms-1 | 5km | +70ms-1 | 5km | -80ms-1 |

**Q4.** (7 marks)

A linear chirp FMCW radar altimeter, mounted on airborne platform, measures the height at which it flies. The antennas of the radar are pointed towards the ground and the height is determined by analyzing the echo signal from ground and estimating the height. The Frequency band is 2.925-3.075 GHz. The height measurement range is 10m to 100m.

1. Determine the sweep time of transmit linear chirp so that the beat frequency is in the range of LF frequency band (30 kHz to 300 kHz). Draw an appropriate diagram illustrating the design.
2. Write the expression for height estimation. What will be height resolution? (2+1 = 3 mark)

Linear chirp- FMCW range estimation can also be done by sequentially transmitting linear chirp signals at different sweep rate; as shown below. This method uses a narrow band receiver with bandwidth (say) for beat frequency analysis. For a specific sweep rate, the receiver band shall correspond to range (flying height) interval of. For different frequency sweep rates, corresponding range interval () will be different. A finite number of sweep rates values are chosen and sequenced in such a manner that complete range of 10m-100m is covered. In this type of operation the target echo is detected during one of these frequency sweeps.

Thus, this method requires multiple frequency sweeps but operates with a narrow band receiver

Time

Frequency

ΔF

Transmission waveform of variable chirp rate FMCW radar

T1

T2

TN

Consider that the receiver bandwidth of this altimeter is 50 kHz ± 2.5 kHz.

(c)What is the minimum (corresponding to 10.5±0.525m, say) sweep time? Approximately how many sweeps are needed to span the complete range? What is the maximum sweep time?

(2marks)

(d) Will FMCW radar with variable chirp rate have advantage in detecting weaker echoes (compared to the conventional single sweep rate radar)? Comment/ explain on advantages and disadvantages? (1 mark)

(e) Quantify the advantage and disadvantage. Specify in terms of ratio, (how many times). (1 Mark)

**MID Semester Examination (EE602: 2020-1)**

(Answers with credit system)

**Q1**

1. The noise power at the input of the receiver must be -110-3-5= **-118 dBm** (1 mark)

= k X290 X B= -118 dBm = 1.5848 X10-15 W= 1.5848 fW.

Therefore Bandwidth **B =396.025 kHz**. (1 mark)

1. Increasing the power by 8 dB will increase in the range by 2 dB🡺 1.5849 times, 58% increase

**OR** 8dB≈6.3. therefore, Range increase (6.3)0.25 = 1.58429 🡺 by ≈58% (1 mark)

1. 1Knot= 1.852km/hr= 1.852/3.6=0.51444ms-1.

1 knot = 0.5144 m/s, so 100 kts = 51.44 m/s or 5144 cm/s (conversion to m/s or cm/s 0.5 marks)

Doppler shift = (2v/λ)= 2 X 5144 cm / 5cm = 2057.6 Hz (correct computation 0.5)

For a course change of 60o, the radial velocity component will be

Cos(60o) X 100 knot = 0.5 X 5144 cm/s= 2572 cm/s (0.5)

Frequency shift = 2(2572cm/s)/(5 cm) = 1028.8 Hz (0.5)

(Direct calculation, dividing by 2 to get Doppler freq. also gets full marks)

(d) Condition for fast wave structure/ interaction is (ω/k) >c (0.5 Mark)

Example- Gyrotron (0.5 Mark)

Condition for TWT type device is dω/dk>0 or Group velocity is positive (0.5 Mark)

Yes, TWT is a slow wave structure (don’t call it fast confusing with forward wave structure) (0.5 mark)

**Q2**

1. We need to derive the equation for the relation between SNR and power aperture product. Expressing the transmitted power in terms of average power and using following other expressions



Also,, , and 

Substituting for G, B and expressing in terms of Ω, (1 mark for correct conversion substitutions)

We have



Re-arranging and substituting, we have (2 marks)

Computing with approximate dB terms, (also a valid approach)

we have Noise power as Noise power 1.38 X 10-23X 290X 2.5= 200 dBW

**Power Aperture Product**≈ 5+11+207-200+9+3+10-5-11=29 dBWm2=794.32 Wm2. (1mark)

1. Effective area is 5 dbm2= 3 m2, Average power Pav=29-5=24 dBW OR 794/3= 264.67 Watts

With 10% duty, Pt=Pav/(Duty)=24-(-10)=34 dBW OR 264.67/0.1 = 2646.7 W= 2.646 kW (2 marks)

(With actual value calculations, Pav= 282.24 W🡺 Ppeak= 2.82.24 kW)

Q3 (6 Marks)

(a)Find the unambiguous range and unambiguous velocity for each of the PRF?

Unambiguous range and Velocity   Respectively

PRF of 10 KHz: *Run*= 15 km. *Vun*= ±50ms-1

PRF of 15 KHz: *Run*= 10 km. *Vun*= ±75ms-1

PRF of 20 KHz: *Run*= 7.5 km. *Vun*= ±100ms-1 (0.5 X 2 X 3= 3 marks)

(b) Find the correct range and velocity of each of the targets A, B and C.

Background Info:

Range Ambiguity leads to mapping of *R* > *Run* as *R* mod (*Run*)

Velocity ambiguity is explained by following diagram. Frequencies in regions of the same colour get mapped fundamental band of –*fmax*/2 to +*fmax*/2. (PRF= *fmax* for complex sampling)

-Vun 0 + Vun

**Target A:** 9 km and -20ms-1: Shows different (1.5km) range reading @ 20kHz due to range ambiguity. 7.5 +1.5 9km, matches with other PRF readings

**Target B:** 4 km and 30ms-1: Parameters are within *Run* and *Vun* Shows consistent readings at all PRFs. **Target C:** 5km and -80ms-1: Out of ±*Vun*, Shows different velocity readings at PRF1 and PRF2

-50 0 + 50

PRF-1

-80

-75 0 + 75

PRF-2

-80

Give credit for any equivalent explanation (1 X 3=3 marks)

ΔF= 3075-2925= 150 MHz

fb

2H/c

T

Q4. **(a)**

 🡺 Diagram and expression (0.5 X 2= 1 mark)

It is seen that ***fb*** is proportional to the range (height)

So, minimal value of ***fb*** = 30 kHz shall correspond to 10m

With these values, we have, **T= 0.3334 ms.** Or **333.4 μs.**  (0.5 mark)

Corrspondingly, we have ***fb*** = 300 kHz for 100m. (0.5 Mark)

**Additional info:** This approach will have frequency estimation by the expression H= fb / 3000

The total observation time (Sweep time) is 1/3 ms. (can be used as part of explanation)

**(b)** The **frequency resolution will be 3 KHz.** (0.5 Mark)

Hence the **range (height) resolution will be 1m.** (0.5 Mark)

We know that

* ***fb*** is proportional to Height. Therefore,
* Filter Bandwidth is 50 KHz ± 2.5 kHz. (± 5 % bandwidth)

Frequency is proportional to height; a sweep will cover 10% range of height estimation

**(c)** Optimal selection of first will be corresponding to 10.5m (approximately).

This sweep will cover ± 5 % range. 🡺 10.5 ± 0.525m (9.975-11.025m)

The sweep time (T1) = 210 **μs**  (0.5 Marks)

* In order to efficiently cover the complete range (with minimal overlap), the subsequent sweeps will be have 10% more time duration compared to earlier sweep. (as each sweep covers ± 5 % range)
* Sweep timings form a geometric series with ratio =1.1 & first value T1 = 210 **μs.** The timings of subsequent sweeps will be will be **210, 231, 254…..**
* The last sweep timing (TN) should correspond to 91m or more. We can calculate the total number of sweeps (N) by using 🡺. This equation can be solved by taking log of both the sides🡺🡺🡺 N=24 (sweeps) (1 Mark)
* Maximum Sweep time = 210 X 1.123= 1880 **μs** (corresponding to 94 m) (0.5 marks)

If the system is planned with first sweep for 10m and last sweep for 100m, total of 26-27 sweeps are required. Such approach may be given partial credit of 1.5 marks.

1. The variable sweep system shall have
2. better sensitivity (can detect weaker echoes) due to lower detection bandwidth.

This will reduce the thermal noise🡺 Advantage (0.5 marks)

longer processing time due to multiple sweeps🡺 Disadvantage (0.5 marks)

2. Sensitivity advantage: Noise is proportional to bandwidth. Fixed sweep system has bandwidth of 270 kHz(30-300 kHz). Whereas variable sweep system has bandwidth of 5 kHz.

Advantage by a factor of 270/5= 54. 0R sensitivity increase of 17.3 dB (0.5 Mark)

1. Total time required for the sequence of sweeps.

μs = 18.587ms

This is the maximum time. One can assume average time is the geometrical mean.

1975μs. Estimation time advantage 1975/ 333.4= 5.924 or 7.72 **dB** (0.5 marks)

**OR** other approach gives 210 X 45=9.575ms (time for 55m)

2084 μs. Estimation time advantage 9575/ 333.4= 28.72or 14.5 dB

Any other assumptions (like average processing time to be arithmetic mean) with correct approach, may be given full credit.