MID Semester Examination (EE602: 2021-2)

Date 19.10.2020 **Timings: 1800-2030 (Upload limit 2045, hard-limit 2115)** Max. 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 Short Questions (2+1+3+2= **8 Marks**)

(i) A triode requires a supply of 9kV (1 amp) between cathode and anode. It also has a filament which a DC supply requires 5V (15A). In order to power this device, one has to ensure the right Voltage potentials (with respect to the ground) at the 4 terminals. Write the voltage potential values for V_{anode}, $V_{cathode}$, V_{fil+ve} and V_{fil-ve}. Justify you answers.

(ii) Consider a low flying airplane flying at an altitude (height from the ground) of 'h' meters. This target is being tracked by a radar operating at 1 GHz, at 40 km from the airplane the and located at the top of a hill. Assume that the radar altitude is also 'h' and the ground is flat. Find the minimum value of 'h' so that the signal gets no (or negligible) obstruction. (Hint: Fresnel Zone)

(iii) A pulsed radar designed to detect aircraft targets with the range resolution of 150m and up to the range of 150 km. Its receiver has a noise figure of 4dB and detects the presence of the target with simple threshold detection in to 50Ω; (this means using a detector of impedance 50Ω). The total gain of 100dB before the signal is subjected to the detector. If the Voltage threshold is adjusted to 300mV, compute the probability of false alarm.

(iv) A radar receiver requires RF gain of 33.8 dB in the front-end RF stage (before the first mixer). Two amplifier blocks A1 (G=16 dB, NF=0.5dB) and A2(G=17.8dB, NF=3dB). What is the sequence (from the antenna input of the receiver) in which they may be connected? Will it have any advantage on the maximum range? How much (in percentage increase or decrease of R_{max}).

Q2 Scanning radar (5 marks)

Ku band scanning radar operates at 15GHz. It scans a solid angle Ω =2sr (Steradian) by covering the scan volume by sequential spots of radar beam. The radar acquires the echoes from three pulses (*n*) for each beam spot. Assume that the total number of beam spots to be $\Omega/d\theta d\phi$; where, $d\theta$ and $d\phi$ being the widths of radar beam in orthogonal directions. Total scan time (time required for all beam spots) is T_{SC}=3 seconds. Effective antenna aperture= 3m^2. Assume that there is no extra radio-noise from celestial or terrestrial sources.

(a) Compute the 'average transmitted power' power $\mathbf{P_{average}}$, for following parameters: signal-to-noise ratio SNR=10dB; cable losses L=9dB and noise figure F=4 dB. Assume target cross section of 11dB m^2 and range R=150 km. (Boltzmann constant= 1.38 X 10^{-23} m^2 kg s^{-2} K^{-1}). Derive relevant expression with proper explanation/ justification. Advice: It is easier to calculate in dB. (4 Marks)

(b) Also, compute the peak transmitted power corresponding to 10% duty factor. (1Mark)

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 target 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	$-80ms^{-1}$

Explanation with suitable diagrams is encouraged

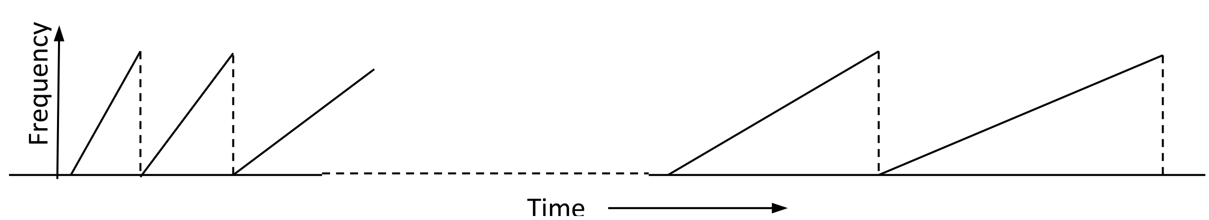
Q4. (6 marks)

FMCW radar altimeter is used to measure the height of a flying platform. 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 range. The operating frequency range is 2.925-3.075 GHz. This system measures the heights from 10m to 100m.

(a) 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. Write the expression for height estimation. What will be height resolution?
(2 marks)

The range estimation is using linear chirp signal can also be done by varying the frequency sweep rate as shown below. In this method, a narrow band receiver is used for the processing the beat frequency signal which can process narrow band beat frequency signals (say Δf_b). Due to this the echoes from a small range slice (ΔH , corresponding to Δf_b) can be processed from one sweep rate. To cover the complete range of interest, the FM signals at different chirp rates are transmitted one after another. The process stops when beat frequency in the range Δf_b is received. The sweep time is further adjusted so that the exact center frequency is obtained. Thus, the [product of sweep time and f_b (50 kHz, in this case) is indicative of the range.

$$H\left(\frac{2\Delta F}{cT}\right) = f_b \implies \Delta H\left(\frac{2\Delta F}{cT}\right) = \Delta f_b \qquad \Delta H\left(\frac{2\Delta F}{c}\right) = \Delta f_b T$$



(b) If the distance estimation is performed by adjusting sweep rate to get 50 kHz (with the filter bandwidth 50 kHz ± 2.5 kHz) What is the minimum and maximum sweep time? Approximately how many sweeps are needed to span the complete range? (2 marks)

(c) What will be the advantage of the of the beat frequency detection method by changing the sweep rate? What will be the disadvantage?
(1 mark)

(d) Give approximate quantification of these advantage and disadvantage. (The signal advantages in ratio of sensitivity/ signal power and the time advantage should be quoted in the approximate ratio of processing time. Make convenient assumptions) (1 marks)

EE 602 (2021-2) Mid-Sem: Key and evaluation guidelines

Q1 (i) Triode Voltages

The voltages shall be as follows:

V_{anode}: 0 Volts (Earth Potential) (0.5 Marks

In vaccum devices, the electrons start with high (≈ 5 X $10^7 ms^{-1}$, in this case) velocity and terminate on the anode. Due to the impact of these electrons, the anode has 'bulk metallic' structure. In other words, it is heavy to resist 'impact erosion' and for good 'heat-dissipation'. Therefore, it is kept at earth potential.

$V_{cathode}$: - 9kV (0.5 Marks)

The cathode voltage is kept at -9kV to meet the device requirement of the negative potential difference.r.t anode. (0.5 Marks)

V_{fil+ve} and V_{fil-ve}. The filament is needed to heat the cathode. Therefore, one of the (preferably -ve terminal) is in firm electrical contact (shorted) with the cathode. Therefore,

V_{fil+ve}= - 8.995 V and V_{fil-ve}= - 9kV (0.5 Marks)

(ii) Fresnel Zone:

For obstruction free transmission of the radar signals, Fresnel ellipsoid must not touch ground/ be obstruction free. Therefore, the height, $h_{radar}=h_{airplane}=h \geq R_{Fresnel}$. (0.5 Marks)

For the given parameters $R_{Fresnel}$.= 0.5X λ X $(Range)^{0.5}$ = 0.5 X 0.3 X $(40000)^{0.5}$= 30m

OR H_{min}= 30m (0.5 Marks)

(iii) Probability of false detection

The pulsed radar has a range resolution (Δr) of 150 m→ Radar Pulse width(τ) = 1 μs. (Δr=cτ/2)

The receiver bandwidth is =(1/τ) = 1 MHz. (0.5 Marks)

Noise power into the receiver (N_0)= kT_0B= 1.38 X10^{-23} X 290 X 10^6= 4 X 10^{-15} W≈ -144dBW (0.5 Marks)

The receiver with the gain of 100 dB shall amplify the noise to -44 dB. The NF=4dB shall increase the noise power to -40dBW= 10^{-4} W. (0.5 Marks)

Considering that the impedance is 50 Ω, also,

The noise power, can be expressed in terms of noise voltage variance as $N_0 = 10^{-4} = \frac{\bar{v}^2}{50} = \frac{\sigma_N^2}{50}$

(0.5 Marks)

Hence, σ_N^2 =5X 10^{-3}. And v_T^2= $(0.3)^2$= 9 X $10^{-2}V^2$, (0.5 Marks)

The probability of false alarm is given by

$$Prob(f_a) = P_{fa} = \int_{v_T}^{\infty} \frac{A}{\sigma^2} \exp\left(-\frac{A^2}{2\sigma^2}\right) dA = \exp\left(\frac{-v_T^2}{2\sigma^2}\right)$$ = exp(9X 10^{-2}/(2X 5X10^{-3})=1.23 X 10^{-4}.

(0.5 Marks)

(iv) Noise figure of cascaded blocks

The gain and noise figure values in dB are converted into ratio values as

A1 (G=0, NF= 1.122) and A2(G=40, NF≈2).: (0.5 Marks)

The values in Noise factor of cascaded blocks is given by $= F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots + \frac{F_n - 1}{G_1 G_2 .. G_{n-1}}$

The cascaded noise figure is computed in both cases

Case 1: A1 followed by A2 NF (case-1)= 1.122 + (1/40)= 1.147

Case-2 A2 Followed by A1 NF (case-2)= 2 + (0.122/60)= 2.002

We must use the sequence A1 followed by A2 (0.5 Marks)

This is because, the noise factor is lower in case 1. The advantage is by a factor 2.002/1.147= 1.7454

(0.5 Marks)

The increase sensitivity will give advantage in Rmax increase by a factor of $(1.7454)^{0.25}$=1.1494

Hence the Maximum range (R_{max}) will increase by 14.94% (0.5 Marks)

Q2 Scanning Radar

(a) 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

$\left(\frac{P_r}{Noise}\right) = SNR = \frac{P_t G_t \sigma A_e}{(4\pi)^2 R^4 k T_0 BLF} = \frac{T_{PRP} P_{av} G_t \sigma A_e}{\tau (4\pi)^2 R^4 k T_0 BLF}$ (0.5 Marks)

Also, Expression for gain $G = \frac{4\pi}{d\theta d\phi}$, The generic expression uses T_e for T_0+ T_{sky}

Since there is no extra radio noise, T_e=T_o (0.5 Marks)

Bandwidth is the reciprocal of the pulse width $B = \frac{1}{\tau}$,

and $T_{sc} = n \times T_{PRF} \times Noof beamspots(\Omega / d\theta\, d\phi)$ (0.5 Marks)

Substituting for G, B and expressing in terms of Ω, We have

$SNR = \frac{T_{PRP} P_{av} G \sigma A_e}{\tau (4\pi)^2 R^4 k T_0 BFL} = \frac{T_{sc} P_{av} \sigma A_e}{n 4\pi R^4 k T_0 F L \Omega}$ (0.5 Marks)

Re-arranging and substituting, we have (1 mark)

$$P_{av} = \frac{n 4\pi R^4 k T_e F L \Omega \times SNR}{T_{sc} \sigma_e A_e} = \frac{3 \times 4\pi \times (1.5 \times 10^5)^4 \times 1.38 \times 10^{-23} \times 290 \times 2.512 \times 8 \times 2 \times 10}{3 \times 12 \times 3}$$
$$= 284.1W$$

Alternatively, Computing with approximate dB terms,

we have the effective input Noise power 1.38 X 10^{-23}X 290X 2.5= 200 dBW

Average Power = 5+11+207-200+9+3+10-5-11-5=24 dBW=251.18 W. (1mark)

Error this magnitude (0.5 dB)is acceptable when approximate dB calculations are done.

(b) Average power P_{av}=29-5=24 dBW OR 284.1 (by direct calculation)

(Any value in this range is acceptable, as this can come with different approximations)

With 10% duty, P_t=P_{av}/(Duty)=24-(-10)=34 dBW (2511.8 W) OR 284.1/0.1 = 2841 W (1 marks)

Q3 (6 Marks)

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

Unambiguous range and Velocity $R_{un} = \frac{cT_p}{2} = \frac{c}{2f_p}$ $v_{un} = \frac{(PRF)c}{4f}$ Respectively

PRF of 10 KHz: R_{un}= 15 km. V_{un}= ±50ms^{-1}

PRF of 15 KHz: R_{un}= 10 km. V_{un}= ±75ms^{-1}

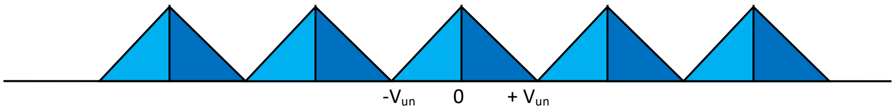
PRF of 20 KHz: R_{un}= 7.5 km. V_{un}= ±100ms^{-1} (0.5 X 2 X 3= 3 marks)

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

Background Info:

Range Ambiguity leads to mapping of $R > R_{un}$ as R mod (R_{un})

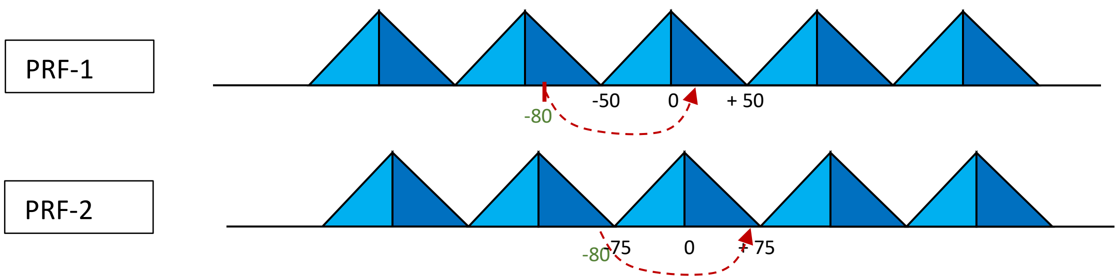
Velocity ambiguity is explained by following diagram. Frequencies in regions of the same colour get mapped fundamental band of $-f_{max}/2$ to $+f_{max}/2$. (PRF= f_{max} for complex sampling)



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

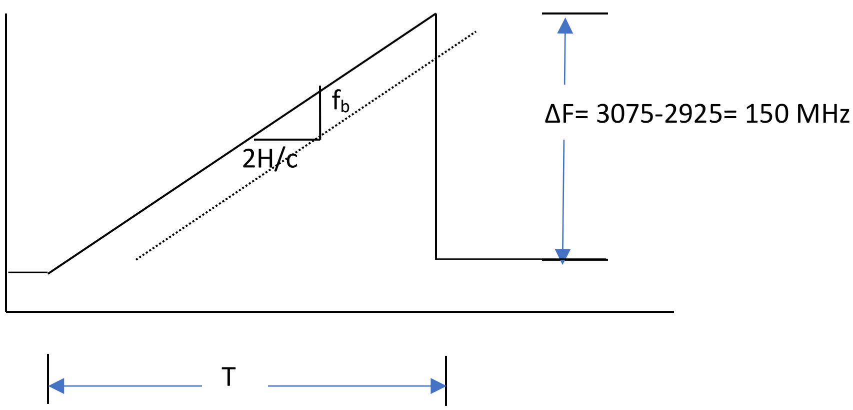
Target B: 4 km and 30ms⁻¹: Parameters are within R_{un} and V_{un} Shows consistent readings at all PRFs.

Target C: 5km and -80ms⁻¹: Out of $\pm V_{un}$, Shows different velocity readings at PRF1 and PRF2



Only one diagram is OK. Give credit for any equivalent explanation (1 X 3=3 marks)

4.(a)For altimeter, the target is the ground on ehich.



(0.5 Marks)

$$H\left(\frac{2\Delta F}{cT}\right) = H\left(\frac{2\times1.5\times10^8}{3\times10^8\times T}\right) = f_b$$ (0.5 Marks)

The values of the parameters in the bracket are known, f_b is measured and the height is computed

For 10 m, f_b will be minimum= 30 kHz. For that condition, **T= 0.3334 ms. Or 333.4 µs.** (0.5 Marks)

For 100m the f_b will be 300 kHz.

Hence the signal processing will estimate height by the expression. **H= f_b / 3000**

As the signal is observed for ≈1/3 ms, **frequency resolution will be 3 KHz.**

Corresponding height **resolution will be 1m** (0.5 Marks)

(b) **Varying sweep to get pre-determined f_b** :-In order to get a fixed f_b of 50 kHz,

The sweep time corresponding to 10 m will be **200 µs** (Minimum) (0.5 Marks)

And that corresponding to 100m will be **2 ms** (Maximum). (0.5 Marks)

In order to cover entire range, the radar must transmit different frequency sweeps one after another.

Considering the bandwidth IF filter (for the measurement of f_b) is ±5 %, it will support $H_{50kHz;T}$ ± 5%. $H_{50kHz,T}$ is the height that has f_b =50kHz for sweep time T. Therefore, a specific frequency sweep would cover height slice of ±5 % (Total of 10 %). Hence, the sweep times of the consecutive sweeps must have the ratio of ≈10.5%. The frequency sweep time values will form a geometric series of ratio 1.105.

(0.5 Marks)

The ratio H_{max} / H_{min} is 10. Number of sweeps can be calculated by

$(1.1)^y$= 10 ➔ **y=24 Hence 24 sweeps will be required** (0.5 Marks)

The total time is calculated by the sum of geometric series formula.

Not asked in the question.

Approximate time for all the sweeps, the total time = 2 {(1-0.1)/(1-0.9)}= **18 ms**

But depending on the height, different number of sweeps are used.

Additionally, for the adjustment time will be for one-two sweeps.

c) Advantage less bandwidth less noise (0.5 Marks)

Disadvantage more processing time (0.5 Marks)

d) Advantage: Quantitative Method of Changing sweep time requires only 5 KHs of bandwidth.

Whereas the classical scheme requires 270 KHz. Bandwidth.

Hence noise power advantage by a factor of 54.

The sensitivity advantage is also by a factor of 54! (0.5 Marks)

We assume that the seep-time variation is done with initial sweep of duration of 200µs.

For maximum range, the system must reach till the last sweep. The total time required for the series of the sweeps is given by the expression for the summation of 'N terms' of a geometric series.

$T_{total} = T_{init} \times \left(\frac{r^N-1}{r-1}\right)$=2× 10^{-4} $\left(\frac{10.9823-1}{1.105-1}\right)$ =19.01 ms

This is maximum time.

So the time advantage for max height is ratio 19.01/ 0.334≈ 56 times

(in favor of single sweep FMCW system) (0.5 Marks)

Some may argue, that statistically the time will be much reduced.

Such arguments are not expected.

But mentioning this point show good insight.

Any reasonably convincing calculation in that direction may earn '1 bonus mark'.