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Internal Assessment Test 1 – May 2022 (QP-3)(Scheme & Solutions)

Sub:	RADAR ENGINEERING					Sub Code:	17EC833/ 15EC833	Branch:	ECE
Date:	14-05-2022 (Sunday)	Duration:	90 mins (11am-12.30pm)	Max Marks:	50	Sem/Sec:	VIII - E		OBE

Answer any **FIVE FULL** Questions.

		MARKS	CO	RBT
1	Derive an expression for simple form of the RADAR range equation in three different forms starting from the power density of isotropic antenna.	[10]	CO 1	L2

Solution.

- The radar equation relates the range of a radar to the characteristics of the –
  - Transmitter
  - Receiver
  - Antenna
  - Target
  - Environment
- It is useful for -
  - ✓ Determining the maximum range at which a particular radar can detect a target.
  - ✓ Understanding the factors affecting radar performance.
  - ✓ Radar system design as an important tool.

- If the transmitter power P_t is radiated by an isotropic antenna (one that radiates uniformly in all directions), the *power density* at a distance R from the radar is given by,

$$\text{Power density at range } R \text{ from an isotropic antenna} = \frac{P_t}{4\pi R^2} \qquad [1.3]$$

- Power density is measured in units of watts per square meter.
- Radars, however, employ *directive* antennas (with narrow beamwidths) to concentrate the radiated power P_t in a particular direction.
- The *gain* of an antenna is a measure of the increased power density radiated in some direction as compared to the power density that would appear in that direction from an isotropic antenna.

The maximum gain G of an antenna may be defined as

$$G = \frac{\text{maximum power density radiated by a directive antenna}}{\text{power density radiated by a lossless isotropic antenna with the same power input}}$$

- The power density at the target from a directive antenna with a transmitting gain G is then

$$\text{Power density at range } R \text{ from a directive antenna} = \frac{P_t G}{4\pi R^2} \quad [1.4]$$

- The target intercepts a portion of the incident energy & reradiates it in various directions.
- It is only the power density reradiated in the direction of the radar (the echo signal) that is of interest.
- The *radar cross section of the target* determines the power density returned to the radar for a particular power density incident on the target.
- It is denoted by σ and is often called, for short, *target cross section*, *radar cross section*, or simply *cross section*.

The radar cross section is defined by the following equation :

$$\text{Reradiated power density back at the radar} = \frac{P_t G}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \quad [1.5]$$

- The radar cross section has units of area, but it can be misleading to associate the radar cross section directly with the target's physical size.
- Radar cross section is more dependent on the target's shape than on its physical size.

The radar antenna captures a portion of the echo energy incident on it.
The power received by the radar is given as the product of the incident power density times the effective area Ae of the receiving antenna.
The effective area is related to the physical area A by the relationship Ae=ρaA, where ρa= antenna aperture efficiency.

- The received signal power P_r (watts) is then

$$P_r = \frac{P_t G}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \cdot A_e = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4} \quad [1.6]$$

- The maximum range of a radar R_{max} is the distance beyond which the target cannot be detected.
- It occurs when the received signal power P_r just equals the minimum detectable signal S_{min}.
- Substituting $S_{min}=P_r$ in Eq.(1.6) and rearranging the terms gives

$$R_{\max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{\min}}\right]^{1/4} \quad [1.7]$$

- This is the fundamental form of the *radar range equation*. It is also called for simplicity, the *radar equation* or *range equation*.
- The important antenna parameters are the transmitting gain & the receiving effective area.
- The transmitter power Pt has not been specified as either the average or the peak power.

- It depends on how Smin is defined. Here, Pt denotes the peak power.
- If the same antenna is used for both transmitting & receiving, as it usually is in radar, from antenna theory, we have

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi\rho_a A}{\lambda^2}$$

where λ = wavelength. (Wavelength $\lambda = c/f$, where c = velocity of propagation and f = frequency.) Equation (1.8) can be substituted in Eq. (1.7), first for A_e and then for G, to give two other forms of the radar equation

$$R_{max} = \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}}\right]^{1/4} \quad [1.9]$$

$$R_{max} = \left[\frac{P_t A_e^2 \sigma}{4\pi\lambda^2 S_{min}}\right] \quad [1.10]$$

- These three forms of the radar equation given by Eqs. (1.7), (1.9), and (1.10) are basically the same, but with different interpretations.
- These simplified versions of the radar equation do not adequately describe the performance of actual radars.
- Many important factors are not explicitly included.
- Hence, it predicts too high a value of range, sometimes by a factor of two or more.

2	With a neat block diagram, explain the conventional pulse radar with a superheterodyne receiver. Solution.	[10]	CO1	L2

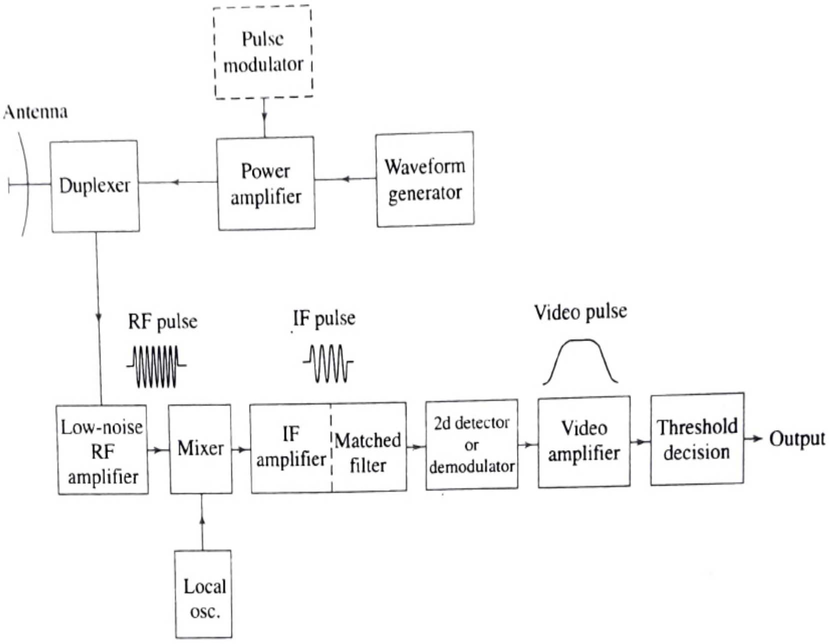

Figure 1.4 Block diagram of a conventional pulse radar with a superheterodyne receiver.

- The operation of a pulse radar may be described with the aid of the sim block diagram of Fig.1.4.
- The transmitter may be a *power amplifier*, such as the klystron, travel wave tube, or transistor amplifier.
- It might also be a power oscillator, such as the magnetron (used for pu radars of modest capability).
- But, the amplifier is preferred when
  - ✓ High average power is necessary.
  - ✓ Other than simple pulse waveforms are required.
  - ✓ Good performance is needed in detecting moving targets amidst m larger clutter echoes using doppler frequency shift.

A power amplifier is indicated in Fig.1.4.
The radar signal is produced at low power by a waveform generator.
This is then the input to the power amplifier.
In most power amplifiers, except for solid state power sources, a modulator tu the transmitter on and off.
This is in synchronism with the input pulses.
When a power oscillator is used, it is also turned on & off by a pulse modula to generate a pulse waveform.

- The output of the transmitter is delivered to the *antenna* by a wavegu or other form of transmission line, from where it is radiated into space.
- Antennas can be –
  - ✓ Mechanically steered parabolic reflectors.
  - ✓ Mechanically steered planar arrays.
  - ✓ Electronically steered phased arrays.

The duplexer allows a single antenna to be used on a time-shared basis for b transmitting and receiving.
The duplexer is generally a gaseous device.
It produces a short circuit (an arc discharge) at the input to the receiver when

transmitter is operating.
This is so that high power flows to the antenna & not to the receiver.
On reception, the duplexer directs the echo signal to the receiver & not to transmitter.

- The receiver is almost always a *superheterodyne*.
- The input, or RF, stage can be a low-noise transistor amplifier.
- The mixer & local oscillator (LO) convert the RF signal to intermediate frequency (IF), where it is amplified by the IF amplifier.
- The signal bandwidth of a superheterodyne receiver is determined by bandwidth of its IF stage.

The IF frequency, for example, might be 30 or 60 MHz when the pulse widt of the order of 1 μs.
With a 1 μs pulse width, the IF bandwidth would be about 1 MHz.
The IF amplifier is designed as a matched filter ; that is, one which maximi the output peak-signal-to-mean-noise ratio.
Thus, the matched filter maximizes the detectability of weak echo signals attenuates unwanted signals.
With the approx. rectangular pulse shapes commonly used in many rad conventional radar receiver filters are close to that of a matched filter.
The above assumption is true when the receiver bandwidth B is the inverse of pulse width τ, or $B\tau = 1$.

- Sometimes, the low-noise input stage is omitted & the mixer becomes 1st stage of the receiver.
- A receiver with a mixer as the input stage will be less sensitive becaus the mixer's higher noise figure.
- But, compared to a receiver with low-noise 1st stage, it will have –
  - Greater dynamic range.
  - Less susceptibility to overload.
  - Less vulnerability to electronic interference.
- These attributes of a mixer input stage might be of interest for milit radars subject to the noisy environment of hostile electronic cou measures (ECM).

The IF amplifier is followed by a crystal diode, which is traditionally called second detector, or demodulator.
Its purpose is to assist in extracting the signal modulation from the carrier.
The combination of IF amplifier, second detector, & video amplifier acts as envelope detector.
This is because it passes the pulse modulation (envelope) & rejects the car frequency.
In radars that detect the doppler shift of the echo signal, the envelope detecto replaced by a phase detector.

- The combination of IF amplifier & video amplifier is designed to prov sufficient amplification, or gain.
- This gain is used to raise the level of the input signal to a magnit where it can be seen on a display.
- The display can be a cathode-ray tube (CRT), or be the input to a dig computer for further processing.

At the output of the receiver, a decision is made whether or not a targe present.

The decision is based on the magnitude of the receiver output.
If the output is large enough to exceed a predetermined threshold, the decisio that a target is present.
If it does not cross the threshold, only noise is assumed to be present.
The threshold level is set so that the rate at which false alarms occur due to nc crossing the threshold (in the absence of signal), is below some specifi tolerable value.
An integrator is often found in the video portion & a signal processor (Matched Filter) is found in the receiver before detection decision is made.

- A typical radar display for a surveillance radar is the PPI, or *plan posit indicator*.
- The PPI is a presentation that maps in polar coordinates the location of target in azimuth & range.
- A B-scope display is similar to a PPI except that it utilizes a rectangu format, rather than the polar format, to display range versus angle.
- Both the PPI & B-scope are intensity modulated & hence have limi dynamic range.
- An A-scope is sometimes used for tracking radar or continuous star applications.
- It is an amplitude-modulated rectangular display with the receiver out on the y-axis & the range (or time delay) on the x-axis.

3 a) Write a brief note on maximum unambiguous range. [10 = 3+2+5] CO1 L2

Solution.

- Once a signal is radiated into space by a radar, sufficient time must elapse to allow all echo signals to return to the radar before the next pulse is transmitted.
- The rate at which pulses may be transmitted, therefore, is determined by the longest range at which targets are expected.
- If the time between pulses T_P is too short, an echo signal from a long-range target might arrive *after* the transmission of the next pulse.
- In such a situation, it will be mistakenly associated with the next pulse rather than the actual pulse transmitted earlier.
- This can result in an incorrect or ambiguous measurement of the range.

Echoes that arrive after the transmission of the next pulse are called second-time-around echoes (or multiple-time-around echoes if from even earlier pulses).
Such an echo would appear to be at a closer range than actual & its range measurement could be misleading.
This is because it is not known that it is a second-time-around echo.
The range beyond which targets appear as second-time-around echoes is the maximum unambiguous range, Run.

- The maximum unambiguous range is given by,
$R_{un} = (cT_p)/2 = c/(2f_P)$ --- [1.2]
where T_P = pulse repetition period = $1/f_P$, and f_P= pulse repetition frequency (prf), usually given in hertz or pulses per second (pps).

b) What is meant by Minimum detectable signal power of receiver?
Solution.

- The maximum range of a radar R_{max} is the distance beyond which the target cannot be detected.
- It occurs when the received signal power P_r just equals the minimum detectable signal S_{min}.

c) A ground based RADAR operates at 4cm. The RADAR transmitter using an antenna of gain 60dB produces 150kW. The receiver minimum detectable signal is Smin =10^{-13}W. The maximum RADAR range is given as 260km. Find the cross section of the target the radar can detect.
Solution .
Cross Section = [Smin * (4*pi)^3 * (Rmax)^4]/[Pt * (G)^2 * (lambda)^2].

Here, Smin=10^-13, Rmax= 260kms= 260*10^3 m, Pt= 150kW = 150 * 10^3 W, G(dB)= 60 hence G= 10^6, lambda = 4cm= 4*10^-2 m.

Hence, Cross Section of the target = 0.0037784 sq.m

4	Write a note on - a) Origins of RADAR , b) Applications of RADAR.	[10 = 5+5]	CO1	L1
5	a) Explain the basic principle of Radar with a neat diagram. Solution.	[10 =05+05]	CO1	L2

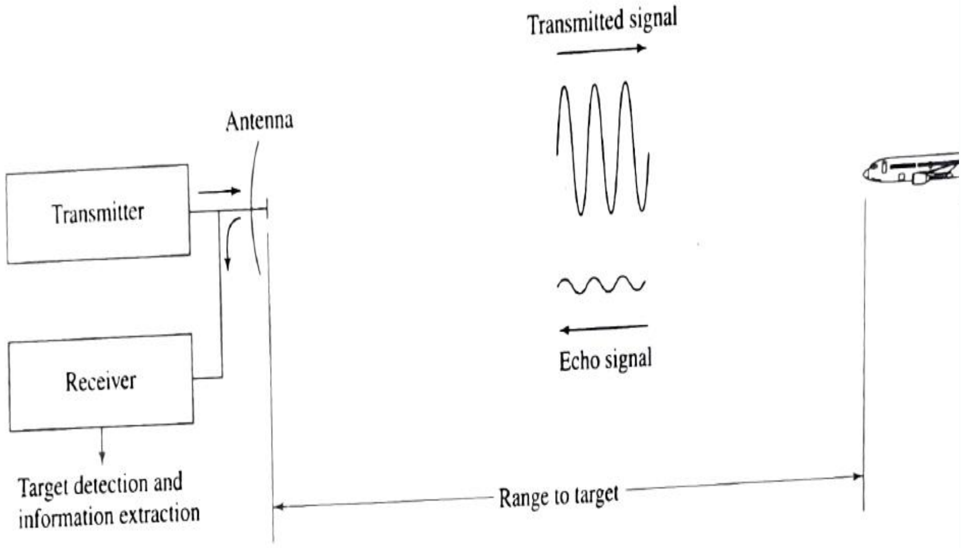

Figure 1.1 Basic principle of radar.

- RADAR is a contraction of the words "**Radio Detection and Ranging**"
- Radar is an electromagnetic system.
- It is used for the detection & location of reflecting objects such as –
- ✓ Aircrafts
- ✓ Ships
- ✓ Spacecraft
- ✓ Vehicles
- ✓ People
- ✓ Natural Environment

Radar operates by radiating energy into space & detecting the echo reflected from an object, or target.

The reflected energy that is returned to the radar –

Indicates the presence of a target.

Determines location along with other target-related informatic comparing the received echo signal with the transmitted signal).

- Radar can perform its function at long or short distances & under con impervious to optical & infrared sensors.
- It can operate in –
- ➢ Darkness
- ➢ Haze
- ➢ Fog
- ➢ Rain

Snow

- Radar's important attributes are –
- ➢ It has ability to measure distance with high accuracy.
- ➢ It has ability to operate in all weather conditions.
- The basic principle of radar is illustrated in Fig.1.1.

- A transmitter (in the upper left portion of the figure), genera electromagnetic signal (such as a short pulse of sinewave).
- This signal is radiated into space by an antenna.
- A portion of the transmitted energy is intercepted by the target.
- This intercepted energy is reradiated by the target in many directions.
- The reradiation directed back towards the radar is collected by th antenna.
- The radar antenna now delivers it to a receiver.

  In the receiver, it is processed to detect the presence of the target & det its location.

  A single antenna is usually used on a time-shared basis.

  This is useful for both transmitting & receiving when the radar wavefo repetitive series of pulses.

  The range, or distance, to a target is found by measuring the time it ta the radar signal to travel to the target & return back to the radar.

  The target's location, in angle, can be found from the direction in wh narrow-beamwidth radar antenna points, when the received echo sign maximum amplitude.
- If the target is in motion, there is a shift in the frequency of the echo due to the **doppler effect**.
- This frequency shift is proportional to the velocity of the target relative radar (also called the **radial velocity**).
- This frequency shift is called the **doppler frequency shift**.
- The doppler frequency shift is widely used in radar.
- It is the basis for separating desired moving targets from fixed (unv "clutter" echoes reflected from the natural environment such as –
  - Land
  - Sea
  - Rain
- Radar can also provide information about the nature of the target observed.

  The term radar is a contraction of the words radio detection and ranging

  The name reflects the importance placed by the early workers in this f the need for a device to –

  Detect the presence of a target.

  To measure the range of the target from it.

  Modern radars can extract more information from a target's echo sign its range.

  Still, the measurement of range is one of its most important functions.

  There are no competitive techniques other than radar that can acc measure long ranges in both clear & adverse weather.

b) Calculate the maximum range of a radar system which operates at 4cm with a peak pulse power of 600kW if its minimum receivable power is 10^{-13} W, the capture area of its antenna is 6 m^2 and the radarcross sectional area of the target is $30m^2$.

Solution.

Rmax= [{Pt * Ae^2 * (radar cross section)}/{4*PI* (lambda)^2 *

Smin}]^(1/4)

Here, Pt=600 kW = 600*10^3 W, Ae=6 sq.m, radar cross section= 30 Sq.m, lambda= 4cm= 4*10^-2 m, Smin = 10^-13.

Hence , Rmax= 753.46 kms.

6 a) Compute the following related to radar: [10 = 3+7] CO1 L3

i) What should be the p.r.f of radar in order to achieve R_{un} of 60nmi?

ii) How long does it take for the radar to travel out and back when the target is at the maximum unambiguous range?

iii) If radar has a peak power of 800kW, what is its average power? Choose pulse width 1.5 µs.

Solution.

Q6) Compute the following related to radar:

(i) What should be the pulse repetition frequency of a radar in order to achieve maximum unambiguous range of 60 nmi?

(ii) How long does it take for the radar signal to travel out and back when the target is at the maximum unambiguous range?

(iii) If radar has a peak power of 800kW, what is its average power? Choose pulse width 1.5µs.

[03 Marks, June/July 2019 VTU Exams]

Soln → (i) $R(nmi) = 0.081\, T_R(\mu s) \Rightarrow T_R(\mu s) = \frac{R(nmi)}{0.081}$

$\Rightarrow f_R(MHz) = \frac{0.081}{R(nmi)} = \frac{0.081}{60} = \frac{1}{T_R} = 1.35\times10^{-3}$

$f_R = 1.35\times10^{-3}\times10^{6}\,Hz = 1350\,Hz$.

(ii) At max. unambiguous range, $T_R = T_P\ (\mu s)$

$= \frac{R(nmi)}{0.081} = \frac{60}{0.081} = 740.740\,\mu s$

$T_P = 0.74\,ms$.

(iii) $P_t = 800\,kW = 800\times10^{3}\,W$; pulse width $= \tau = 1.5\,\mu s$

$\Rightarrow \tau = 1.5\times10^{-6}\,s$; $P_{av} = \frac{P_t \tau}{T_P} = \frac{800\times10^{3}\times1.5\times10^{-6}}{740.740\times10^{-6}}$

$\Rightarrow P_{av} = 1620\,W = 1.62\,kW$

b) A ground based air-surveillance radar operates at a frequency of 1300 MHz (L Band). Its maximum range is 200 nmi for the detection of a target with a radar cross section of one square meter($\sigma = 1m^2$). Its antenna is 12m wide by 4m high and the antenna aperture efficiency is $\rho_a = 0.65$. The receiver minimum detectable signal is $S_{min} = 10^{-13}$ W. Determine the following:

i) Antenna effective aperture A_e (sq. mts) and Antenna gain G in dB.

ii) Peak transmitter power.

iii) P.r.f to achieve Run of 200nmi.

iv) P_{av}, if pulse width is 2µs.

v) Duty cycle.

vi) Horizontal Beam width (in degrees).

Solution.

Q7 A ground based air-surveillance radar operates at frequency of 1300 MHz (L band). Its maximum range is 200 nmi for the detection of a target with a radar cross section of one square meter ($\sigma = 1 m^2$). Its antenna is 12 m wide by 4 m high, and the antenna aperture efficiency is $\rho_a = 0.65$. The receiver minimum detectable signal is $S_{min} = 10^{-13} W$. Determine the following:

(i) Antenna effective aperture A_e (square meters) and antenna gain G in numerically and decibel.

(ii) Peak transmitter power.

(iii) Pulse repetition frequencies to achieve a maximum unambiguous range of 2 nmi.

(iv) Average transmitter power, if the pulse width is 2 μs.

(v) Duty cycle.

(vi) Horizontal beam width (in degrees).

[08 Marks, June/July 2019 VTU Exams]

Soln → $f = 1300 \times 10^6 Hz$; $R_{max} = 200 nmi$;

$\sigma = 1 m^2$, Antenna Physical Area $A_P = \frac{2}{3} \times b \times h$

$\Rightarrow A_P = \frac{2}{3} \times 12m \times 4m = 32 m^2$; $\rho_a = 0.65$;

$S_{min} = 10^{-13} W$

R_{max} in kms $\Rightarrow$ 0.081 nmi = 0.15 km

∴ 200 nmi = ? $\Rightarrow R_{max} = \frac{200 \times 0.15}{0.081} = 370.370 kms$

(i) $A_e = \rho_a \times A_p = 0.65 \times 32 m^2 = 20.8 m^2$.

Also, $\frac{G}{4\pi} = \frac{A_e}{\lambda^2} \Rightarrow G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \times 20.8}{(0.23)^2}$

$\Rightarrow G = 4941$. Hence $G(dB) = 10 \log_{10}(G) = 36.938 dB \simeq 37 dB$.

(ii) $S_{min} = \frac{P_t G \sigma A_e}{(4\pi R_{max}^2)^2} \Rightarrow P_t = \frac{S_{min}(4\pi R_{max}^2)^2}{G \sigma A_e}$

$\Rightarrow P_t = \frac{10^{-13} \times [4\pi \times (370.37 \times 10^3)^2]^2}{4941 \times 1 \times 20.8}$

$\Rightarrow P_t = 7806.3666 W \simeq 7.8 kW$

(iii) $R(nmi) = 0.081 T_R(\mu s) \Rightarrow 200 = 0.081 T_R(\mu s)$

$\Rightarrow T_R(\mu s) = \frac{200}{0.081} \Rightarrow f_P(MHz) = \frac{1}{T_R(\mu s)} = \frac{0.081}{200}$

$f_P(MHz) = 4.05 \times 10^{-4} MHz = 4.05 \times 10^{-4} \times 10^6 Hz$

$f_P = 405 Hz$

(iv) $\tau = 2 \mu s = 2 \times 10^{-6} s$; $P_{av} = \frac{P_t \tau}{T_P} = P_t \tau f_P$

$\Rightarrow P_{av} = 7806 \times 2 \times 10^{-6} \times 405 \simeq 6.323 W$

(v) Duty cycle $= \frac{\tau}{T_P} = \tau f_P = 2 \times 10^{-6} \times 405$

$= 810 \times 10^{-6} = 0.81 \times 10^{-3}$

$= 0.081\%$

(vi) Beamwidth $= \frac{65 \lambda}{D}$ for parabolic Antenna $\Rightarrow \frac{65 \times 0.23}{12}$

$\Rightarrow$ Beamwidth (Horizontal) $= 1.245833^\circ \simeq 1.246^\circ$

7	a) Tabulate the IEEE standard radar frequency range and their letter band nomenclature. Solution.	[10 = 06+04]	CO1	L2

Table 1.1 IEEE standard radar-frequency letter-band nomenclature*

Band Designation	Nominal Frequency Range	Specific Frequency Ranges for Radar based on ITU Assignments in Region 2
HF	3–30 MHz	
VHF	30–300 MHz	138–144 MHz 216–225 MHz
UHF	300–1000 MHz	420–450 MHz 850–942 MHz
L	1–2 GHz	1215–1400 MHz
S	2–4 GHz	2300–2500 MHz 2700–3700 MHz
C	4–8 GHz	5250–5925 MHz
X	8–12 GHz	8500–10,680 MHz
K_u	12–18 GHz	13.4–14.0 GHz 15.7–17.7 GHz
K	18–27 GHz	24.05–24.25 GHz
K_a	27–40 GHz	33.4–36 GHz
V	40–75 GHz	59–64 GHz
W	75–110 GHz	76–81 GHz 92–100 GHz
mm	110–300 GHz	126–142 GHz 144–149 GHz 231–235 GHz 238–248 GHz

*From "IEEE Standard Letter Designations for Radar-Frequency Bands," IEEE Std 521-1984.

b)

radar can detect ...

4) A 10GHz radar has the following char: P_t = 25[illegible] pr̄f = 1500 pps, pulse width = 0.8μs, power gain of ante[nna] = 2500, $S_{min} = 10^{-14}$ W, $A_e = 10m^2$, $\sigma = 2m^2$.
Find (i) R_{unamb} (ii) Max possible range. (iii) Duty cyc[le] (iv) Av. power.

Soln: (i) $R_{unamb} = \frac{c}{2f_p}$

Given: $f_p = 1500$ pps.
$\tau = 0.8\,\mu s$

$= \frac{3\times10^8}{3000} = 100\,km$

(ii) $R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 \cdot S_{min}}\right]^{1/4} = \left[\frac{1.25\times10^{10}}{1.58\times10^{-12}}\right]^{1/4} = \underline{298\,km}$

(iii) Duty cycle $= \frac{\tau}{T_p} = \tau f_p = \underline{0.12\%}$

(iv) Avg. Power $\Rightarrow P_{av} = \frac{\tau}{T_p} \cdot P_t = \tau f_p P_t = \underline{300\,W}$.

ALL THE BEST