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JABATAN PENDIDIKAN POLITEKNIK DAN KOLEJ KOMUNITI

DEP50072
RADAR FUNDAMENTAL

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Appreciation

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Abstract

The range of applications for radars is huge in every field in these modern days. From military to meteorology and to self-driving car radar has play important part in our live. This e-book is written to provide fundamental knowledge of radar systems specifically for Diploma Kejuruteraan Elektronik Perhubungan (DEP) for the subject DEP50072. It is written in easy-to-understand manners with 9 subtopics arrange systematically to enable reader to get a thorough knowledge of the radar system. Through the e-books the readers are provided with figures and examples to help understanding of the topics. Readers also provided with tutorial questions to test their knowledge and solution for calculation are provided at the end of the e-book.

TABLE OF CONTENT

1.0 PRINCIPLES OF RADAR SYSTEM

What is RADAR?

RADAR is basically an acronym for, Radio Detection and Ranging. RADAR is an object detection system that uses electromagnetic waves to identify the range, altitude, direction or speed of both moving and fixed objects such as aircrafts, ships, motor vehicles, weather formations and terrain.

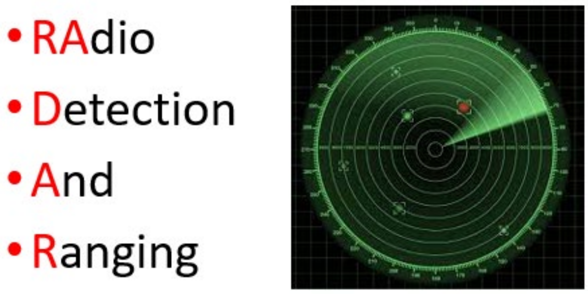


Figure 1: RADAR Acronym

1.1 Basic Principles of Radar System

The principle of radar starts when a radio-frequency (RF) energy is transmitted from radar antenna to where the direction of the targeted object. When the object cross the RF beam a small portion of the RF energy reflected from the object back towards the radar antenna. This returned energy is called an ECHO. Radar sets use the echo to determine the direction and distance of the reflecting object.

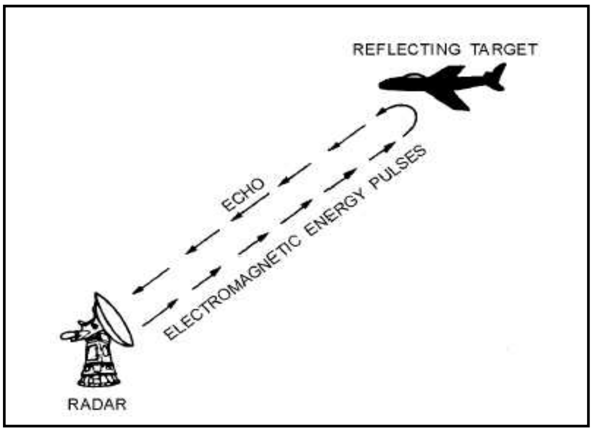


Figure 2: Basic Principles of Radar System

1.2 Application of Radar System

Radar has been employed to detect targets on the ground in the sea, in the air in space, and even below ground. The major area of applications of radar are military application, weather formation, air traffic control and also law enforcement.

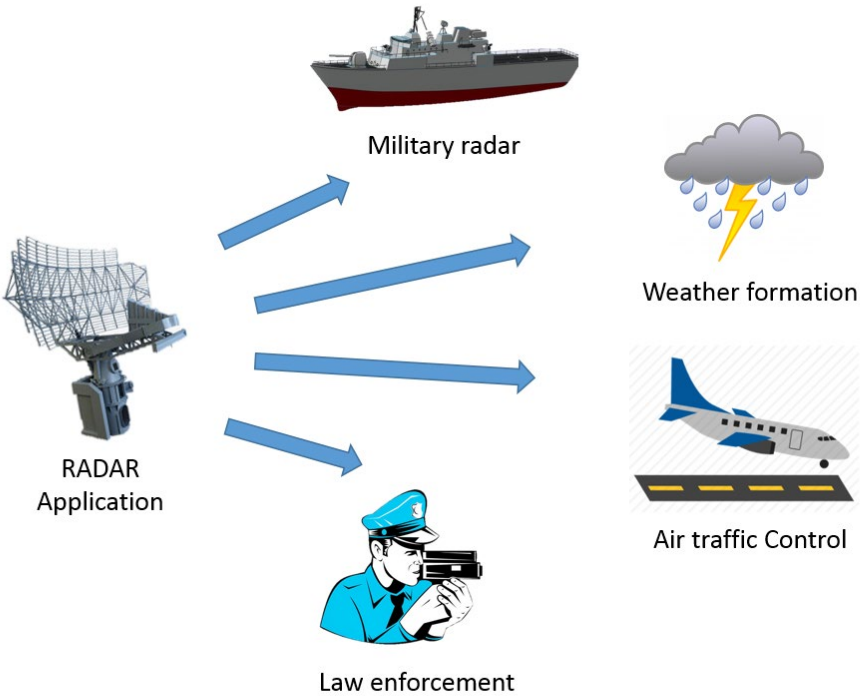


Figure 3: Application of Radar System

1.3 Types of Radar

1. <u>Primary Radar</u>

A Primary radar is a conventional radar sensor that illuminates a large portion of space with an electromagnetic wave and receives back the reflected waves from targets within that space.

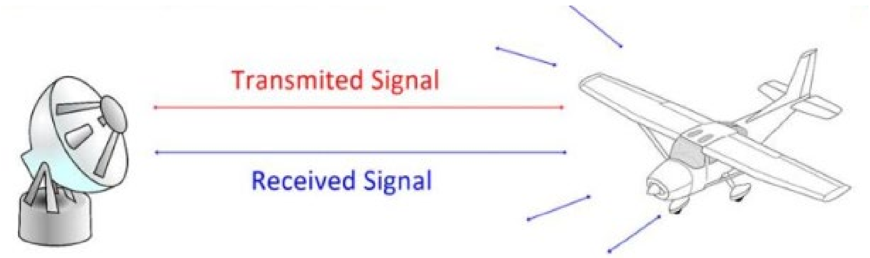


Figure 4: Primary Radar

2. <u>Secondary Radar</u>

Secondary surveillance radar (SSR) is a radar system used in air traffic control (ATC), that not only detects and measures the position of aircraft, but also requests additional information from the aircraft itself such as its identity (aircraft number) and altitude.

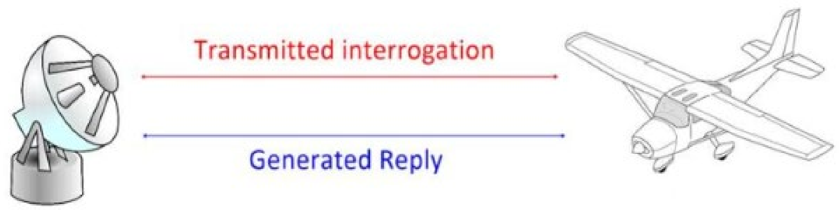


Figure 5: Secondary Radar

1.4 Types of Radar Signal

1. Pulse Radar

A Pulse Radar is a radar device that emits short and powerful pulses and in the silent period receives the echo signals. Pulse radar transmit the high frequency waves in bursts or “pulses”, and measure the time interval between transmitting the pulse and receiving the echo.

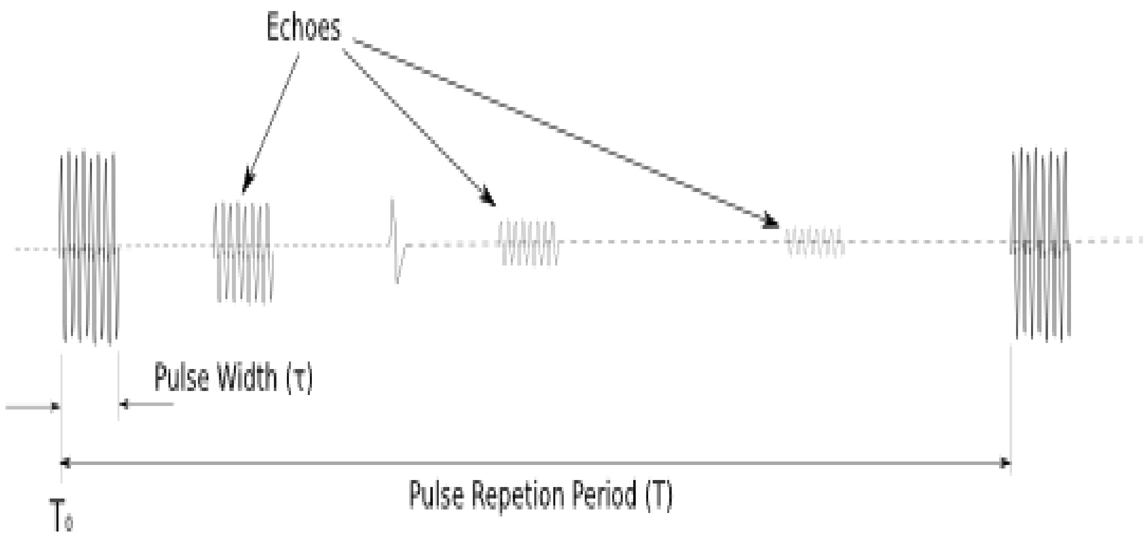


Figure 6: Pulse Radar Signal

2. Continuous Wave Radar

Continuous Wave radar sets transmit a high-frequency signal continuously. When the object crosses the emitted wave a small portion energy or echo reflected back to radar set.

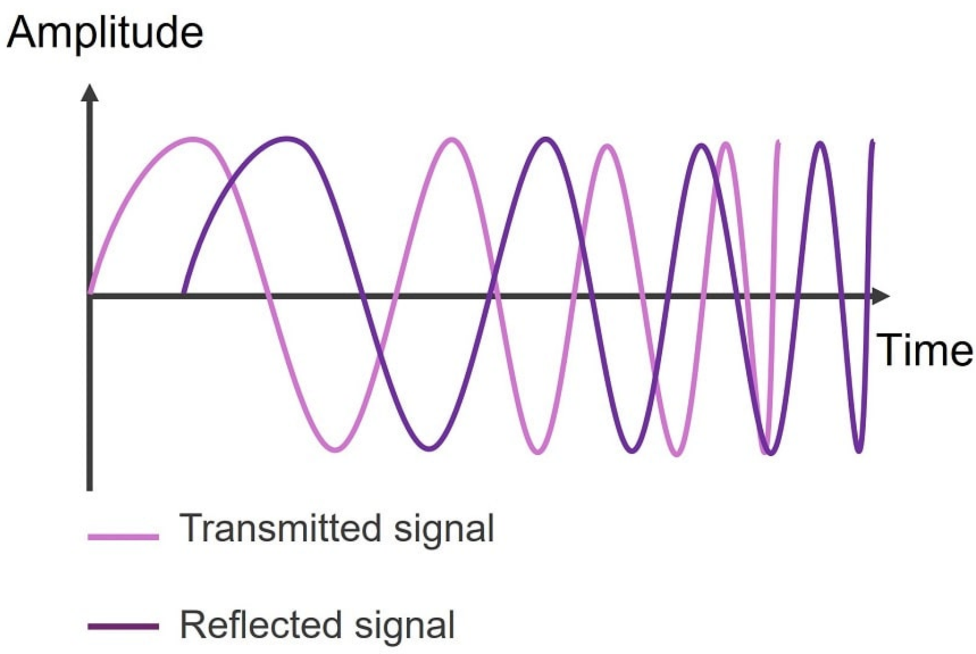


Figure 7: Continuous Wave Radar Signal

1.5 Line of Sight (LOS) Range Limitation Radar

Line-of-sight propagation is a characteristic of electromagnetic radiation or acoustic wave propagation which means waves travel in a direct path from the source to the receiver.

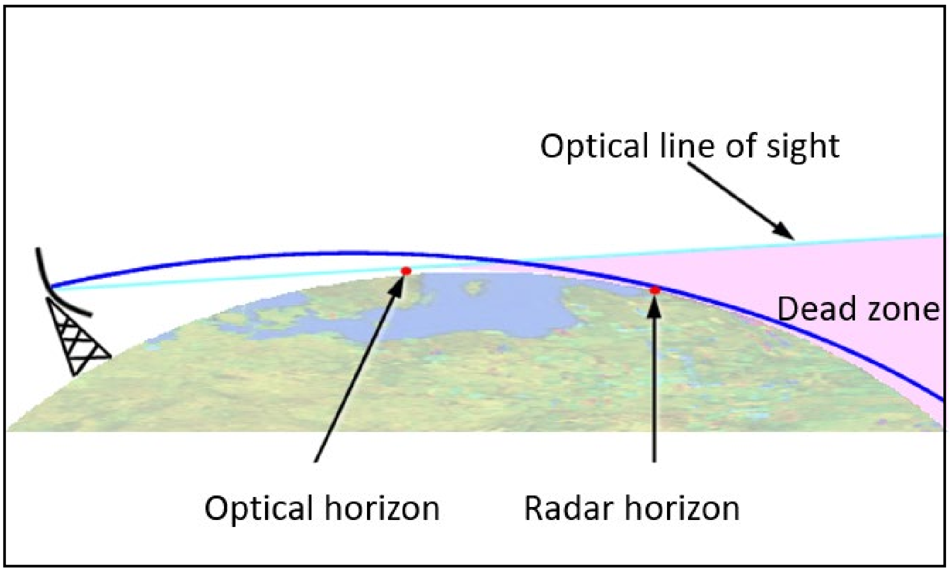


Figure 8: Radar Limitation

The earth's curvature may prevent the radar seeing a target within the maximum range. Therefore, results a dead zone for every radar system in which one targets can't be detected.

Tutorial 1

1. Define RADAR.
2. Describe basic principles of radar system.
3. List 3 applications of radar system.
4. Explain primary and secondary radar.
5. Recognize 2 types of radar signals.
6. Describe Line of Sight (LOS) range limitation radar.

2.0 TYPES OF RADAR

2.1 Block Diagram of Typical Radar System

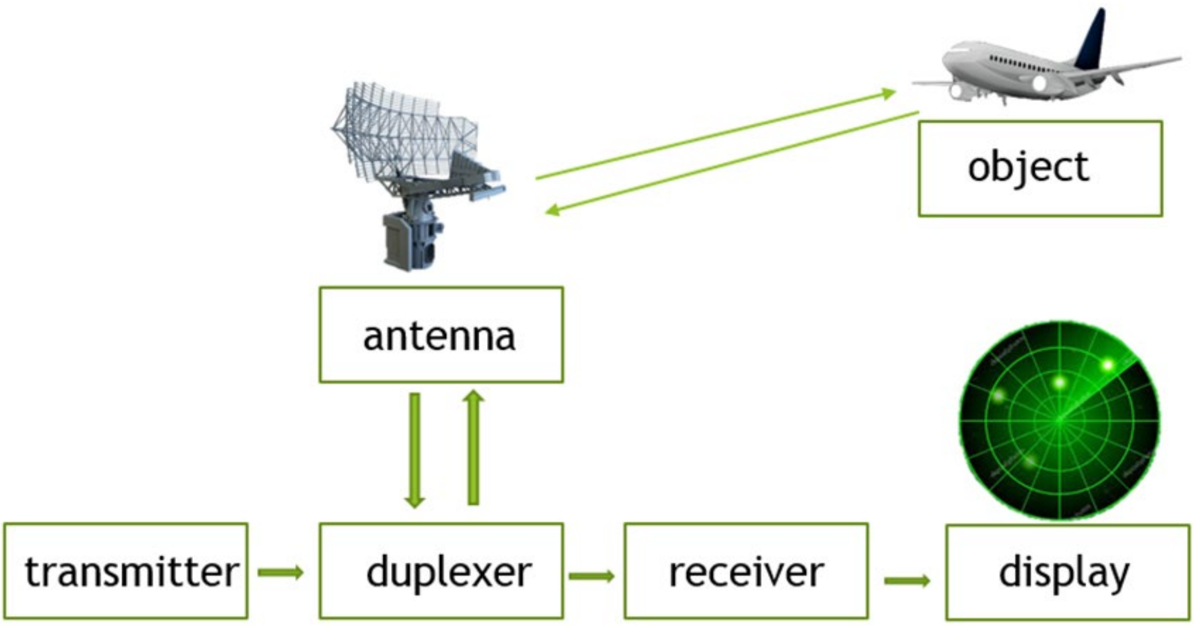


Figure 9: Block Diagram of Typical Radar System

- Transmitter

  The radar transmitter produces the short duration high-power RF pulses of energy that are into space by the antenna.

- Duplexer

  The duplexer alternately switches the antenna between the transmitter and receiver so that only one antenna need be used. This switching is necessary because the high-power pulses of the transmitter would destroy the receiver if energy were allowed to enter the receiver.

- Receiver

  The receivers amplify and demodulate the received RF-signals. The receiver provides video signals on the output.

- Radar Antenna

  The Antenna transfers the transmitter energy to signals in space with the required distribution and efficiency. This process is applied in an identical way on reception

3.0 TYPES OF RADAR DISPLAY

3.1 Types of Display in Radar System

A radar display is an electronic device to present radar data to the operator. The radar system transmits pulses or continuous waves of electromagnetic radiation, a small portion of which backscatter off targets (intended or otherwise) and return to the radar system. There are three type of display in radar system

1. A scan (A scope).
2. Height Positioning Indicator (HPI).
3. Plan Positioning indicator (PPI).

1. A scan (A scope)

   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.

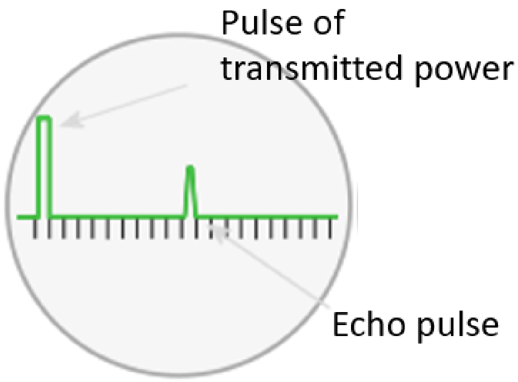


Figure 10: A scan Radar Display

The A-scope normally uses an electrostatic-deflection crt. The A- scope display is using in older radar sets only as monitoring oscilloscope. In modern digital radar sets don't exist a similar video signal of the backscatter.

2. Height Positioning Indicator (HPI)

   Radar display which shows simultaneously angular elevation, slant range, and height of objects detected in the vertical sight plane. It determines height of the object to be detect.

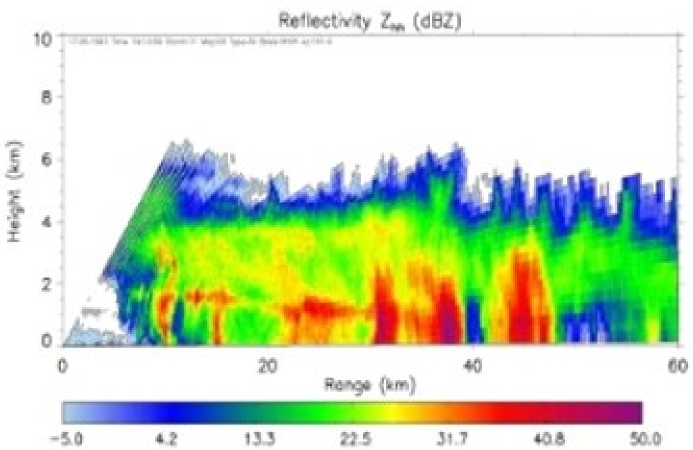


Figure 11: HPI Radar Display

3. <u>Plan Positioning indicator (PPI)</u>

   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.

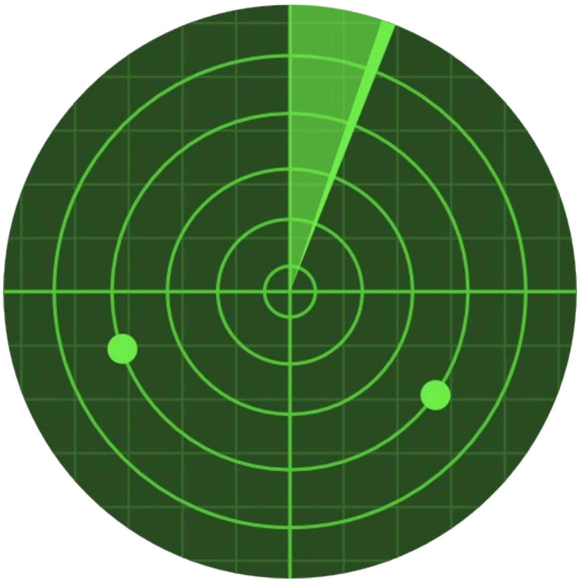


Figure 12: PPI Radar Display

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.

4.0 RADAR MEASUREMENT FACTOR

4.1 Range of Object

Range of object is the distance from the radar site to the target (object) measured along the line of sight.

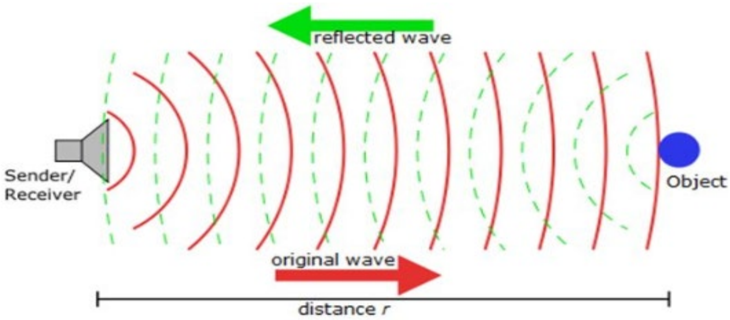


Figure 13: Range of Object

4.2 Factors That Affect Echo

a. Material of the target.

   Some material such as ferrite can absorbed radio frequency therefore very small energy can reflect back as echo.

b. Surface area of the target.

Small object with small surface area can only reflect small amount of energy back to radar and very small energy sometime may lost due to other factors.

c. Types of surface of the target.

   Object with curvy surface can reflect signal to different direction then to the radar antenna.

d. Distance of the target.

   The longer the distance to target the lower the chance for the signal to hit the object and therefore affect the echo itself.

Tutorial 2

1. Visualize block diagram of typical radar system.
2. Explain the function of duplexer in radar systems
3. Compare the function of transmitter and receiver n radar system.
4. State 2 types of radar display.
5. Picture the Plan Positioning Indicator (PPI) display
6. Express range of object in radar measurement.
7. Discuss TWO factor that affect Radar echo.

5.0 FORMULA IN RADAR MEASUREMENT

5.1 Parameters in Target Measurement

1. Time, *t*

Time in radar measurement is the time taken when radar transmit radio wave and hit the object and reflected back to radar antenna.

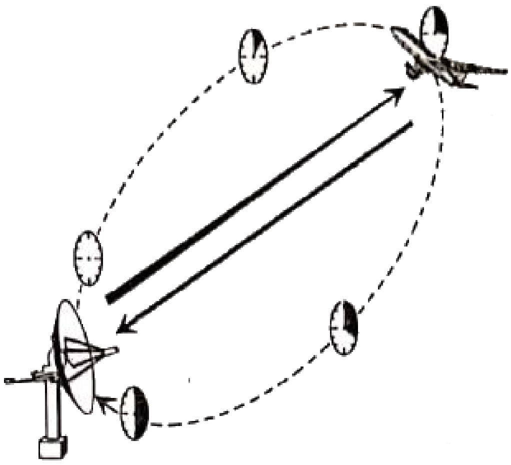


Figure 14: Full period of Radar Transmission and Detection

2. Target Distance, S

   Since the propagation of radio waves happens at constant speed (the speed of light, c_0) and the waves travel to a target and back, the round trip time is dividing by two in order to obtain the time the wave took to reach the target. Therefore,

$$S = Co \times \frac{t}{2}$$

Where,
t = time
Co = speed of light ($3x10^{8\ m/s}$)

Example 1

A pulse is sent to detect an object and it takes 2µs for the radar recapture the echo. Calculate the distance of the object from radar.

Solution,

Given t =2µs and Co = 3x 10^8 m/s

$S = Co \times \frac{t}{2}$

$S = (3 \times \ 10^8\ ) \times \frac{2\mu}{2}$

$S = 300\ m$

3. Velocity, v

Velocity measure how fast the object moving. The velocity of an object can be found by diving distance over time.

$$\boldsymbol{v = \frac{S}{t/2}}$$

Where
S = target distance
t = time

Example 2

Juara ship has moved as far as 65nmi from the radar station. Find the velocity of the ship if the time interval, t between emission pulse and echo pulse is 1 hour. (1nmi =1852m)

Solution,

t = 1 hour, in second t= 1 x 60x 60

t = 3600s

S = 65nmi, in m S = 65 x 1852

S = 120380m

$$v = \frac{S}{t/2} ,$$

$$v = \frac{120380}{3600/2}$$

v = 66.88 m/s

4. <u>Height (H)</u>

The height of a target over the earth's surface is called height or altitude. Height can be found by using formula below,

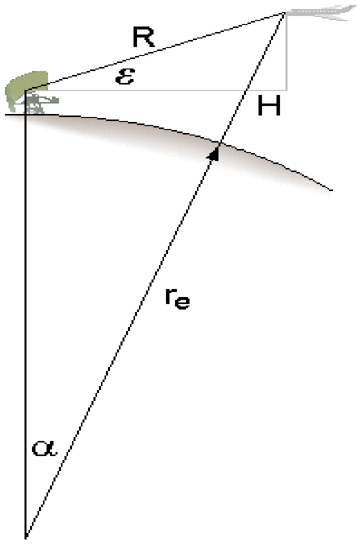


Figure 15: Object Height Calculation

$$H = R \sin \varepsilon + R^2/2re$$

Where
R = slant range
ε = elevation angle
re = earth radius (6370km)

Example 3

Calculate the altitude of an airplane by taking earth curve at elevation angle of 45 degree with slant range of 2km. The earth radius is about 6370km.

Solution,

$H = R \sin \varepsilon + R^2 / 2re$

$= 2000 \sin 45 + 2000^2 / 2(6370k)$

$= 1414.2 + 2000^2 / 2(6370k)$

$= 1414.5m$

5. <u>Bearing</u>

The True Bearing (referenced to true north) of radar target is the angle between true north and a line pointed directly at the target. This angle is measured in the horizontal plane and in a clockwise direction from true north. For example, in Figure 16, the object bearing can be read as 59 degree from north.

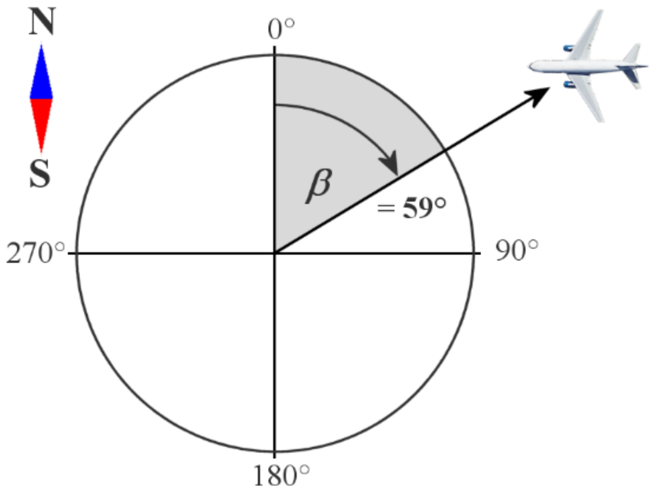


Figure 16: Bearing of An Airplane

6.0 CONTINUOUS WAVE RADAR FORMULA

6.1 Investigate the performance of Continuous Wave Radar

Important Parameters

Pt = transmitter power

Gt = transmit antenna gain

Gr = receiver antenna gain

Λ = wavelength (c/f)

σ = radar cross section

R = range

fd = received signal frequency

v = target velocity

Continuous wave formula

1. Transmit Power (watt)

$$Pt = \frac{Pr(4\pi)^3 R^4}{GtGr\lambda^2\sigma}$$

2. Received Power (watt)

$$Pr = \frac{PtGtGr\lambda^2\sigma}{(4\pi)^3 R^4}$$

3. Radar Cross Section (meter)

$$\sigma = \frac{Pr(4\pi)^3 R^4}{PtGtGr\lambda^2}$$

4. Range of object

$$R = \sqrt[4]{\frac{PtGtGr\lambda^2\sigma}{Pr(4\pi)^3}}$$

5. Receive signal frequency (Hz)

$$f_d = \frac{2V}{\lambda}$$

Example 4

A K-Band radar is used for speed limit camera. The radar shown used to find velocity of approaching vehicle using 18GHz signal. It use 20dBi gain antenna for both transmitting and receiving signal. The transmit power is 100W. If the received power from antenna is 0.28pW when R=1km, calculate

a. Radar cross section

b. Determine frequency different if vehicle travelling at 140km/h.

Solution,

From continuous wave formula,

$$\sigma = \frac{Pr(4\pi)^3 R^4}{PtGtGr\lambda^2}$$

Given,
Pt = 100w
Pr = 0.28pw
R = 1000m
f = 18GHz
Gt=Gr=20dB

Step 1

Antilog gain to convert from dB,

10 log X = 20dB

log X = 20/10

X = antilog (2)

X = 10^2

X = 100

So, Gt=Gr=100

Step 2

Find wavelength, λ

$\lambda = c/f$

$\lambda = 3x10^8 / 18G$

$\lambda = 0.0167m$

Step 3

Find radar cross section, σ

$$\sigma = \frac{Pr(4\pi)^3 R^4}{PtGtGr\lambda^2}$$

$$\sigma = \frac{(0.28p)(4\pi)^3(1000)^4}{(100)(100)(100)(0.0167)^2}$$

$$\sigma = \frac{555.6}{278.9}$$

$$\sigma = 1.99\text{m @ 2m}$$

Step 4

Find Receive signal frequency (Hz)

Find velocity, v (m/s)

$$v = \frac{140\ x\ 1000m}{60x\ 60}$$

$$v = 38.89\ m/s$$

Put v in fd,

$$fd = \frac{2V}{\lambda}$$

$$fd = \frac{2(38.89)}{0.0167}$$

$$fd = 4567.49\ Hz$$

7.0 PULSE RADAR FORMULA

7.1 Formula to solve problem related to Pulse radar

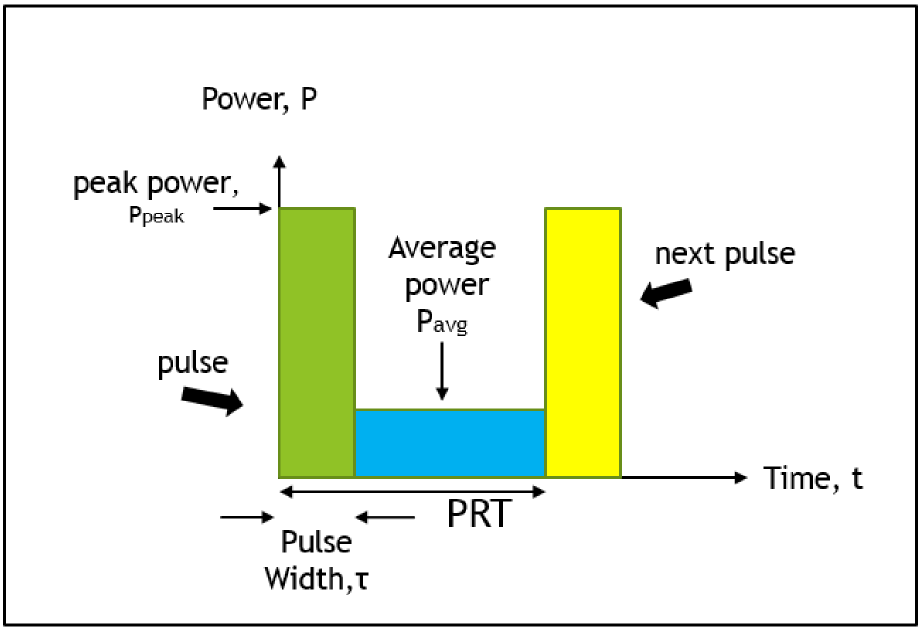


Figure 17: Relationship Between Peak Power and Average Power

1. Pulse repetition frequency (PRF) is the number of pulses of a repeating signal in a specific time unit, normally measured in pulses per second.

$$PRF = 1/PRT$$

2. Duty cycle is the percentage of the ratio of pulse duration.

$$\text{Duty cycle} = \text{Pulse width} \times PRF$$

3. Average power, Pavg

$$P_{avg} = P_{peak} \times \text{duty cycle}$$

Example 5

Calculate pulse width and duty cycle for a pulse radar if average transmitted power is 1kw and Peak power, Ppk is 15kw and pulse repetition time is 150µs. And illustrate relationship peak power to average power.

Solution,

Given,

Pavg = 1kw

Ppk = 15kw

PRT = 150µs

Step 1: Find PRF

PRF = 1/PRT

= 1/150µs

= 6666.7Hz

Step 2: Calculate Duty Cycle

Pavg = Ppeak x duty cycle

Duty cycle = Pavg/Ppk

= 1k / 15k

= 0.067s

Step 3: Find pulse width

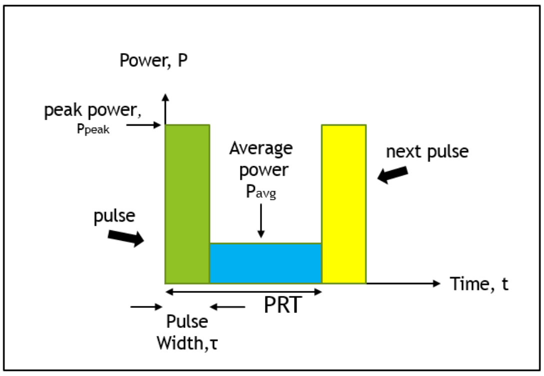
Duty cycle = Pulse width x PRF

Pulse width = Duty cycle / PRF

= 0.067 / 6666.7

= 1µs

Step 4 : Illustrate and label



Tutorial 3

1. Calculate the distance of the object from radar when a pulse is sent to detect an object and it takes 5µs for the radar recapture the echo.

2. A car is moving 50m from the police radar and the time taken between emission and echo to recapture is 2s, calculate the velocity of the car in km/h.

3. Find the altitude of an airplane at elevation angle of 60 degree with slant range of 1.5km. The earth radius is about 6370km.

4. A K-Band radar is used to find velocity of approaching vehicle using 10GHz signal. It has 20dBi gain antenna for both transmitting and receiving signal and the radar cross section is $2m^2$. If the received power from antenna is 0.3pW when R=1km, calculate radar transmitter power, Pt.

5. If the radar unit has a pulse repetition time, PRT of 0.05s and pulse width of 0.05µs, calculate the duty cycle.

6. A Pulse radar operate with average power, Pavg 10kW, Pulse width 15µs and Pulse repetition frequency, PRF 1kHz. Calculate Peak power Ppk and duty cycle. Then Illustrate the relationship between peak power and average power.

8.0 UNDERSTAND RADAR SYSTEM

8.1 Doppler Effect

The Doppler effect is the change in frequency or wavelength of a wave for an observer who is moving relative to the wave source. The popular example is the change of pitch heard when a vehicle sounding a siren approaches, passes, and recedes from an observer.

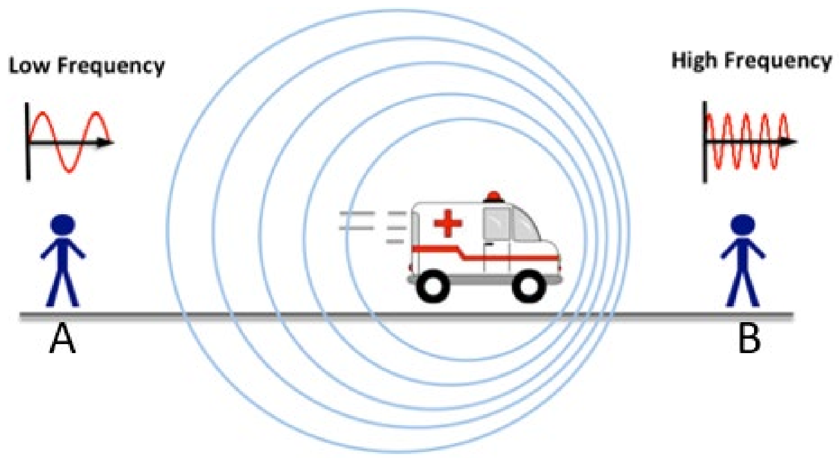


Figure 18: Example of Doppler Effect

From the figure above, the ambulance has pass person A and he heard a lower frequency when ambulance has passed him compare to person B where Ambulance is approaching him and he will be heard higher frequency sound. Compared to the emitted frequency, the received frequency is higher during the approach, identical at the instant of passing by, and lower during the recession.

8.2 Type of Interference in Radar System

1. Noise Occurrence in Radar System

   Noise is usually unwanted signal in a lot of application including radar system. Noise can disturb original signal and modify received data. Noise is most apparent in regions with low signal level, such as the weak received echo-signal in a radar receiver. There are two type of noise:

   a. Internal noise

      Noise which is cause by internal device/component at receiver.

   b. External noise

      Noise which generated outside the system such as weather, geographical factor and etc.

2. Clutter in Radar System

   Clutter is a term used for unwanted echoes in electronic systems, particularly in reference to radars. Such echoes are typically returned from ground, sea, rain, animals/insects, chaff and atmospheric turbulences, and can cause serious performance issues with radar systems. The basic types of clutter are,

   a. Surface Clutter

      Ground or sea returns are typical surface clutter.

   b. Volume Clutter

      Weather or chaff are typical volume clutter.

   c. Point Clutter

      Birds, windmills and individual tall buildings are typical point clutter.

3. <u>Radar Jamming</u>

Radar jamming is the intentional emission of radio frequency signals to interfere with the operation of a radar by saturating its receiver with noise or false information. There are two types of radar jamming,

a. Mechanical jamming

Mechanical jamming is caused by devices which reflect or re-reflect radar energy back to the radar to produce false target returns on the operator's scope. Mechanical jamming devices include chaff, corner reflectors, and decoys.

Figure 19: Chaff Flare to Protect Aircraft from Missile Radar

b. Electronic jamming

Electronic jamming is a form of electronic warfare where jammers radiate interfering signals toward an enemy's radar, blocking the receiver with highly concentrated energy signals.

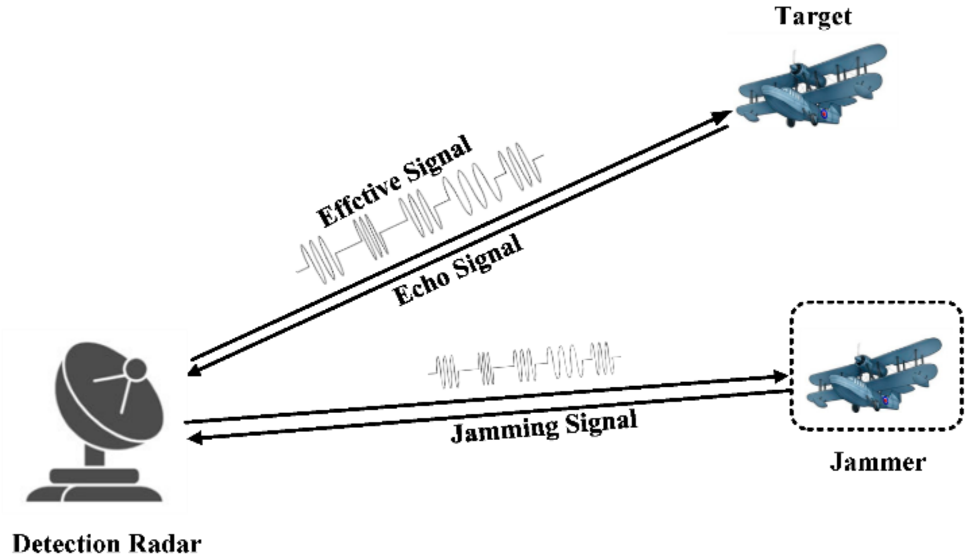


Figure 20: Electronic Jamming

9.0 PRINCIPLE OF DOPPLER EFFECT

9.1 Application of Doppler Effect in Radar System

1. <u>Weather Radar</u>

The basic concept of weather radar works off of the idea of a reflection of energy. The radar sends out a signal, as seen to the right, and the signal is then reflected back to the radar. The stronger that the reflected signal is, the larger the particle.

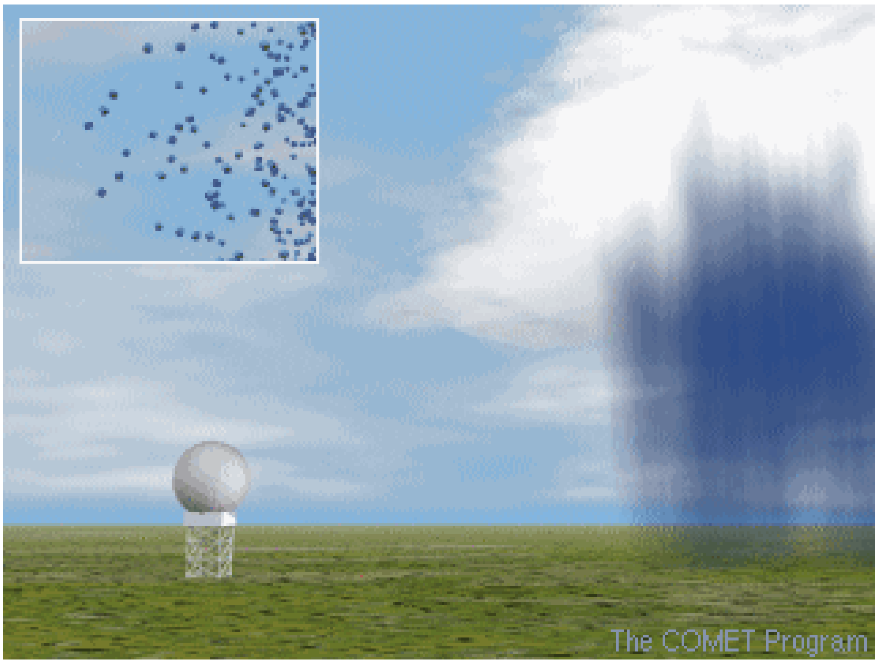


Figure 21: Weather Radar Detecting Rain

Direction of the rain also can be detected using Doppler Effect, the frequency of signal detected will be higher when the rain is approaching and lower if the rain going away from radar.

2. Air Traffic Control (ATC)

The air traffic control radar beacon system (ATCRBS) is a system used in air traffic control (ATC) to enhance surveillance radar monitoring and separation of air traffic. ATCRBS assists ATC surveillance radars by acquiring information about the aircraft being monitored, and providing this information to the radar controllers. The controllers can use the information to identify radar returns from aircraft (known as *targets*) and to distinguish those returns from ground clutter.

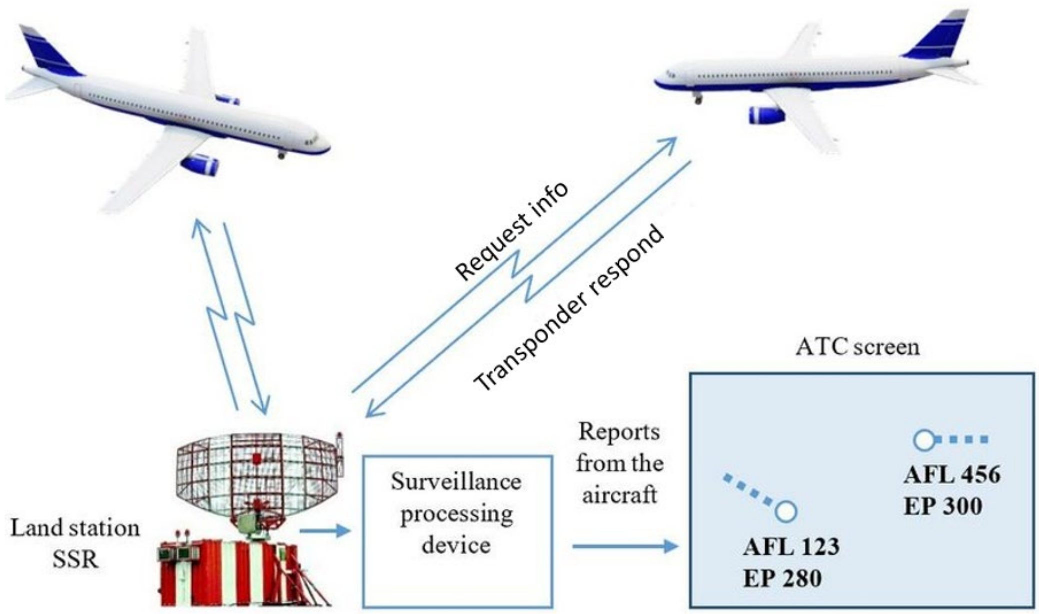


Figure 22: Air Traffic Controller Radar Beacon System

3. Radar Altimeter

Radar Altimeters *or* simply RA, used on aircraft, measures altitude above the terrain presently beneath an aircraft by timing how long it takes a beam of radio waves to reflect from the ground and return to the plane.

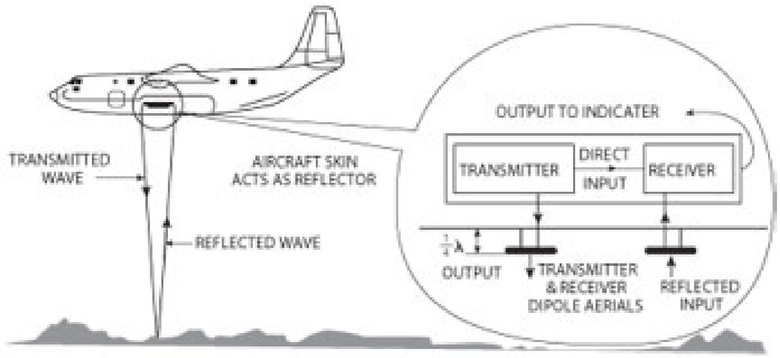


Figure 22: Radar Altimeter

Tutorial 4

1. A Doppler radar is a specialized radar that uses the Doppler Effect to produce velocity data about objects at a distance. Elaborate Doppler Effect with aid of diagram.

2. Define noise occurrence in radar systems.

3. Clutter is a term used for unwanted echoes in electronic systems, particularly in reference to radars. Elaborate TWO basic types of clutter.

4. Define Doppler effect and give 1 application of Doppler radar.

5. Apply the concept of Doppler effect in explaining the operation of Doppler radar.

6. Describe the basic principle of radar altimeter.

7. Interpret 2 types of radar interference

Calculation Answer Scheme (Tutorial 3)

1. Calculate the distance of the object from radar when a pulse is sent to detect an object and it takes 5µs for the radar recapture the echo.

   Given t =5µs and Co = 3x 10^8 m/s

   $$S = Co \times \frac{t}{2}$$

   $$S = (3 \times 10^8) \times \frac{5\mu}{2}$$

   $$\underline{S = 750\,m}$$

2. A car is moving 50m from the police radar and the time taken between emission and echo to recapture is 4s, calculate the velocity of the car in km/h.

   Given t = 4s, S= 50m

   $$v = \frac{S}{t/2},$$

   $$v = \frac{50}{4/2}$$

   v = 25 m/s

   v in Km = $\frac{25\,x\,3600}{1000}$

   $\underline{v = 90 \text{ km/h}}$ (the car is moving 90km/h)

3. Find the altitude of an airplane at elevation angle of 60 degree with slant range of 1.5km. The earth radius is about 6370km.

$H = R \sin \varepsilon + R^2 / 2re$

$= 1500 \sin 60 + 1500^2 / 2(6370k)$

$= 1299 + 1500^2 / 2(6370k)$

<u>H= 1299.18m</u>

4. A K-Band radar is used to find velocity of approaching vehicle using 10GHz signal. It has 20dBi gain antenna for both transmitting and receiving signal and the radar cross section is $2m^2$. If the received power from antenna is 0.3pW when R=1km, calculate radar transmitter power, Pt.

Radar transmitter power, Pt

Formula for pt,

$$Pt = \frac{Pr(4\pi)^3 R^4}{GtGr\lambda^2\sigma}$$

Given,
$\sigma = 2m^2$
Pr = 0.3pw
R = 1000m
f = 10GHz
Gt=Gr=20dB

Step 1: Antilog gain,
$10 \log X = 20dB$

$\log X = 20/10$

$X = \text{antilog}(2)$

$X = 10^2$

$X = 100$

So, Gt=Gr=100

Step 2: Find λ

λ = c/f

= 3x10^8/ 10G

= 0.03m

Step 3: Find pt

$$Pt = \frac{Pr(4\pi)^3 R^4}{GtGr\lambda^2\sigma}$$

$$Pt = \frac{0.3p(4\pi)^3 1000^4}{100.100.\,0.03^2.\,2}$$

Pt = 595.3/ 18

Pt = 33watt

7. If the radar unit has a pulse repetition time, PRT of 0.05s and pulse width of 0.05µs, calculate the duty cycle.

Given PRt =0.05s, Pulse width = 0.05µs

$$PRF = \frac{1}{PRT}$$

$$PRT = \frac{1}{0.05s}$$

$$PRT = 2000Hz$$

Duty cycle = Pulse width x PRF

= 0.05 µs x 2000

= 0.05 µs x 2000

Duty cycle = 0.1ms

5. A Pulse radar operate with average power, Pavg 10kW, Pulse width 15µs and Pulse repetition frequency, PRF 1kHz. Calculate Peak power Ppk and duty cycle. Then Illustrate the relationship between peak power and average power.

Given,

Pavg = 10kW

Pulse width = 15 µs

PRF = 1kHz

Duty cycle = Pulse width x PRF

= 15 µs x 1000 Hz

= <u>0.015s</u>

Ppk = Pavg x duty cycle

= 10kw x 0.015s

= <u>150W</u>

Reference

1. William L. Melvin, James A. Scheer (2014). *Principles of Modern Radar: Radar Applications*. New York, United States: SciTech Publishing Inc

2. G. Richard Curry. (2012). *Radar Essentials: A Concise Handbook For Radar Design And Performance Analysis*. SciTech Publishing Inc.

3. Mark A. Richards, James A. Scheer, William A. Holm (2010). *Principles of Modern Radar Basic Principles*. SciTech Publishing Inc.

4. Grundlagen der Radartechnik. (n.d.). Www.radartutorial.eu. Retrieved October 7, 2023, from https://www.radartutorial.eu/

5. Application of radar - Easy Electronics. (n.d.). Retrieved November 1, 2023, from https://easyelectronics.co.in/tag/application-of-radar/

6. AT, C. (2017, November 18). Pulsed Radar. Electrical & Electronics Engineering. https://www.engineeringdone.com/radar/pulsed-radar/

7. Aviator. (2020, May 27). PSR - SSR principles, advantages, limitations - aviationfile. Aviation Related Posts, Aviation Pioneers and Aviation Accidents. https://www.aviationfile.com/psr-ssr-principles-advantages-limitations/

8. Basics of FMCW Radar Renesas. (2023). Renesas.com. https://www.renesas.com/us/en/blogs/basics-fmcw-radar

9. Zhang, P., Huang, Y., & Jin, Z. (2023). An Electronic Jamming Method Based on a Distributed Information Sharing Mechanism. Electronics, 12(9), 2130.

10. Landry, W. C., René Jr. (2014). Software-defined radio to support aviation efficiency. Substance ÉTS. https://substance.etsmtl.ca/en/software-defined-radio-support-aviation-efficiency

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