EN4353

Radar and Navigation

Kithsiri Samarasinghe
University of Moratuwa

1

Recommended Text Books :

Radar Syastems and Radio Aids to Navigation
Dr. A.K. Sen, Dr. A.B. Bhattacharya
Khanna Publishers, Delhi.
Fifth Edition

Introduction to Radar Systems
Merrill I Skolnik
Tata McGraw-hill Publishing Company, Delhi
Third Edition

3

3

We all do detection and Ranging…

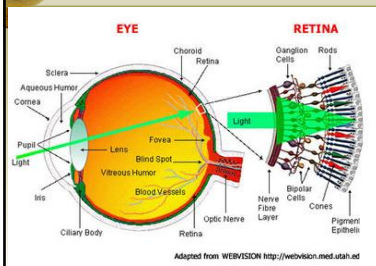
Objects should first be illuminated by frequencies that we can see

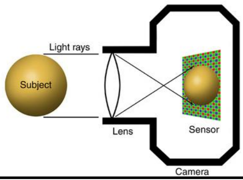
They scatter the light energy

The Eye picks up the scattered energy.

4

My Receiving Antennas…



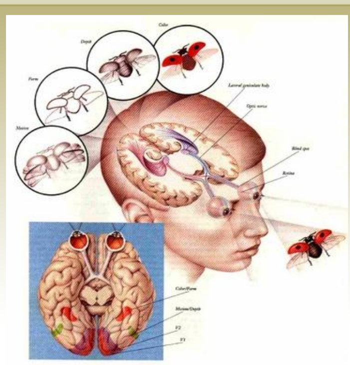


5

An Electronic Eye…

6

Our brain completes the difficult part…

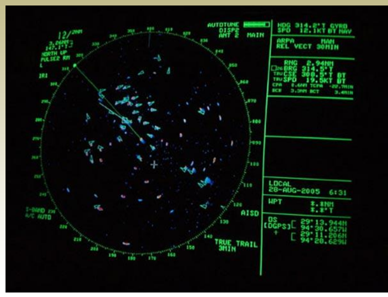


7

The Electronic 'brain' !

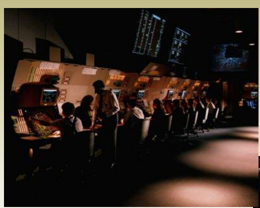
8

This is what it figures out…



9

Needs a human brain to complete the understanding…



10

Human vision

- Should be within Line of Sight
- Target/Object must be illuminated by external source
- Human vision is passive
- Rely on the scattering capability of an object
- Amount of scattered energy received by the eye (Echo in the Radar)
- Our eye is like a Radar receiver at the Radar Head
- Signals captured by the eye should be taken to the brain through Neuron System for processing (similar to Radar)

11

11

Radio Detection and Ranging

Requirement is to locate the position of objects by using Radio waves.

12

12

Design Parameters

1. Transmit power
2. Capture Area
3. Amount of Echo Power
4. Receiver sensitivity, bandwidth….
5. Resolution
6. Data Renewal Rate
7. Probability of Detection
8. Probability of false alarm etc. etc.

13

13

Design Parameters

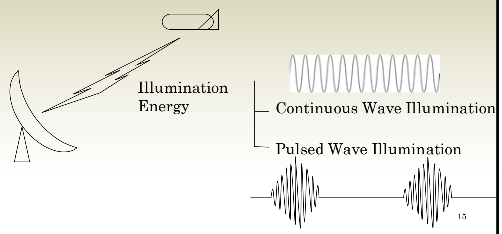
9) Radar Range
10) Permitted amount of noise in the signal
11) Complexity of processor and processing power

14

14

Continuous Wave Illumination

- Microwave Continuous Signal
  - Specially used for speed/velocity measurements

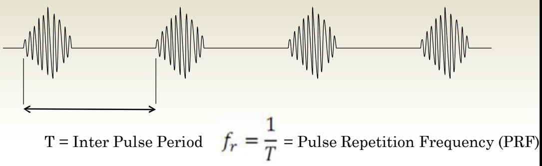


15

15

Pulsed Illumination

Save energy by not illuminating energy during processing period

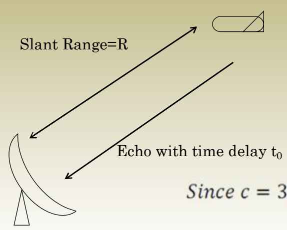


$f_r = \frac{1}{T}$ = Pulse Repetition Frequency (PRF)

16

16

Radar Range



$2R = ct_0$

$R = \left(\frac{c}{2}\right) t_0$

$Since\ c = 3x10^8 ms^{-1}\ and\ t_0\ is\ in\ \mu s$

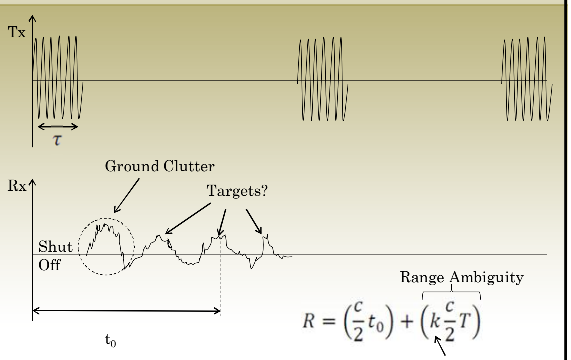
$R = 150\ t_0\ m$

$R\ \alpha\ t_0$

17

17

Pulsed Radar Range Ambiguity



$R = \left(\frac{c}{2}t_0\right) + \overbrace{\left(k\frac{c}{2}T\right)}^{\text{Range Ambiguity}}$

k=0,1,2,...

18

18

Range Ambiguity

There can be spikes in the reception signal due to the previous pulse scatter reflected from any far away object.

This can be avoided by proper matching of the parameters like

- PRF(Pulse Repetition Frequency)
- Transmit Power
- Antenna Gain

19

19

Maximum Range

$$2R_{MAX} = cT$$

$$R_{MAX} = \frac{c}{2}T$$

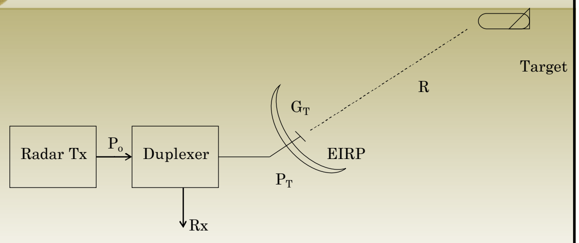
Since $T = \frac{1}{f_r}$ $\qquad R_{MAX} = \frac{c}{2f_r}$

Ex: Find PRF when the maximum range is 200km

20

20

Illumination of Target



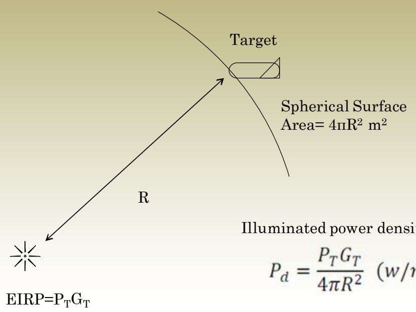
$$P_T = \frac{P_O}{L_B L_F}$$

$$P_T(dBW) = P_O - L_B - L_F\ dBW$$

21

21

Illumination of Target



Illuminated power density at target

$$P_d = \frac{P_T G_T}{4\pi R^2}\ (w/m^2)$$

22

22

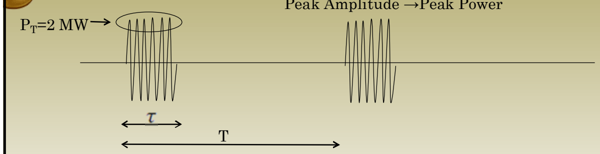
Example

Calculate the illumination level at the target of a Radar feeding 2MW of pulse power to an antenna with 40dB gain. Assume the target is at 300km range.

23

23

Average Power



$Duty\ cycle(\delta) = \frac{\tau}{T}$ $\qquad$ P_{AV} for typical duty cycle of 0.001

$P_T = peak\ pulse\ power$

Average power $P_{AV} = \delta P_T$

24

24

Energy

Transmit pulse energy E is important for illumination of the target and resulting scattering of energy

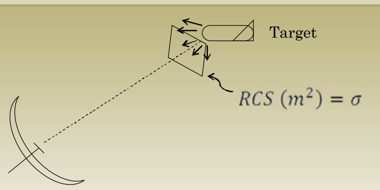
$$E = P_T\ x\ \tau$$

In peak power limited Radars, τ can be used to increase the illumination level as a low cost option.

25

25

Radar Cross Section of a Target



Assume that a certain area is collecting energy from our illumination and reradiate that power Omni-directionally

26

26

Definition of RCS

RCS is an equivalent area at the point of the target which is assumed to collect illumination energy and reradiate it omni-directionally such that the echo power at the receiving antenna will be same as that of the actual target

27

27

Typcal RCS Values

RCS of an air craft depends on many factors

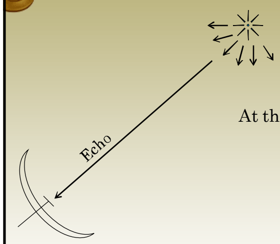
- Orientation of air craft
- Frequency of Radar
- Polarization of the signal
- Type of aircraft

Air craft type	Head on	Side on	Tail on
Small jet fighter	2-3 m^2	10-20m^2	2-3 m^2
2 Engine jet	5-10m^2	100-1000m^2	5-10m^2
4 engine jet	20-50m^2	1000-2000m^2	20-50m^2

28

28

Received Power



Power radiated = $\sigma P_d (W)$

At the antenna,

$$Echo\ Power\ Density = \frac{\sigma P_d}{4\pi R^2}$$

$$P_R = (Echo\ P_d)\ x\ A_e$$

$$P_R = \left[\frac{\sigma P_d}{4\pi R^2}\right] x \left[\frac{G\lambda^2}{4\pi}\right]$$

A_e= Effective aperture of the antenna

$$P_R = \left[\frac{\sigma G P_T}{(4\pi R^2)^2}\right] x \left[\frac{G\lambda^2}{4\pi}\right]$$

$$P_R = \frac{\sigma G^2 \lambda^2 P_T}{(4\pi)^3 R^4}$$

29

29

Losses

Losses in the propagation

- Water vapour absorption
- Atmospheric absorption
- Rain Absorption

For above non ideal situations a loss factor (L) is introduced

$$P_R = \frac{\sigma G^2 \lambda^2 P_T}{(4\pi)^3 R^4 L}$$

For range estimation

$$R = \left[\frac{\sigma G^2 \lambda^2 P_T}{(4\pi)^3 P_R L}\right]^{\frac{1}{4}}$$

30

30

When received power is minimum(lower threshold value for P_R) we get the maximum range.

$$R_{max} = \left[\frac{\sigma G^2 \lambda^2 P_T}{(4\pi)^3 L\ (P_R)_{min}}\right]^{\frac{1}{4}}$$

When the design is finished this should converge to

$$R_{max} = \frac{c}{2 f_r}$$

31

31

Minimum Received Power at Antenna

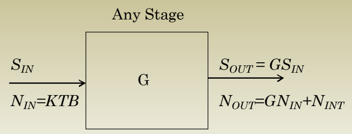
$$R_{max} = \left[\frac{\sigma G^2 \lambda^2 P_T}{(4\pi)^3 L \boxed{(P_R)_{min}}}\right]^{\frac{1}{4}}$$

Depends on the noise performance of the radar receive chain…

32

32

Noise Performance of Rx System



$$SNR_{IN} = \frac{S_{IN}}{N_{IN}} \qquad SNR_{OUT} = \frac{S_{OUT}}{N_{OUT}}$$

33

33

Noise Figure

Although signal strength increased, the signal quality deteriorates due to internal noise.

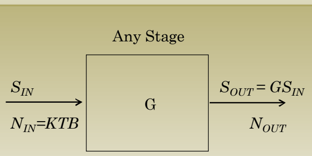
Noise Figure of the circuit module $F = \frac{SNR_{IN}}{SNR_{OUT}}$

Ideally F=1, but all practical circuits have F>1 due to internal noise.

34

34

Output Noise Power (N_{OUT})



$$F = \frac{SNR_{IN}}{SNR_{OUT}}$$

$$F = \frac{S_{IN}/N_{IN}}{S_{OUT}/N_{OUT}}$$

$$F = \frac{S_{IN}}{S_{OUT}} x \frac{N_{OUT}}{N_{IN}}$$

$$F = \frac{1}{G} x \frac{N_{OUT}}{N_{IN}}$$

$$N_{OUT} = FGN_{IN} = FGKTB$$

35

35

Excess Noise Figure

$$N_{OUT} = FGN_{IN} = FGKTB$$

$$N_{INT} = N_{OUT} - GN_{IN}$$

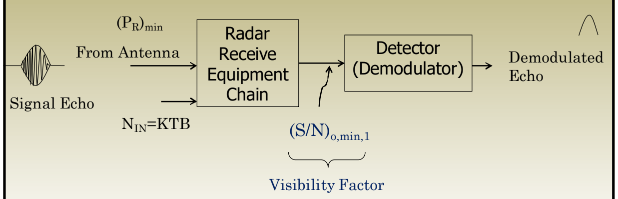
$$N_{INT} = \underbrace{(F-1)}_{\text{Excess Noise Figure}}GKTB$$

Lets see how these concepts can be used to estimate $(P_R)_{min}$ in the radar range equation…

36

36

Visibility Factor



37

37

Visibility Factor

….is the per echo minimum SNR required for demodulator to detect an echo.

This is defined at demodulator input.

It depends on the demodulator design

Lower visibility factor means better Radar

38

38

Effect of Visibility Factor for $(P_R)_{min}$

$$Minimum\ (S/N)_{IN} = \frac{(P_R)_{min}}{KTB}$$

$$F = \frac{(S/N)_{IN}}{(S/N)_{OUT}}$$

$$F = \frac{(P_R)_{min}/KTB}{(S/N)_{O,min,1}}$$

$$(P_R)_{min} = F\ (S/N)_{O,min,1}\ KTB$$

39

39

Effect of Visibility Factor for R_{max}

$$R_{max} = \left[\frac{\sigma G^2\lambda^2 P_T}{(4\pi)^3\ (P_R)_{min} L}\right]^{\frac{1}{4}}$$

$$R_{max} = \left[\frac{\sigma G^2\lambda^2 P_T}{(4\pi)^3 F\ (S/N)_{O,min,1} KTBL}\right]^{\frac{1}{4}}$$

✓ This equitation will give practically correct results than earlier equation

40

40

Practice Execise…

An air-surveillance radar operating at 1250 MHz is designed to detect targets of 4.95 m^2 radar cross section at a maximum range of 300 Km. It transmits RF pulses having a pulse width of 2 µS. The minimum detectable signal at the output of its antenna is -100 dBm. The antenna is 4m wide and 3m high with an aperture efficiency of 60.5%. Assuming an atmospheric absorption loss of 2.5 dB, determine the following.

a) Extend of pulse energy (in meters) in space in the range coordinate
b) Pulse repetition frequency to achieve a maximum unambiguous range of 300 Km.
c) Peak transmitter power
d) Duty cycle
e) Average transmitter power

41

41

Max. Range			300	Km
Pulse Width			2	uS
RF Energy Lenth in Space			600	m
Period			0.002	uS
PRF			500	pps
Duty Cycle			0.001	
Antenna	Aperture	12	m2	
	A. Efficiency	0.605		
	Gain 1583.083333 =		32dB	
	RPM 12			
	Beamwidth	1.2	Deg.	
	PRF 500	Hz.		

42

42

Receiver
Noise Figure 3.765dB = 2.379578301 Noise Temp = 400.0777073
Visibility Factor 15dB = 31.6227766
T(ant) 500 K
T(SKY) 0 K
IF Bandwidth 0.8 MHz
Bandwidth Factor 1
Integration Improvement 6.18dB = 4.15

S(MIN) 1.00149E-13 = 0.100148882 Pico Watts
= -99.99353895 dBm

43

43

Effect of Multiple Echos from the same target

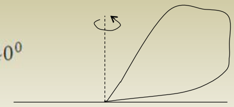
$$R_{max} = \left[\frac{\sigma G^2 \lambda^2 P_T}{(4\pi)^3 F\,(S/N)_{O,min,1} KTBL}\right]^{\frac{1}{4}}$$

45

Radar Beam for surveillance

Surveillance Radar need a wider vertical plane beam width to illuminate and capture targets at different altitudes.

$\theta_V = 20^0 - 40^0$

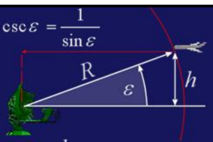


Horizontal Plane beam width should be small as possible

$\theta_H = 1^0 - 3^0$

46

46



$\csc\varepsilon = \dfrac{1}{\sin\varepsilon}$

$R = \dfrac{h}{\sin\varepsilon} = h\cdot\csc\varepsilon$

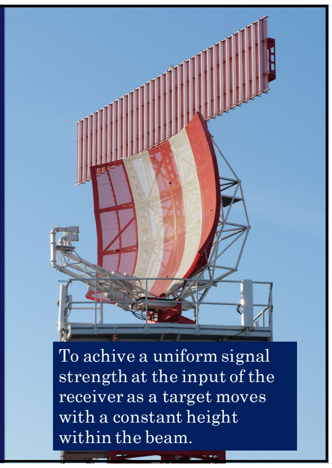
$P_E \sim \dfrac{G^2}{R^4}$ $\quad |P_E = \text{const}$

$G^2 \sim R^4$

$G \sim R^2$

$G \sim (\cancel{h}\cdot\csc\varepsilon)^2$ $\quad |h = \text{const}$

$\boxed{G \sim \csc^2\varepsilon}$



47

Number of Echoes

If the antenna rotates at N rpm, estimate the number of echoes that will be returned by one point target when the beam sweeps across it once.

Number of echoes per second = f_r

Number of rounds per min = N

Number of rounds per second = $N/60$

Time taken for a round = $60/N$

Number of echoes per round = $60f_r/N$

Number of echoes per θ_H = $\dfrac{60 f_r}{N} x \dfrac{\theta_H}{360}$

Number of echoes per target per sweep $\quad n = \dfrac{\theta_H f_r}{6N}$

48

48

Example

Find Number of echoes per target when $\theta_H = 2^0$, N=10 rpm, PRF=750Hz

49

49

Range and Speed of Rotation

Long Range Radar -150 nautical miles or higher

approx. 5 rpm speed of rotation

e.g. Surveillance Radar

A minute of arc on the planet Earth is 1 nautical mile
It is 1,852 meters

Medium Range Radar – 50-150 nautical miles

approx. 10-15 rpm speed of rotation

e.g. Approach Radar

Short Range Radar(Terminal Radar)- less than 50 nautical miles

approx. 20-25 rpm speed of rotation

e.g. Terminal Radar(to monitor runaways)

50

50

Effect of multiple echoes

Energies from echoes from same target can be integrated.

$(S/N)_{O,min,n}$ = Minimum SNR_{out} per echo pulse when energies of n echoes are integrated from same target

$(S/N)_{O,min,n} < (S/N)_{O,min,1}$

51

51

Integration Improvement Factor

$$I_{(n)} = \frac{(S/N)_{O,min,1}}{(S/N)_{O,min,n}}$$

$$(S/N)_{O,min,n} = \frac{(S/N)_{O,min,1}}{I_{(n)}}$$

52

52

Effect of $I_{(n)}$ for R_{max}

$$(P_R)_{min} = F\ (S/N)_{O,min,n}\ KTB$$

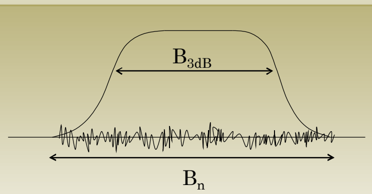
$$(P_R)_{min} = \frac{F\ (S/N)_{O,min,1}\ KTB}{I_{(n)}}$$

$$R_{max} = \left[\frac{\sigma G^2 \lambda^2 P_T I_{(n)}}{(4\pi)^3 F\ (S/N)_{O,min,1} KTBL}\right]^{\frac{1}{4}}$$

53

53

Noise Bandwidth



$$B_n \approx 1.1 B_{3dB}$$

54

54

Integration of Echoes

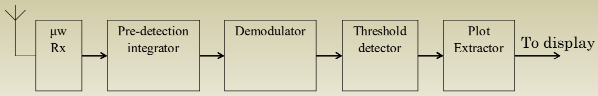
1. Pre detection integration
   - ➢ Analog delay lines are used in the IF section of the receiver to coincide subsequent echoes and increase the resultant echo signal energy

2. Post detection integration
   - ➢ After the demodulation
   - ➢ Signal processing techniques in digital domain

55

55

Pre-detection Integrator



* Display unit is independent from other units

56

56

Post-detection Integrator

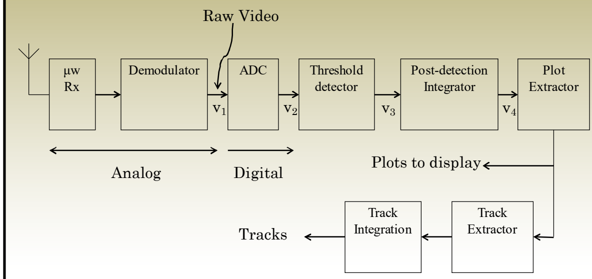
Integrator can be moved to a position after the threshold detector. Then it is called post detection integrator

57

57

Post-detection Integrator

Raw video is an analog waveform coming out from the envelop detector

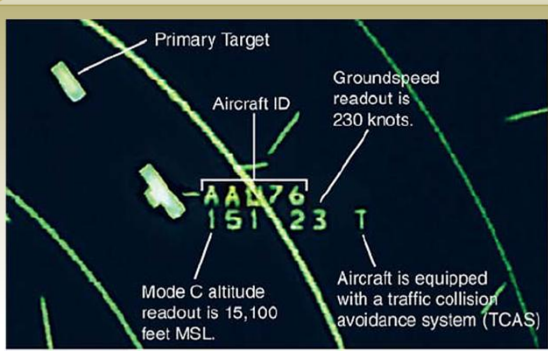


58

58

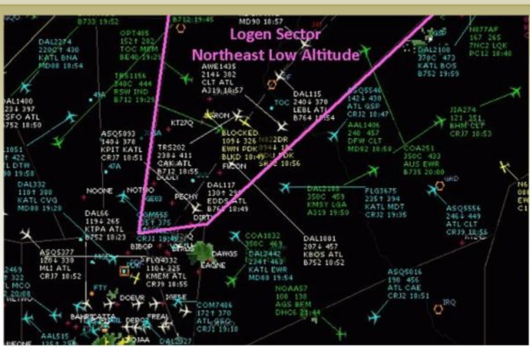
Basic Concepts of
Radar Signal Processing

59



60

60



61

61

Probabilities involved

Probability of Detection (P_d)
- ✓ Probability that an echo coming from actual target is detected as an actual target
  - ➢ 0.95-0.98 for civilian Radar
  - ➢ More than 0.99 for military Radar

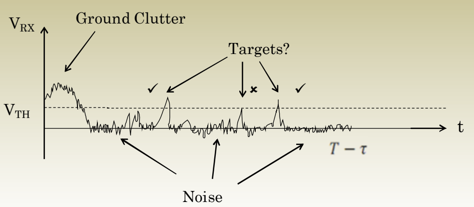
Probability of Target Miss= 1-P_d

Probability of False Alarm(P_{fa})
- ✓ Probability that Radar indicated a target although there isn't an actual target in the place
  - ➢ Typical values $1 \times 10^{-8} - 1 \times 10^{-10}$

62

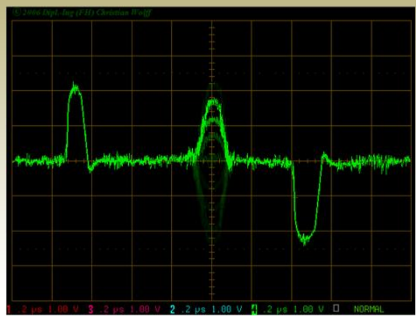
62

Threshold Detection



63

63



64

64

Threshold Detection

Compare the received signal with a threshold voltage(VTH)

$V_{RX} > V_{TH}$ → ✓ a target
$V_{RX} < V_{TH}$ → ✗ not a target

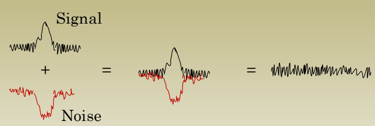
Objectives of designer are to improve P_d and minimize P_{fa}

65

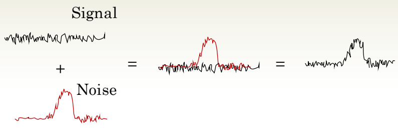
65

Unwanted Scenarios

Missing a target

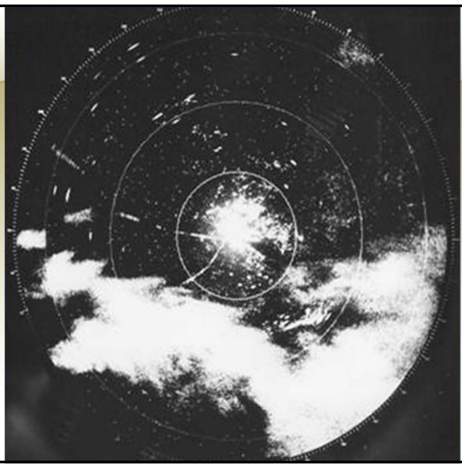


False Alarm



66

66

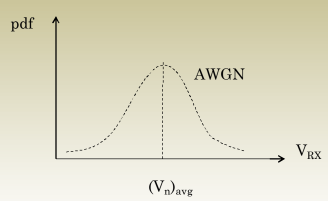


67

67

Fast Threshold

Noise can be generated due to clouds, rain, circuit components…etc. Lets assume AWGN.



To maintain P_d and Pfa objectives for targets at different ranges

68

68

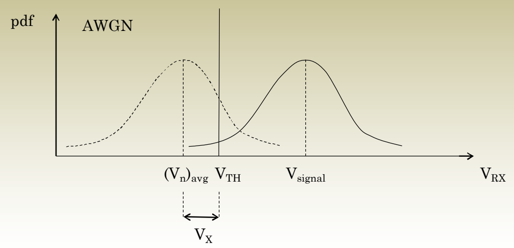
$(V_n)_{avg}$ is the average noise level which depends on the following factors.

- Clouds – Appear in different ranges
- Antenna pointing direction
  i.e Hills increase $(V_n)_{avg}\uparrow$
- Time of the day
  i.e In the day time $(V_n)_{avg}\downarrow$
- Polarization of the signal frequency

$(V_n)_{avg}$ should be dynamically estimated by the receiver

69

69



70

70

$(V_n)_{avg}$ will be dynamically changed and V_x may remain fixed.

$$V_{TH} = (V_n)_{avg} + V_x$$

V_{TH} becomes fast changing to keep P_{miss} and P_{fa} constant

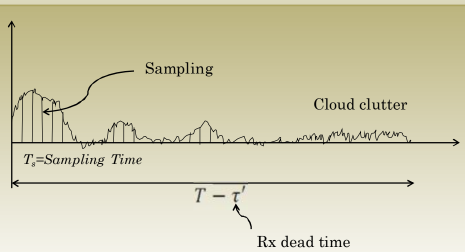
In civilian Radar : $P_{fa}\downarrow$

In military Radar: $P_{miss}\downarrow$

71

71

Sampling the Raw Video Signal



$\tau' > \tau$

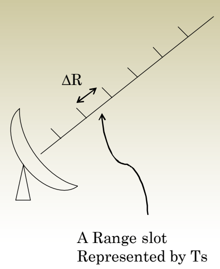
Shut off time is little longer than pulse transmission time

72

72

Analog to Digital Conversion

Sampling
Quantizing
Coding

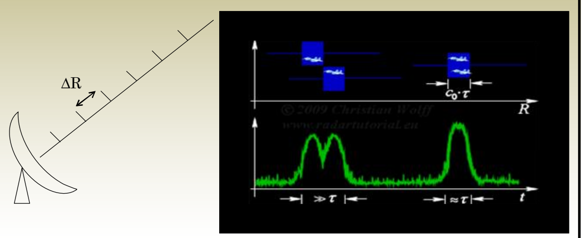


$\Delta R = 150T_S$

73

73

Range Resolution



74

74

Analog to Digital Conversion

If there are N time slots

Each sample is quantized and coded into a n-bit number (eg. n=10,12,16)

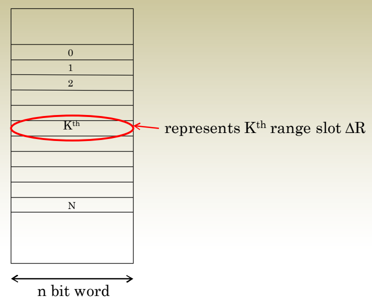
Raw video bit rate= nNf_r

e.g. if N=4096, n=12, fr=1000Hz

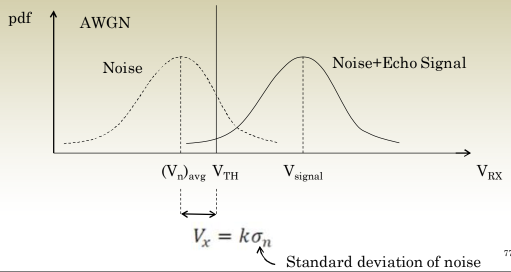
Raw video bit rate = 4096 x 12 x 1000 bits/s
= 49.152Mbps

Threshold Detector

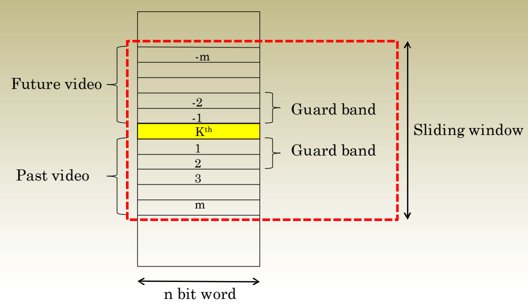
The raw video output should go into a FIFO memory for threshold detection



Each sample should be compared with the fast threshold amplitude that corresponds to particular range slot



Noise averaging algorithm



Noise averaging algorithm

$$(v_n)_{avg} = \frac{\sum(Past\ video) + \sum(Future\ video)}{Number\ of\ samples}$$

Assuming guard band = j samples

$$(v_n)_{avg} = \frac{\sum_{i=j+1}^{m}(Past\ video) + \sum_{i=-j-1}^{-m}(Future\ video)}{2(m-j)}$$

If m is smaller, a small air crafts can be detected, but if m is large, then a formation of several planes may even be detected as a single target

Guard bands are introduced because a energy of a target echo may affect the adjacent samples and considering them as noise is not correct at all

$$v_{TH} = (v_n)_{avg} + k\sigma_n$$

V_{TH} for K^{th} range slot is calculated as shown above

Then, K^{th} sample amplitude is compared with this.

If K^{th} sample amplitude $> V_{TH}$ then
$V_{3,k}=1$
Otherwise
$V_{3,k}=0$

Post detection integration

If $V_{3,k}$=1 keep it as a tentative target which will be verified later. These binary outputs go into another memory which has a word length of N

Time slots (Range slots)

Transmit Pulse Number

	1	2	3	4	5	6	7			N
1	0	0	0	0	1	0	0	.		0
2										
3										
4										
i										

81

Post detection integration

Time slots (Range slots)

Transmit Pulse Number

	1	2	3	4	5	6	7			N
1	0	0	0	0	1	.	.	.		
2	0	0	1	0	1	.	.	.		
3	0	1	0	0	1	.	.	.		
4	0	0	0	0	1	.	.	.		
	0	0	1	0	1	.	.	.		
	0	0	0	0	0	.	.	.		
	0	1	0	0	1	.	.	.		
	0	0	0	0	1	.	.	.		
	0	0	0	0	0	.	.	.		
i	0	0	0	0	1	.	.	.		

Due to random noise

Take count

82

Post detection integration

If,

Count >½[Expected echoes per target per scan]

Can be decided by the designer

Then, there is a target in that range slot

Advantages

1) Very simple and low cost (no need of delay lines)
2) Parameters can be controlled easily using DSP

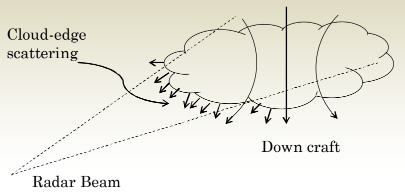
Software for this process is called post detection integration algorithm

83

Cloud detection

Rain clouds can have down-craft which are dangerous as they generate electrical charge. So they have to be avoided by pilots.

e.g. Cloud/weather detection



84

Cloud detection

There are other s/w modules which may be operating on this same memory attempting to extract some more information

	1	2	3	4	5	6	7			N
1	0	0	0	0	1	0	0.	.		
2	0	0	1	0	0	1	0	.		
3	0	1	0	0	0	0	1	.		
4	0	0	0	0	0	0	0.	.		
	0	1	0	0	0	0	1	.		
	0	0	1	0	0	0	0.	.		
	0	1	0	0	1	1	0	.		
	0	0	0	0	0	0	0	.		
	0	0	0	0	0	0	0	.		
i	0	0	0	0	0	0	0	.		

Edge of the cloud can be detected by DSP algorithms

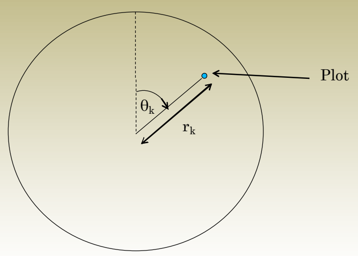
85

Multiple software modules can operate on this memory, looking for different types of patterns.

Once we verify that there is a target in the K^{th} Range slot, the corresponding θ(asimuth) value is obtained from the antenna rotation encoder to identify the plot as (r_k, θ_k) coordinates.

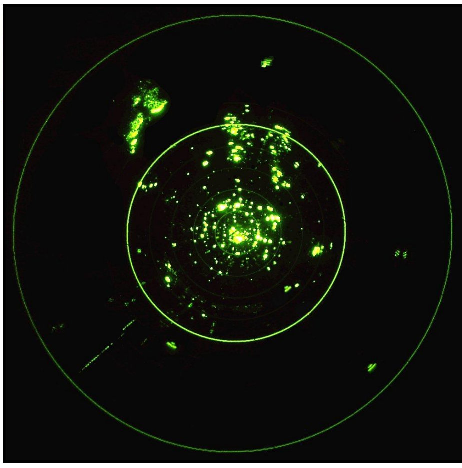
86

The Plot on Radar Display



Plot- The coordinates of the target

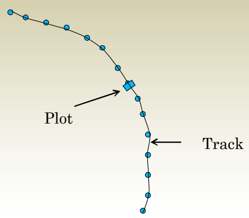
87



88

A Track

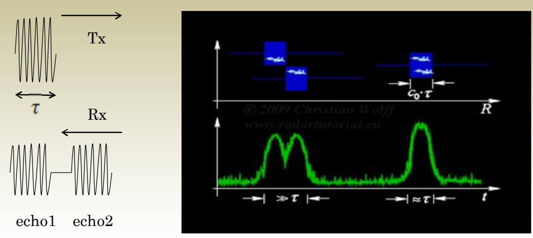
Track - The history of the targets path and the predicted future path.



89

Radar Resolution

Ability of the Radar to discriminate between two close by targets and identify them separately

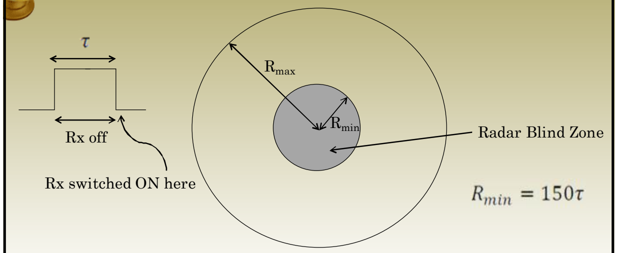


Not to overlap echo1 and echo2 $\Delta R_{min} = 150\tau$

Longer pulse width→Poor resolution

90

Radar Blind Zone

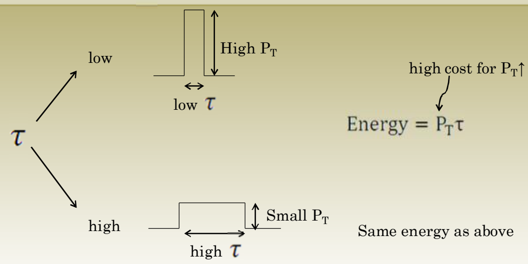


$\tau\uparrow \rightarrow R_{min}\uparrow \rightarrow Blind\ Zone \uparrow$

Terminal Radar has $\tau\downarrow$ and RPM↑ to eliminate this

91

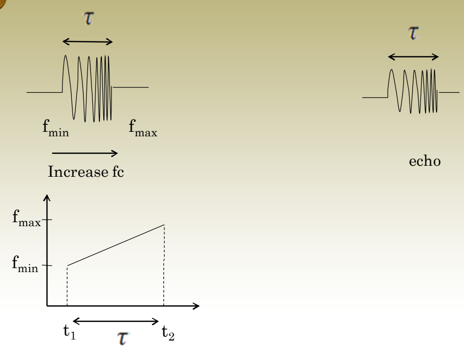
Effect of τ



First method→high cost
Second method→ high Blind Zone and poor resolution

92

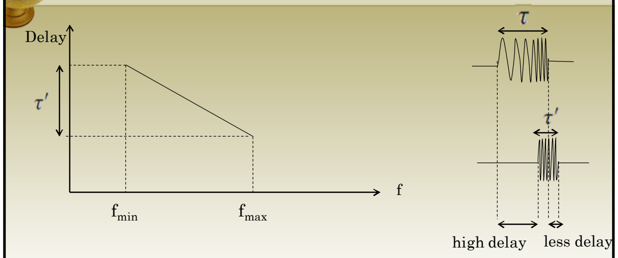
Pulse Frequency Modulation (PFM)



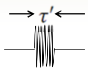
93

93

Equalizing Filter



Equalizing filter can compress a pulse frequency modulated signal

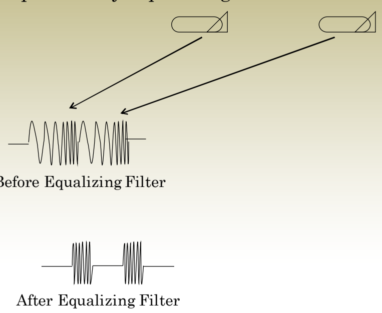


$\tau' < \tau$

94

94

Two targets giving overlapped echoes will be separated by Equalizing Filter

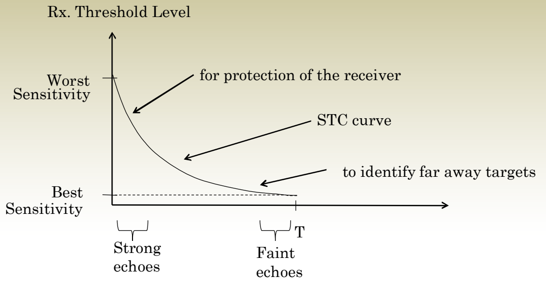


95

95

Sensitivity Time Control

High energy echoes from near targets will damage the front end of Rx, therefore we need to increase the threshold level

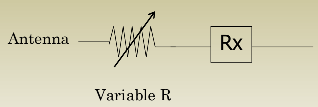


96

96

PIN diode for STC

PIN diode resistance can be varied by adjusting the d.c level.



97

97

Implementation

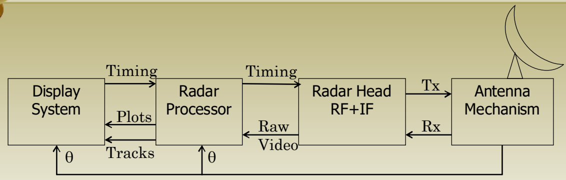
Wall painting from the Technical School of the Air Force in Kaufbeuren (Germany)

98

98

99

Pulsed Radar Implementation



➢Practically processor and display systems are in two places

➢Radar Head and Antenna may also be kept away from processor

100

100

Radar Head and the Processor

101

101

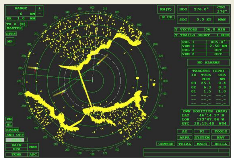
Display Systems

Phospher type(r,θ)

➢ Phospher has a memory so that light stays for a while
➢ Good for dark places(e.g. Control room)

Bright Display(x,y)

➢ With raster scanning(e.g. runway control towers)
➢ Used where ambient light is present(bright places)
➢ Data is in semiconductor memory



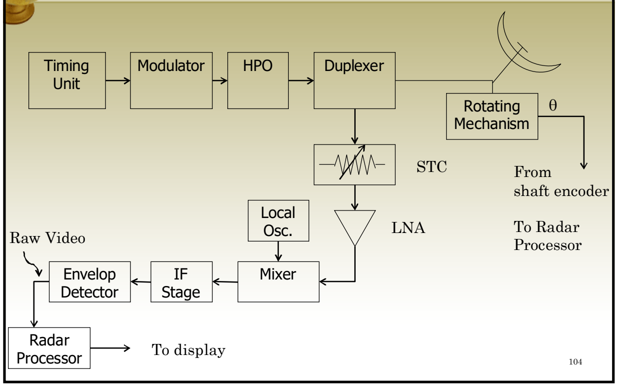
102

102

Displays in ATC center

103

Radar Head



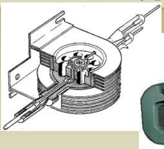
104

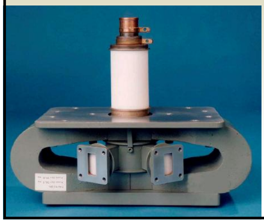
104

HPO (High Power Oscillator) Type

Technology options are;

- Magnetron
- Crossed Field Oscillator
- Reflex Klystron

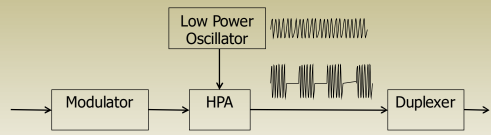





105

HPA Type System

HPA design has some modifications



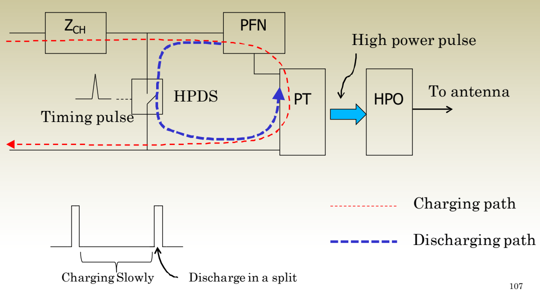
HPA is used instead of HPO
e.g. Klystron

106

106

HPO type Radar Transmitter

Line Type Modulator



107

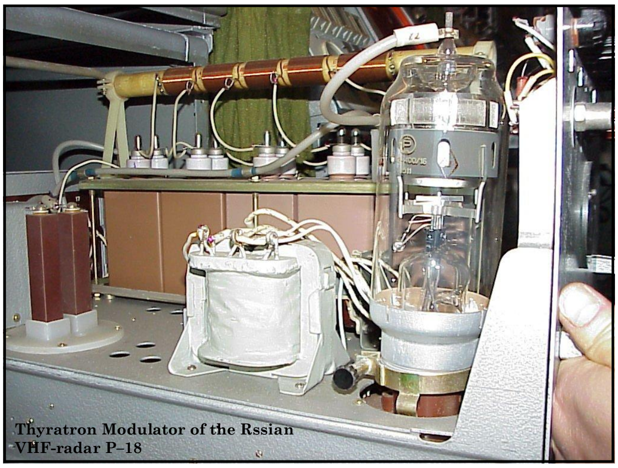
107

During inter-pulse period, energy will be stored in the Pulse Forming Network(PFN)

When HPDS is triggered by the timing pulse, PFN discharges the stored energy to the HPO in a short time through PT


108

108

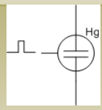


Thyratron Modulator of the Rssian VHF-radar P-18

109

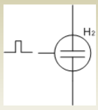
HDPS

Mercury Filled Gas Tubes(Hg Ignition)
Used in earlier Radar due to good ignition rate of Hg



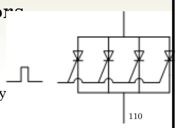
H_2 filled Gas Tubes(H2 Thyratron)

Has better ionization rate than Hg and can produce dI/dt of 8000-10000 A/s



Solid State Modulator Using Thyristor or IGBT

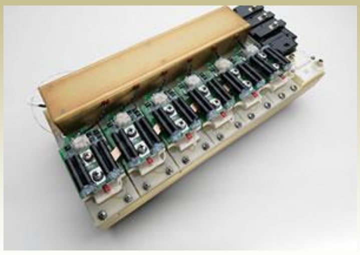
Used since 1995 to overcome the discharge of limited lifetime of gas filled tubes. However it will create a noisy pulse



110

110

IGBT Solid State Modulator



111

HPDS

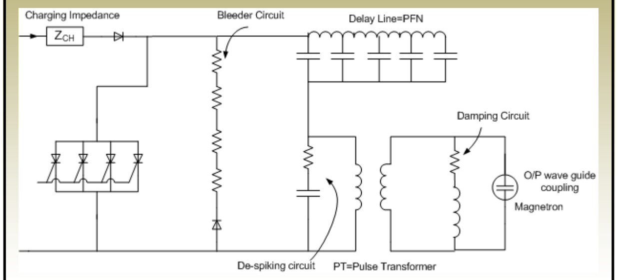
In HPDS ignition should happen very fast

H_2 ignition is better than Hg as it gives better (dI/dt)

Both Hg and H_2 types have fairly low life span and they are expensive

112

Solid State Modulator Circuit



113

All Thyristors must be activated at the same time, otherwise all the current will flow through one Thyristor.

Life time is theoretically infinite

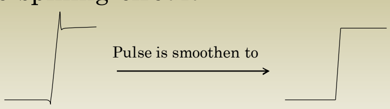
114

- When discharge circuit is short circuited, a pulse is created and sent to o/p waveguide coupling
- Each time circuit is charged and discharged, negative voltage will increase at PFN.
- Bleeder circuit is used to short circuit the remaining negative pulse of the PFN at the end of transmission

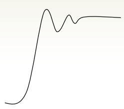
115

De-spiking and damping circuits are used to avoid the effects to the pulse while transmitting through transformer.

De-spiking circuit

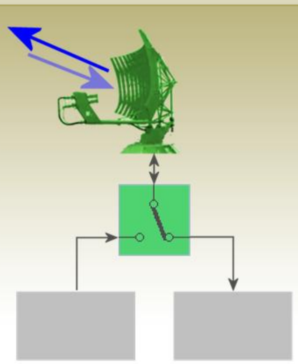


Damping Circuit



116

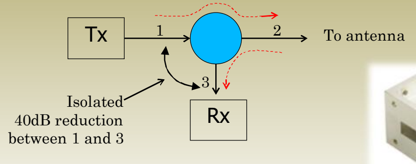
Duplexer



117

Duplexers

1) Ferrite Circulators



Circulators are ferrite cored, high frequency, bulky devices.
Can't be used in small devices

Curie Temp is about 500°C.
Cant be used in high power applications

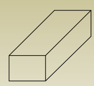
118

- Popular for low power Radars
- This is because 40dB isolation is not sufficient to isolate high transmit powers.
  - With 40dB isolation the power sent to the Rx can still be more than the maximum power limit.
- "Curie Temperature" for ferrites
  - The temperature at which they loose all their magnetic properties.

119

Wave Guides

Wave guides transmit TE or TM waves. There are two types of waveguides



Rectangular

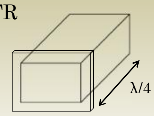
Circular

120

Branch Type Duplexer

In this case dual TR tubes with 3dB power couplers are used.

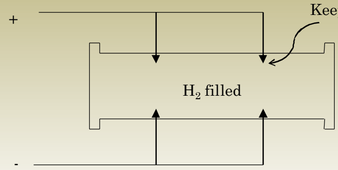
ATR

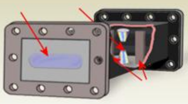


When H_2 is not ionized, the short cct wall will create an open cct at mouth since it is $\lambda/4$ distance away.

121

TR

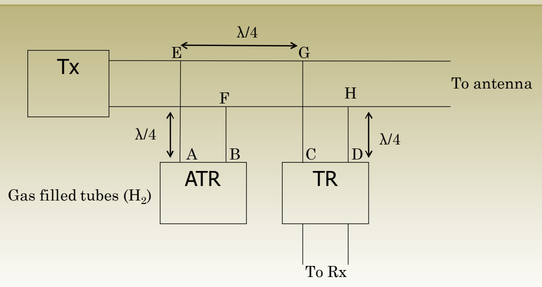




When high power signal enters, two points will fire and H_2 will get ionized.
A short cct will be created to prevent energy to enter Rx

122

Branch Type Duplexer block diagram



ATR=Anti-Transmit Receive
TR=Transmit Receive

123

123

During Tx of pulse

Both tubes get ionized immediately due to the high power in the pulse and the resulting electric fields in the tubes.

$Z_{AB} = Z_{CD} = 0$ (Short circuit)
$Z_{EF} = Z_{GH} = \infty$ (Open circuit)

An open cct will occur λ/4 distance away from a short cct.

Therefore energy of the pulse will continue to the antenna along the main feeder

124

124

During Reception

Both tubes are not ionized
$Z_{AB} = \infty$ (open cct)

After λ/2 distance we will get an open cct again
$Z_{IJ} = \infty$ (open cct)

Therefore incoming echo sees an open cct. Condition in the main waveguide at IJ

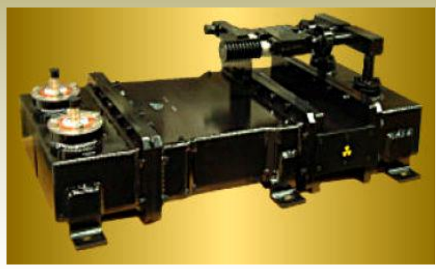
A matching impedance presented by the receiver part.

Isolation of 60-90dB

125

125

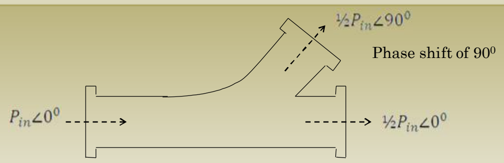
Balanced Type Duplexer



126

126

Hybrid 3dB coupler

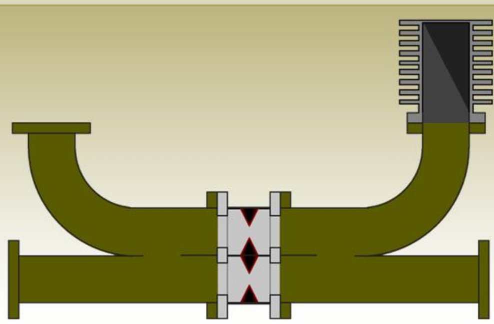


Because of the phase shift of 90^0, we call this Quadrature coupler

127

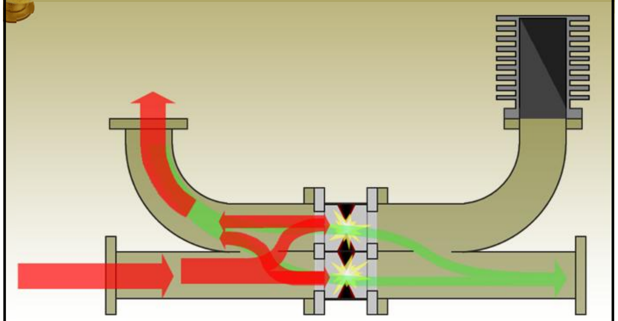
127

Balanced Type Duplexer



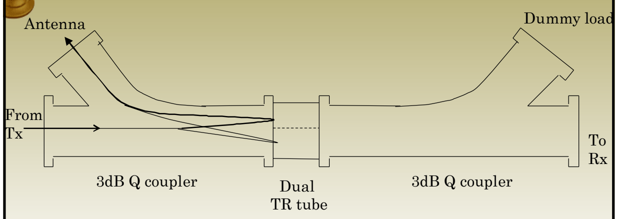
128

128



129

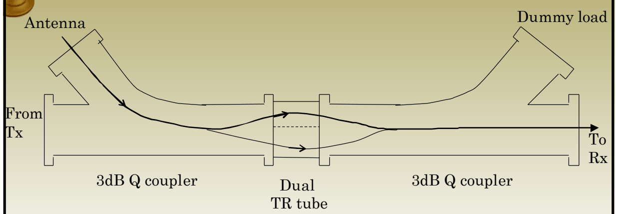
Dual TR Tube



- During Tx both Tubes will be ionized and power will be reflected and come to antenna.
- Nothing comes towards Tx because the two signals are 180⁰ shifted in phase and they cancel out each other
- Can handle 30-40MW

130

Dual TR Tube



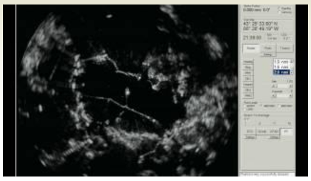
When a signal is received, it is divided and gone through both TR tubes and then added and gone to Rx

Dummy load dissipates the leakage current as heat to prevent the damage of equipment

131

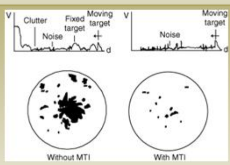
MTI Radar (Moving Target Indication)

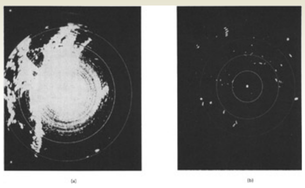
- Doppler Principle to identify the moving targets.
- Additional Processing Channel that can be combined with a pulse radar.
- Stationary targets can be eliminated from the display



132

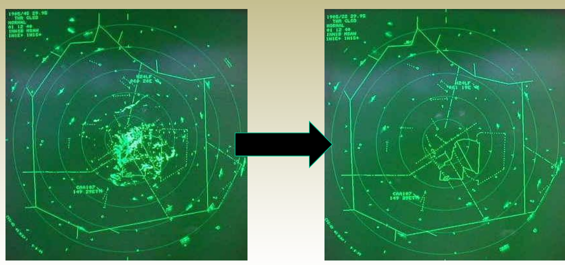
Effect of MTI





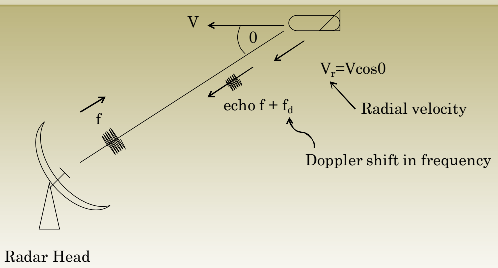
133

Effect of MTI



134

Doppler Frequency Shift



When the target is approaching f_d is +ve
When the target is leaving then f_d is -ve

135

135

Total distance = *2R*

Phase delay= $\frac{2\pi}{\lambda}(2R) + \phi$

When R varies the phase delay also varies.

The rate of change of phase is the angular frequency.

$$\omega_d = (-)\frac{d\theta}{dt}$$

136

136

$$\omega_d = (-)\frac{d\theta}{dt} \qquad f_d = \frac{-1}{2\pi}\frac{d\theta}{dt}$$

$$f_d = \frac{-1}{2\pi}\frac{d}{dt}\left[\frac{4\pi R}{\lambda} + \phi\right]$$

$$f_d = \frac{-1}{2\pi}\left[\frac{4\pi}{\lambda}\frac{dR}{dt} + \frac{d\phi}{dt}\right]$$

Where $\frac{dR}{dt} = (-)V_r$ (-)ve sign is because R is decreasing

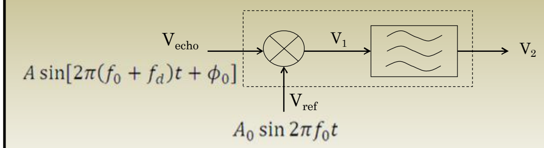
$$f_d = \frac{-1}{2\pi}\left[\frac{4\pi}{\lambda}(-V_r) + \frac{d\phi}{dt}\right]$$

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

137

137

Phase Detector(Synchronous Detector)



Here we use a product detector instead of envelop detector

138

138

$$V_1 = A\sin[2\pi(f_0 + f_d)t + \phi_0].A_0\sin 2\pi f_0 t$$

$$V_1 = \frac{-AA_0}{2}\{\cos[2\pi(f_0 + f_d)t + \phi_0 + 2\pi f_0 t] - \cos(2\pi f_d t + \phi_0)\}$$

$$V_1 = -A'\{\cos[2\pi(2f_0 + f_d)t + \phi_0] - \cos(2\pi f_d t + \phi_0)\}$$

After filtering $V_2 = A'\cos(2\pi f_d t + \phi_0)$

139

139

For stationary targets f_d=0 and $V_2 = A'\cos\phi_0$
This is a DC voltage

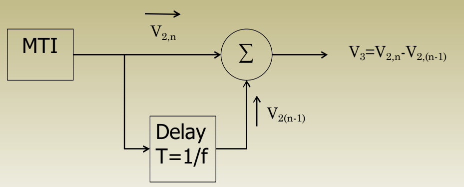
For moving targets f_d is present and V_2 is an AC signal.

Practical values for f_d is few hundreds of Hz.
∴DC blocking capacitor approach is not suitable to separate DC and AC.

140

140

Delay Line MTI Canceller



$$V_{2,n} = A' \cos(2\pi f_d t + \phi_0)$$

$$V_{2,(n-1)} = A' \cos(2\pi f_d (t-T) + \phi_0)$$

141

141

$$V_3 = V_{2,n} - V_{2,(n-1)}$$

$$V_3 = A' \cos(2\pi f_d t + \phi_0) - A' \cos(2\pi f_d (t-T) + \phi_0)$$

$$V_3 = A'(-2) \sin(-\pi f_d T + \phi_0 + 2\pi f_d t) \sin(\pi f_d T)$$

$$V_3 = A'' \sin \pi f_d (2t - T) + \phi_0)$$

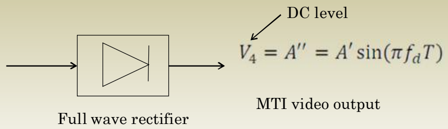
Where $A'' = A' \sin(\pi f_d T)$

This amplitude becomes zero for fixed targets.
V_3 output will be a sinusoidal appearing only for moving targets and frequency is very low

142

142

Signal V3 is full wave rectified and this amplitude is detected



143

143

Blind Speeds

Certain f_d values can make V_4=0.

These speeds are known as Blind Speeds. So even though a target is moving we may think it is stationary.

$$V_4 = 0 \qquad A'' \sin(\pi f_d T) = 0$$

$$\pi f_d T = n\pi$$

$$f_d = n\frac{1}{T}$$

$$f_d = n f_r$$

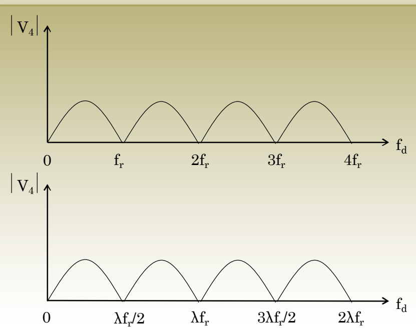
since $f_d = \frac{2V_r}{\lambda}$ $\quad \frac{2V_r}{\lambda} = n f_r$

Blind Speeds $V_r = 2\left(\frac{\lambda f_r}{2}\right)$

144

144

Blind Speeds



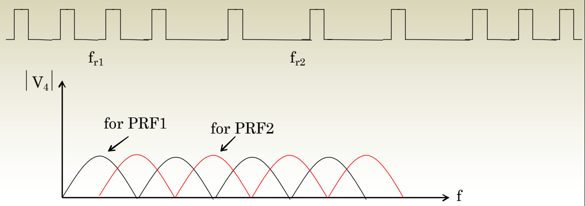
145

145

Solution for Blind Speeds

Use two pulse repetition frequencies.

Alternatively employ each one for a short duration

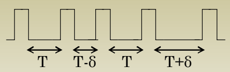


146

146

Wobulation

Jitter After Pulse Repetition Frequency



147

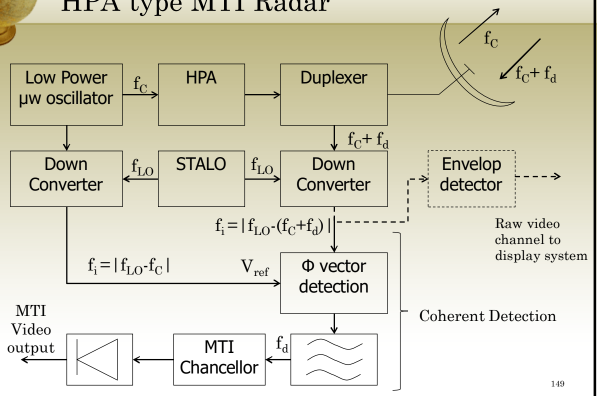
MTI Radar Design Types

- HPA type design
- HPO type design

In both cases, the objective should be that the receiver should be coherent detection with the frequency of pulse transmitted.

148

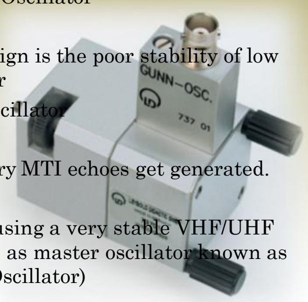
HPA type MTI Radar



149

STALO-Stable Local Oscillator

Weakness in this design is the poor stability of low power μw oscillator
e.g.Gunn Diode Oscillator

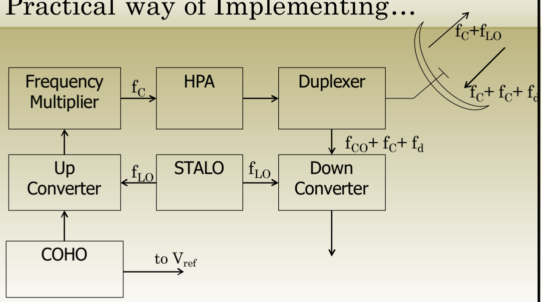


Therefore unnecessary MTI echoes get generated.

This is improved by using a very stable VHF/UHF Crystal Oscillators as master oscillator known as COHO(Coherent Oscillator)

150

Practical way of Implementing…



151

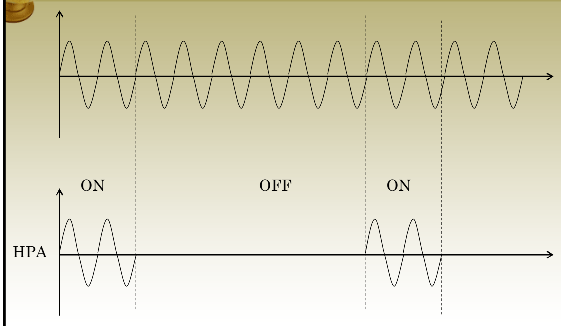
Stability of COHO is very high

STALO<<COHO

Multiplier is not recommended unless it is a very high frequency radar.

If we use multiplexers, we have to provide a corresponding frequency Divider in the receiver.

152

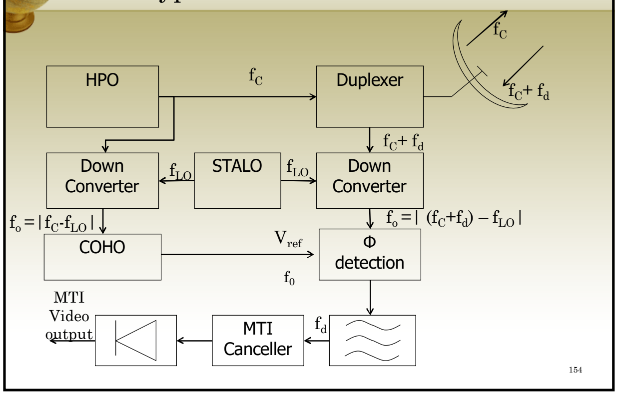


But HPA is turned ON and OFF.

153

153

HPO type MTI Radar



154

154

Display subsystem

Raw Video i/p:

coming from the raw video o/p of conventional Radar (use envelop and threshold detector)

MTI video i/p:

Coming from MTI processing channel

Synthetic Video i/p:

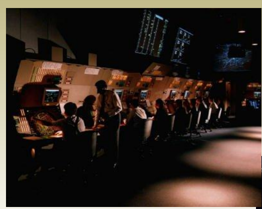
Coming from fixed mapped stored in ROM

e.g. Cities, mountains, firing ranges.

155

155

Radar Operations in ATC



156

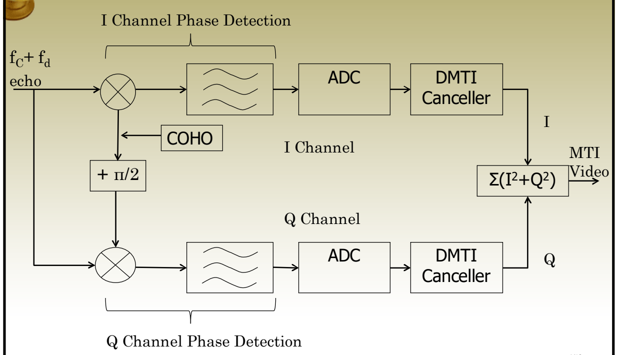
Digital MTI

- MTI canceller in both HPO type and HPA type is also implemented in Digital domain
- It is called a Quadrature DMTI canceller which use phase Quadrature Detection
- Two phase references are used(sin and cosine). Accuracy is higher.

157

157

DMTI



158

158

Velocity Detection Radar

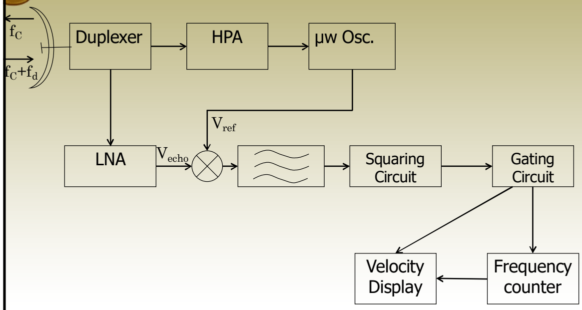
- Continuous waves to measure the velocity
- Since $f_d = 2V_r/\lambda$, V_r can be found by counting f_d
- Can be designed with our without range detection capability

e.g. Police Radar

159

159

Police Radar



160

160

Police Radar contd…

Gating cct stores square pulses over a period of time and calculate how many pulses arrive at a time.

Radar is severely affected by raining.

161

161

Effects of Polarization

Normally we use linear polarization.

- Vertical
- Horizontal

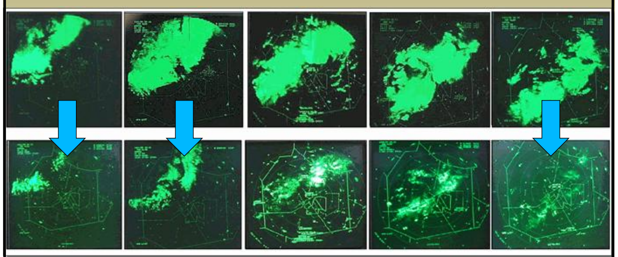
- Better sensitivity and less noise under normal conditions
- Get severely affected by rain,mist,fog, etc.

Circular polarization can overcome this problem and increase the range

162

162

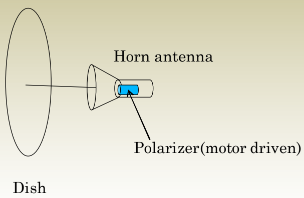
Effect of Circular Polarization



163

163

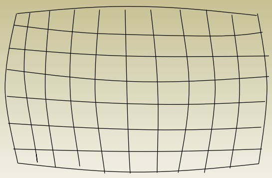
Horn Antenna



164

164

Cosecant Antenna



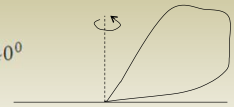
165

165

Radar Beam for surveillance

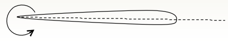
Surveillance Radar need a wider vertical plane beam width to illuminate and capture targets at different altitudes.

$\theta_V = 20^0 - 40^0$



Horizontal Plane beam width should be small as possible

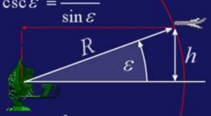
$\theta_H = 1^0 - 3^0$



166

166

$\csc\varepsilon = \dfrac{1}{\sin\varepsilon}$



$R = \dfrac{h}{\sin\varepsilon} = h\cdot\csc\varepsilon$

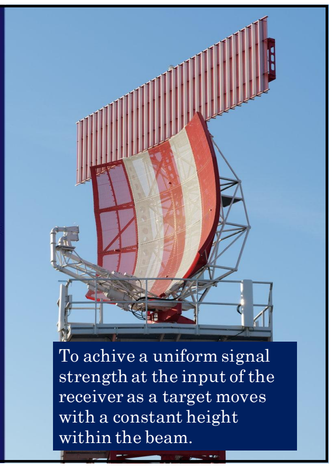
$P_E \sim \dfrac{G^2}{R^4}$ | $P_E = \text{const}$

$G^2 \sim R^4$

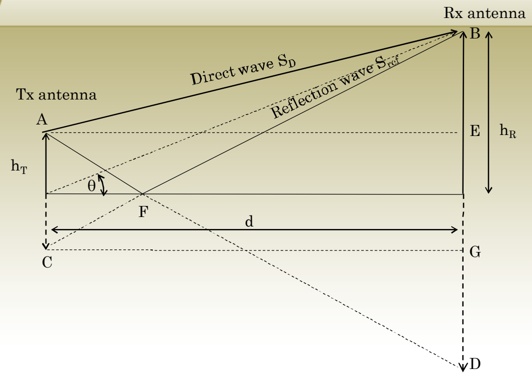
$G \sim R^2$

$G \sim (\cancel{h}\csc\varepsilon)^2$ | $h = \text{const}$

$\boxed{G \sim \csc^2\varepsilon}$



167



168

168

Consider ABEΔ,

$$S_D = \sqrt{d^2 + (h_R - h_T)^2}$$

Consider CBGΔ,

$$S_R = \sqrt{d^2 + (h_R + h_T)^2}$$

$$S_R^{\ 2} - S_D^{\ 2} = (h_T + h_R)^2 - (h_T - h_R)^2$$

$$\underbrace{(S_R - S_D)}_{\Delta d}\underbrace{(S_R + S_D)}_{2d} = 4h_T h_R$$

Since angle is very low(3^0) $S_R \approx S_D \approx d$

$$\Delta d = \frac{2h_T h_R}{d}$$

169

169

Phase Difference

In addition to phase delay, reflected wave has phase lead of 180^0 due to the earth reflection.

Therefore,

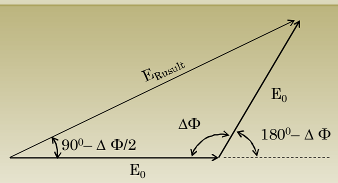
Total phase lead = $180^0 - \left(\dfrac{2\pi}{\lambda} x \dfrac{2h_T h_R}{d}\right)$

$= 180^0 - \left(\dfrac{4\pi h_T h_R}{\lambda d}\right)$

170

170

Resultant Signal



$$E_{Result} = E_0 \sin\left(\frac{\Delta\phi}{2}\right) + E_0 \sin\left(\frac{\Delta\phi}{2}\right)$$

$$E_{Result} = 2E_0 \sin\left(\frac{\Delta\phi}{2}\right)$$

$$E_{Result} = 2E_0 \sin\left(\frac{2\pi h_T h_R}{\lambda d}\right)$$

171

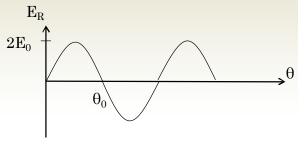
171

From geometry, $\tan\theta = \frac{h_R}{d}$

Since θ is very small, $\theta = \frac{h_R}{d}$

$$E_{Result} = 2E_0 \sin\left(\frac{2\pi h_T \theta}{\lambda}\right)$$

$$E_{Result} = E_{Rx} = 2E_0 \sin(k\theta) \quad where, k = \frac{2\pi h_T}{\lambda}$$



$$k\theta_0 = \pi$$

$$\theta_0 = \frac{\pi}{k} = \frac{\pi\lambda}{2\pi h_T}$$

$$\theta_0 = \frac{\lambda}{2h_T}$$

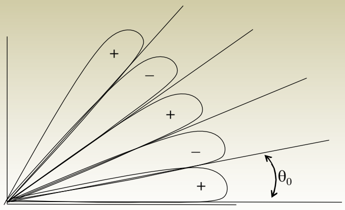
172

172

Radiation Pattern

$$\frac{2\pi h_T}{\lambda} = m\pi$$

$$at\ \theta_0; m = 1 \rightarrow \lambda = 2h_T$$

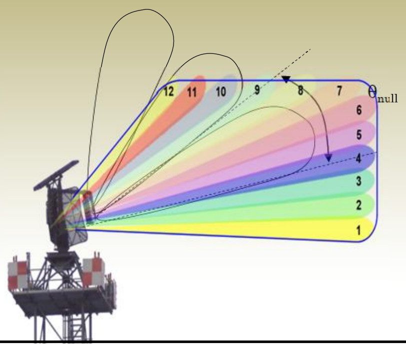


We can radiate the +SBO signal using this beam
It automatically creates the – SBO signal as shown above

173

173

Radar Beam Lobes

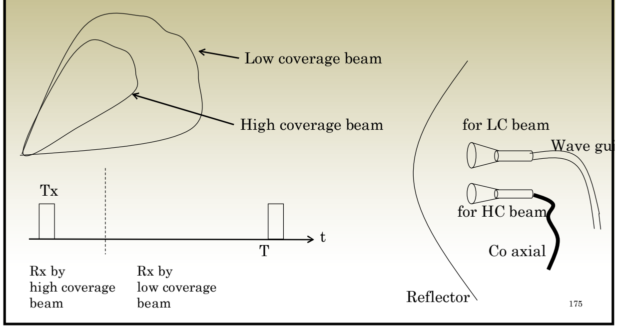


174

174

Beams in Surveillance Radar

Two beams are used in surveillance Radar
One is used for transmission and both are used for reception



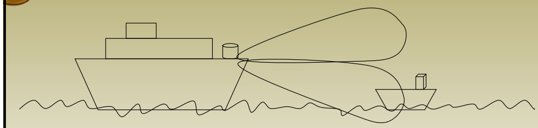
175

175

176

176

Marine Radar



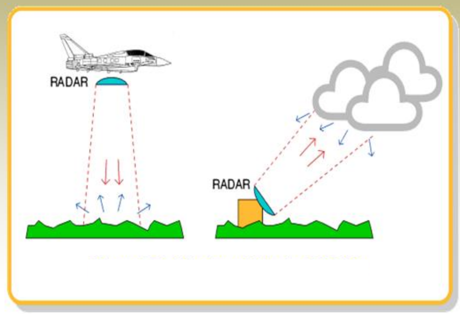
µw X-band(around 10GHz) to get the lobe from the ship down in order to detect smaller ships

Lower lobes get affected by Tide Clutter

177

177

Altimeter & Weather Radar



178

Instrument Landing Systems

Navigational Aids
1. Landing Aids
2. En-Route Navigational Aids

Three major events of a flight.
1. Take-off
2. Flying
3. Landing

(Landing is the event having the highest risk and danger. Therefore high accuracy electronic landing support is required)

179

179

Landing Technologies

- ILS(Instrument Landing System)
- MLS(Microwave Landing System)
- Satellite Based Landing System

ILS is mature and proven. Most air ports prefer to go with existing ILSs

MLS is implemented from 1990 onwards. MLS is superior to ILS but uncommon in market as it is more expensive and ILSs do the job with enough accuracy.

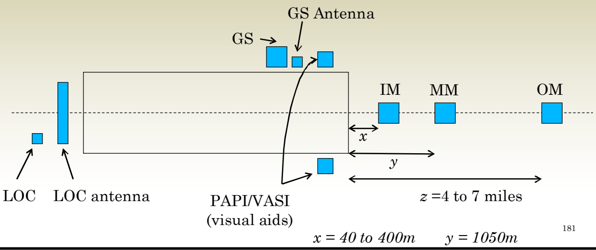
Satellite based landing system is still in under development

180

180

ILS

ILS consists of following equipment
1. Localizer(LOC)
2. Glide Slope(GS)
3. Markers(MKR)



181

181

Landing needs a lot of support

Electronic landing system is called ILS

ILS is a combination of several systems

182

Visual Landing Aids (VLA)

PAPI-Precision Approach Path Indicator
VASI-Visual Approach Path Indicator

- ILS is a Radio Landing Aid(RLA).
- VLAs are available with ILS for double check.
- Red, Green and Amber colour beams are used
- Disturbed by rain, fog, or mist.
- Range is limited compared to ILS

183

183

ILS Consists of...

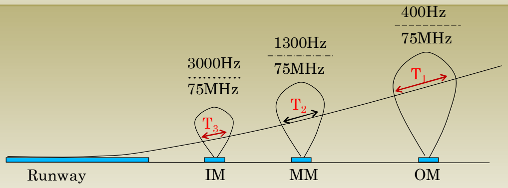
1. Localizer(LOC) is a VHF radio(108-118MHz)
2. Markers(MKR) are also VHF(75MHz)
3. Glide Slope(GS) is UHF (335-1000 MHZ)

Low frequencies are used to penetrate bad weather and achieve a steady range under different weather conditions..

184

184

Markers



Provide proximity indication to the pilot w.r.t. runway

Both visual and oral indications are given over.

185

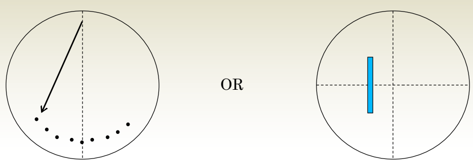
185

Navigational Parameters

186

Localizer(LOC)

- Guidance in the horizontal plane to align the air craft with the extended runaway centre line.
- Indication is provided in the form of fly left or fly right pointers
- Fly to the needle rule.



Type1 Type2

187

187

Localizer principles

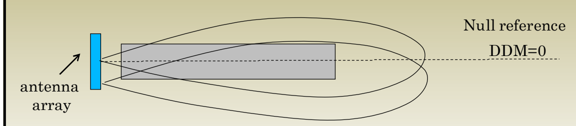
Two types of localizers

1. Single Frequency Null Reference Localizer
2. Dual Frequency Null Reference Localizer

188

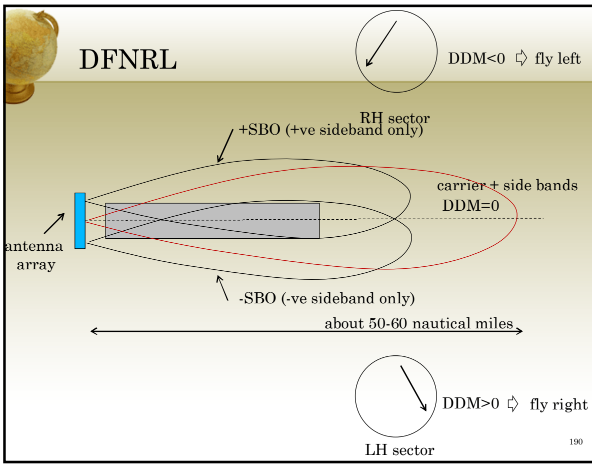
188

SFNRL



189

DFNRL



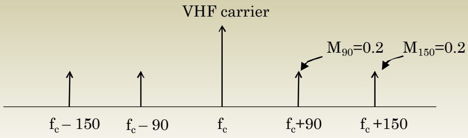
190

LOC Antenna at the End of the Runway

191

Main Beam/Lobe : (C+SB) Signal

The main beam radiates the VHF carrier modulated by 90Hz and 150Hz tones to the same depth of 0.2 using AM



192

DDM and SDM of Main Lobe

Modulation Index of AM signal= $\frac{\text{Amp. Of the Modulated signal.}}{\text{Amplitude Of the carrier}}$

$$M = E_m/E_c$$

Here; Modulation Index = 0.2 (standard)

Deference of Depth of Modulation(DDM) = 0.2 – 0.2 = 0

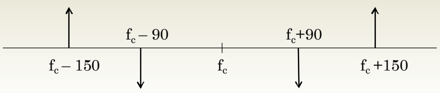
Sum of Depth of Modulation(SDM) = 0.2 + 0.2 = 0.4

193

+SBO Signal

SBO signals are DSBSC modulated by the same two tones. However the phase of the two tones are as follows;

+ SBO Signal 150Hz, 0^0 Phase
90Hz, 180^0 Phase

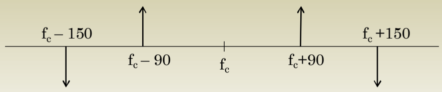


Note : 180^0 phase shift is represented by negative amplitude

194

–SBO Signal

–SBO Signal 150Hz, 180^0 Phase
90Hz, 0^0 Phase



The inverse of +SBO is –SBO

– SBO can be obtained by sending +SBO signal by λ/2 cable section

195

195

Reception

The air craft localizer receives the combination/ summation of 3 the signals mentioned above.

a) Along the extended runway centre line
+SBO and –SBO cancel each other and only C+SB signal will remain.

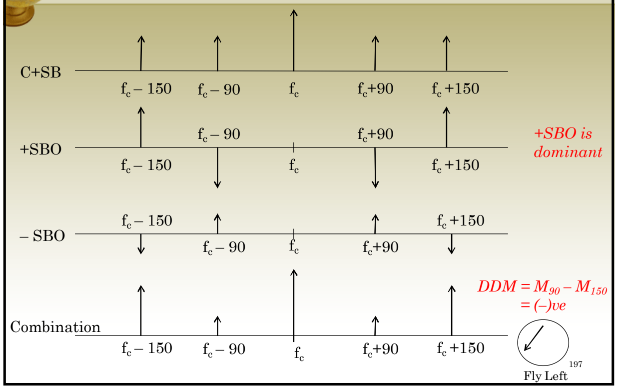
Therefore, DDM=0 and SDM=0.4

SDM is to double check whether equipment is working properly.

196

196

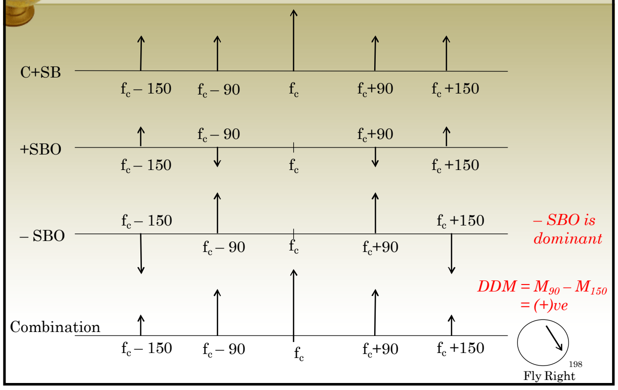
Reception of the RH Sector



197

197

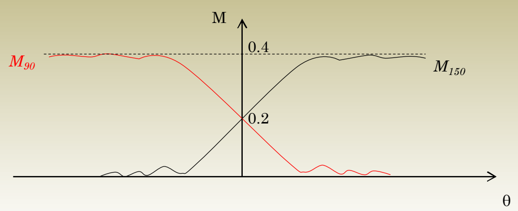
Reception of the LH Sector



198

198

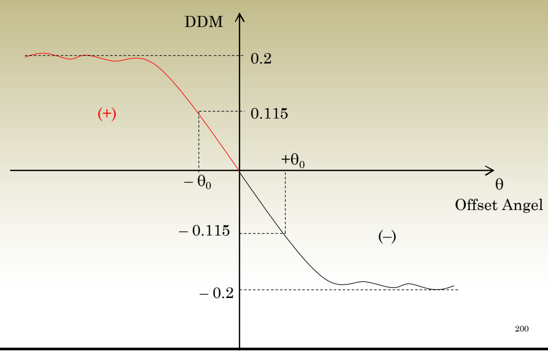
Modulation depth with offset angle



199

199

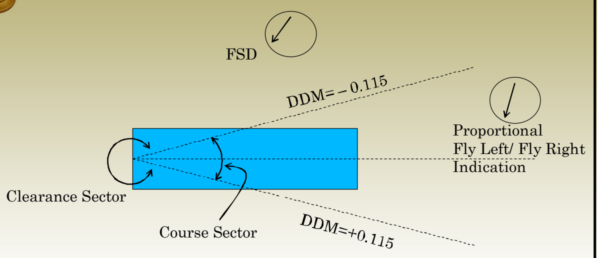
Variation of DDM with offset angle



200

200

Full Scale Deflection(FSD)



201

201

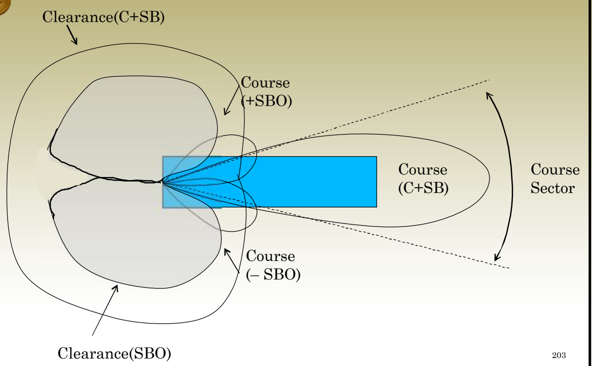
FSD

- 0.115 is the Maximum DDM value for Fly Left or Fly Right
- In the clearance sector, only full scale indications are available
- This technique may look very reliable, but practically reflection from hanger, and side lobes of antenna array will cause problems
- The solution is to transmit another pattern called clearance pattern on an offset carrier

202

202

Clearance pattern



203

203

Within course sector,

The course pattern should be at least 10dB higher than the clearance pattern. Then the course carrier will capture the receiver.

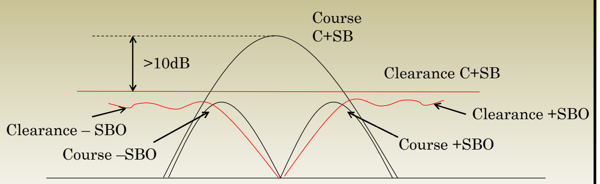
Outside the course sector,

The clearance captures the Rx and provide only full scale fly left or fly right indication

204

204

Clearance Patterns of Rx



205

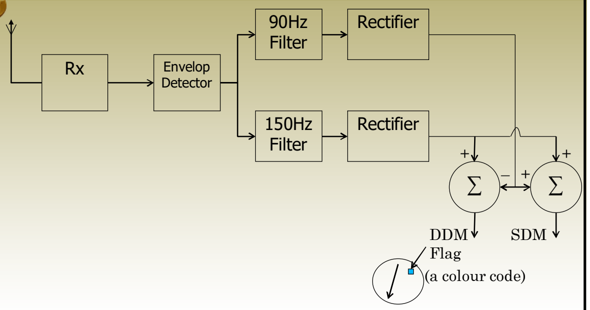
205

- When captured by clearance carrier, DDM indicates only full-scale fly left or fly right.
- Weaker side lobes and reflections are therefore suppressed by the clearance signal.

206

206

Receiver Block Diagram



207

207

208

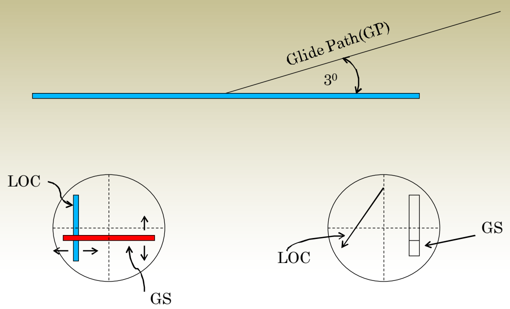
Glide Slope(GS)

- Provides the glide path in the vertical plane
- It is a UHF equipment that radiates signal to guide the air crafts in the vertical plane.
- Give fly-up or fly-down indication
- The recommended glide angle is 3^0.
- Considering this as a reference proportional fly-up and fly-down guidance is provided

209

209

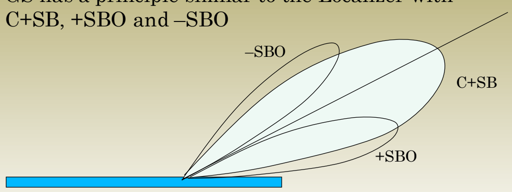
Glide Slope(GS)



210

210

GS has a principle similar to the Localizer with C+SB, +SBO and –SBO

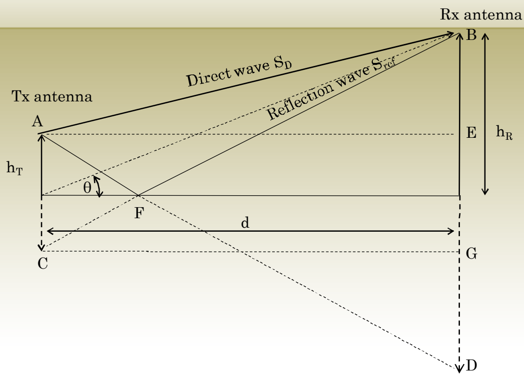


- Vertical movement is very critical
- The scale sensitivity should be high
- The depth of modulation is 0.4

$$M_{90} = M_{150} = 0.4$$

211

211



212

212

Consider ABE∆,

$$S_D = \sqrt{d^2 + (h_R - h_T)^2}$$

Consider CBG∆,

$$S_R = \sqrt{d^2 + (h_R + h_T)^2}$$

$${S_R}^2 - {S_D}^2 = (h_T + h_R)^2 - (h_T - h_R)^2$$

$$\underbrace{(S_R - S_D)}_{\Delta d}\underbrace{(S_R + S_D)}_{2d} = 4h_T h_R$$

Since angle is very low(3^0) $S_R \approx S_D \approx d$

$$\Delta d = \frac{2h_T h_R}{d}$$

213

213

Phase Difference

In addition to phase delay, reflected wave has phase lead of 180^0 due to the earth reflection.

Therefore,

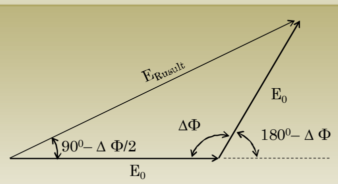
Total phase lead = $180^0 - \left(\frac{2\pi}{\lambda} x \frac{2h_T h_R}{d}\right)$

$= 180^0 - \left(\frac{4\pi h_T h_R}{\lambda d}\right)$

214

214

Resultant Signal



$$E_{Result} = E_0 \sin\left(\frac{\Delta\phi}{2}\right) + E_0 \sin\left(\frac{\Delta\phi}{2}\right)$$

$$E_{Result} = 2E_0 \sin\left(\frac{\Delta\phi}{2}\right)$$

$$E_{Result} = 2E_0 \sin\left(\frac{2\pi h_T h_R}{\lambda d}\right)$$

215

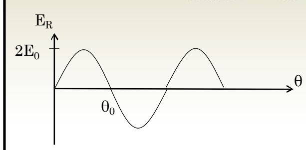
215

From geometry, $\tan\theta = \frac{h_R}{d}$

Since θ is very small, $\theta = \frac{h_R}{d}$

$$E_{Result} = 2E_0 \sin\left(\frac{2\pi h_T \theta}{\lambda}\right)$$

$$E_{Result} = E_{Rx} = 2E_0 \sin(k\theta) \quad where, k = \frac{2\pi h_T}{\lambda}$$



$$k\theta_0 = \pi$$

$$\theta_0 = \frac{\pi}{k} = \frac{\pi\lambda}{2\pi h_T}$$

$$\theta_0 = \frac{\lambda}{2h_T}$$

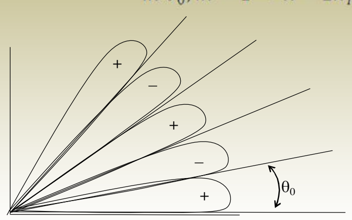
216

216

Radiation Pattern

$$\frac{2\pi h_T}{\lambda} = m\pi$$

$$at\ \theta_0; m = 1 \rightarrow \lambda = 2h_T$$

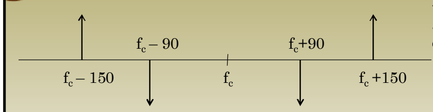


We can radiate the +SBO signal using this beam
It automatically creates the – SBO signal as shown above

217

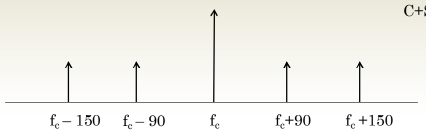
217

+SBO Signal



+SBO is fed to the antenna, it automatically creates – SBO

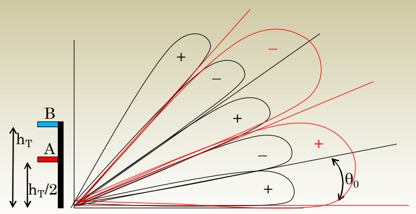
C+SB Signal



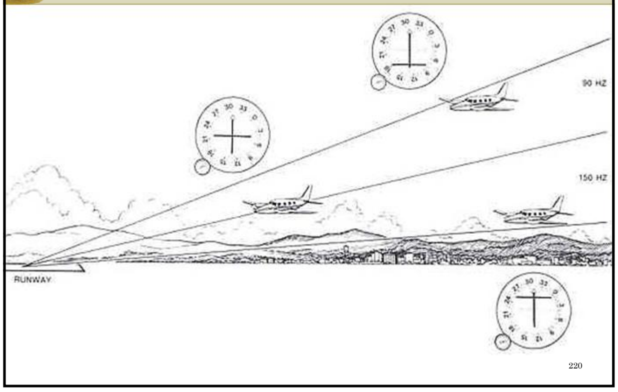
C+SB to antenna A

218

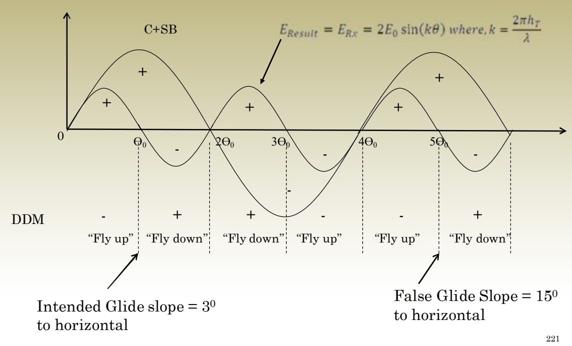
218



219

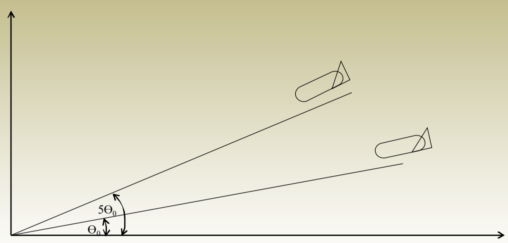


220



221

False Glide Slope



222

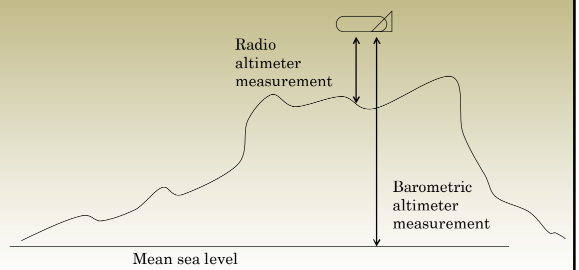
Measures to avoid false GS

1. Localizer beams are made more powerful than the GS beams.

   Aircrafts will first receive the LOC beams at long distance and achieve horizontal plane alignment at a given height and then makes a level flight towards runaway until it receives a GS beam.

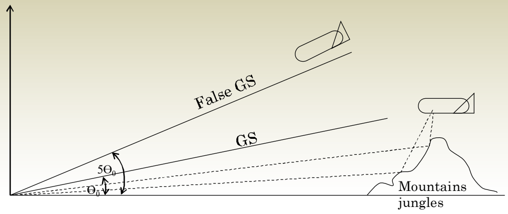
2. While descending, the radio altimeter calculates the descend and use an alarm if it is $5\Theta_0$

223



224

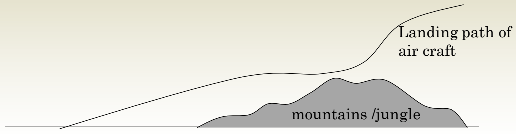
- If the ground is uneven along extended runway centerline SBO & C+SB signals may get reflected
- This may cause unsteadiness in the readings and some unwanted GS.



225

225

- Transmit power is reduces below 1^0 angle not to illuminate the unevenness.
- M-array is designed to reduce illumination at low angles and there by avoid the problems of course bending.

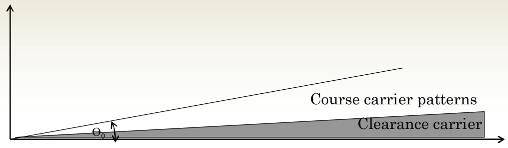


226

226

GS Clearance Signal

- Clearance signal has a full scale DDM to indicate fly-up to full scale.
- It is transmitted with an offset of Δf which is typically 18kHz.
- This should be strong below 1^0 angle($\Theta_0/3$)
- Air craft receiver will capture clearance signal up to 1^0.
- Above 1^0 angle, it will capture course carrier(f_c)



227

227

228

228

M-Array Design

$$R_{A2} = \sin\left[\left(\frac{\pi}{\theta_0}\right)\theta\right]$$

$$R_{A1} = \sin\left[\left(\frac{\pi}{2\theta_0}\right)\theta\right]$$

$$R_{A3} = \sin\left[\left(\frac{3\pi}{2\theta_0}\right)\theta\right]$$

	C+SB	SBO	Clearance
A1	$2<0^0$	$1<\pi$	$1<0^0$
A2	$1<\pi$	$2<0^0$	-
A3	-	$1<\pi$	$1<0^0$

Signal radiation patterns in the sky can be found in following manner.

$$R_{(C+SB)} = 2R_{A1} - R_{A2}$$

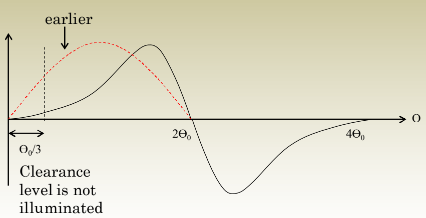
$$R_{SBO} = -R_{A1} + 2R_{A2} - R_{A3}$$

$$R_{Clearance} = R_{A1} + R_{A3}$$

229

229

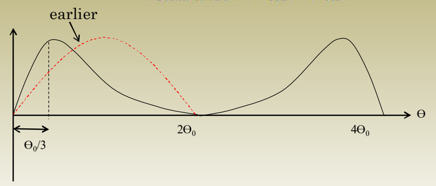
$$R_{(C+SB)} = 2R_{A1} - R_{A2}$$



230

230

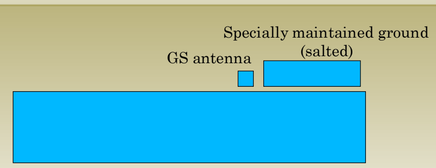
$$R_{Clearance} = R_{A1} + R_{A3}$$



231

231

Specially maintained ground

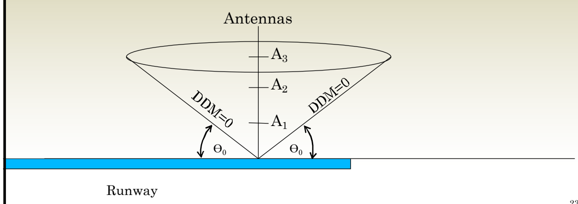


After every 6 months the specially maintained ground should be salted to get proper reflection

232

232

- GS antenna is fixed to the side of runway, instead of the landing path.
- It allows a smoother landing(along the cone, DDM=0 line) as shown below.



233

233

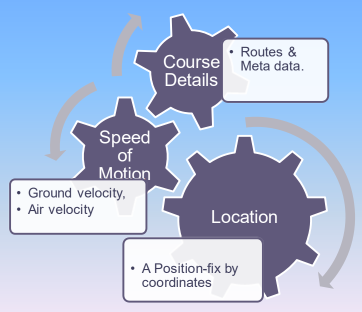
Electronic Navigational Aids

Navaids supply the navigator or the control center at an airport or seaport with required navigational parameters

Navigates on behalf

234

Navigational Parameters

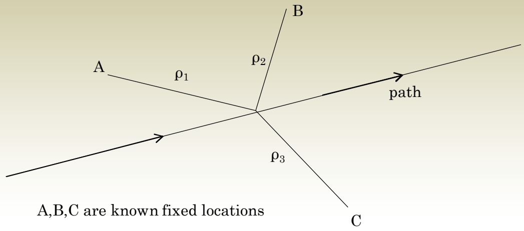


235

En-route Navigation

Continuously identify the position of a vehicle with respect to known locations on the path

1) Rho-Rho-Rho Navigation(Triangulation)



A,B,C are known fixed locations

When ρ_2, ρ_2, ρ_2 is known we have the position fixed

236

236

LORAN

Long Range Navigation System

- Low frequencies (10kHz-14kHz) are used
- High accuracy because of phase change accuracy of low frequencies while they propagate.
- There are eight LORAN stations strategically placed to cover entire world
- Disadvantage-large antennas→ cost↑

237

237

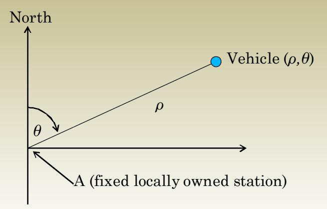
GPS

- Rho-Rho-Rho technique.
- But GPS gives a 3D location
- A,B,C are fixed in LORAN, but in GPS A,B,C, (satellites) are on the move.
- At least 4 satellites are needed.

238

238

2) Rho-theta Navigation



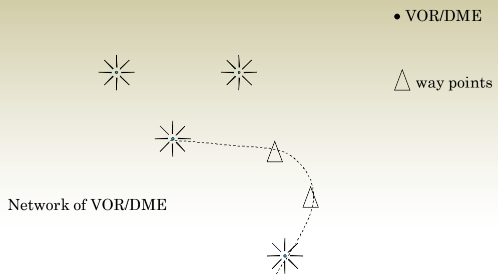
To make a global system , a combined effect of a large no of locally owned stations are used.

These stations are known as VOR(VHF Omni Range)/DME(Distance Measuring Equipment) systems

239

239

VOR =>θ
DME =>ρ

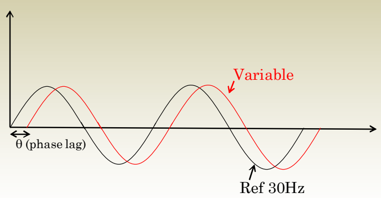


240

240

VOR(VHF Omni Range)

- Frequency: 108-118MHz given by ICAO(International Civil Aviation Organization)
- In Sri Lanka Freq: 112.7MHz

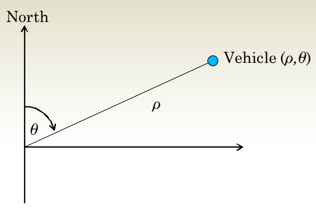


241

241

- The reference signal is received with the same phase at every position.
- The variable 30Hz signals phase differs from place to place.

e.g. if the phase difference is 90^0 →East



242

242

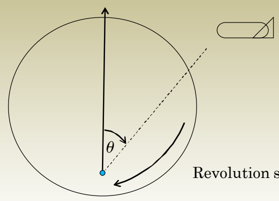
243

Conventional VOR

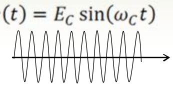
Radiation is done by an antenna which has Limacon offset

244

Unmodulated VHF carrier is spread to a rotation Limacon radiation pattern and then identify signal in a vehicle.

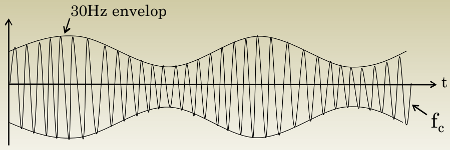


$e(t) = E_C \sin(\omega_C t)$



245

Received signal at the air craft in the time domain, assume air craft is stationary



$$U_{RX} = E[1 + m\sin(\omega_m t)]\sin(\omega_C t)$$

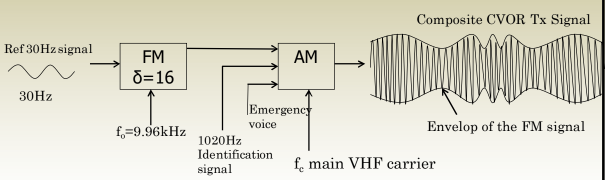
246

- The received signal will be a 30Hz AM Signal.
- This can be considered as AM happening in space.
- Known as Space Amplitude Modulation.
- $m\sin(\omega_m t)$ will vary according to planes location,
- Received : $m\sin(\omega_m t - \theta)$

Transmission is unmodulated but variable 30Hz signal get modulated on the carrier due to the rotation of the "Limacon". Therefore received signal has the AM envelop. This concept is called the "Space AM".

247

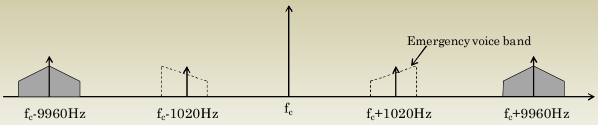
- The reference 30Hz signal should be same at every point.
- So we send it on a subcarrier which is modulated on the same carrie



Identification code is 3 letter Morse code which helps to locate the station

248

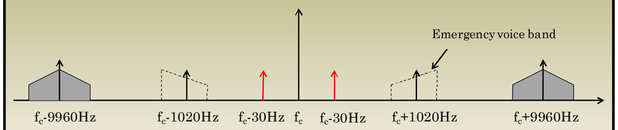
Composite Tx VOR signal



249

249

Composite Rx VOR signal



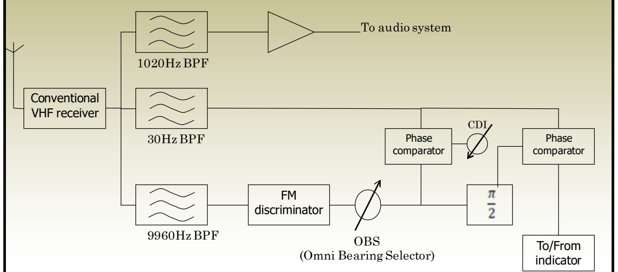
Ident code — FM sub carrier — Space AM

$$V_{RX} = E[1 + x_1(t) + x_2(t)\sin\omega_1 t + M_1\sin(\omega_c t - \delta\cos\omega_m t) + M_2\sin(\omega_m t - \theta)]\sin\omega_c t$$

emergency — $2\pi x1020Hz$ — $2\pi x9960Hz$ — $2\pi x30Hz$

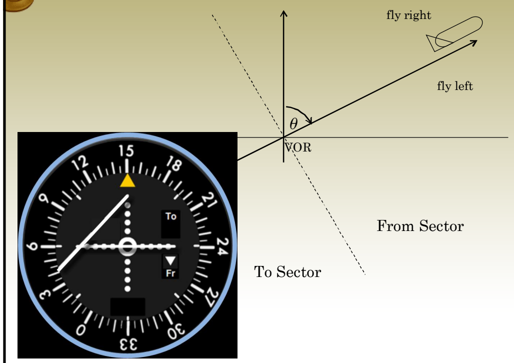
250

250



251

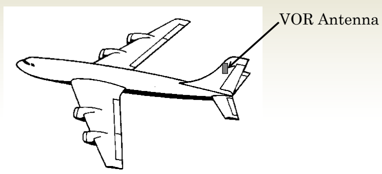
251



252

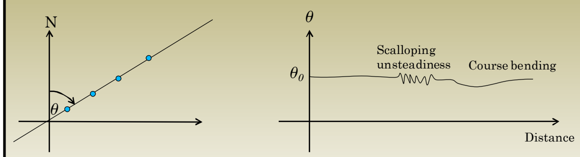
252

- OBS is a phase adjustment that can be used by pilot to adjust the reference space from north.
- Usually, it is adjusted to the Radial of the flight path
- Then CDI will directly indicate the course offset
- Plane is provided the indication of *"To Sector"* or *"From Sector"*



253

253



Disadvantage
- 600m radius from the equipment should be completely cleared of any obstacle, else course bending or scalloping results.

254

254

VOR's are normally installed along the extended runway centerline, means the runway is a particular radial.

When the plane is landing, it first receives VOR, then LOC and at last GS

255

255

256

256

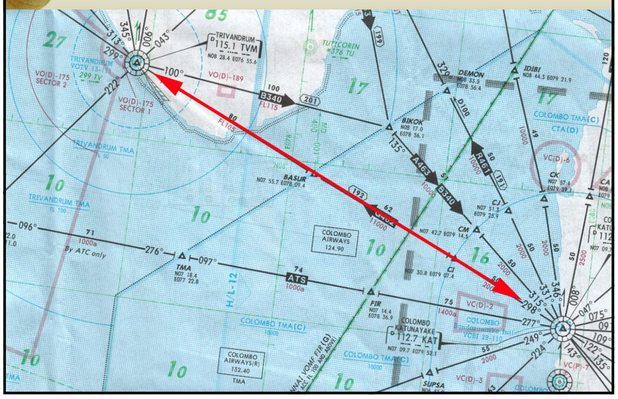
257

257

258

258

Flight Route between Katunayaka (VCBI) and Trivandrum (VOTV)



259

260

260

Investigation topics

1. Secondary Radar
2. SAR (Synthetic Aperture Radar)
3. Weather Radar
4. Radio Altimeter
5. ADS
6. Monopulse traking
7. Cognitive cockpit
8. OTH Radar
9. Collision Avoidance
10. INS
11. Software Defined Radar
12. FANS
13. GPS

261

261

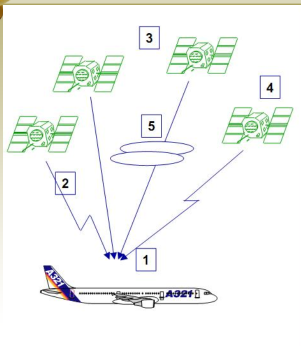
Satellite based Navigation Systems

- In ICAO terminology, satellite navigation is termed GNSS
  - GNSS stands for Global Navigation Satellite System
- GNSS includes all satellite navigation systems and relevant ground augmentations systems to be used by civil aeronautical users..
  - GPS, GLONASS, GALILEO
  - ABAS, SBAS, GBAS, GRAS

262

262

Key Points…



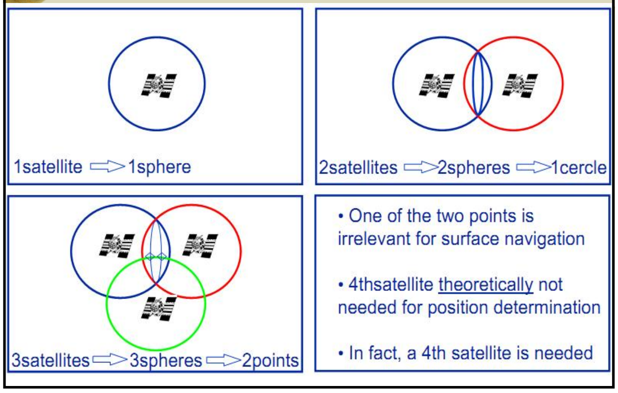
Key points :

- 1 **Position is determined by triangulation**
- 2 **Measurement of satellite-user range**
- 3 **Knowledge of exact time**
- 4 **Knowledge of satellites position**
- 5 **Error sources**

263

263

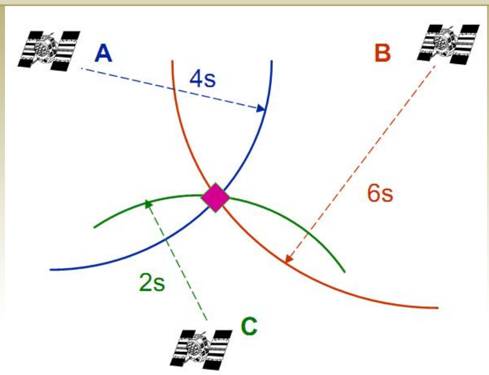
1. Triangulation



- One of the two points is irrelevant for surface navigation
- 4thsatellite theoretically not needed for position determination
- In fact, a 4th satellite is needed

264

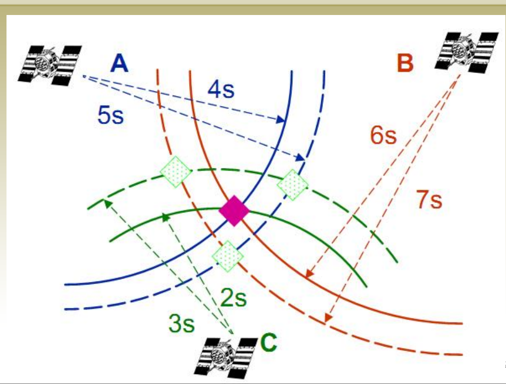
3. Time Measurements if synchronized



265

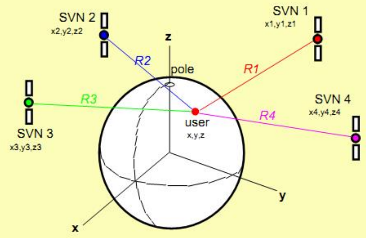
265

Time Measurements : non-synchronized



266

266

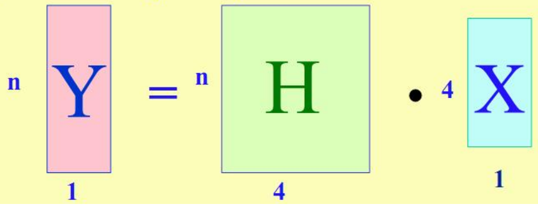


$$\sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2} + c.bu = R'i$$

267

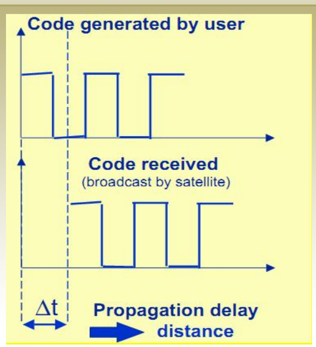
$$R'i = \sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2} + c.bu$$

The n equations are linearized around an estimated position to yield the following linear system



268

2. Measurement of Range from each Satellite



269

4. Knowledge of Satellite Position

- The satellite position at the signal emission time is needed to compute the user position.
  - As a satellite follows the physical laws of space mechanics, its trajectory (i.e. the orbit) is perfectly predictable and can be represented by few parameters : the ephemeris
  - The satellites broadcast the ephemeris data and its position is computed by the user receiver using these data

270

4. Knowledge of Satellite Position

- However satellites do not follow exactly the intended orbits (atmospheric perturbations, solar radiation...)
  - Real time ephemeris data are determined by the ground segment using satellite measurement and orbit determination techniques.
  - These data are then uploaded to the satellites which broadcast them to the users
- Ephemeris data are broadcast to users in the navigation message that is added to the pseudorandom code used for distance measurement.

271

Error Sources

1. Ephemeris Data
2. Atomic Clocks
3. Ionospheric and Tropospheric Delays
4. Multi-paths
5. Receiver Noise

272

Errors…

ERROR ON PSEUDO-RANGE MEASUREMENT	
SATELLITE CLOCK	3 m
SATELLITE EPHEMERIS	4 m
PROPAGATION IONOSPHERE	6 m
PROPAGATION TROPOSPHERE	2 m
MULTIPATH	1 m
RECEIVER NOISE	1 m
σ U.E.R.E	17 m

273

273

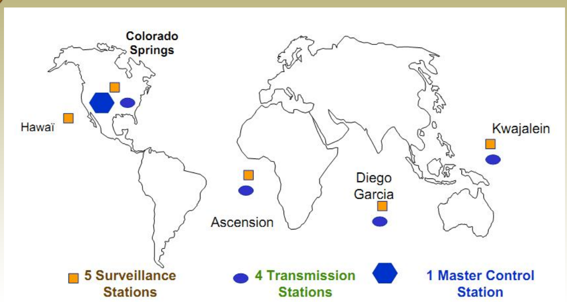
GPS System Architecture

1. Control System
2. User System
3. Space Segment

274

274

Control System



275

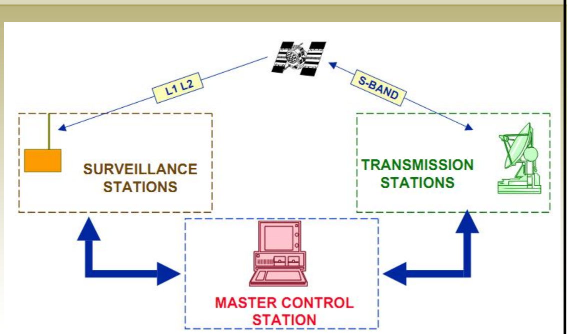
275

GPS System Architecture

3 SEGMENTS	INPUT	FUNCTION	OUTPUT
CONTROL SEGMENT	*Signals from satellites (data + telemetry)* *UTC time* *Other terrestrial data*	Time calibration Ephemeris prediction Constellation management	*Navigation message* *Commands*
SPACE SEGMENT	*Navigation message* *Commands*	Satellite atomic time generation PRN codes generation Navigation message storage & emission	*RF signals & PRN codes* *Navigation message* *Telemetry signals*
USER SEGMENT	*RF signals & PRN codes* *Navigation message*	Resolves the PVT equations	*Position* *Velocity* *Time*

276

Control System



277

277

Space Segment

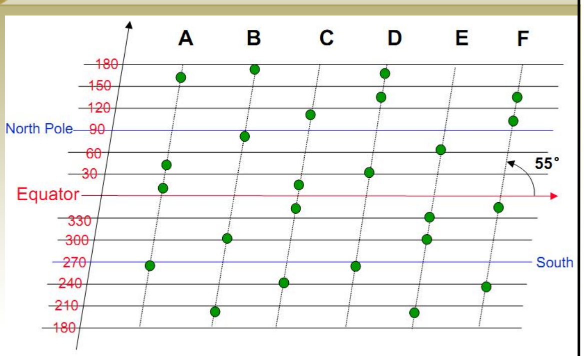
24 CONSTELLATION SATELLITES (21 Active + 3 Spares)
- Operational since September 1994
- Orbiting Satellites (circular orbits)
- 6 orbital planes : inclined at 55 degrees
- Altitude 20200 Kilometres
- Revolution period 11H 58mn
- Linear speed 3900 m/s
- 6 to 10 satellites in view at earth surface level

SEVERAL TYPES OF SATELLITES
- Block I (no longer)
- Blocks II A and II R
- Blocks IIF (Final sat sent in 2016) and IIIA (2020)

278

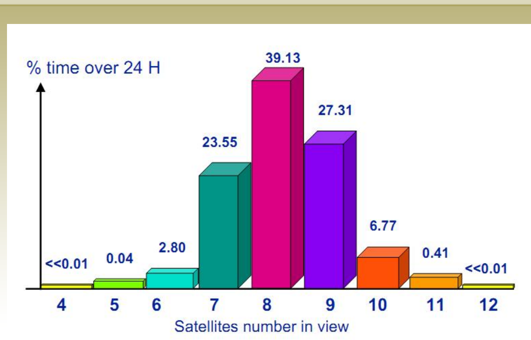
278

Constellation



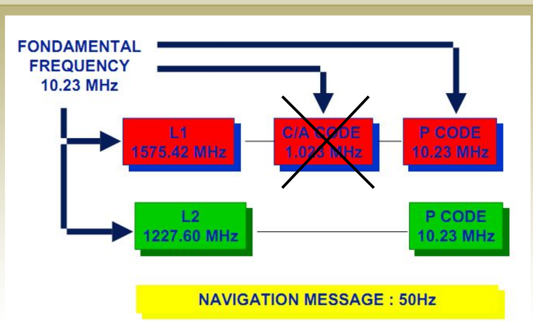
279

Satellites in View



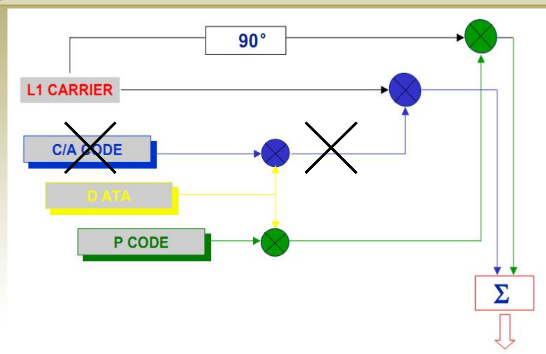
280

Transmitted Signal



281

Transmitted Signal : L1 Modulation



282

Navigation Message

- Contains the necessary data to allow the user receiver to compute the position
  - Almanac
    - raw parameters to roughly compute other satellites' position
  - Ephemeris
    - detailed parameters to accurately compute the satellite's position
  - Parameters for ionospheric model, clock corrections, ….

283

283

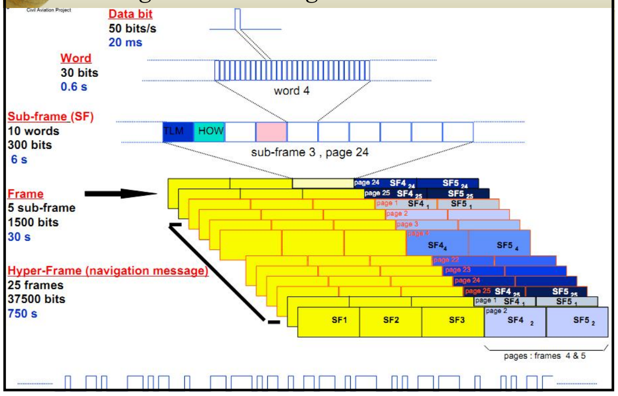
Navigation Message

- Superposed to P Code
- Transmitted at 50 bits per second
- Identical on L1 & L2 carriers
- Made of 25 frames of 37500 bits
- Duration of 12.5 minutes

284

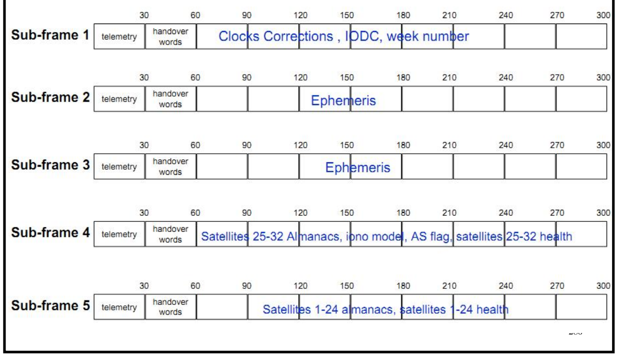
284

Navigation Message Structure



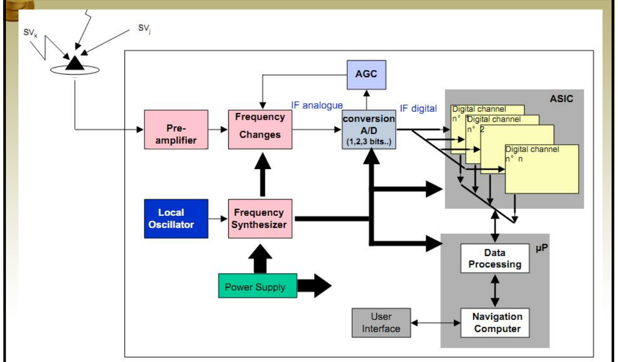
285

Nav Message : Frame Details



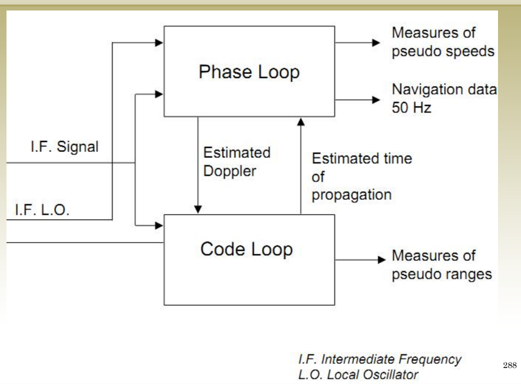
286

User Segment : GPS Receiver



287

Processing Channel



288

Secondary Surveillance Radar (SSR)

289

Drawbacks of PSR

- High Power Output is required
- Clutter
- No automatic identification of the A/C
  - Voice
  - Requested manure is required
- Normally altitude is not given
- No data/information link is set up

290

Secondary Surveillance Radar

- Usually co-located with a PSR
- SSR Interrogator is on the ground
  - Interrogator has a directional beam
- SSR Transponder is on board of A/C
  - Transponder has an omnidirectional beam
- Several modes of interrogation

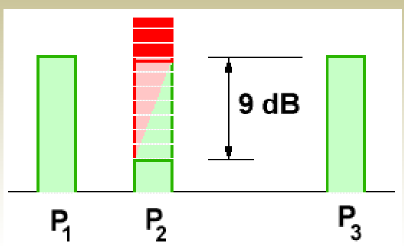
291

Interrogation

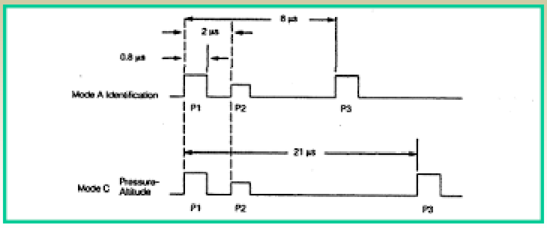
- Carrier = 1030 MHz : Universal
- Two pulse Interrogation P1 & P3
- Pulse spacing gives the mode.
  - Mode A = 8 µS : Identity
  - Mode B = 17 µS : Identity
  - Mode C = 21 µS : Altitude
  - Mode D = 25 µS : Unassigned
- Pulse width os 0.8 µS.
- Max. interrogation rate is 450.

292

Interrogation



293



294

Interrogation (Cont.)

- Peak Power around 1 kW
- Vertical Polarization
- Airborne Transponder should have a minimum peak power of 500 Watts
- Reply rate capability is 1200 replies per second

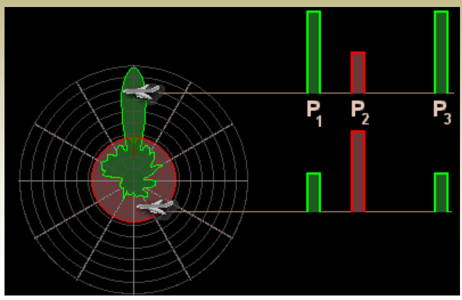
295

Side Lobe Suppression

- P1 & P3 are sent through the directional beam
- P2 goes thro' an omnidirectional low gain beam
- P1 to P2 : 12 µS gap
- Threshold is set to 9 dB.

296

SLS



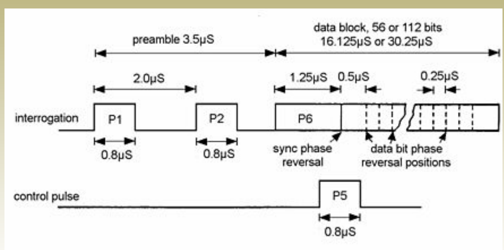
297

Reply

- Reply is framed between two framing pulses F1 & F2
- F1 = F2 = 0.45 µS
- Coded reply (12 pulses) on 1090 MHz
  - 3 bit code for each digit sent.
- F2 is followed by a SPI pulse
  - ABCD = 7600 :Radio Failure
  - ABCD = 7700 : Emergency

298

Mode S for Data Communication

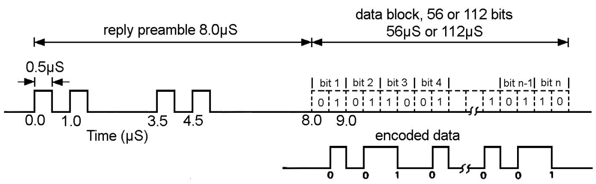


- Three pulses P1, P2 & P6
- P5 is for sidelobe suppression

299

Mode Reply

- Data block can have 56 or 112 bit packets/blocks.
- 8 µS preamble consisting of 4 pulses
- Descriptor and Block parity (24 bit) is essential.



300

Mode S Enhanced

- Mode S can be configured as Mode S Elementary Surveillance (ELS) or Enhanced Surveillance.
- Enhanced Surveillance (EHS) includes Downlink Aircraft Parameters (DAP) in the information returned
- While ELS allows for selective interrogation of a Mode S transponder to obtain barometric altitude, EHS allows also to request DAP.
- The use of DAP is expected to limit voice communication between ATC and crews.

301

Downlink Aircraft Parameters (DAP)

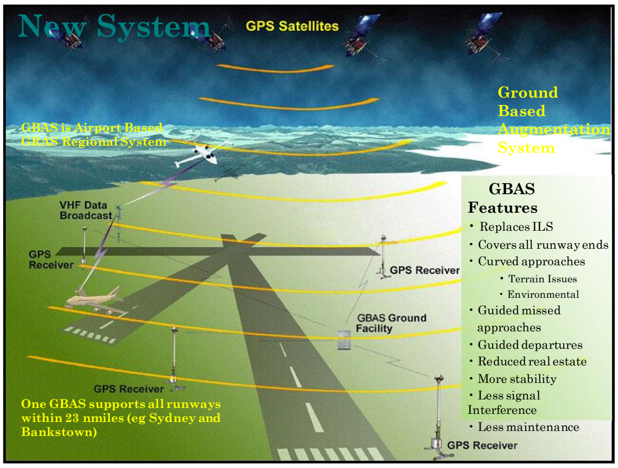
BDS Register	**Basic DAP Set** (if Track Angle Rate is available)	**Alternative DAP Set** (if Track Angle Rate is **not** available)
BDS 4,0	Selected Altitude	Selected Altitude
BDS 5,0	Roll Angle	Roll Angle
	Track Angle Rate	
	True Track Angle	True Track Angle
	Ground Speed	Ground Speed
BDS 6,0	Magnetic Heading	Magnetic Heading
	Indicated Airspeed (IAS) / Mach no. (Note: IAS and Mach no. are considered as 1 DAP (even if technically they are 2 separate ARINC labels). If the aircraft can provide both, it must do so).	Indicated Airspeed (IAS) / Mach no. (Note: IAS and Mach no. are considered as 1 DAP (even if technically they are 2 separate ARINC labels). If the aircraft can provide both, it must do so).
	Vertical Rate (Barometric rate of climb/descend or baro-inertial)	Vertical Rate (Barometric rate of climb/descend or baro-inertial)
		True Airspeed (provided if Track Angle Rate is not available)

302

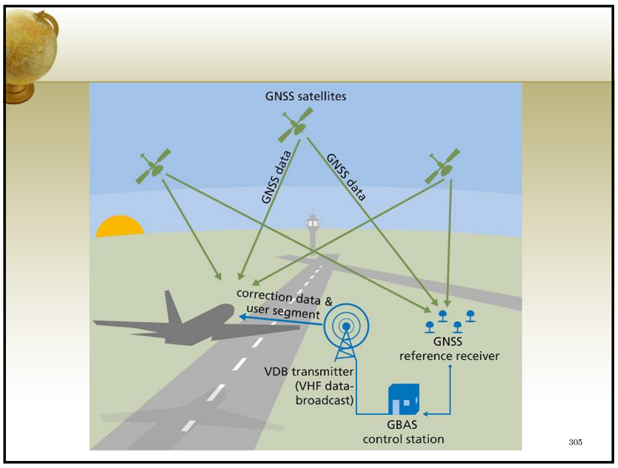
FANS Benefits

1. Reduced separation between airplanes.
2. More efficient route changes.
3. Satellite communication.
4. No altitude loss when crossing tracks.
5. More direct routings.

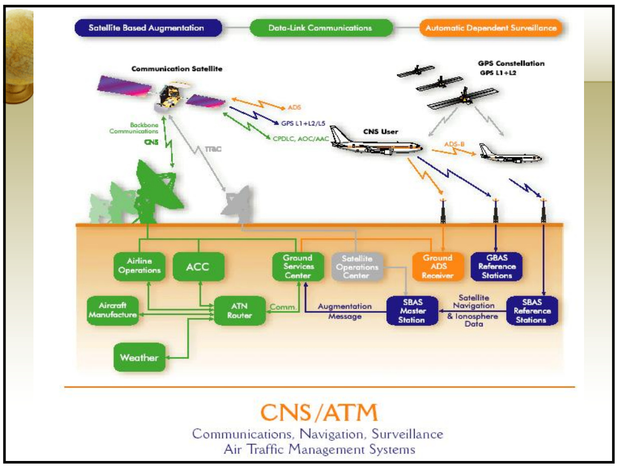
303



304



305



306

307

308

Investigation topics

1. SAR (Synthetic Aperture Radar)
2. Weather Radar
3. Radio Altimeter
4. ADS-B
5. Monopulse traking
6. Cognitive cockpit
7. OTH Radar
8. Collision Avoidance
9. INS
10. Software Defined Radar
11. FANS
12. GBAS Implementation
13. SBAS Implementation
14. I-SAR

309

309