RADAR WORKSHOP

Presented by

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RADAR WORKSHOP
Introduction to Radars

- Topics
  - EM Spectrum
  - Plane Waves
    - Attenuation Characteristics
  - Radar Equation
    - Point target
    - Plane Reflector
    - Distributed target
  - Examples
- Pulse compression
  - Principle
  - Range sidelobes
    - Solutions
  - SAR
    - Principle
    - Range equation

Radars

- Radar
  - Radio Detection and Ranging.
  - Texts:
    - Stimson, G. W., "Introduction to Airborne Radar", SciTech Publishing, 1998.
    - Skolnik, M. I., "Introduction to Radar Systems", McGraw Hill, 1981.

Applications

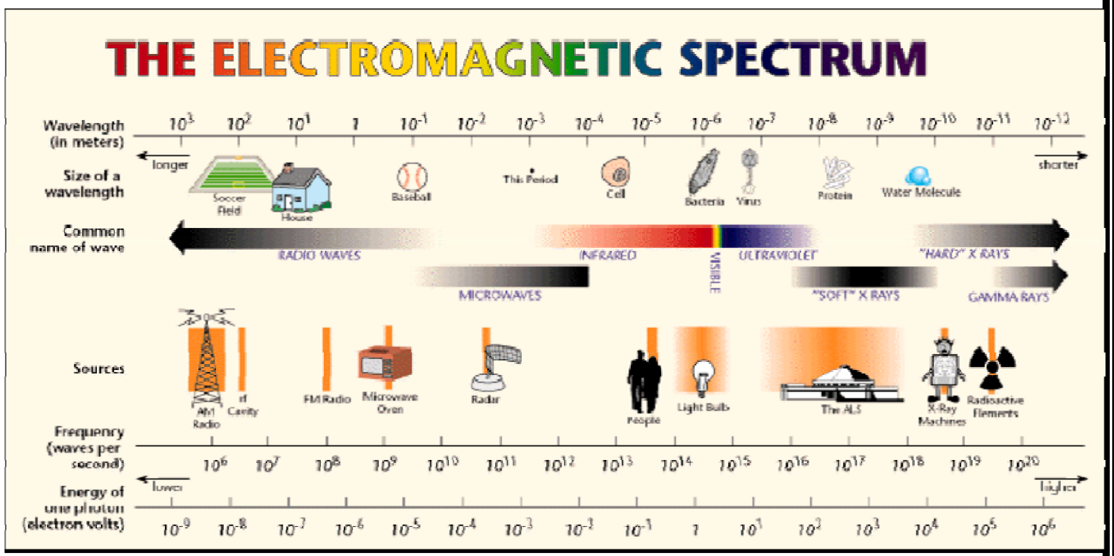
Civilian

- Navigation and tracking
- Search and surveillance
- Imaging & Mapping
- Weather
- Sounding/imaging
- Probing
- Remote sensing

Military

- Navigation and tracking
- Search and surveillance
- Imaging & Mapping
- Weather
- Proximity fuses
- Counter measures

EM Spectrum



http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html

Sounders/imagers

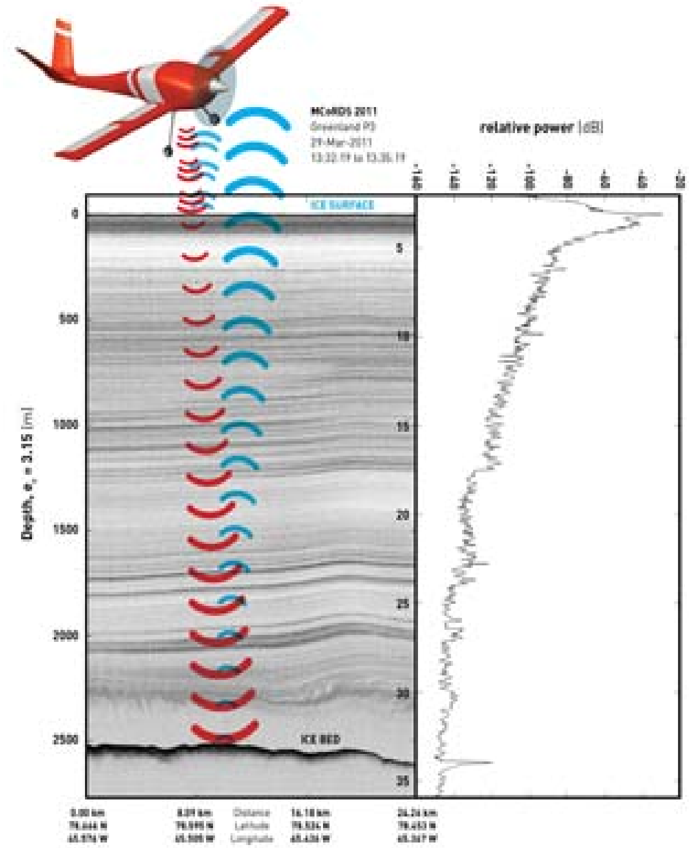
- 1-1000 MHz
  - Temperate ice
    - LF and HF
  - Ice sheets
    - HF, VHF and UHF
- Microwave region
  - 300 MHz – 30 GHz
    - Internal layers
    - Snow cover sea ice.
- Millimeter wave
  - 30 GHz – 300 GHz.
  - Internal layers
- IEEE uses a different definition
  - 300 MHz – 100 GHz

Radars for Glaciological Applications

- An essential tool in glaciology
  - Ice thickness
  - Internal layers
  - Structure
  - Surface roughness
  - Bed conditions
  - 3-D topography

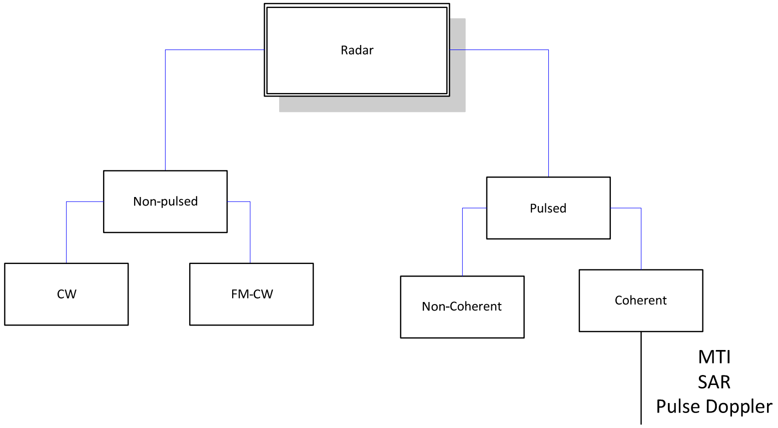
- Advantages
  - Wide-area coverage
    - Airborne platforms
  - Established

- Disadvantages
  - Data are difficult to interpret
  - Coarse resolution except for SAR]
- Pulse radar
- Impulse radars
- FM-CW radars
  - Step-frequency radars



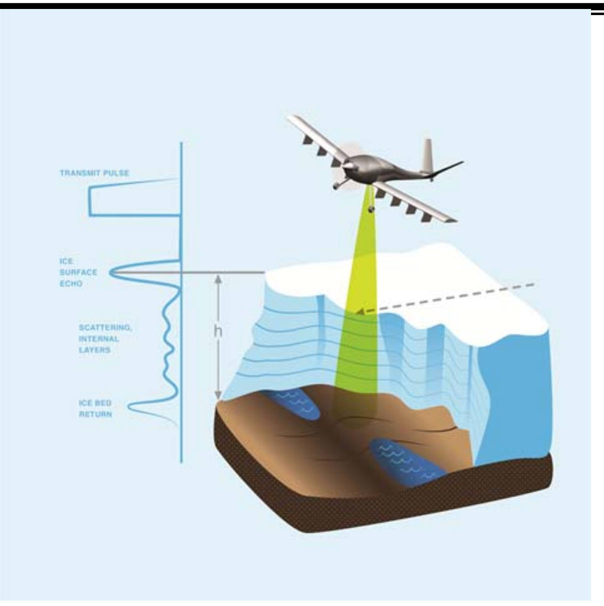
Radar Principles

- Radar classified according to the transmit waveform.
  - Continuous
    - Doppler
    - Altimeter
    - Scatterometer
  - Pulse
    - Wide range of applications
    - Sounders/imagers
  - Impulse radar
    - LF and HF
      - Temperate ice



Radar Principle

- Radar measures distance by measuring time delay between the transmit and received pulse.
- Measured time delay is converted to ice thickness.
- In freespace
  - 1 us = 150 m
  - 1 ns = 15 cm



$$\partial t = \tau_2 - \tau_1 = \frac{2R_2}{c} - \frac{2R_1}{c}$$

h = ∂t vp

where v_p = velocity of propagation in ice.

EM Theory

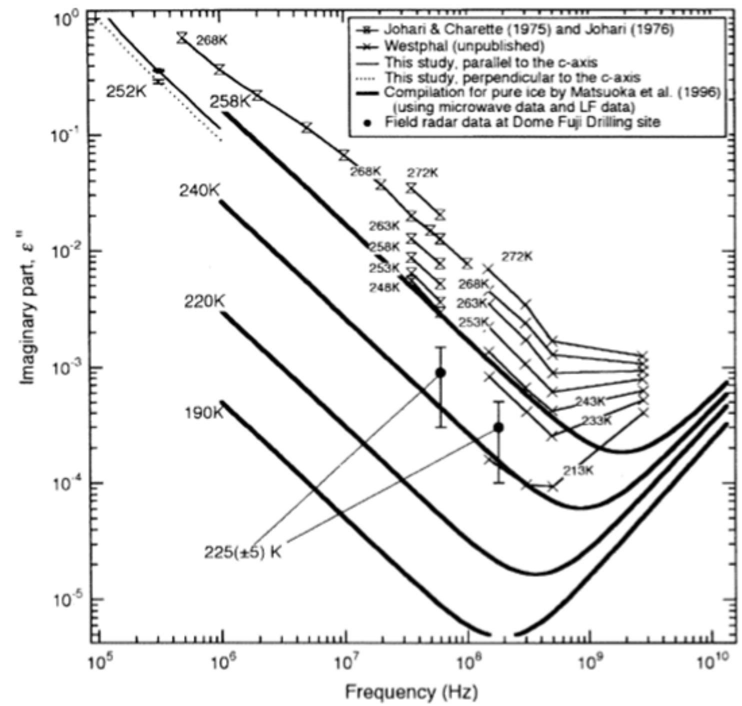
- Consider a plane wave in a dielectric
- $E(z) = E_0 e^{-\gamma z}$

$$\gamma = \alpha + j\beta = j\omega\sqrt{\mu\varepsilon} = j\omega\sqrt{\mu_0\varepsilon'\left(1 - j\frac{\varepsilon''}{\varepsilon'}\right)}$$

$$\approx j\omega\sqrt{\mu_0\varepsilon'}\left(1 - j\frac{\varepsilon''}{2\varepsilon'}\right)$$

$$\beta \approx \omega\sqrt{\mu_0\varepsilon'}$$

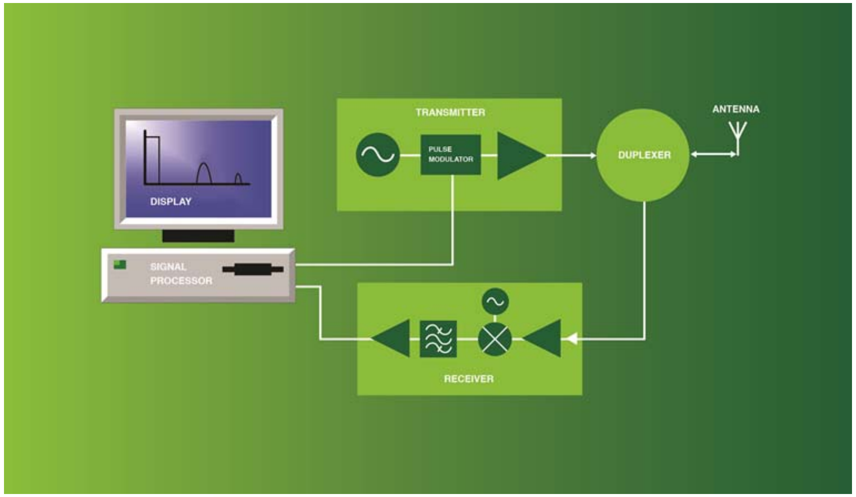
$$\alpha \approx \omega\sqrt{\mu_0\varepsilon'}\,\frac{\varepsilon''}{2\varepsilon'} = \frac{\pi}{\lambda}\,\frac{\varepsilon^{11}}{\sqrt{\varepsilon^{1}}}$$

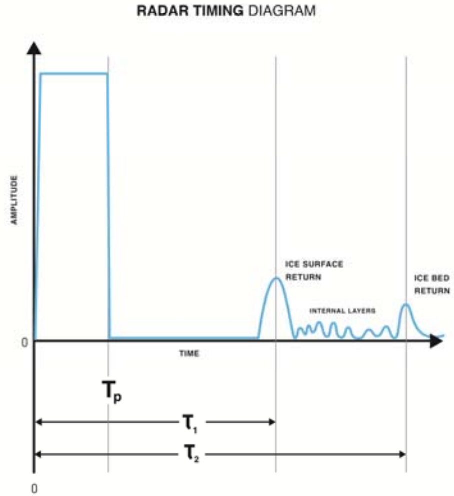


Imaginary part of the dielectric constant adapted from Fujita et al.,[2000]

Radar

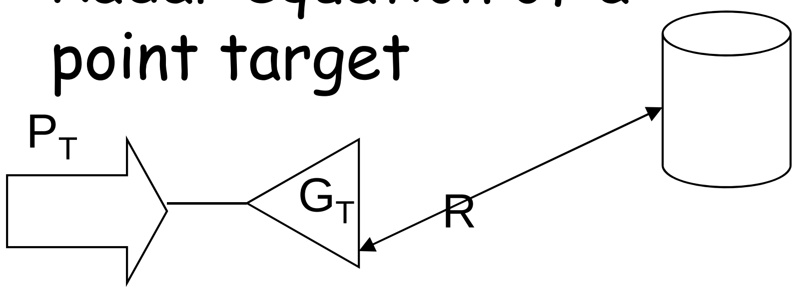
- Block diagram of a simple pulse radar
  - It consists of a transmitter to generate a pulse-modulated carrier signal.
  - A receiver to amplify and filter the received signal.
  - A Dupluxer that enables same antenna to be used for transmission and reception.
  - Signal processor.
  - Display unit – PPI, B-scope etc.





Radar—Principle

- Radar equation of a point target



Power density at the target is given byP

$$P_d = \frac{P_T G_T}{4\pi R^2}$$

Target with radar cross section, σ, intercepts
a part of this signal and reradiates
in the direction of the radar.

$$P_{dr} = \frac{P_T G_T}{4\pi R^2}\sigma$$

Reradiated power incident on the antenna is given by

$$P_{ri} = \frac{P_T G_T}{4\pi R^2}\sigma \frac{1}{4\pi R^2}$$

The receive antenna with an effective aperture, Ae, incident signal and it is given by

$$P_r = \frac{P_T G_T}{4\pi R^2}\sigma \frac{A_e}{4\pi R^2}$$

$$P_r = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R^4}$$

$$where\ G_R = \frac{4\pi A_e}{\lambda^2}$$

- For a monostatic radar
- $G_T = G_R$
- Radar sensitivity is determined by the minimum detectable signal set by the receiver noise.
- No = kTBF
- F= noise figure, T= temperature
- Signal-to-noise ratio

$$\frac{S}{N} = \frac{P_r}{N_o} = \frac{P_T G_T^2 \lambda^2 \sigma}{(4\pi)^3 R^4 KTBF} = \frac{[P_T A_e] G_T \sigma}{(4\pi) R^4 KTBF}$$

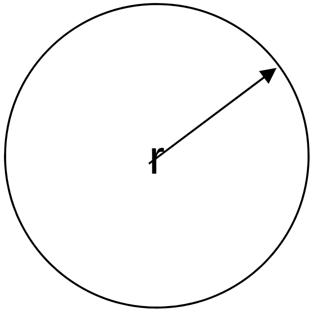
$$R_{max} = \sqrt[4]{\frac{P_T G_T^2 \lambda^2 \sigma}{(4\pi)^3 \frac{S}{N} KTBF}} = \sqrt[4]{\frac{[P_T \tau] G_T^2 \lambda^2 \sigma}{(4\pi)^3 \frac{S}{N} KTF}}$$

Radar Cross-Section

- Radar cross section characterizes the size of the object as seen by the radar.

- Where?
  E_s = scattering field
  E_i = incident field

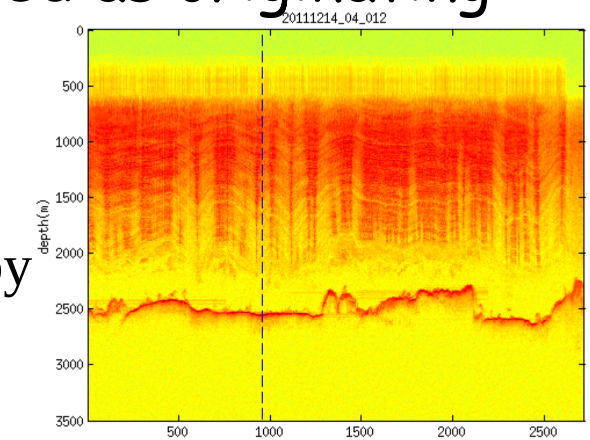
$$\sigma = \lim_{R \to \infty} 4\pi R^2 \frac{|E_s|^2}{|E_i|^2}$$



$$\sigma = \pi r^2$$

Planar Reflector

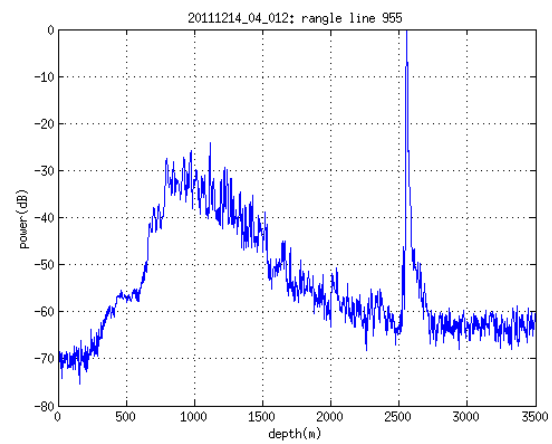
- Coherent reflections can be treated as originating from a planar reflector.



Power received from a planar reflector given by

$$P_r = \frac{P_T G_T A_e}{4\pi(2R)^2}|\Gamma|^2, where\; G_R = \frac{4\pi A_e}{\lambda^2}$$

$$P_r = \frac{P_T G_T G_R \lambda^2 |\Gamma|^2}{(4\pi)^2 R^2}$$



For ice, we must add additional terms as

Radar Equation

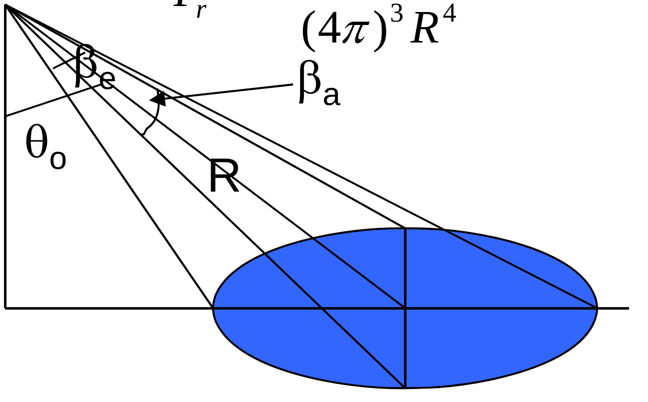
- A distributed target contains many scattering centers within the illuminated area.
- It is characterized by radar cross section per unit area, which is referred to as scattering coefficient.

$$\sigma = \sigma^o A$$

$$\sigma^o = \text{scattering coefficient}$$

$$A = \text{Illuminated area}$$

$$P_r = \frac{P_T G_T^2 \lambda^2 \sigma^0 A}{(4\pi)^3 R^4}$$



$$A = \frac{\pi}{2} R\cos(\theta_0)\left(\tan(\theta_o + \frac{\beta_e}{2}) - \tan(\theta_o - \frac{\beta_e}{2})\right) R\tan(\frac{\beta_a}{2})$$

$$\text{If } \theta_0 << 1 \;\&\; \beta << 1$$

$$A \approx \frac{\pi}{4} R^2 \beta_e \beta_a$$

Radar Equation

$$P_r = \frac{P_T G_T^2 \lambda^2 \sigma^0}{(4\pi)^3 R^4} \frac{\pi R \beta_e R \beta_a}{4}$$

$$P_r = \frac{P_T G_T^2 \lambda^2 \sigma^0}{(4\pi)^2 R^2} \frac{\beta_e \beta_a}{16}$$

For a distributed target and coherent reflector, power received falls off as $1/R^2$

For a point target power received falls off as $1/R^4$

For a distributed target with SAR processing power can fall-off as $1/R^{2.5}$ or $1/R^3$

Radar Equations for Ice

- Planar Reflector

$$P_r = \frac{P_T G_T A_e \left(1 - |\Gamma_{as}|^2\right)|\Gamma_b|^2}{4\pi (2h)^2 L_{is}}$$

$$\left(\frac{S}{N}\right)_1 = \frac{P_r}{P_n} = \frac{P_T G_T A_e \left(1 - |\Gamma_{as}|^2\right)|\Gamma_b|^2}{4\pi (2h)^2 L_{is} kTBF}$$

For a coherent radar with pulse compression

$$\left(\frac{S}{N}\right)_M = \frac{P_T G_T A_e \left(1 - |\Gamma_{as}|^2\right)|\Gamma_b|^2 C_g M}{4\pi (2h)^2 L_{is} kTBF}$$

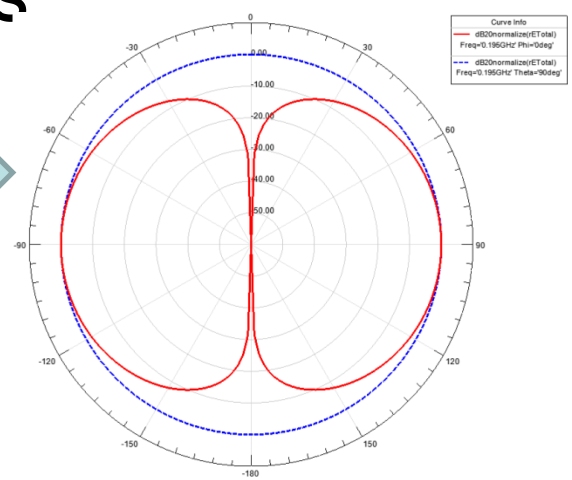
- Distributed target with SAR processing

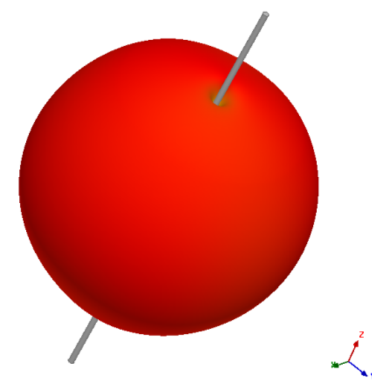
$$\frac{S}{N}_M = \frac{P_r}{P_n} = \frac{P_T G_T A_e \sigma^o \pi h \beta_e \sqrt{c\tau_{pc} h}\,\tau_{pu} M}{2(4\pi)^2 h^4 L_{is} kTF}$$

$$\frac{S}{N}_M = \frac{P_r}{P_n} = \frac{M P_T G_T A_e \sigma^o \beta_e \sqrt{c\tau_{pc}}\,\tau_{pu}}{32\pi h^{2.5} L_{is} kTF}$$

Antennas

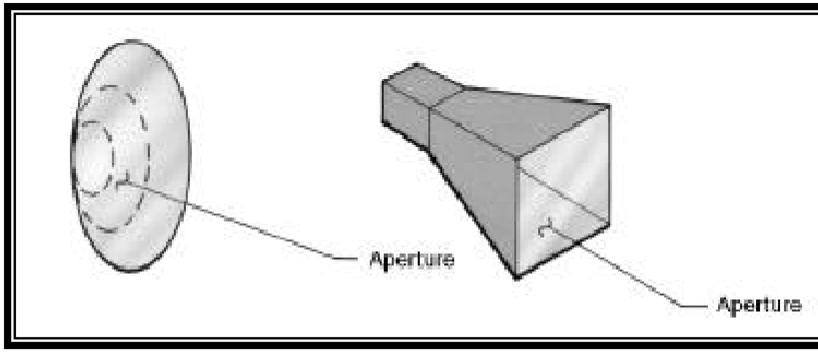
- Antennas are used to couple electromagnetic waves into free space or capture electromagnetic waves from free space.
- Type of antennas
  - Wire
    - Dipole
    - Loop antenna
  - Aperture
    - Parabolic dish
    - Horn





Antennas

- Antennas are characterized by their:
  - Directivity
    - It is the ratio of maximum radiated power to that radiated by an isotropic antenna.
  - Efficiency
    - Efficiency defines how much of the power is the total power radiated by the antenna to that delivered to the antenna.
  - Gain
    - It is the product of efficiency and directivity
  - Beamwidth
    - Width of the main lobe at 3-dB points.

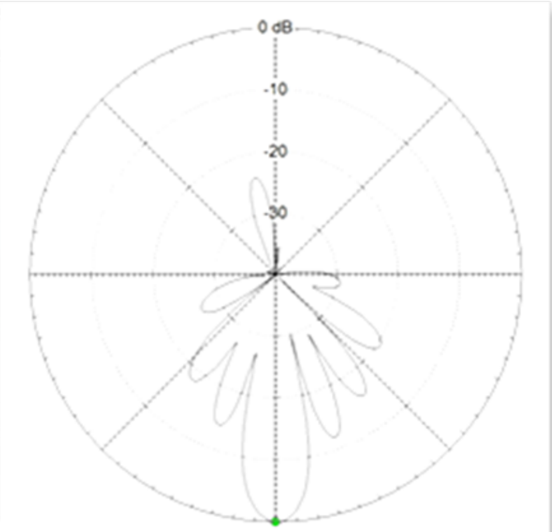


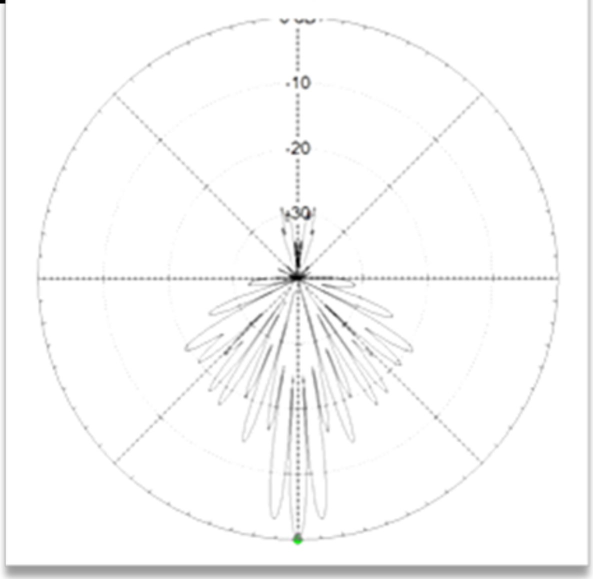
Antenna gain

Aperture-Type	Beamwidth (From Aperture)	Directive gain (From Aperture)	Directive gain (From Beamwidth)	Antenna Efficiency (Aperture illumination Efficiency)
Uniformly illuminated circular aperture-hypothetical parabola a 18 dB side-lobe level	$\theta = \frac{58\lambda}{a}$ $\theta = \theta_1 = \theta_2$	$g_d = \frac{15\,a^2}{\lambda^2}$ $g_d = \frac{9.87\,a^2}{\lambda^2}$	$g_d = \frac{52{,}525}{\theta^2}$ $\theta = \theta_1 = \theta_2$	100%
Uniformly illuminated rectangular aperture or linear array a b 13 dB side-lobe level	$\theta_1 = \frac{51\lambda}{a}$ $\theta_2 = \frac{51\lambda}{b}$	$g_d = \frac{1.6\,a\,b}{\lambda^2}$	$g_d = \frac{41{,}253}{\theta_1 \theta_2}$	100%
Rectangular horn a) Polarization plane: E-plane a_E 13 dB side-lobe level b) Orthogonal polarization plane: H-plane a_H 26 dB side-lobe level	$\theta_1 = \frac{56\lambda}{a_E}$ $\theta_2 = \frac{67\lambda}{a_H}$	$g_d = \frac{7.5\,a_E\,a_H}{\lambda}$	$g_d = \frac{31{,}000}{\theta_1 \theta_2}$	60%
Nonuniformly illuminated circular aperture (10 dB taper)–normal parabola a 26 dB side-lobe level	$\theta = \frac{72\lambda}{a}$ $\theta = \theta_1 = \theta_2$	$g_d = \frac{5\,a^2}{\lambda^2}$	$g_d = \frac{27{,}000}{\theta^2}$ $\theta = \theta_1 = \theta_2$	50%
	$a >> \lambda$	$G_d = 10 \log_{10} g_d$ dB	$G_d = 10 \log_{10} g_d$ dB	

Antennas

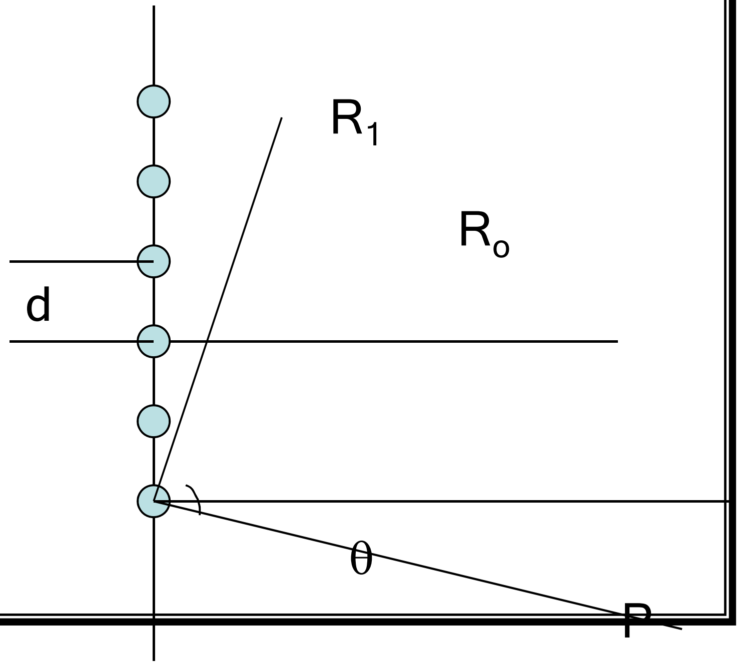
- An array of antennas is used whenever higher directivity is needed.
- Directivity is related to number of elements.
- Can be used for electronic scanning.
  - Most of the SAR antennas are arrays.





Antenna Array

- Let us consider simple array consisting of isotropic radiators.



$$R_1 = R_o + d\sin(\theta) -$$

$$\partial R = d\sin(\theta)$$

$$\partial\varphi = \frac{2\pi}{\lambda} d\sin(\theta)$$

$$E_t = E_o\left(e^{-j\frac{2\pi R_0}{\lambda}} + e^{-j\frac{2\pi(R_o + d\sin(\theta))}{\lambda}}\right)$$

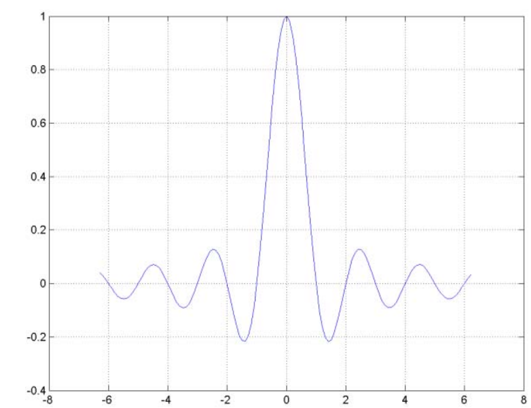
$$E_t = E_o e^{-j\frac{2\pi R_0}{\lambda}} e^{-j\frac{\pi d\sin(\theta)}{\lambda}}\left(e^{j\frac{\pi d\sin(\theta)}{\lambda}} + e^{-j\frac{\pi d\sin(\theta)}{\lambda}}\right)$$

$$E_t = 2E_o e^{-j\frac{2\pi R_0}{\lambda}} e^{-j\frac{\pi d\sin(\theta))}{\lambda}} \cos\frac{\pi d\sin(\theta)}{\lambda})$$

$$E_t \propto \sum_i E_{oi}\cos\left(\frac{2\pi d\sin(\theta)}{\lambda}\right)$$

If we increase from 0 to 90 degrees and reduce the resulting expression.

$$\mathrm{E_t} \propto \frac{\sin x}{x}$$



DC-8 and P-3B Antenna Configurations

MCoRDS, Accumulation, Snow, and Ku-band radars

Example S/N ratio

See notes

1	Transmit power		500.00	W	71.44	dBm		
2	Transmit antenna gain		118.08		20.72	dB		
3	Receive antenna gain		118.08		20.72	dB		
4	Surface reflection loss		0.97		-0.26	dB		
5	Wavelength		1.54		3.74			
6	Bed reflection loss		0.10		-20.00	dB		
7	Ice loss		20.00	dB/km	60.00	dB		
8	Spreading loss		0.00		-98.89	dB	dBm^2	
9	Received power					-133.96		dB
10	Pulse compression gain		150.00		21.76	dB		
9	Coherent integration gain		1000		30.00	dB		
	Signal processing gain					51.76		
10	Boltzmann constant		0.00		-228.60			
11	Temperature		290.00	K	24.62			
12	Noise figure		2.00		3.01			
13	Bandwidth		30000000.00	Hz	74.77			
14	KTBF					-96.20	dBm	
	Signal-to-noise ratio						13.99	

$$\left(\frac{S}{N}\right)_M = \frac{P_T G_T G_r \left(1-\left|\Gamma_{as}\right|^2\right)\left|\Gamma_b\right|^2 \lambda^2 C_g M}{(4\pi)^2 (2h)^2 L_{is} kTBF}$$

Modern Radar