RADIOLOCATION

Pulsed Radar (VI)
Radar Antennas

Jordi Mateu – Jordi Berenguer

Pulsed Radar

Radar Antennas

i. Antenna parameters and Basics
ii. Radar antenna patterns
iii. Resolution Angle
iv. Uncertainty volume (resolution Cell)
v. Polarization of electromagnetic waves
vi. Slotted and waveguide antennas
vii. Aperture antennas

Antenna parameters and Basics

THE ANTENNA FUNCTIONS:

- As a transductor, it transforms an electrical signal into an Electromagnetic wave with an specific space orientation.
- In 2-D Radar Systems, among these functions, it determines the **azimuth angle** of the target.
- In 3-D Radar Systems, it provides the **elevation angle** of the target.

Antenna parameters

In Transmission

*The antenna, **focus** the energy to the target direction.*

- The **Directivity** (D) or the maximum radiation gain.
- The **antenna gain** (G) related with the antenna radiation efficiency.
- The antenna **radiation efficiency** (η_r), as the looses between the transmitter output power and the radiated power.

In Reception

*The antenna **captures** the energy coming from the target.*

- The **physical area** of the antenna: A_{phys}
- The **effective area** of the antenna, A_{eff} which captures the transmitted power density of the electromagnetic wave.
- The **antenna illumination efficiency** (η_i), or the ratio between the effective and the physical areas of the antenna,

Both roles related through the reciprocity principle

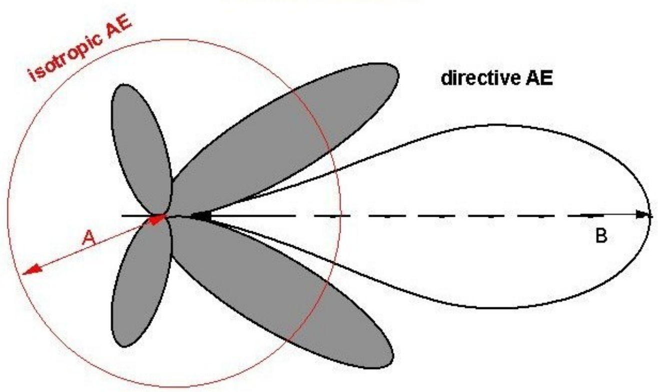
Antenna parameters and Basics

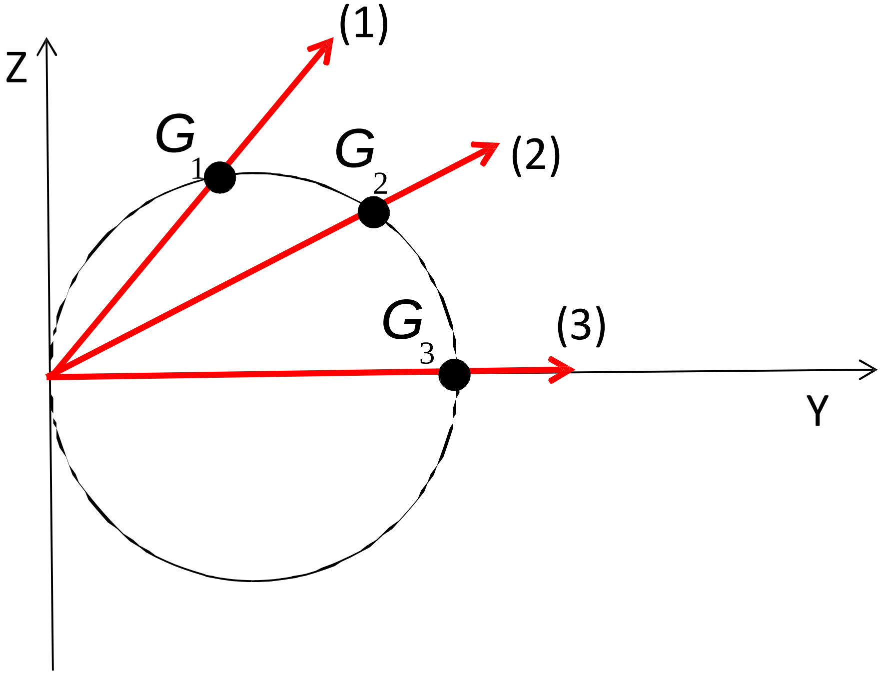
Antenna Directivity

The relationship between the power density radiated in one direction and at a distance R, relative to the power density radiated at the same distance from an isotropic antenna.

$$\boxed{D(\theta,\phi)=\frac{\mathcal{P}(\theta,\phi)}{P_t/_{4\pi R^2}}}$$

θ: azimuth angle
ϕ: elevation angle





Antenna parameters and Basics

Antenna Directivity

If no direction is specified, the Directivity means the power density radiated in the **direction of maximum radiation**

$$\boxed{D = \frac{\mathcal{P}_{max}}{P_t/_{4\pi R^2}}}$$

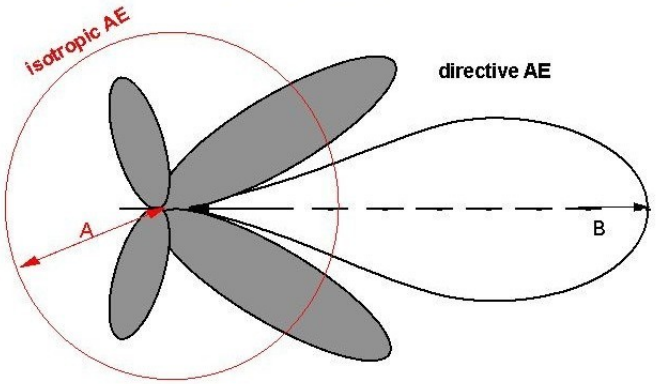
The looses between the transmitter output power and the radiated power are usually computed as the antenna **radiation efficiency** (η_r), as a reduction of the transmitted power.

Antenna parameters and Basics

Antenna gain:

The relationship between the power density radiated in one direction and at a distance R, relative to the power density radiated at the same distance from an isotropic antenna by the power delivered to the antenna. It takes into account the radiation efficiency η_r.

$$\boxed{G(\theta,\phi)=\frac{\mathcal{P}(\theta,\phi)}{P_{delivered}/_{4\pi R^2}}=\frac{P_{radiated}}{P_{delivered}}\cdot\frac{\mathcal{P}(\theta,\phi)}{P_{radiated}/_{4\pi R^2}}=\eta_r\cdot D(\theta,\phi)}$$



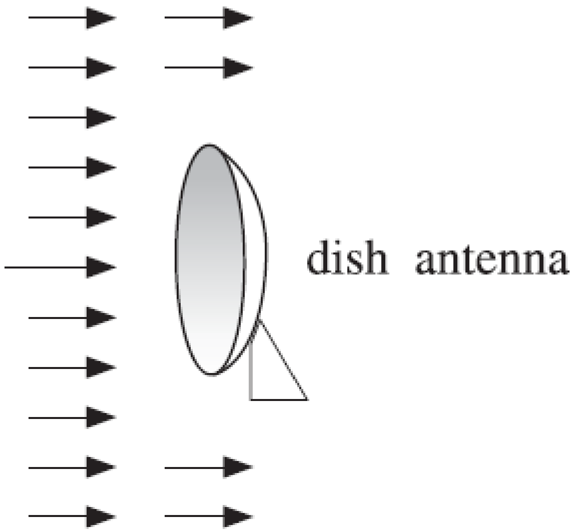
Antenna parameters and Basics

Effective Area

Capacity of the antenna to capture energy. Related with its physical dimensions through the antenna illumination efficiency η_i :

$$\boxed{A_{eff}(\theta,\phi) = \eta_i A_{phys}(\theta,\phi)}$$

$$\boxed{\frac{\mathcal{P}}{4\pi R^2} \quad (W/m^2)}$$



$$\boxed{P_r = \frac{\mathcal{P}}{4\pi R^2} A_{eff}}$$

Antenna parameters and Basics

RELATION BETWEEN GAIN AND EFFECTIVE AREA

Capacity of the antenna to capture energy. Related with its physical dimensions

$$\boxed{\frac{D}{A_{eff}} = \frac{4\pi}{\lambda^2}}$$

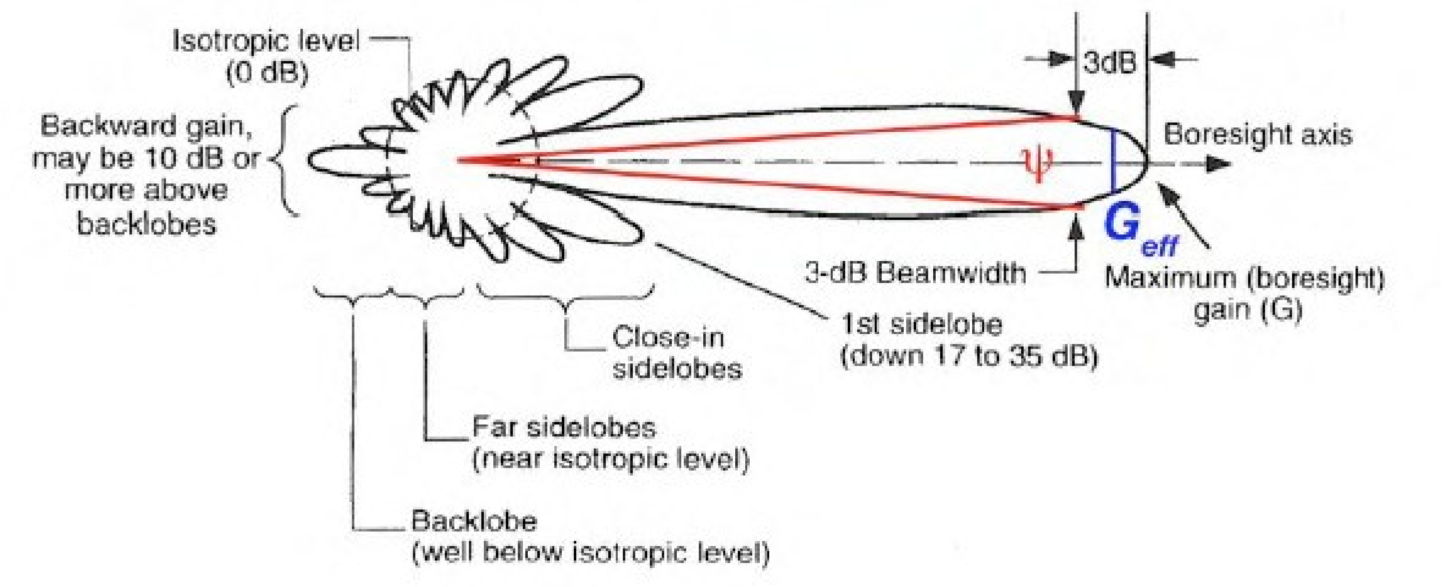
λ: Carrier wavelength

And the radar equation for the same antenna in transmission and reception:

$$R_{max}^4 = \frac{P_t D \sigma A_{eff} n E_i(n)}{(4\pi)^2 k T_0 B F (S/N)_1} = \frac{P_t D^2 \lambda^2 \sigma n E_i(n)}{(4\pi)^3 k T_0 B F (S/N)_1} = \frac{P_t \sigma A_{eff}^2 n E_i(n)}{4\pi \lambda^2 k T_0 B F (S/N)_1}$$

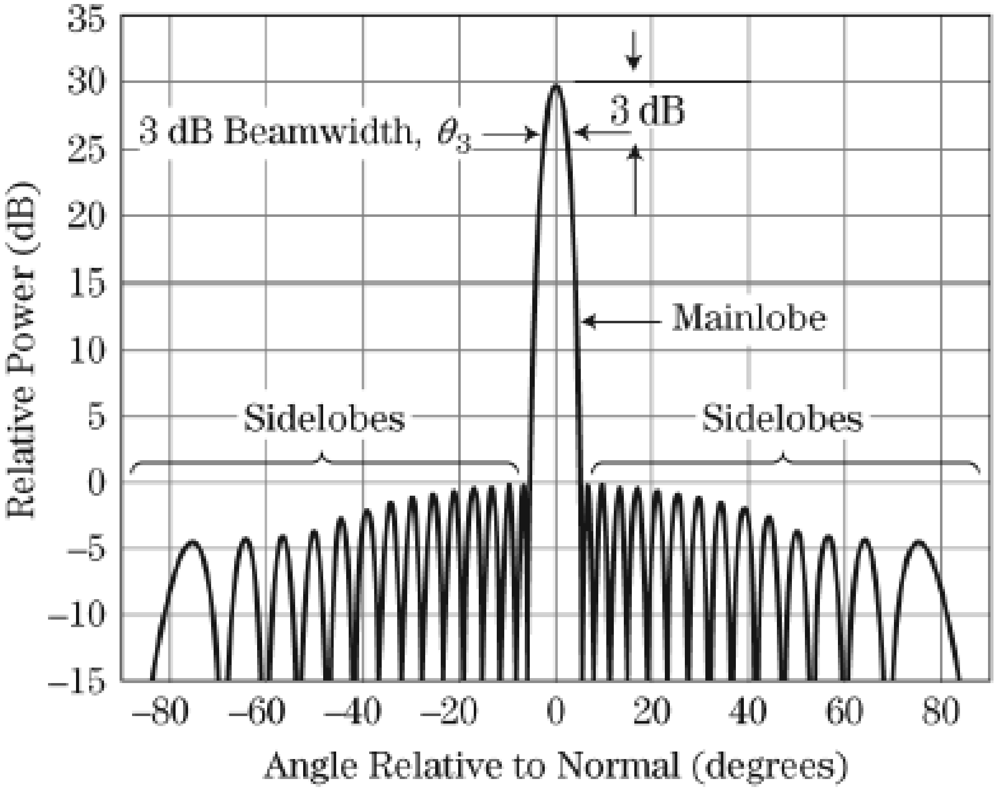
Antenna parameters and Basics

Diagram of radiation

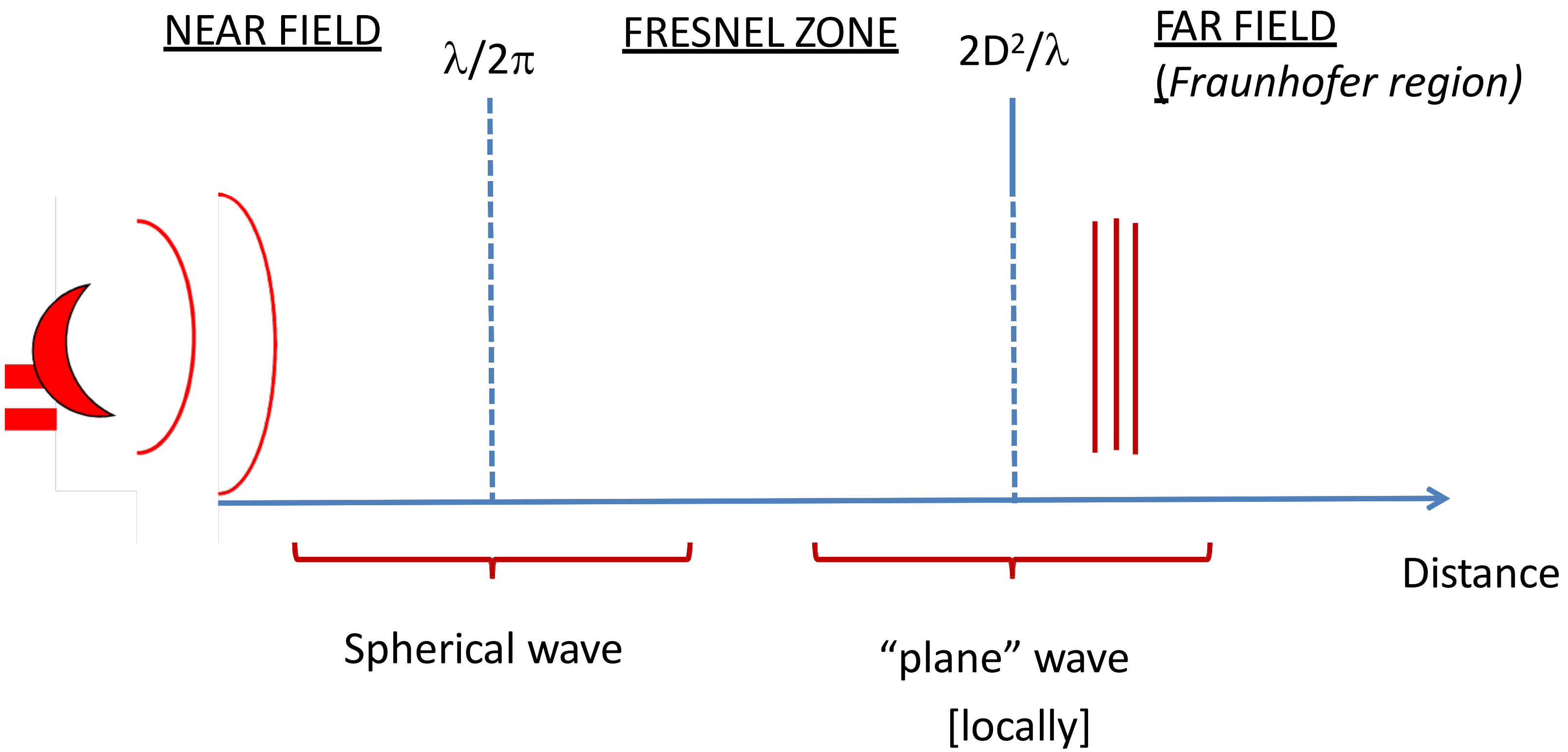


Antenna parameters and Basics

Diagram of radiation



Antenna parameters and Basics



NEAR FIELD

$\lambda/2\pi$

FRESNEL ZONE

$2D^2/\lambda$

FAR FIELD

(Fraunhofer region)

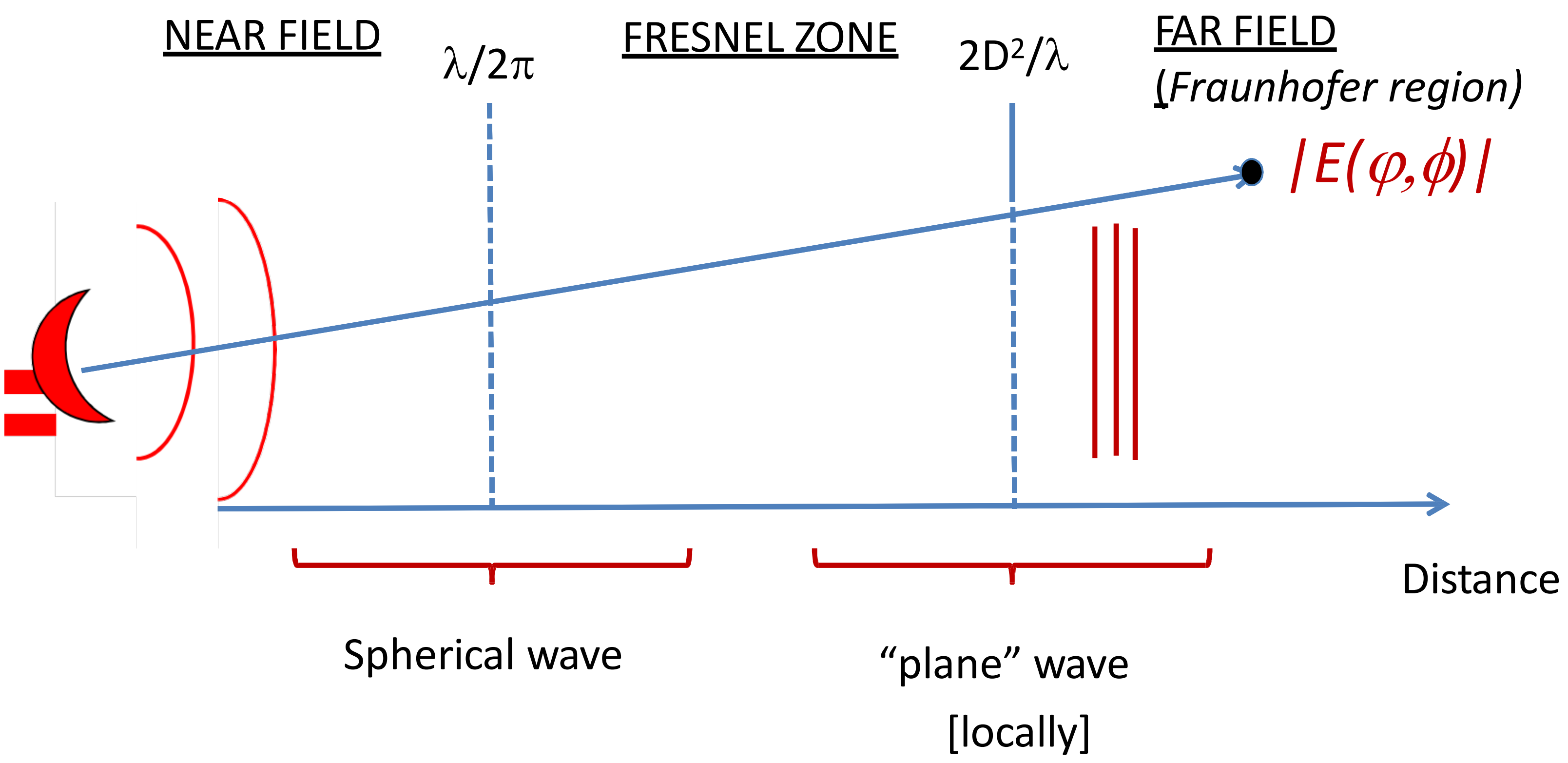
Distance

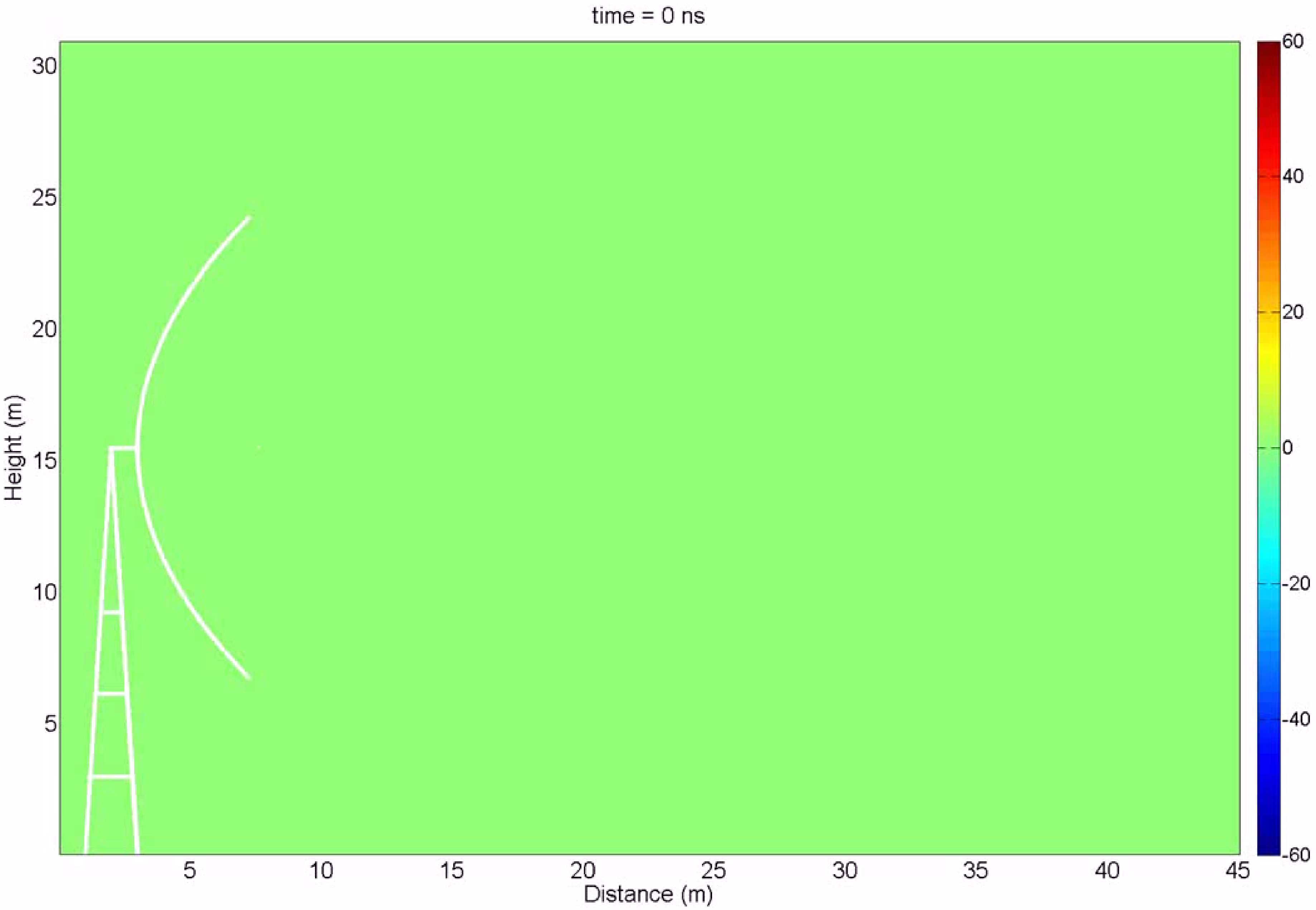
Spherical wave

“plane” wave

[locally]

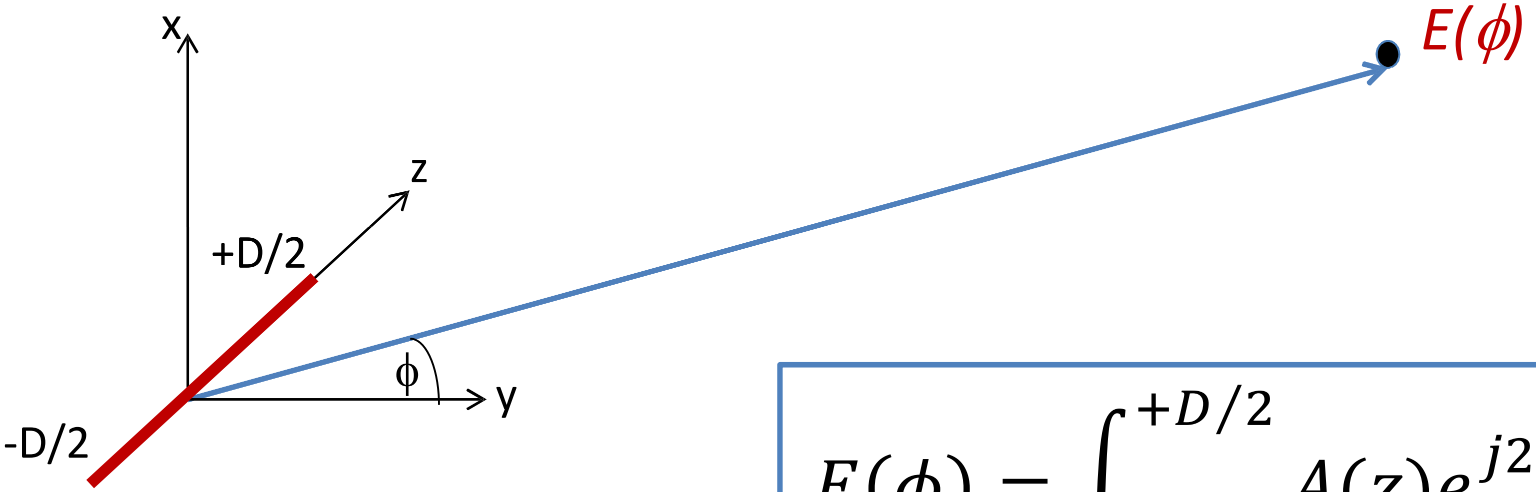
Antenna parameters and Basics




time = 0 ns
Height (m)
30
25
20
15
10
5
Distance (m)
5
10
15
20
25
30
35
40
45
60
40
20
0
-20
-40
-60

Antenna radiation pattern and aperture illumination

FAR FIELD RADIATION PATTERN



$$E(\phi) = \int_{-D/2}^{+D/2} A(z) e^{j2\pi\frac{z}{\lambda}\sin\phi} dz$$

A(z): Current distribution along the antenna

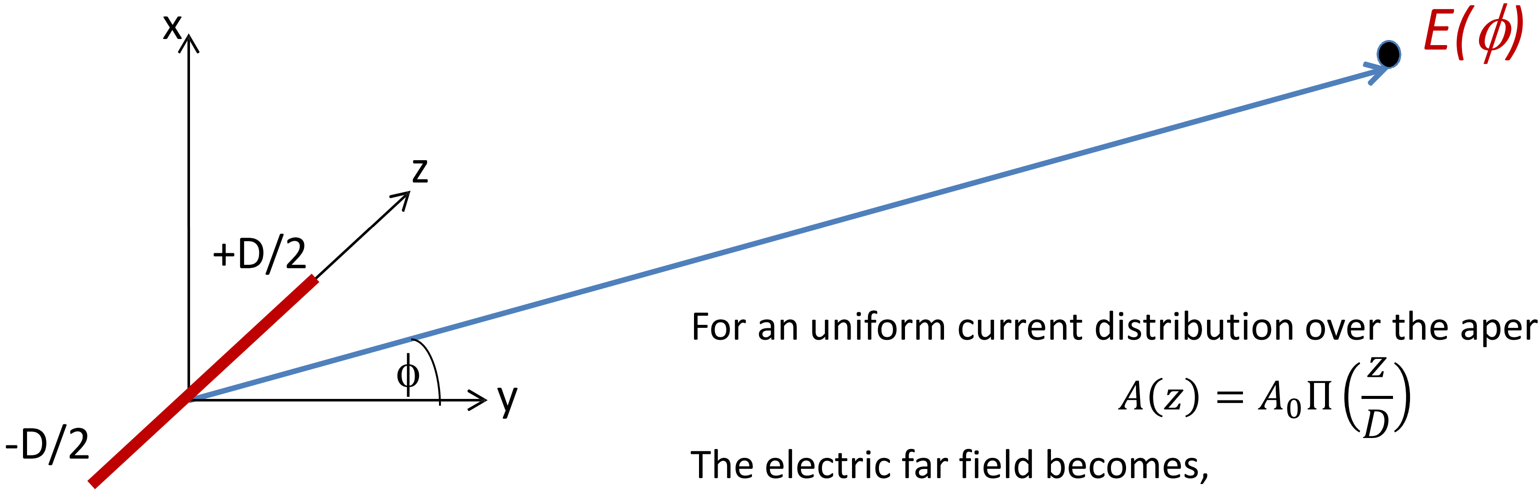
Inverse Fourier Transform:

$$s(t) = \int_{-\infty}^{+\infty} S(f) e^{j2\pi f t} df$$

The electric far field pattern is the inverse Fourier transform of the aperture illumination.

Antenna radiation pattern and aperture illumination

FAR FIELD RADIATION PATTERN



For an uniform current distribution over the aperture,

$$A(z) = A_0 \Pi\left(\frac{z}{D}\right)$$

The electric far field becomes,

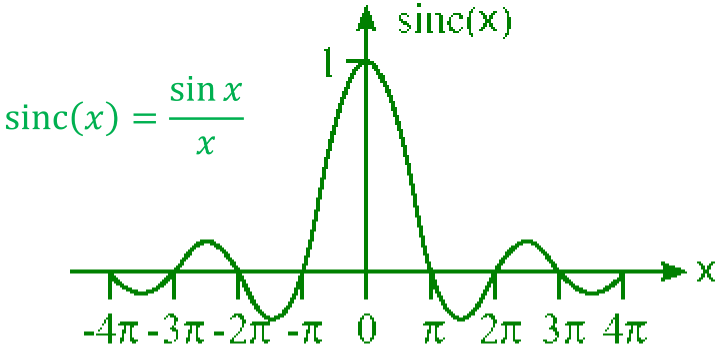
$$E(\phi) = A_0 \int_{-a/2}^{a/2} e^{j2\pi\frac{z}{\lambda}\sin\phi}\,dz = A_0 D\,\frac{\sin[\pi(D/\lambda)\sin\phi]}{\pi(D/\lambda)\sin\phi},$$

And after normalizing E(0)=1, then we obtain:

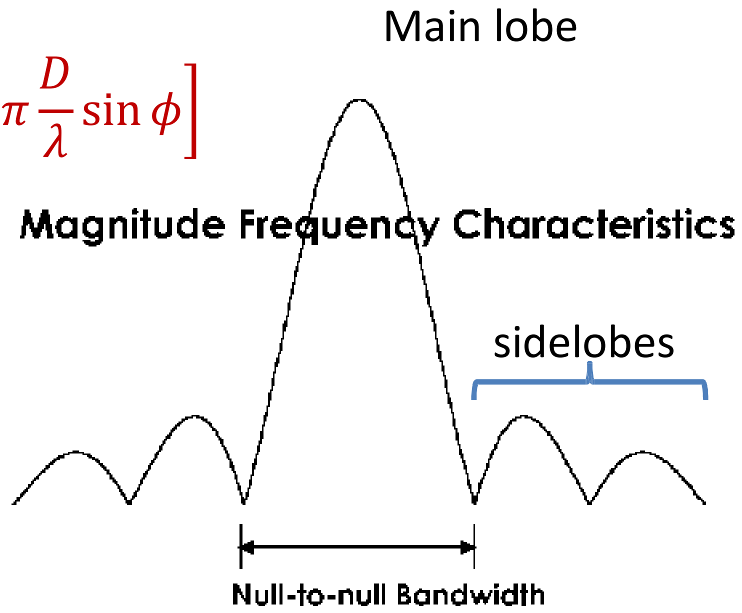
$$\boxed{E(\phi) = \frac{\sin[\pi(D/\lambda)\sin\phi]}{\pi(D/\lambda)\sin\phi} = \mathrm{sinc}\left[\pi\frac{D}{\lambda}\sin\phi\right]}$$

Antenna radiation pattern and aperture illumination

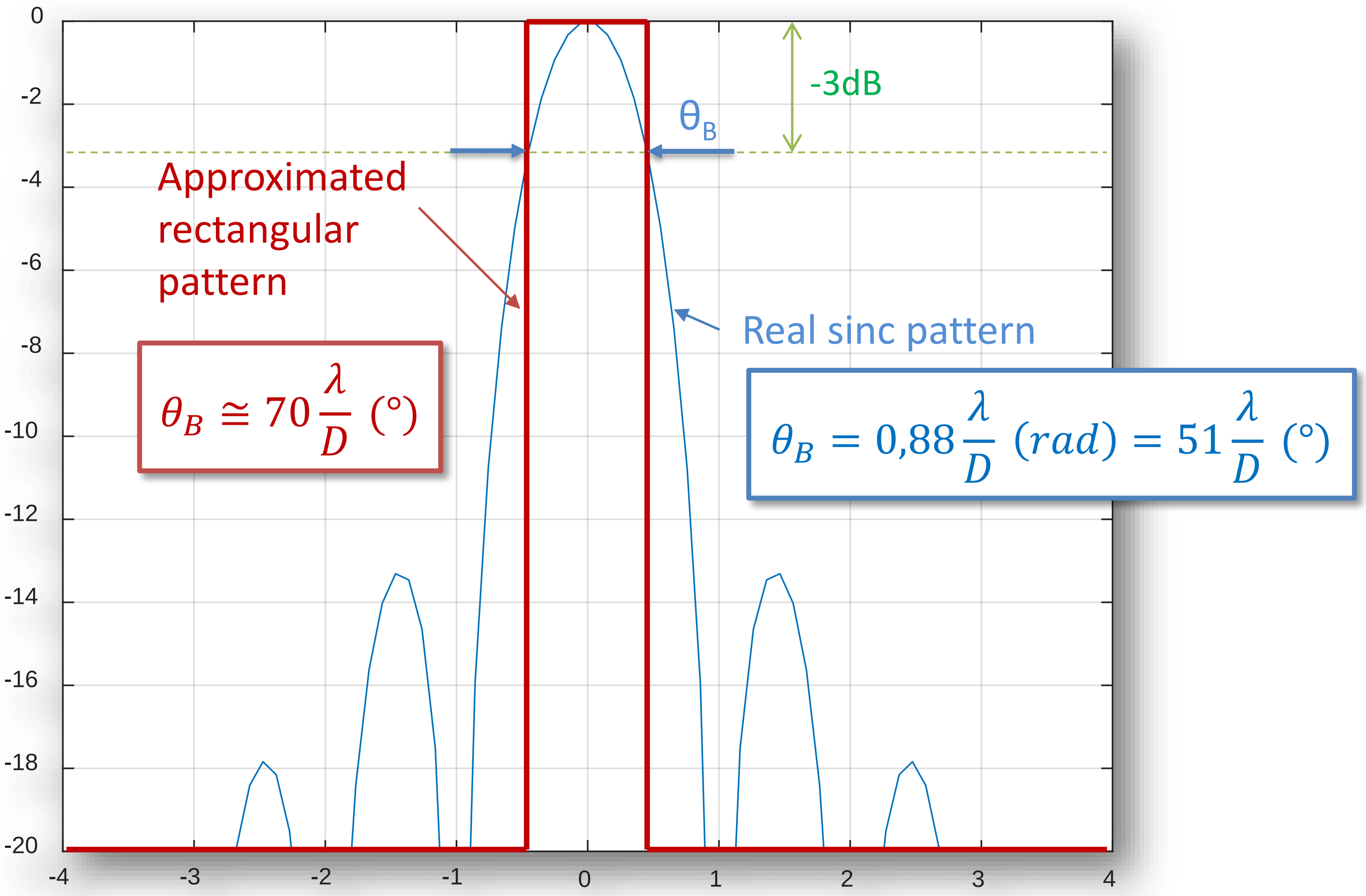
FAR FIELD RADIATION PATTERN



$$|E(\phi)| = \mathrm{sinc}\left[\pi \frac{D}{\lambda} \sin\phi\right]$$



Antenna radiation pattern and aperture illumination



Approximated rectangular pattern

$$\theta_B \cong 70\frac{\lambda}{D}\ (°)$$

Real sinc pattern

$$\theta_B = 0{,}88\frac{\lambda}{D}\ (rad) = 51\frac{\lambda}{D}\ (°)$$

Antenna radiation gain in terms of the beamwidth

The antenna gain can be calculated from the antenna beamwidths θ_B and ϕ_B by the following approximated equations:

Rectangular beam, without sidelobes

$$G \approx \frac{4\pi}{\theta_B\,(rad)\;\phi_B\,(rad)}$$

Gaussian beam

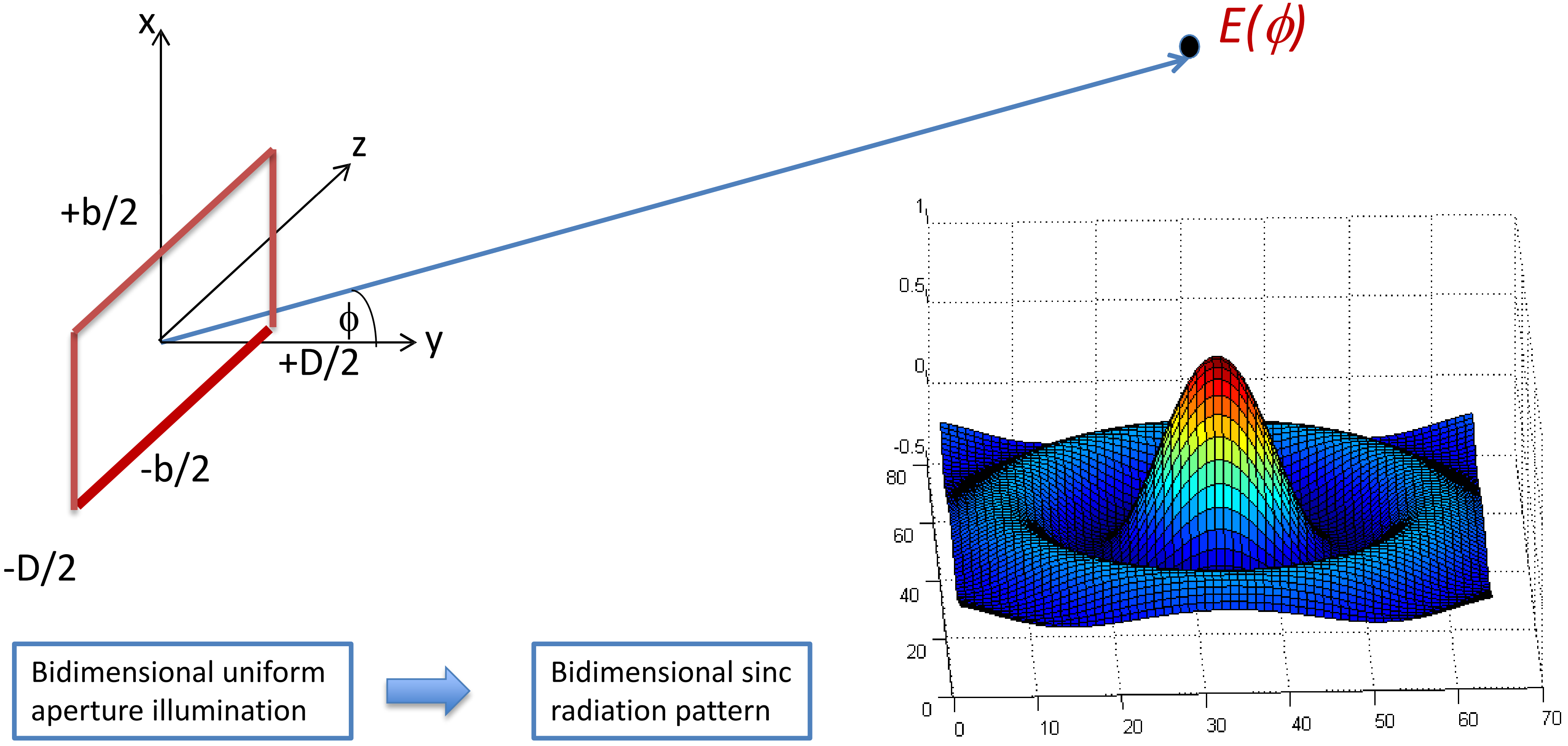
$$G \approx \frac{\pi^2}{\theta_B\,(rad)\;\phi_B\,(rad)}$$

Practical antennas, ***from Warren Stutzman***

$$G \approx \frac{26000}{\theta_B\,(°)\;\phi_B\,(°)}$$

Antenna radiation pattern and aperture illumination

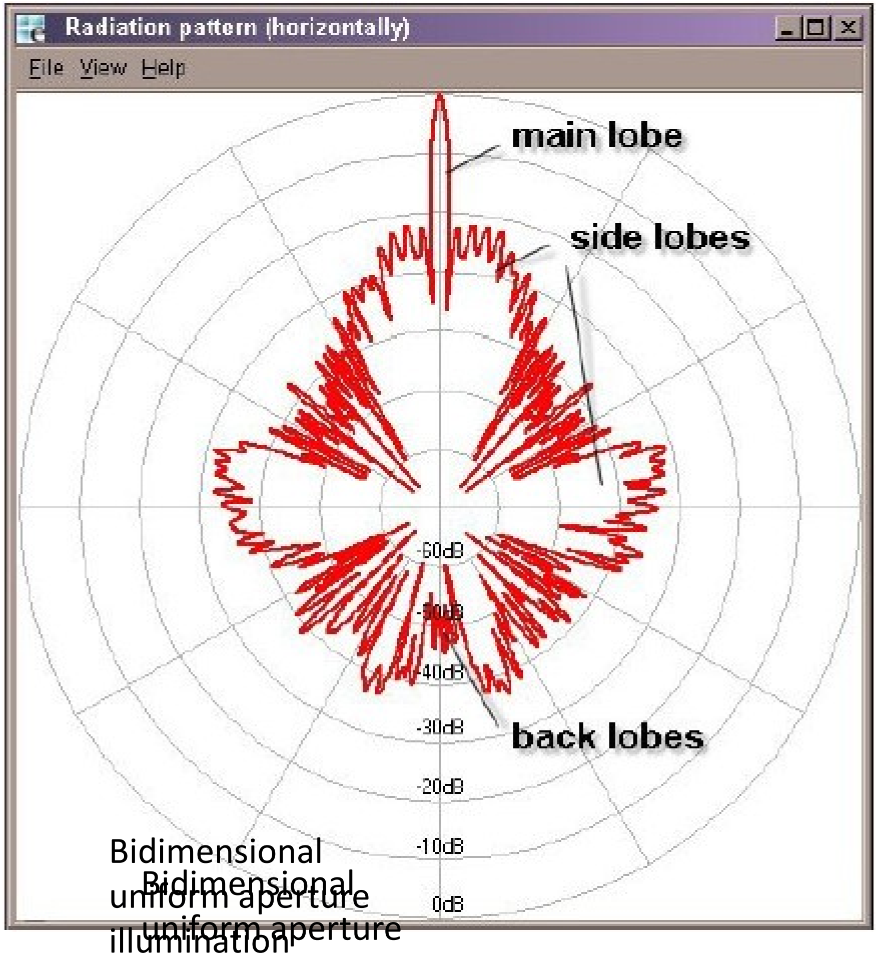
FAR FIELD RADIATION PATTERN



Bidimensional uniform aperture illumination → Bidimensional sinc radiation pattern

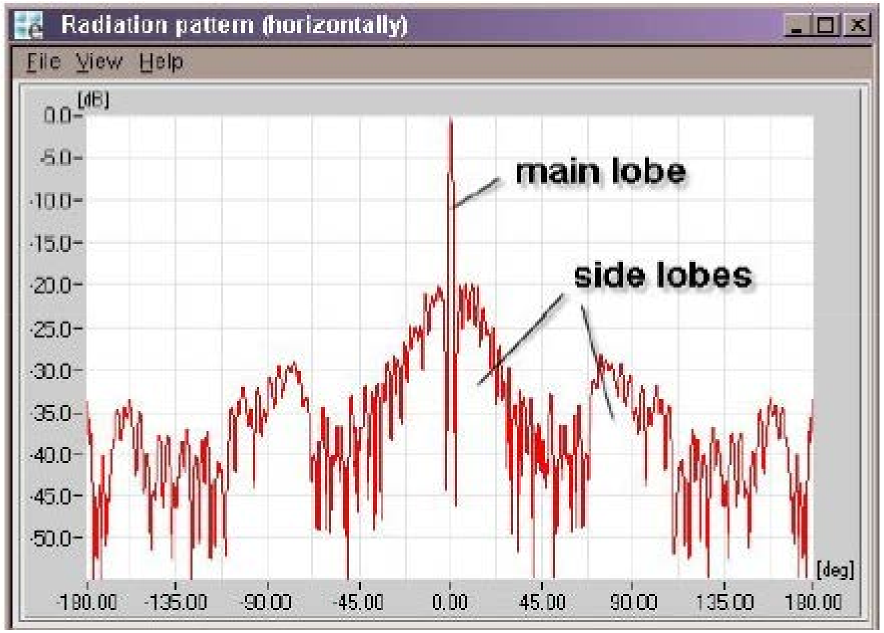
Antenna radiation pattern and aperture illumination

FAR FIELD RADIATION PATTERN



Bidimensional uniform aperture illumination

Bidimensional uniform aperture illumination

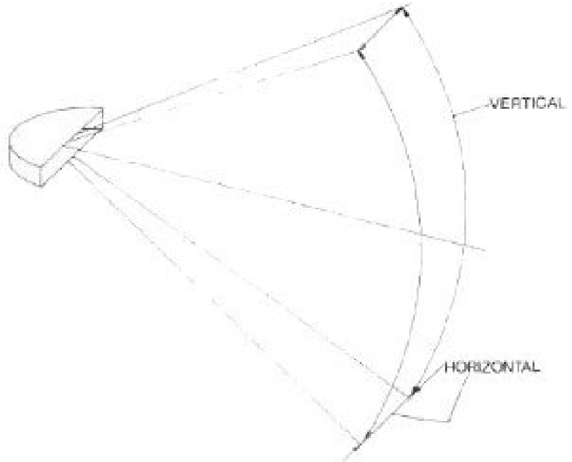


Radar Antennas

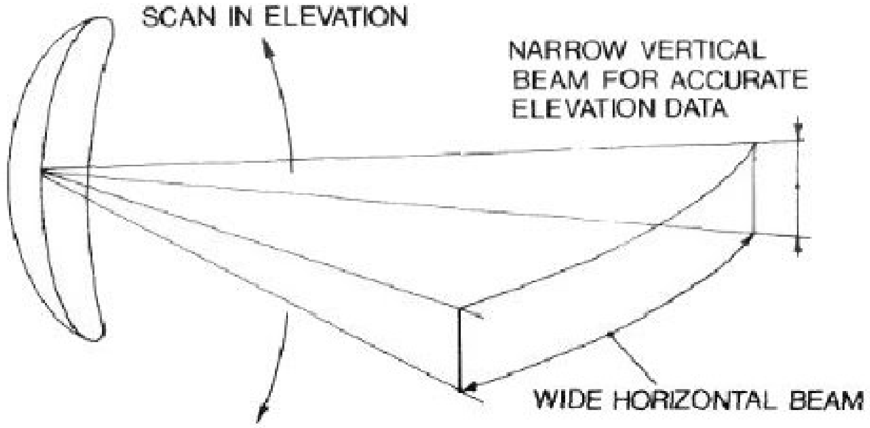
i. Antenna parameters and Basics
ii. Radar antenna patterns
iii. Resolution Angle
iv. Uncertainty volume (resolution Cell)
v. Polarization of electromagnetic waves
vi. Slotted and waveguide antennas
vii. Aperture antennas

Typical antenna 2D-Radar patterns

Fan Beam



'Cheese' beam form.



A typical height-finder ('orange peel' antenna).

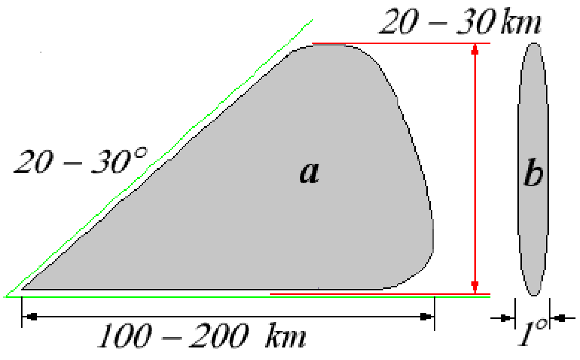
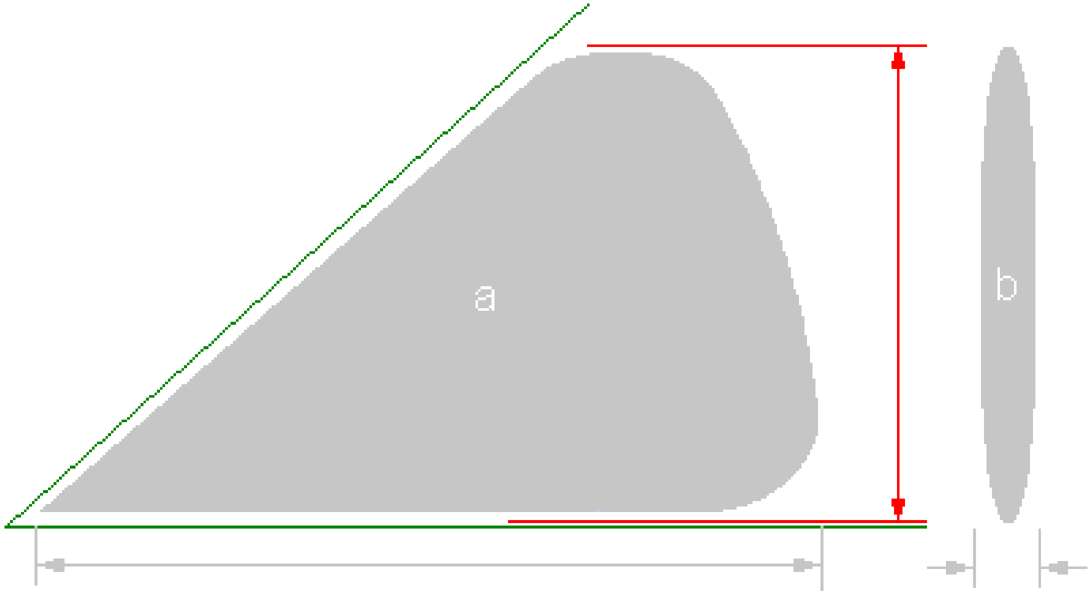


Figure 12: Fan-beam antennae pattern

a) lateral view b) frontal view

Non symmetric lobe
Only high resolution in azimuth (not in elevation)
Only provides (r,ϕ) coordinates.

FAN-BEAM ANTENNA (2D-Radar)



Fan-beam antennae pattern
a) lateral view
b) frontal view

Stacked antenna pattern (3D-Radar)

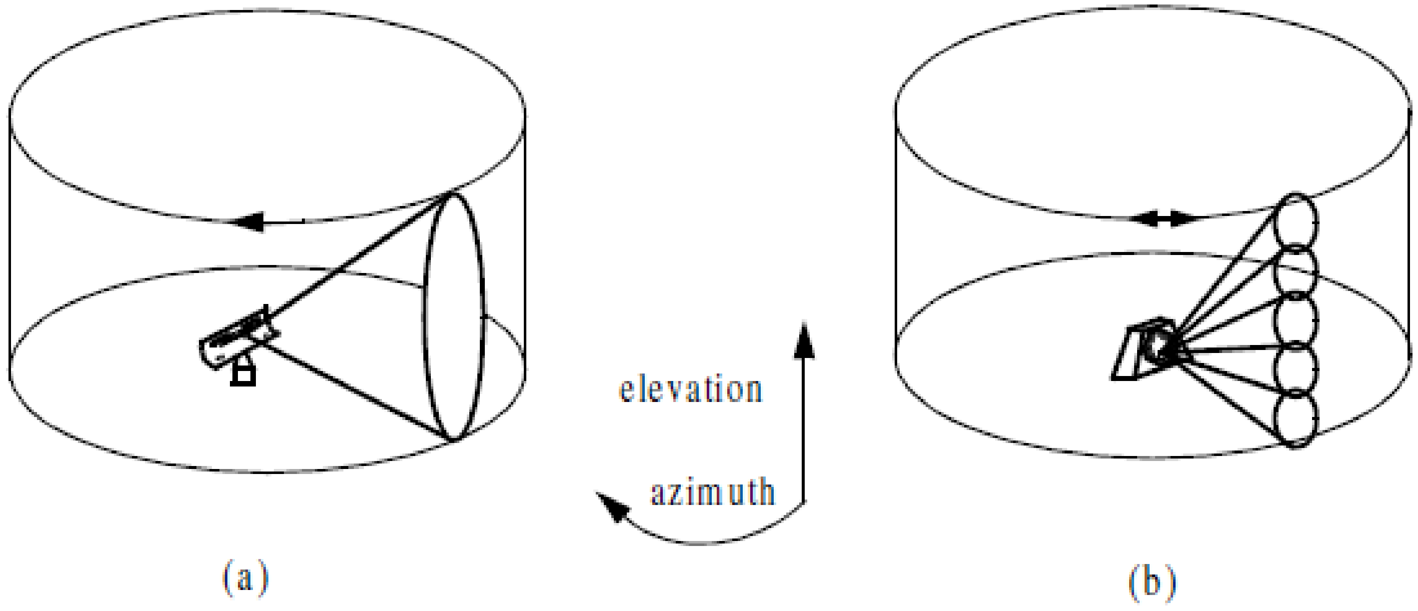


Figure 1.22. (a) 2-D fan search pattern; (b) stacked search pattern.

Made with a phased-array antenna.
Gives high resolution in azimuth and elevation
Provides (r, θ, ϕ) coordinates (3-D).
ATC applications

Radar Antenna

- A narrow beam in azimuth combined with a wide beam in elevation is the usual requirement in Air Traffic Control
- This combination is achieved through consideration to antenna (scanner) shape, size, and height above the ground.
- Note that if a narrow beam is required, the antena dimensions must be large in relation to wavelength.

Typical radar antenna

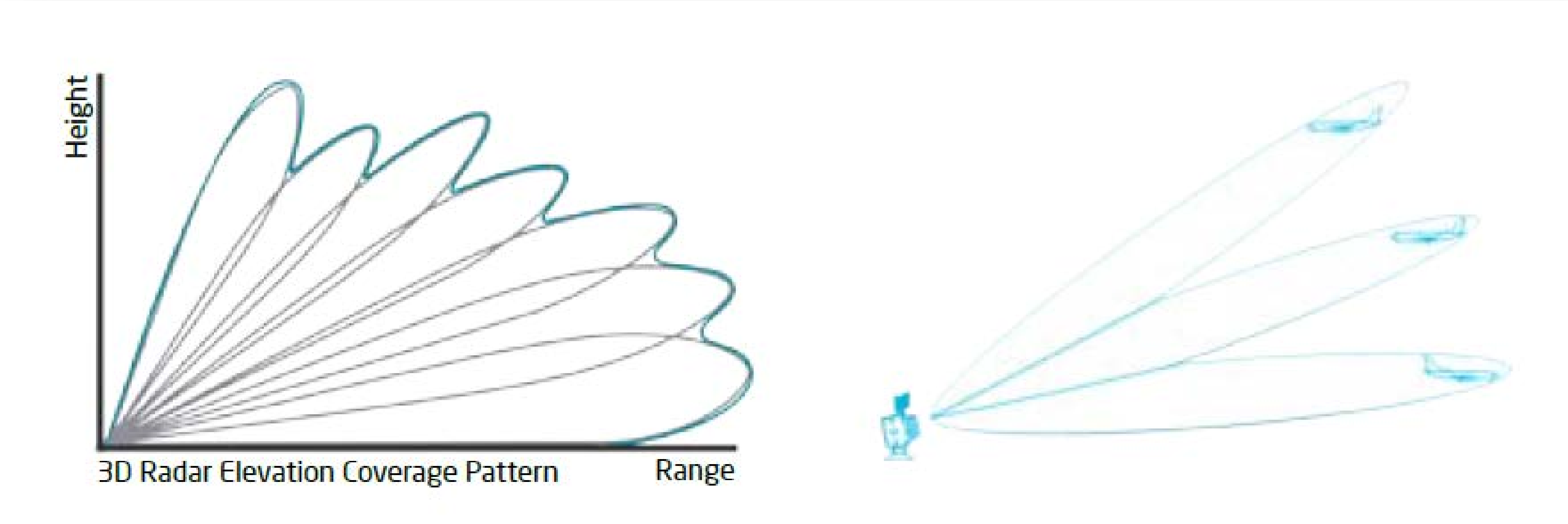
PRIMARY 3D-RADAR

Última Tecnología radar 3D de medio y largo alcance para Aeropuertos y Vigilancia de Rutas Aéreas

Proporciona información precisa sobre la posición de aeronaves, incluyendo la altura de vuelo. Estas capacidades de detección y estimación de posición 3D se consiguen Incluso en condiciones climáticas extremas, clutter terrestre e interferencias naturales o artificiales, sea con aeronaves cooperativas o no-cooperativas.

Además de las capacidades de detección y seguimiento, el radar incluye un procesador meteorológico que proporciona al controlador información meteorológica necesaria para la gestión segura del tráfico aéreo.

PRIMARY 3D-RADAR



High flexibility supported by modular, repetitive and redundant architecture providing soft-fail capability, in case of failure of any array element, and easy maintainability with a minimum number of spares.

Very reliable system:
MTBCF >20.000 hours,
MTTR < 30 minutes
System Availability > 99,99%.

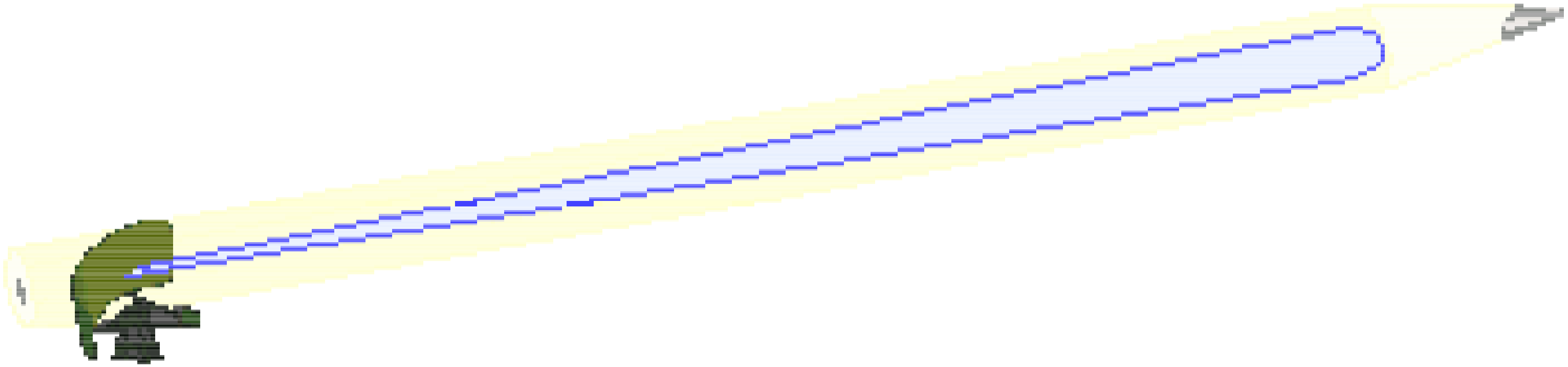
indra

PRIMARY 3D-RADAR

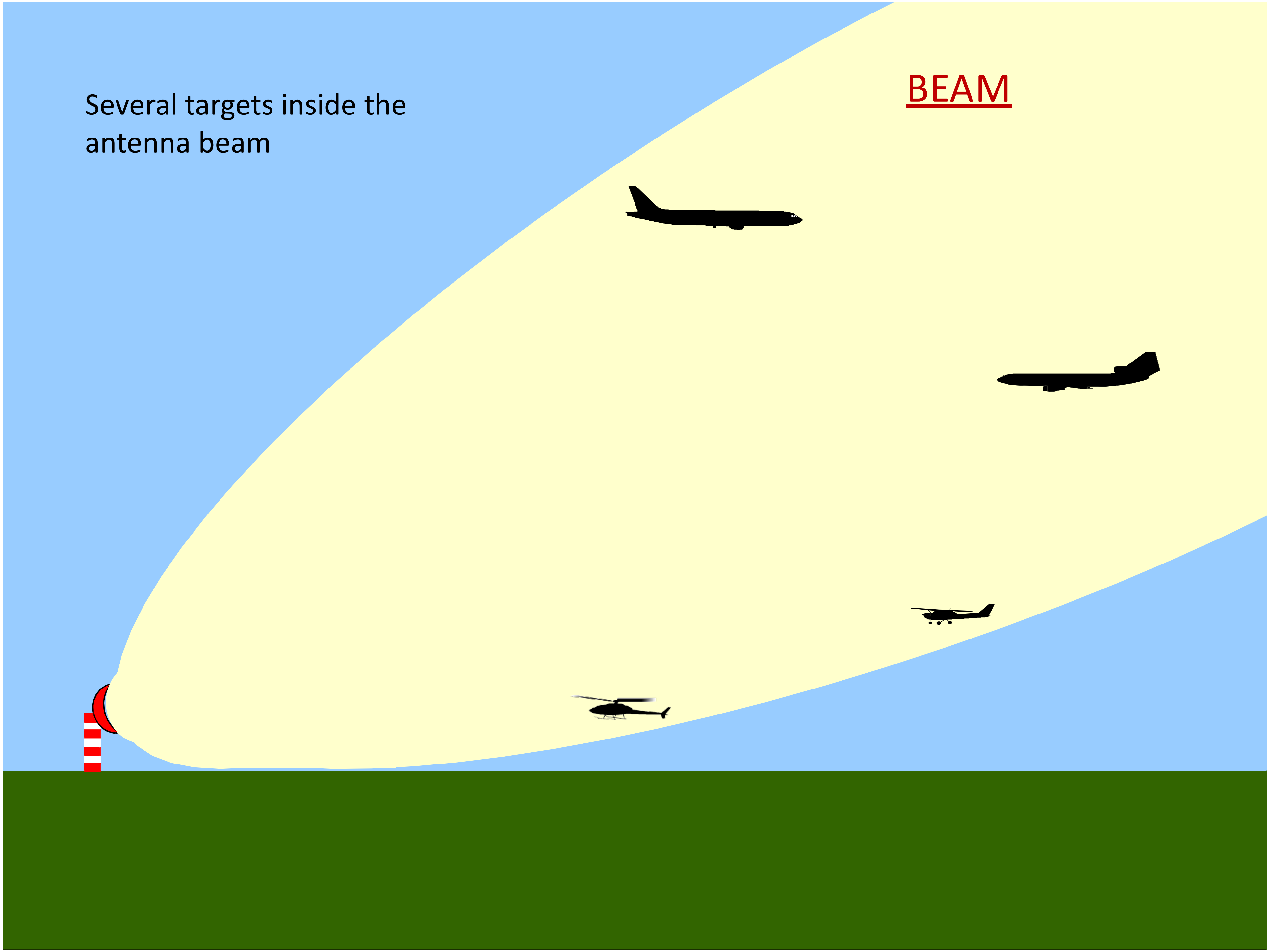
TECHNICAL CHARACTERISTICS

GENERAL CHARACTERISTICS	
Frequency Operating Band	1250 to 1350 MHz
Frequency Modes	2 Frequency channels More than 70 selectable frequency codes Dual frequency code operation mode
Power amplifier modules	16 (graceful degradation)
RF Tx and blanking	Up to 16 sectors in azimuth
Tx waveforms	Complex waveform scheduling with long length (high energy)LFM pulses: Up to 500 us
Duty Cycle	11 % mean, 15% peak
PRF	Complex staggered interpulse period scheme
MTI improvement factor	60 dB
COVERAGE	
Range	70, 100, 110, 120 or 180 NM
Heigth	Up to 80000 feet
Elevation	> 30°
RELIABILITY	
Availability	99.99%
MTBCF	> 20000 hours
MTTR	< 30 minutes
RESOLUTION	
Range	200 m
Azimuth	3°
ACCURACY	
Range	50 m
Azimuth	0.2°
Height	2500 feet up to 60 NM
RECEIVER	
Architecture	Distributed front-end elements
Sensitivity	-115 dBm
Dynamic Range	> 80 dB
STC	> 60 dB
ANTENNA	
Architecture	Planar array with 16 row antennas. Digitally controllable beamforming
Patterns	Tx pattern 3 simultaneous Rx patterns (Sum, Diff Azim, Diff Elev)
Gain	Tx: 33.3 dBi Rx: 33 dBi
Azimuth beamwidth	2.8°
Elevation Beamwidth	6°
Rotation Speed	From 5 rpm to 15 rpm in relation to range coverage
Polarization	Linear
Receiving channels	Sum-F1, Sum-F2, Diff Az-F1, Diff Az-F2, Diff Elev-F1, Diff Elev-F2
SIGNAL & DATA PROCESSOR	
Architecture	COTS multiprocessor boards Configurable processes: MTI, MTD, Non-Coherent Integration
Processing channels	Adaptive clutter suppression by coherent processing
Detection Process	Based on combination of range CFAR and clutter maps
Coordinate estimation	Monopulse in azimuth and elevation (target height)
Weather Channel	US-NWS / ICAO 6 level detection
Capacity	1000 plots per scan 500 tracks per scan

Pencil beam antenna pattern (3D-Radar)

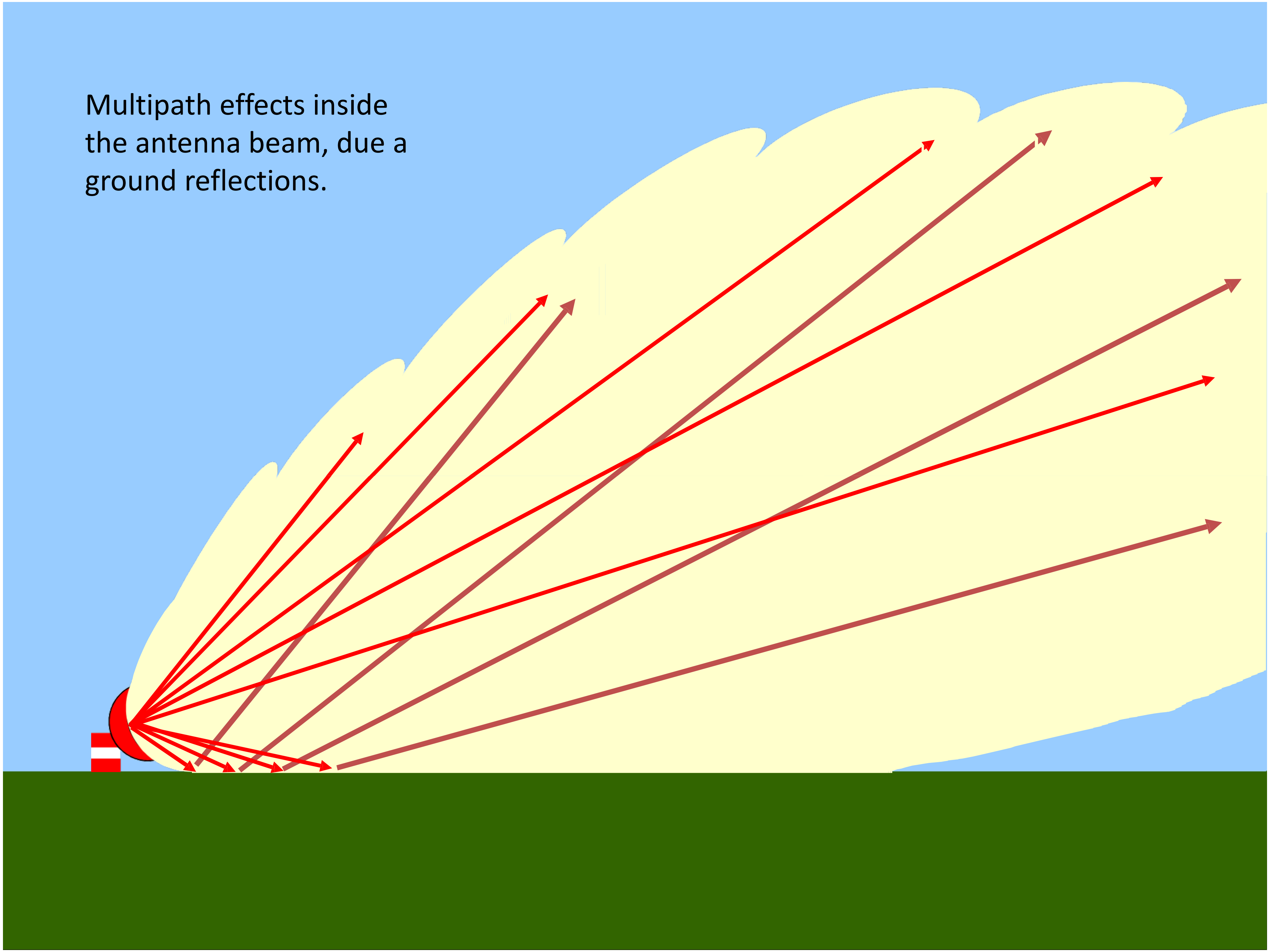


Symmetric lobe
High space resolution
Provides (r, θ, ϕ) coordinates
Tracking target applications



Several targets inside the antenna beam

Multipath effects inside the antenna beam, due a ground reflections.

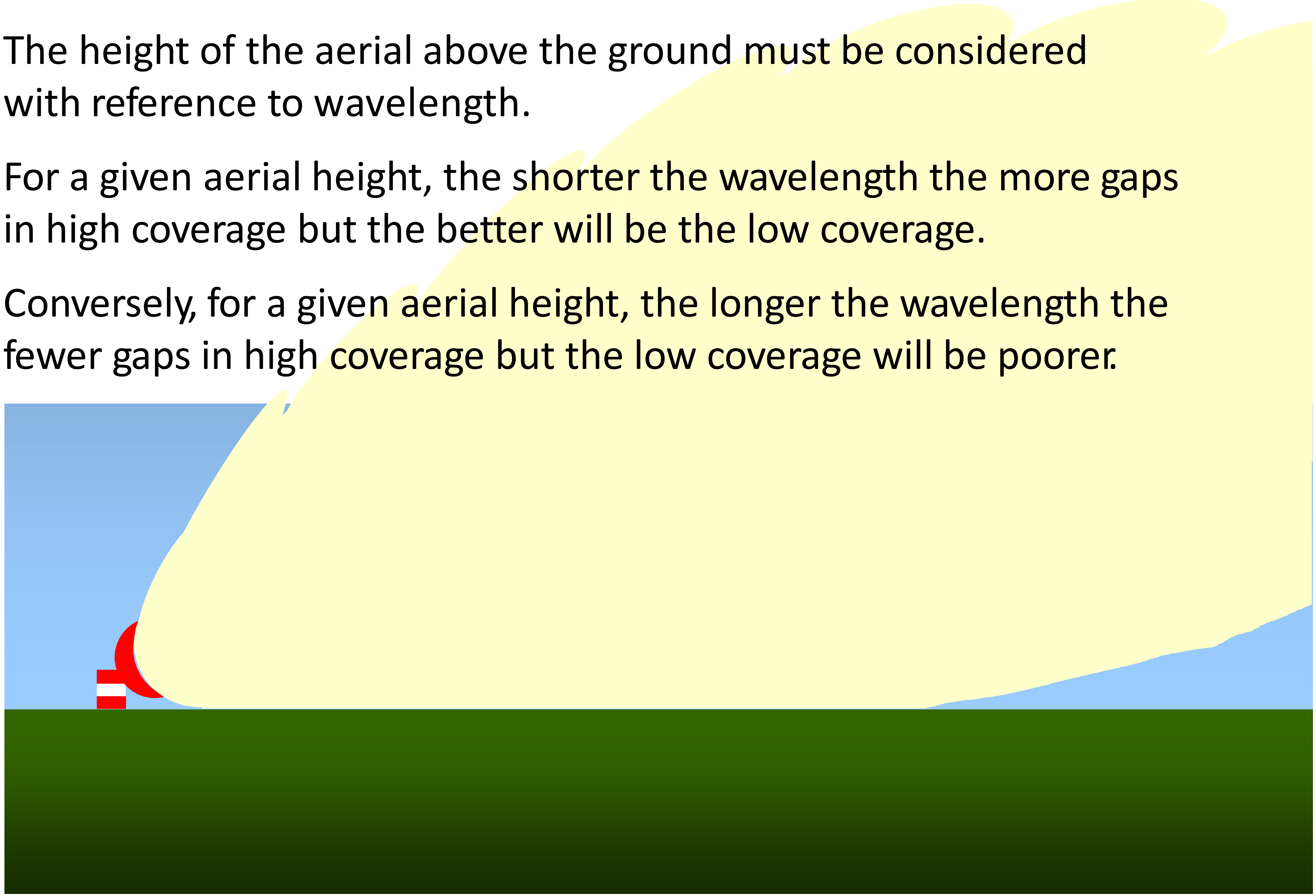


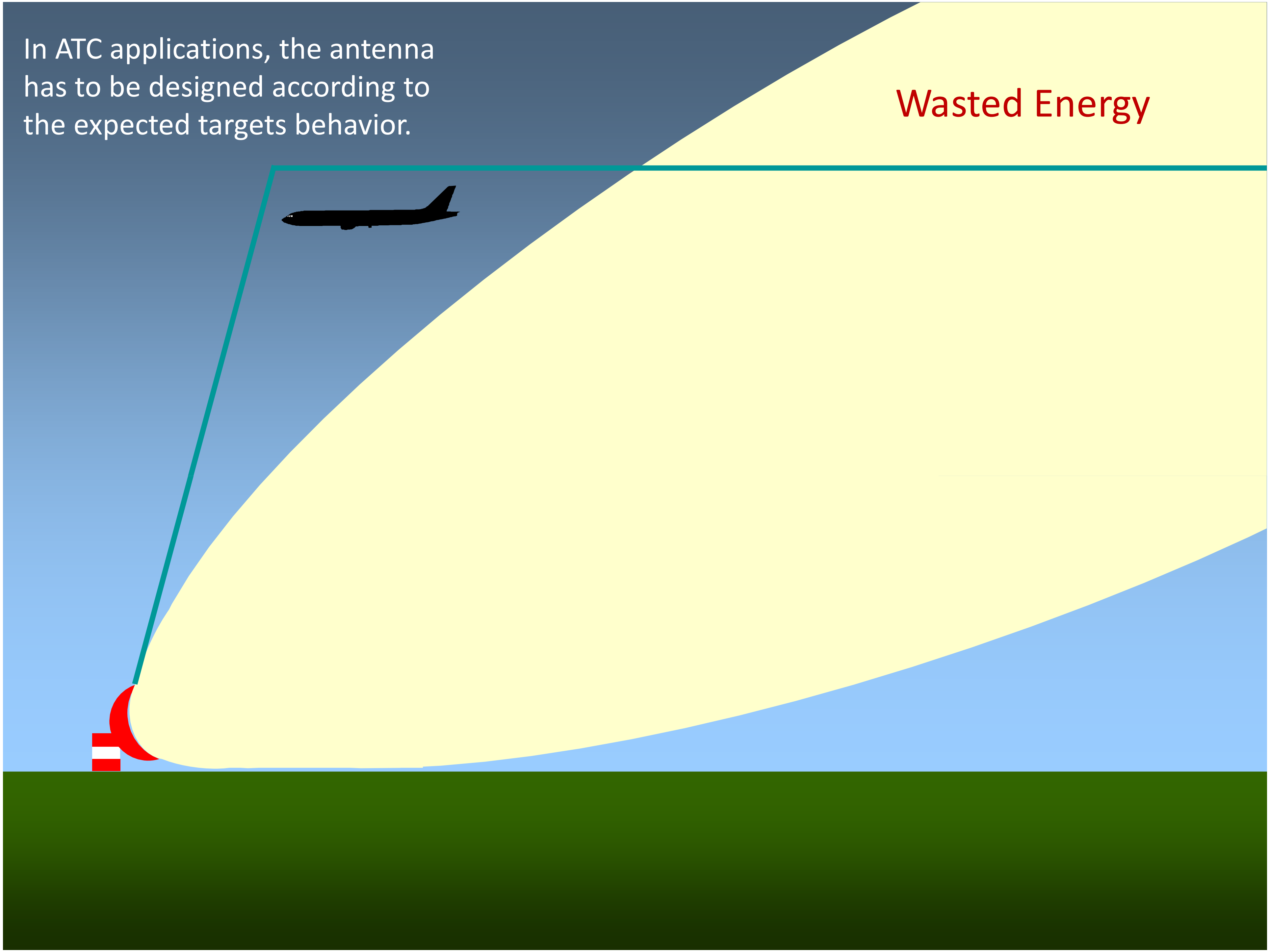
Wavelength antenna dependence

The height of the aerial above the ground must be considered with reference to wavelength.

For a given aerial height, the shorter the wavelength the more gaps in high coverage but the better will be the low coverage.

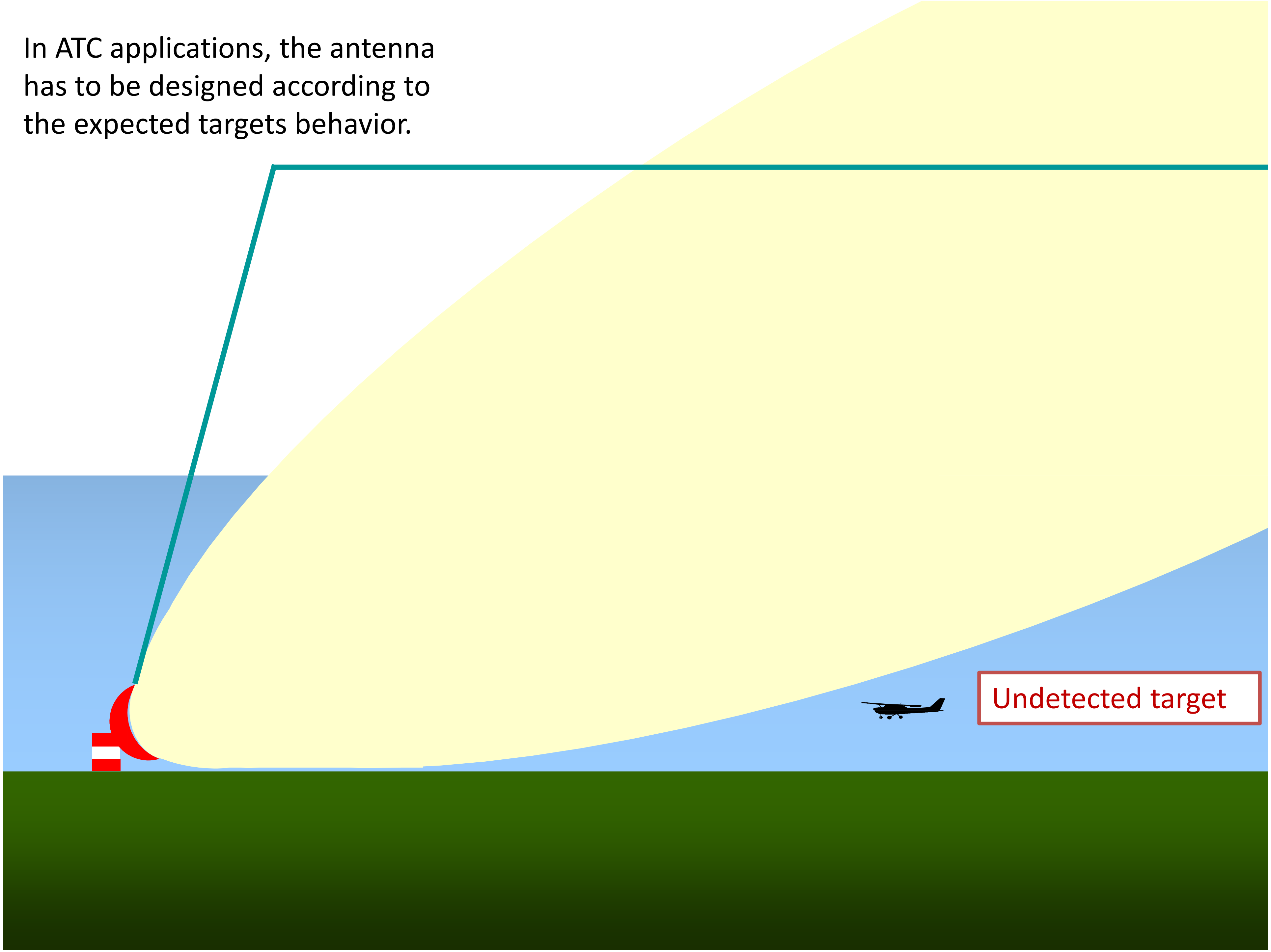
Conversely, for a given aerial height, the longer the wavelength the fewer gaps in high coverage but the low coverage will be poorer.



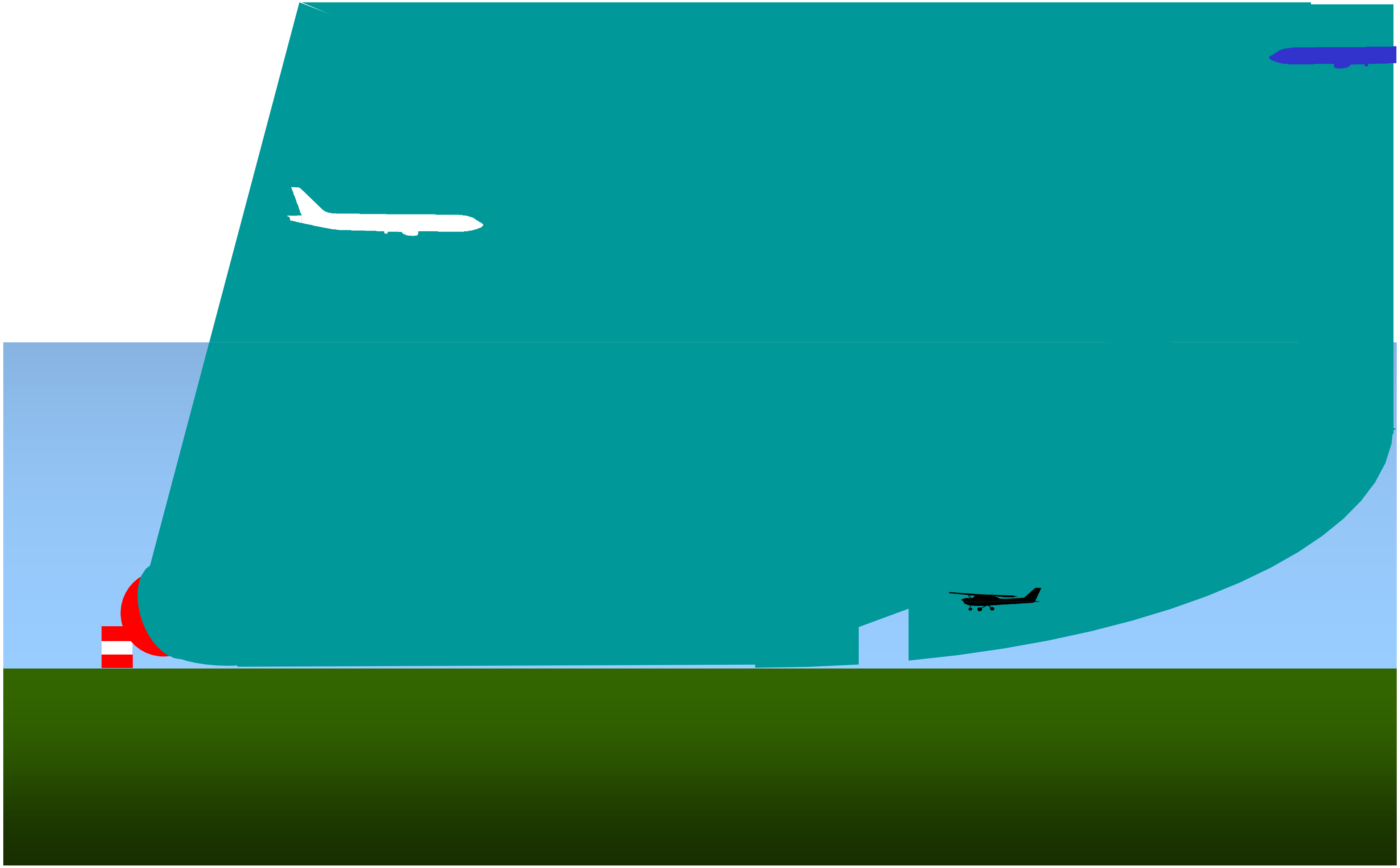


In ATC applications, the antenna has to be designed according to the expected targets behavior.

In ATC applications, the antenna has to be designed according to the expected targets behavior.

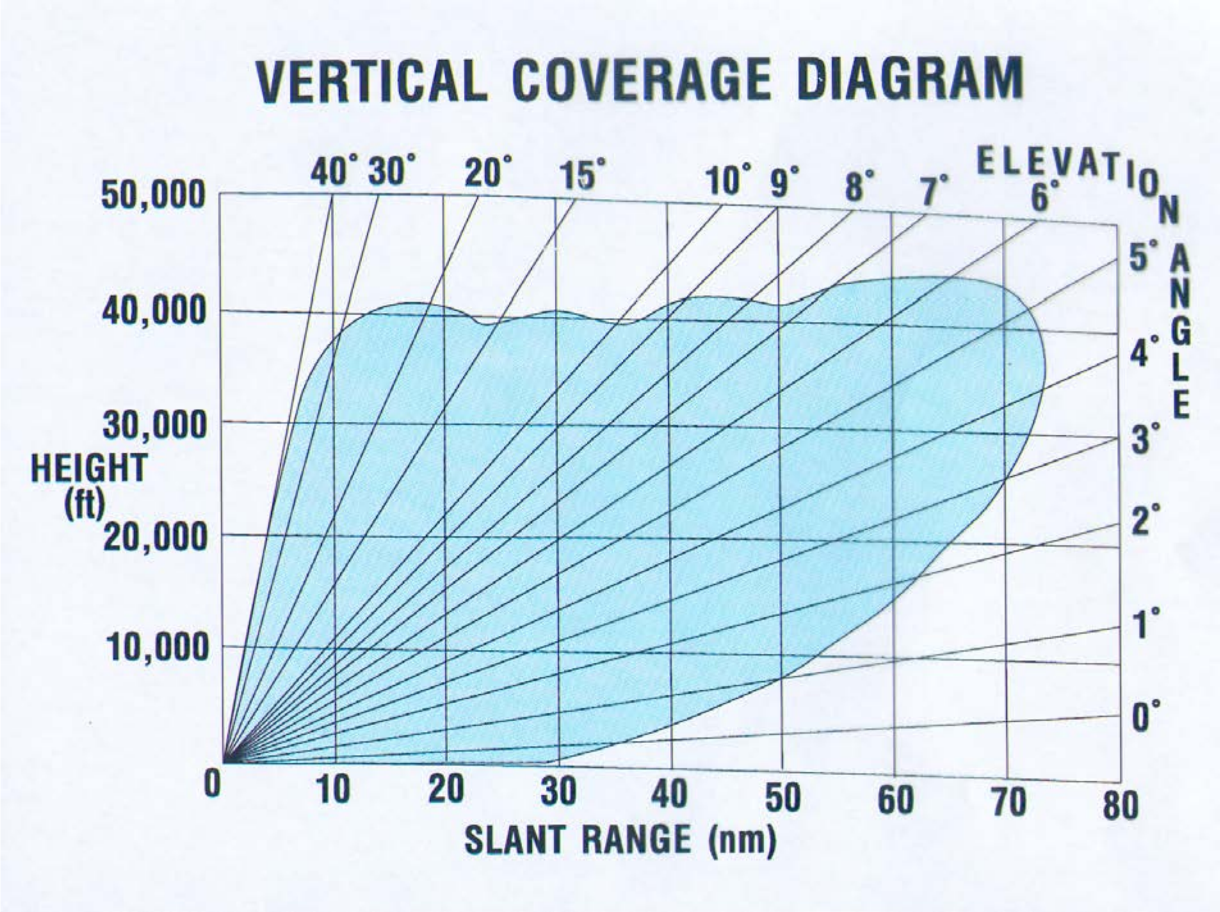


Antenna pattern adjusted to the ATC demands.



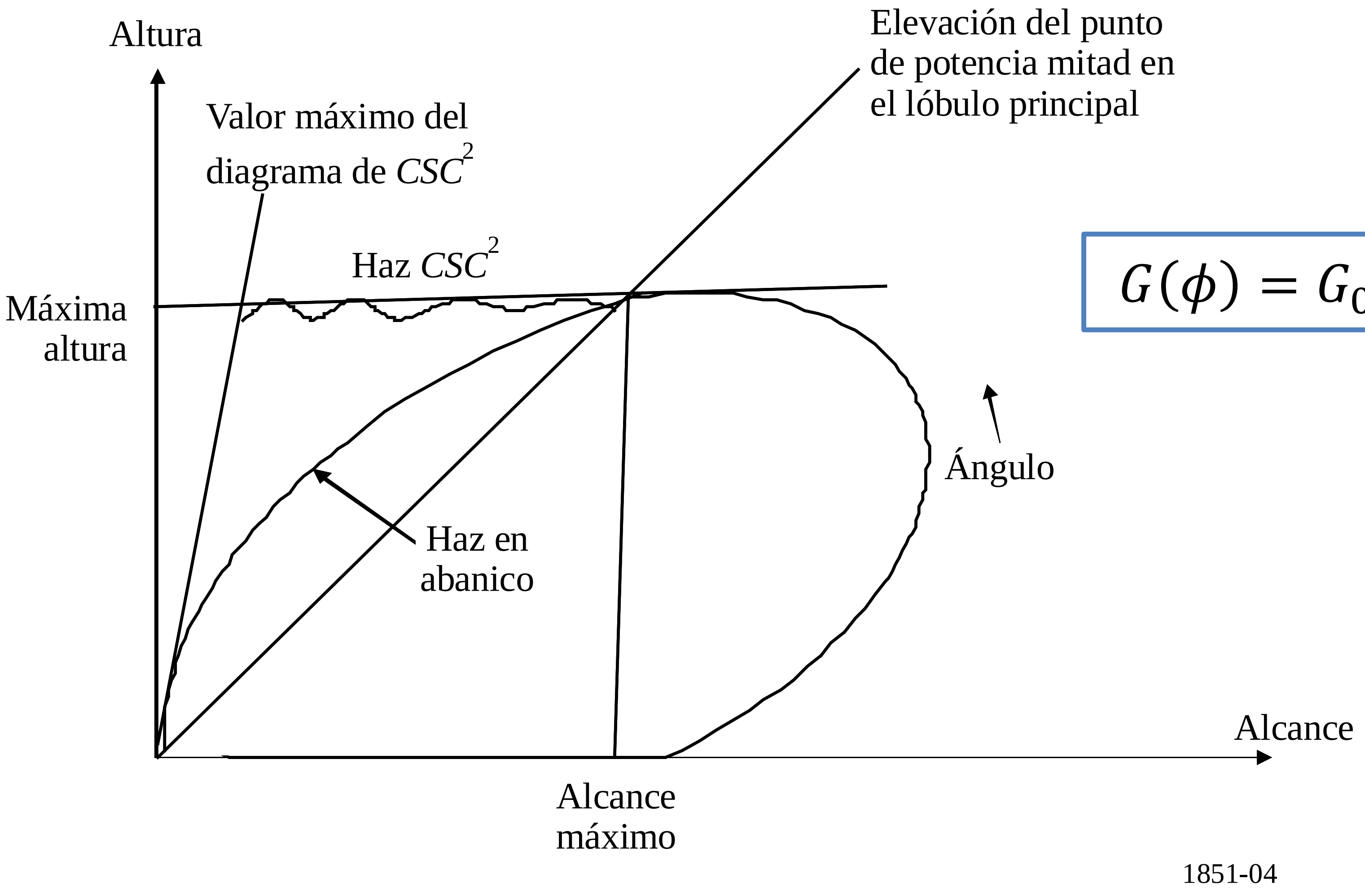
Cosecant squared radar antenna pattern

Meets the ATC requirements.



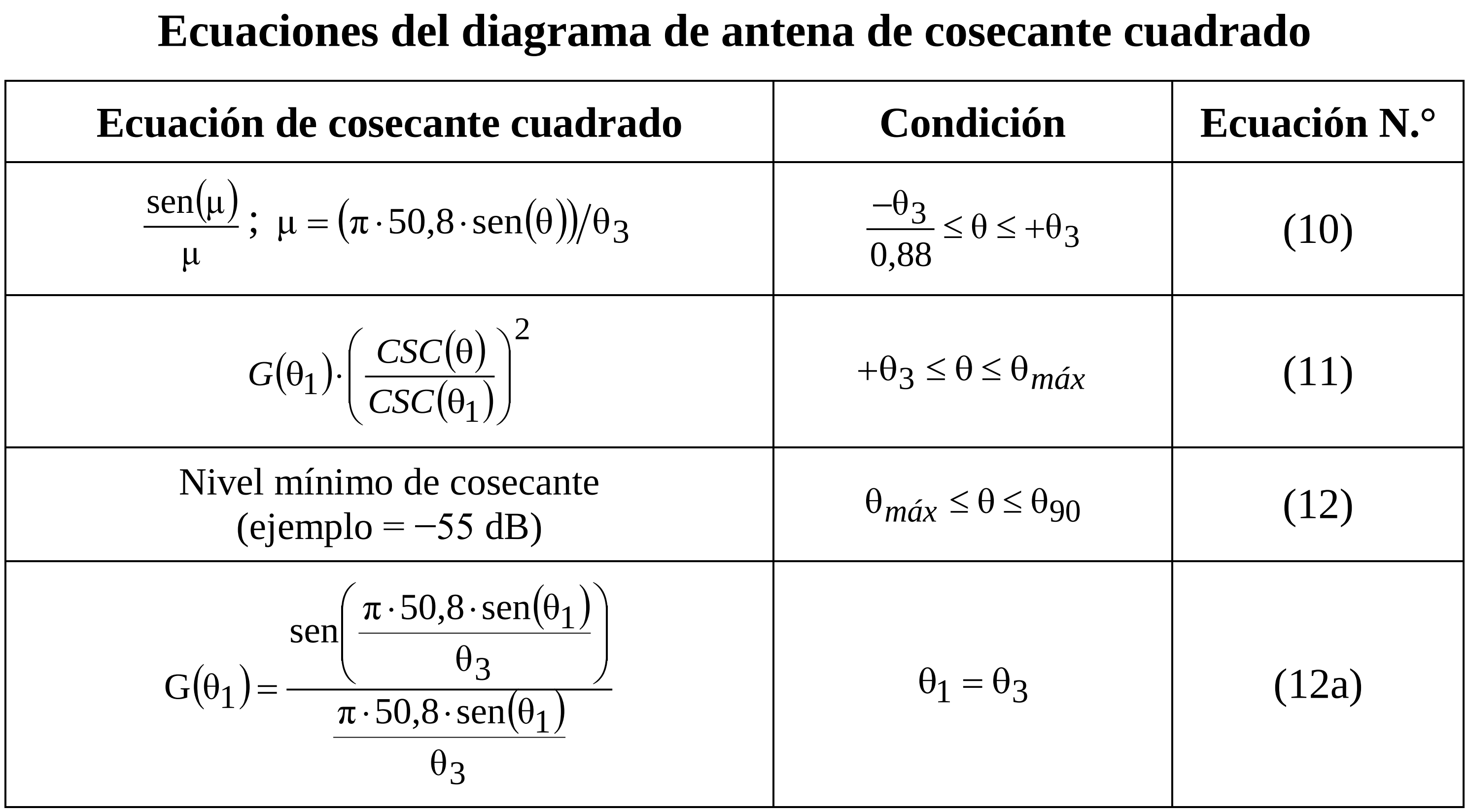
$$G(\phi) = G_0 \csc^2 \phi$$

Cosecant squared radar antenna pattern



$$G(\phi) = G_0 \csc^2 \phi$$

Cosecant squared radar antenna pattern

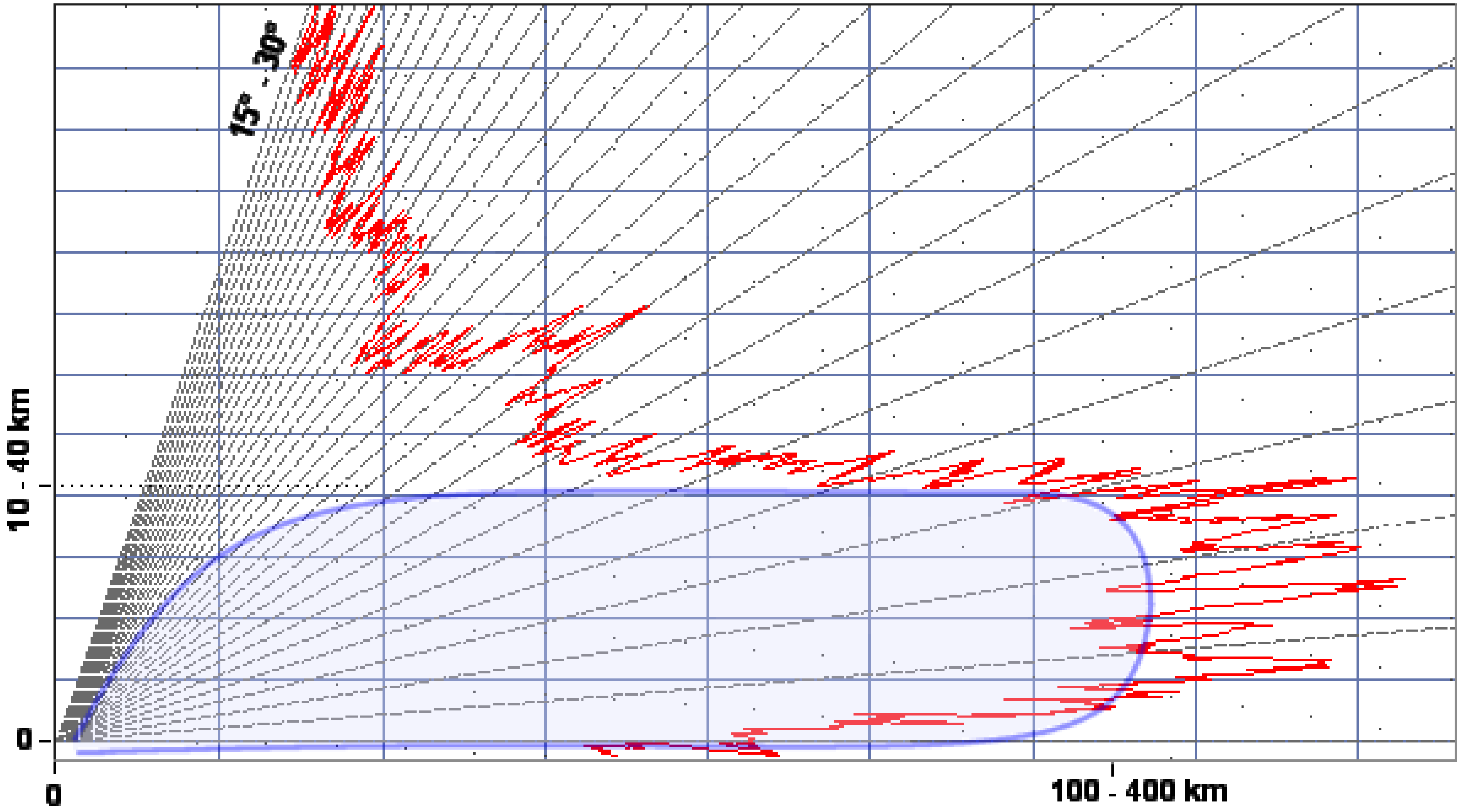


Ecuaciones del diagrama de antena de cosecante cuadrado

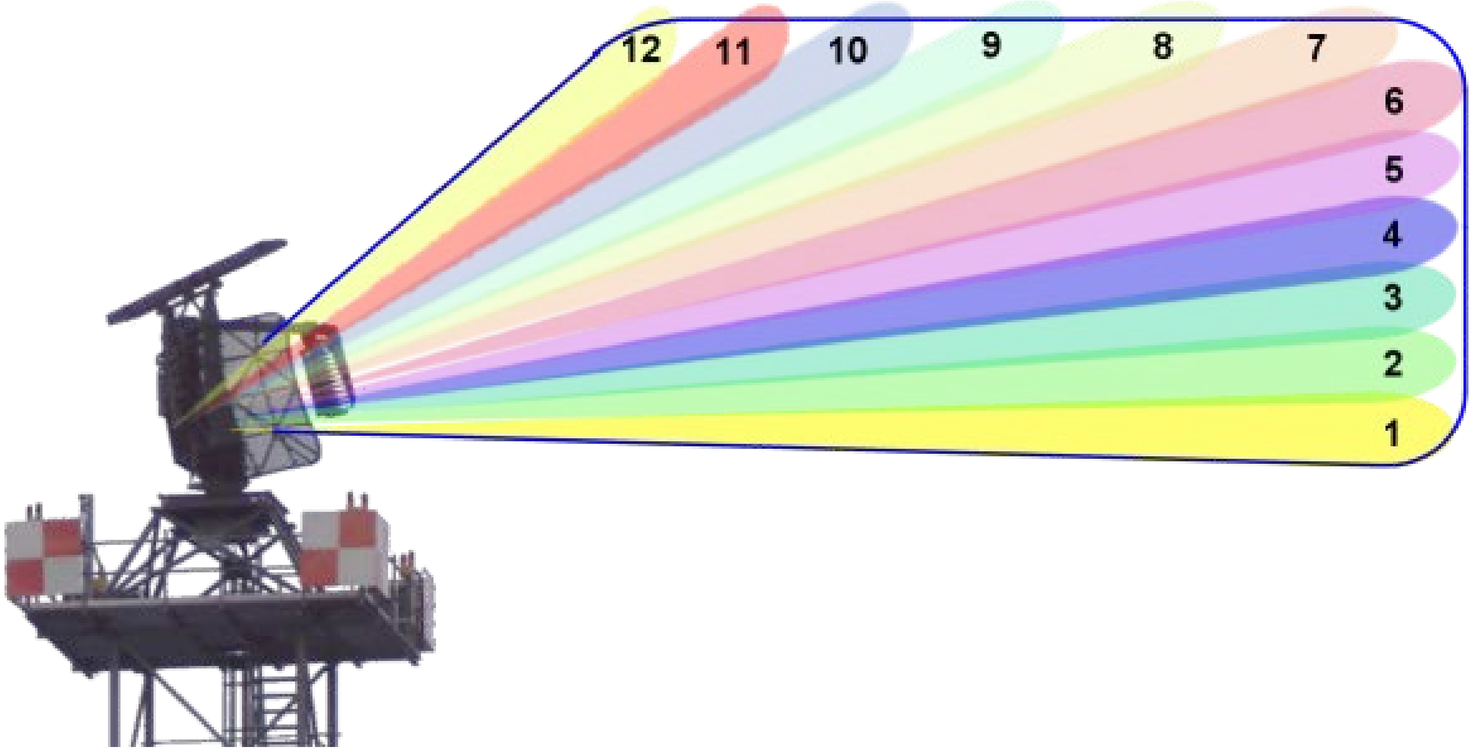
Ecuación de cosecante cuadrado	**Condición**	**Ecuación N.°**
$\frac{\operatorname{sen}(\mu)}{\mu}$; $\mu = (\pi \cdot 50{,}8 \cdot \operatorname{sen}(\theta))/\theta_3$	$\frac{-\theta_3}{0{,}88} \le \theta \le +\theta_3$	(10)
$G(\theta_1) \cdot \left(\frac{CSC(\theta)}{CSC(\theta_1)}\right)^2$	$+\theta_3 \le \theta \le \theta_{\text{máx}}$	(11)
Nivel mínimo de cosecante (ejemplo = −55 dB)	$\theta_{\text{máx}} \le \theta \le \theta_{90}$	(12)
$G(\theta_1) = \frac{\operatorname{sen}\left(\frac{\pi \cdot 50{,}8 \cdot \operatorname{sen}(\theta_1)}{\theta_3}\right)}{\frac{\pi \cdot 50{,}8 \cdot \operatorname{sen}(\theta_1)}{\theta_3}}$	$\theta_1 = \theta_3$	(12a)

Cosecant squared radar antenna pattern

Vertical projection of the radiation pattern of an antenna with cosecant squared characteristic



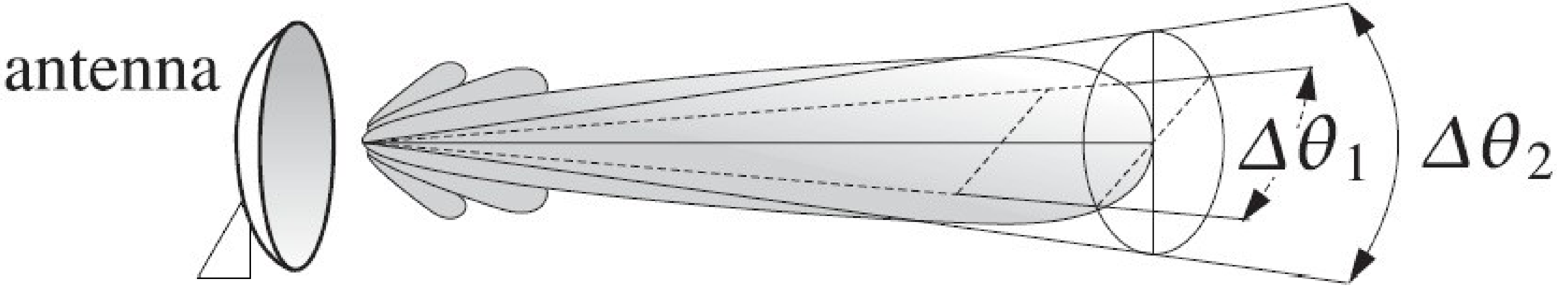
Stacked beam cosecant squared pattern



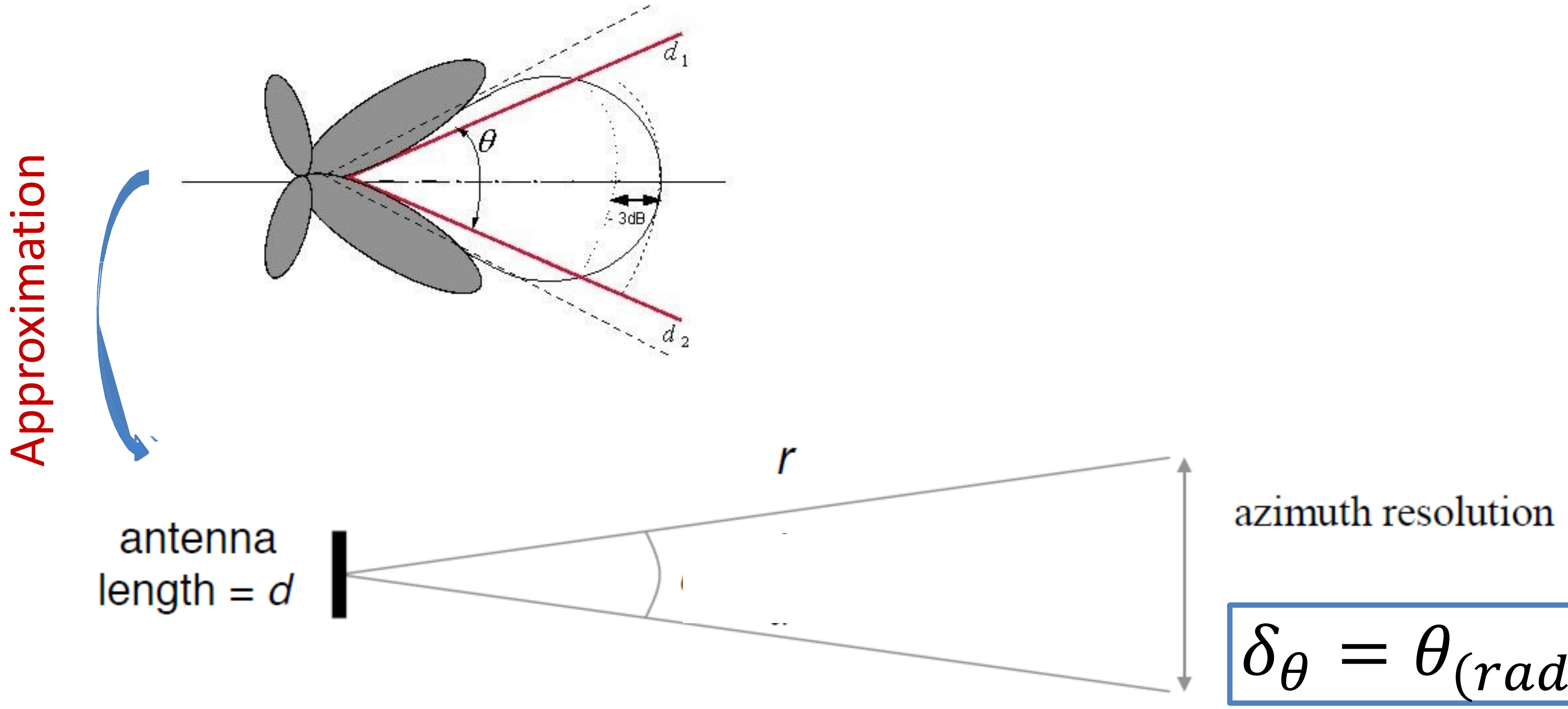
Radar Antennas

i. Antenna parameters and Basics
ii. Radar antenna patterns
iii. Resolution Angle
iv. Uncertainty volume (resolution Cell)
v. Polarization of electromagnetic waves
vi. Slotted and waveguide antennas
vii. Aperture antennas

Beamwidth antenna angle



Angular resolution



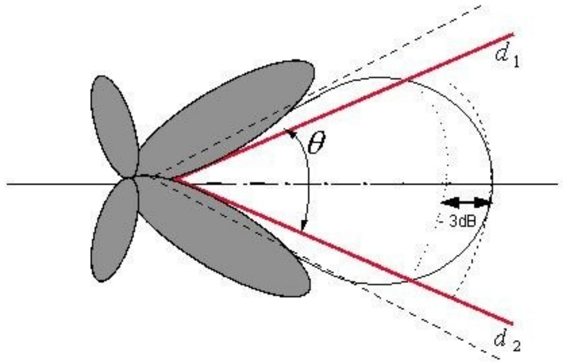
$$\boxed{\delta_\theta = \theta_{(rad)} \cdot r}$$

Radar Antennas

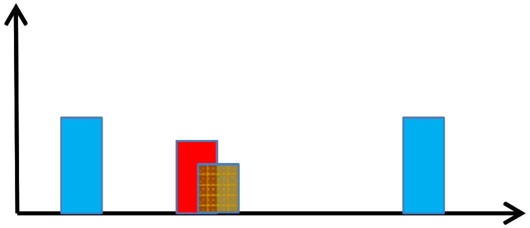
i. Antenna parameters and Basics
ii. Radar antenna patterns
iii. Resolution Angle
iv. Uncertainty volume (resolution Cell)
v. Polarization of electromagnetic waves
vi. Slotted and waveguide antennas
vii. Aperture antennas

Uncertain volume

Angular Resolution

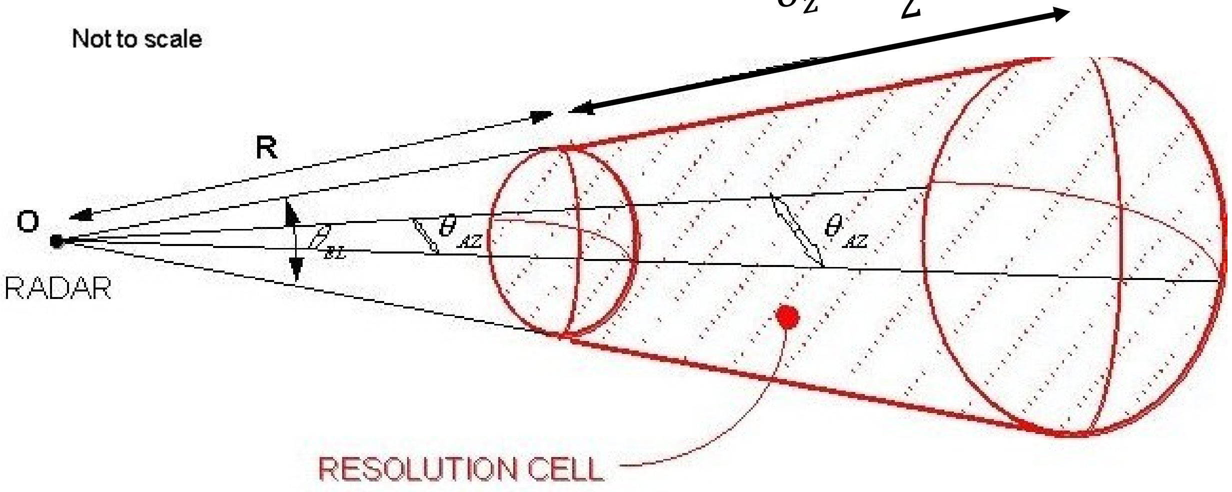


Range Resolution



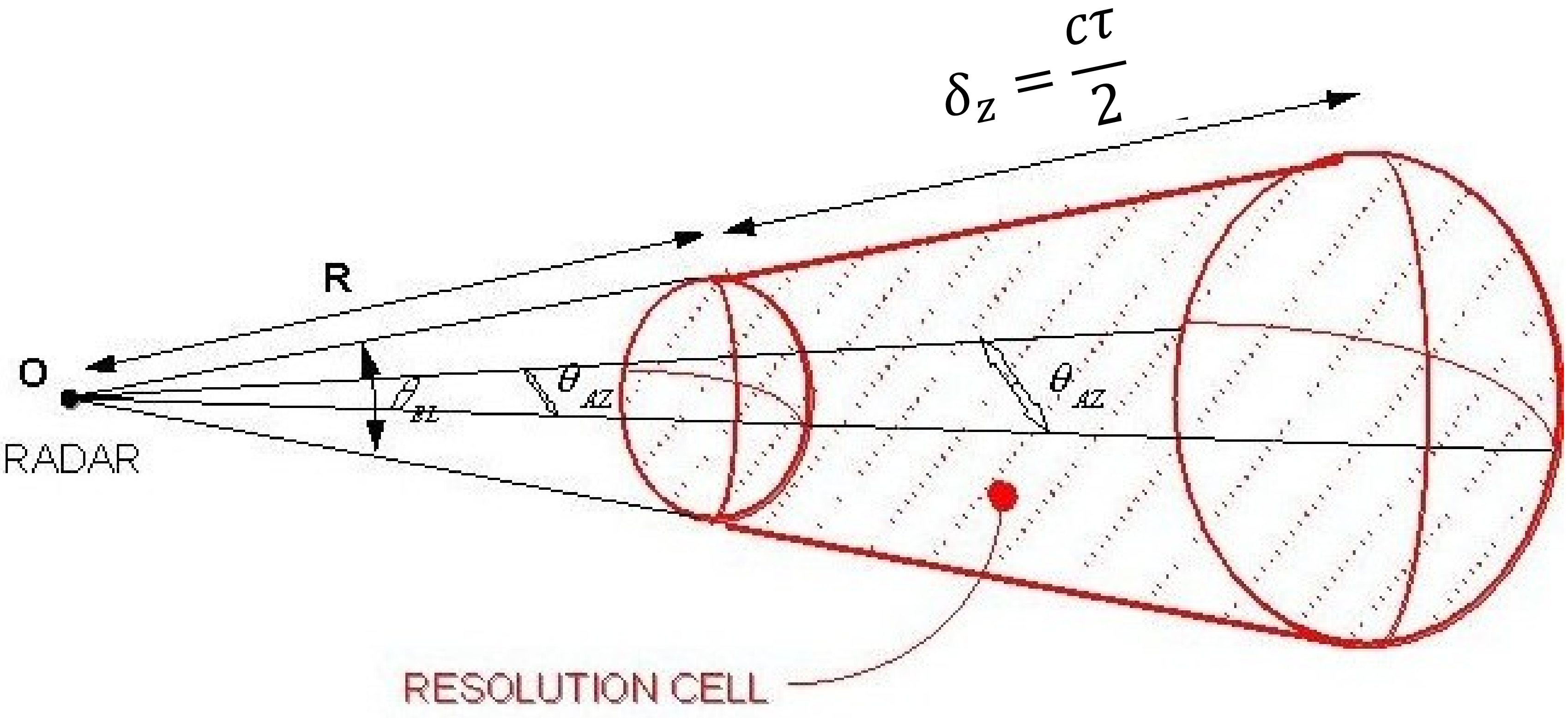
$$\delta_z = \frac{c\tau}{2}$$

Not to scale



UNCERTAIN VOLUME

Uncertain volume



$$\boxed{V_i = \delta_{\theta_H}\delta_{\theta_V}\delta_z = \theta_H\theta_V R^2\frac{c\tau}{2} = \theta_H\theta_V R^2\frac{c}{2B}}$$

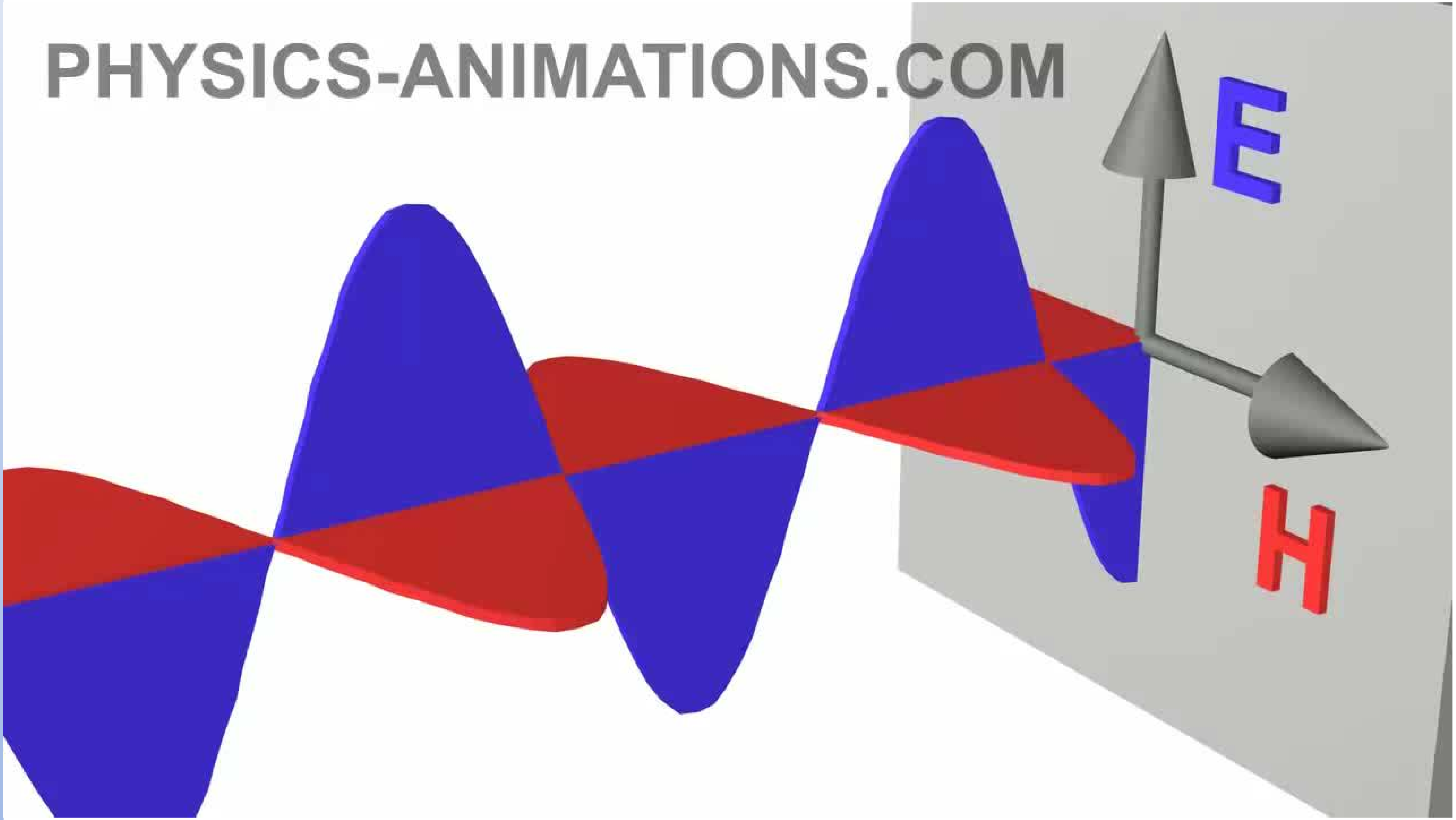
Beamwidths in azimuth and elevation in radians

Pulse bandwidth

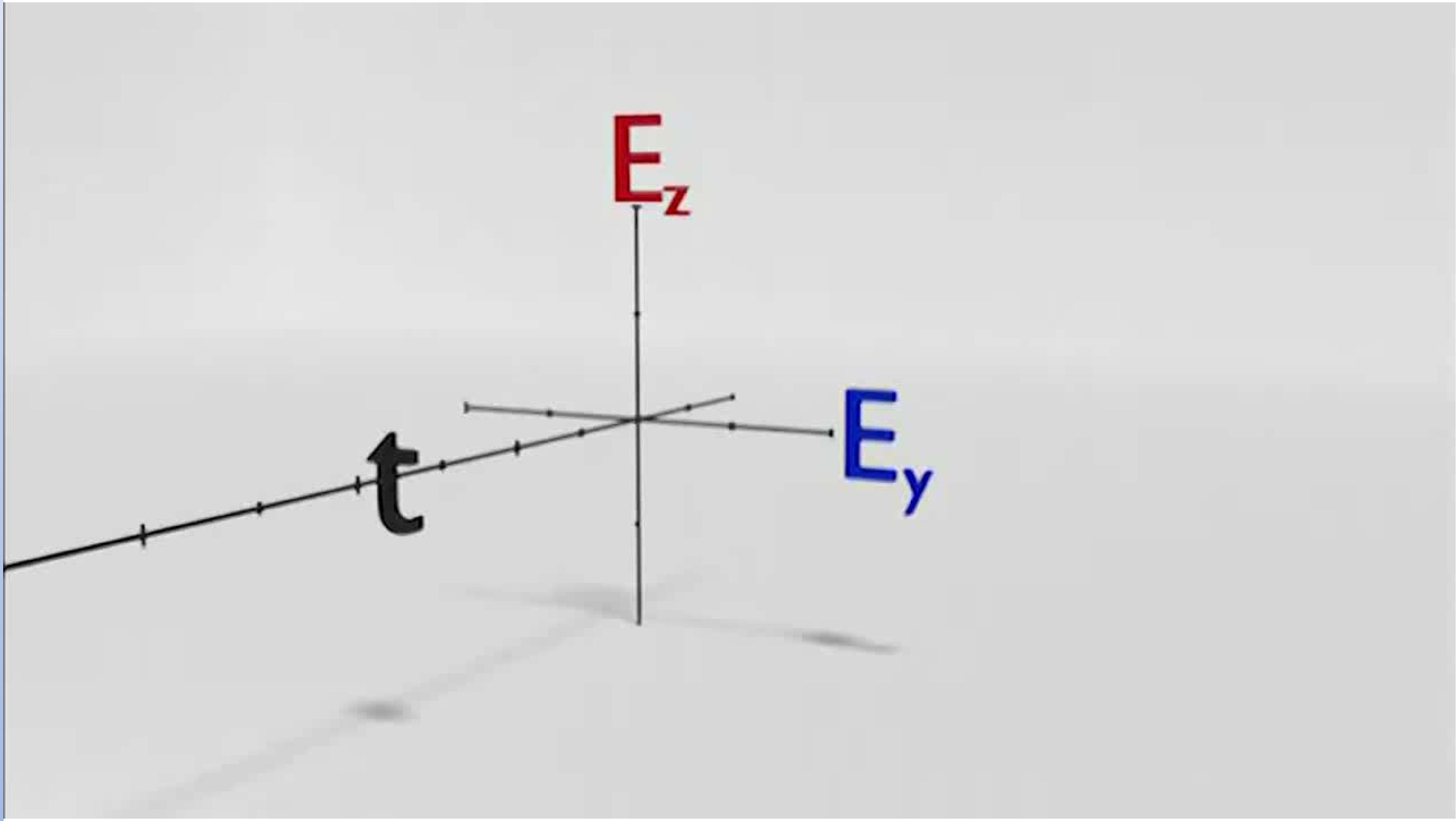
Radar Antennas

i. Antenna parameters and Basics
ii. Radar antenna patterns
iii. Resolution Angle
iv. Uncertainty volume (resolution Cell)
v. Polarization of electromagnetic waves
vi. Slotted and waveguide antennas
vii. Aperture antennas

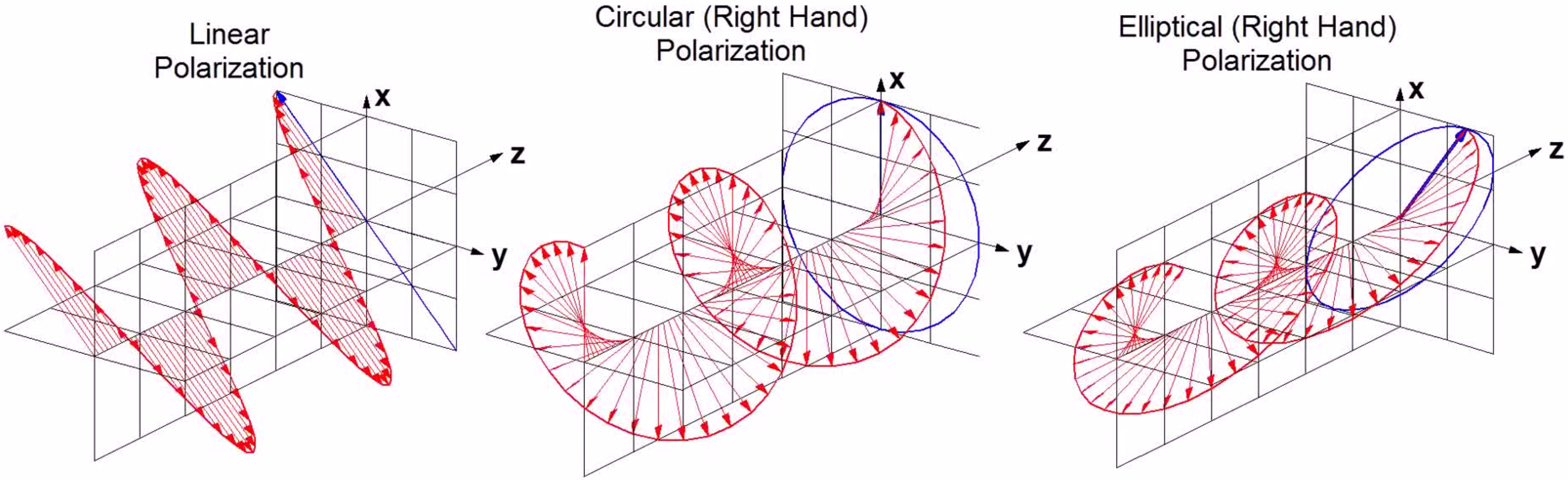
Planar waves polarization

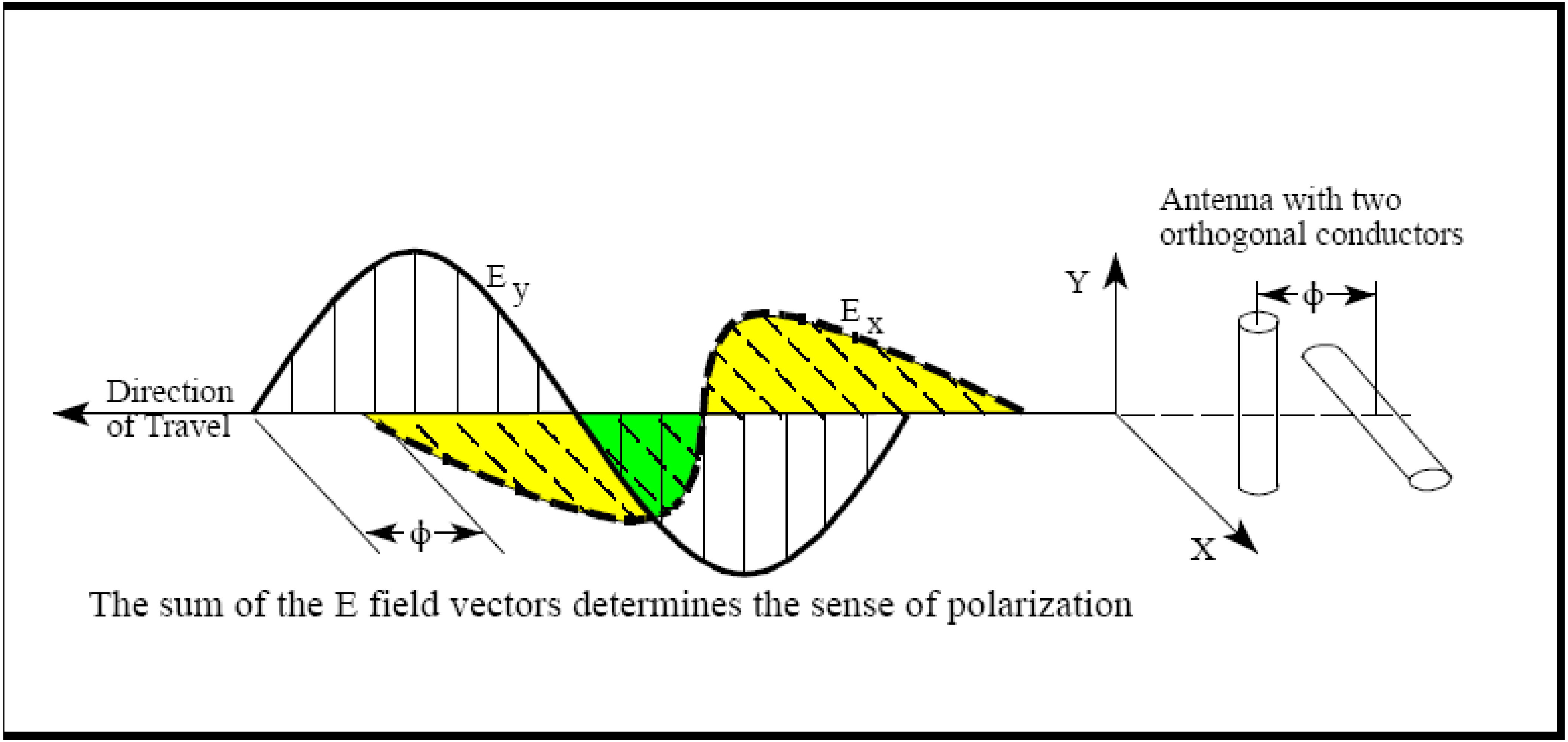


Planar waves polarization



Linear, Circular and Elliptical Polarization





The sum of the E field vectors determines the sense of polarization

Figure 1. Polarization Coordinates

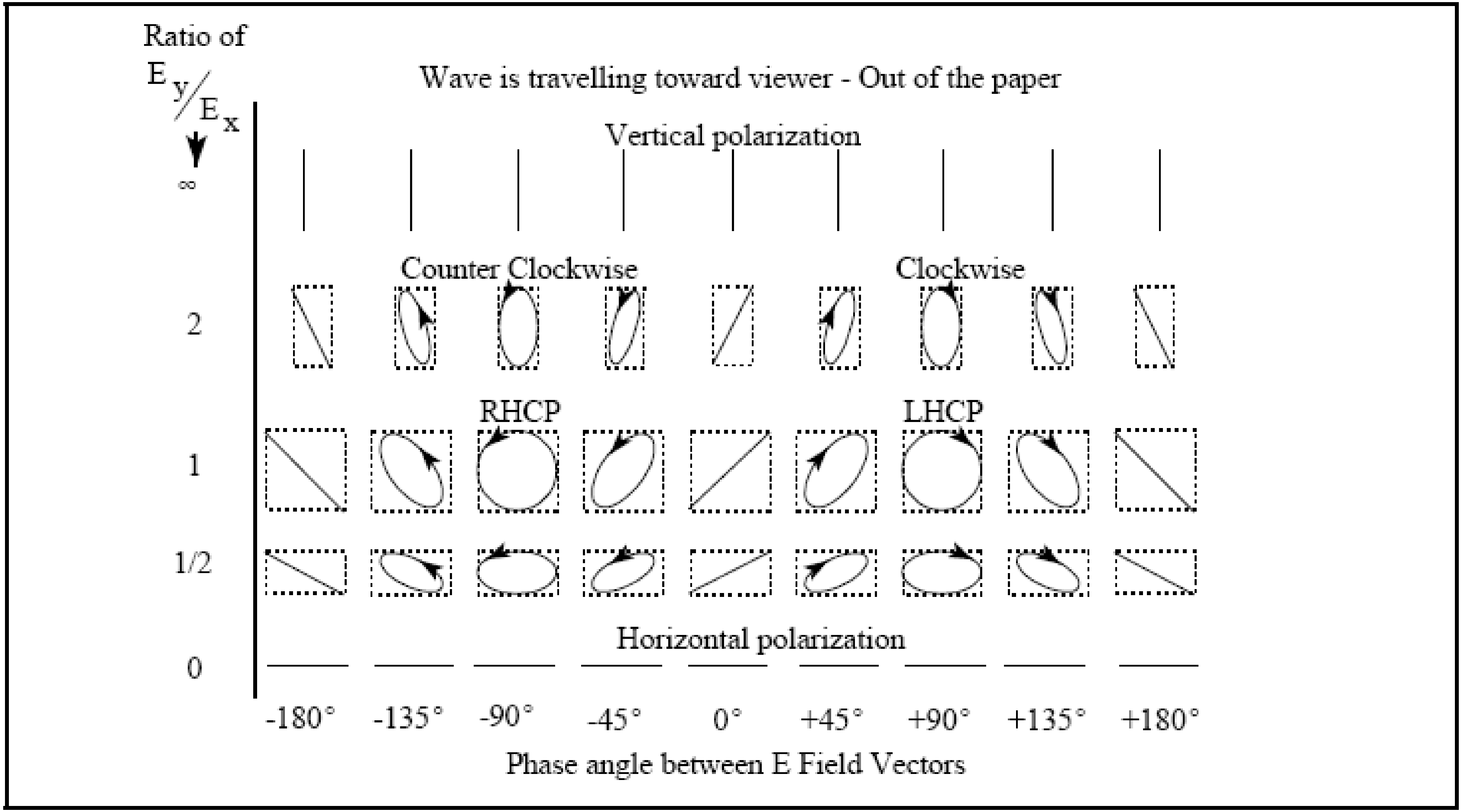


Figure 2. Polarization as a Function of E_y/E_x and Phase angle

Radar Antennas

i. Antenna parameters and Basics
ii. Radar antenna patterns
iii. Resolution Angle
iv. Uncertainty volume (resolution Cell)
v. Polarization of electromagnetic waves
vi. Slotted and waveguide antennas
vii. Aperture antennas

Slotted antennas

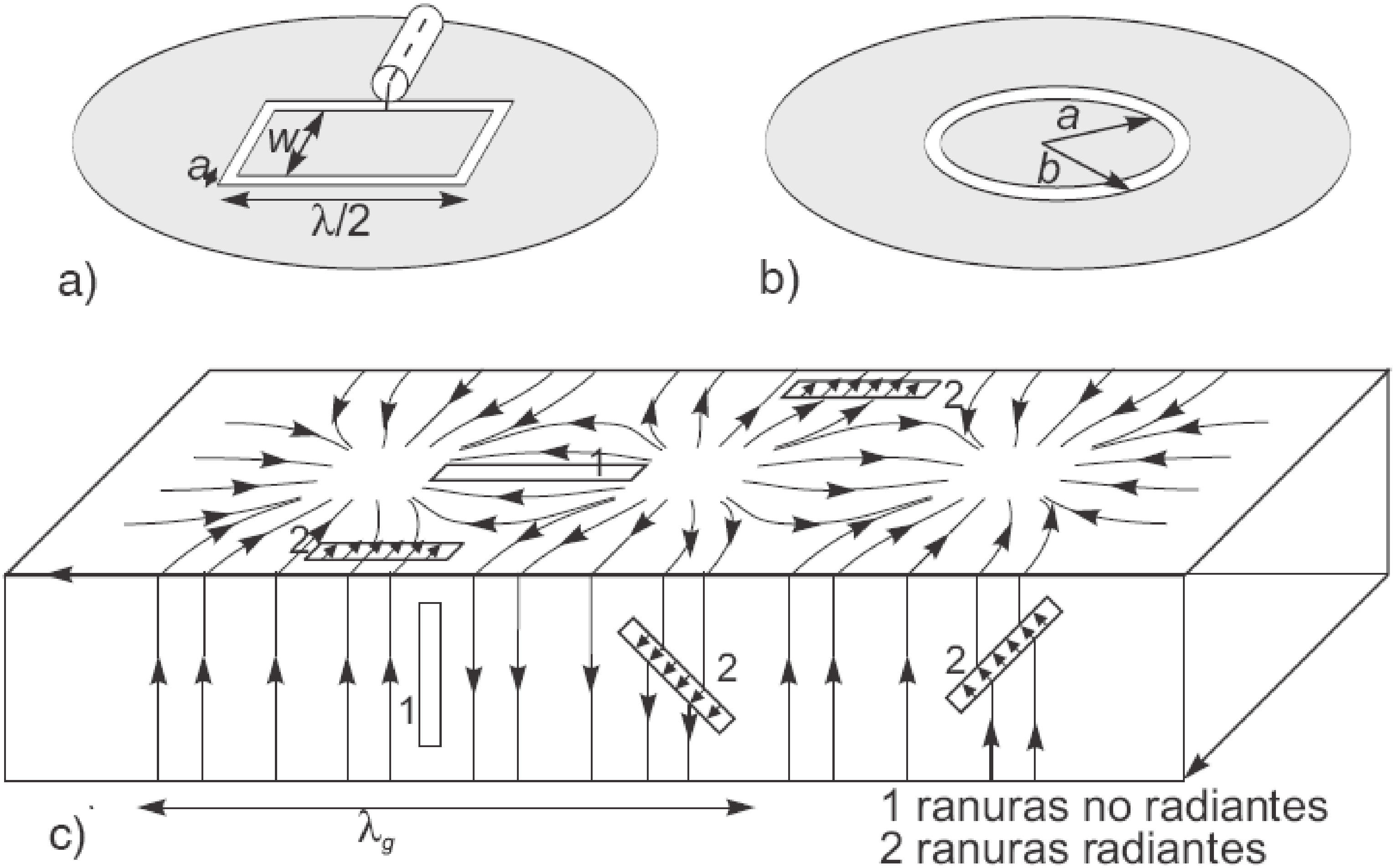
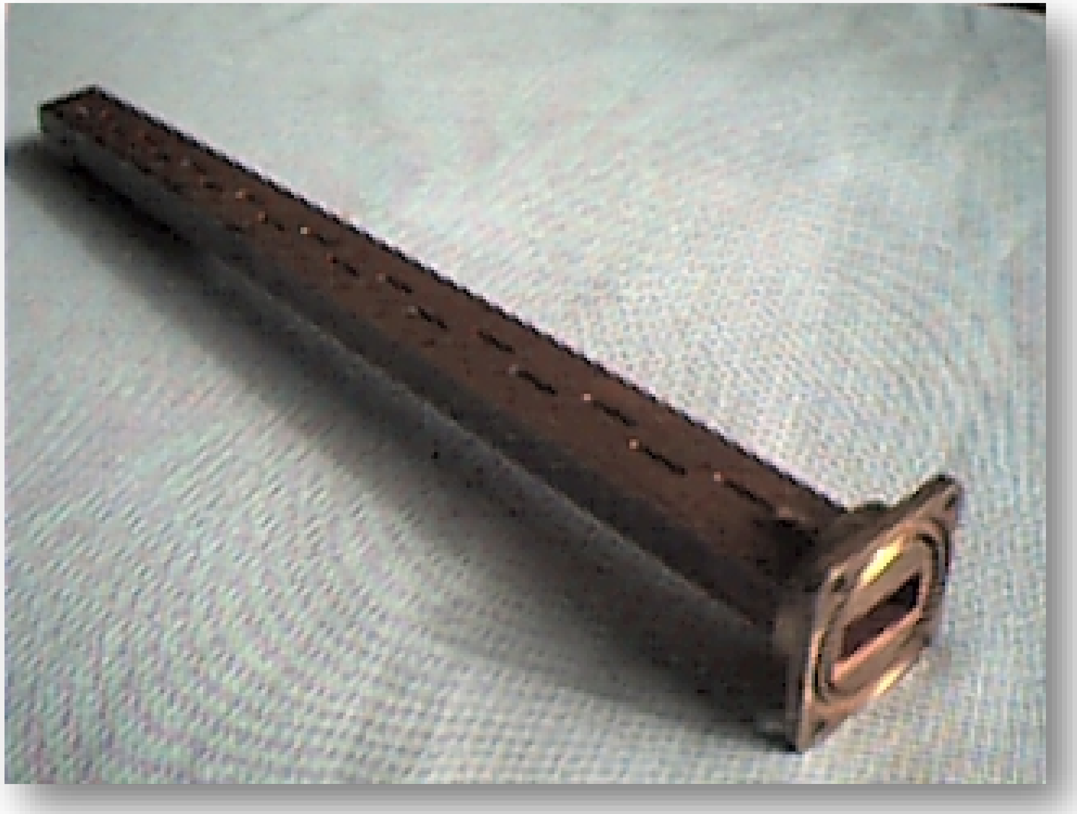
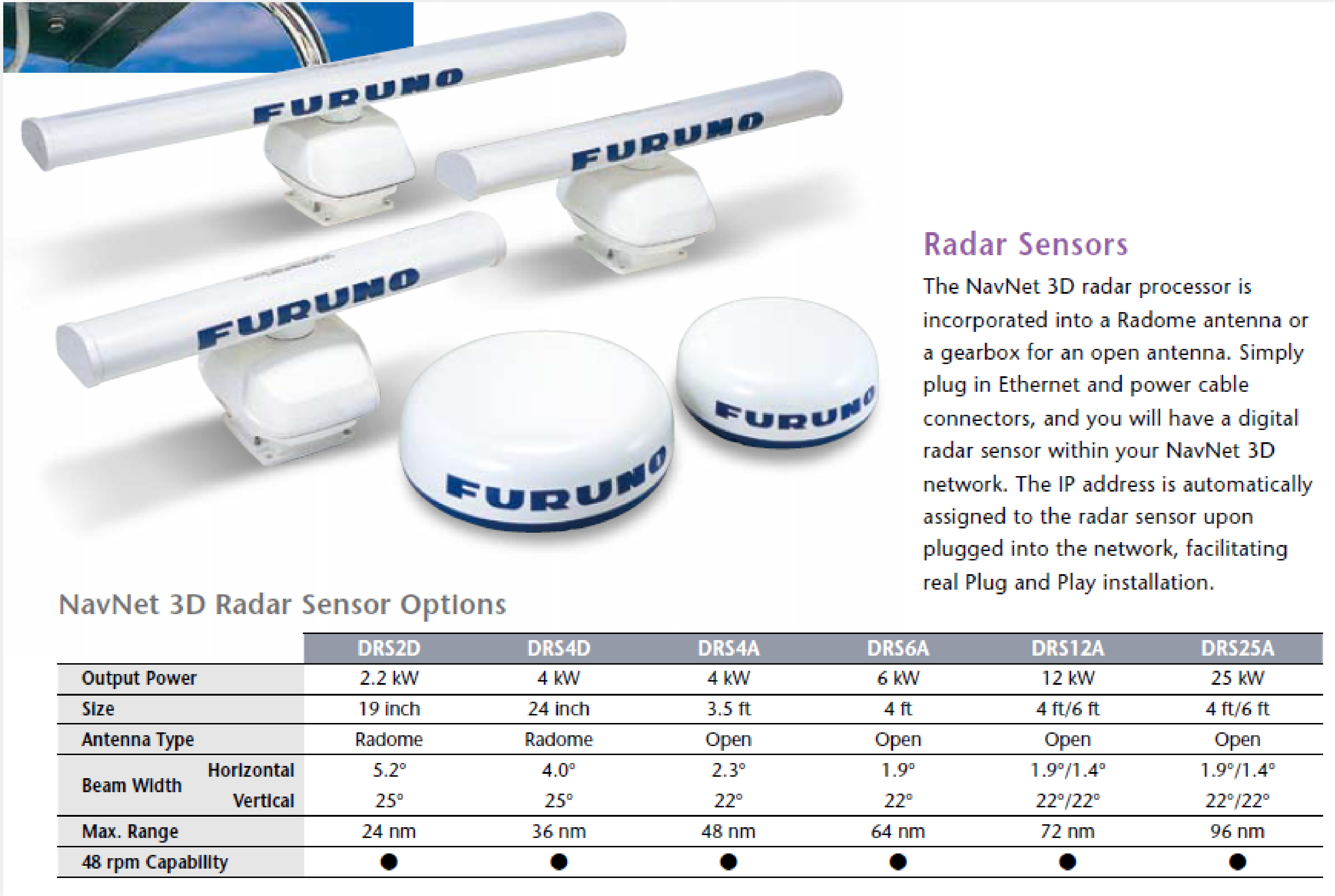


Fig. 6.21 Realizaciones habituales con ranuras: a) ranura doblada, b) coaxial abierto en un plano conductor y c) guía rectangular ranurada



Marine Radar Antennas



Radar Sensors

The NavNet 3D radar processor is incorporated into a Radome antenna or a gearbox for an open antenna. Simply plug in Ethernet and power cable connectors, and you will have a digital radar sensor within your NavNet 3D network. The IP address is automatically assigned to the radar sensor upon plugged into the network, facilitating real Plug and Play installation.

NavNet 3D Radar Sensor Options

		DRS2D	DRS4D	DRS4A	DRS6A	DRS12A	DRS25A
Output Power		2.2 kW	4 kW	4 kW	6 kW	12 kW	25 kW
Size		19 inch	24 inch	3.5 ft	4 ft	4 ft/6 ft	4 ft/6 ft
Antenna Type		Radome	Radome	Open	Open	Open	Open
Beam Width	**Horizontal**	5.2°	4.0°	2.3°	1.9°	1.9°/1.4°	1.9°/1.4°
	Vertical	25°	25°	22°	22°	22°/22°	22°/22°
Max. Range		24 nm	36 nm	48 nm	64 nm	72 nm	96 nm
48 rpm Capability		●	●	●	●	●	●

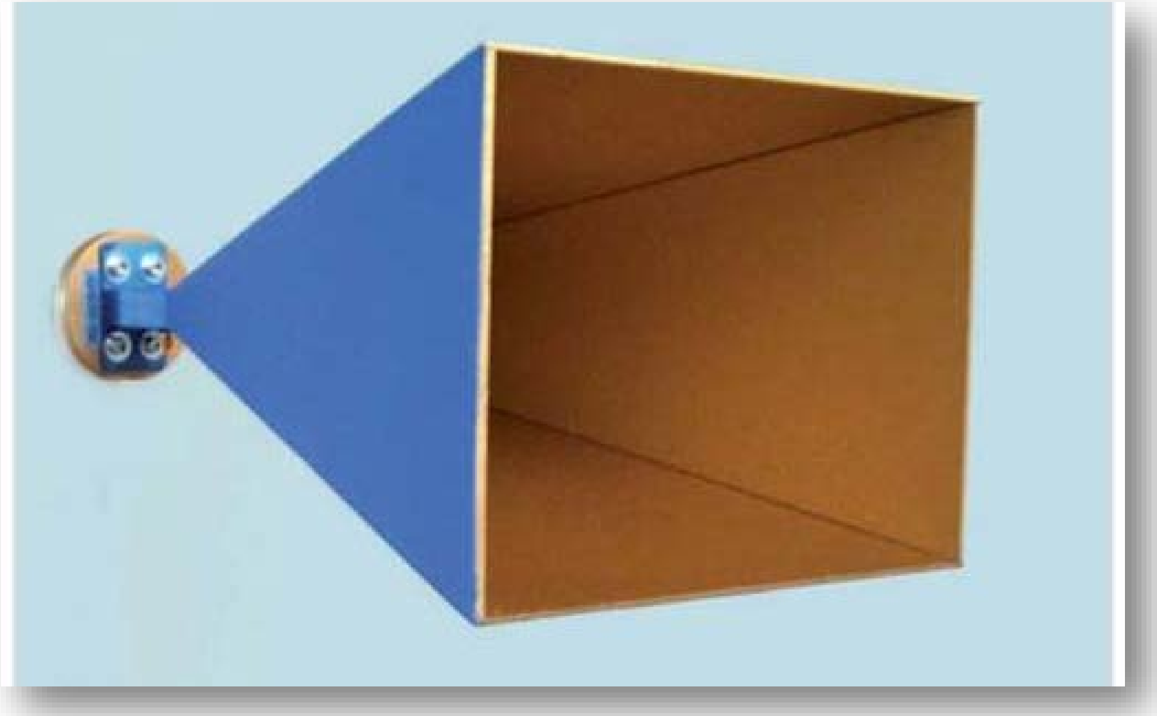
er

Radar Antennas

i. Antenna parameters and Basics
ii. Radar antenna patterns
iii. Resolution Angle
iv. Uncertainty volume (resolution Cell)
v. Polarization of electromagnetic waves
vi. Slotted and waveguide antennas
vii. Aperture antennas

Aperture antennas

Horn antennas



Horn Antennas

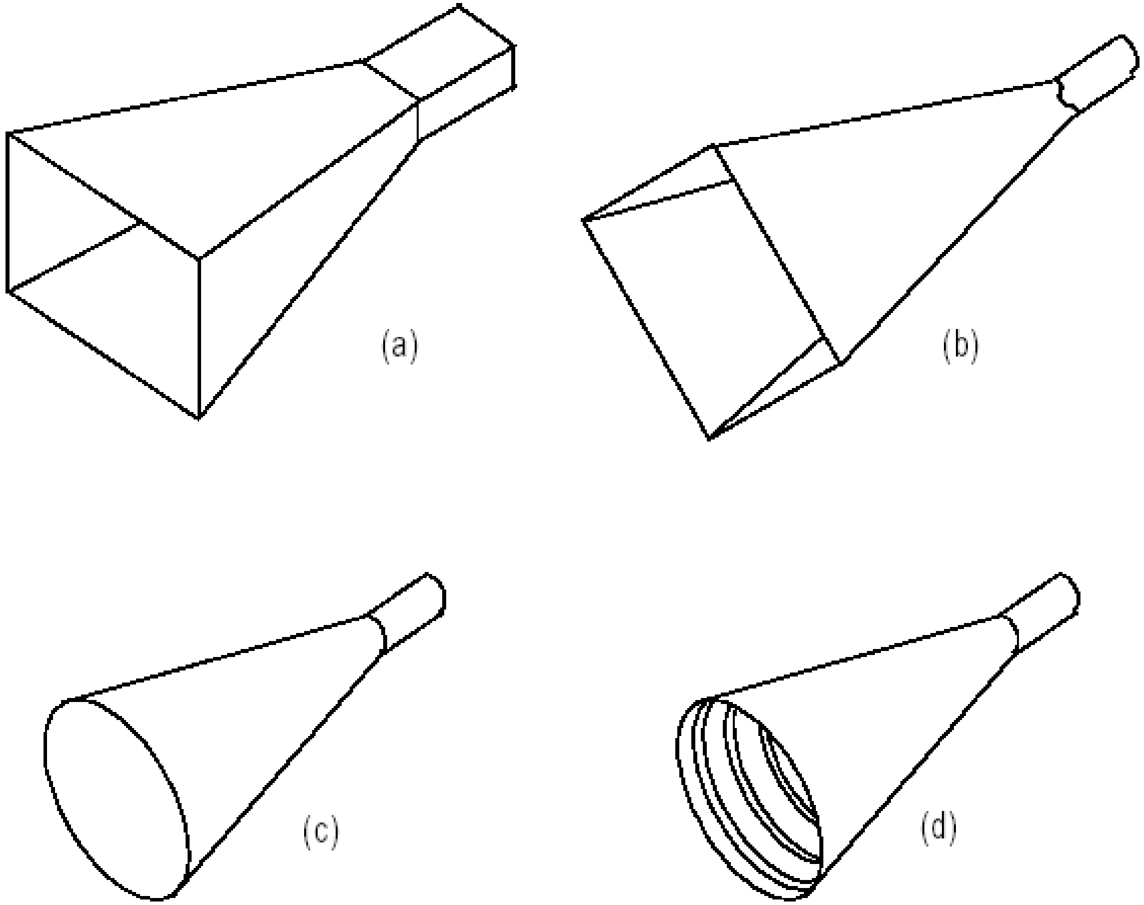
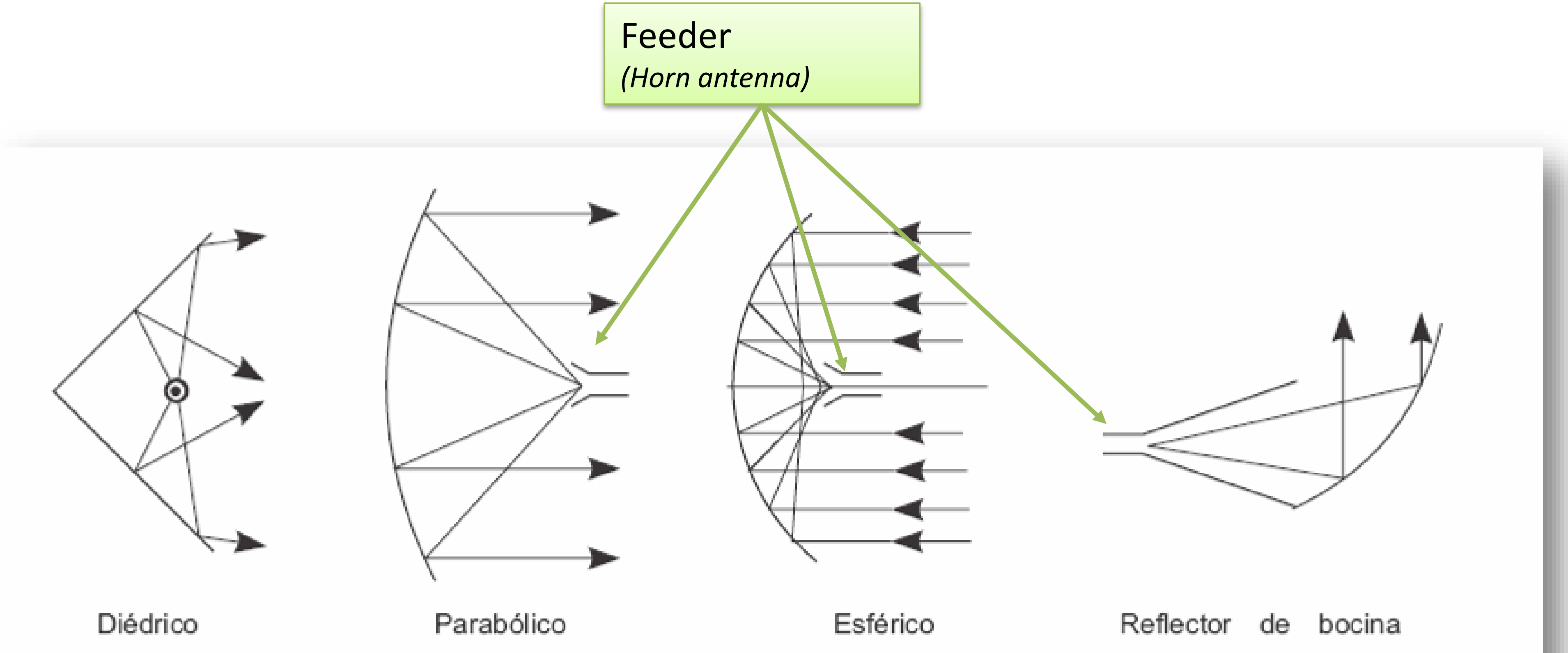


Figure A59 Common types of horn antennas: (a) pyramidal horn; (b) diagonal horn; (c) conical horn; (d) corrugated horn (after Currie, 1987, Fig. 12.12, p. 539).

Reflector Antennas

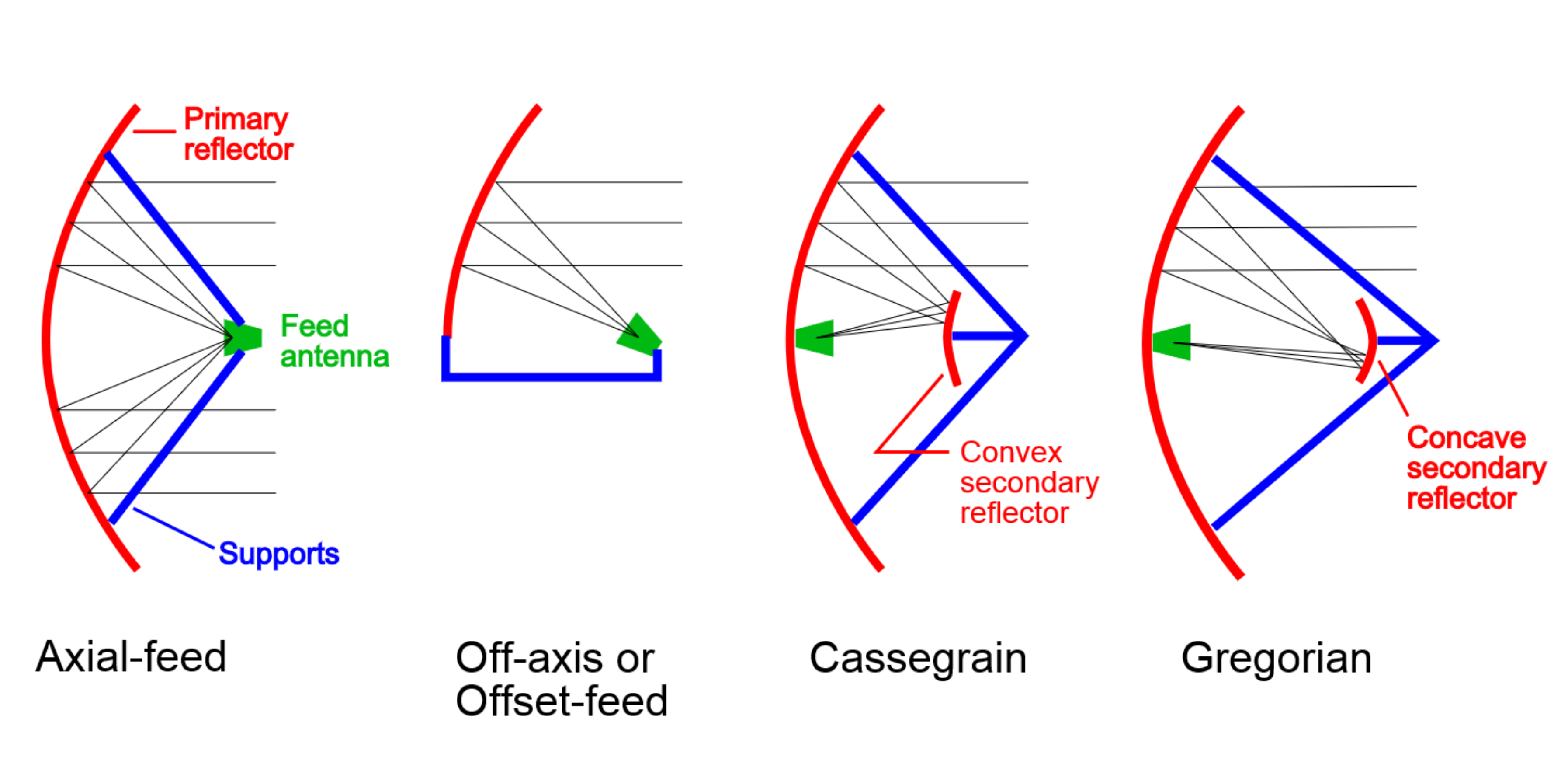


Feeder

(Horn antenna)

Fig. 6.23 Distintas geometrías de reflector

Parabolic reflectors



Parabolic reflector antennas

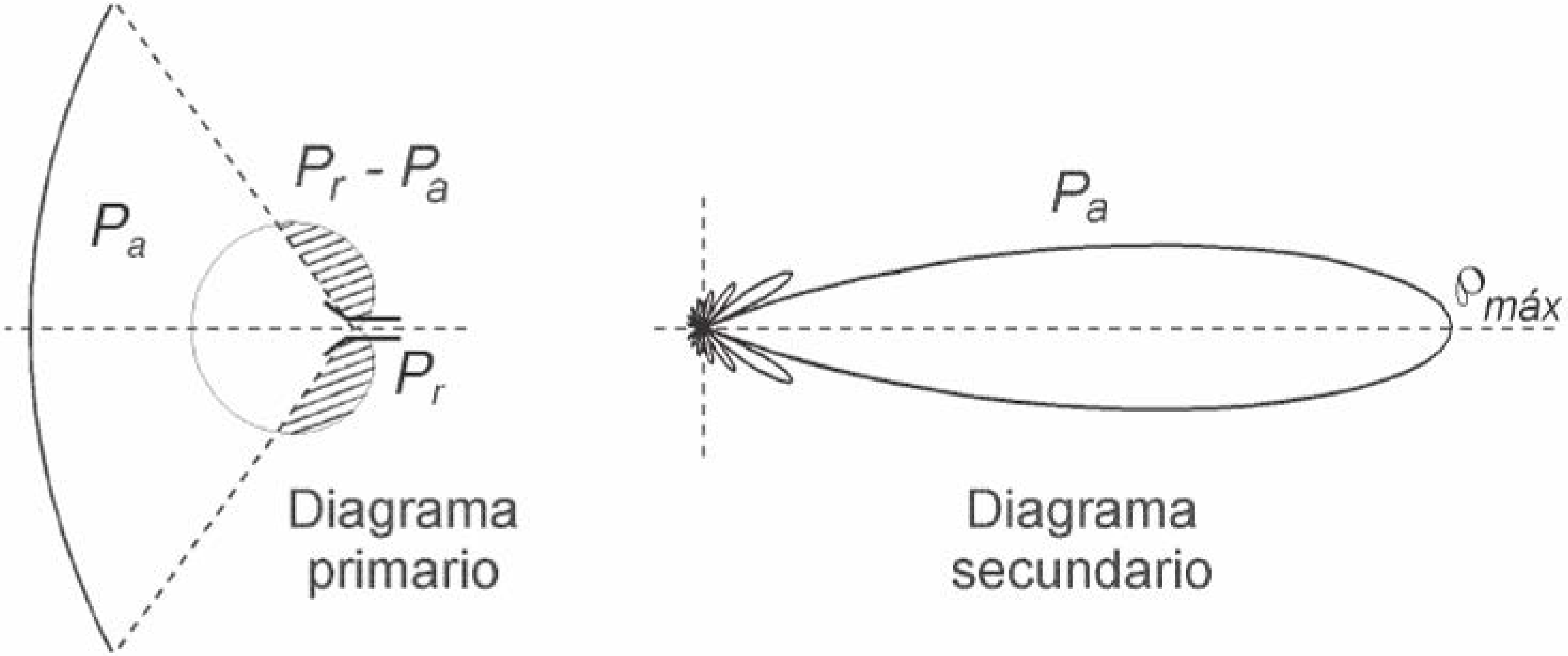


Fig. 6.40 Balance de potencias en un reflector parabólico

Parabolic offset reflector antenna

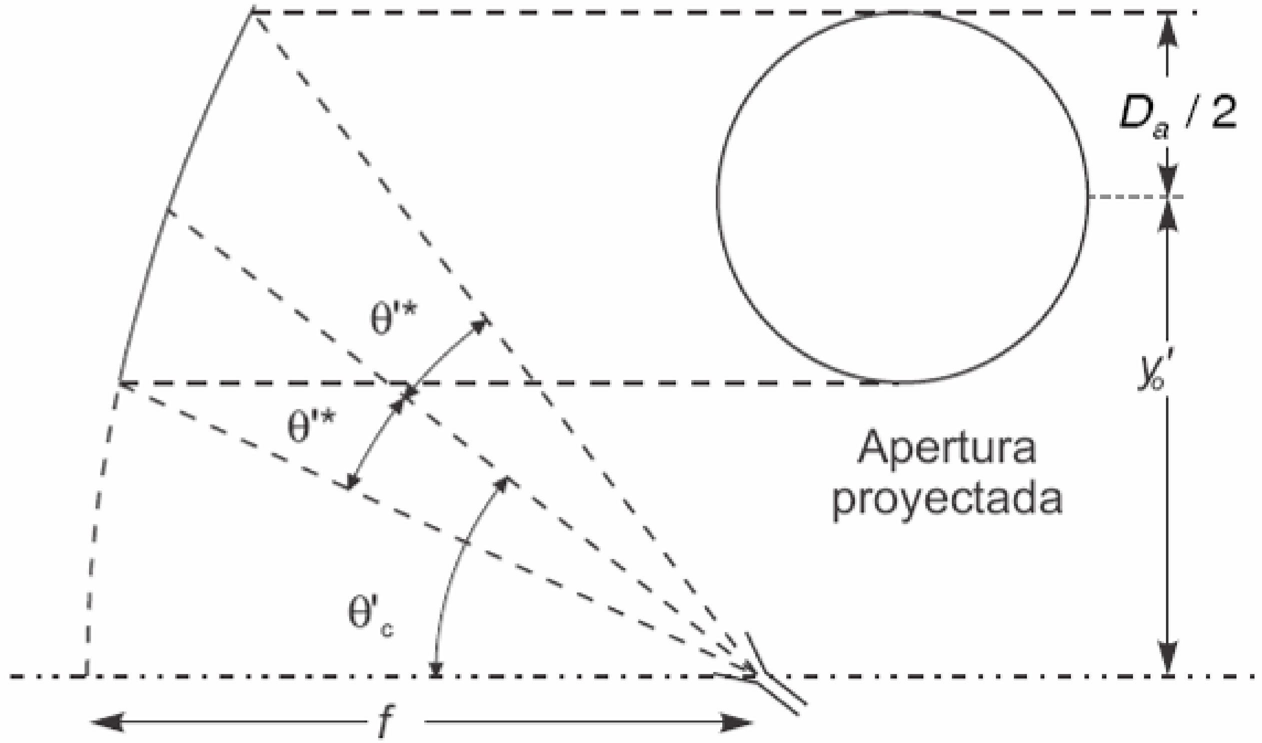


Fig. 6.50 Geometría de reflector asimétrico (*offset*)

Cassegrain parabolic antenna

Reduces the antenna blocking aperture by the transmitter.

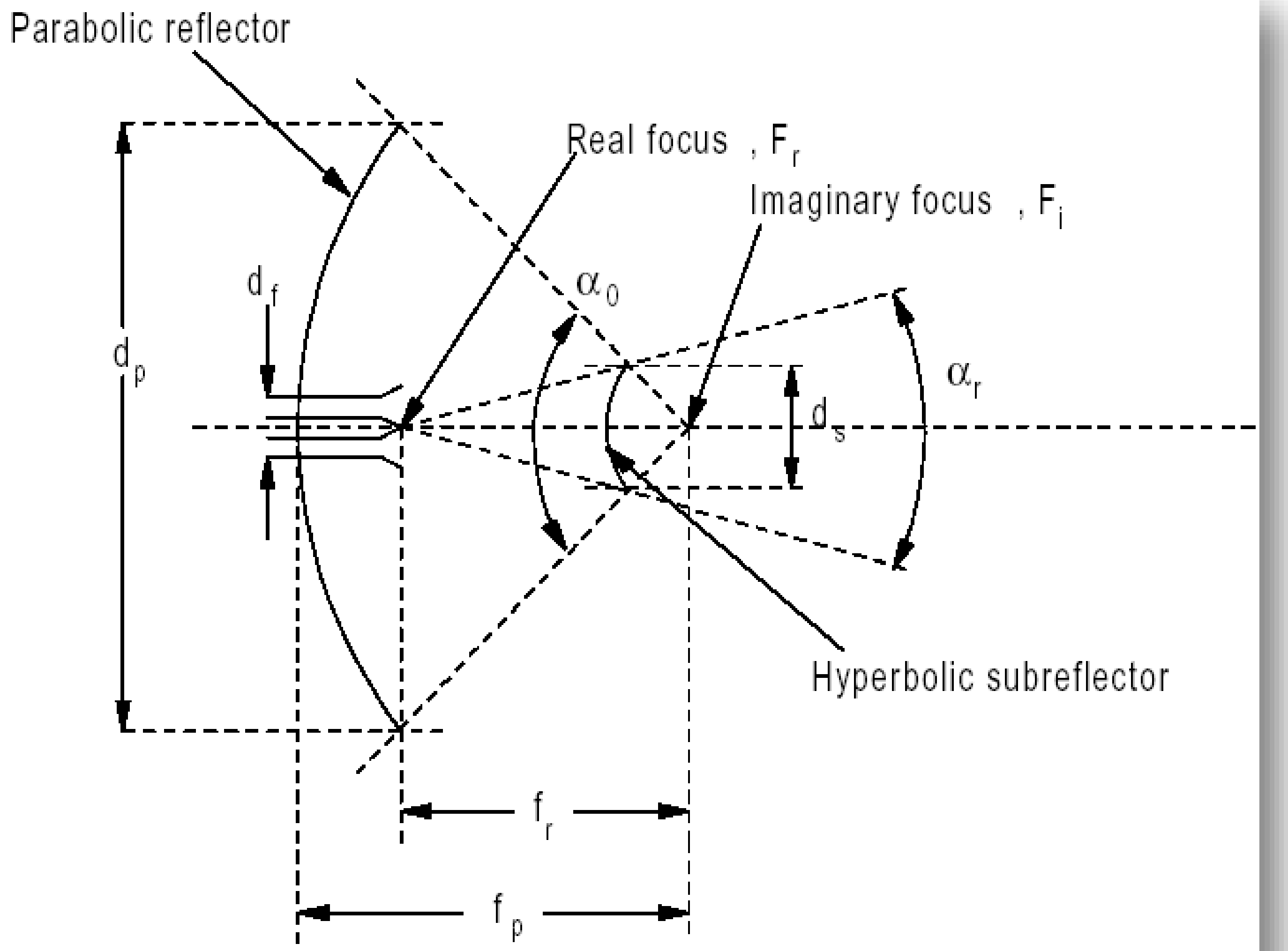


Figure A50 Cassegrainian reflector antenna. (after Leonov, 1986, Fig. 2.3, p. 15).

Cassegrain parabolic antenna

Ref.: Johnston (1979), p. 58.

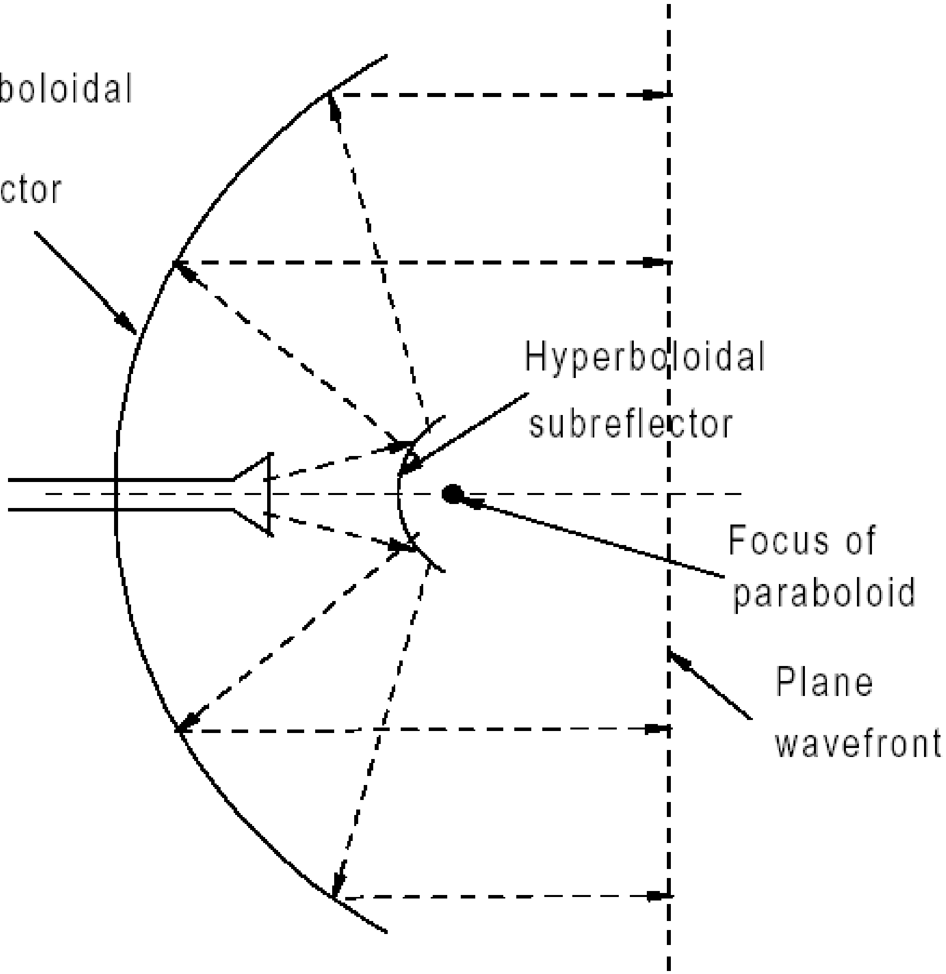


Figure A56 Geometry of the Cassegrainian dual-reflector antenna.

Gregorian parabolic antenna

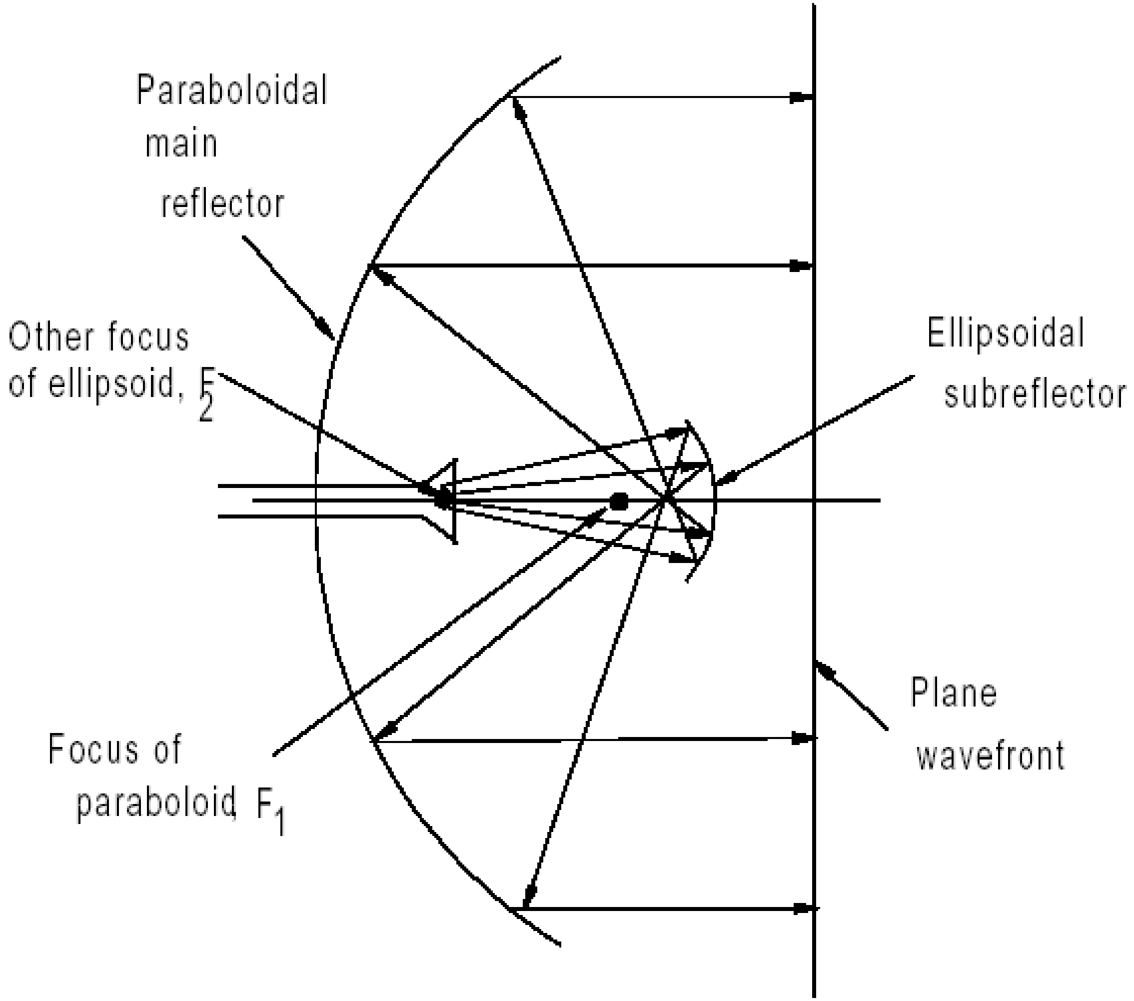
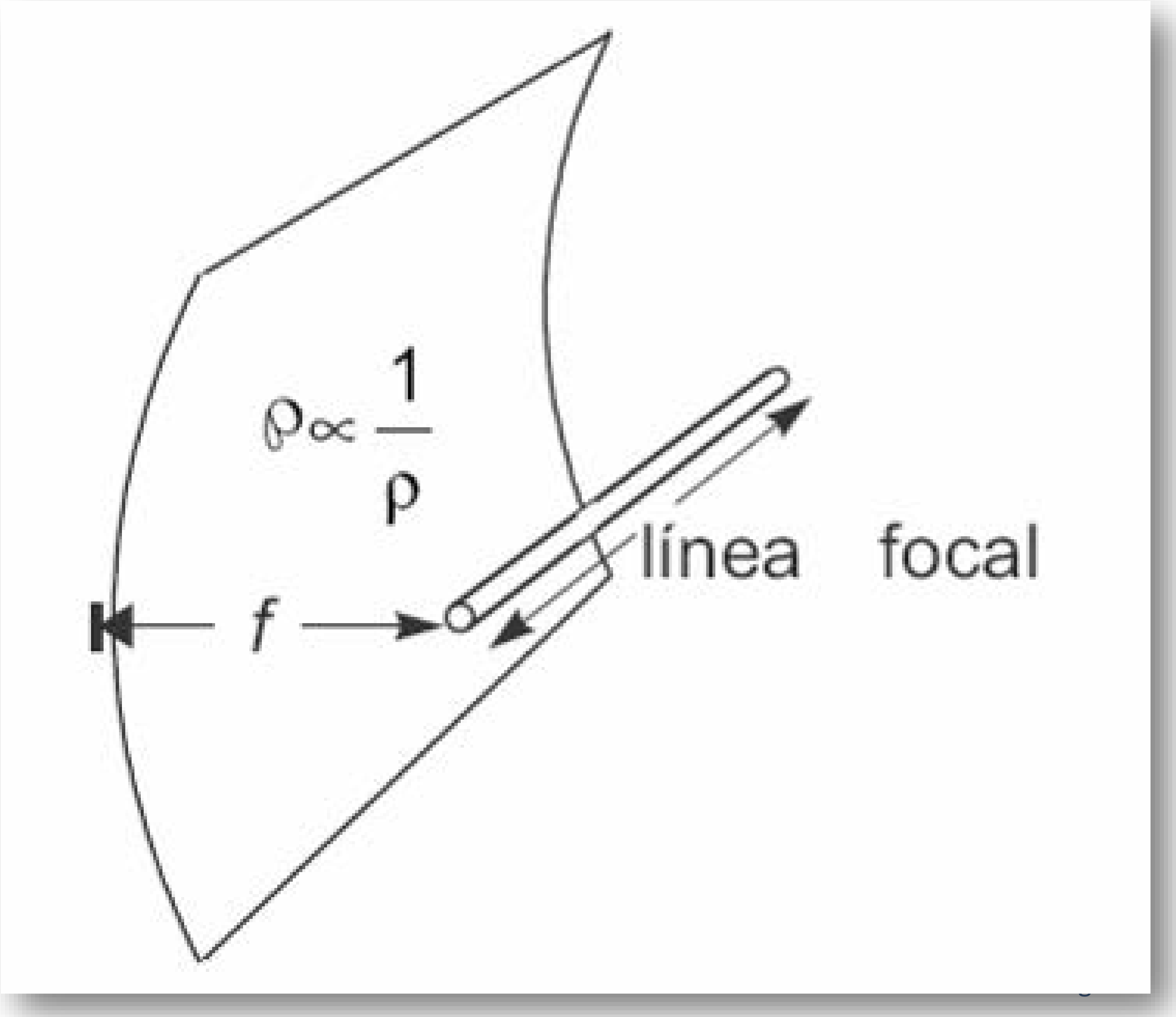
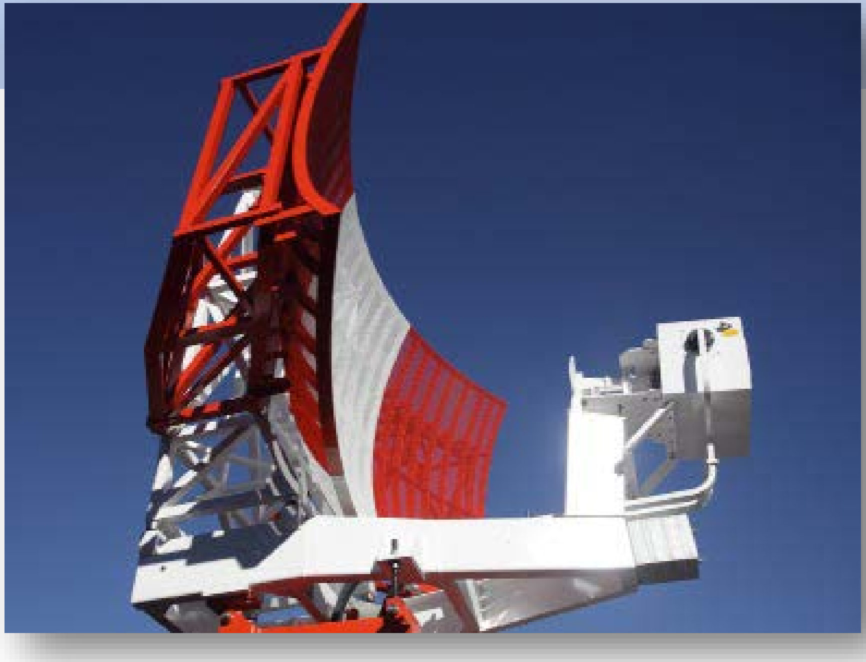


Figure A57 Dual-reflector Gregorian antenna.

Cylindrical parabolic reflector



PRIMARY RADAR



Last mejores prestaciones con la última tecnología
Indra posee más de 40 años de experiencia en el diseño, fabricación, operación e integración de Sistemas , con una amplia gama de productos que cubren todas las necesidades de nuestros clientes.

El Radar de Vigilancia Primario de Indra es un sistema totalmente de estado sólido-que incorpora las últimas tecnologías para proporcionar características excepcionales en términos de resolución de alcance, rango de detección mínimo, fiabilidad y disponibilidad.

Asimismo, la solución PSR de Indra’s incorpora el algoritmo AMTA-IV y el uso del mapa síncrono de clutter que mejora la visibilidad y detección tangencial en entornos de fuerte clutter; por tanto, este sistema permite al controlador de tránsito aéreo la monitorización de todas las aeronaves en el espacio aéreo, de forma simultánea y sin interferencias.

indra

Characteristics summary

Frequency	2.7 to 2.9 GHz
Frequency Diversity & Agility	2 frequencies (Long/short pulse) 75 MHz frequency diversity. Possible exchange of frequencies for subsequent CPI
Peak power	19.2 Kw
RF TX & Blanking	Sectorize (1.4º) Synchronous clutter map
Pulse width	Short pulse: 1.2 μs Long pulse: from 60 to 90 μs
PRF	735 to 1300 Hz (custom-built)
Stability	62 dB
MTI improvement factor	55 dB
Sub-Clutter visibility	>42 dB (till 800 knots)
Instrumented range	60 nm or 80 nm
Detection range	>60 nm or >80 nm
Reliability	
Availability	99.999%
MTBCF	45,000 hours
MTTR	20 minutes
Resolution	
Range	230 m rms (short pulse) 170 m rms (long pulse)
Azimuth	2.8º rms
Accuracy	
Range	50 m, rms
Azimuth	0.15º, rms

Receiver	
Noise figure	2.35 dB
Sensitivity	-108 dBm (short pulse) -126 dBm (long pulse)
Dynamic range	84 dB at signal processor input (without pulse compression)
STC	3 stages (2 RF and digital)
ADC	14 bits @ 93.2144 MHz
Antenna	
Beams	1 transmit, 2 receive
Gain	34.5 dB (low beam) 32.5 dB (high beam)
Azimuth beamwidth	1.35º
Elevation beamwidth	4.5º cosecant squared +40º
Rotation speed	12/15 rpm
Polarization	Linear (vertical) Circular (right hand)
Receiving channels	4 simultaneous
Processing	
Type	MTD-IV doppler filter bank
Filters	6/8 (low/high PRF) - 80 nm 8/10 (low/high PRF) - 60 nm
False alarm control	Interference suppression/detect GO-CFAR, MTAT, MTAC Clutter and geo-censor map Anomalous prop detection
Weather channel	Ground clutter suppression filters US-NWS 6 level detection
Capacity	1000 plots/600 tracks per scan

Bibliography

- Ángel Cardama Aznar, Lluís Jofre Roca, Juan Manuel Rius Casals, Jordi Romeu Robert, Sebastián Blanch Boris, Miguel Ferrando Bataller. *"ANTENAS".* Segunda edición. Edicions UPC 2002. https://cataleg.upc.edu/record=b1247049~S1*cat
- Balanis, Constantine A. *"Antenna theory: analysis and design".* 4th Ed. Hoboken, NJ. John Wiley, 2015. https://cataleg.upc.edu/record=b1484875~S1*cat
- R. Johnson. "Designer notes for Microwave Antennas", Artech House, 1991.
- Naval air systems command & Naval air warfare center. "Electronic Warfare and Radar Systems Engineering Handbook"