Course Topics

-Fundamental parameters of antenna CH2

Linear wire antennas CH4
-Infinitesimal dipole(sec 4.2), small dipole, finite length dipole(half wavelength dipole)
-Image theory and monopole antenna

-loop antenna CH5

-Arrays CH6 , Smart antenna

-Microstrip antenna CH14

-Independent frequency antennas CH11

-Required Report: application for selected antenna type

Assessment

Quizzes (2-3)	10
Mid Term Examination	15
Project	5
Report and Oral Exam	15
Assignment	5
Final Examination	75
Total	**125**

Reference

- Book : Antenna theory analysis and design [3rd edition-Constantine A.Balanis

Introduction to Antennas

Antennas

An antenna is a device(transducer) that is used to transmit and/or receive an electromagnetic wave.

It converts signals on electric circuits (V&I) to EM waves (E&H) radiate in space and vise versa.

The antenna itself can always transmit or receive, but it maybe used for only one of these functions in an application.

Examples:

- Cell-phone antenna (transmit and receive)
- TV antenna in your home (receive only)
- Wireless LAN antenna (transmit and receive)
- FM radio antenna (receive only)
- Satellite dish antenna (receive only)
- AM radio broadcast tower (transmit only)
- GPS position location unit (receive only)
- GPS satellite (transmit only)

Introduction to Antennas

A good antenna would radiate almost the power delivered to it from the transmitter in a desired direction or directions. A receiver antenna does the reciprocal process, and delivers power received from a desired direction or directions.

Types of Antennas

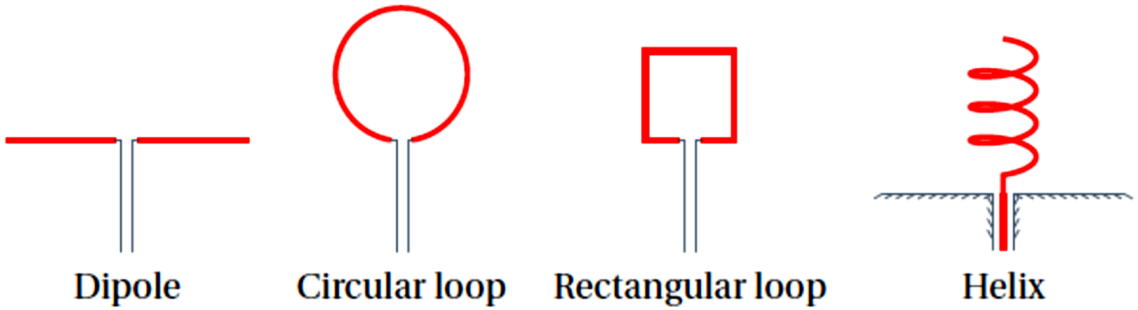
- **Antenna can be categorized by:**
- Narrow band versus broadband
- Size in comparison to the wavelength (e.g., electrically small antennas)
- Omni-directional versus directional antennas
- Polarization (linear, circular, or elliptic)
- **Antenna Types According to Physical Structure**

  - Wire antennas
  - Aperture antennas
  - Microstrip antennas
  - Antenna arrays
  - Reflector antennas

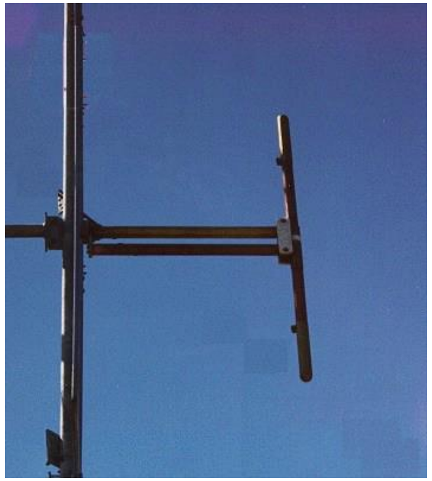
Introduction to Antennas

Types of Antennas

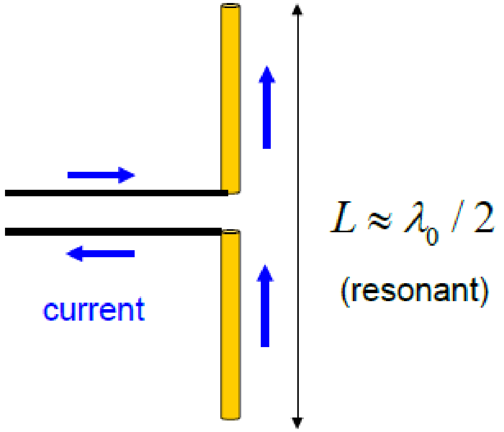
Wire Antennas



Dipole Wire Antennas



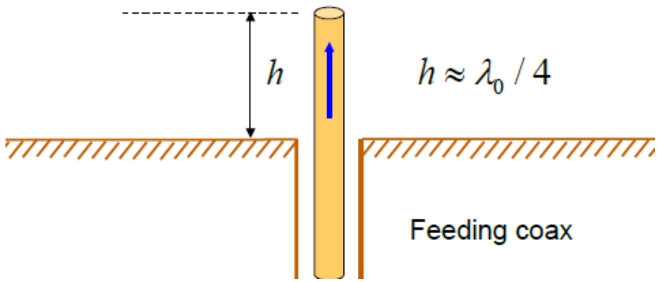
- Very simple
- Moderate bandwidth
- Low directivity
- Omnidirectional in azimuth
- Most commonly fed by a twin-lead transmission line
- Linear polarization (*E*θ , assuming wire is along *z* axis)
- The antenna is resonant when the length is about one-half free-space wavelength



Introduction to Antennas

Types of Antennas (Cont.)

Monopole Wire Antennas



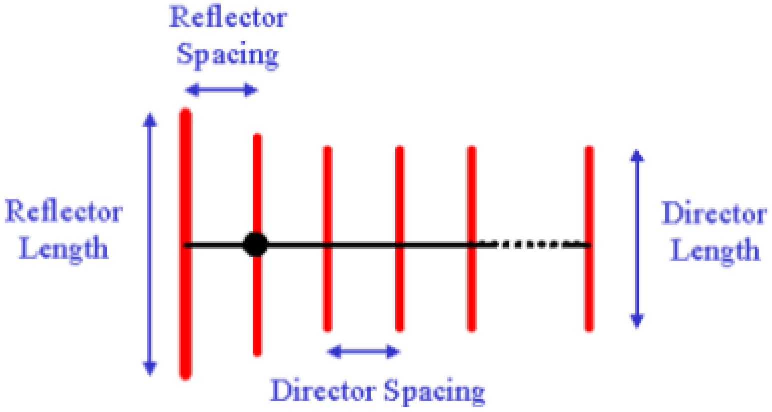
This is a variation of the dipole, using a ground plane instead of a second wire.

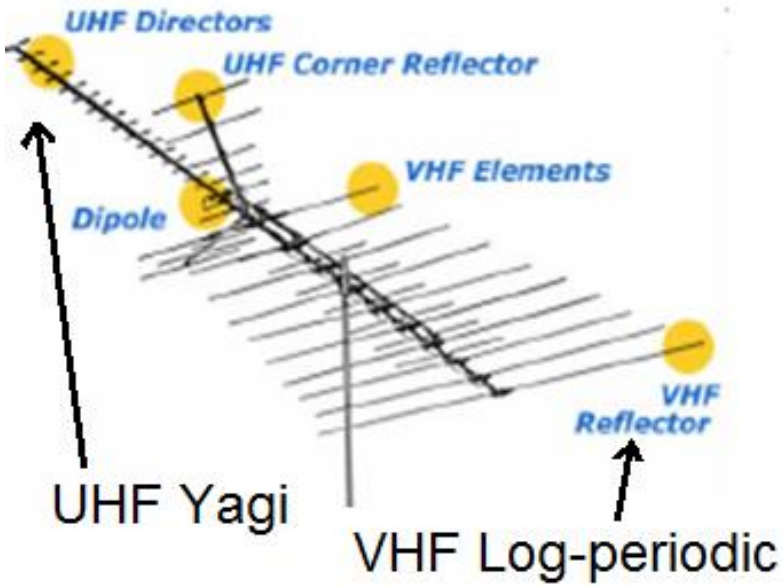
- Similar properties as the dipole
- Mainly used when the antenna is mounted on a conducing object or platform
- Usually fed with a coaxial cable feed

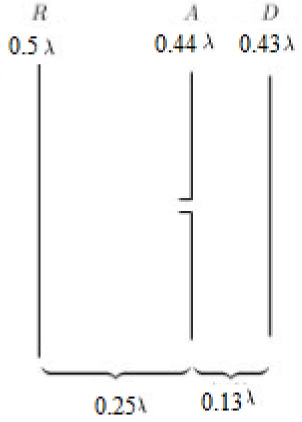
Introduction to Antennas

Types of Antennas (Cont.)

Yagi Antenna







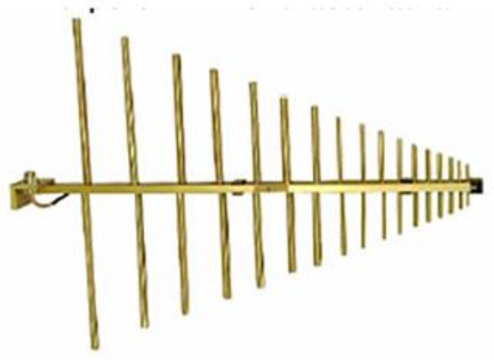
- Low bandwidth
- Moderate to high directivity
- Commonly used as a UHF TV antenna

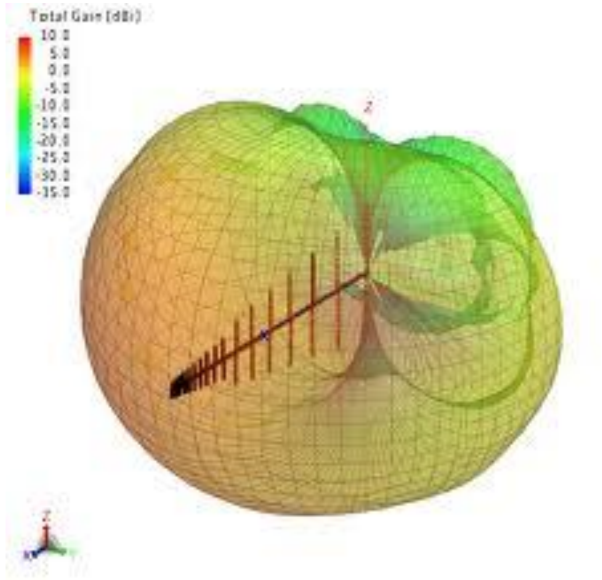
There is a tradeoff between gain and bandwidth, with the bandwidth narrowing as more elements are used

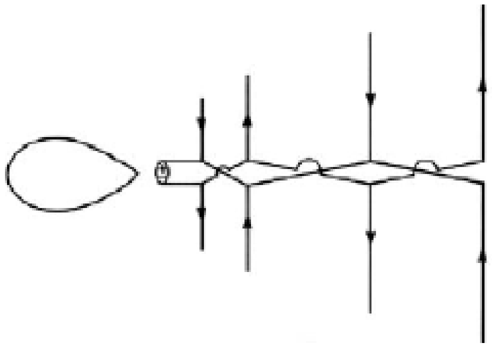
Introduction to Antennas

Types of Antennas (Cont.)

Log Periodic Antenna







This consists of multiple dipole antennas of varying lengths, connected together.

- High bandwidth
- Moderate directivity
- Commonly used as a VHF TV antenna

Introduction to Antennas

Types of Antennas (Cont.)

Aperture Antenna
HORN ANTENNA

Pyramidal horn

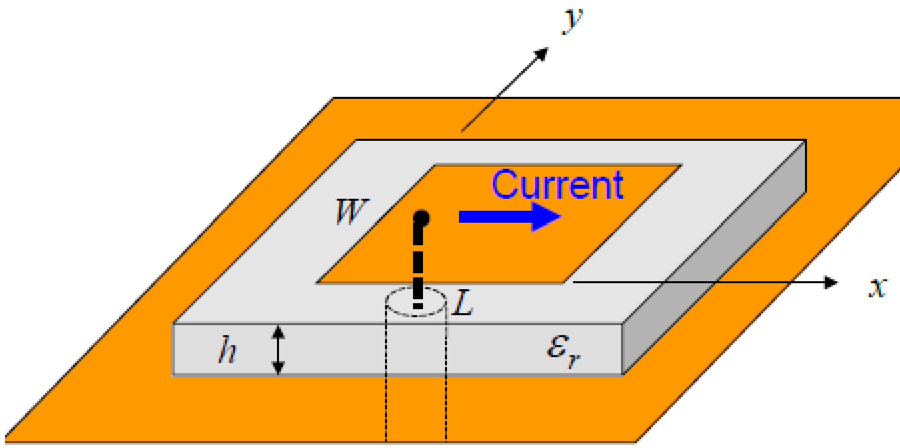
Conical horn

- Horn antennas are very popular at UHF (300 MHz-3GHz)frequencies.
- Wide bandwidth
- Directional radiation pattern(1.5 degree HPBW).
- Moderate gain 10-20 dBi

Introduction to Antennas

Types of Antennas (Cont.)

Microstrip Antenna



$$L \approx \lambda_d / 2 = \frac{1}{2}\frac{\lambda_0}{\sqrt{\varepsilon_r}}$$

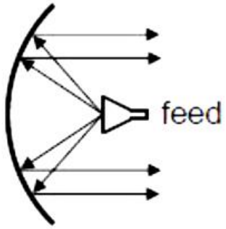
- Low bandwidth
- Low directivity (unless used in an array)
- Easily fed by microstrip line or coaxial cable
- Commonly used at microwave frequencies and above

Introduction to Antennas

Types of Antennas

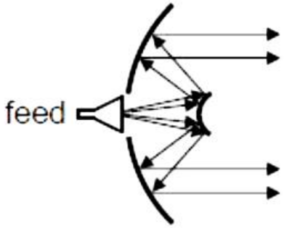
Reflector (Dish) Antennas

Reflector



Parabolic reflector
(front feed)

Reflector



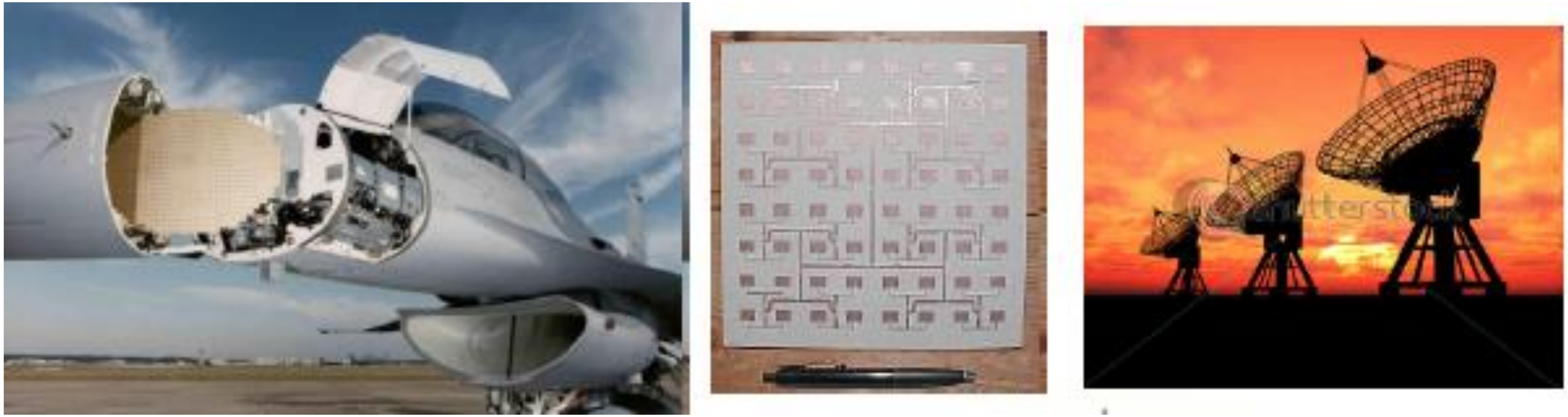
Parabolic reflector and
hyperbolic subreflector
(Cassegrain feed)

- Very high bandwidth
- Medium to high directivity (directivity is determined by the size)
- Linear or CP polarization (depending on how it is fed)
- Works by focusing the incoming wave to a collection (feed) point

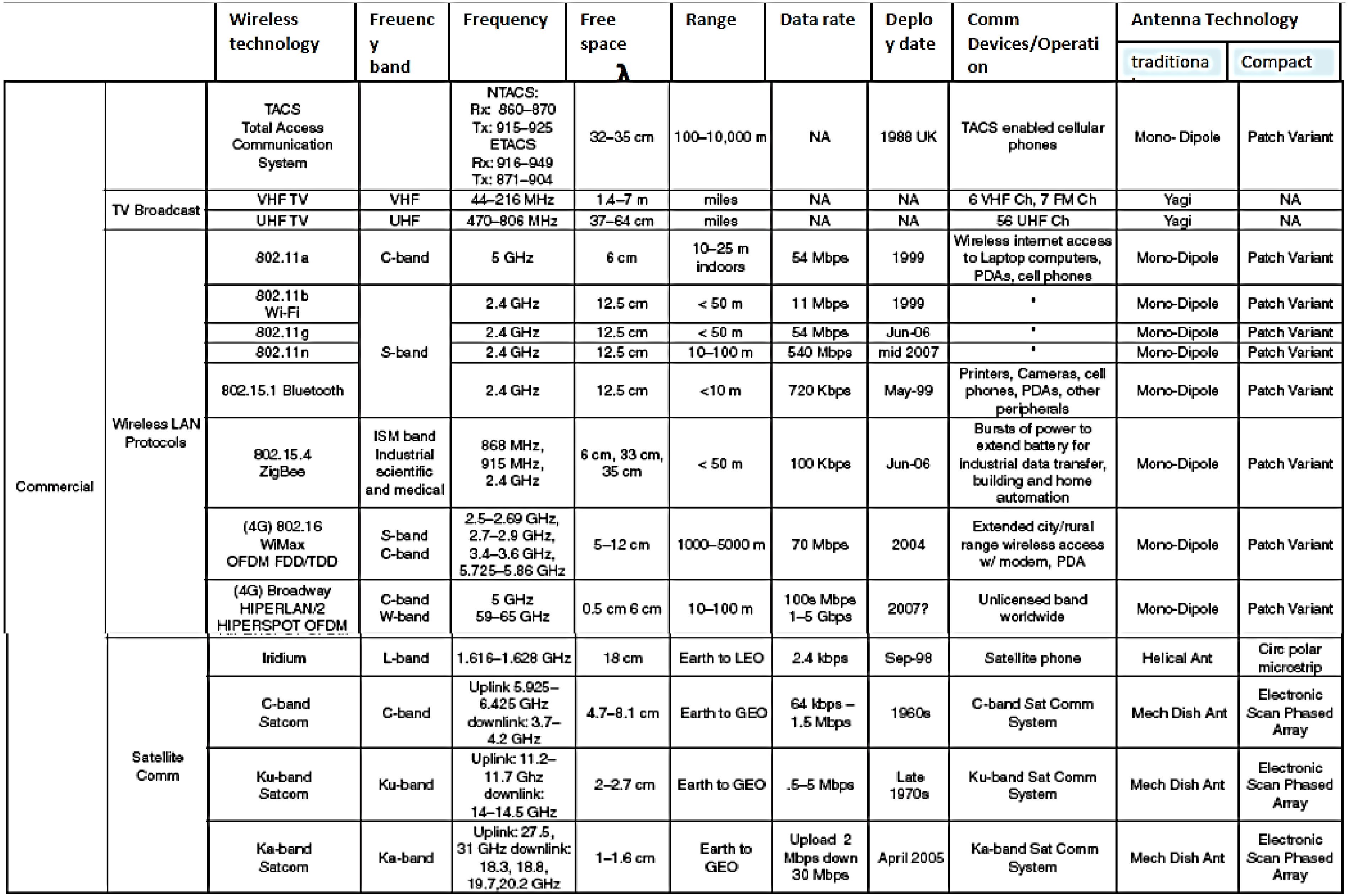
Introduction to Antennas

Types of Antennas (Cont.)

Array Antenna



- Combine elements to make a higher gain antenna.
- Highly effective for beam-steering and tracking



		Wireless technology	Freuency band	Frequency	Free space λ	Range	Data rate	Deploy date	Comm Devices/Operation	Antenna Technology	
										traditiona	Compact
Commercial		TACS Total Access Communication System		NTACS: Rx: 860–870 Tx: 915–925 ETACS Rx: 916–949 Tx: 871–904	32–35 cm	100–10,000 m	NA	1988 UK	TACS enabled cellular phones	Mono- Dipole	Patch Variant
	TV Broadcast	VHF TV	VHF	44–216 MHz	1.4–7 m	miles	NA	NA	6 VHF Ch, 7 FM Ch	Yagi	NA
		UHF TV	UHF	470–806 MHz	37–64 cm	miles	NA	NA	56 UHF Ch	Yagi	NA
	Wireless LAN Protocols	802.11a	C-band	5 GHz	6 cm	10–25 m indoors	54 Mbps	1999	Wireless internet access to Laptop computers, PDAs, cell phones	Mono-Dipole	Patch Variant
		802.11b Wi-Fi	S-band	2.4 GHz	12.5 cm	< 50 m	11 Mbps	1999	"	Mono-Dipole	Patch Variant
		802.11g		2.4 GHz	12.5 cm	< 50 m	54 Mbps	Jun-06	"	Mono-Dipole	Patch Variant
		802.11n		2.4 GHz	12.5 cm	10–100 m	540 Mbps	mid 2007	"	Mono-Dipole	Patch Variant
		802.15.1 Bluetooth		2.4 GHz	12.5 cm	<10 m	720 Kbps	May-99	Printers, Cameras, cell phones, PDAs, other peripherals	Mono-Dipole	Patch Variant
		802.15.4 ZigBee	ISM band Industrial scientific and medical	868 MHz, 915 MHz, 2.4 GHz	6 cm, 33 cm, 35 cm	< 50 m	100 Kbps	Jun-06	Bursts of power to extend battery for industrial data transfer, building and home automation	Mono-Dipole	Patch Variant
		(4G) 802.16 WiMax OFDM FDD/TDD	S-band C-band	2.5–2.69 GHz, 2.7–2.9 GHz, 3.4–3.6 GHz, 5.725–5.86 GHz	5–12 cm	1000–5000 m	70 Mbps	2004	Extended city/rural range wireless access w/ modem, PDA	Mono-Dipole	Patch Variant
		(4G) Broadway HIPERLAN/2 HIPERSPOT OFDM	C-band W-band	5 GHz 59–65 GHz	0.5 cm 6 cm	10–100 m	100s Mbps 1–5 Gbps	2007?	Unlicensed band worldwide	Mono-Dipole	Patch Variant
	Satellite Comm	Iridium	L-band	1.616–1.628 GHz	18 cm	Earth to LEO	2.4 kbps	Sep-98	Satellite phone	Helical Ant	Circ polar microstrip
		C-band Satcom	C-band	Uplink 5.925–6.425 GHz downlink: 3.7–4.2 GHz	4.7–8.1 cm	Earth to GEO	64 kbps – 1.5 Mbps	1960s	C-band Sat Comm System	Mech Dish Ant	Electronic Scan Phased Array
		Ku-band Satcom	Ku-band	Uplink: 11.2–11.7 Ghz downlink: 14–14.5 GHz	2–2.7 cm	Earth to GEO	.5–5 Mbps	Late 1970s	Ku-band Sat Comm System	Mech Dish Ant	Electronic Scan Phased Array
		Ka-band Satcom	Ka-band	Uplink: 27.5, 31 GHz downlink: 18.3, 18.8, 19.7,20.2 GHz	1–1.6 cm	Earth to GEO	Upload 2 Mbps down 30 Mbps	April 2005	Ka-band Sat Comm System	Mech Dish Ant	Electronic Scan Phased Array

FIGURE 2-4 Wireless technologies for commercial communication systems

Fundamental Parameters of Antennas

To describe the performance of an antenna, definitions of various parameters will be discussed

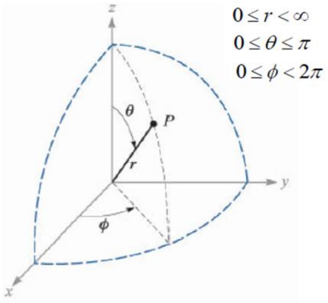
- **Radiation Pattern**
- **Beam-width**
- **Radiation Power Density**
- **Radiation Intensity**
- **Directivity**
- **Efficiency**
- **Gain**
- **Polarization**
- **Effective Aperture (effective area)**
- **Input impedance**
- **Friis Transmission Equation**

Fundamental Parameters of Antennas

Radiation Pattern

radiation pattern is defined as a mathematical function or a graphical representation of the radiation properties (Amplitude or Power) of the antenna as a function of space coordinates.

- Radiation patterns are conveniently represented in spherical coordinates.

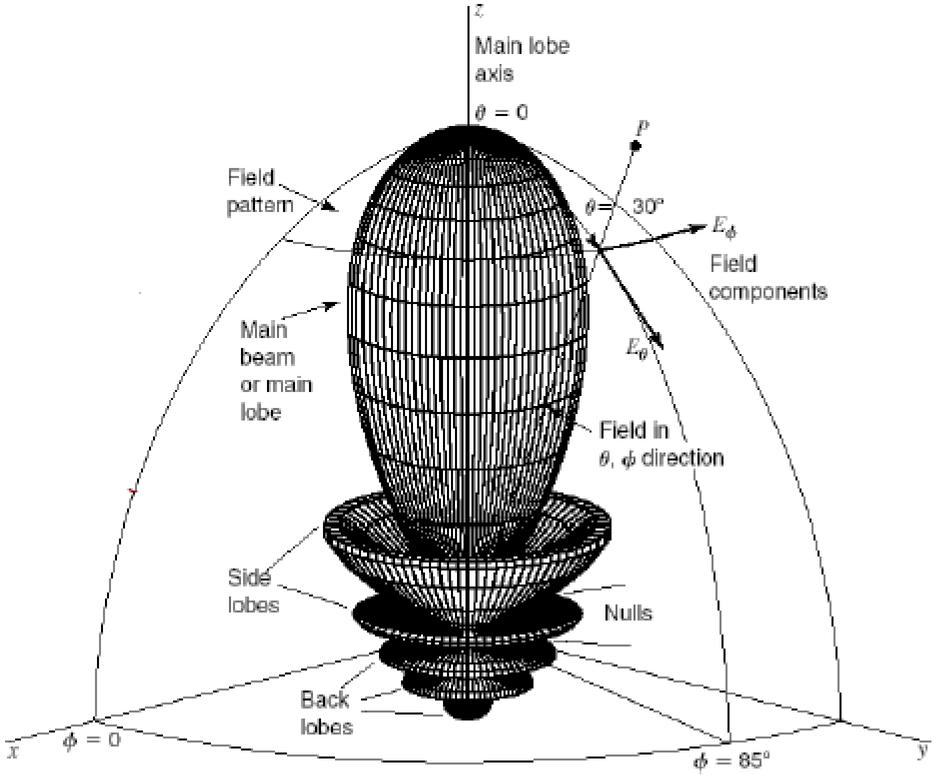


- Defined for the **Far Field Region**

It is drawn as**:**

- **Field patterns : Normalized |E|**
- **Or Power patterns: Normalized power $|E|^2$ vs. spherical coordinate position.**

(normalized with respect to their maximum value).



Electric Field, *f(θ,Φ)*

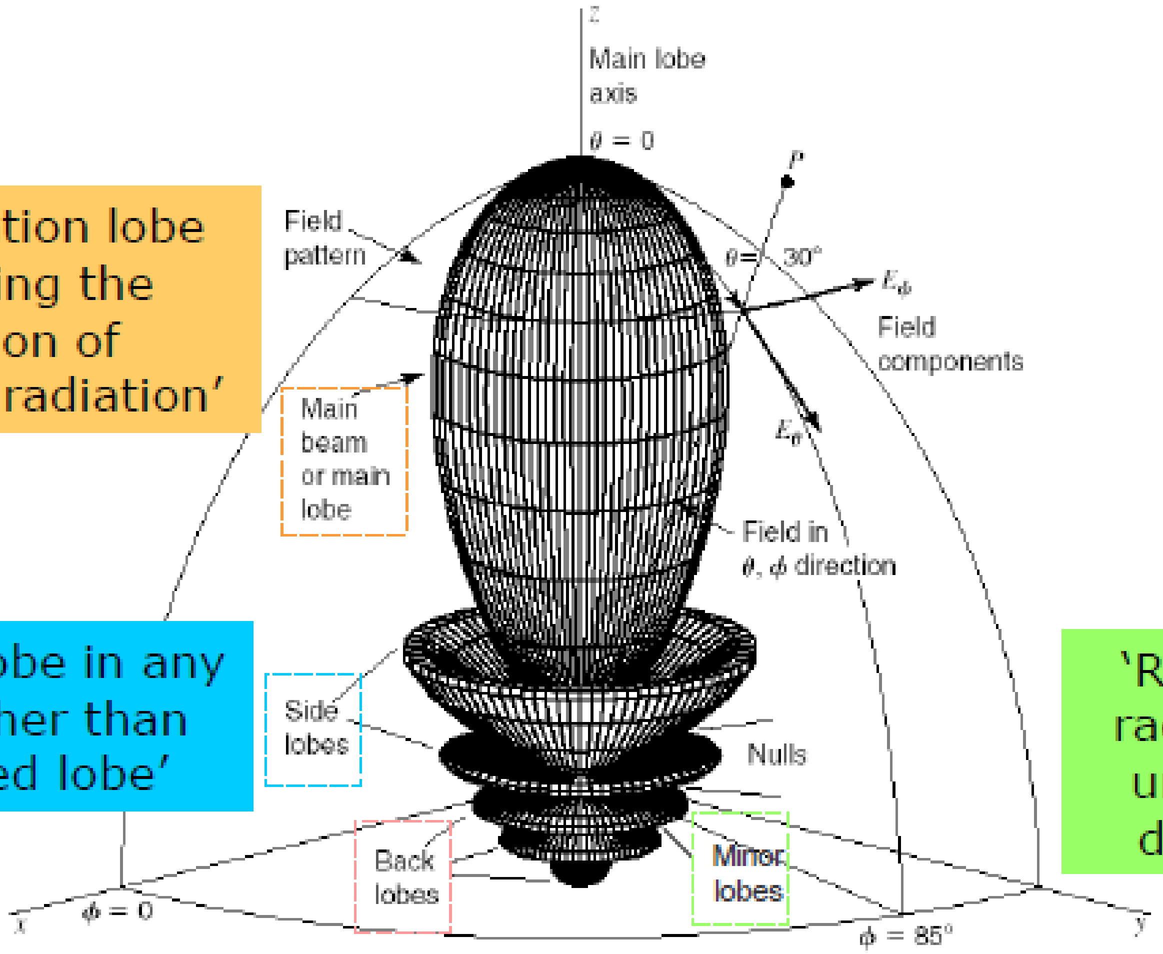
Fundamental Parameters of Antennas

Radiation Pattern

Components in the Amplitude Pattern

- There would be, the electric-field components (E_θ, E_ϕ) at each observation point on the surface of a sphere of constant radius.
- In the far field, the radial E_r component for all antennas is zero or vanishingly small.
- Some antennas, depending on their geometry and also observation distance, may have only one, or two components.
- In general, the magnitude of the total electric field would be $|E| = \sqrt{|E_\theta|^2 + ||E_\phi|^2}$

Fundamental Parameters of Antennas



'The radiation lobe containing the direction of maximum radiation'

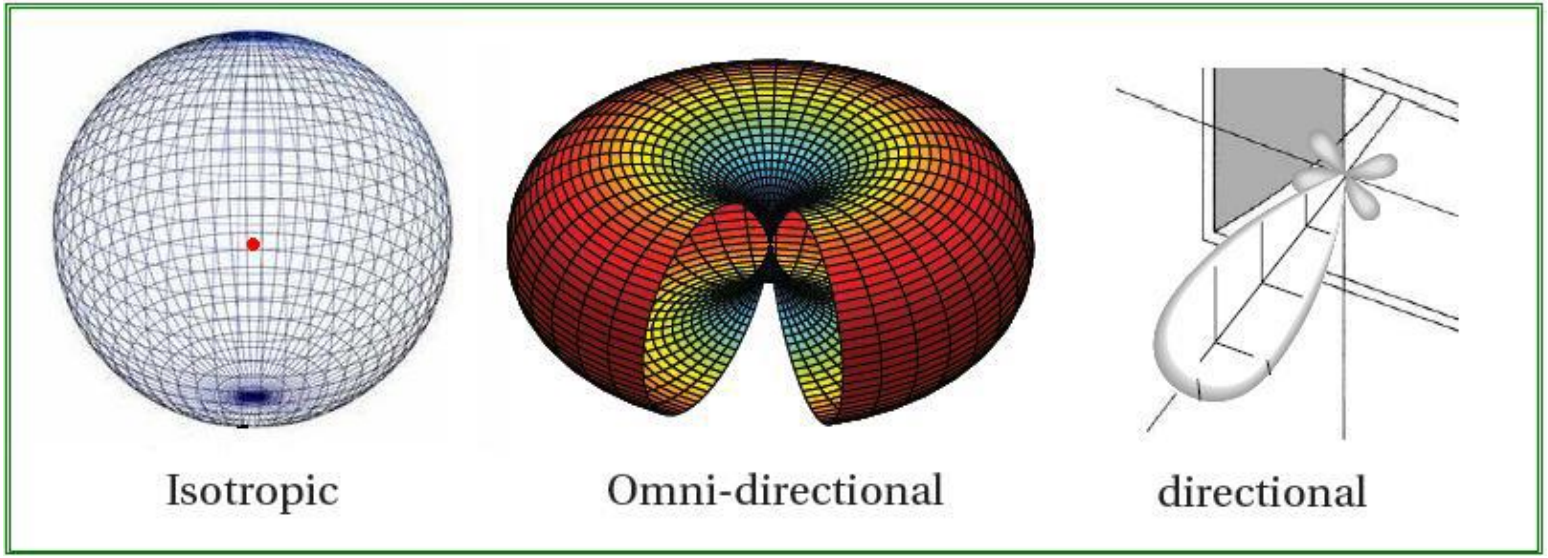
'A radiation lobe in any direction other than the intended lobe'

'Represent radiation in undesired direction'

'A radiation lobe whose axis makes an angle of approximately 180º with respect to the beam of an antenna'

Fundamental Parameters of Antennas

Radiation Patterns



- Isotropic Radiator : “A hypothetical lossless antenna having equal radiation in all directions”.
- Omni-directional: “Having an essentially non-directional pattern in a given plane and a directional pattern in any orthogonal plane”.
- Directional Radiator : “Radiate or receive electromagnetic waves more effectively in some directions than in others”.

Fundamental Parameters of Antennas

Radiation Pattern

Principal Plane Patterns

- Any field pattern can be presented in three-dimensional spherical coordinates ,or by plane cuts through the main lobe axis. Two such cuts at right angles, called the *principal plane patterns* (as in the *xz* and *yz* planes) may be required but If the pattern is symmetrical around the *z* axis, one cut is sufficient.

- Azimuth Plane: $f(\pi/2,\Phi)$
- Elevation Plane: $f(\theta,Constant)$
- E plane & H plane

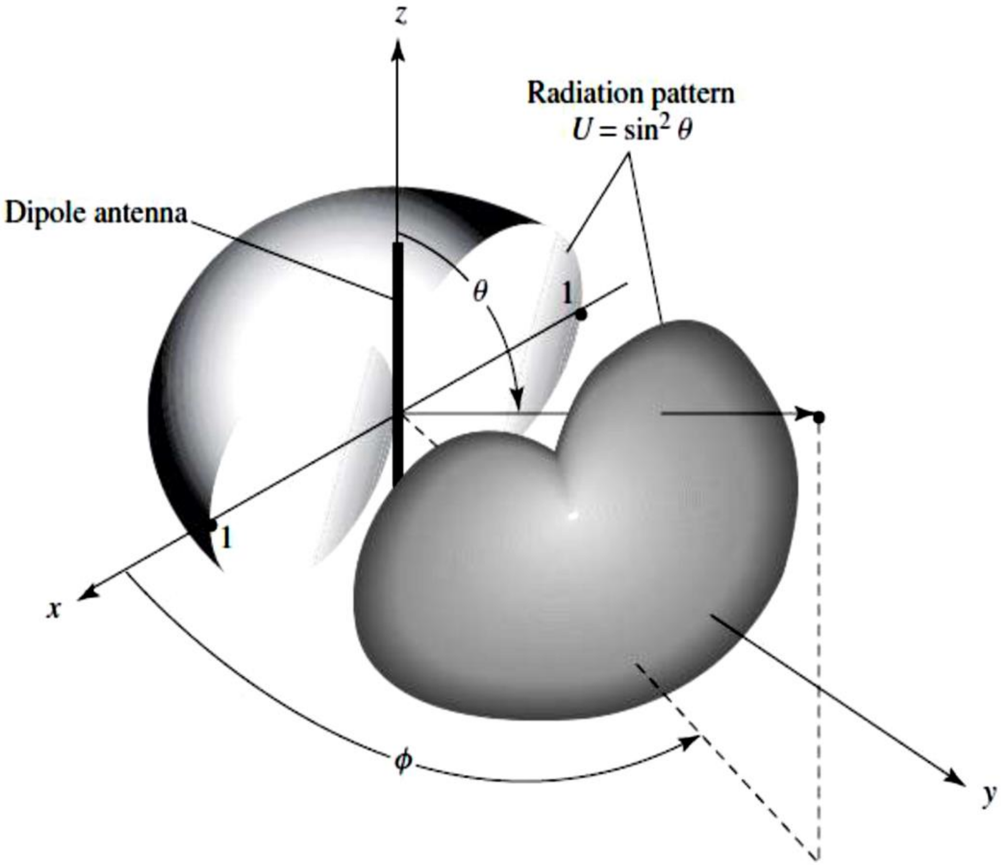


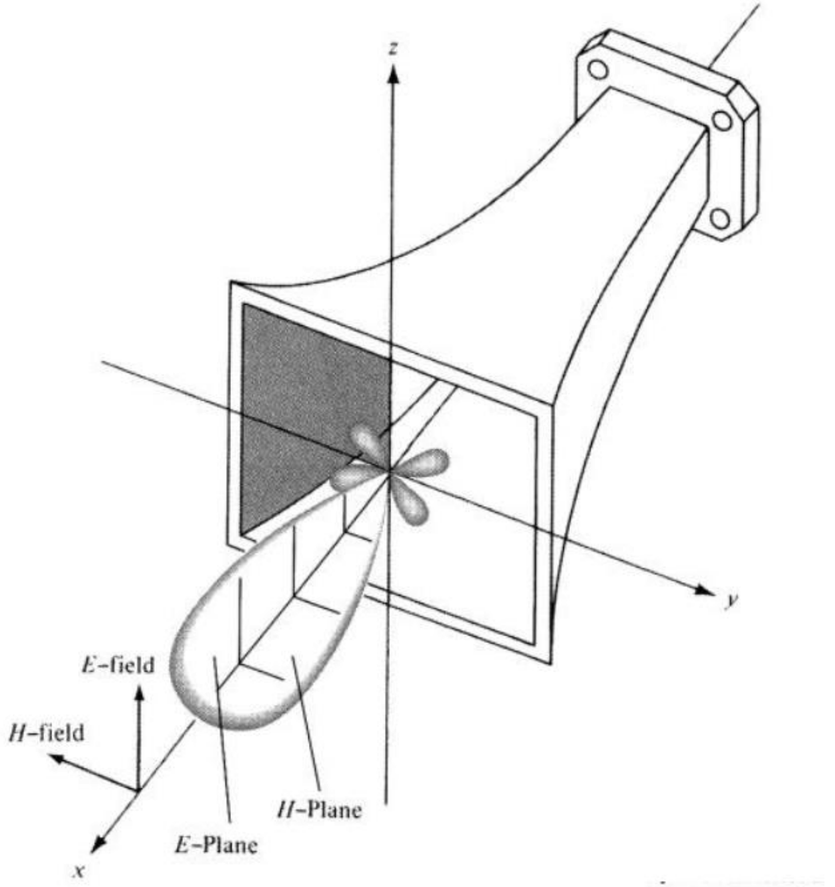
Figure 4.3 Three-dimensional radiation pattern of infinitesimal dipole.

Fundamental Parameters of Antennas

Radiation Pattern

Principal Plane Patterns

- **E-plane pattern**: The plan containing the electric-field vector and the direction of maximum radiation.
- **H-plane pattern**: The plane containing the magnetic vector and the direction of maximum radiation

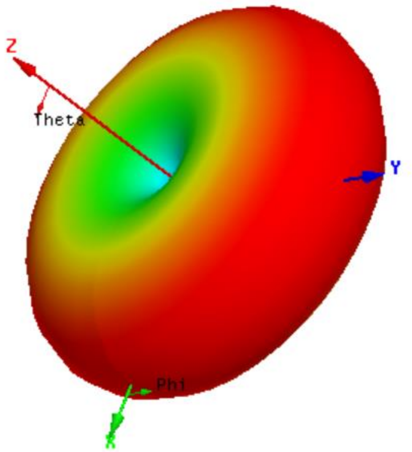


Fundamental Parameters of Antennas

Radiation Pattern

Example 1

Draw radiation pattern for infinitesimal dipole directed along z axis in xy Plane [H-plane] and xz plane[E plane]



By calculator(mode rad):
Mode/table/sin(x)/start 0=/
End π=/step 15π/180=

For Infinitesimal Dipole

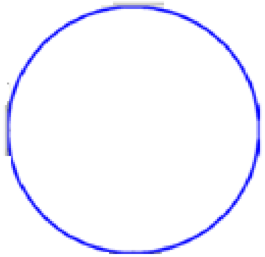
$$\mathbf{W}_{av} = \frac{1}{2}\text{Re}(\mathbf{E}\times\mathbf{H}^*) = \hat{\mathbf{a}}_r \frac{1}{2\eta}|E_\theta|^2 = \hat{\mathbf{a}}_r \frac{\eta}{2}\left|\frac{kI_0 l}{4\pi}\right|^2 \frac{\sin^2\theta}{r^2}$$

$$U = r^2\, W_{av} = \frac{\eta}{2}\left(\frac{kI_0 l}{4\pi}\right)^2 \sin^2\theta = \frac{r^2}{2\eta}|E_\theta(r,\theta,\phi)|^2$$

$$U_{max} = \frac{\eta}{2}\left(\frac{kI_0 l}{4\pi}\right)^2$$

Radiation pattern $U/U_{max} = \sin^2\theta$

- To Draw at X-Y plane (θ= π/2 , φ=0-2 π)
Radiation pattern=$\sin^2(\pi/2)=1$ for all φ values.



Field pattern sinθ

- To draw at X-Z plane (φ=0, θ=0-π then φ=180, θ=0-π)

0	*15*	*30*	*45*	*60*	*75*	*90*
0	0.258	0.5	0.7	0.866	0.96	1
105	***120***	***135***	***150***	***165***	***180***	
0.96	0.866	0.7	0.5	0.258	0	

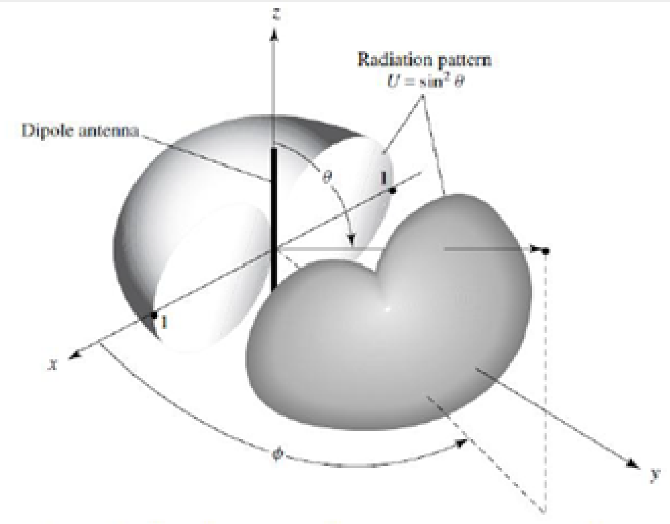
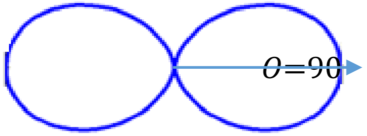
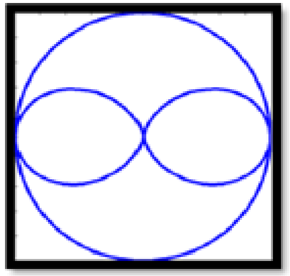


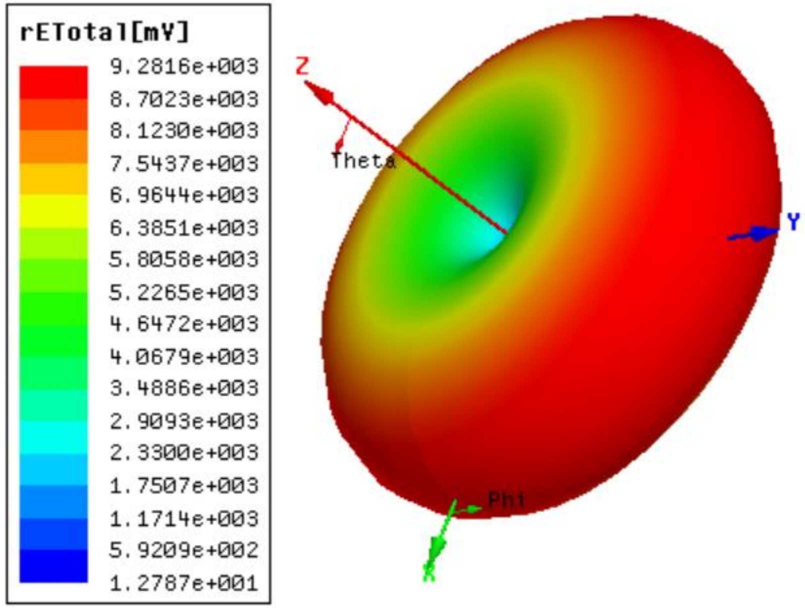
Figure 4.3 Three-dimensional radiation pattern of infinitesimal dipole.

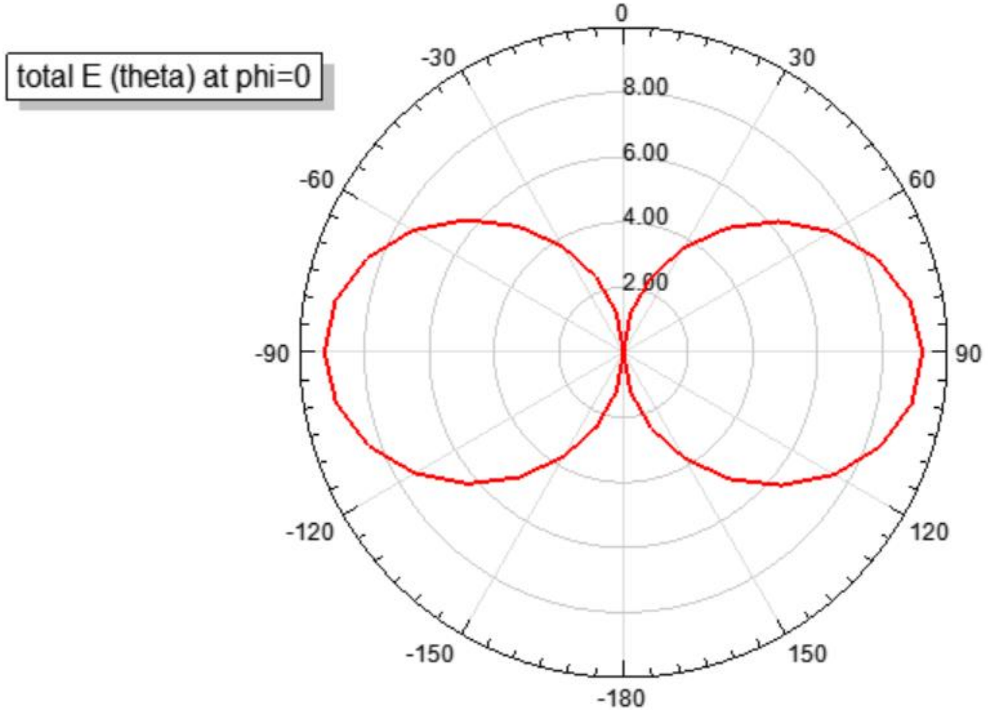


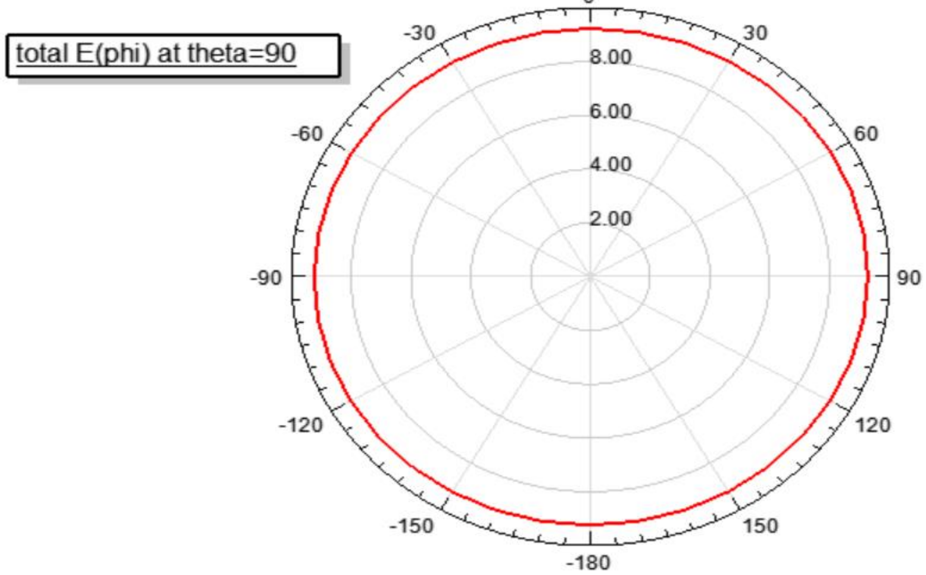


HPBW=90^0
FNBW=180^0

Hfss/dipole


rETotal[mV]
9.2816e+003
8.7023e+003
8.1230e+003
7.5437e+003
6.9644e+003
6.3851e+003
5.8058e+003
5.2265e+003
4.6472e+003
4.0679e+003
3.4886e+003
2.9093e+003
2.3300e+003
1.7507e+003
1.1714e+003
5.9209e+002
1.2787e+001
Z
Theta
Y
Phi
X


total E (theta) at phi=0
0
30
60
90
120
150
-180
-150
-120
-90
-60
-30
8.00
6.00
4.00
2.00

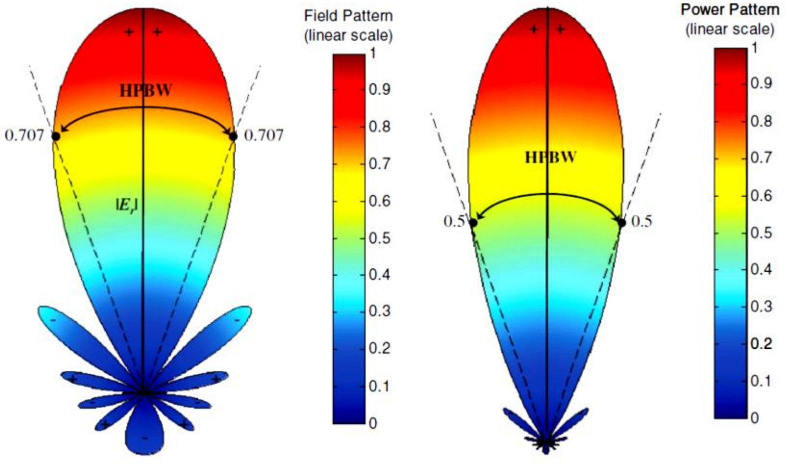

total E(phi) at theta=90
0
30
60
90
120
150
-180
-150
-120
-90
-60
-30
8.00
6.00
4.00
2.00

Fundamental Parameters of Antennas

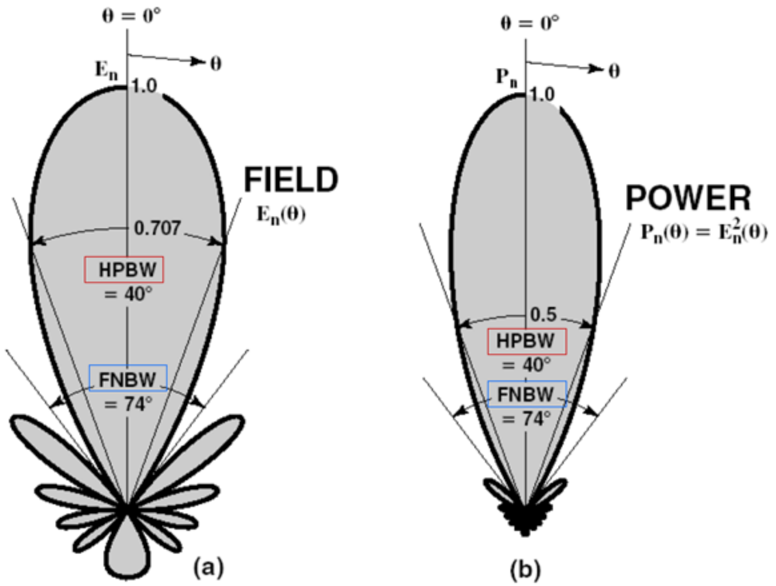
Radiation Pattern

HPBW is the angle between two directions having radiation intensity equal to one half of the beam maximum (measured at plane contains beam maximum)

FNBW is the angle separated between first nulls in the patterns.



(a) Field pattern (in linear scale)   (b) Power pattern (in linear scale)



HPBW = Half Power Beam Width
FNBW = First Null Beam Width

Same HPBW and FNBW values for both patterns

Fundamental Parameters of Antennas

Example 2

An antenna has a field pattern given by $E(\theta) = \cos^2\theta$ for $0 \le \theta \le 90^o$
Find the half-power beamwidth (HPBW)

Solution

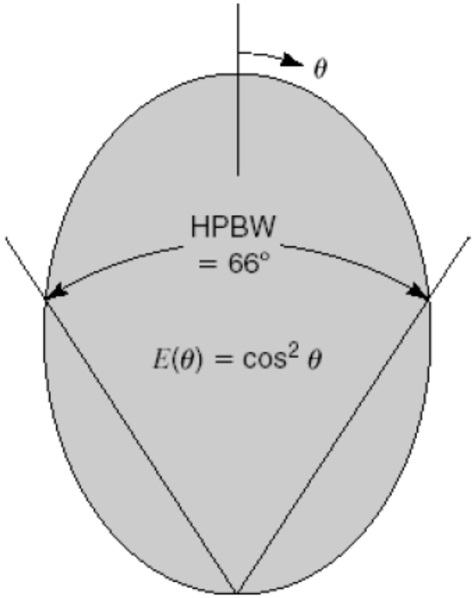
$$E(\theta) = 1 = \cos^2\theta_{max}$$

$$\theta_{max} = 0$$

$$E(\theta) = \frac{1}{\sqrt{2}} = \cos^2\theta_h$$

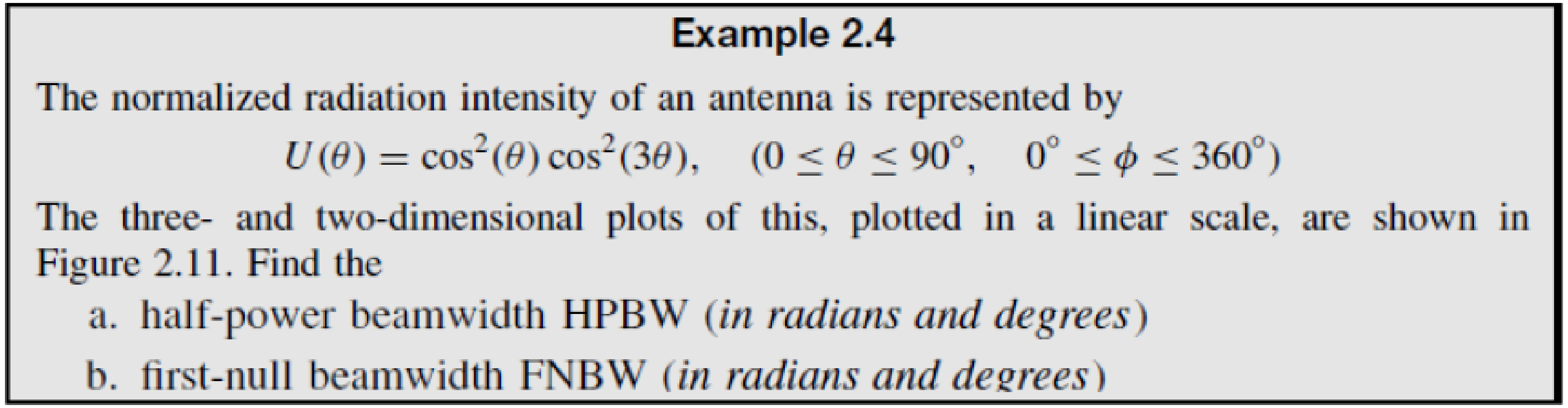
$$\theta_h = 32.7651^o$$

$$\boxed{HPBW = 2\theta_h = 65.53^o}$$



Fundamental Parameters of Antennas

Example 3



Example 2.4

The normalized radiation intensity of an antenna is represented by

$$U(\theta) = \cos^2(\theta)\cos^2(3\theta), \quad (0 \le \theta \le 90^\circ, \quad 0^\circ \le \phi \le 360^\circ)$$

The three- and two-dimensional plots of this, plotted in a linear scale, are shown in Figure 2.11. Find the

a. half-power beamwidth HPBW (*in radians and degrees*)

b. first-null beamwidth FNBW (*in radians and degrees*)

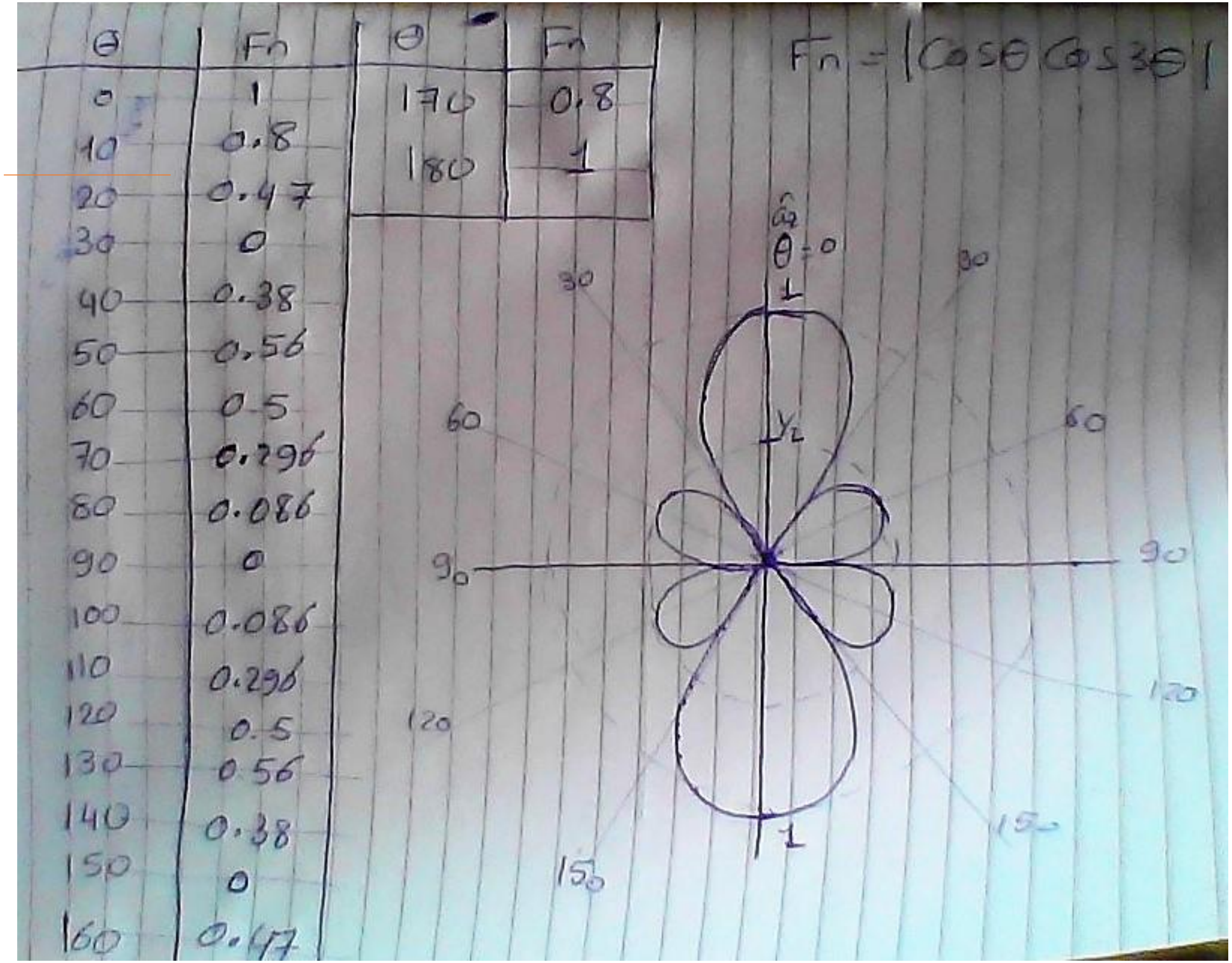
Max at θ=0,180
Nulls at θ=30,90,150

$\text{Cos}\theta_h \; .\text{Cos}3\theta_h = \sqrt{.5}$
$.5\ (\text{Cos}4\theta_h + \text{Cos}2\theta_h) = .707$
$.5\ (2\text{Cos}^2 2\theta_h - 1 + \text{Cos}2\theta_h) = .707$
LET $\text{Cos}2\theta_h = X$ solve equation THEN $X = .876$ so $\text{Cos}2\theta_h = .876$
$2\theta_h = 28.74^0$
HPBW= $28.74^0 = .5$ radians

Same for nulls $.5\ (2\text{Cos}^2 2\theta_n - 1 + \text{Cos}2\theta_n) = 0$
$\text{Cos}^2 2\theta_n - .5 + .5\text{Cos}2\theta_n = 0$ solve $2\theta_n = 60^0$ or 180^0 take the smallest for first null. FNBW= $60^0 = \pi/3$ radians

Field Radiation Pattern if $0 < \theta < 180^o$

$\theta_h = 14.37^\circ$

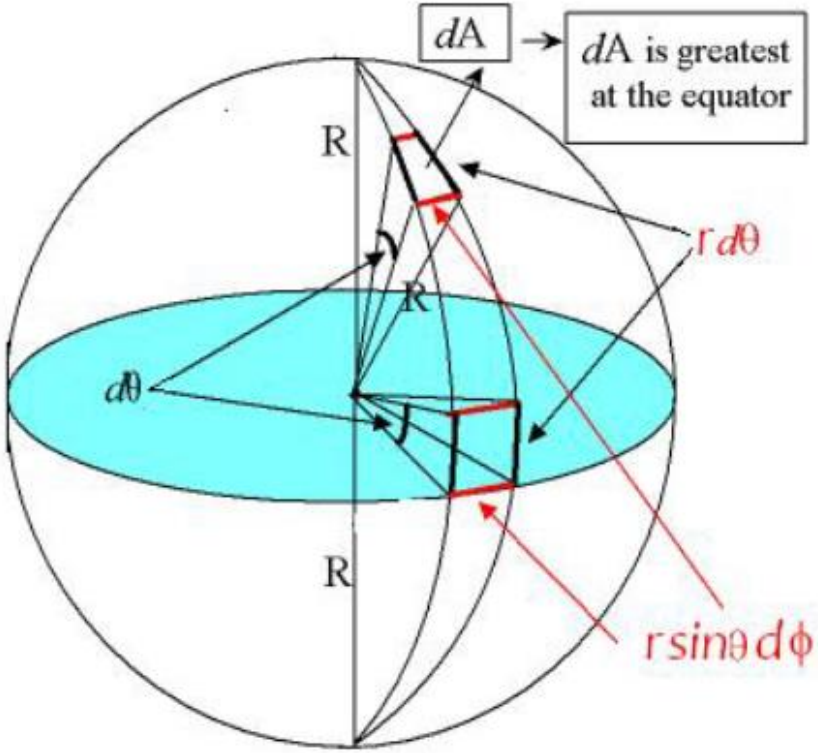


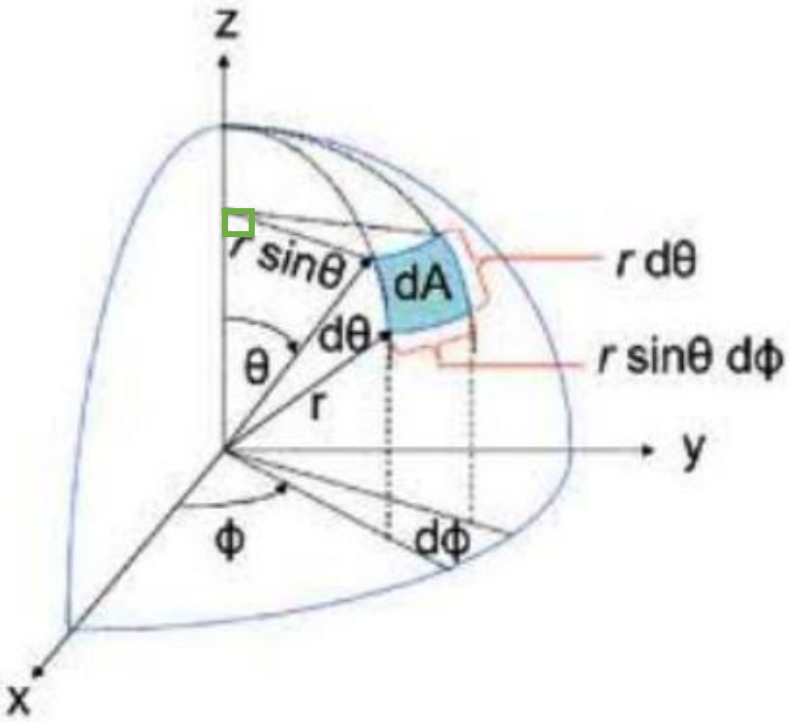
θ	Fn
0	1
10	0.8
20	0.47
30	0
40	0.38
50	0.56
60	0.5
70	0.296
80	0.086
90	0
100	0.086
110	0.296
120	0.5
130	0.56
140	0.38
150	0
160	0.47

θ	Fn
170	0.8
180	1

$F_n = |\cos\theta \cos 3\theta|$

Spherical coordinates
Infinitesimal area on a sphere of radius r





$$dA = (r\,d\theta)(r\sin\theta\,d\phi) = r^2 \sin\theta\,d\theta\,d\phi = r^2\,d\Omega$$

$d\Omega$ solid angle expressed in steradians (sr)

Fundamental Parameters of Antennas

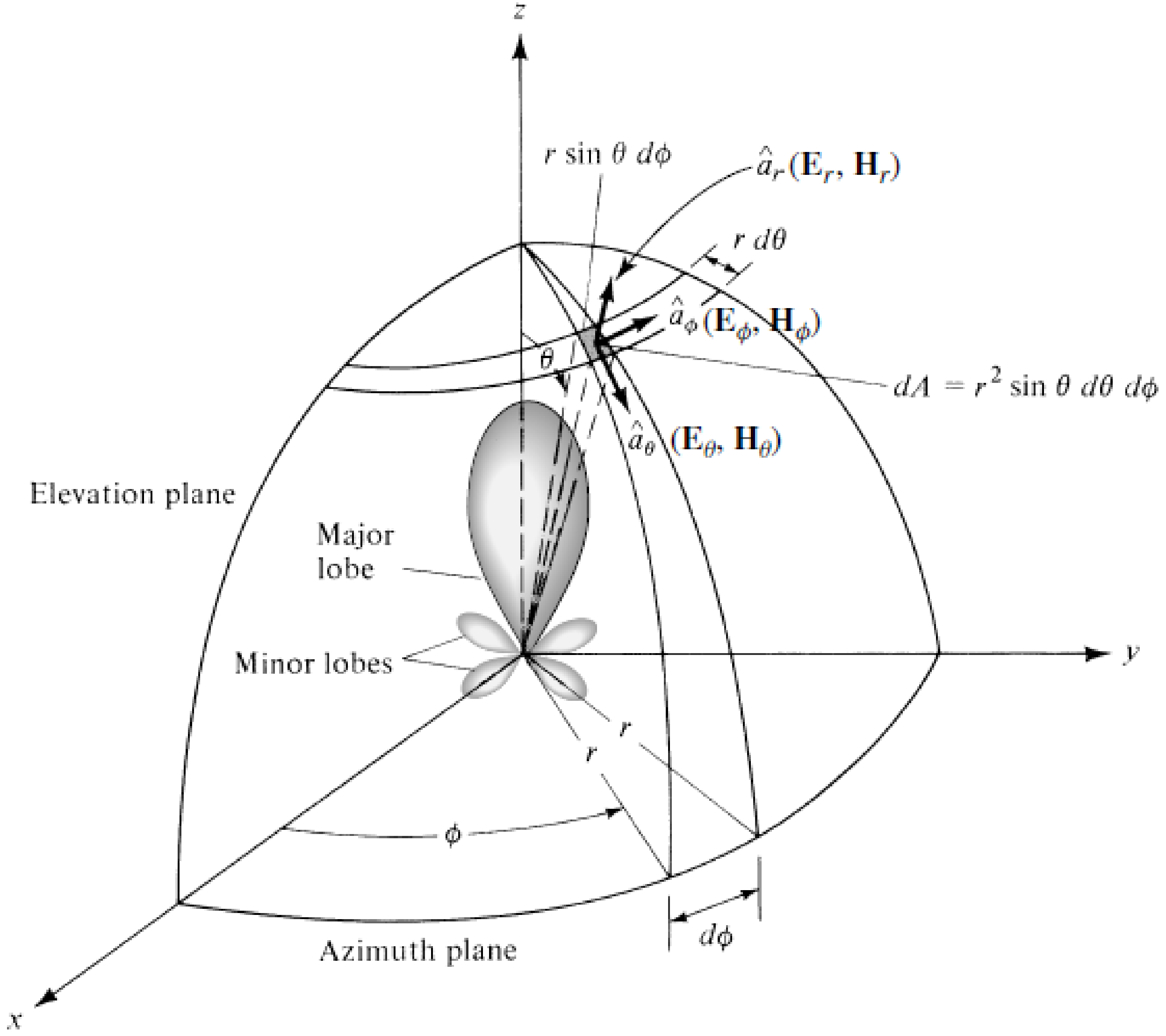


Figure 2.1 Coordinate system for antenna analysis.

Integrating *d*A gives sphere area

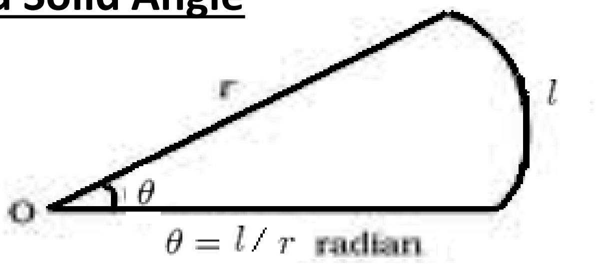
$$\int_0^{2\pi}\left[\int_0^{\pi} r^2 \sin\theta \, d\theta\right] d\phi = 4\pi r^2$$

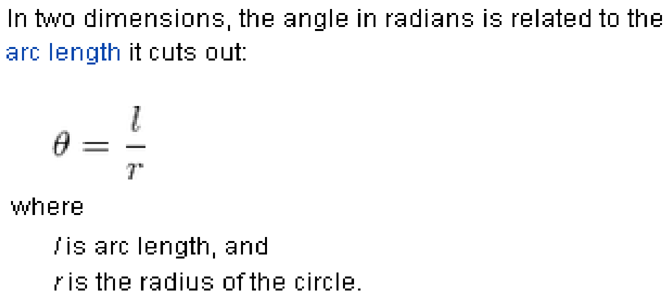
$$\boxed{\begin{array}{l} 0 \le \theta \le \pi \\ 0 \le \phi \le 2\pi \end{array}}$$

✓

Fundamental Parameters of Antennas

Plane angle and Solid Angle



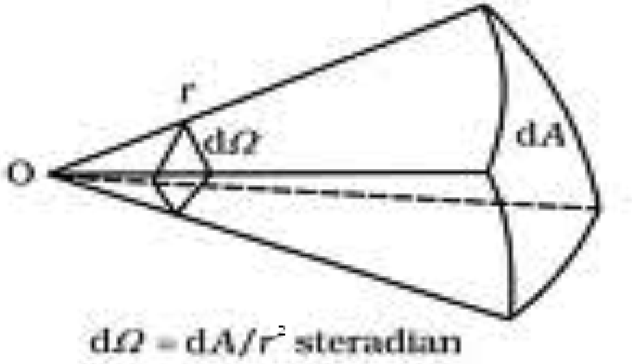

In two dimensions, the angle in radians is related to the arc length it cuts out:

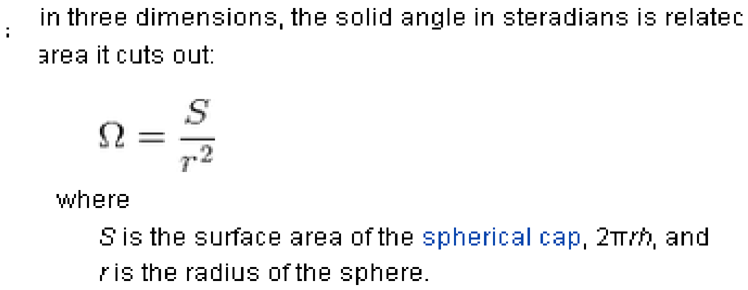
$$\theta = \frac{l}{r}$$

where

l is arc length, and

r is the radius of the circle.




in three dimensions, the solid angle in steradians is relatec

area it cuts out:

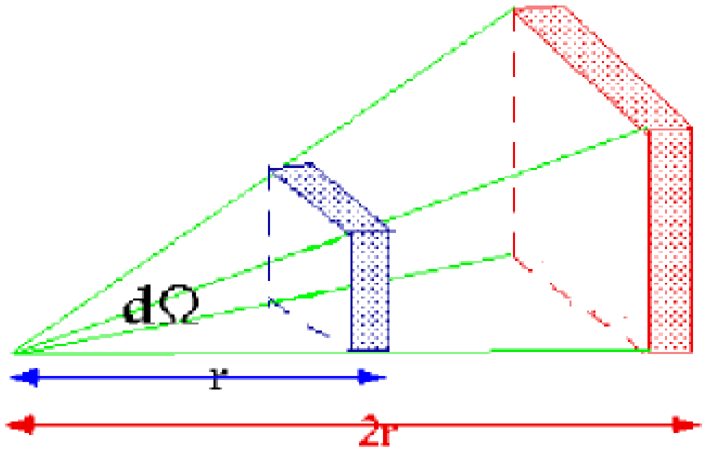
$$\Omega = \frac{S}{r^2}$$

where

S is the surface area of the spherical cap, 2π*rh*, and

r is the radius of the sphere.

One radian defined as plane angle with
Its vertex at center of circle of radius r
And subtend an arc whose length is r



One steradian(square radians) defined as solid angle with
Its vertex at center of sphere of radius r
And subtend by spherical surface area
Equal to r^2

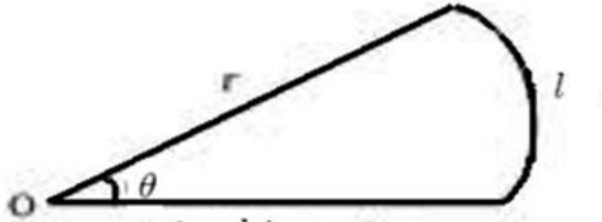
-Number of steradian in sphere=4π

-since $dA = r^2 \sin\theta . d\theta . d\phi$

so $d\Omega = dA/ r^2 = \sin\theta . d\theta . d\phi$

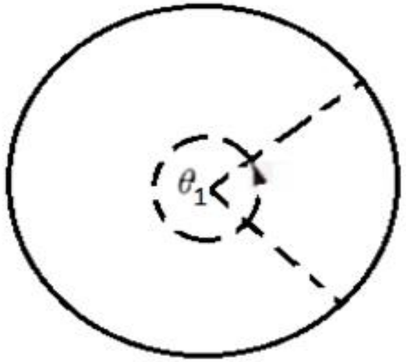
Fundamental Parameters of Antennas

Plane angle and Solid Angle

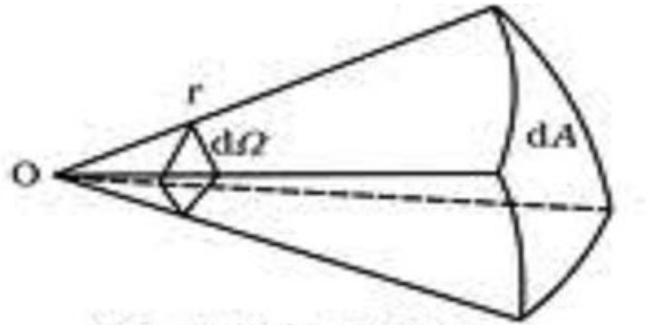


$\theta = l / r$ radian

$$\theta = \frac{l}{r}$$



$$\theta_1 = C/r$$
$$= 2\pi r / r$$
$$= 2\pi$$



$d\Omega = dA/r^2$ steradian

$$\Omega = \frac{S}{r^2}$$

$$\Omega_1 = \frac{4\pi r^2}{r^2} = 4\pi$$

$$d\,\Omega = dA/r^2 = \sin\theta\, d\theta\, d\phi$$

$$\Omega 1 = \int_0^{2\pi}\int_0^{\pi} \sin\theta\, d\theta\, d\phi$$

$$= 2\pi\left[-\cos\theta\right]_0^{\pi} = 4\,\pi$$

Fundamental Parameters of Antennas

Solid angle
in 1 steradian ≅ 3283□
in sphere ≅ 41,253□

4π = solid angle subtended by a sphere, sr.

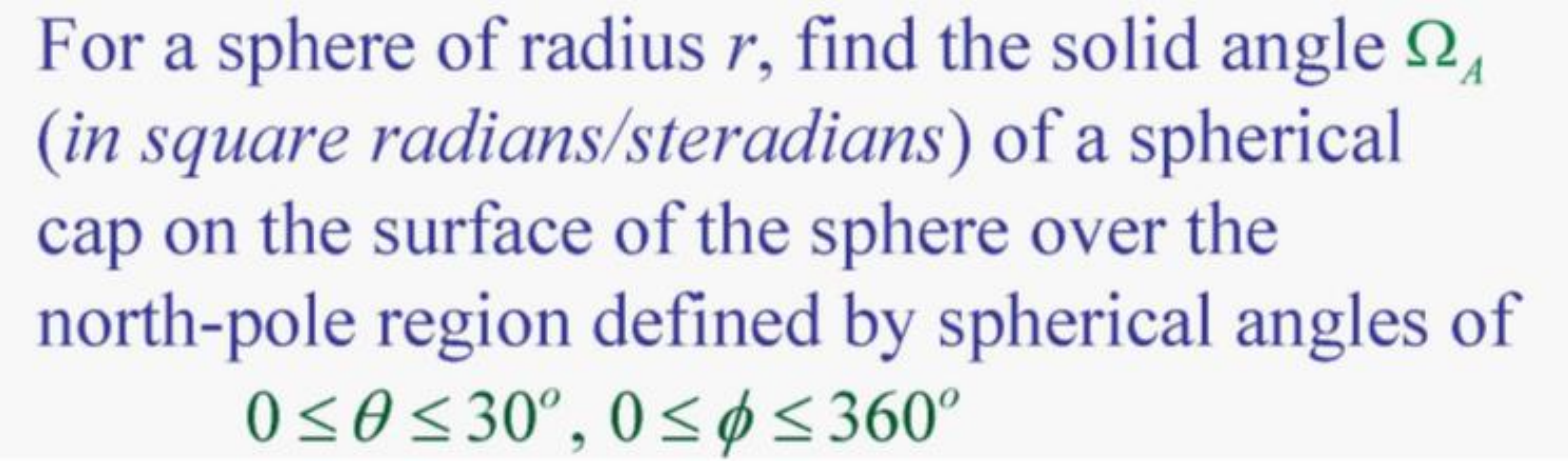
$$1 \text{ steradian} = 1 \text{ sr} = 1\,rad^2 = \left(\frac{180}{\pi}\right)^2 (\deg^2) = 3282.8064 \text{ square degrees}$$

$$4\pi \text{ steradians} = 3282.8064 \times 4\pi = 41{,}252.96 \text{ square degrees} = 41{,}252.96\ \square$$

= solid angle in a sphere

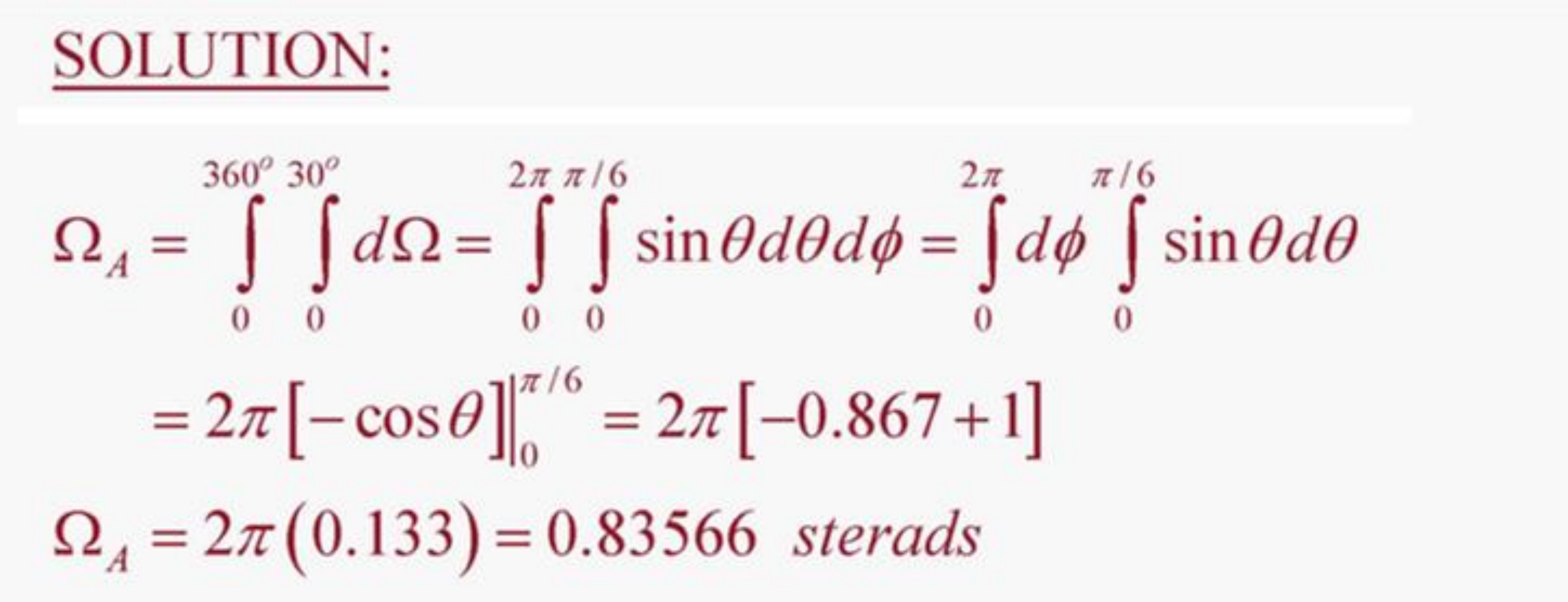
Fundamental Parameters of Antennas

Example 4



For a sphere of radius *r*, find the solid angle Ω_A (*in square radians/steradians*) of a spherical cap on the surface of the sphere over the north-pole region defined by spherical angles of

$$0 \le \theta \le 30^o,\ 0 \le \phi \le 360^o$$



SOLUTION:

$$\Omega_A = \int_0^{360^o}\int_0^{30^o} d\Omega = \int_0^{2\pi}\int_0^{\pi/6} \sin\theta d\theta d\phi = \int_0^{2\pi} d\phi \int_0^{\pi/6} \sin\theta d\theta$$

$$= 2\pi\left[-\cos\theta\right]\Big|_0^{\pi/6} = 2\pi\left[-0.867+1\right]$$

$$\Omega_A = 2\pi(0.133) = 0.83566 \ \ sterads$$

Fundamental Parameters of Antennas

Example 5

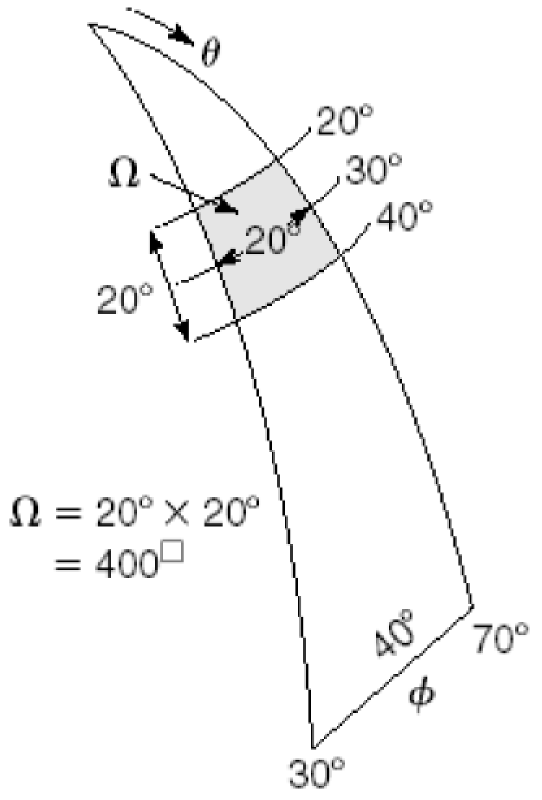
Find the number of square degrees in the solid angle on a spherical surface that is between $\theta = 20^o$ and $\theta = 40^o$ and between $\Phi = 30^o$ and $\Phi = 70^o$.

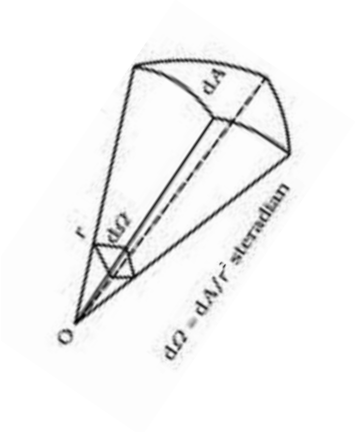
S

$$d\Omega = \sin\theta d\theta d\phi \qquad \Omega = \int_{\phi=30^o}^{\phi=70^o}\int_{\theta=20^o}^{\theta=40^o} \sin\theta d\theta d\phi$$

$$\Omega = \phi\Big|_{\frac{\pi}{6}}^{\frac{7\pi}{18}}\left[-\cos\theta\right]_{20^o}^{40^o} = 0.12122 \text{ (steradians)}$$

$$\Omega = 0.12122\times\left(\frac{180}{\pi}\right)^2 = 397.97 \text{ square degrees}$$





Fundamental Parameters of Antennas

Beam solid Angle(or Beam Area):

The beam area *A* is the solid angle through which all of the power radiated by the antenna would stream if *P*(*θ, Φ*) maintained its maximum value over *A* and was zero elsewhere(one main lobe). The *beam area* of an antenna can often be described *approximate* in terms of the angles subtended by the *half-power points* of the main lobe in the two principal planes. So For antennas with one narrow major lobe and very negligible minor lobes, the beam solid angle is approximately equal to the product of the half-power beam widths in two perpendicular planes

$$\boxed{Beam\ Area \cong \Omega_A \cong \theta_{HP}\phi_{HP}} \quad \text{(sr)}$$

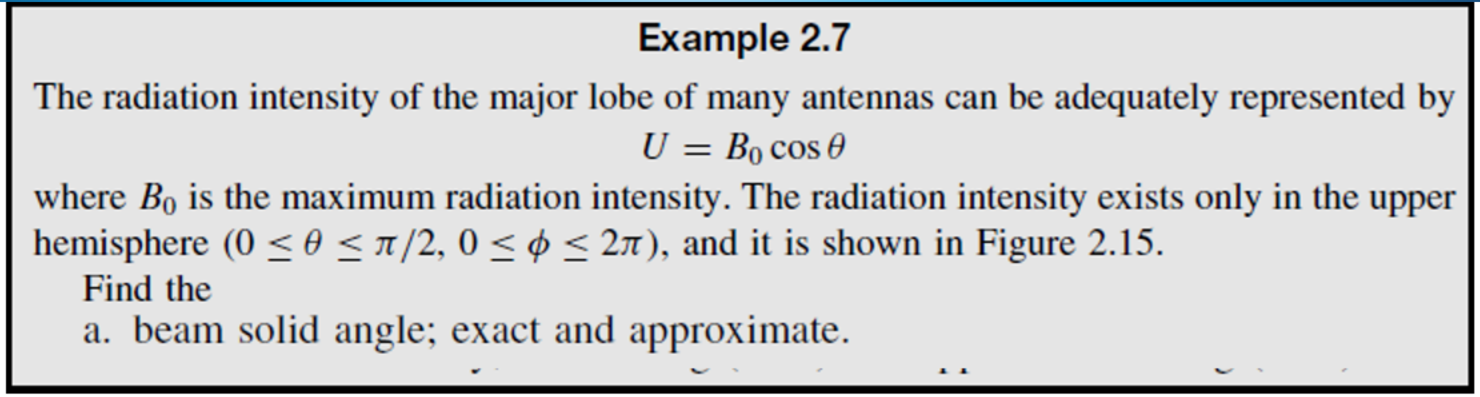
Where *θHP* and *ΦHP* are the half-power beamwidths (HPBW) in the two principle planes, minor lobes being neglected.

$$The\ beam\ area\ or\ beam\ solid\ angle = \Omega_A = \int_{\phi=0}^{\phi=2\pi}\int_{\theta=0}^{\theta=\pi} P_n(\theta,\phi)\sin\theta d\theta d\phi$$

$$\boxed{\Omega_A = \iint_{4\pi} P_n(\theta,\phi)d\Omega} \quad \text{(sr)} \quad \text{where} \quad d\Omega = \sin\theta d\theta d\phi$$

Fundamental Parameters of Antennas

Example 6



Example 2.7

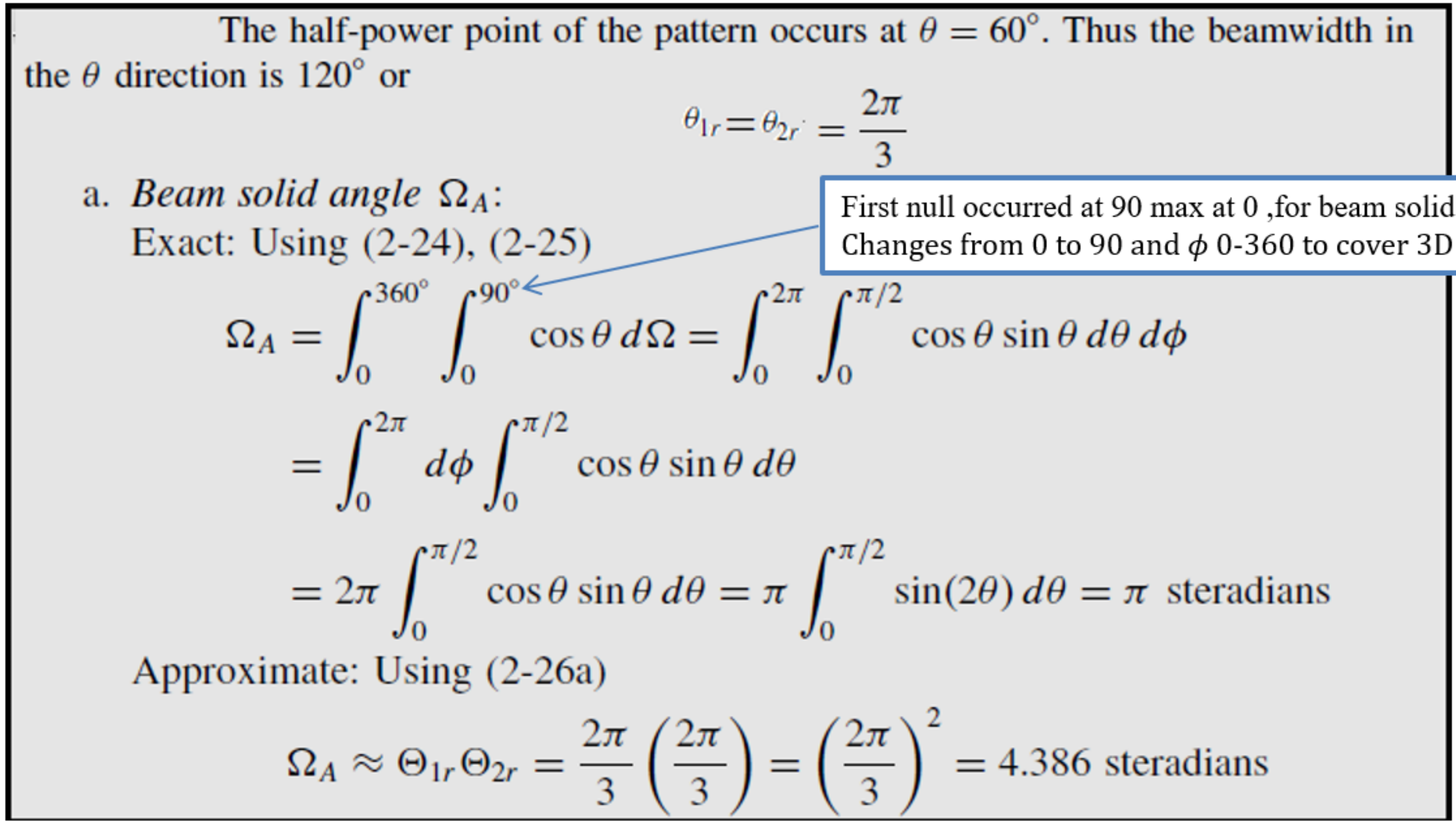
The radiation intensity of the major lobe of many antennas can be adequately represented by

$$U = B_0 \cos\theta$$

where B_0 is the maximum radiation intensity. The radiation intensity exists only in the upper hemisphere ($0 \le \theta \le \pi/2$, $0 \le \phi \le 2\pi$), and it is shown in Figure 2.15.

Find the

a. beam solid angle; exact and approximate.



The half-power point of the pattern occurs at $\theta = 60^\circ$. Thus the beamwidth in the θ direction is 120° or

$$\theta_{1r} = \theta_{2r} = \frac{2\pi}{3}$$

a. *Beam solid angle* Ω_A:

Exact: Using (2-24), (2-25)

$$\Omega_A = \int_0^{360^\circ}\int_0^{90^\circ} \cos\theta \, d\Omega = \int_0^{2\pi}\int_0^{\pi/2} \cos\theta \sin\theta \, d\theta \, d\phi$$

$$= \int_0^{2\pi} d\phi \int_0^{\pi/2} \cos\theta \sin\theta \, d\theta$$

$$= 2\pi \int_0^{\pi/2} \cos\theta \sin\theta \, d\theta = \pi \int_0^{\pi/2} \sin(2\theta) \, d\theta = \pi \text{ steradians}$$

Approximate: Using (2-26a)

$$\Omega_A \approx \Theta_{1r}\Theta_{2r} = \frac{2\pi}{3}\left(\frac{2\pi}{3}\right) = \left(\frac{2\pi}{3}\right)^2 = 4.386 \text{ steradians}$$

First null occurred at 90 max at 0 ,for beam solid angle θ
Changes from 0 to 90 and ϕ 0-360 to cover 3D beam angle

Dexact=4
Dapprox=2.86