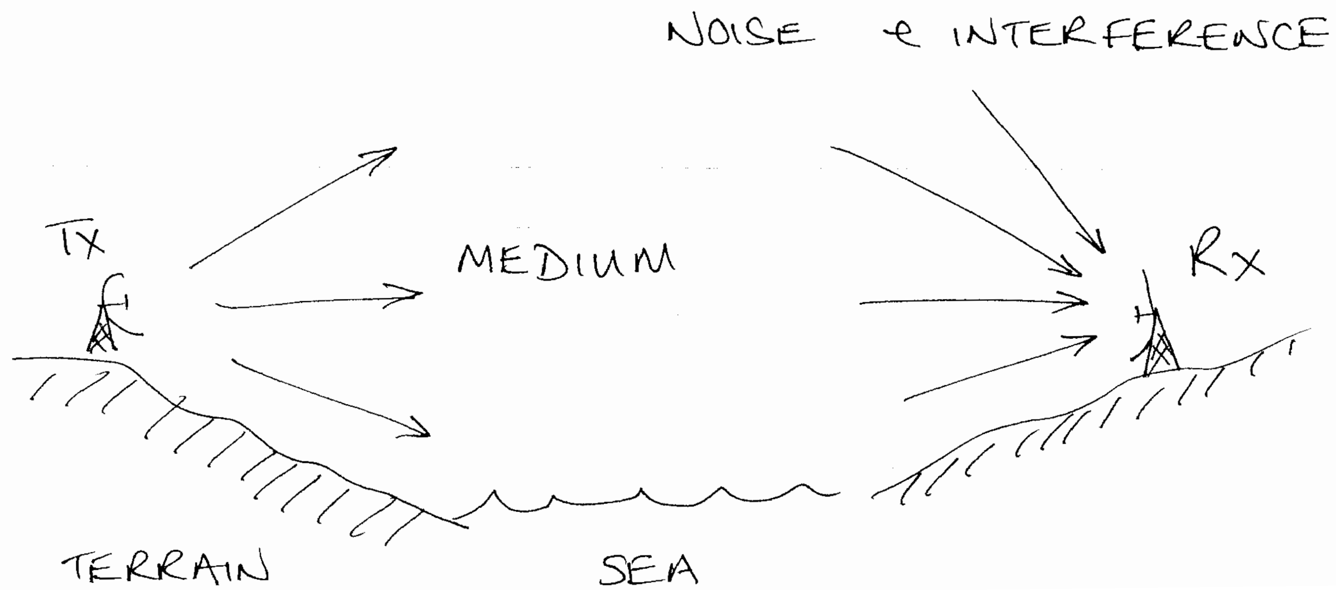
ELEMENTS OF A RADIO TRANSMISSION SYSTEM

SIX BASIC ELEMENTS:

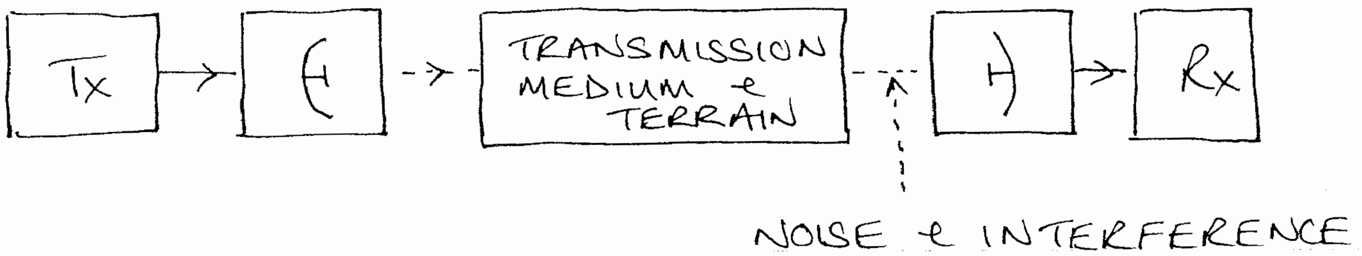
* SIGNAL SOURCE
* RECEIVER
* ANTENNAS
* MEDIUM - USUALLY THE EARTH'S ATMOS.
* ENVIRONMENT - TERRAIN, VEGETATION, SEA ETC.
* INTERFERENCE & NOISE - NATURAL AND MAN MADE.



THE ANTENNA AS A SYSTEM ELEMENT

WHAT IS AN ANTENNA?

- ANY STRUCTURE ON WHICH TIME-VARYING CURRENTS CAN BE EXCITED (WIRE ANTENNAS) OR TIME-VARYING ELECTRIC FIELDS CAN BE SUPPORTED. (APERTURE-TYPE ANTENNAS)

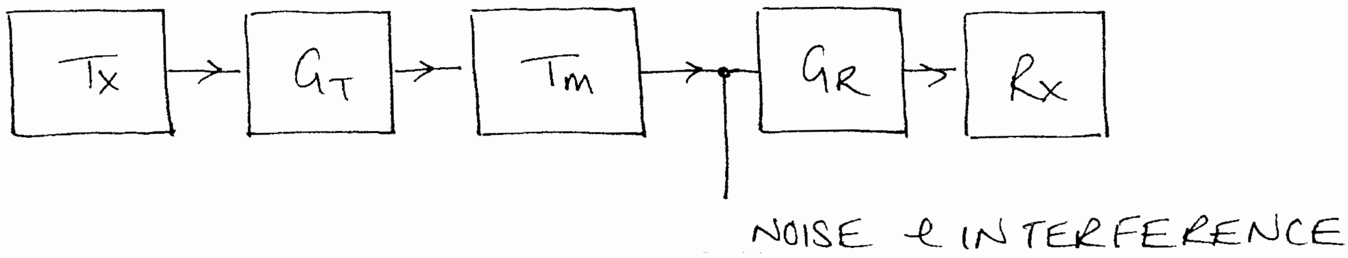


- NOT EASY TO SEPARATE ANTENNA FROM INTERACTIONS WITHIN SURROUNDING ENVIRONMENT.

HOWEVER, FOR <u>FIRST ORDER</u> CALCULATIONS AT UHF AND ABOVE WE CAN MAKE A GOOD APPROXIMATION.

NOTE: AN EXCEPTION TO THIS IS UHF MOBILE RADIO WHERE THE HUMAN HEAD AND ANTENNA CANNOT BE CONSIDERED INDEPENDENTLY

FIRST-ORDER APPROXIMATION



G_T AND G_R REPRESENT THE GAINS OF THE ANTENNAS IN THE OPTIMUM (WANTED) DIRECTION

Tm COULD BE A TRANSMISSION MATRIX OR SIMPLY A LOSS.

TYPES OF ANTENNAS

TWO GENERIC TYPES OF ANTENNAS (DISTINGUISHED BY THEIR SIZE COMPARED TO THE WAVE LENGTH)

* APERTURE-TYPE ANTENNAS:
  SIZE $> \lambda$ (OFTEN $\gg \lambda$)

* WIRE ANTENNAS FOR WHICH:
  SIZE $< \lambda$ (OFTEN $\ll \lambda$)

WE CAN EMPLOY ARRAYS OF BOTH WIRE AND APERTURE ANTENNAS.

TYPICAL WIRE ANTENNAS;

MONOPOLE, DIPOLE, LONG-WIRE

NOTE: AT VLF OR LF A LONG PIECE OF WIRE IS STILL ELECTRICALLY SMALL COMPARED TO THE WAVELENGTH

SOME EXAMPLES:

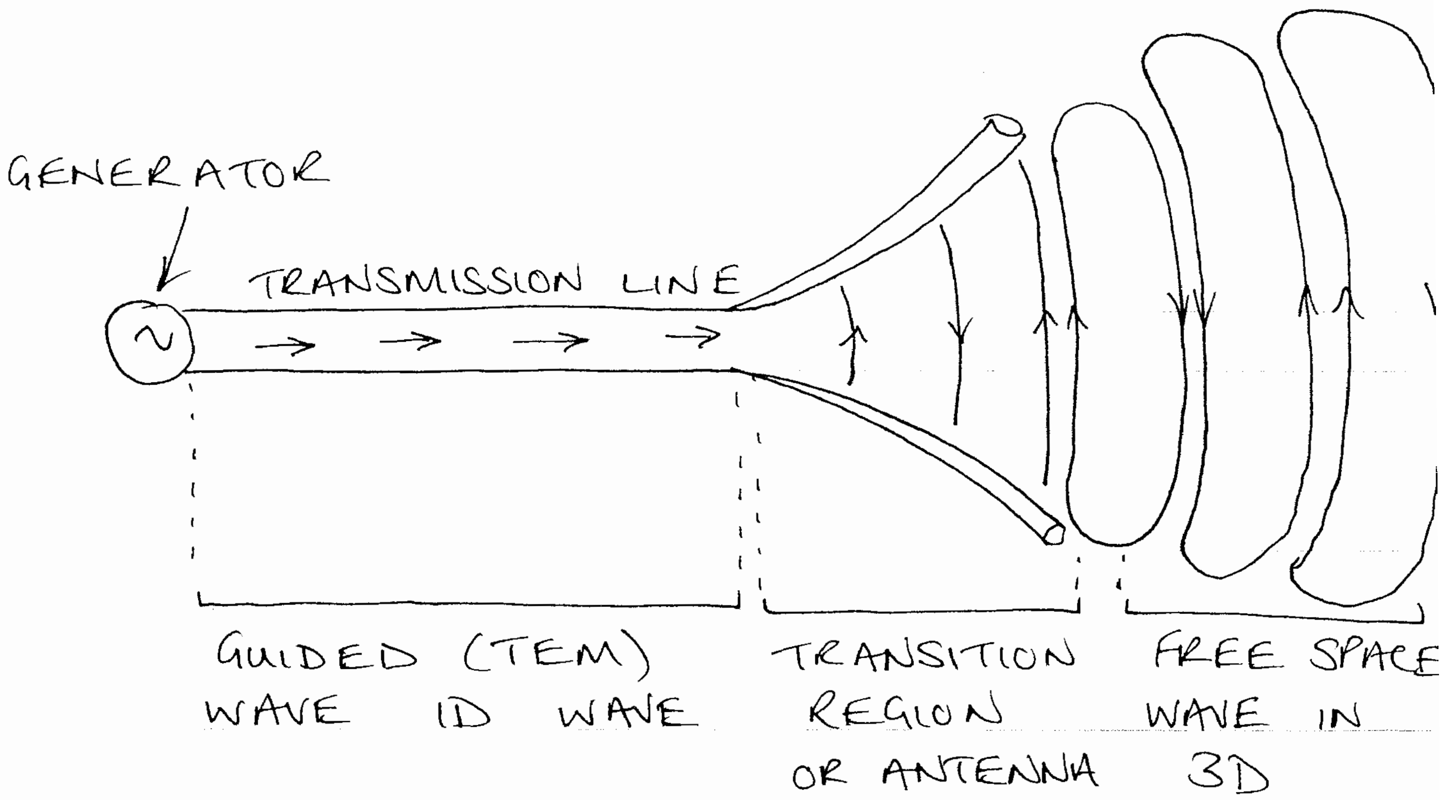
TELECOMMUNICATIONS SYSTEM	ANTENNA
* PERSONAL MOBILE	* MONOPOLE
* SATELLITE FIXED SERVICE (GEO)	* PARABOLIC DISH
* SATELLITE MOBILE (GEO) (VEHICLE MOBILE) E.G. INMARSAT	* STEERABLE DISH * STEERABLE PLANAR ARRAY * BI-CONICAL
* SATELLITE MOBILE (LEO) E.G. IRIDIUM	* MONOPOLE ?
* SATELLITE BROADCAST E.G ASTRA	* DISH * PLANAR ARRAY

* TERRESTRIAL FIXED (POINT - TO - POINT)	* DISH
* TERRESTRIAL BROADCAST (FM & TV)	* YAGI - UDA (ENDFIRE ARRAY) * LOG - PERIODIC * LOOP * SLOT
* STRATOSPHERIC BALLOONS (SKY - STATION)	* DISH

RADAR SYSTEM	ANTENNA
* WEATHER	* STEERABLE DISHES
* AIR TRAFFIC AND MARINE	* SECTIONS OF DISHES OR SLOTTED ARRAYS
* WEAPONS GUIDANCE	* STEERABLE DISHES
* TRACKING / INTERCEPTION	* STEERABLE DISHES OR ARRAYS

RADIATION FROM ANTENNAS

THE ANTENNA IS A DEVICE THAT IS THE TRANSITION BETWEEN A GUIDED WAVE IN A TRANSMISSION LINE (E.G. CO-AXIAL CABLE, WAVEGUIDE ETC) AND THE TRANSMISSION MEDIUM (USUALLY EITHER FREE-SPACE OR SOME DIELECTRIC)



AN ANTENNA CAN BE VIEWED AS AN <u>IMPEDANCE MATCHING DEVICE</u> BETWEEN THE TRANSMISSION LINE AND FREE-SPACE (OR A DIELECTRIC)

WHAT TYPE OF WAVES ARE RADIATED FROM AN ANTENNA? ARE THEY <u>PLANE</u> WAVES?

IN FREE-SPACE, THE SOURCE-FREE WAVE EQUATION FOR $\underline{E}$

$$\underline{\nabla}^2 \underline{E} - \frac{1}{c^2} \frac{\partial^2 \underline{E}}{\partial t^2} = 0$$

WHERE:

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}.$$

FOR TIME-HARMONIC FIELDS, THIS REDUCES TO: (LOSSLESS CASE)

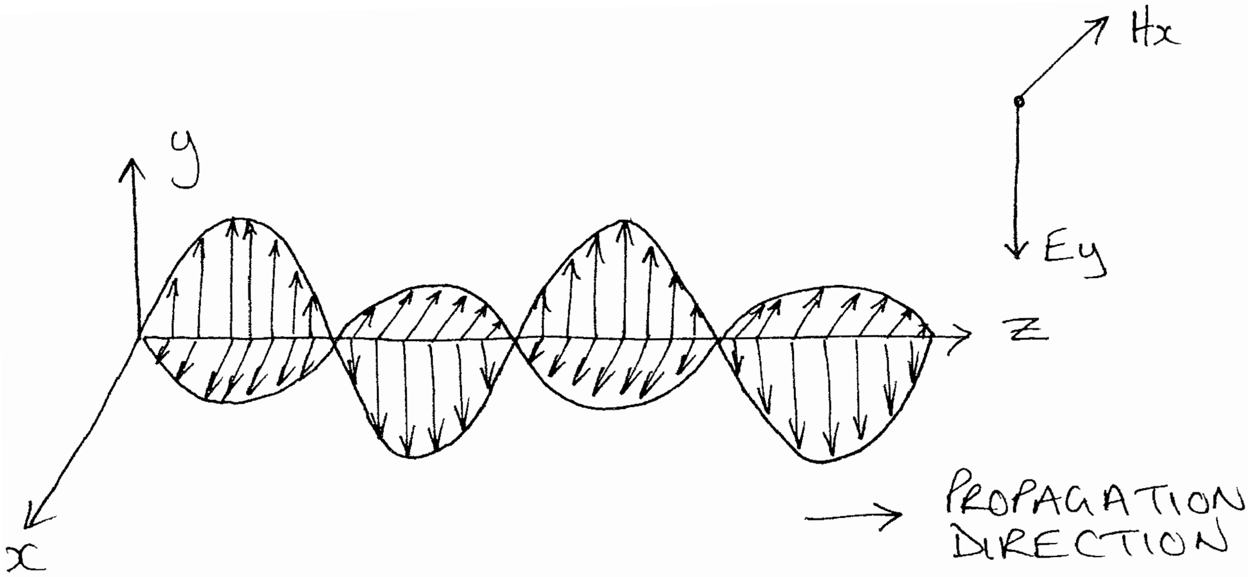
$$\underline{\nabla}^2 \underline{E} + k_0^2 \underline{E} = 0$$

k_0 - FREE SPACE WAVENUMBER

$$k_0 = \omega\sqrt{\mu_0 \epsilon_0} = \frac{\omega}{c} = \frac{2\pi}{\lambda_0}$$

RE-ARRANGING, INTO CARTESIAN FORM WE CAN OBTAIN (FOR E)

$$E_y = E_{y0} \exp(\gamma z - j\omega t)$$



PLANE WAVES IN DIELECTRIC MEDIA AND FREE-SPACE

γ - PROPAGATION CONSTANT $= \alpha + j\beta$

α - ATTENUATION CO-EFFICIENT
($\alpha = 0$ FOR A DIELECTRIC MEDIUM & FREE SPACE)

β - PHASE-SHIFT WITH DISTANCE

$$\beta = \frac{2\pi}{\lambda}$$

IN FREE SPACE $\lambda = c/f$, WE USUALLY WRITE $\beta = k$ (FREE-SPACE PROP. CONSTANT)

NOTE :

$\gamma = jk_c$ $\quad$ k_c - COMPLEX WAVE NUMBER

WE WILL DEAL WITH COMPLEX WAVE NUMBERS WHEN WE LOOK AT SURFACE REFLECTIONS

PLANE WAVES HAVE THE FOLLOWING PROPERTIES;

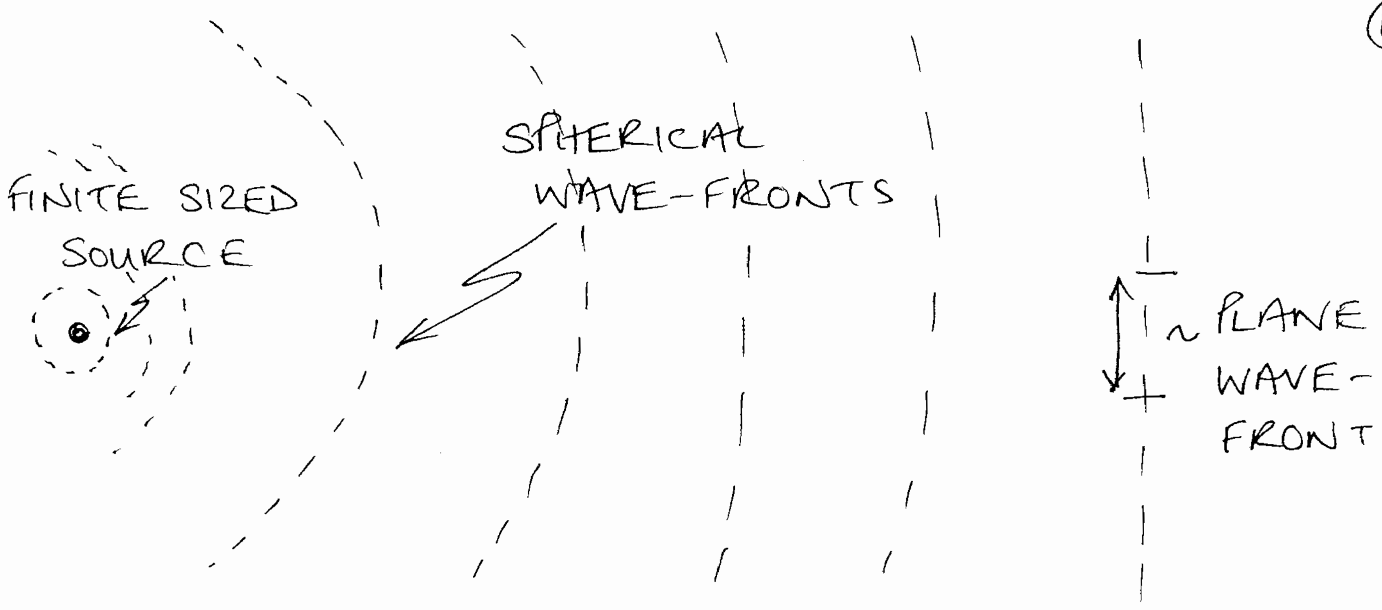
* WE HAVE A WAVEFRONT OF INFINITE EXTENT

* THE FIELD STRENGTH DOES NOT DIMINISH WITH DISTANCE

PLANE-WAVES ARE THUS AN ABSTRACT CONCEPT, REQUIRING A SOURCE OF INFINITE POWER AND/OR EXTENT FOR THEIR GENERATION.

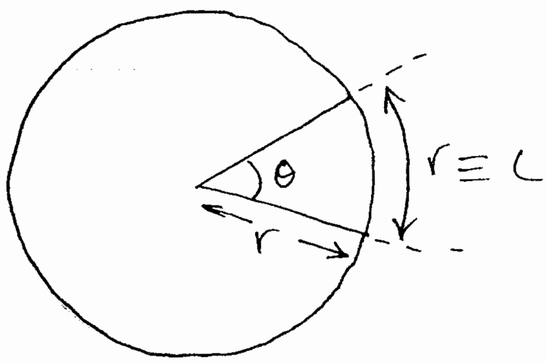
THEY CANNOT BE GENERATED BY A REAL ANTENNA SYSTEM, WHERE WE HAVE TO CONSIDER FINITE-SIZED SOURCES AND SPHERICAL WAVEFRONTS

HOWEVER, AT A VERY LARGE DISTANCE THE RADIUS OF CURVATURE OF THE WAVE FRONT MAY BE A GOOD APPROXIMATION TO A PLANE WAVEFRONT OVER A SMALL APERTURE:



SOLID ANGLE: THE STERADIAN

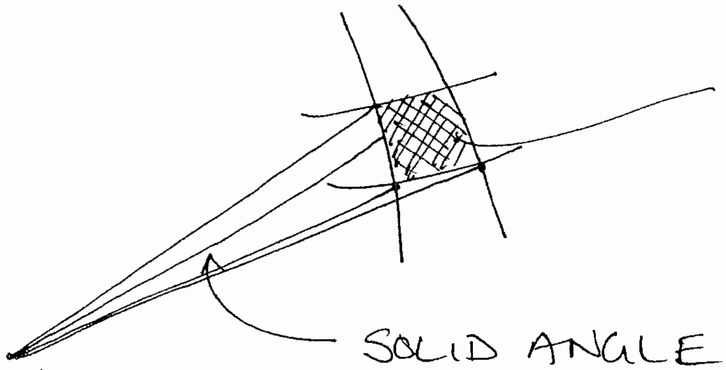
2D CASE, THE RADIAN:



THE ARC LENGTH $L = r\theta$, IF $L \equiv r$ THEN $\theta = 1$ RADIAN.

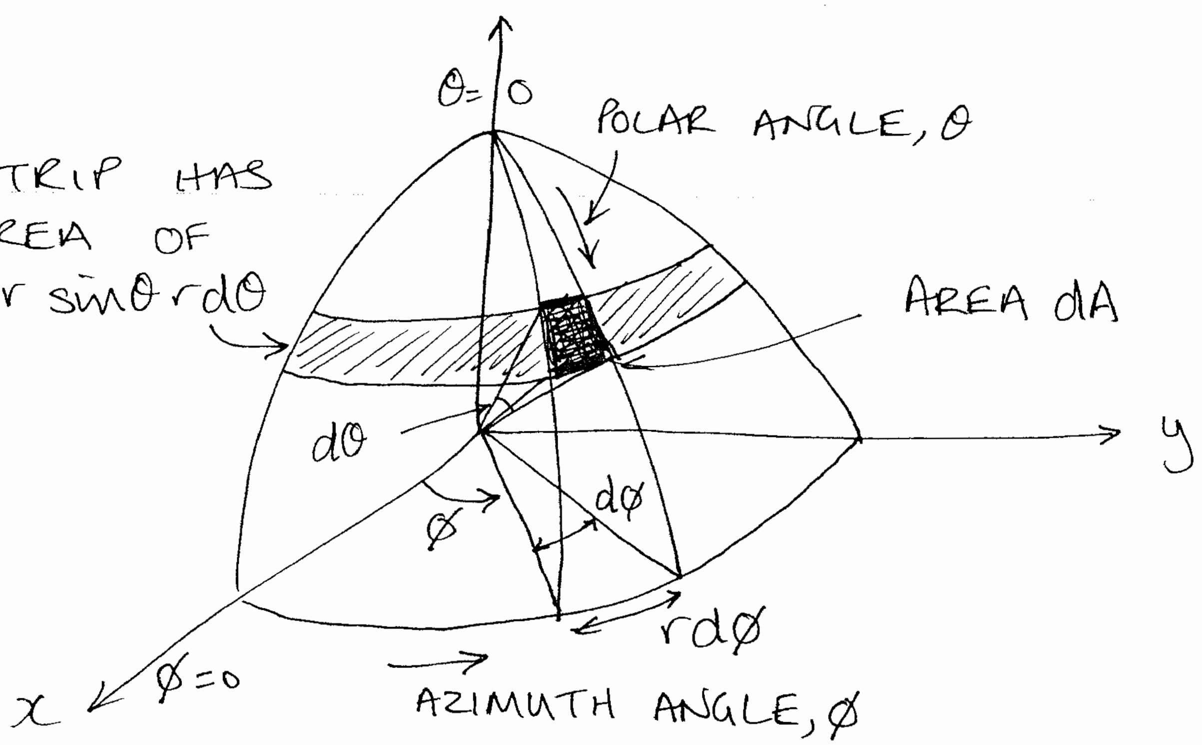
TOTAL ANGLE IN CIRCLE IS 2π RADS.
TOTAL ARC LENGTH IS $2\pi r$.

3D CASE: THE STERADIAN



AREA A ON THE SURFACE OF A SPHERE SUBTENDS A <u>SOLID ANGLE</u> Ω

IF THE AREA A, COVERS THE WHOLE SURFACE OF THE SPHERE, THE SOLID ANGLE SUBTENDED IS 4π STERADIANS (OR SQUARE RADIANS) (OFTEN DENOTED sr.)



FOR THE ELEMENTAL AREA dA
IT CAN BE SHOWN THAT

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

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

$$= \text{SOLID ANGLE}$$

INTEGRATING THE AREA OF THE STRIP OVER ALL $0 \leq \theta \leq \pi$ TO GIVE AREA OF SPHERE

$$\text{AREA OF SPHERE} = \int_0^{\pi} 2\pi r \sin\theta \, r \, d\theta$$

$$= -2\pi r^2 \cos\theta \Big|_0^{\pi}$$

$$= 4\pi r^2$$

HENCE, 4π sr. IS SOLID ANGLE IN A SPHERE

THE ISOTROPIC ANTENNA

AN ISOTROPIC RADIATOR HAS NO PREFERRED DIRECTION OF RADIATION

AN ISOTROPIC ANTENNA RADIATES UNIFORMLY IN ALL DIRECTIONS OVER A SPHERE CENTRED ON THE ANTENNA.

THE ISOTROPIC ANTENNA IS USED AS A REFERENCE WITH WHICH OTHER ANTENNAS ARE COMPARED.

IF THE POWER SUPPLIED TO AN ISOTROPIC RADIATOR IS P_T WATTS, THE POWER DENSITY AT A DISTANCE R FROM THE ISOTROPIC SOURCE IS;

$$\text{POWER DENSITY} = \frac{P_T}{4\pi R^2} \; W m^{-2}$$

(POWER PER UNIT AREA)

$4\pi R^2$ ← AREA OF SPHERE.

WE CANNOT CONSTRUCT AN ISOTROPIC RADIATOR IN PRACTICE. FOR E-M WAVES TO PROPAGATE, THE E-FIELD, H-FIELD AND PROPAGATION MUST FORM A MUTUALLY ORTHOGONAL SET. (THIS CAN SHOWN FROM THE WAVE EQ^N)

WE CANNOT ACHIEVE THIS FOR EACH POINT ON A SPHERE, THERE WILL BE A SINGULARITY SOMEWHERE

→ THIS IS THE HAIRY BALL PROBLEM

NOTE: AN OMNI-DIRECTIONAL ANTENNA IS NOT AN ISOTROPIC ANTENNA. THE TERM "OMNI-DIRECTIONAL" IS A MISNOMER

AN OMNI-DIRECTIONAL ANTENNA IS ONE THAT RADIATES UNIFORMLY IN EITHER AZIMUTH OR ELEVATION, BUT NOT BOTH SIMULTANEOUSLY.

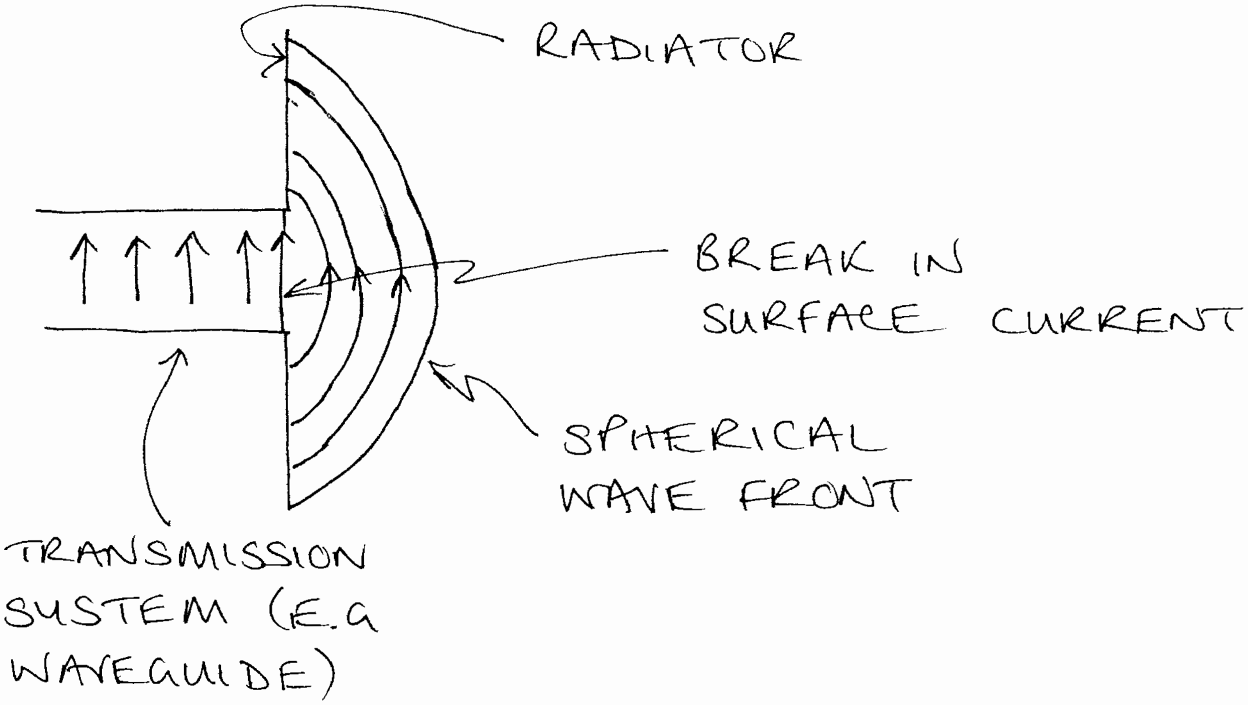
ANTENNA PROPERTIES

WE NEED TO DEFINE SOME PROPERTIES OF ANTENNAS TO PROCEED;

* RADIATION RESISTANCE
* BEAM AND FIELD PATTERNS
* BEAM AREA
* RADIATION INTENSITY
* DIRECTIVITY
* GAIN.
* POLARIZATION.

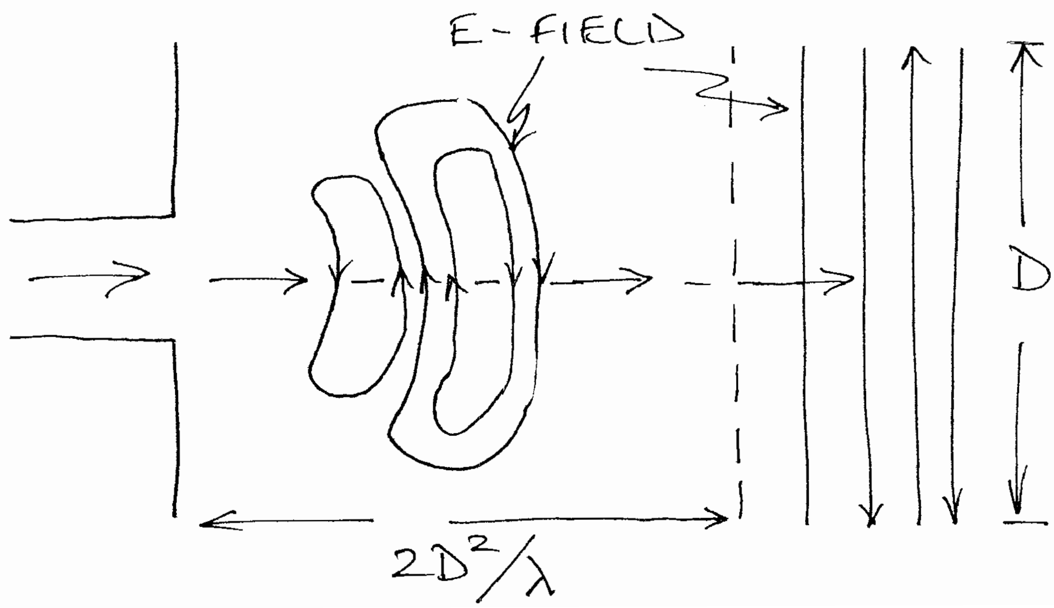
WE ALSO NEED TO MAKE THE DISTINCTION BETWEEN <u>NEAR</u> AND <u>FAR</u> FIELDS.

NEAR FIELD AND FAR FIELD REGIONS



DUE TO THE AMPLITUDE AND PHASE DISTRIBUTION OF THE FIELDS OVER THE APERTURE OF THE RADIATOR, THE FIELD COMPONENTS SEE A DIFFERENT DISCONTINUITY.

⇒ THE E-FIELD LINES FOR A SPHERICAL WAVE FRONT.



AS THE FIELDS ARE PROPAGATED AWAY FROM THE RADIATOR, THEY MAKE A TRANSITION BETWEEN THE FUNDAMENTAL MODE TO A HIGHER MODE IN WHICH THE E-FIELD FORMS CLOSED LOOPS.

THE E-FIELD IS TRANSVERSE AT THE CENTRE OF THE LOOPS, AND AT THE ENDS HAS A RADIAL COMPONENT

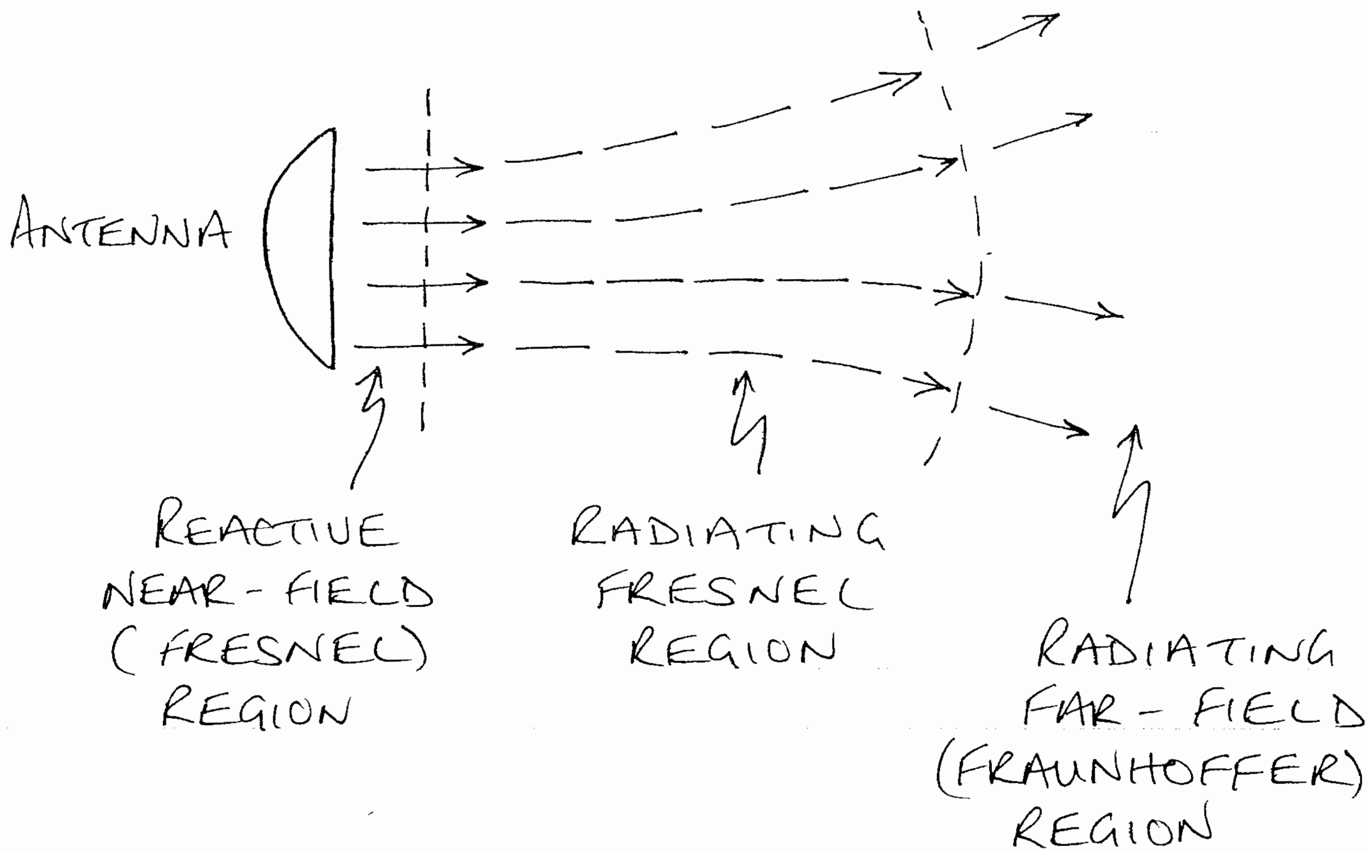
* THIS IS A CHARACTERISTIC OF BEING IN THE NEAR FIELD (OR FRESNEL) REGION.

THE RADIAL COMPONENTS ARE ATTENUATED VERY QUICKLY TO LEAVE A PURELY TRANSVERSE COMPONENT

* WHEN THIS HAS OCCURED WE ARE SAID TO BE IN THE FAR FIELD (OR FRAUNHOFFER) REGION

FOR ANTENNA PATTERN MEASUREMENTS THE TRANSITION BETWEEN NEAR AND FAR FIELDS IS ASSUMED TO TAKE PLACE WHEN THE WAVEFRONT VARIES FROM A PURE PLANE WAVE BY $\pm \lambda/16$ THIS GIVES RISE TO A DISTANCE OF ROUGHLY $2D^2/\lambda$

SCHEMATIC ILLUSTRATION OF THE THREE REGIONS SURROUNDING THE ANTENNA



* ANTENNA MEASUREMENTS CAN BE MADE IN THE NEAR OR FAR FIELD.

* FROM NEAR-FIELD MEASUREMENTS, THE FAR-FIELD CAN BE DEDUCED VIA FOURIER TECHNIQUES.

  E.G. BAe DEFENCE SYSTEMS FACILITY ON ISLE OF WIGHT

RADIATION RESISTANCE

THE ANTENNA APPEARS FROM THE TRANSMISSION LINE AS A 2-TERMINAL CIRCUIT ELEMENT.

THE ANTENNA HAS AN IMPEDANCE Z, WITH A RESISTIVE COMPONENT CALLED THE RADIATION RESISTANCE R_r. $Z = R_r + jX + R_L$

THE RADIATION RESISTANCE IS AN EFFECTIVE (NOT PHYSICAL) RESISTANCE COUPLED FROM THE ANTENNA AND ITS ENVIRONMENT.

CLOSELY RELATED TO THE RADIATION RESISTANCE IS THE ANTENNA TEMPERATURE, T_A.

THE REACTIVE COMPONENT OF THE ANTENNA IS USUALLY NULLIFIED BY A CONJUGATE MATCHING REACTANCE.

IDEALLY $R_r = Z_0$ OF DRIVING SOURCE, AND $X = 0$

BEAM AND FIELD PATTERNS

WE GENERALLY SPECIFY OUR ANTENNA FIELD PATTERNS IN A SYSTEM OF SPHERICAL POLAR COORDINATES.

TO COMPLETELY SPECIFY THE RADIATION PATTERN WITH RESPECT TO FIELD INTENSITY AND POLARIZATION REQUIRES THREE PATTERNS;

* $E_\theta(\theta, \phi)$ Vm^{-1}
* $E_\phi(\theta, \phi)$ Vm^{-1}
* PHASES OF THESE FIELDS $\delta_\theta(\theta, \phi), \delta_\phi(\theta, \phi)$

FIELD PATTERNS ARE USUALLY NORMALIZED E.G.

$$E_\theta(\theta, \phi)_n = \frac{E_\theta(\theta, \phi)}{E_\theta(\theta, \phi)|_{MAX}}$$

PATTERNS ARE ALSO SPECIFIED USING THE POYNTING VECTOR (POWER DENSITY)

$$P_n(\theta, \phi) = \frac{S(\theta, \phi)}{S(\theta, \phi)|_{max}} \qquad S(\theta, \phi) = \frac{[E_\theta^2 + E_\phi^2]}{Z_0}$$

$$Z_0 \simeq 120\pi \ \Omega$$

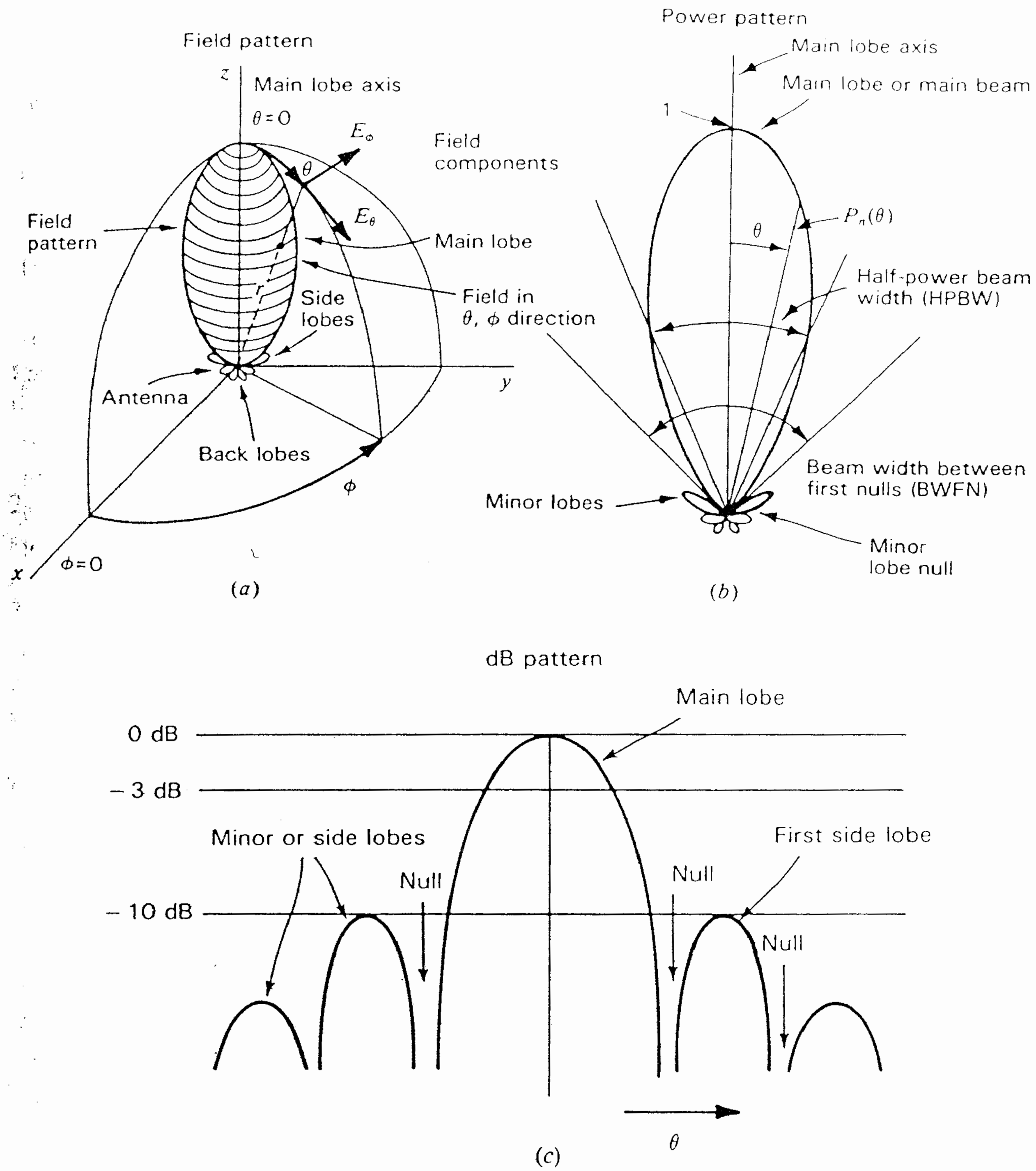


Figure 2-3 (*a*) Antenna field pattern with coordinate system. (*b*) Antenna power pattern in polar coordinates (linear scale). (*c*) Antenna pattern in rectangular coordinates and decibel (logarithmic) scale. Patterns (*b*) and (*c*) are the same.