ANTENNA PROPERTIES (CONT'D)

RADIATION INTENSITY

THE RADIATION INTENSITY IS THE POWER RADIATED FROM AN ANTENNA PER UNIT SOLID ANGLE. RADIATION INTENSITY IS DENOTED U, (WATTS PER STERADIAN)

WE CAN USE THE RADIATION INTENSITY TO SPECIFY THE NORMALIZED POWER PATTERN AS WE DID WITH THE POYNTING VECTOR LAST LECTURE.

$$P_n(\theta,\phi) = \frac{U(\theta,\phi)}{U(\theta,\phi)|_{MAX}} = \frac{S(\theta,\phi)}{S(\theta,\phi)|_{MAX}}.$$

THE ADVANTAGE OF USING RADIATION INTENSITY OVER THE POYNTING VECTOR IS THAT IT DOES NOT DEPEND ON DISTANCE. THE TWO ARE RELATED BY;

$$U = r^2 S$$

$W\ sr^{-1}$ $\qquad\qquad$ $W\ m^{-2}$

CONSIDER AN ISOTROPIC ANTENNA RADIATING A POWER P SPREAD OVER A SPHERE OF RADIUS r.

THE POWER DENSITY AT A DISTANCE r IN ANY DIRECTION IS;

$$S = \frac{P}{\text{AREA OF SPHERE}} = \frac{P}{4\pi r^2}$$

THE RADIATION INTENSITY IS:

$$U = r^2 S = \frac{P}{4\pi}$$

SOME COMMON PARAMETERS USED TO COMPARE RADIATION PATTERNS ARE DEFINED AS FOLLOWS;

* HALF - POWER - BEAMWIDTH (HPBW) OR "3dB BEAMWIDTH" OR JUST "BEAMWIDTH" - THE ANGLE SUBTENDED BY THE HALF-POWER POINTS OF THE MAIN LOBE

* FRONT-BACK RATIO: THE RATIO BETWEEN THE PEAK AMPLITUDES OF THE FRONT AND BACK LOBES, USUALLY EXPRESSED IN dB

* SIDELOBE LEVEL: THE AMPLITUDE OF THE LARGEST SIDELOBE USUALLY EXPRESSED IN dB RELATIVE TO THE PEAK OF THE MAIN LOBE.

BEAM SOLID ANGLE (OR BEAM AREA)

THE BEAM SOLID ANGLE IS THE INTEGRAL OF THE NORMALIZED POWER PATTERN OVER A SPHERE, HENCE

$$\Omega_A = \int_0^{2\pi}\int_0^{\pi} P_n(\theta,\phi)\, d\Omega \quad (\text{sr.})$$

$$d\Omega = \sin\theta \, d\theta \, d\phi .$$

THE BEAM SOLID ANGLE CAN BE APPROXIMATED BY;

IN RADIANS

$$\Omega_A = \theta_{HPBW}\,\phi_{HPBW} \quad (\text{sr.})$$

BEAM SOLID ANGLE IS USED TO DEFINE BEAM EFFICIENCY, ε_M

$$\Omega_A = \Omega_M + \Omega_m \qquad \varepsilon_M = \frac{\Omega_M}{\Omega_A}$$

TOTAL BEAM AREA

MAIN BEAM AREA

MINOR LOBE AREA

DIRECTIVITY

THE DIRECTIVITY OF AN ANTENNA AS A FUNCTION OF DIRECTION IS DEFINED AS;

$$D(\theta, \phi) = \frac{\text{RADIATION INTENSITY ALONG } (\theta, \phi)}{(\text{MEAN RADIATION INTENSITY IN ALL DIRECTIONS})}$$

$$= \frac{U(\theta, \phi)}{U_{AV.}} \quad [\text{DIMENSIONLESS}]$$

OR

$$D(\theta, \phi) = \frac{\text{RADIATION INTENSITY ALONG } (\theta, \phi)}{(\text{RADIATION INTENSITY OF AN ISOTROPIC ANTENNA RADIATING THE SAME TOTAL POWER})}$$

MORE OFTEN THAN NOT WE SPECIFY DIRECTIVITY WITHOUT SPECIFYING A DIRECTION IN WHICH CASE WE ARE REFERRING TO THE MAXIMUM VALUE,

DIRECTIVITY IS USUALLY SPECIFIED IN dB, SINCE THE REFERENCE IS AN ISOTROPIC ANTENNA THIS IS OFTEN DENOTED dBi

$$D \text{ (IN dBi)} = 10 \log_{10} D.$$

WE CAN ALSO SPECIFY THE DIRECTIVITY IN TERMS OF THE POYNTING VECTOR, S.

$$D(\theta,\phi) = \frac{S(\theta,\phi)}{S_{AV}} , \quad D_{MAX} = \frac{S(\theta,\phi)|_{MAX}}{S_{AV}}$$

THE AVERAGE POYNTING VECTOR OVER A SPHERE IS;

$$S_{AV} = \frac{1}{4\pi} \int_0^{2\pi}\int_0^{\pi} S(\theta,\phi)\, d\Omega \quad (Wm^{-2})$$

HENCE THE MAXIMUM DIRECTIVITY CAN BE WRITTEN AS;

$$D = \frac{S(\theta,\phi)|_{MAX}}{\frac{1}{4\pi}\iint S(\theta,\phi)\, d\Omega} = \frac{1}{\frac{1}{4\pi}\iint \frac{S(\theta,\phi)}{S(\theta,\phi)|_{MAX}}\, d\Omega}$$

$$= \frac{1}{\frac{1}{4\pi}\iint P_n(\theta,\phi)\, d\Omega}, \quad \text{SINCE } \Omega_A = \iint P_n(\theta,\phi)\, d\Omega ,$$

$$= \frac{4\pi}{\Omega_A}$$

THE SMALLER THE BEAM SOLID ANGLE THE GREATER THE DIRECTIVITY

EXAMPLES

1) FOR AN ISOTROPIC ANTENNA;

$$P_n(\theta, \phi) = 1, \quad \text{FOR ALL } \theta \text{ AND } \phi.$$

SO $\Omega_A = 4\pi$ HENCE $D = 1$

THIS IS THE SMALLEST DIRECTIVITY AN ANTENNA CAN HAVE, SO $\Omega_A \leq 4\pi$ AND $D \geq 1$.

2) $$D \cong \frac{4\pi}{\underbrace{\theta_{HPBW}\,\phi_{HPBW}}_{\text{RADIANS}}} \cong \frac{41{,}000}{\underbrace{\theta^{\circ}_{HPBW}\,\phi^{\circ}_{HPBW}}_{\text{DEGREES}}}$$

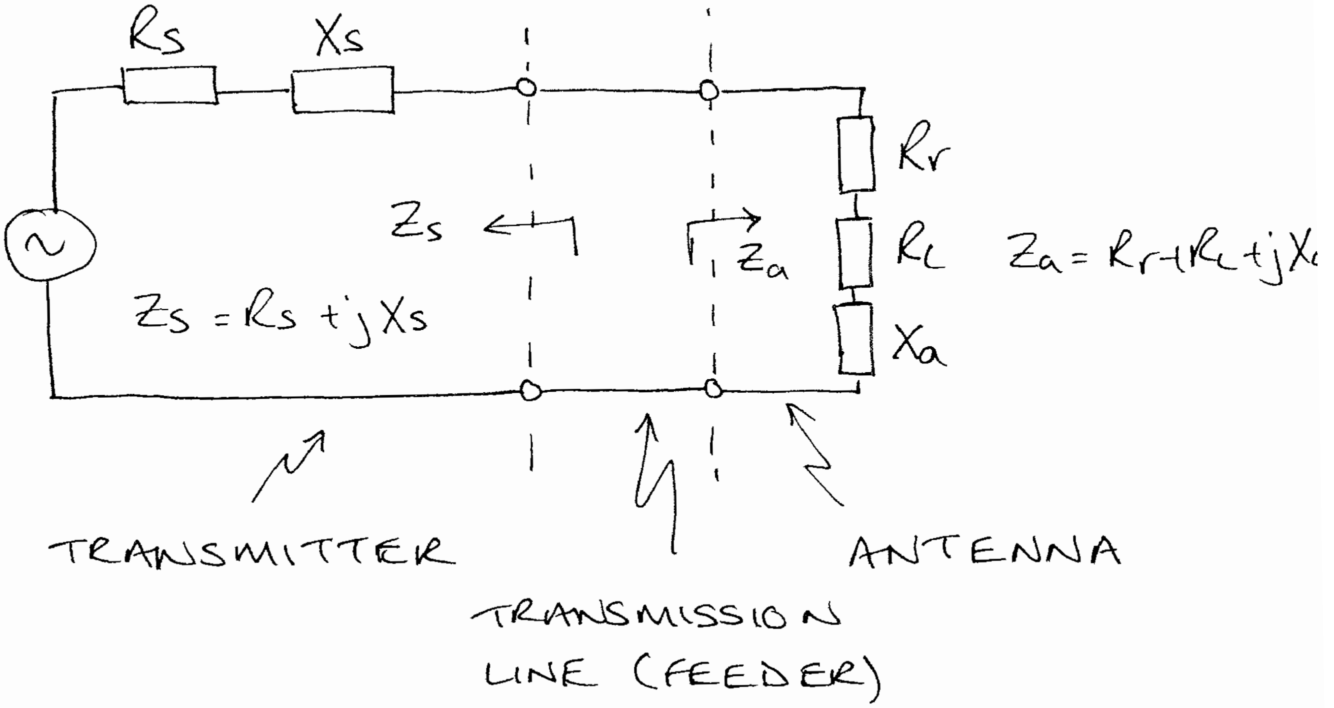
SO, IF $\theta^{\circ}_{HPBW} = \phi^{\circ}_{HPBW} = 1^{\circ}$

THEN $D \cong 41{,}000 \cong 46\,\text{dBi}$

THIS MEANS THAT THE ANTENNA RADIATES A POWER IN THE DIRECTION OF THE MAIN-LOBE 41,000 TIMES AS MUCH AS WOULD BE RADIATED BY AN NON-DIRECTIONAL (ISOTROPIC) ANTENNA FOR THE SAME INPUT POWER.

RADIATION RESISTANCE AND EFFICIENCY

THE EQUIVALENT CIRCUIT OF A TRANSMITTER AND ITS ASSOCIATED ANTENNA CAN BE DRAWN AS;



R_r - RADIATION RESISTANCE (NOT A PHYSICAL RESISTANCE) - POWER DISSIPATED IN R_r IS THE POWER ACTUALLY RADIATED BY THE ANTENNA.

R_L - LOSS RESISTANCE (PHYSICAL) - OHMIC LOSSES IN THE CONDUCTIVE ELEMENTS OF THE ANTENNA

X_a - REACTIVE COMPONENT IF $X_a = 0$ ANTENNA IS SAID TO BE <u>RESONANT</u>

IF $Z_s = Z_a^*$, ANTENNA AND Tx ARE <u>MATCHED</u>

BANDWIDTH

THE BANDWIDTH OF AN ANTENNA EXPRESSES ITS ABILITY TO OPERATE OVER A WIDE FREQUENCY RANGE.

BANDWIDTH IS OFTEN DEFINED AS THE FREQUENCY RANGE OVER WHICH THE POWER GAIN IS MAINTAINED TO WITHIN 3dB OF ITS MAXIMUM VALUE, OR THE RANGE OVER WHICH THE VSWR IS NO GREATER THAN 2:1, WHICHEVER IS SMALLER.

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

Γ - REFLECTION COEFFICIENT.

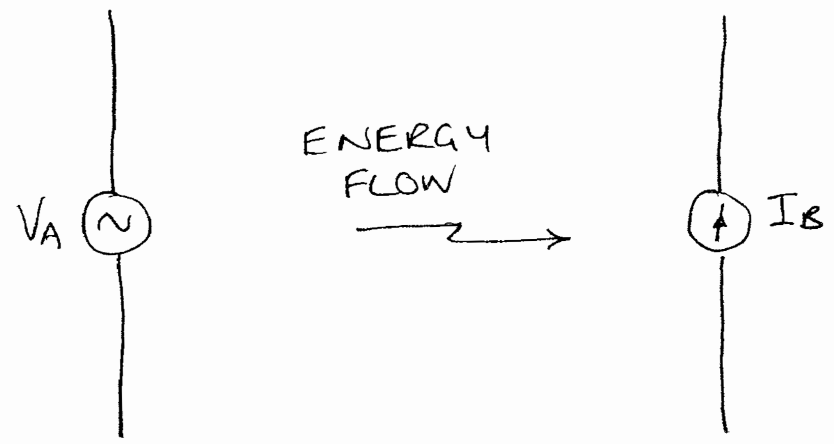
$$\Gamma = \frac{Z_a - Z_s}{Z_a + Z_s}$$

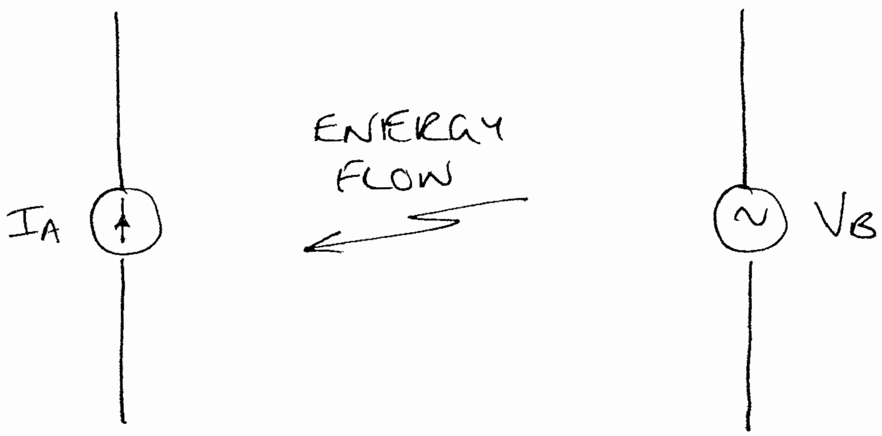
RECIPROCITY

THE RECIPROCITY THEOREM STATES:

IF A VOLTAGE IS APPLIED TO THE TERMINALS OF AN ANTENNA A AND THE CURRENT MEASURED AT THE TERMINALS OF ANOTHER ANTENNA B THEN AN EQUAL CURRENT WILL BE OBTAINED AT A IF THE SAME VOLTAGE IS APPLIED TO B

ANTENNA A ANTENNA B



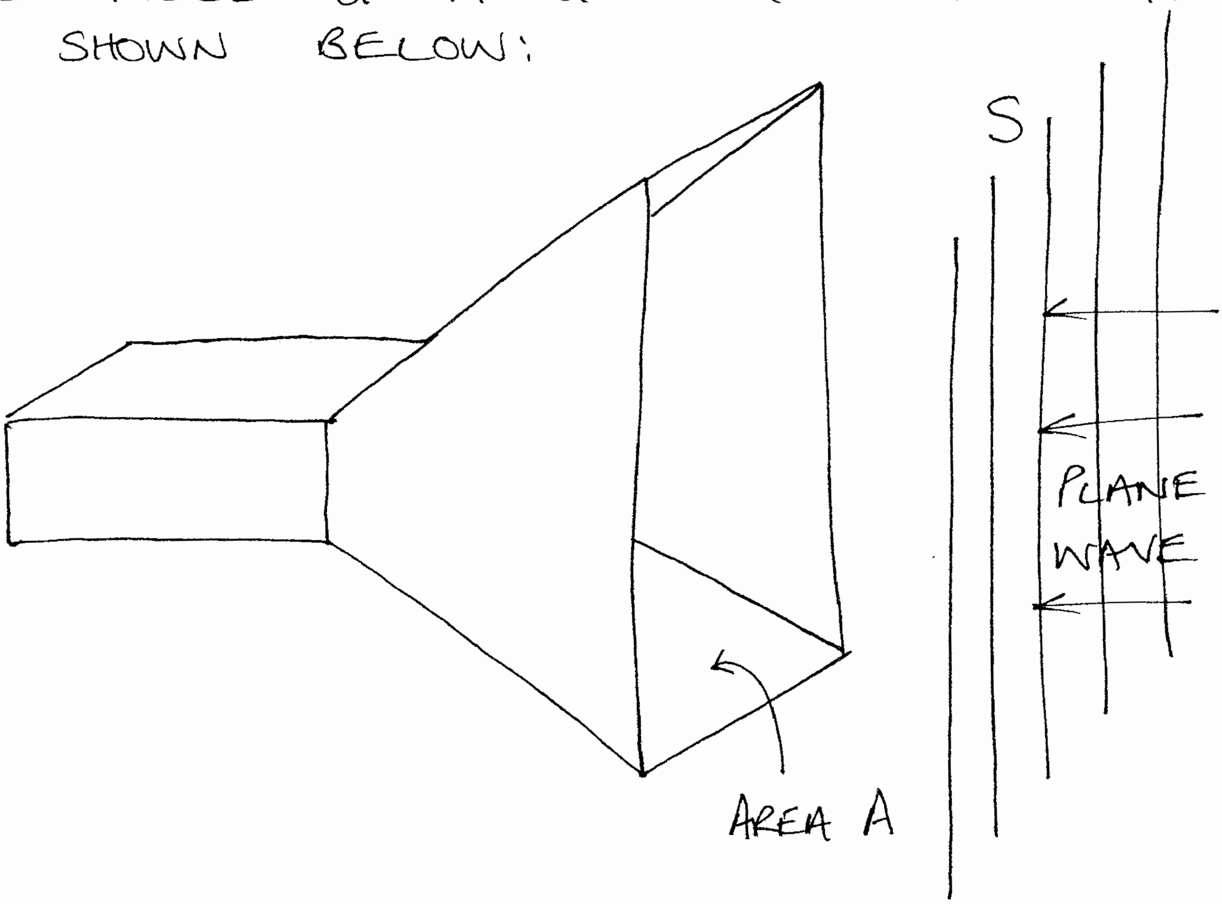


SO, RECIPROCITY STATES THAT IF $V_A = V_B$ THEN $I_A = I_B$, A CONSEQUENCE OF THIS THEOREM IS THAT THE ANTENNA GAIN MUST BE THE SAME WHETHER USED FOR RECEIVING OR TRANSMITTING. THIS MEANS THAT ALL OF THE GAIN AND PATTERN CHARACTERISTICS APPLY TO BOTH THE TRANSMITTING AND RECEIVING CASES.

ANTENNA APERTURE

THE CONCEPT OF ANTENNA APERTURE IS MOST SIMPLY INTRODUCED BY CONSIDERATION OF A RECEIVING ANTENNA.

SUPPOSE THAT OUR RECEIVING ANTENNA IS A HORN ANTENNA IMMERSED IN THE FIELD OF A UNIFORM PLANE WAVE AS SHOWN BELOW:



THE POWER DENSITY OF THE PLANE WAVE (THE POYNTING VECTOR) IS S ($W m^{-2}$) THE AREA OF THE MOUTH OF THE HORN IS A (m^2). IF THE HORN EXTRACTS ALL OF THE POWER FROM THE WAVE OVER THE WHOLE OF THE AREA A, THE POWER IS;

$$P = SA \quad (W)$$

THE HORN MAY BE REGARDED AS AN APERTURE, THE TOTAL POWER IT EXTRACTS FROM A WAVE IS PROPORTIONAL TO THE <u>APERTURE</u> OR AREA OF ITS MOUTH

ALTHOUGH THE CONCEPT OF ANTENNA APERTURE IS EASIEST TO VIZUALIZE FOR APERTURE-TYPE ANTENNAS, THE CONCEPT APPLIES TO ALL ANTENNAS

THERE ARE SEVERAL TYPES OF APERTURE USED IN THE DEFINITION OF ANTENNA SYSTEMS;

* EFFECTIVE APERTURE

* LOSS APERTURE

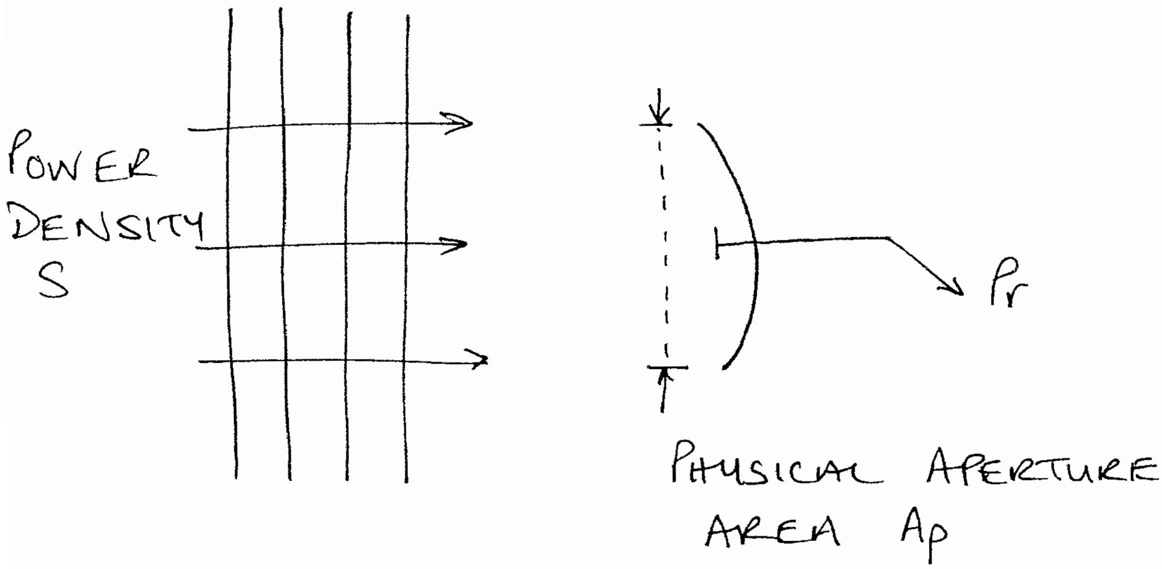
* COLLECTING APERTURE

* PHYSICAL APERTURE

* SCATTERING APERTURE

THE TWO MOST USEFUL APERTURES ARE THE EFFECTIVE AND PHYSICAL APERTURES. THEY ARE RELATED BY THE <u>APERTURE EFFICIENCY</u>

APERTURE EFFICIENCY



THE POWER EXTRACTED FROM THE PLANE WAVE INCIDENT UPON THE ANTENNA IS P_r.

$$P_r = A_e S$$

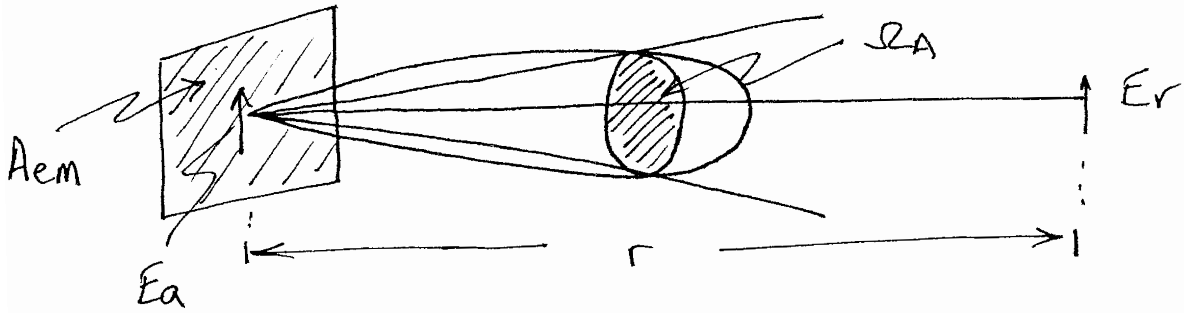
A_e IS THE <u>EFFECTIVE APERTURE</u>, (m^2) RELATING THE DENSITY OF THE INCIDENT WAVE TO THE EXTRACTED POWER.

THE RATIO OF THE EFFECTIVE APERTURE TO THE PHYSICAL APERTURE IS THE <u>APERTURE EFFICIENCY</u>, η_A

$$\eta_A = \frac{A_e}{A_p} \qquad \eta_A \leq 1$$

EFFECTIVE APERTURE AND DIRECTIVITY

CONSIDER THE DIAGRAM BELOW;



IF THE FIELD INTENSITY IN THE APERTURE IS CONSTANT AT E_a, THE RADIATED POWER IS

$$P = \frac{|E_a|^2}{Z} A_{em}$$

Z - IMPEDANCE OF THE MEDIUM

WE CAN ALSO WRITE

$$P = \frac{|E_r|^2}{Z} r^2 \Omega_A$$

AND

$$|E_r| = \frac{|E_a|}{r\lambda} A_{em}$$

HENCE WE FIND THAT;

$$\lambda^2 = A_{em}\,\Omega_A$$

A_{em} IS THE <u>MAXIMUM EFFECTIVE APERTURE</u>

IF THE ANTENNA IS LOSS-LESS, $A_e = A_{em}$

THE RATIO OF THE EFFECTIVE APERTURE TO THE MAXIMUM EFFECTIVE APERTURE DEFINES ANOTHER WAY OF CALCULATING THE <u>RADIATION EFFICIENCY</u>, k

$$k = \frac{A_e}{A_{em}} \quad \left[= \frac{R_r}{R_r + R_L} \right]$$

THIS IS NOT TO BE CONFUSED WITH THE <u>APERTURE EFFICIENCY</u> η_A

$$\eta_A = \frac{A_e}{A_p.} \quad \begin{matrix} \leftarrow \text{EFFECTIVE} \\ \leftarrow \text{PHYSICAL.} \end{matrix}$$

<u>EXAMPLE</u>

FOR A LOSSLESS ISOTROPIC ANTENNA, $A_e = A_{em}$ $(k=1)$ WE HAVE $\Omega_A = 4\pi$, SO WE CAN WRITE,

$$\underline{\lambda^2 = A_e 4\pi} \quad , \Rightarrow \quad A_e = \frac{\lambda^2}{4\pi}$$

SINCE $D = \frac{4\pi}{\Omega_A}$, AND $\lambda^2 = A_{em}\Omega_A$

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

HENCE WE CAN WRITE

$$G = kD = k \frac{4\pi A_{em}}{\lambda^2} = \frac{4\pi}{\lambda^2} A_p \eta_A$$

APERTURE EFFICIENCY

THE APERTURE EFFICIENCY OF AN ANTENNA IS A FUNCTION OF A NUMBER OF VARIABLES INCLUDING.

* SURFACE ERRORS (REFLECTOR SYSTEMS)
* FEED EFFICIENCY (BLOCKAGE, SPILLOVER)
* APERTURE BLOCKING
* FEED DISPLACEMENT (BEAM SQUINT, ASTIGMATISM)

TYPICAL VALUES FOR APERTURE EFFICIENCY ARE;

0.5 POOR

0.8 GOOD