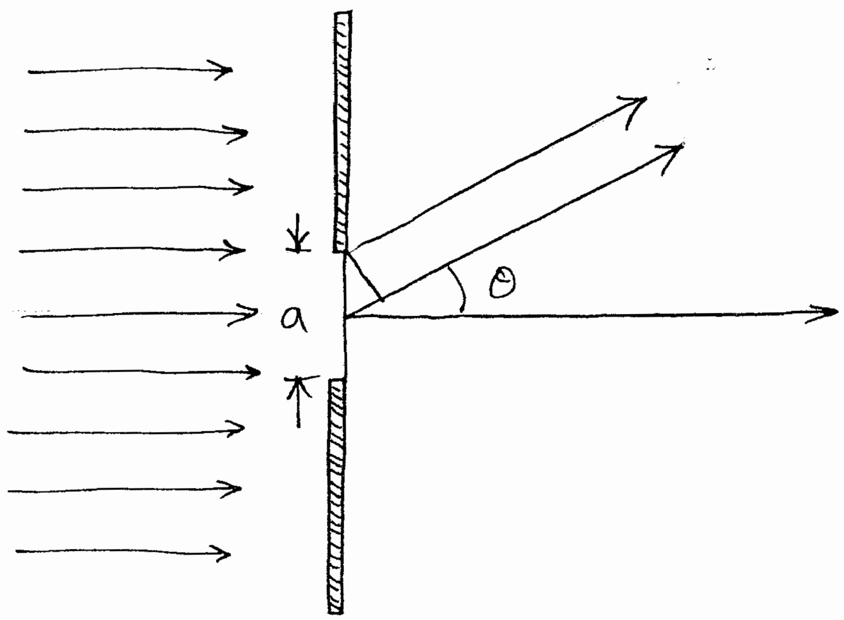
APERTURE DISTRIBUTIONS

SO FAR WE HAVE IMPLICITLY ASSUMED THAT THE E-FIELD DISTRIBUTION ACROSS THE APERTURE TO BE UNIFORM.

IN GENERAL WE WILL NOT HAVE A UNIFORM DISTRIBUTION IN PRACTICAL ANTENNA SYSTEMS - INDEED, THERE ARE GOOD REASONS WHY WE DON'T WANT TO HAVE A UNIFORM DISTRIBUTION.

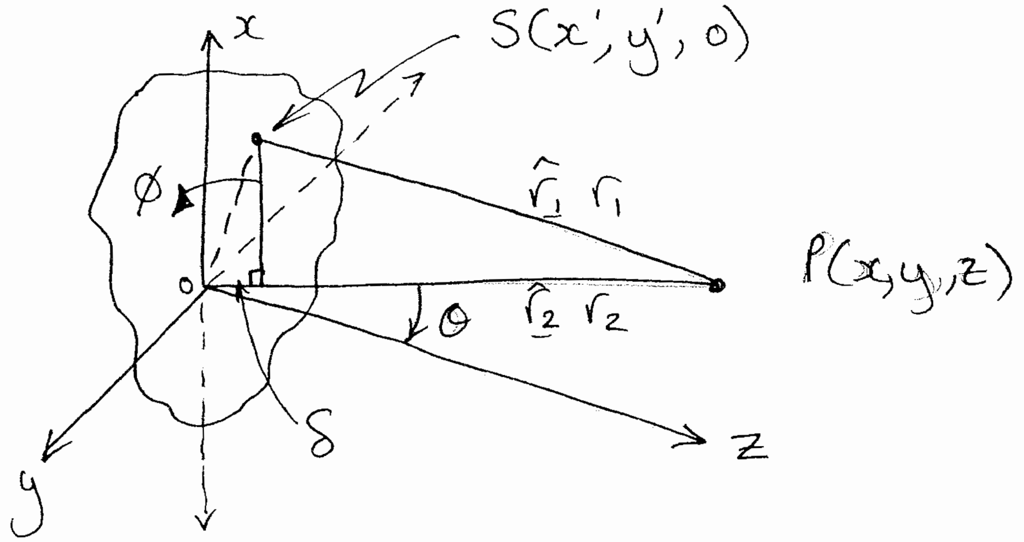
CONSIDER A SLIT OF WIDTH "a" ILLUMINATED BY A UNIFORM FIELD;

PLANE WAVE



WAVES SPREAD OUT FROM EVERY PART OF THE APERTURE, BUT COMPONENTS FROM DIFFERENT POINTS WILL IN GENERAL, ARRIVE AT A DISTANT RECEIVER WITH DIFFERENT PHASES

CONSIDER AN ABITRARY SHAPED APERTURE (IN THE x-y-PLANE)



S - POINT IN x-y-PLANE WITH COORDINATES IN PLANE (x', y')

IN THE FAR-FIELD REGION, SUCH THAT $\cos\theta \simeq 1$, AND RAYS EMERGING FROM THE ORIGIN AND ANY POINT WITHIN THE APERTURE MAY BE CONSIDERED AS BEING PARALLEL.

THE PHASE DIFFERENCE BETWEEN RAYS EMERGING FROM THE ORIGIN AND ANY POINT IN THE APERTURE CAN BE APPROXIMATED BY;

$$\delta = k \sin\theta \, (x' \cos\phi + y' \sin\phi)$$

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

δ - PATH LENGTH PHASE FACTOR

WE WILL NOW LOOK AT HOW WE CAN CALCULATE THE FAR-FIELD RADIATION PATTERN FROM THE APERTURE DISTRIBUTION.

SUPPOSE WE HAVE AN ARBITRARY SHAPED APERTURE AS BEFORE. WE CAN DEFINE THE AMPLITUDE AND PHASE OVER THE APERTURE AS;

$$F(x',y') = A(x',y')\exp[-j\psi(x',y')]$$

THE FAR-FIELD PATTERN CAN BE DETERMINED BY THE SUPERPOSITION OF THE CONTRIBUTIONS OF EACH POINT THROUGHOUT THE APERTURE (THIS IS HUYGENS' PRINCIPLE).

WE CAN APPLY THIS TECHNIQUE TO WIRE ANTENNAS AS WELL AS APERTURE ONES - JUST SWAP THE APERTURE DISTRIBUTION FOR THE CURRENT DISTRIBUTION.

WE CAN COMBINE THE CONTRIBUTIONS OF EACH POINT VIA THE SCALAR DIFFRACTION INTEGRAL, THE E FIELD CAN BE WRITTEN AS;

$$E_R \doteqdot \underbrace{\frac{j}{\lambda R}\exp[-jkR]}_{\text{DISTANCE RELATED TERM}} \underbrace{\int_{\text{APERTURE}} F(x',y')\exp(j\delta)\,dx'\,dy'}_{\text{INTEGRAL OVER APERTURE}}$$

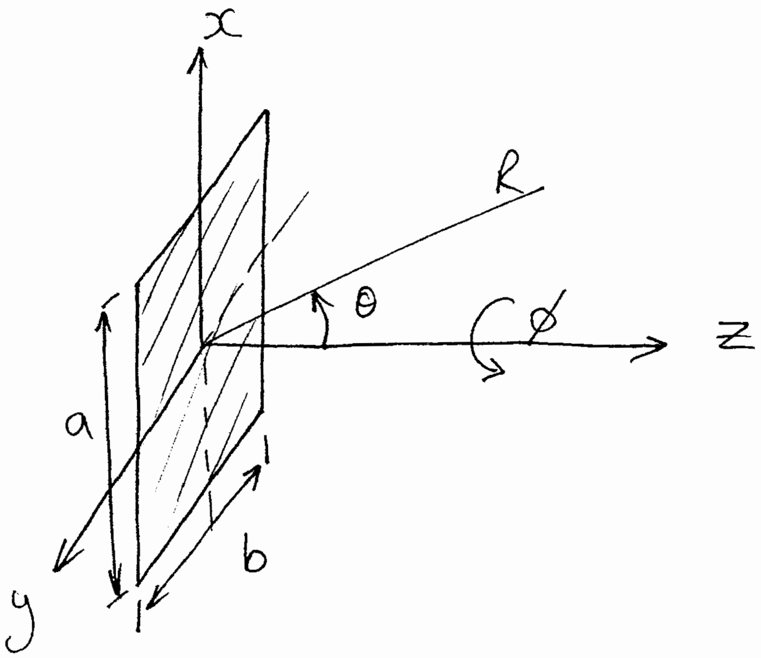
FOR A LOSSLESS ANTENNA, WE CAN WRITE THE E-FIELD AS

$$E_R \cong \frac{j}{\lambda R} \exp[-jkR] \; G(\theta, \phi)$$

WHERE $G(\theta,\phi)$ IS THE GAIN FUNCTION;

$$G(\theta,\phi) = \int_{\text{APERTURE}} F(x',y') \exp[jk\delta(x',y')] \, dx' \, dy'$$

EXAMPLE: UNIFORMLY DISTRIBUTED RECTANGULAR APERTURE



$$G(\theta,\phi) = \int_{-a/2}^{+a/2} \int_{-b/2}^{+b/2} F(x',y') \exp(jk\delta(x',y')) \, dx' \, dy'$$

So, IF WE ASSUME THAT OUR APERTURE IS UNIFORMLY DISTRIBUTED THE INTEGRAL BECOMES;

$$G(\theta, \phi) = \int_{-a/2}^{+a/2} \int_{-b/2}^{+b/2} \exp[jk \sin\theta (x' \cos\phi + y' \sin\phi)] \, dx' \, dy'$$

AS $F(x', y') \equiv 1$.

SOLVING THIS INTEGRAL YIELDS;

$$G_A(\theta, \phi) = A \left[\frac{\sin[(\pi a/\lambda) \sin\theta \cos\phi]}{(\pi a/\lambda) \sin\theta \cos\phi} \right] \times \left[\frac{\sin[(\pi b/\lambda) \sin\theta \sin\phi]}{(\pi b/\lambda) \sin\theta \cos\phi} \right]$$

WE CAN NOW EXAMINE THE GAIN IN θ FOR THE $x-z$ AND $y-z$ PLANES

FOR THE $x-z$ PLANE: $\phi = 0°$

$$G_A(\theta) = A \frac{\sin[(\pi a/\lambda) \sin\theta]}{[(\pi a/\lambda) \sin\theta]}$$

FOR THE $y-z$ PLANE: $\phi = 90°$

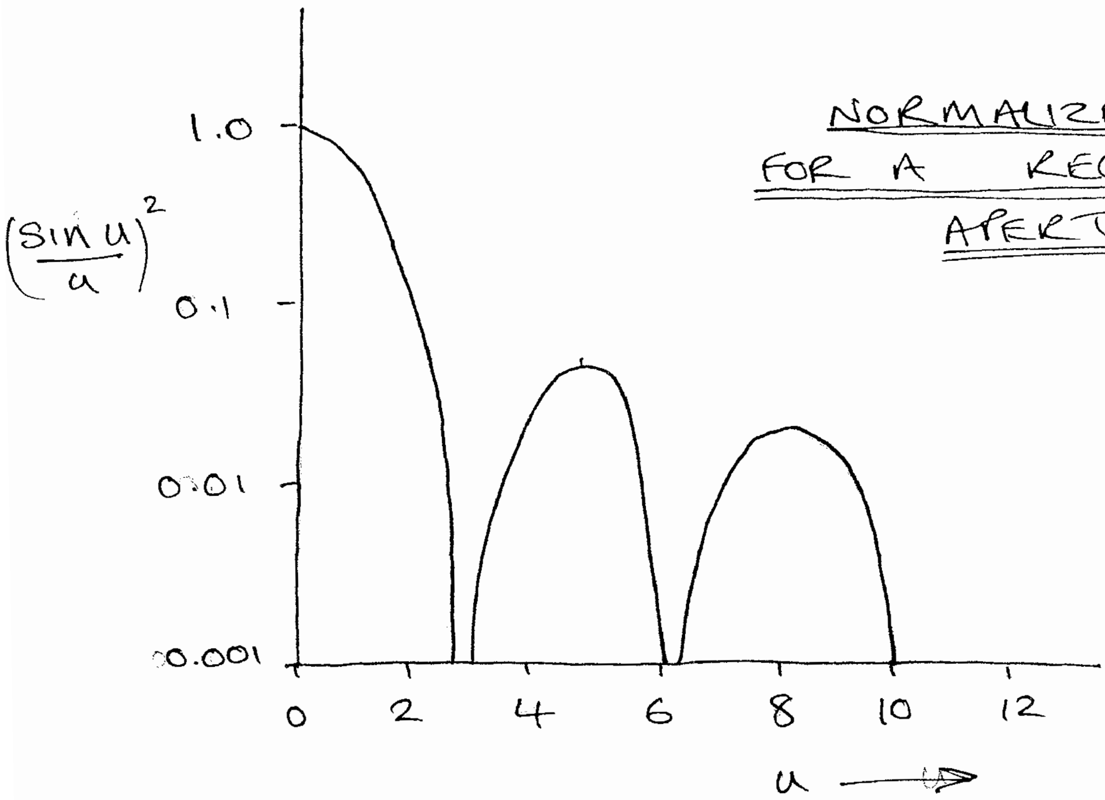
$$G_A(\theta) = A \frac{\sin[(\pi b/\lambda) \sin\theta]}{[(\pi b/\lambda) \sin\theta]}$$

WE CAN SEE THAT EACH PATTERN TAKES THE FORM OF A "sinc" FUNCTION AND CAN BE WRITTEN IN A NORMALIZED FORM:

$$G_A(\theta) = A\,\mathrm{sinc}(u) = A\,\frac{\sin(u)}{u}$$

WHERE

$$u = \begin{bmatrix} a \\ b \end{bmatrix} (\pi/\lambda) \sin\theta.$$



NORMALIZED PATTERN FOR A RECTANGULAR APERTURE

AS EXPECTED FOR THIS TYPE OF FUNCTION WE SEE A SERIES OF LOBES SEPARATED BY NULLS WHICH REACH DOWN TO ZERO.

FROM THE sinc^2 FUNCTION WE CAN DEDUCE THE FOLLOWING CHARACTERISTICS

* NULLS OCCUR AT $u_n = n\pi$ $n = \pm 1, \pm 2$ ETC.

* THE MAIN LOBE FULL WIDTH BETWEEN NULLS IS GIVEN BY:

  - FOR THE $x-z$ PLANE:

    $2 \arcsin(\lambda/a)$ WHICH FOR SMALL ANGLES $\simeq 2\lambda/a$ (RADIANS)

  - FOR THE $y-z$ PLANE:

    $2 \arcsin(\lambda/b)$ WHICH FOR SMALL ANGLES $\simeq 2\lambda/b$ (RADIANS)

* THE MAIN LOBE 3dB BEAMWIDTH (OCCURS AT $u = \pm 1.39$) IS GIVEN BY:

  - FOR THE $x-z$ PLANE:

    $$2 \arcsin(1.39\lambda/(\pi a)) = 0.88\,\lambda/a$$

  - FOR THE $y-z$ PLANE:

    $$2 \arcsin(1.39\lambda/(\pi b)) = 0.88\,\lambda/b$$

* THE BEAMWIDTH (HOWEVER WE CHOOSE TO DEFINE IT) IS PROPORTIONAL TO THE INVERSE OF THE APERTURE DIMENSION FOR SMALL ANGLES

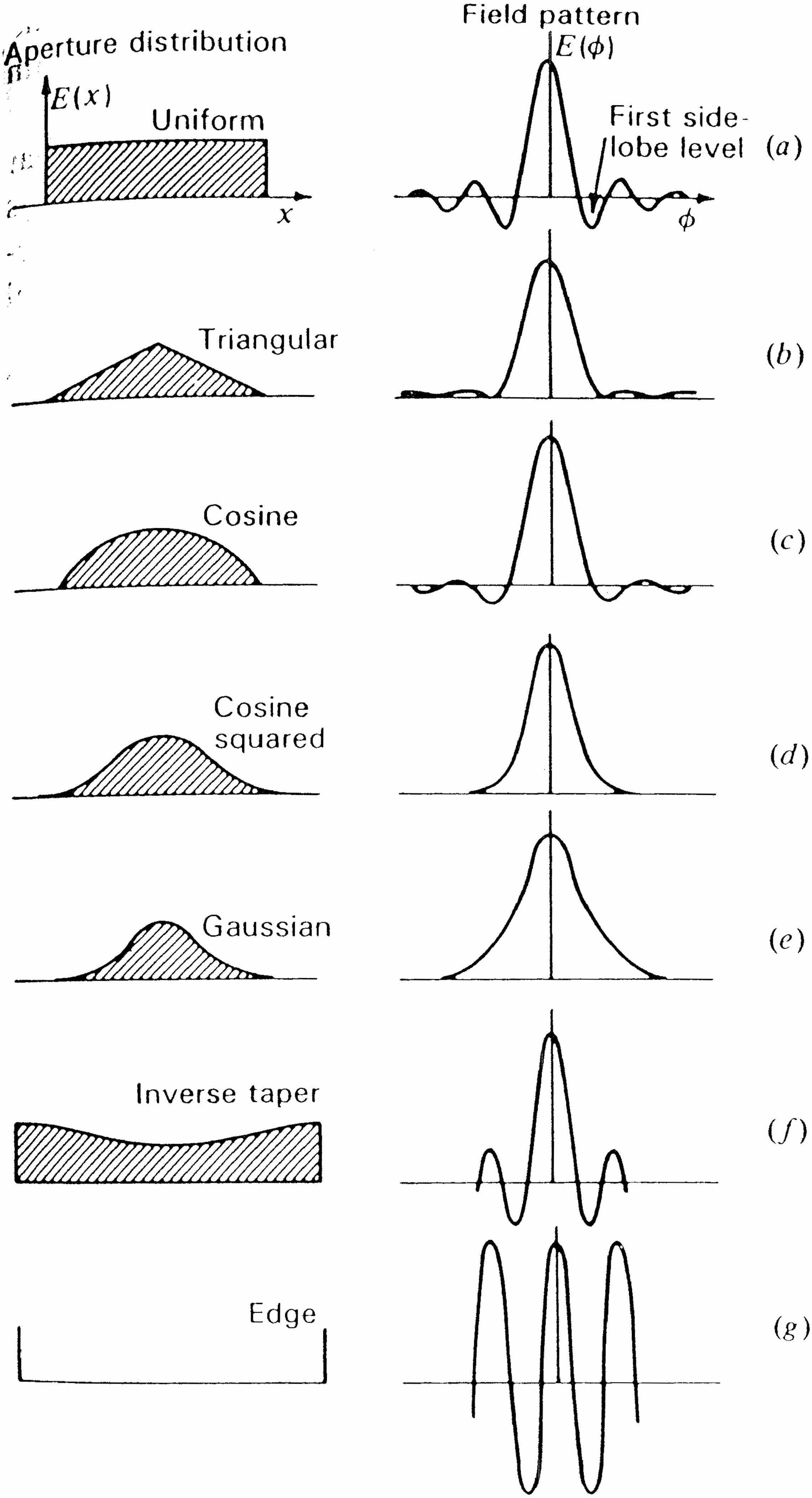
THE EFFECTS OF TAPERED ILLUMINATION

ALTHOUGH IT CAN BE SHOWN THAT A UNIFORM APERTURE ILLUMINATION SHOULD RESULT IN MAXIMUM GAIN, WE CANNOT REALIZE SUCH AN ILLUMINATION IN PRACTISE FOR A WHOLE APERTURE.

AS WE MENTIONED EARLIER THERE ARE GOOD REASONS WHY WE DO NOT DESIRE TO HAVE A UNIFOR APERTURE ILLUMINATION.

IN ORDER TO HAVE A UNIFORM APERTURE ILLUMINATION WE MUST FULFILL <u>BOUNDARY CONDITIONS</u> IMPOSED BY MAXWELL'S EQUATIONS. EXAMINATION OF THESE SHOWS THAT WE CANNOT FULFILL THE BOUNDARY CONDITIONS OVER THE ENTIRE APERTURE.

IN MOST IF NOT ALL APPLICATIONS WE DO NOT DESIRE A UNIFORM DISTRIBUTION. IF WE CONSIDER THE FAR-FIELD PATTERN, WE SEE IMMEDIATELY THE HIGH MAGNITUDE OF THE SIDELOBES. THE FIRST SIDELOBE IS LESS THAN 20dB DOWN ON THE MAIN LOBE. – THIS IS <u>MUCH TOO HIGH</u> FOR MOST TELECOMMS. AND RADAR APPLICATIONS


Aperture distribution
E(x)
Uniform
x
Field pattern
E(ϕ)
First side-
lobe level
ϕ
(a)
Triangular
(b)
Cosine
(c)
Cosine
squared
(d)
Gaussian
(e)
Inverse taper
(f)
Edge
(g)

PRACTICAL FIELD TAPERS

EXAMPLES OF MORE PRACTICAL FIELD DISTRIBUTIONS (OR TAPERS) FOR A CIRCULAR APERTURE ARE GIVEN IN "THE HANDBOOK OF ANTENNA DESIGN" (PUB. PETER PEREGRINUS 1982)

IF THE E-FIELD AT THE EDGE OF A CIRCULAR APERTURE IS GIVEN BY;

$$E \propto (1 - r^2)^p \quad \text{WHERE} \quad r = 2\rho/D$$

D - DIAMETER OF APERTURE
p - INTEGER ; 0, 1, 2, ETC

FROM THE FOURIER TRANSFORM RELATION WE CAN DEDUCE THE FOLLOWING PATTERN CHARACTERISTICS:

p	APERTURE EFFICIENCY η_A	3dB BEAMWIDTH (RADIANS)	FIRST SIDELOBE (dB)
0	1.0	$1.02\,\lambda/D$	-17.6
1	0.75	$1.27\,\lambda/D$	-24.6
2	0.56	$1.47\,\lambda/D$	-30.6

ACCEPTABLE COMPROMISE FOR MOST APPLICATIONS.

TYPES OF ANTENNA

HERE WE LIST SOME OF THE COMMON TYPES OF ANTENNA;

* WIRE ANTENNAS : THE WIRE NEED NOT BE STRAIGHT

* LOOP ANTENNAS : THE LOOP NEED NOT BE CIRCULAR. MORE THAN ONE LOOP CAN BE USED

* ROD ANTENNAS: THE DIAMETER OF THE ROD IS SIGNIFICANT. EXAMPLES ARE WHIPS AND DI-POLES

* APERTURE ANTENNAS: EXAMPLES ARE WAVEGUIDE HORNS

* SLOT ANTENNAS: HOLES IN WAVEGUIDES

* REFLECTOR ANTENNAS: USED IN COMBINATION WITH A "FEED" FORMED FROM ONE OF THE ABOVE

* HELICAL ANTENNAS: GENERATES CIRCULAR POLARIZATION.

* MICROSTRIP ANTENNAS: SMALL & CHEAP

* ARRAY ANTENNAS: ACTIVE & PASSIVE

Derivation of path difference phase factor δ

From the geometry on page 2

$$r_1 = \left[(x - x')^2 + (y - y')^2 + z^2\right]^{1/2} \quad — ①$$

if $z \gg |x - x'|, |y - y'|$ then we can expand r_1;

$$r_1 \simeq z + \frac{(x - x')^2}{2z} + \frac{(y - y')^2}{2z} + \ldots \quad — ②$$

From a s.p.c representation of r_2 we have;

$$\left.\begin{aligned} x &= r_2 \sin\theta \cos\phi \\ y &= r_2 \sin\theta \sin\phi \\ z &= r_2 \cos\theta \end{aligned}\right\} - ③$$

Subst. ③ into ② we obtain...

$$r_1 \simeq r_2 - (\sin\theta \cos\phi\, x' + \sin\theta \sin\phi\, y')$$
$$+ \frac{x'^2 + y'^2 - \left[(\sin\theta\cos\phi)x' - (\sin\theta\sin\phi)y'\right]^2}{2 r_2}$$
$$+ \text{ higher order terms}$$

$r_2 - r_1 \simeq \delta / k$, assuming $\cos\theta \simeq 1$, neglect high order terms; ($k = 2\pi/\lambda$)

$$\delta \simeq [x' \cos\phi \sin\theta + y' \sin\theta \sin\phi]\, k$$
$$\simeq k \sin\theta\, [x' \cos\phi + y' \sin\phi],$$