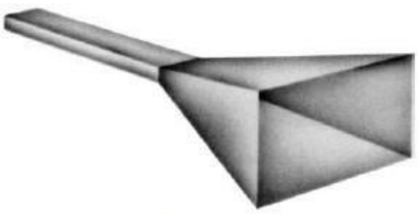
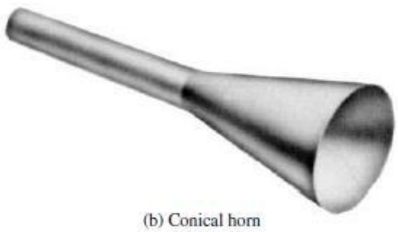
Aperture Antennas

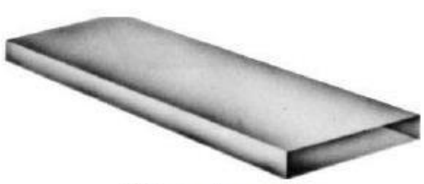
Antennas in aperture form are used very often. The antennas below are some examples of the aperture antennas:



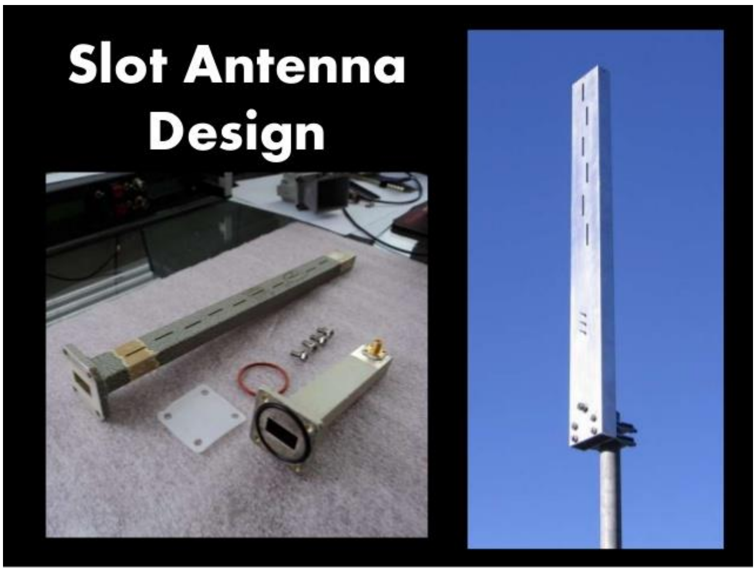
(a) Pyramidal horn



(b) Conical horn



(c) Rectangular waveguide



d) Slot Antenna

e) Paraboloidal Antenna

Apertures are generally large antennas $(>5\lambda)$ used at microwave frequencies to obtain narrow beams.

For current sources we know that we can obtain $I \rightarrow \bar{A} \rightarrow \bar{H} \rightarrow \bar{E}$

For apertures, the fields at the apertures are known.

"Field Equivalence Principles" are used to obtain equivalent currents from known aperture fields.

For these applications we define magnetic surface currents as well $(\bar{M})$ (magnetic surface currents do not exist in reality)

It can be shown that, if the field over a closed surface is known, equivalent currents are obtained by:

$\bar{J}_s = \hat{n} \times \bar{H}_1$ (Equivalent electric surface current)

$\bar{M}_s = -\hat{n} \times \bar{E}_1$(Equivalent magnetic surface current)

$\bar{H}_1, \bar{E}_1$ are tangential fields over the aperture surface

Define an electric vector potential similar to $\bar{A}$ in terms of the magnetic current:

$$\bar{F} = \frac{\varepsilon}{4\pi} \int \bar{M}_s \frac{e^{-jkr}}{r} ds$$

Then,

$$\bar{E} = \bar{E}_A + \bar{E}_F$$

$$\bar{H} = \bar{H}_A + \bar{H}_F$$

where,

$$\bar{E}_A = \frac{1}{j\omega\varepsilon} \nabla \times \bar{H}_A$$

$$\bar{H}_A = \frac{1}{\mu}\left(\nabla \times \bar{A}\right)$$

$$\bar{E}_F = -\frac{1}{\varepsilon}\left(\nabla \times \bar{F}\right)$$

$$\bar{H}_F = -\frac{1}{j\omega\mu}\left(\nabla \times \bar{E}_F\right)$$

So, $\bar{E}$ and $\bar{H}$ can be obtained.

The following steps are used:

Aperture fields $(\bar{E}_1, \bar{H}_1) \rightarrow (\bar{J}_s, \bar{M}_s) \rightarrow (\bar{A}, \bar{F}) \rightarrow (\bar{E}, \bar{H})$

Aperture Integration Method

If we can assume that we take a closed surface around an aperture antenna which contains the aperture antenna and over this closed surface field only exists on the aperture and is zero elsewhere, we can show that the far fields can be obtained as follows:

Assume that the aperture is in the xy-plane (i.e. z=0 plane). E-field is defined on this surface as $\bar{E}_a(x', y')$.

In the far field:

$$\bar{E}_\theta = jk\frac{e^{-jkr}}{2\pi r}[f_x \cos\phi + f_y \sin\phi]$$

$$\bar{E}_\phi = jk\frac{e^{-jkr}}{2\pi r}[f_y \cos\phi - f_x \sin\phi]$$

In the far field we have uniform plane wave.

For the above expressions:

$$f_T = (k_x, k_y) = \iint \bar{E}_a(x', y')e^{j(k_x x + k_y y)}dx'dy'$$

$$f_T = \hat{a}_x f_x(k_x, k_y) + \hat{a}_y f_y(k_x, k_y)$$

$$k_x = k\sin\theta\cos\phi \qquad k_y = k\sin\theta\sin\phi$$

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

Rectangular Apertures

Assuming that the aperture field $\bar{E}'_a$ has single polarization (aperture in the x-y plane $-\frac{a}{2} \le x \le \frac{a}{2}$, $-\frac{b}{2} \le y \le \frac{b}{2}$). Then,

$$f_T = f(\theta,\phi)$$

$$\bar{f}_T = f(\theta,\phi)\hat{a}_x \text{ or } \bar{f}_T = f(\theta,\phi)\hat{a}_y$$

So, if $\hat{a}_x \quad f \to f_x\,(f_y = 0)$ or if $\hat{a}_y \quad f \to f_y\,(f_x = 0)$

We also assume that $E'_a(x, y)$ is separable function, i.e.

$$E'_a = E_1(x')E_2(y')$$

Then,

$$f(\theta,\phi) = \int_{-\frac{a}{2}}^{\frac{a}{2}} E_1(x)e^{jkx\sin\theta\cos\phi}dx * \int_{-\frac{b}{2}}^{\frac{b}{2}} E_1(y)e^{jky\sin\theta\sin\phi}dy$$

We are interested in two main planes:

$$\phi = 0 \quad x - z\ plane$$

$$\phi = \frac{\pi}{2} \quad y - z\ plane$$

Take the $\phi = 0$ plane:

$$f(\theta) = \int_{-\frac{a}{2}}^{\frac{a}{2}} E_1(x')e^{jkx\sin\theta}dx' * \int_{-\frac{b}{2}}^{\frac{b}{2}} E_2(y')dy'$$

$\int_{-\frac{b}{2}}^{\frac{b}{2}} E_2(y')dy'$ constant with θ . $\int_{-\frac{b}{2}}^{\frac{b}{2}} dy' = b$

Assume $E_2(y') = 1$

$$f(\theta) = b\int_{-\frac{a}{2}}^{\frac{a}{2}} E_1(x')e^{jkx\sin\theta}dx'$$

Define $X' = \frac{2x'}{a}$ $\quad\quad U = \frac{\pi a}{\lambda}\sin\theta$

$$kx'\sin\theta = \frac{2\pi}{\lambda}x'\sin\theta = \left(\frac{2x'}{a}\right)\left(\frac{\pi a}{\lambda}\sin\theta\right) = X'U$$

$f(U) = \frac{ab}{2}\int_{-1}^{1} E_1(X')e^{jX'U}dX'$ where $dx' = \frac{a}{2}dX'$

Similarly for $\phi = \frac{\pi}{2}$ plane,

$$f(U) = \frac{ab}{2}\int_{-1}^{1} E_2(Y')e^{jY'V}$$

$Y' = \frac{2y'}{b}$ and $V = \frac{\pi b}{\lambda}\sin\theta$

The integral:

$$\int_{-c/2}^{c/2} e^{j\alpha z}dz = c\left[\frac{\sin\left(\frac{\alpha}{2}c\right)}{\frac{\alpha}{2}c}\right]$$