# Antenna \& Wave Propagation (EC0602) Unit-4 <br> B.Tech. (Electronics and Communication) Semester-VI 

Asst. Prof. Zalak Patel

## "Microstrip Patch Antenna"

## Microstrip Antenna - Basic Structure



Basic structure of a rectangular microstrip patch antenna ( $\varepsilon r=$ relative permittivity, $\delta=$ loss tangent, $\sigma=$ conductivity)

## Microstrip Antenna - Geometries



Square


Rectangle


Equilateral Triangle


Ellipse


Ring


Disk

## Microstrip Antenna - Performance features

## Pros

lightweight and have a small volume and a low-profile planar configuration.
conformal to the host surface.
ease of mass production using PCB technology leads to a low fabrication cost.
easier to integrate with other MICs on the same substrate.
both linear polarization and circular polarization are supported.
They can be made compact for use in personal mobile communication.
$\square$ They allow for dual- and triple-frequency operations.

## Cons

## Darrow Bandwidth.

$\square$ Lower gain.
Low power-handling capability.
$\square$ Excitation of surface waves.
$\square$ Poor isolation between feed \& radiating elements.
Polarization purity is difficult to achieve.

## Microstrip Antenna - Radiation Mechanism



## Microstrip Antenna - Principle Plane Radiation Pattern



# Microstrip Antenna- Feeding Techniques 

$\square_{\text {Co-axial feed }}$
$\square_{\text {Inset feed }}$
Aperture coupled feed
$\square$ Proximity coupled feed

## Basic feeding technique- Probe fed Patch Antenna



## Coaxial feed- Microstrip Antenna

## Feeding method:

$>$ inner conductor of co-axial cable is connected to radiating patch \& outer conductor is connected to ground plane.

## Advantages:

$>$ Simple
> Directly compatible with coaxial cables
$>$ Easy to obtain input match by adjusting feed position

## Disadvantages:

$>$ Significant probe (feed) radiation for thicker substrates
$>$ Significant probe inductance for thicker substrates (limits bandwidth)
$>$ Not easily compatible with arrays

## Inset fed Microstrip Antenna



## Disadvantages:

- Significant line radiation for thicker substrates
$>$ For deep notches, patch current and radiation pattern may show distortion


## Aperture Coupled fed Microstrip Antenna



Feeding method:
$>$ On bottom side of lower substrate, there is Microstrip feed line whose energy is coupled to the patch through a slot on ground plane separating two substrates.

## Advantages:

$>$ Allows for planar feeding
$>$ Feed-line radiation is isolated from patch radiation
$>$ double-resonance can be created
> Allows for use of different substrates to optimize antenna and feed-circuit performance

## Disadvantages:

$>$ Requires multilayer fabrication
$>$ Alignment is important for input match

## Proximity coupled fed Microstrip Antenna



Advantages:
$>$ Allows for planar feeding
$>$ Less line radiation compared to microstrip feed (the line is closer to the ground plane)

- Can allow for higher bandwidth (no probe inductance, so substrate can be thicker)
Length of feeding stub, $\mathrm{W} / \mathrm{L}$ ratio of patch is used to control the input match.
Disadvantages:
$>$ Requires multilayer fabrication
- Alignment is important for input match


## Microstrip Antenna - Design Parameters

## User Inputs

- Operating Frequency ( $\mathrm{f}_{\mathrm{r}}$ )
- Characteristic Impedance $\left(Z_{o}\right)$
- Substrate's dielectric constant $\left(\varepsilon_{r}\right)$ height (h), and loss tangent Physical Parameters
- Length of patch (L)
- Width of patch (W)
- Feed point location (x)
- Length \& width of substrate and ground plane.


## Radiation Parameters

- Radiation Resistance
- Effective dielectric constant, Phase Constant
- Input Impedance
- Beamwidth in H-Plane and in EPlane
- Bandwidth
- Directivity
- Gain
- Efficiency


## Microstrip Antenna- Resonance frequency

$$
\begin{aligned}
& \text { r---------- } \quad L_{e}=L+2 \Delta L \\
& W_{e}=W+2 \Delta W \\
& \Delta L \simeq \frac{h}{\sqrt{\epsilon_{e}}} \\
& f_{0}=\frac{c}{2 \sqrt{\epsilon_{e}}}\left[\left(\frac{m}{L}\right)^{2}+\left(\frac{n}{W}\right)^{2}\right]^{1 / 2}
\end{aligned}
$$

$>$ Where m and n shows half wave variation of field along length and width of patch respectively.
$>$ Fundamental mode is $\mathrm{TM}_{10}$ mode where $\mathrm{m}=1$ and $\mathrm{n}=0$.

## Microstrip Antenna- Design Procedure

1. Effective dielectric constant ( $\varepsilon_{\mathrm{e}}$ ):
$>$ Due to fringing fields extending from path to ground plane all round, effective dielectric constant is slightly lesser than the dielectric constant of the patch.

$$
\epsilon_{e}=\frac{\left(\epsilon_{r}+1\right)}{2}+\frac{\left(\epsilon_{r}-1\right)}{2}\left[1+\frac{10 h}{W}\right]^{-1 / 2}
$$

2. Length of the patch ( L ):
$>$ Physical length will be shorter than effective length of patch by 2 times the extended length due to fringing field on both sides of patch.

$$
\mathrm{L}=\mathrm{L}_{\mathrm{e}}-2 \Delta \mathrm{~L}
$$

$$
\mathrm{L}_{\mathrm{e}}=\frac{c}{2 f_{0} \sqrt{\epsilon_{e}}}
$$

$$
\Delta L \simeq \frac{h}{\sqrt{\epsilon_{e}}}
$$

## Microstrip Antenna- Design Procedure

3. Width of the patch (W):
$>$ As a starting point, width can be taken as

$$
W=\frac{c}{2 f_{0} \sqrt{\frac{\left(\epsilon_{r}+1\right)}{2}}}
$$

$>$ Larger values of width give larger gain and bandwidth improvement.
$>$ Smaller values of W lead to compact antenna.
4. Feed point location (x):
$>$ At $\mathrm{x}=\mathrm{L} / 2$, input impedance of patch antenna is maximum.
$>$ At $x=0$, input impedance of patch antenna is zero.
$>$ In between, where the input impedance of antenna is $50 \Omega$, practical co-axial cable (having $50 \Omega$ characteristic impedance) can be connected.

$$
Z_{i n}(x)=Z_{e} \sin ^{2}(\pi x / L)
$$

## Dual Feed Circularly Polarized Square Microstrip Antenna


$>$ It can be realized by exciting two orthogonal modes (TM10 \& TM01) with equal magnitude and in phase quadrature at the same resonant frequency.
$>$ Square patch with dual feed yields CP at same frequency.
$>$ Rectangular patch with dual feed yields dual polarization at two different frequencies.
$>$ Using two feeds at orthogonal position which are fed by $1 \angle 0^{\circ}$ and $1 \angle 90^{\circ}$ respectively.

Limitation: External 2-way power divider or Complex offset fed line or 3 dB branch coupler is required.

## Single feed Circularly Polarized Microstrip Antenna


(a) Diagonal fed nearly square. Square with (b) two stubs, (c) two notches, (d) two corners chopped, (e) square notches at two corners, and (f) diagonal slot.

## Single feed Circularly Polarized Microstrip Antenna

CP with single feed can be achieved using perturbation methods as follows:
(1) Diagonally feeding nearly square patch
(2) Modifying the shape of square patch across diagonal
$>$ This arrangement provides good bandwidth for impedance matching but limits the bandwidth for Axial ratio.



Resonance curvés of two orthogonal modes off Square Microstrip AntennaNarrow band \& Wide band

## Horn Antenna

## Introduction


(a) E-plane

(c) Pyramidal

(b) H-plane

(d) Conical

## E-Plane Sectoral Horn


(a) E-plane horn


## E-Plane Sectoral Horn

It can be shown that if the (1) fields of the feed waveguide are those of its dominant TE10 mode and (2) horn length is large compared to the aperture dimensions, the lowest order mode fields at the aperture of the horn are given by,

$$
\begin{gathered}
E_{z}^{\prime}=E_{x}^{\prime}=H_{y}^{\prime}=0 \\
E_{y}^{\prime}\left(x^{\prime}, y^{\prime}\right) \simeq E_{1} \cos \left(\frac{\pi}{a} x^{\prime}\right) e^{-j\left[k y^{\prime 2} /\left(2 \rho_{1}\right)\right]} \\
H_{z}^{\prime}\left(x^{\prime}, y^{\prime}\right) \simeq j E_{1}\left(\frac{\pi}{k a \eta}\right) \sin \left(\frac{\pi}{a} x^{\prime}\right) e^{-j\left[k y^{\prime 2} /\left(2 \rho_{1}\right)\right]} \\
H_{x}^{\prime}\left(x^{\prime}, y^{\prime}\right) \simeq-\frac{E_{1}}{\eta} \cos \left(\frac{\pi}{a} x^{\prime}\right) e^{-j\left[k y^{\prime 2} /\left(2 \rho_{1}\right)\right]} \\
\rho_{1}=\rho_{e} \cos \psi_{e}
\end{gathered}
$$

## E-Plane Sectoral Horn

- The primes are used to indicate the fields at the aperture of the horn. The expressions are similar to the fields of a TE10-mode for a rectangular waveguide with aperture dimensions of $a$ and $b 1(b 1>a)$. The only difference is the complex exponential term which is used here to represent the quadratic phase variations of the fields over the aperture of the horn.
- Let us assume that at the imaginary apex of the horn(shown dashed) there exists a line source radiating cylindrical waves. As the waves travel in the outward radial direction, the constant phase fronts are cylindrical.
- At any point $y$ at the aperture of the horn, the phase of the field will not be the same as that at the origin $(y=0)$. The phase is different because the wave has traveled different distances from the apex to the aperture.


## E-Plane Sectoral Horn

- The difference in path of travel, designated as $\delta(\mathrm{y})$, For any point $y^{\prime}$

$$
\begin{gathered}
{\left[\rho_{1}+\delta\left(y^{\prime}\right)\right]^{2}=\rho_{1}^{2}+\left(y^{\prime}\right)^{2}} \\
\delta\left(y^{\prime}\right)=-\rho_{1}+\left[\rho_{1}^{2}+\left(y^{\prime}\right)^{2}\right]^{1 / 2}=-\rho_{1}+\rho_{1}\left[1+\left(\frac{y^{\prime}}{\rho_{1}}\right)^{2}\right]^{1 / 2}
\end{gathered}
$$

- Using the binomial expansion and retaining only the first two terms of it

$$
\delta\left(y^{\prime}\right) \simeq-\rho_{1}+\rho_{1}\left[1+\frac{1}{2}\left(\frac{y^{\prime}}{\rho_{1}}\right)^{2}\right]=\frac{1}{2}\left(\frac{y^{\prime 2}}{\rho_{1}}\right)
$$

## H-PLANE SECTORAL HORN


(a) H-plane sectoral horn

(b) $H$-plane view

## PYRAMIDAL HORN



## CONICAL HORN

This horn is excited with a circular guide carrying a TE11 mode wave. The modes within the horn are found by introducing a spherical coordinate system and are in terms of spherical Bessel functions and Legendre polynomials.


## Corrugated Horn

- This horns can provide reduced edge diffraction, improved pattern symmetry and reduced cross-polarization. Corrugation on the horn walls acting as $\lambda / 4$ chokes are used to reduce E to very low values at all horn edges for all polarizations.

These prevent waves from diffracting around the edges of the horn. The dominant mode of this horn is hybrid $\mathrm{HE}_{11}$ mode which is a combination of TE11 and TM11. This horn is excited by a circular waveguide carrying a dominant TE11 mode.


Parabolic Reflector

## Introduction

- It has been shown by geometrical optics that if a beam of parallel rays is incident upon a parabolic reflector, the radiation will converge (focus) at a spot which is known as the focal point. In the same manner, if a point source is placed at the focal point, the rays reflected by a parabolic reflector will emerge as a parallel beam. This is one form of the principle of reciprocity, and it is demonstrated geometrically in Figure.
- The symmetrical point on the parabolic surface is known as the vertex. Rays that emerge in a parallel formation are usually said to be collimated.


## Continue



Front Feed: The transmitter (receiver) is placed at the focal point of the parabola, the configuration is usually known as front fed. The disadvantage of the front-fed arrangement is that the transmission line from the feed must usually be long enough to reach the transmitting or the receiving equipment, which is usually placed behind or below the reflector.

This may necessitate the use of long transmission lines whose losses may not be tolerable in many applications, especially in low-noise receiving systems.

Cassegrain Feed : The main(primary) reflector must be a parabola, the secondary reflector (sub reflector) a hyperbola, and the feed placed along the axis of the parabola usually at or near the vertex.

A parabolic reflector can take two different forms. One configuration is that of the parabolic right cylinder, shown in Figure, whose energy is collimated at a line that is parallel to the axis of the cylinder through the focal point of the reflector. The most widely used feed for this type of a reflector is a linear dipole, a linear array, or a slotted waveguide.


The other reflector configuration is that of Figure which is formed by rotating the parabola around its axis, and it is referred to as a paraboloid (parabola of revolution). A pyramidal or a conical horn has been widely utilized as a feed for this arrangement.

Reflector<br>(paraboloid)



## Parabola: General Properties



- choosing a plane perpendicular to the axis of the reflector through the focus, it follows that $O P+P Q=$ constant $=2 f$.

$$
\begin{gathered}
\mathrm{OP}=\mathrm{r} \\
\mathrm{PQ}=\mathrm{r} \cos \theta \\
\mathrm{r}(1+\cos \theta)=2 \mathrm{f} \\
r^{\prime}=\frac{2 f}{1+\cos \theta^{\prime}}=f \sec ^{2}\left(\frac{\theta^{\prime}}{2}\right) \quad \theta \leq \theta_{0}
\end{gathered}
$$

- Since a paraboloid is a parabola of revolution (about its axis), is also the equation of a paraboloid in terms of the spherical coordinates $r, \theta, \varphi$. Because of its rotational symmetry, there are no variations with respect to $\varphi$.

The above equ. can also be written in terms of the rectangular coordinates $x^{\prime}, y^{\prime}, z^{\prime}$.

$$
\begin{aligned}
& r^{\prime}+r^{\prime} \cos \theta^{\prime}=\sqrt{\left(x^{\prime}\right)^{2}+\left(y^{\prime}\right)^{2}+\left(z^{\prime}\right)^{2}}+z^{\prime}=2 f \\
& \left(x^{\prime}\right)^{2}+\left(y^{\prime}\right)^{2}=4 f\left(f-z^{\prime}\right) \quad \text { with }\left(x^{\prime}\right)^{2}+\left(y^{\prime}\right)^{2} \leq(d / 2)^{2}
\end{aligned}
$$

In the analysis of parabolic reflectors, it is desirable to find a unit vector that is normal to the local tangent at the surface reflection point.

$$
f-r^{\prime} \cos ^{2}\left(\frac{\theta^{\prime}}{2}\right)=S=0
$$

and then a gradient is taken to form a normal to the surface.

$$
\begin{aligned}
\mathbf{N} & =\nabla\left[f-r^{\prime} \cos ^{2}\left(\frac{\theta^{\prime}}{2}\right)\right]=\hat{\mathbf{a}}_{r}^{\prime} \frac{\partial S}{\partial r^{\prime}}+\hat{\mathbf{a}}_{\theta}^{\prime} \frac{1}{r^{\prime}} \frac{\partial S}{\partial \theta^{\prime}} \\
& =-\hat{\mathbf{a}}_{r}^{\prime} \cos ^{2}\left(\frac{\theta^{\prime}}{2}\right)+\hat{\mathbf{a}}_{\theta}^{\prime} \cos \left(\frac{\theta^{\prime}}{2}\right) \sin \left(\frac{\theta^{\prime}}{2}\right)
\end{aligned}
$$

A unit vector, normal to S ,

$$
\hat{\mathbf{n}}=\frac{\mathbf{N}}{|\mathbf{N}|}=-\hat{\mathbf{a}}_{r}^{\prime} \cos \left(\frac{\theta^{\prime}}{2}\right)+\hat{\mathbf{a}}_{\theta}^{\prime} \sin \left(\frac{\theta^{\prime}}{2}\right)
$$

To find the angle between the unit vector ${ }^{\text {n }}$ which is normal to the surface at the reflection point, and a vector directed from the focus to the reflection point

$$
\begin{aligned}
\cos \alpha=-\hat{\mathbf{a}}_{r}^{\prime} \cdot \hat{\mathbf{n}} & =-\hat{\mathbf{a}}_{r}^{\prime} \cdot\left[-\hat{\mathbf{a}}_{r}^{\prime} \cos \left(\frac{\theta^{\prime}}{2}\right)+\hat{\mathbf{a}}_{\theta}^{\prime} \sin \left(\frac{\theta^{\prime}}{2}\right)\right] \\
& =\cos \left(\frac{\theta^{\prime}}{2}\right)
\end{aligned}
$$

In a similar manner we can find the angle between the unit vector ${ }^{\wedge} n$ and the $z$-axis

$$
\cos \beta=-\hat{\mathbf{a}}_{z} \cdot \hat{\mathbf{n}}=-\hat{\mathbf{a}}_{z} \cdot\left[-\hat{\mathbf{a}}_{r}^{\prime} \cos \left(\frac{\theta^{\prime}}{2}\right)+\hat{\mathbf{a}}_{\theta}^{\prime} \sin \left(\frac{\theta^{\prime}}{2}\right)\right]
$$

$$
\begin{aligned}
\cos \beta & =-\left(\hat{\mathbf{a}}_{r}^{\prime} \cos \theta^{\prime}-\hat{\mathbf{a}}_{\theta}^{\prime} \sin \theta^{\prime}\right) \cdot\left[-\hat{\mathbf{a}}_{r}^{\prime} \cos \left(\frac{\theta^{\prime}}{2}\right)+\hat{\mathbf{a}}_{\theta}^{\prime} \sin \left(\frac{\theta^{\prime}}{2}\right)\right] \\
& =\cos \left(\frac{\theta^{\prime}}{2}\right)
\end{aligned}
$$

Now relating the subtended angle $\theta 0$ to the $\mathrm{f} / \mathrm{d}$ ratio

$$
\begin{gathered}
\theta_{0}=\tan ^{-1}\left(\frac{d / 2}{z_{0}}\right) \\
z_{0}=f-\frac{x_{0}^{2}+y_{0}^{2}}{4 f}=f-\frac{(d / 2)^{2}}{4 f}=f-\frac{d^{2}}{16 f}
\end{gathered}
$$

Realationship between half subtended angle \& f/d ratio

$$
\theta_{0}=\tan ^{-1}\left|\frac{\frac{d}{2}}{f-\frac{d^{2}}{16 f}}\right|=\tan ^{-1}\left|\frac{\frac{1}{2}\left(\frac{f}{d}\right)}{\left(\frac{f}{d}\right)^{2}-\frac{1}{16}}\right|
$$

