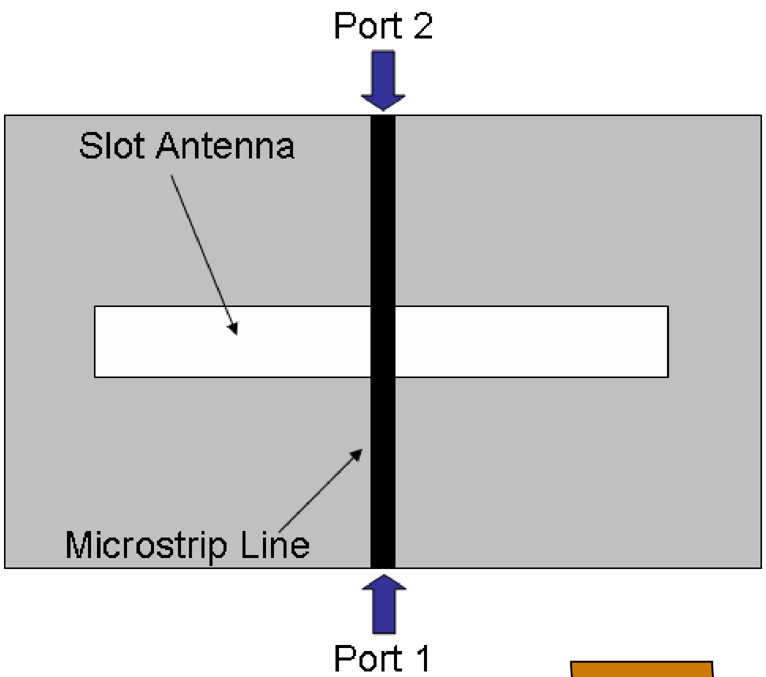
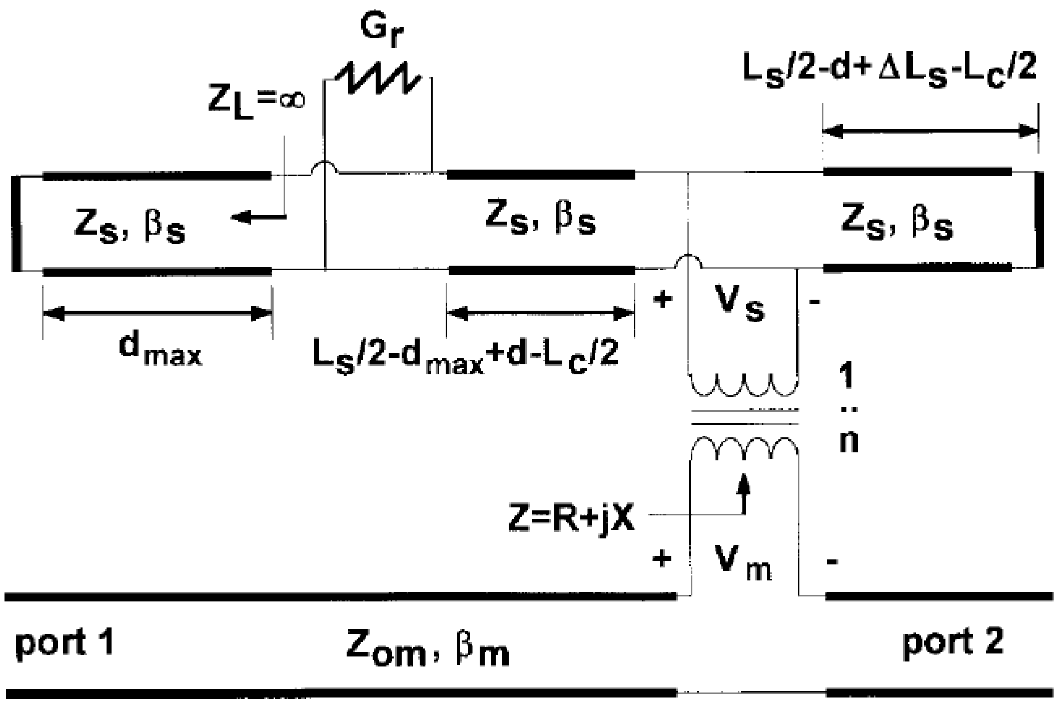
Spring 2019

EECE 588
Lecture 21

Prof. Wonbin Hong

Equivalent Circuit Model of A Microstrip-Fed Slot Antenna





Design of Microstrip-Fed Slot Antennas

- In designing microstrip-fed slot antennas, with rectangular apertures, usually the following information is known:
  - The type of the substrate including its dielectric constant and thickness.
  - The characteristic impedance of feeding microstrip line.
- Therefore, the parameters that need to be determined are:
  - The length and width of the aperture (slot).
  - Location of the microstrip line in relation to the slot antenna (L_s).
  - The length of the open circuited microstrip line, L_m.
- Unlike patch or dipole antennas, there are not many formulas or design curves available for designing slot antennas and some of available formulas are too complex.

Design of Microstrip-Fed Slot Antennas

- We start by choosing the aperture width, w. We have a lot of flexibility in choosing this parameter. The width of the aperture mostly affects the antenna Q (its bandwidth).
- As w increases, so does the antenna BW and vice versa.
- Next step, we have to determine the aperture length, ℓ. The aperture length is approximately $\lambda_s/2$, where λ_s is the slot wavelength.
- λ_s, depends on a number of parameters such as the slot width as well as the thickness and dielectric constant of the substrate on which the slot is fabricated.
- The following formulas can be used to determine the slot line wavelength.

Design of Microstrip-Fed Slot Antennas

- These two formulas can be used to determine the resonant length of the slot antenna.
- Be careful about the range of validity of the following formulas.

$$\lambda_s/\lambda_0 = 1.045 - 0.365\ln\varepsilon_r + \frac{6.3(w/h)\,\varepsilon_r^{0.945}}{238.64+100w/h} - \left[0.148 - \frac{8.81(\varepsilon_r+0.95)}{100\varepsilon_r}\right]\cdot\ln\left(h/\lambda_0\right)$$

$$2.22 \le \varepsilon_r \le 3.8$$

$$0.0015 \le w/\lambda_0 \le 0.075$$

$$\lambda_s/\lambda_0 = 0.9217 - 0.277\ln\varepsilon_r + 0.0322(w/h)\left[\frac{\varepsilon_r}{w/h+0.435}\right]^{1/2} - 0.01\ln\left(h/\lambda_0\right)\left[4.6 - \frac{3.65}{\varepsilon_r^2\sqrt{w/\lambda_0}\,(9.06-100w/\lambda_0)}\right]$$

$$3.8 \le \varepsilon_r \le 9.8$$

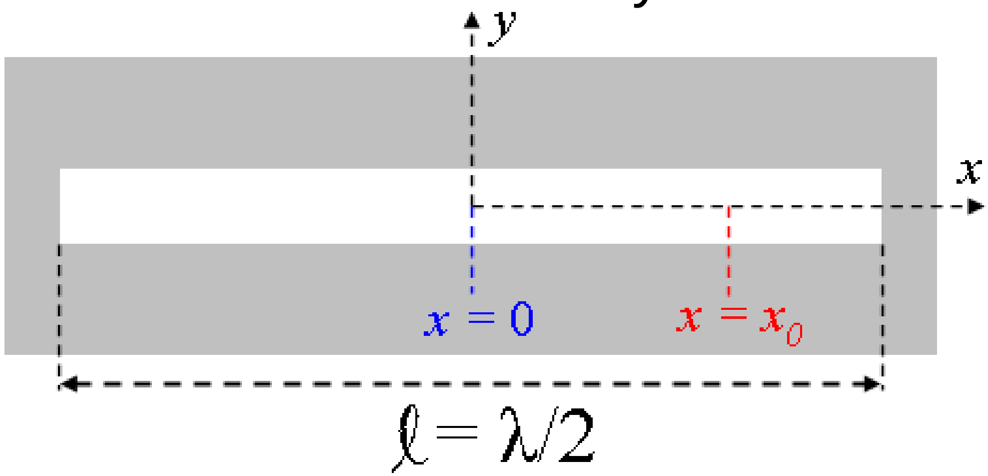
$$0.0015 \le w/\lambda_0 \le 0.075$$

Design of Microstrip-Fed Slot Antennas

- Next step is to determine the width of the microstrip line. Knowing the parameters of the substrate and the desired impedance of the feed, you can determine the width of the microstrip line using the formulas provided in many Microwave Circuit handbooks.
- The location of the microstrip feed must then be determined. Approximate location of the feed can be obtained by:

$$R_{in}(x = x_0) =$$

$$R_{in}(x = 0)\cos^2\left(\frac{\pi}{\ell}x_0\right)$$

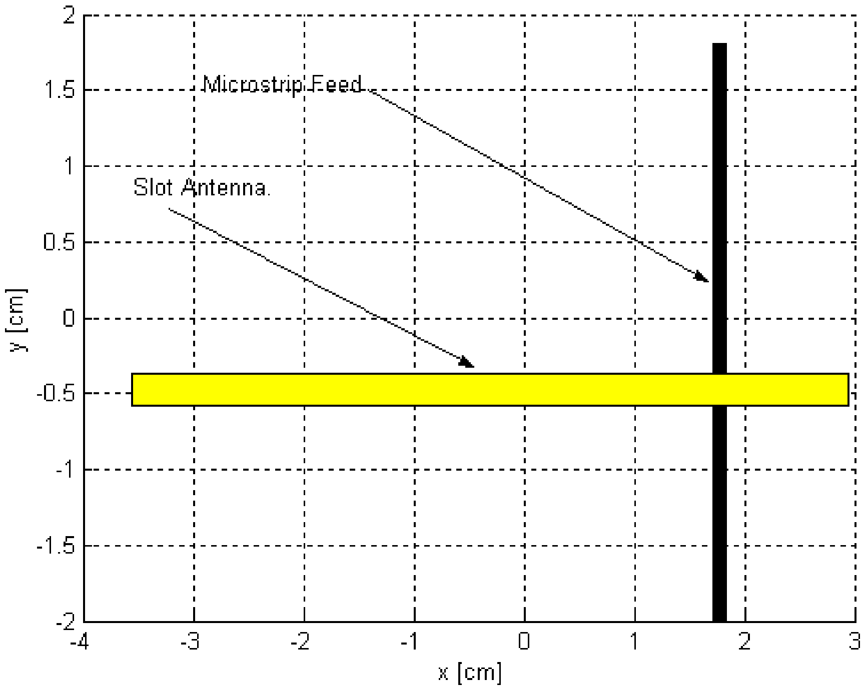


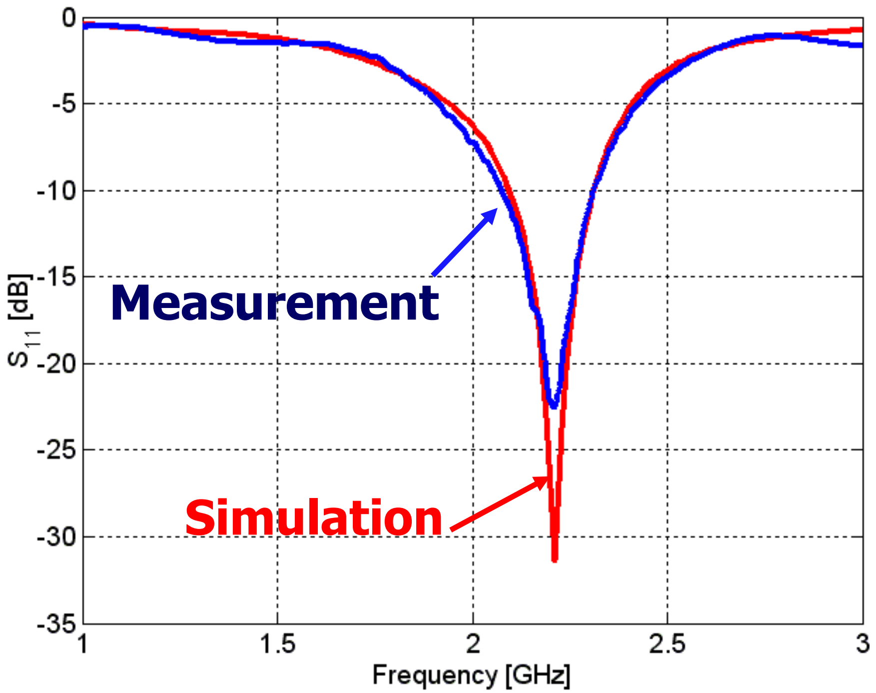
POSTECH

Design of Microstrip-Fed Slot Antennas

- The input impedance (resistance at resonance) at x=0 can be obtained using Full Wave simulations or the rather complex formulas available in:
  - J. P. Kim and W. S. Park, “Network Modeling of an Inclined and Off-Center Microstrip-Fed Slot Antenna”, IEEE Trans. Antennas Prop., Vol. 46, No. 8, pp. 1182-1187, August 1998.
- The last and final step in the design is to choose the length of the open circuited stub, L_m. A good starting point is to choose it to be equal to $L_m=\lambda_m/4$, where λ_m is the guided wavelength in the microstrip line.
- In designing microstrip-fed slot antennas, the designer has a lot of flexibility in choosing the combination of L_s and L_m values to achieve the desired input impedance.

Microstrip-Fed Slot Antennas



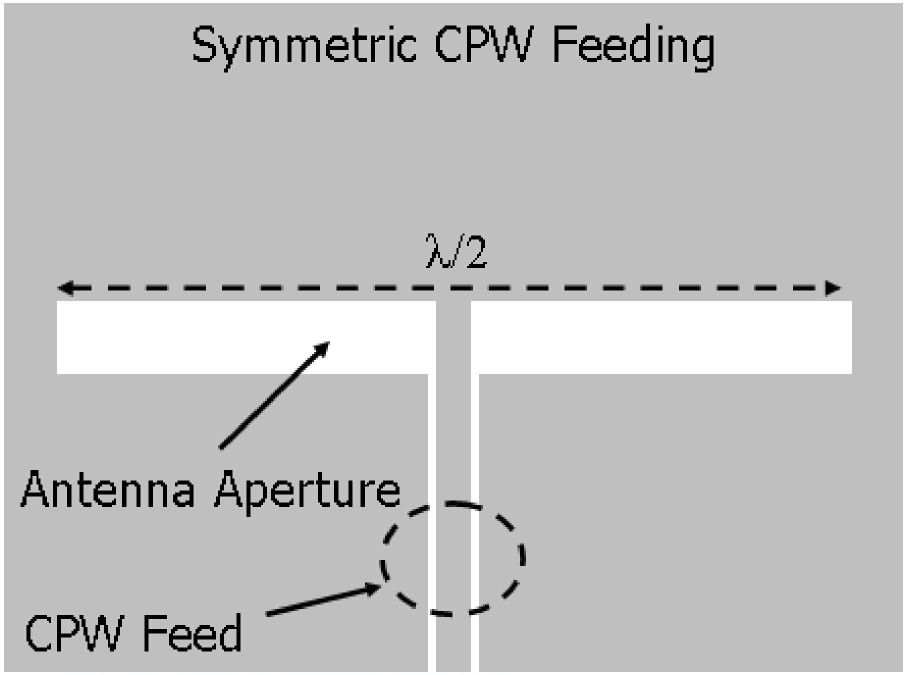


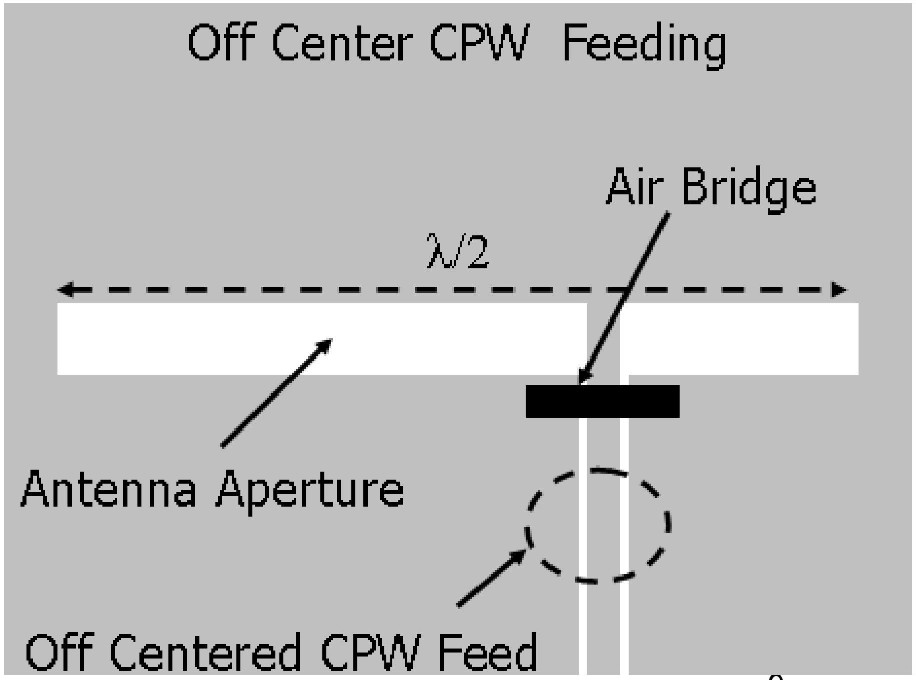
Measurement and simulation results of a microstrip-fed slot antenna. The antenna is fabricated on a substrate with dielectric constant of 3.4 and thickness of 0.5 mm. The slot antenna dimensions are shown on the figure.

POSTECH

CPW-Fed Slot Antennas

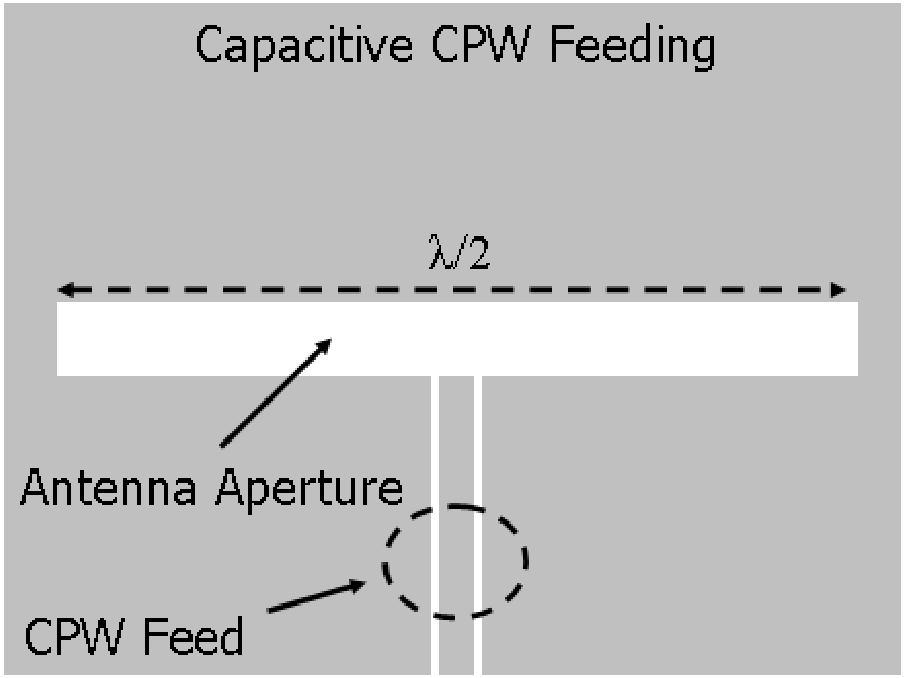
- CPW feeding of slot antennas is attractive because the resulting structure is a uniplanar antenna (i.e., the antenna, feed, and other circuit components are all on the same layer)
- Therefore, the fabrication is much easier.

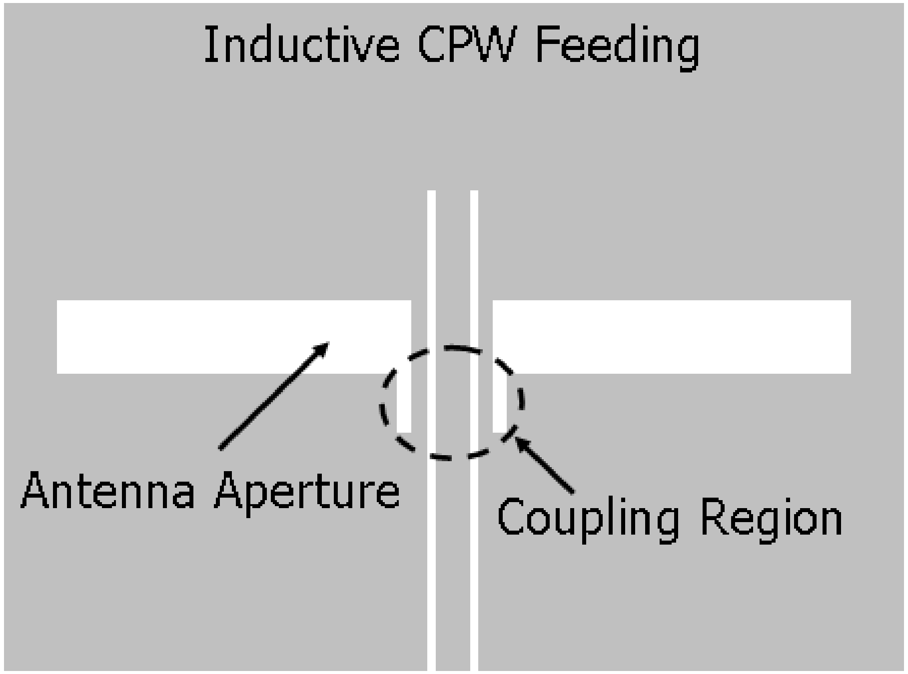




CPW-Fed Slot Antennas

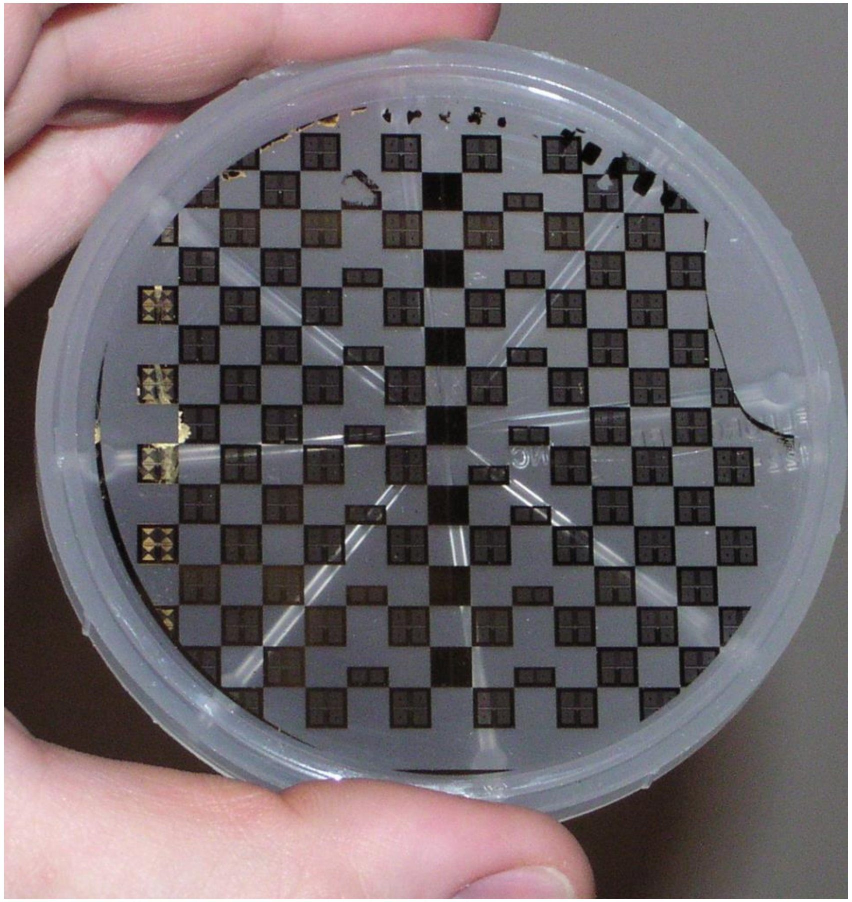
- The inductive feeding is particularly useful for feeding slot antenna arrays in series. The CPW can be extended to feed another antenna on the same layer.

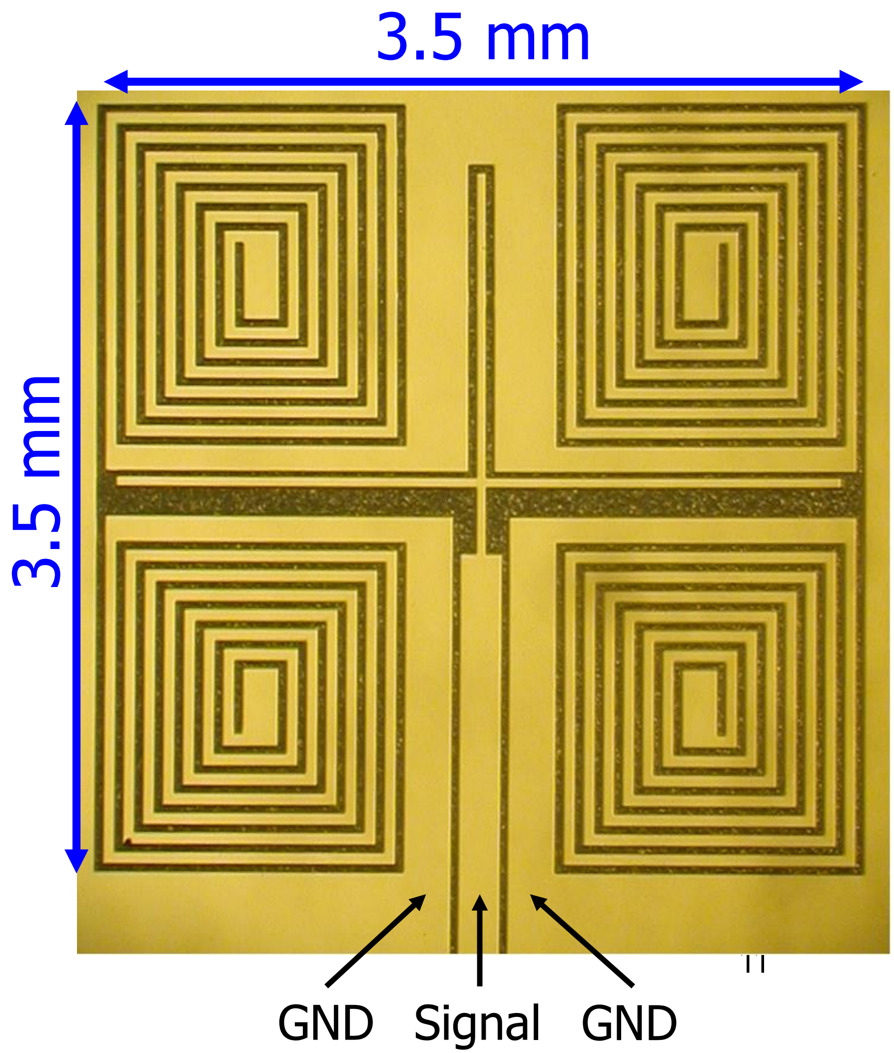




POSTECH

CPW-Fed Slot Antenna

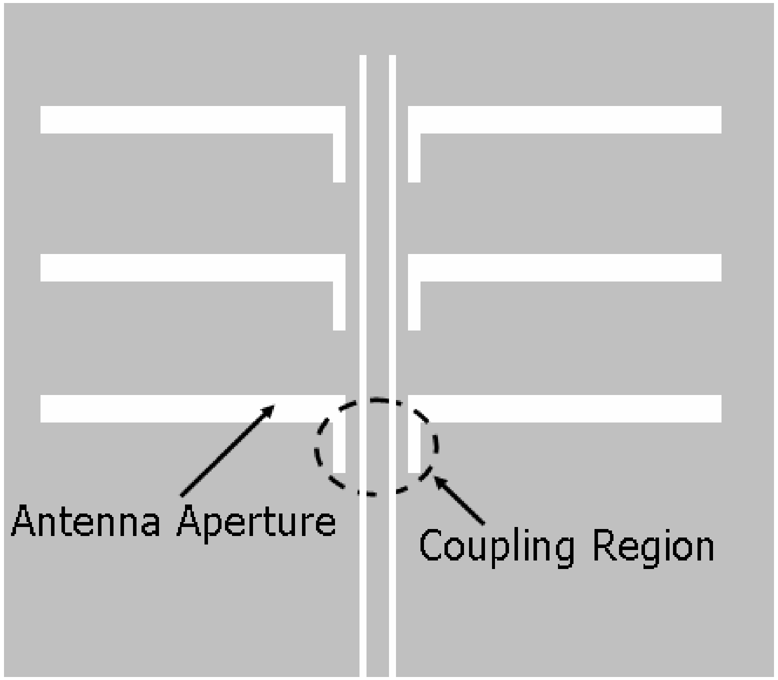




CPW-Fed Slot Antennas

- The inductive feeding is particularly useful for feeding slot antenna arrays in series. The CPW can be extended to feed another antenna on the same layer.

- This mechanism of feeding slot antennas and slot antenna arrays is presented in:
  - S. Sierra-Garcia, J. Laurin, "**Study of a CPW inductively coupled slot antenna**", IEEE Transactions on Antennas and Propagation, Vol. 47, pp. 58 – 64, Jan. 1999



Folded Dipole and Slot Antennas

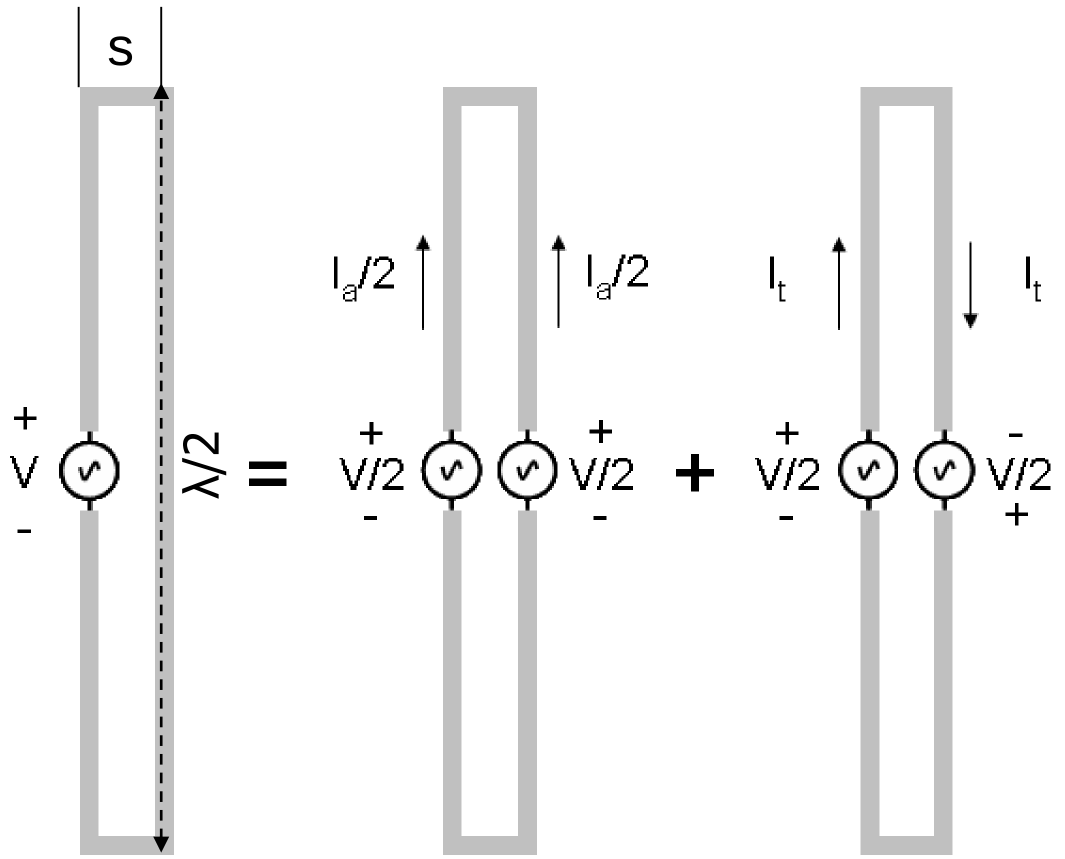
$$I_t = \frac{V/2}{Z_t}$$

$$I_a = \frac{V/2}{Z_d}$$

$$Z_{in} = \frac{4Z_t Z_d}{2Z_d + Z_t}$$

$$Z_{in} = 4Z_d \text{ if } \ell = \lambda/2$$

$$Z_t = jZ_0 \tan(\beta\ell)$$



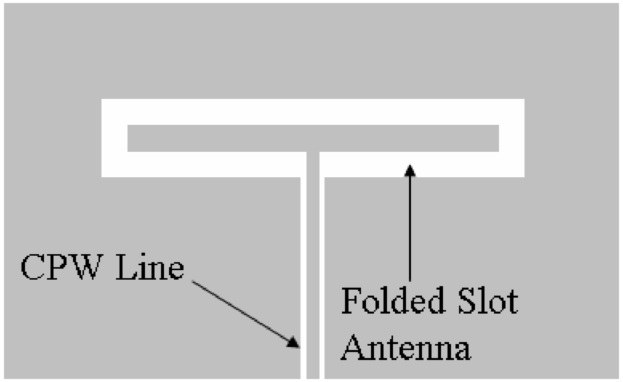
Folded Dipole and Slot Antennas

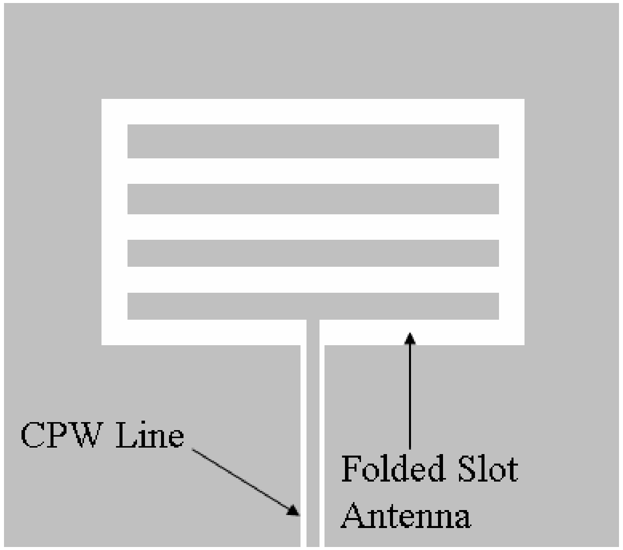
- Similar to the previous case, the input admittance of the folded slot antenna is:

$$Y_{in} = 4Y_s$$

- For folded slot antennas with higher orders the input admittance can be obtained as:

$$Y_{in,N} = N^2 Y_s$$



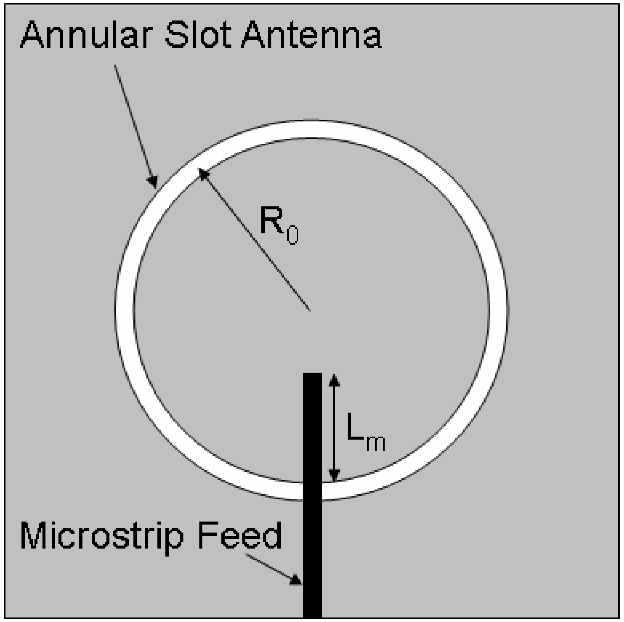


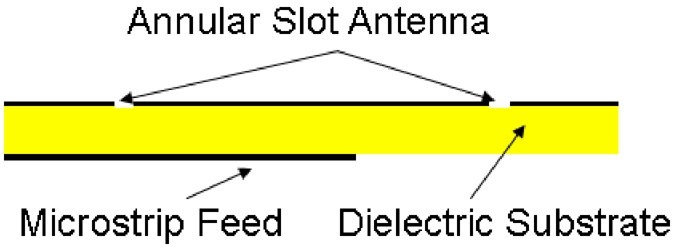
Annular Slot Antennas

- Annular slot antenna is the dual of a loop antenna.
- The main resonance occurs when the circumference of the loop is approximately one wavelength long, i.e.:

$$2\pi R_0 = \lambda$$

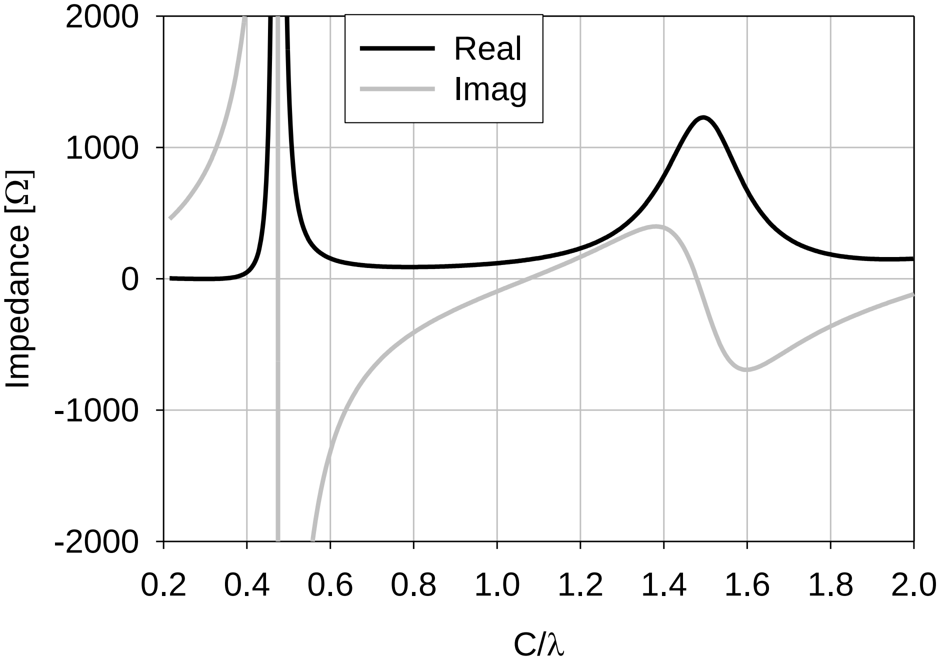
- A number of different feeding techniques can be used to feed this antenna. A microstrip-fed version is shown in the figure on the right.
- CPW feed is also very easy to design and a popular choice.

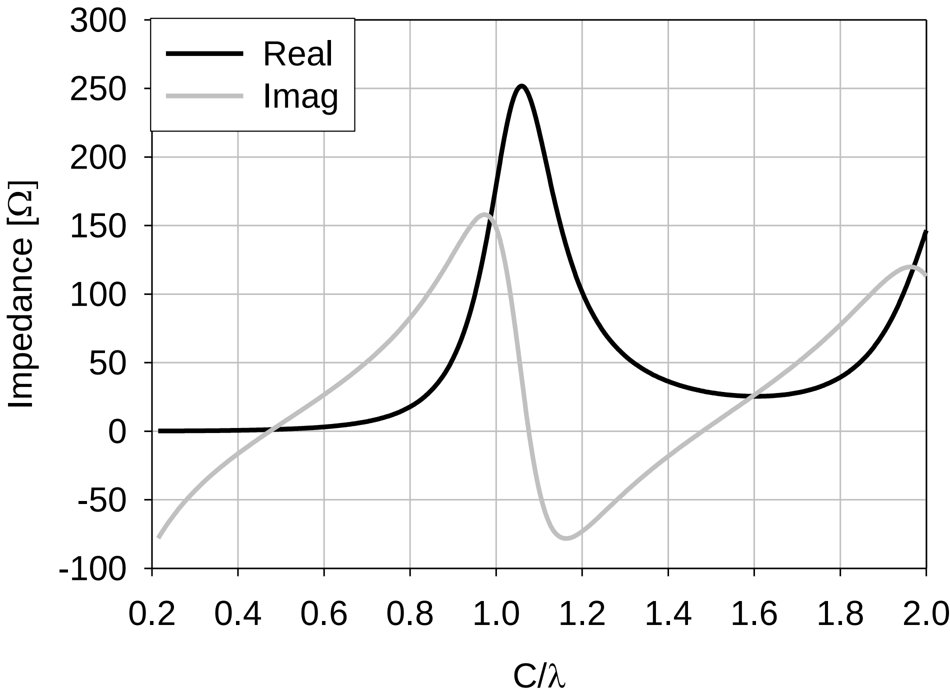




POSTECH

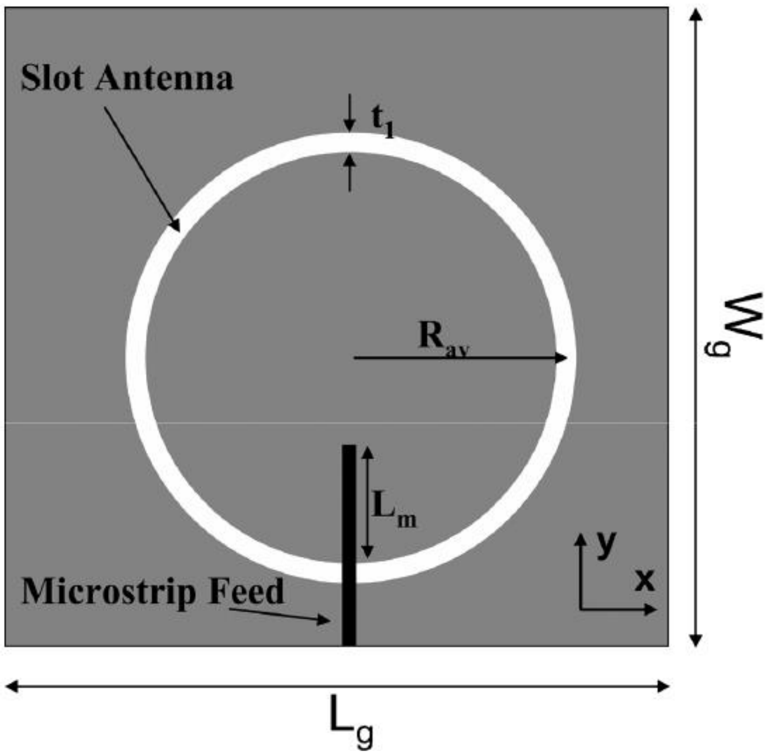
Input Impedance

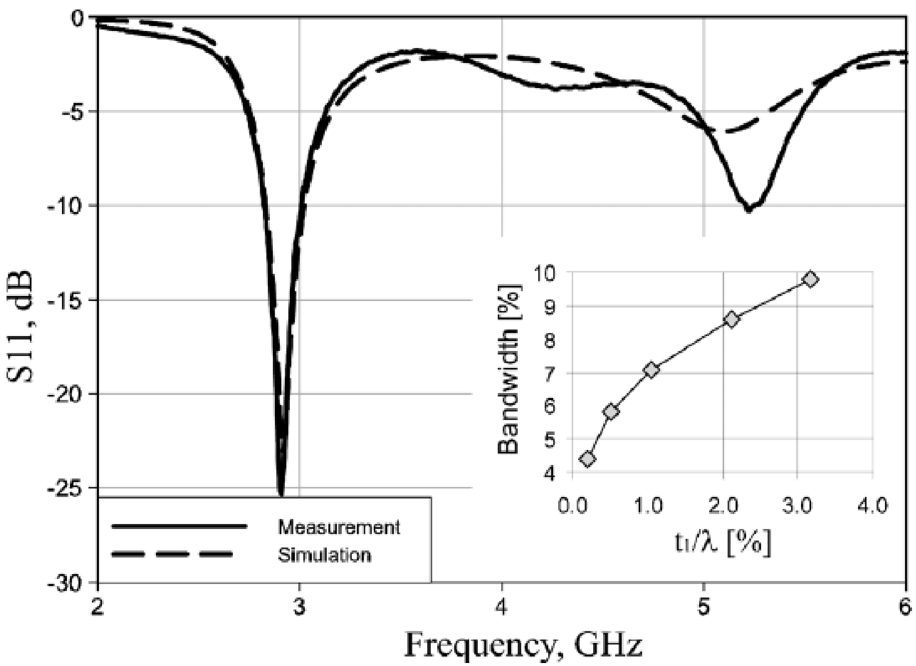




POSTECH

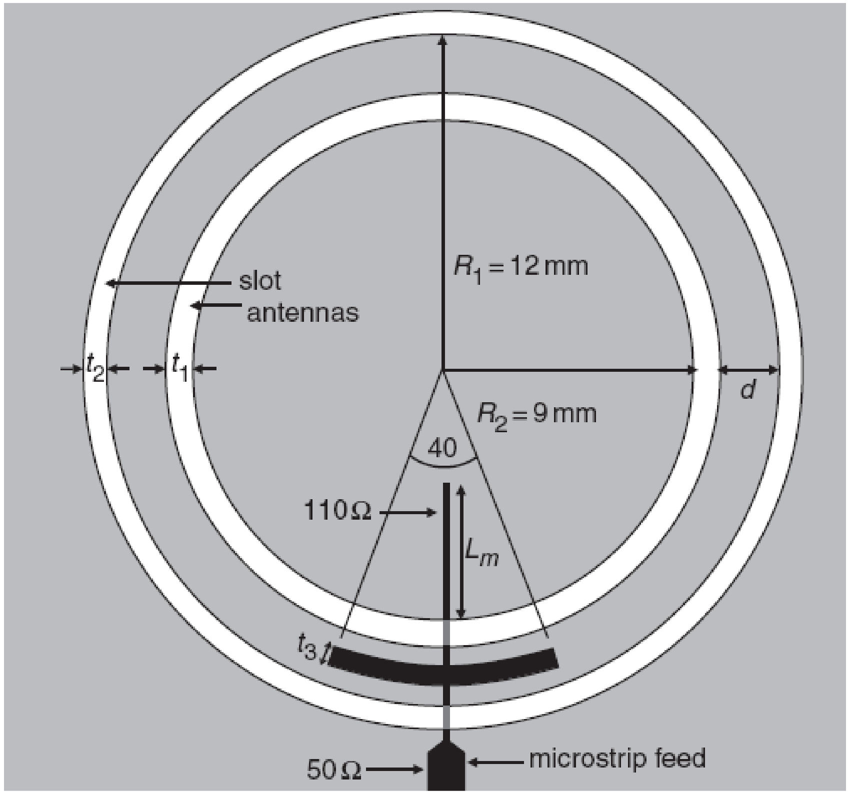
Annular Slot Antenna





Measurement results of an annular slot antenna with Rav=12.5 mm, t_1=1 mm, ε_r=3.4, and h=0.5 mm

Double-Element Annular Slot Antenna



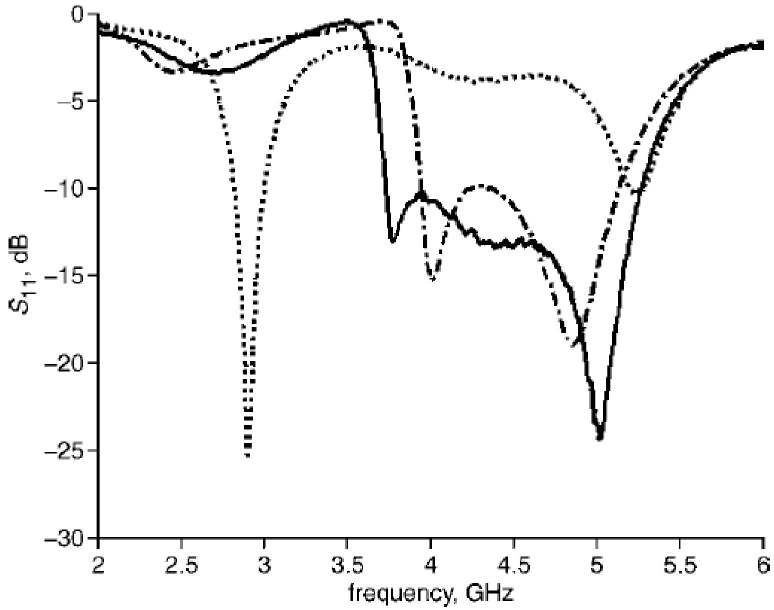


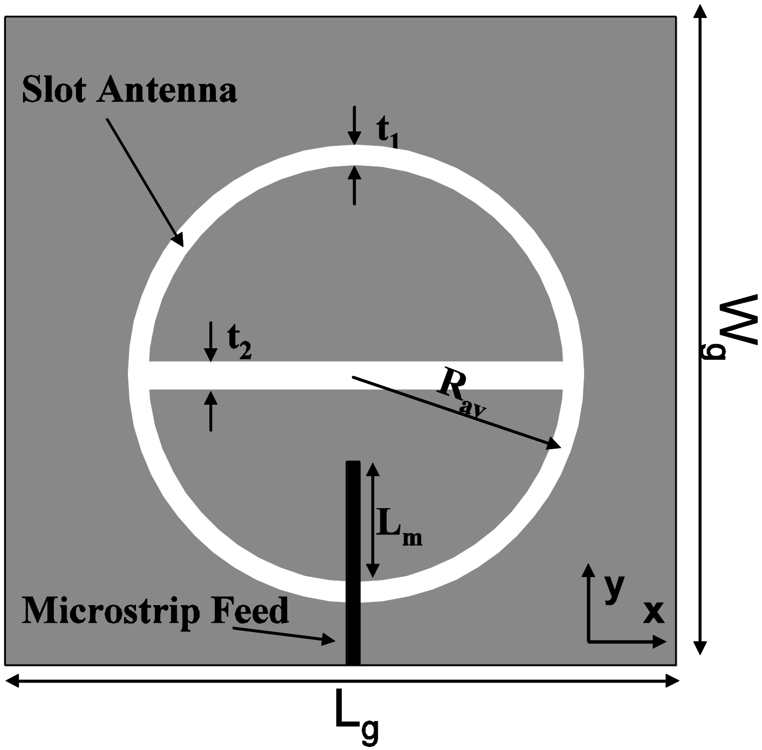
Fig. 2 *Measured return losses of double-element wideband ring antenna and single-element outer ring*

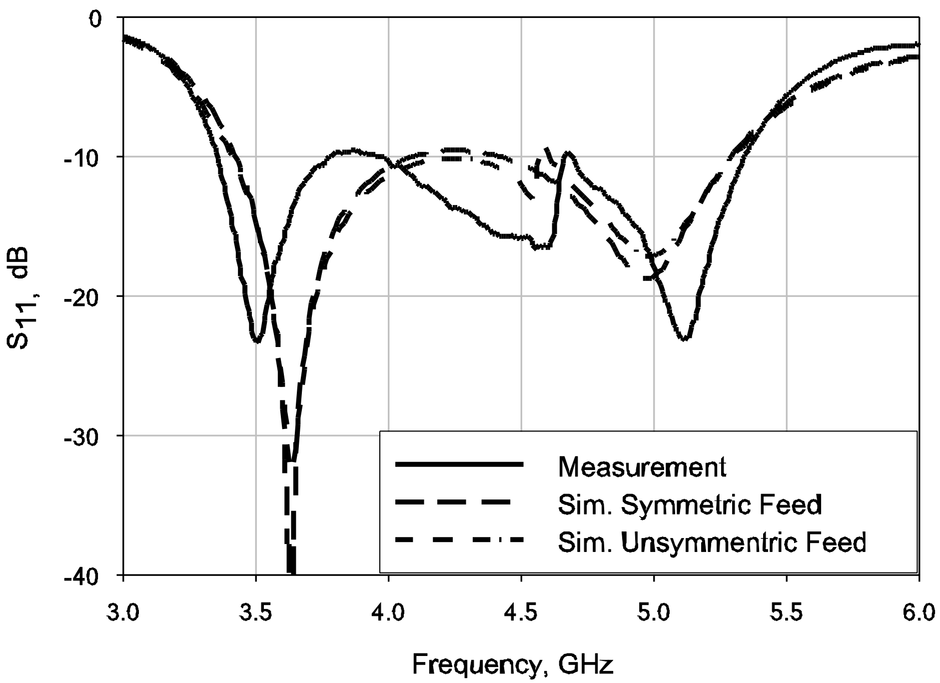
——— double-element antenna (measurement)
– · – · – double-element antenna (simulation)
· · · · · · single-element ring antenna (measurement)

Double-element annular slot antenna for bandwidth enhancement.

N. Behdad and K. Sarabandi, "Wideband double-element ring slot antenna," Electronics Letters, Vol. 40, no. 7, 1 April 2004 pp. 408 - 409

Bandwidth Enhancement of Annular Slot Antennas





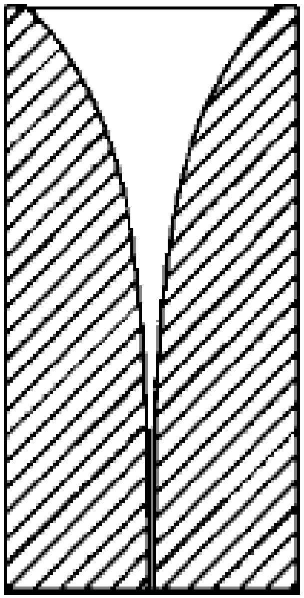
Bandwidth enhancement of annular slot antennas.

N. Behdad and K. Sarabandi, "Improved slot and wire loop antennas,"

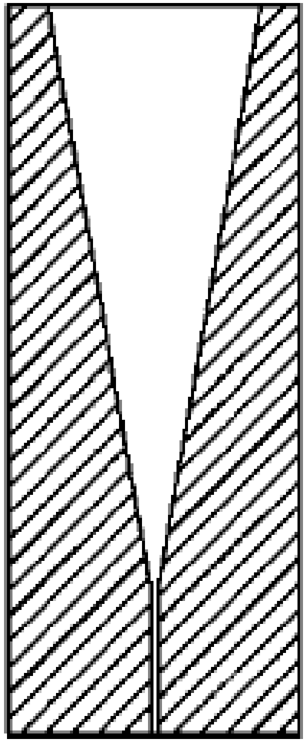
IEE Proceedings on Microwaves Antennas and Propagation, Vol. 153, no. 3, 1 June 2006 pp. 287 – 292.

POSTECH

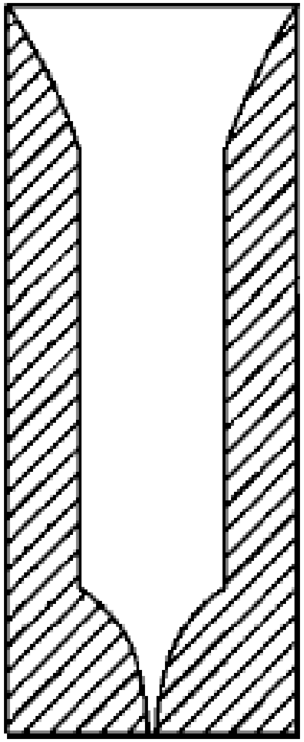
Tapered Slot Antennas



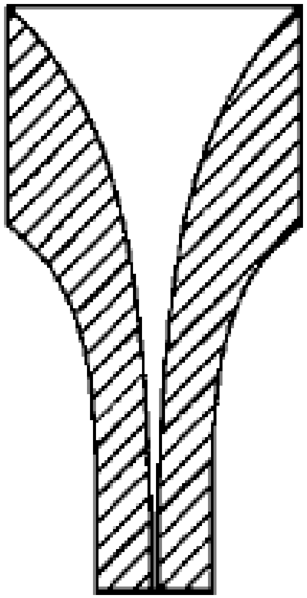
Exponential Taper



Linear Taper



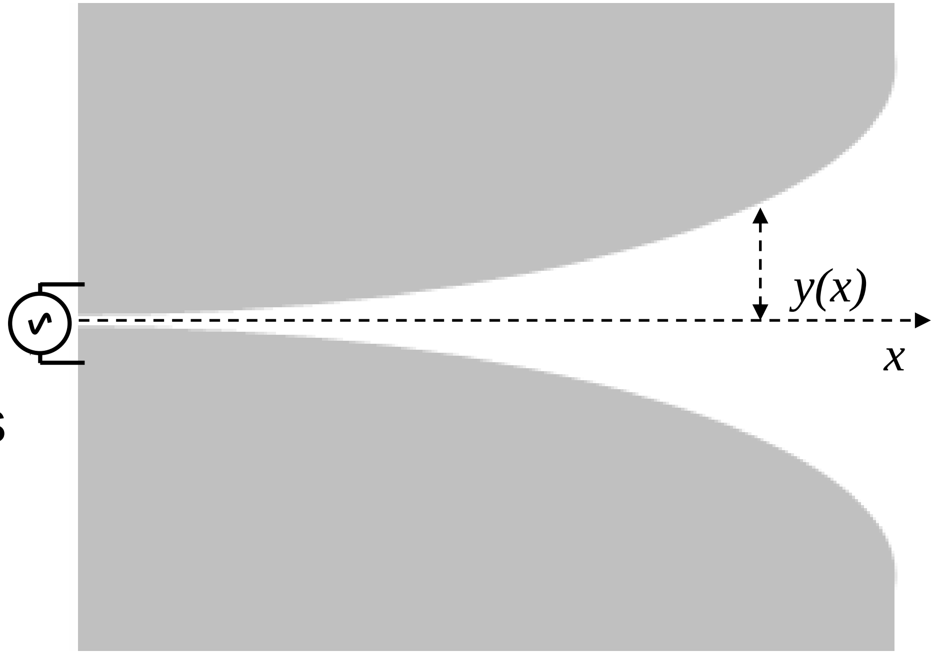
Continuous Width



Dual Exponential Taper

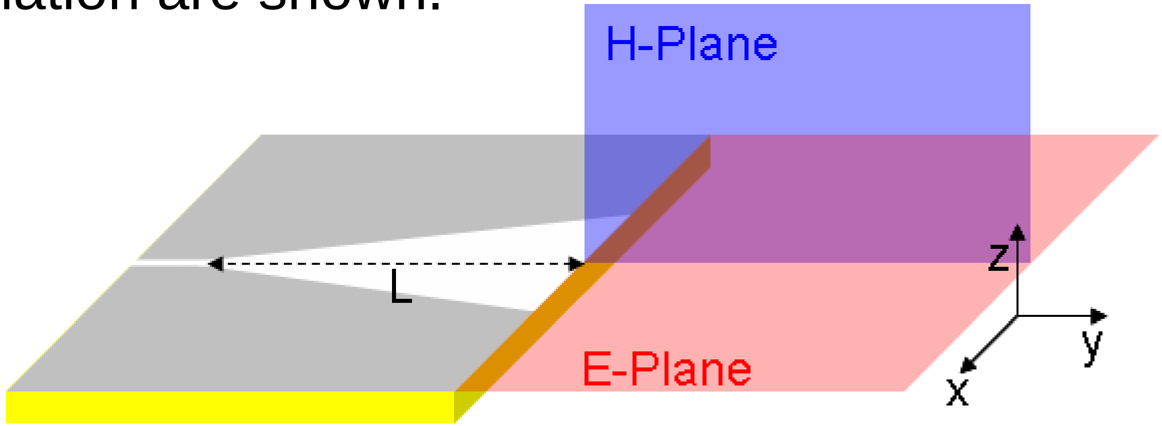
Tapered Slot Antennas

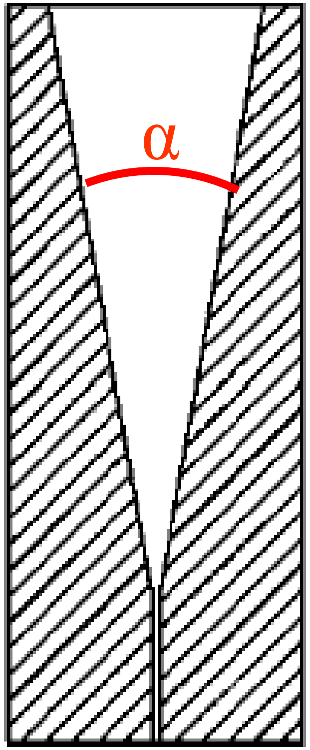
- In a narrow slot line, the wave is tightly bound to the transmission line.
- As the transmission line (slot) widens, it starts to radiate.
- Opening the slot line increases the radiation.
- This structure acts as a traveling wave antenna with an end fire radiation beam.



LTSA

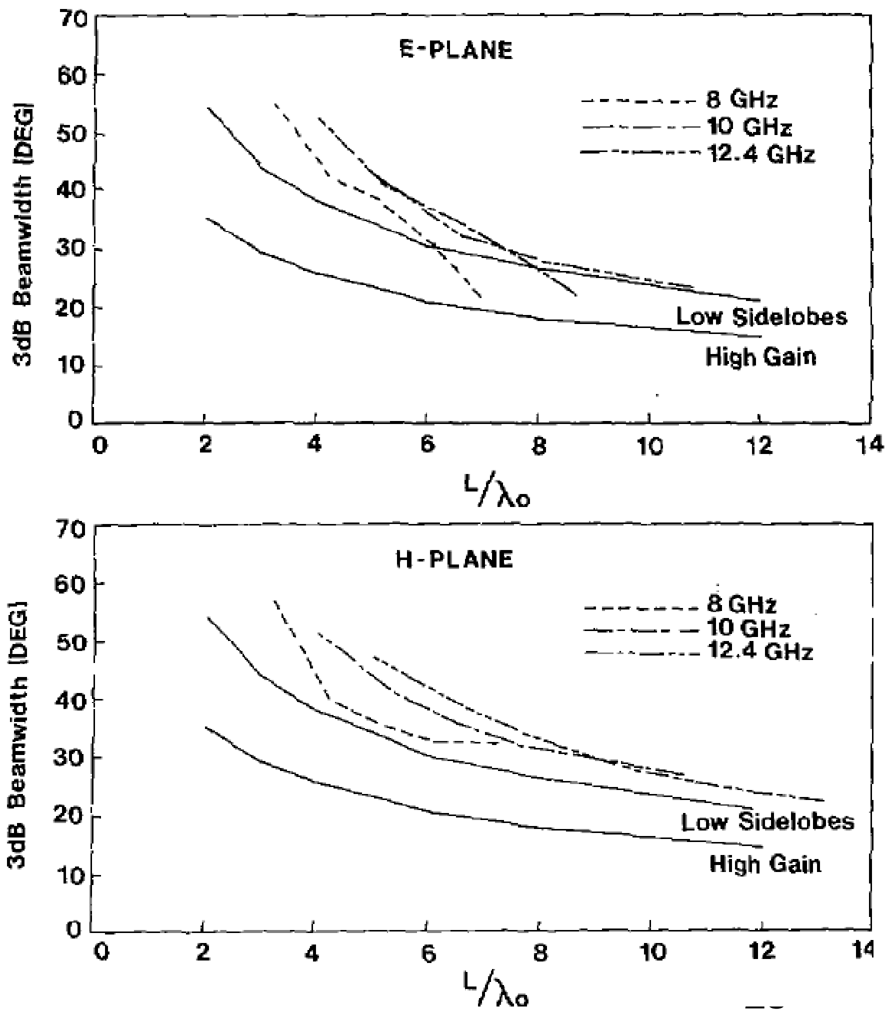
- In a linearly tapered antenna (LTSA):
  - $y(x)=a\,x$
- LTA and other Tapered Slot Antennas have end-fire radiation patterns.
- The E-Plane and H-principal planes of radiation are shown.





LTSA

- The parameters that determine the response of this antenna are:
  - Thickness and dielectric constant of the substrate.
  - The flare angle
  - Overall length of the antenna.
- The results for an LTA with flare angle of 11.2° and no dielectric substrate is shown.



POSTECH

Vivaldi Antenna

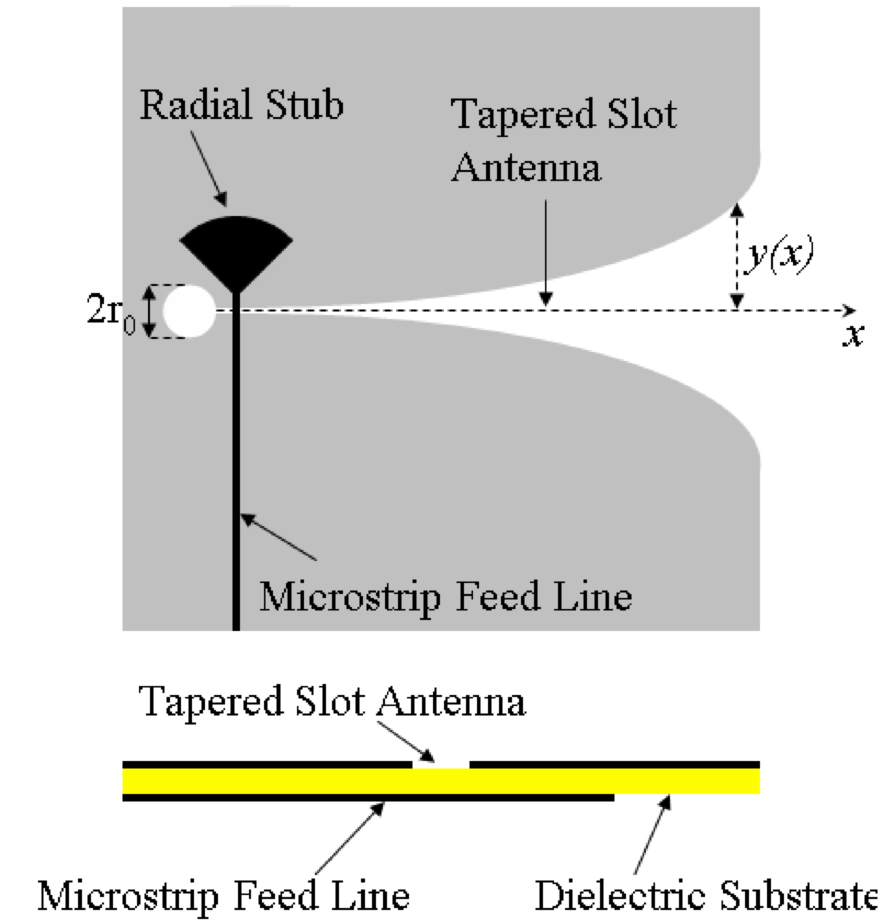
- An Exponentially Tapered Slot Antenna (ETSA) is also called a Vivaldi Antenna and is widely used.
- The shape of a Vivaldi antenna is defined by:

$$y(x) = \pm A e^{px}$$

- A long Vivaldi antenna with the exponential taper can essentially be frequency independent and extremely broadband.
- At a given frequency, only a section of the exponential will radiate efficiently.
- At a different frequency, the radiation will occur from a different section which is scaled in size in proportion to the wavelength and has the same relative shape.

Vivaldi Antenna

- Rapidly opening up the Exponential ➔ <u>Very</u> Wide Bandwidth.
- Slowly opening the exponential ➔ Narrow beams.
- E- and H-plane beamwidths in the range of 40-60 degrees can be achieved from typical versions of this antenna.
- One popular method of feeding ETSA is to use a microstrip line feed.
- The radial sub provides a wideband short circuit.
- The circular slot, provides a wideband open circuit.



POSTECH