Loop and Slot Antennas

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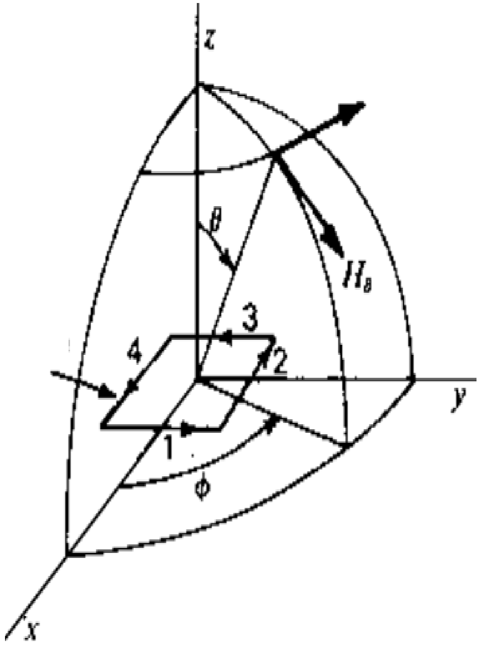
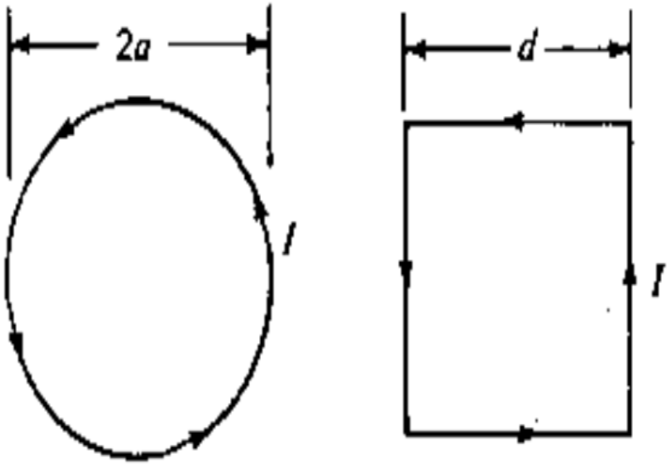
Loop Antenna

Loop antennas can have circular, rectangular, triangular or any other shape. It can have number of turns and can be wrapped in the air or around dielectric (solid or hollow) or ferrite material.





Circular Loop

Square Loop

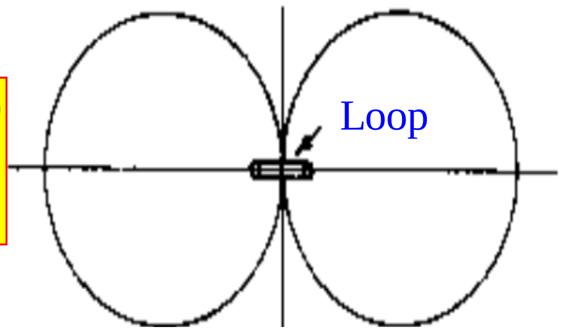
A small electric loop is equivalent to a small linear magnetic dipole of constant current amplitude I_m.

Loop Antenna Radiation Pattern

Radiation pattern of circular loop antenna of different diameter assuming uniform current distribution along the loop

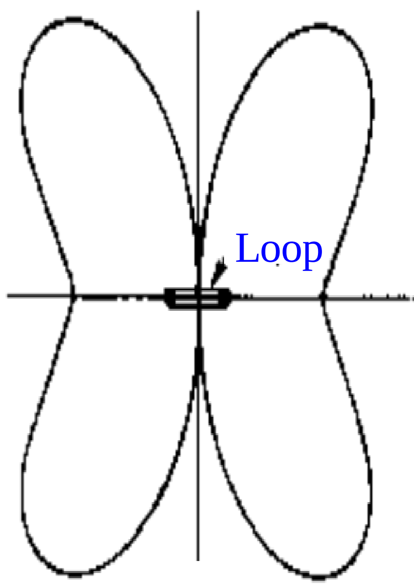
$Diameter = \lambda / 10$

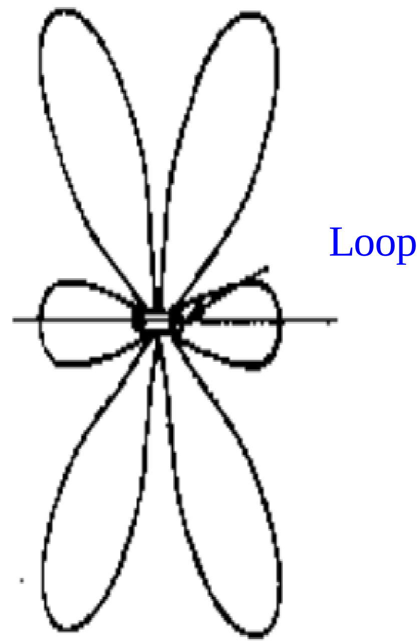
$C_\lambda = 0.314$



$Diameter = \lambda$

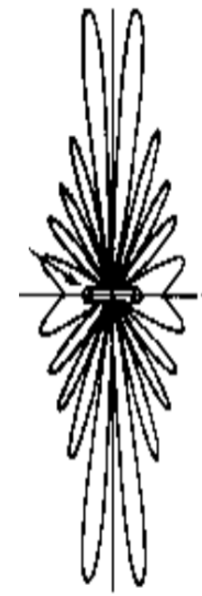
$C_\lambda = 3.14$





$Diameter = \frac{3\lambda}{2}$

$C_\lambda = 4.71$



$Diameter = 5\lambda$

$C_\lambda = 15.7$

Loop Antenna Radiation Resistance

For Single Turn Small Loop Antenna

$$R_r = 20\pi^2 \left(\frac{C}{\lambda}\right)^4$$

where C = 2 π a is circumference of the Loop Antenna

For N turns $$R_r = 20\pi^2 N^2 \left(\frac{C}{\lambda}\right)^4$$

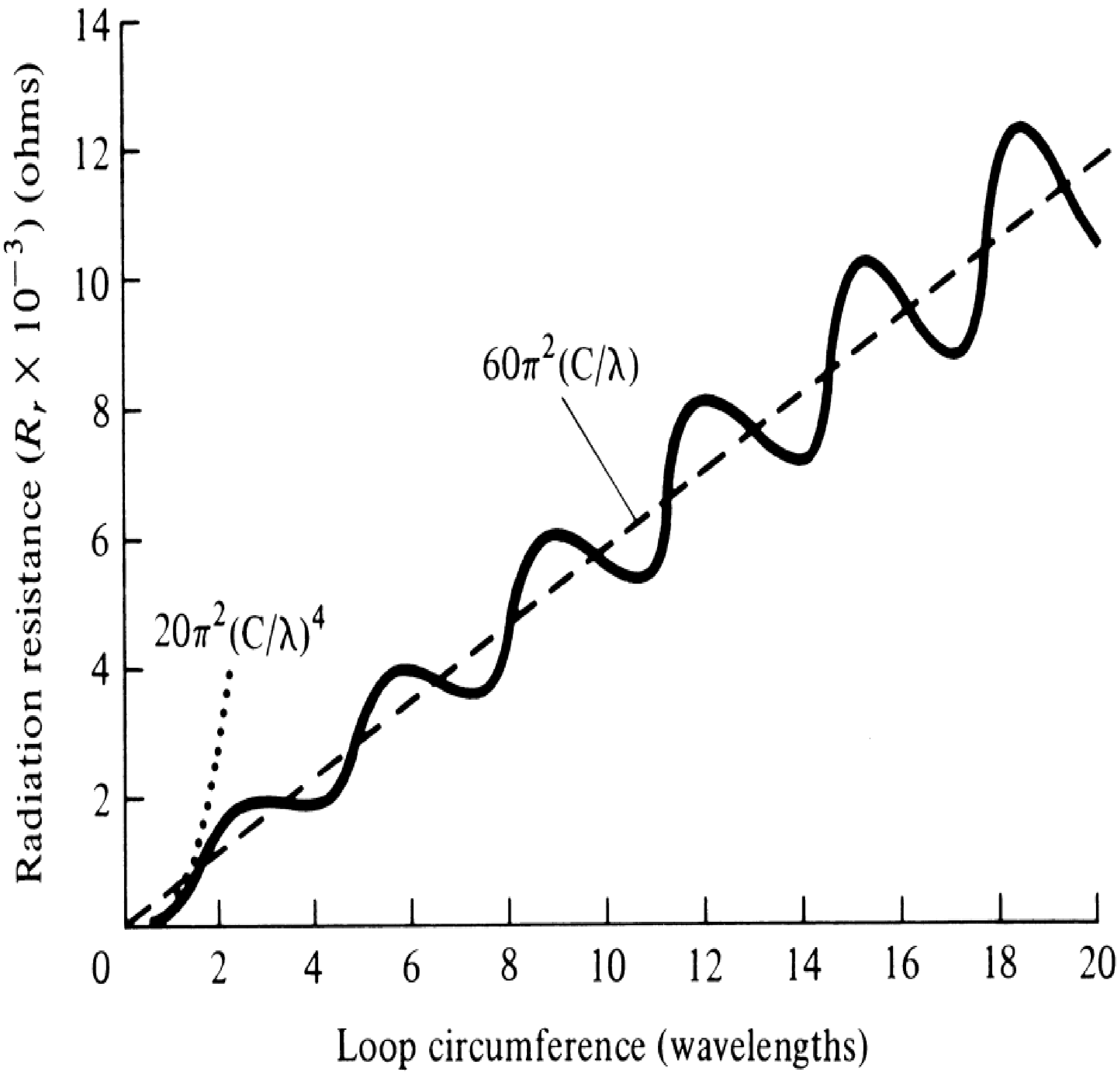
For large loop($C \geq 3.14\lambda$) antenna $$R_r = 60\pi^2 \left(\frac{C}{\lambda}\right)$$

Example: If $\frac{C}{\lambda} = 0.1 \rightarrow R_r = 20\pi^2 \left(\frac{C}{\lambda}\right)^4 = 20\pi^2 \times (0.1)^4 = 0.02\Omega$(very small)

For N = 50

$$R_r = 20\pi^2 N^2 \left(\frac{C}{\lambda}\right)^4 = 20\pi^2 \times (50)^2 x (0.1)^4 = 50\Omega$$

Radiation Resistance vs Loop Circumference



Radiation Resistance of Loop Antenna on Ferrite

$$R_f = \mu_{cer}{}^2 R_r = \left(\frac{\mu_{ce}}{\mu_0}\right)^2 R_r$$

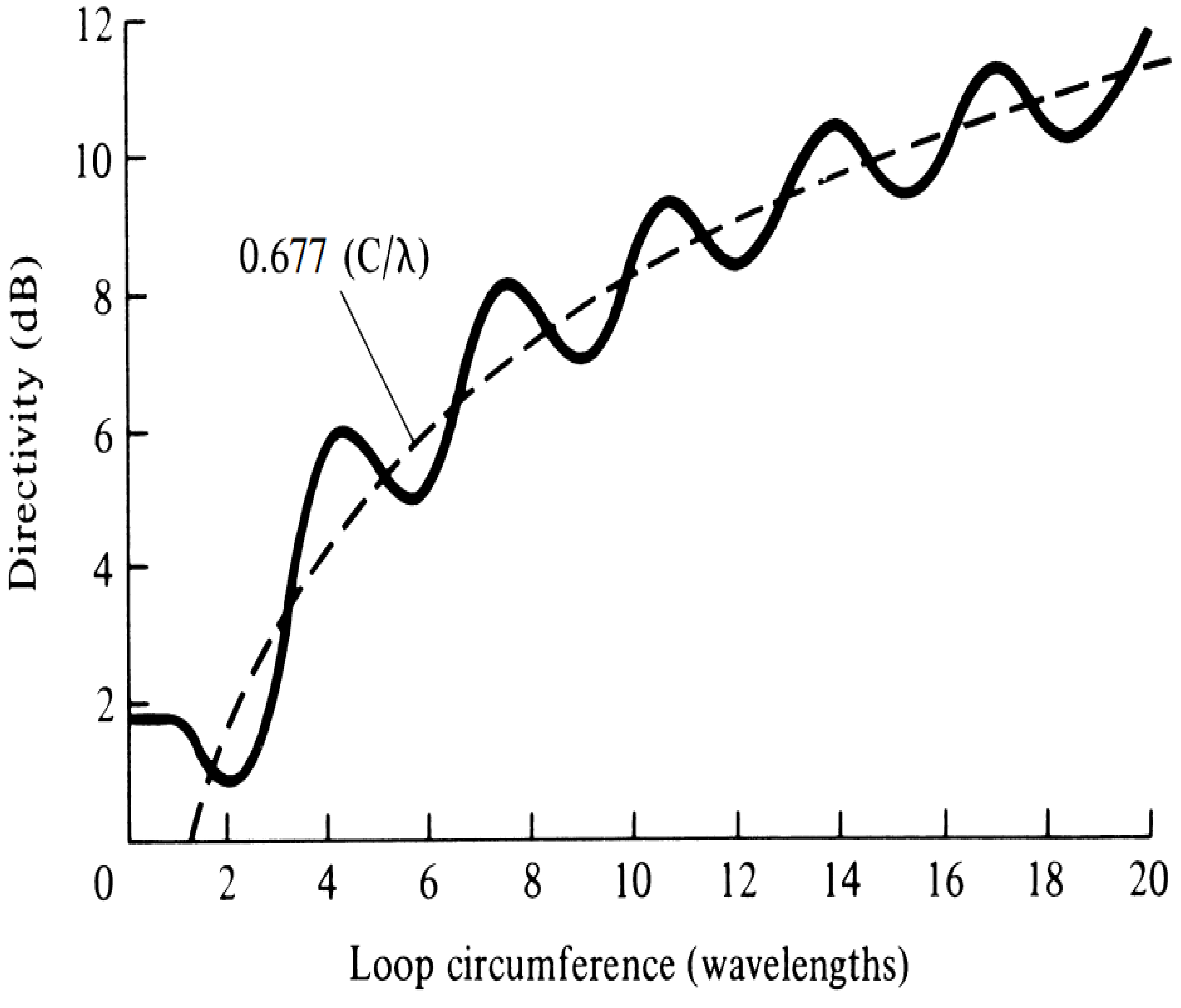
$$= 20\pi^2 \left(\frac{C}{\lambda}\right)^4 \left(\frac{\mu_{ce}}{\mu_0}\right)^2 N^2$$

Example: A N-turn circular loop antenna has a diameter of 2 cm, and the wire diameter is 1 mm. It is wound on the ferrite core, whose effective permeability is 10. How many turns are required to obtain R_{in} = 50 ohm at 3MHz.

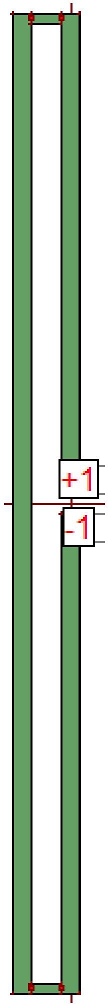
$$N^2 = \frac{R_{in}}{\mu_{cer}{}^2 20\pi^2 \left(\frac{C}{\lambda}\right)^4} = \frac{50}{10^2 20\pi^2 \left(\frac{\pi \text{ x } 2}{10000}\right)^4}$$

$$N = 127485$$

Directivity of Circular Loop Antenna



Folded Dipole vs Rectangular Loop Antenna



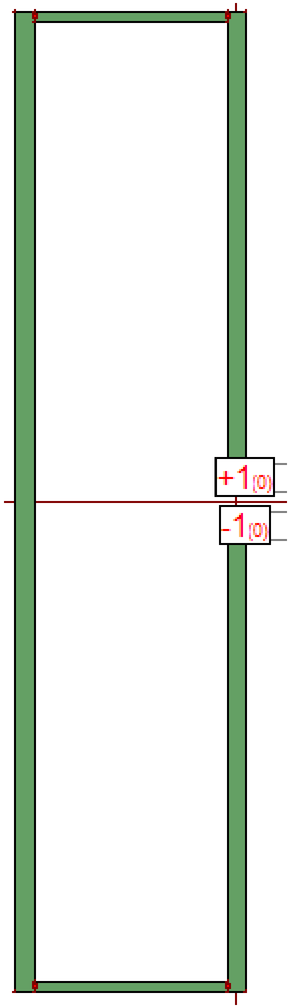
Z_{in} of Folded Dipole Antenna = 4 x Z_{in} of Dipole Antenna

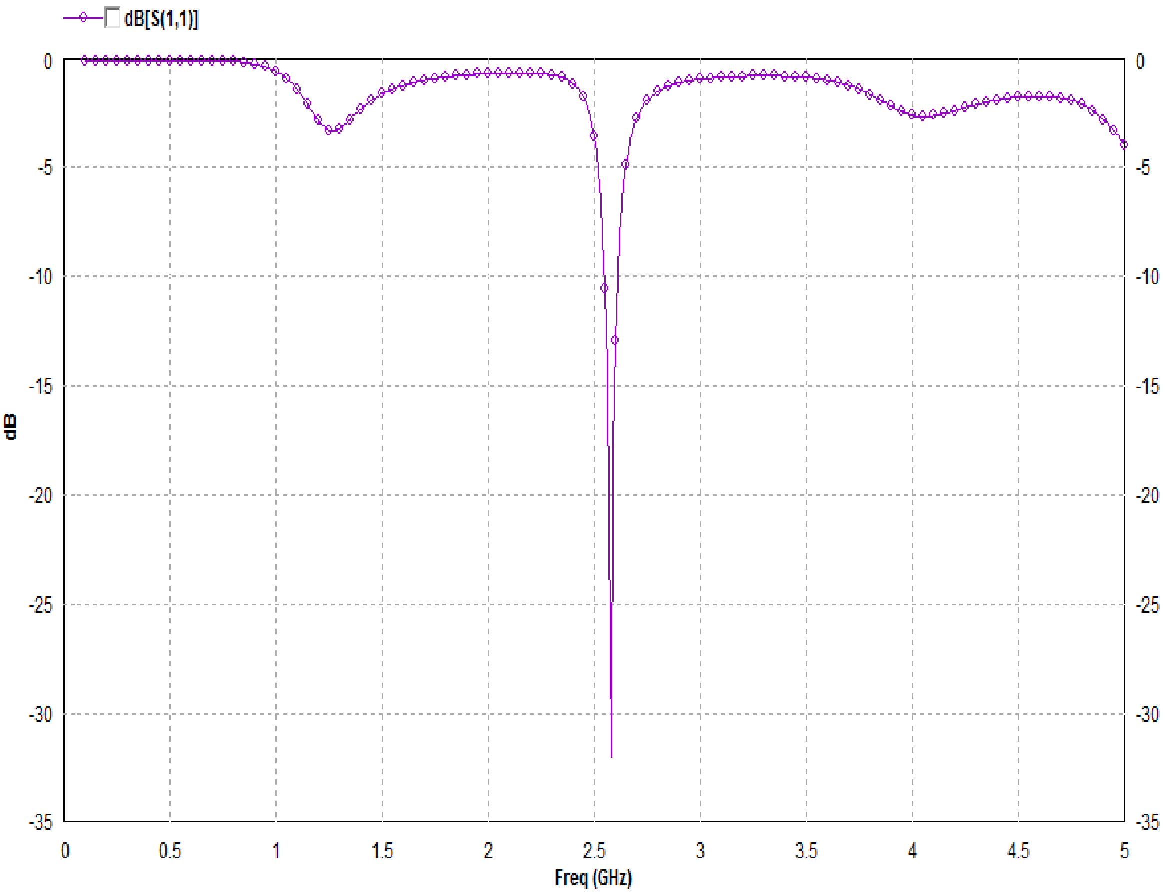
Connecting Strip Length (mm)	Zin (Ω)	**Resonance Frequency (GHz)**
Dipole Antenna	70.3	1.495
3	286.9	1.405
6	292.6	1.396
10	297 .0	1.381
20	303 .0	1.340

As connecting strip length increases, resonance frequency decreases and input impedance increases because rectangular loop length increases (circumference is approximately equal to λ)

Length of the each segment of dipole = 50mm, width = 2mm, air-gap = 2mm
Length of the folded arm = 102mm, connecting strip width = 1mm

S_{11} of Loop Antenna



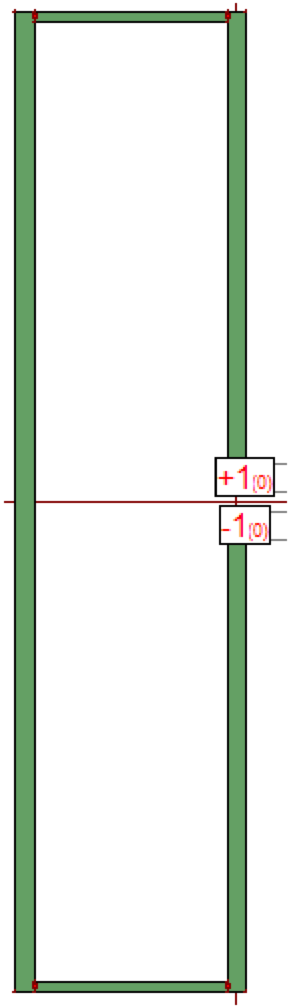


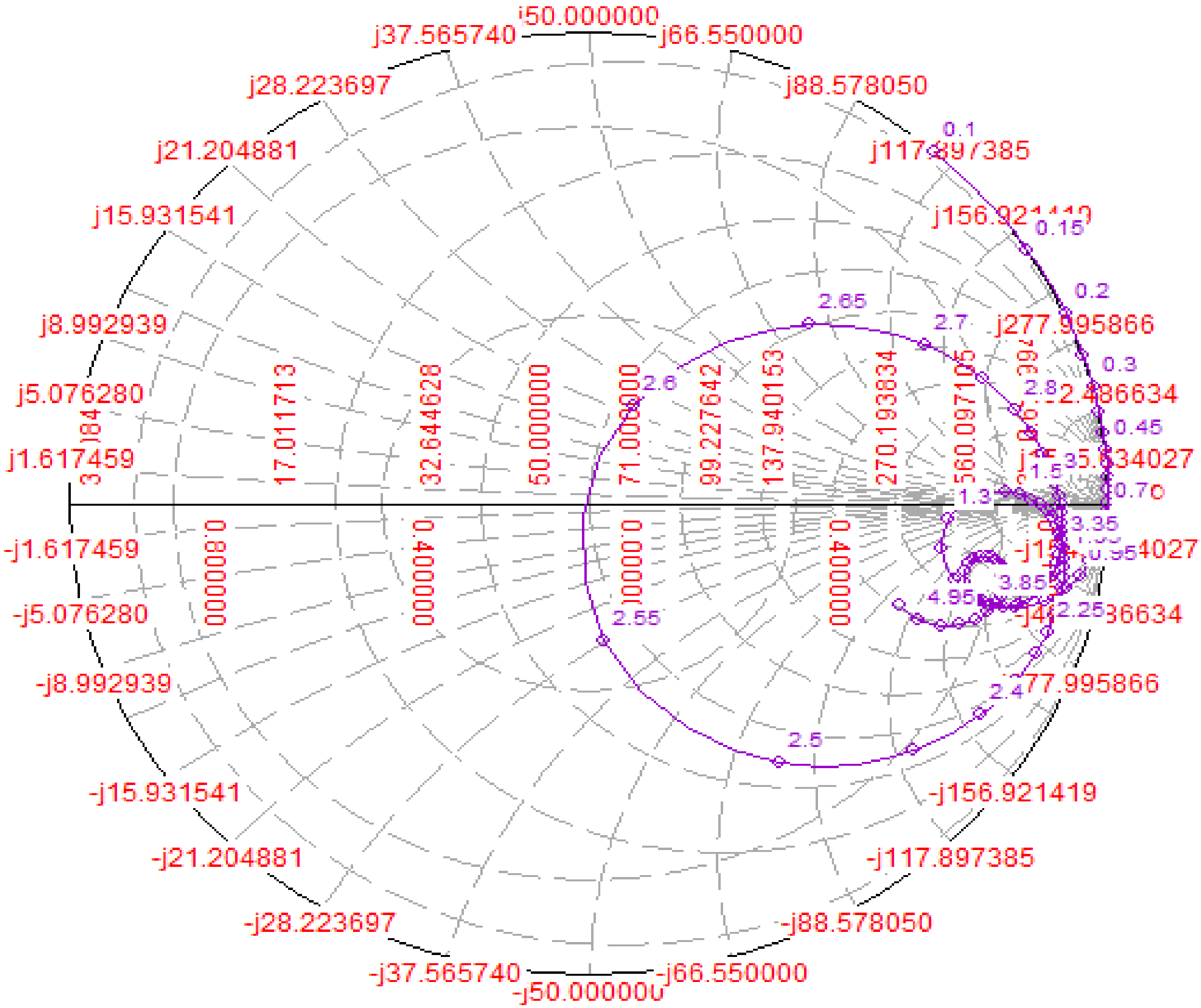
Higher order modes correspond to C = nλ, where n = 2, 3, ...

Length of loop = 102 mm, width of vertical arm = 2mm, air-gap = 2mm

Length of connecting strip = 20mm and width = 1mm

Input Impedance of Loop Antenna

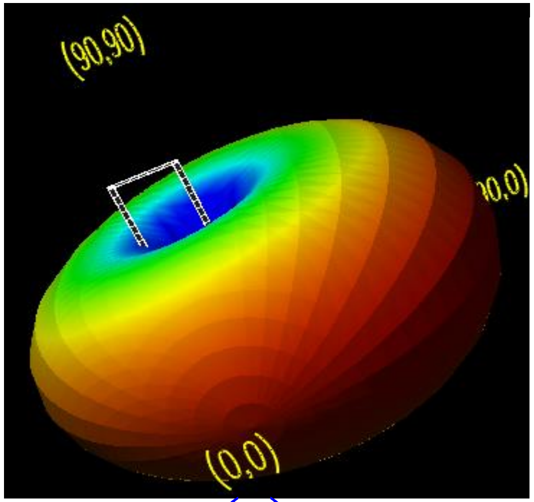




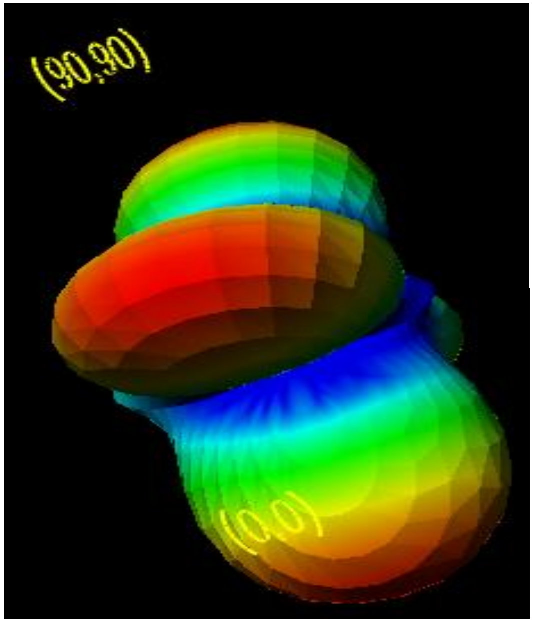
Input Impedance of loop is inductive at lower frequency – loop acts as Inductor.

Various modes correspond to C = nλ, where n = 1, 2, 3….

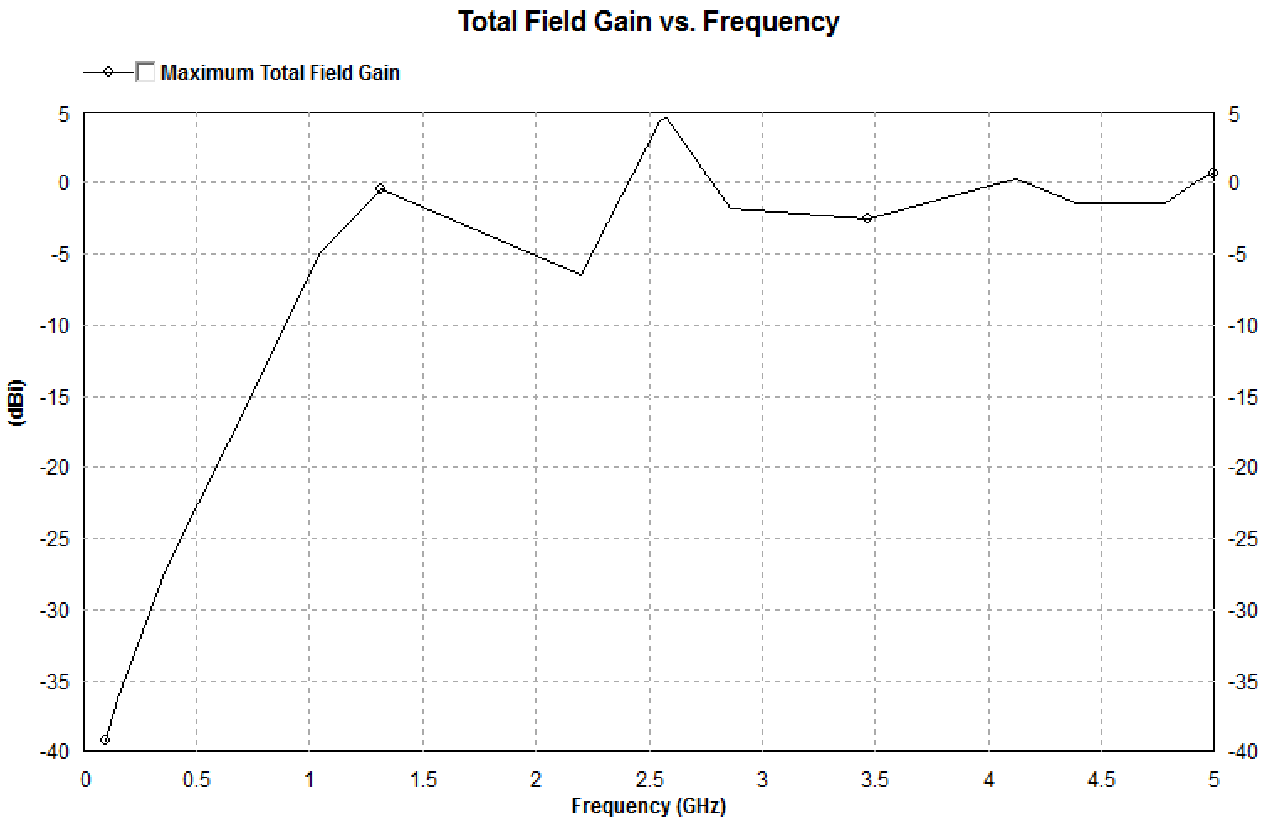
Radiation Pattern and Gain of Loop Antenna



(a)



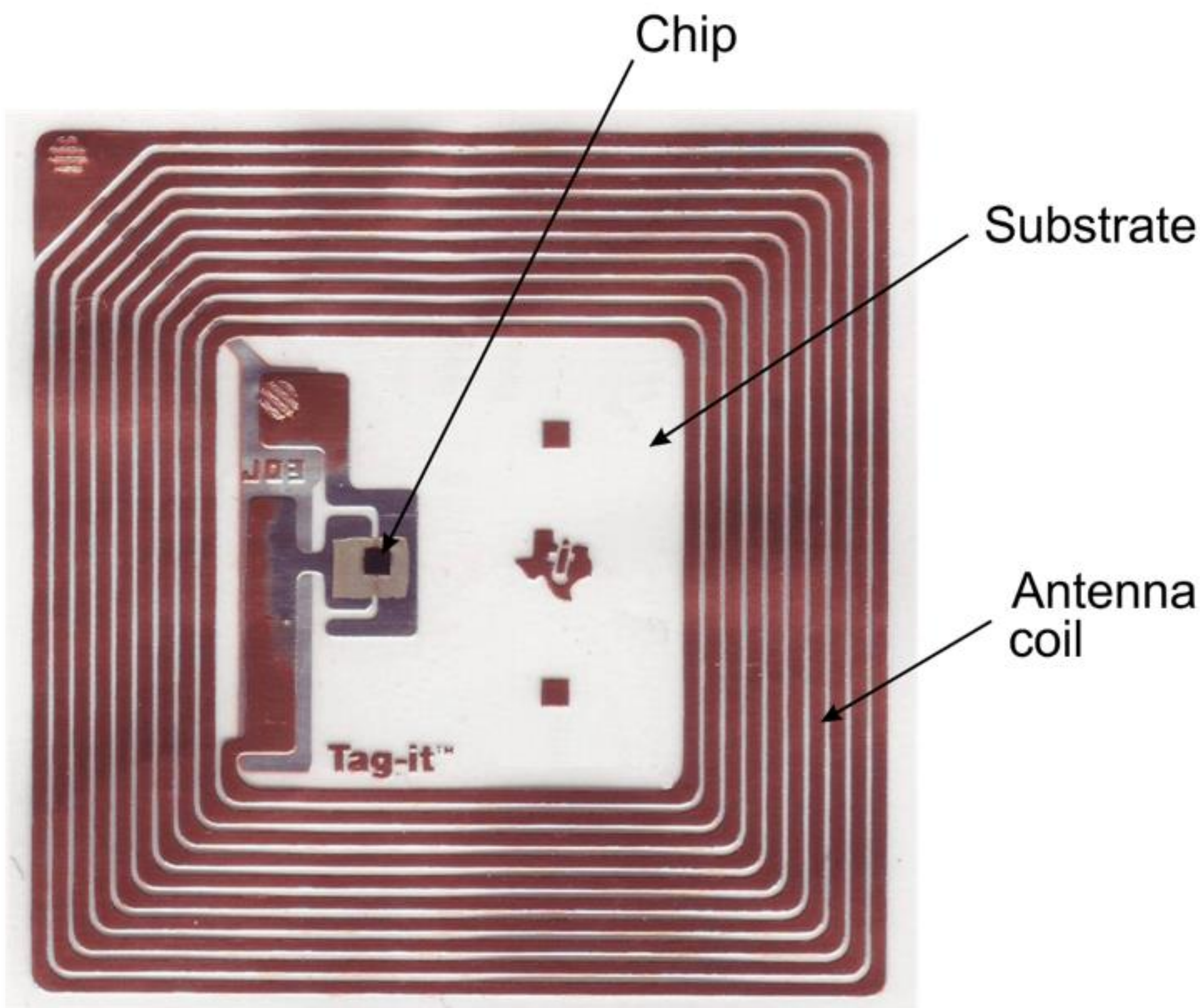
(b)



Gain vs Frequency Plot

Radiation Pattern at (a) 1.32 and (b) 2.55 GHz

Application of Multi-Turn Small Loop Antenna - RFID

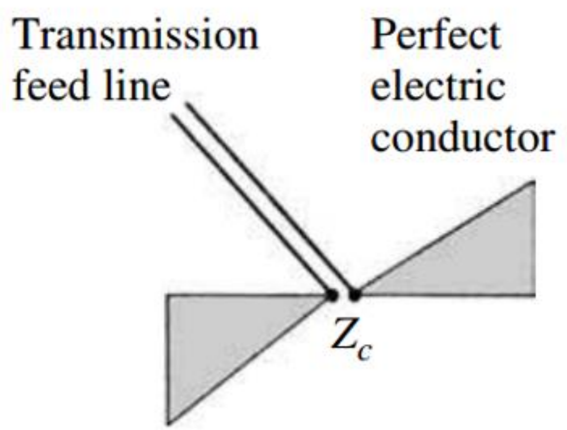


RFID Tag

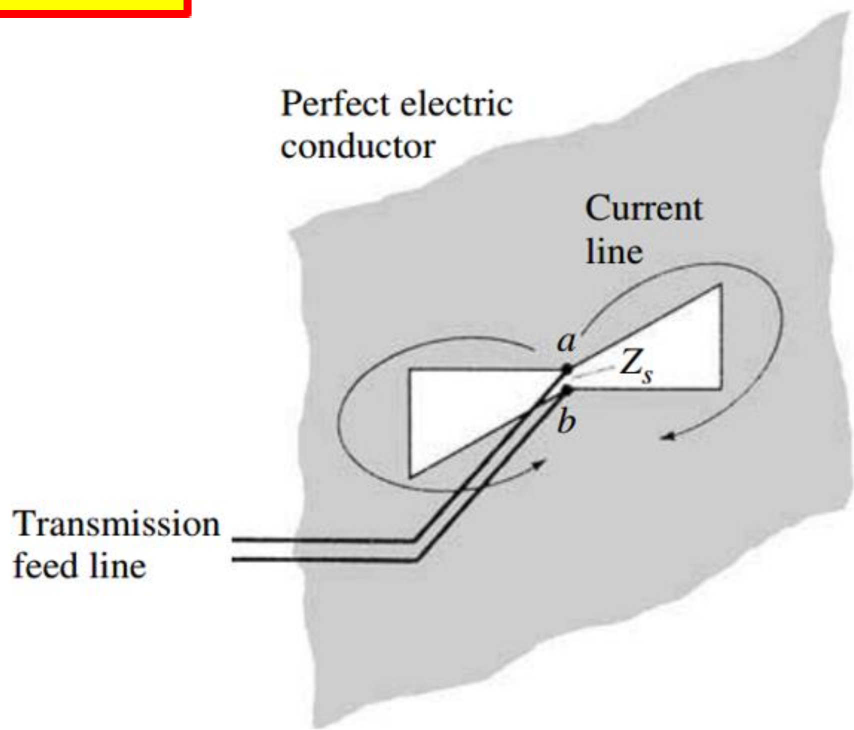
Slot Antenna

If a electric screen (with slot) and its complement (strip dipole) are immersed in a medium with an intrinsic impedance η and have terminal impedances $of\ Z_s and Z_c$, respectively, the impedances are related by

$$Z_s Z_c = \frac{\eta^2}{4}$$



Complementary dipole



Electric Screen with slot

Slot Antenna Far-Fields

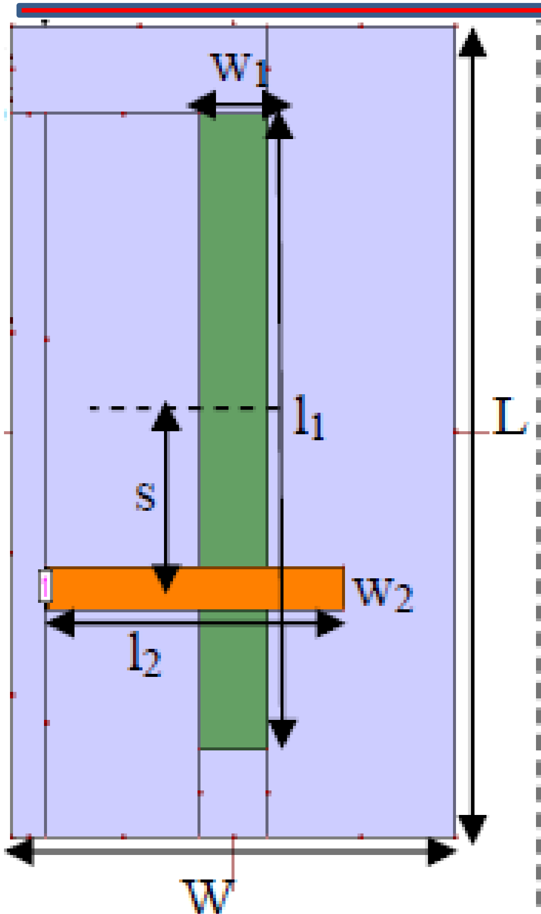
Far Field Electric and Magnetic Fields

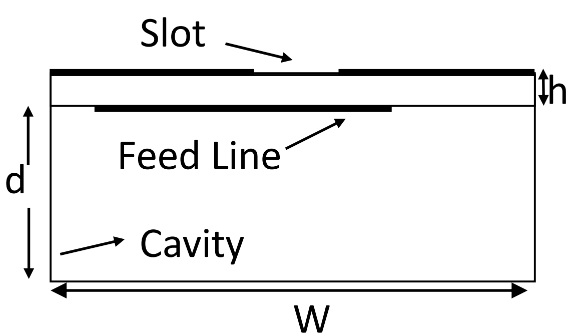
$$E_{\theta s} = H_{\theta c}, E_{\phi s} = H_{\phi c},$$

$$H_{\theta s} = -\frac{E_{\theta c}}{{\eta_0}^2}, H_{\phi s} = -\frac{E_{\phi c}}{{\eta_0}^2}$$

Radiation pattern of the slot is identical in shape to that of the dipole except that the E and H-fields are interchanged.

Cavity Backed Slot Antenna at 5.8 GHz



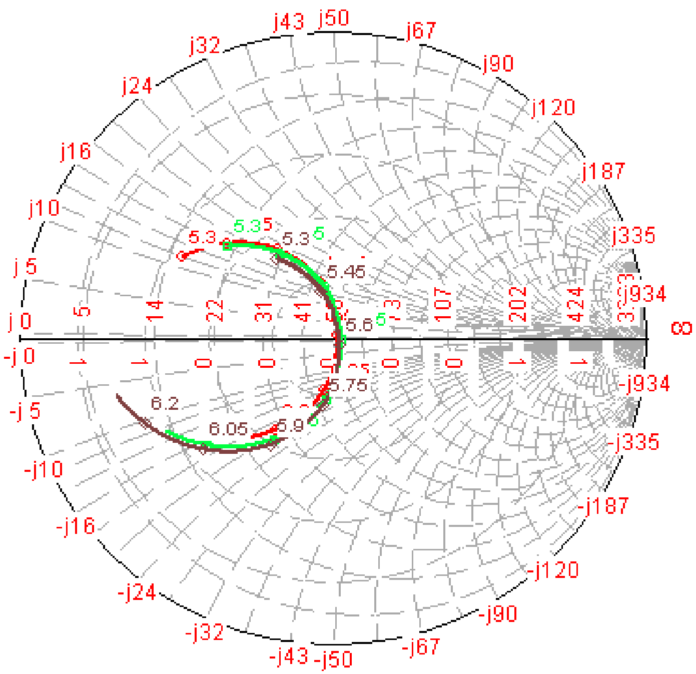


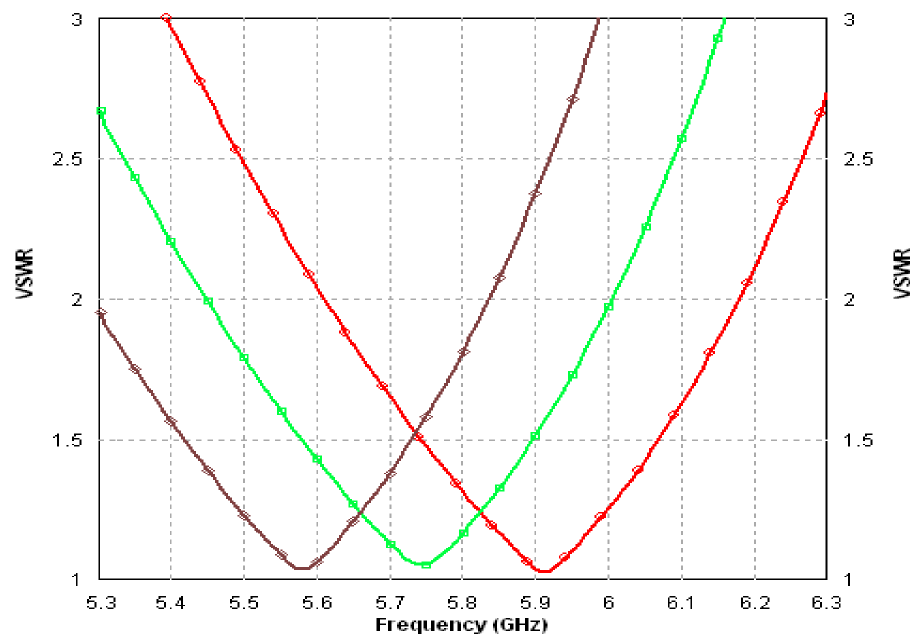
Elements	Dim./Value
Slot (l_1 x w_1)	31.4 mm x 4 mm
Cavity height (d)	13 mm ($\simeq \lambda/4$)
Slot offset (s)	7.7 mm
Cavity (L x W)	40 mm x 26 mm

Substrate: ε_r = 2.55, h = 0.787 mm, tan δ= 0.0015

Slot is cut in the top ground plane. Slot is fed using microstrip line from other side of substrate. Antenna is backed by a metallic cavity for unidirectional coverage

Slot Length Variation in Offset-fed Cavity Backed slot Antenna



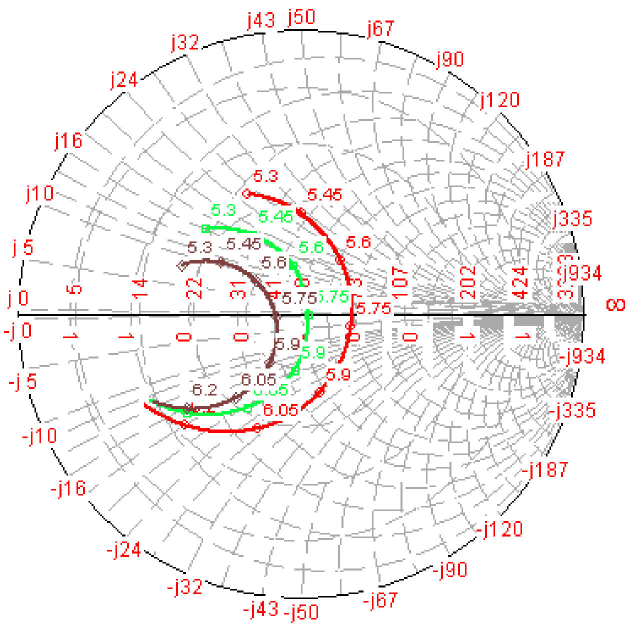


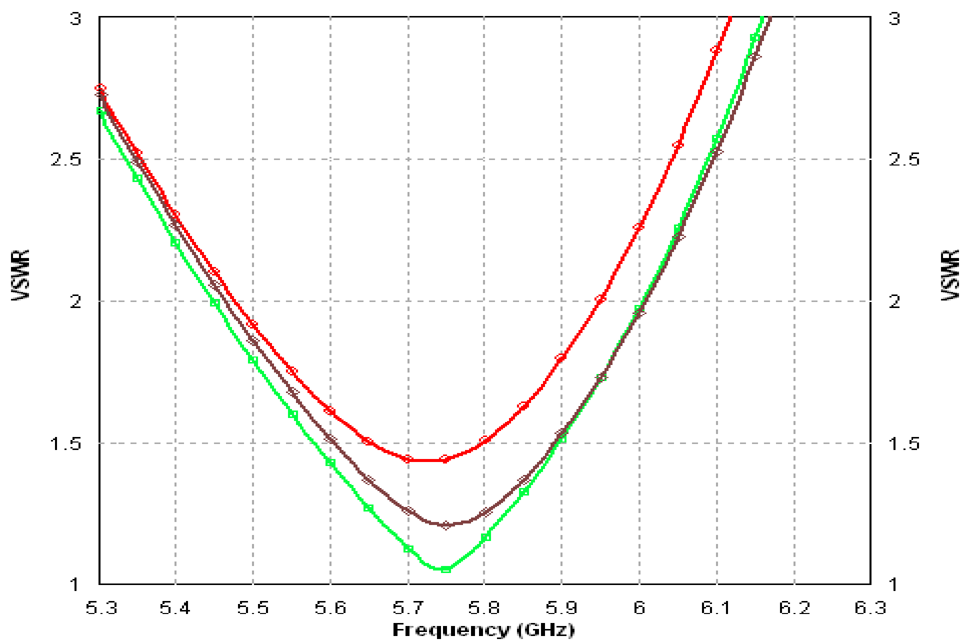
(29.4, 31.4, 33.4mm)

Input Impedance and VSWR vs. Frequency Plots for Three Values of Slot Length (l_1 = 29.4, 31.4, and 33.4mm)

With increase in the slot length, resonance frequency decreases and input impedance locus rotates clockwise

Slot Width Variation in Offset-fed Cavity Backed slot Antenna



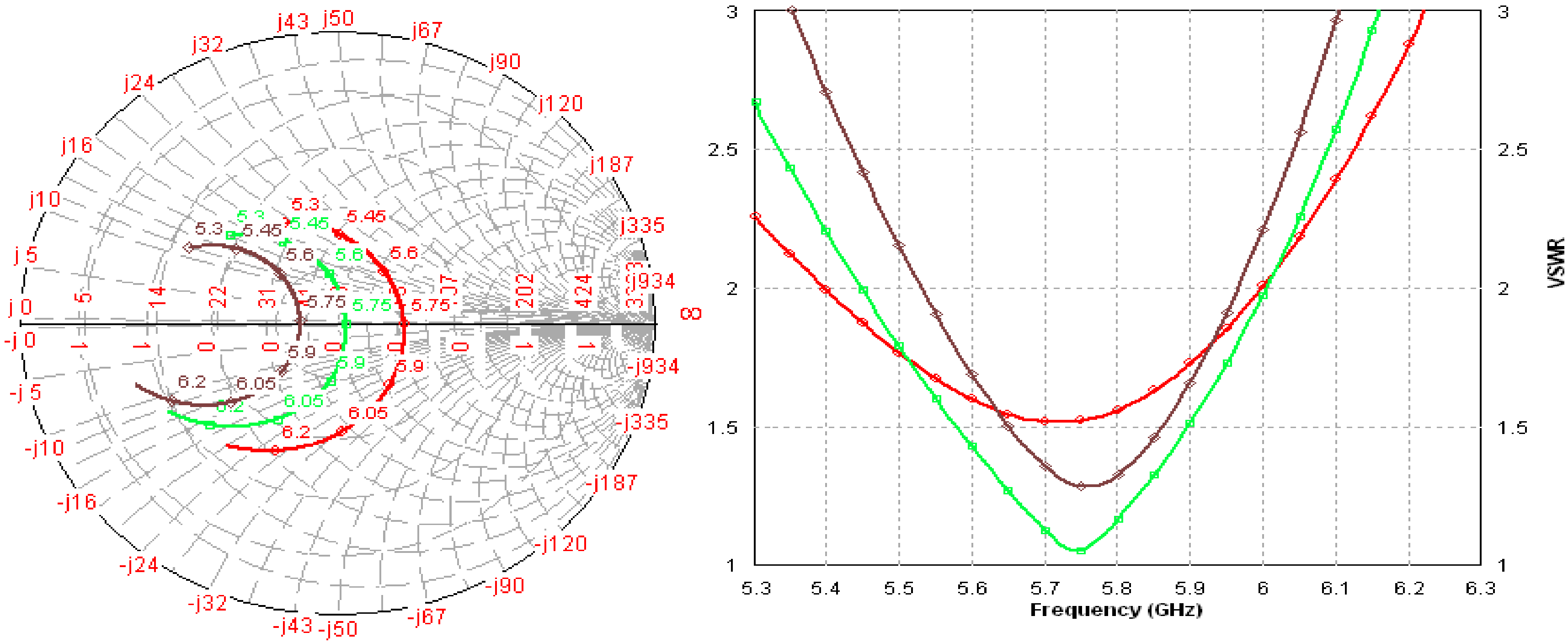


(3, 4, 5mm)

Input Impedance and VSWR vs. Frequency Plots for Three Values of Slot Width Variation (w_1 = 3, 4, and 5mm)

With increase in the slot width, bandwidth increases and input impedance locus shifts towards lower impedance value

Feed Width Variation in Offset-fed Cavity Backed slot Antenna

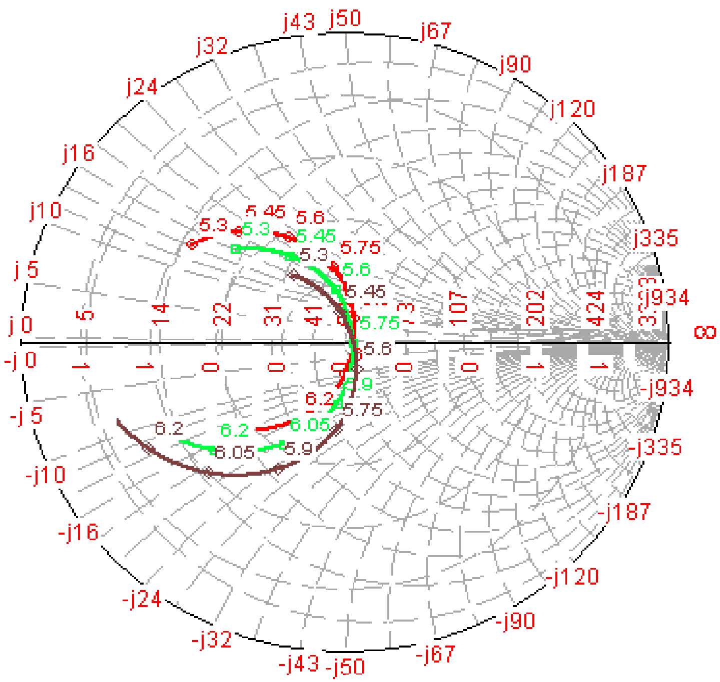


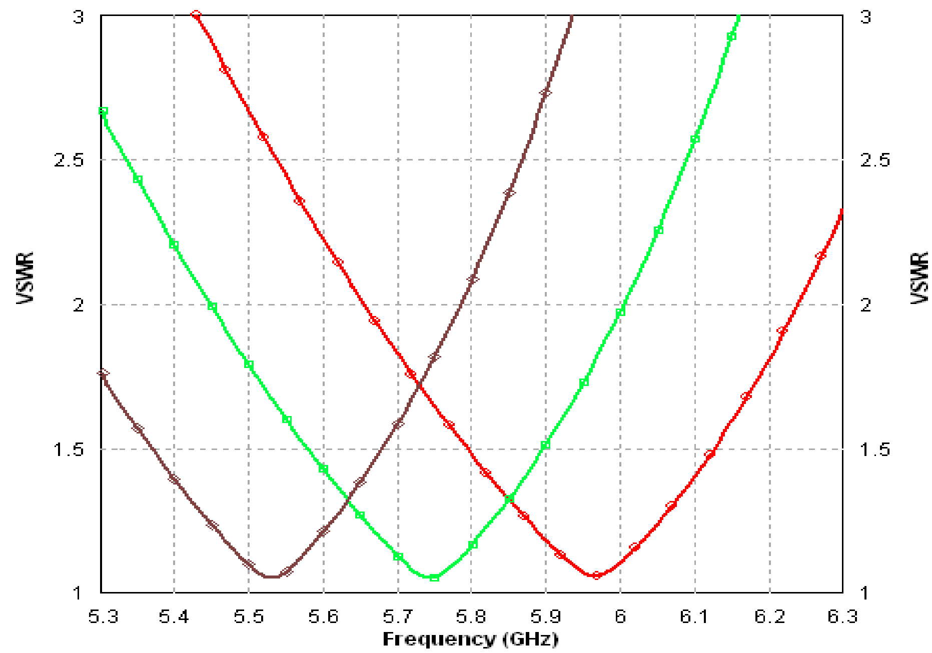
(1.6, 2.1, 2.6mm)

Input Impedance and VSWR vs. Frequency Plots for three Values of Feed Line width (w_2 =1.6, 2.1, and 2.6mm)

With increase in Feed Line width, input impedance locus shifts to lower impedance value

Feed Offset Variation in Offset-fed Cavity Backed slot Antenna





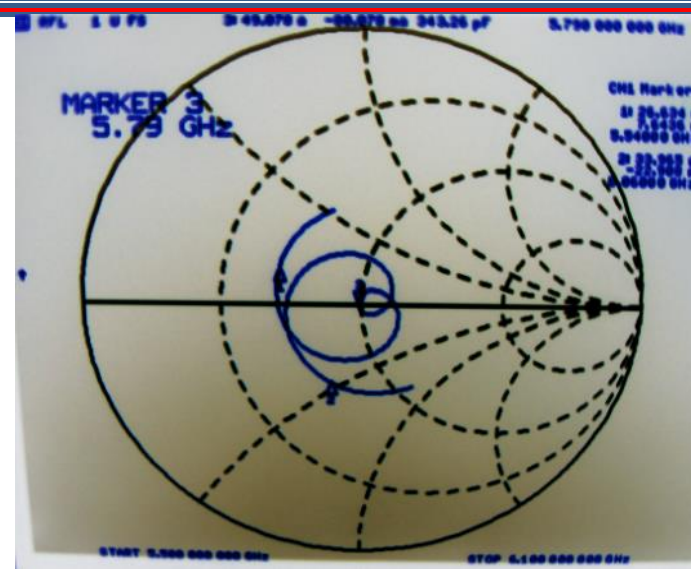
(7, 8, 9mm)

Input impedance and VSWR vs. Frequency Plots for Three Values of Microstrip Feed Offset (s =7, 8, and 9mm)

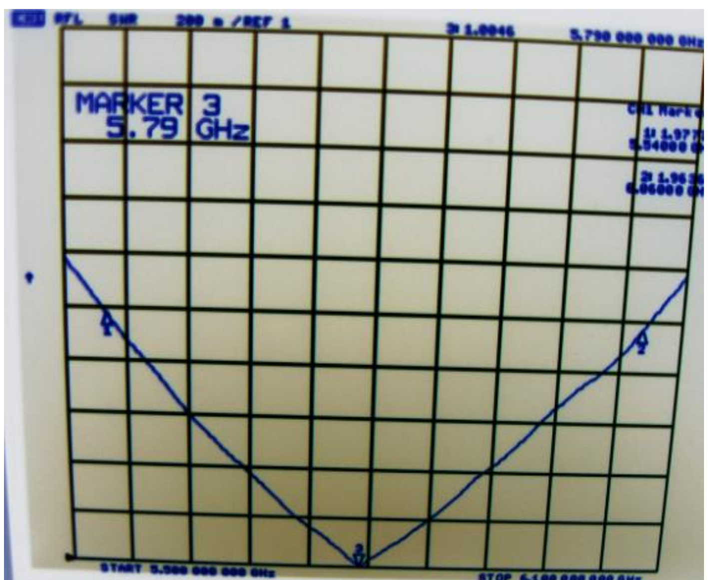
With increase in the offset from center, resonance frequency decreases and input impedance locus rotates clockwise

Measured Results of Cavity Backed slot Antenna

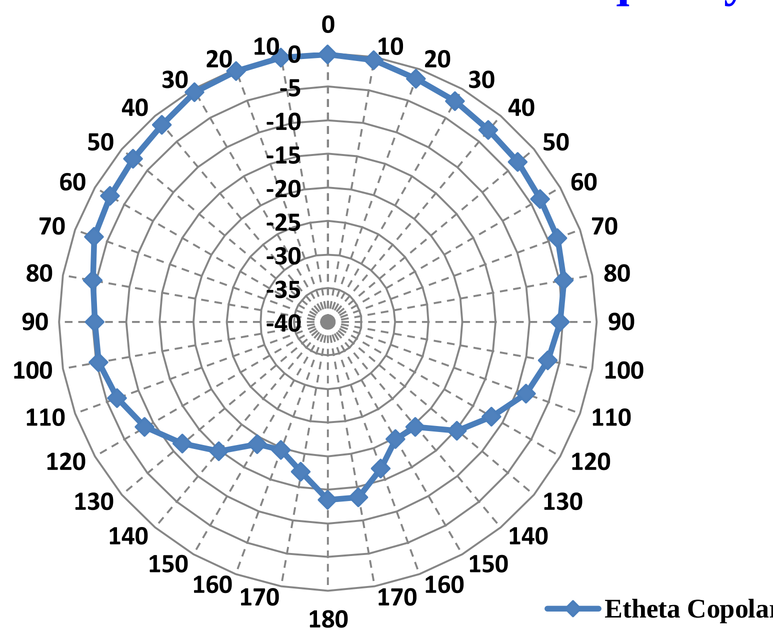
Fabricated Antenna



Smith Chart vs. Frequency



VSWR vs. Frequency

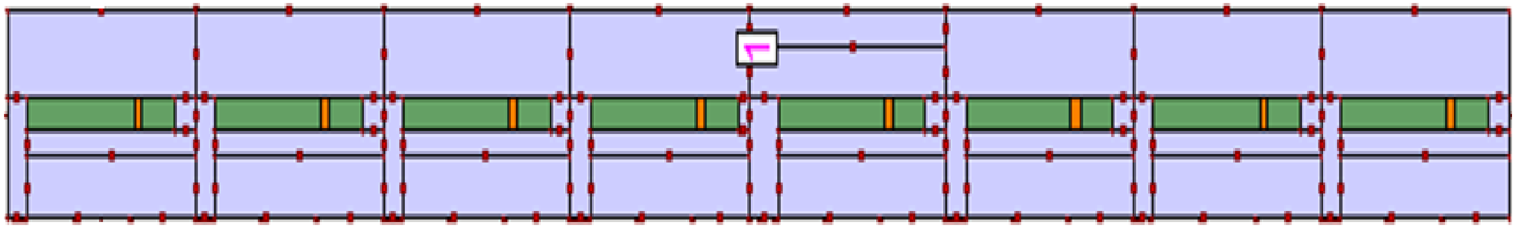


Measured E-plane Radiation Pattern

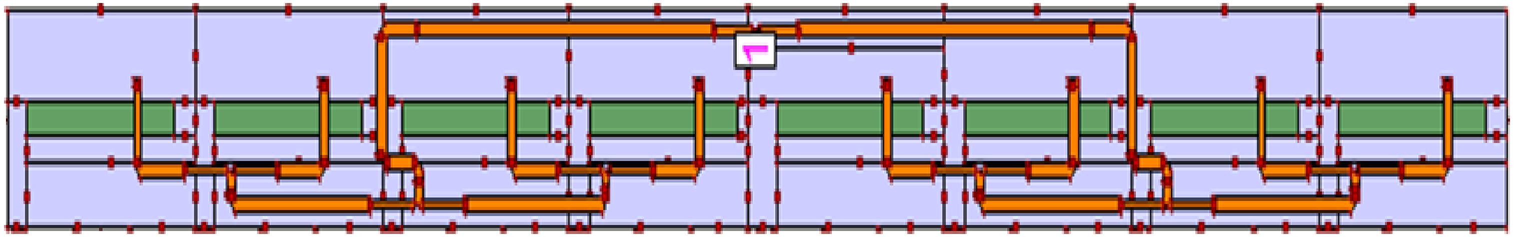
Measured Results of Cavity Backed slot Antenna

Parameters	Simulated	Measured
Frequency Range for VSWR $\leq$ 2 (GHz)	5.45-6	5.53-5.96
Maximum Gain (dB)	5.5	5.4
E-Plane HPBW(degrees)	151°	145°
Front to Back Ratio (dB)	8	12

8x1 Offset fed Cavity Backed Slot Antenna Array

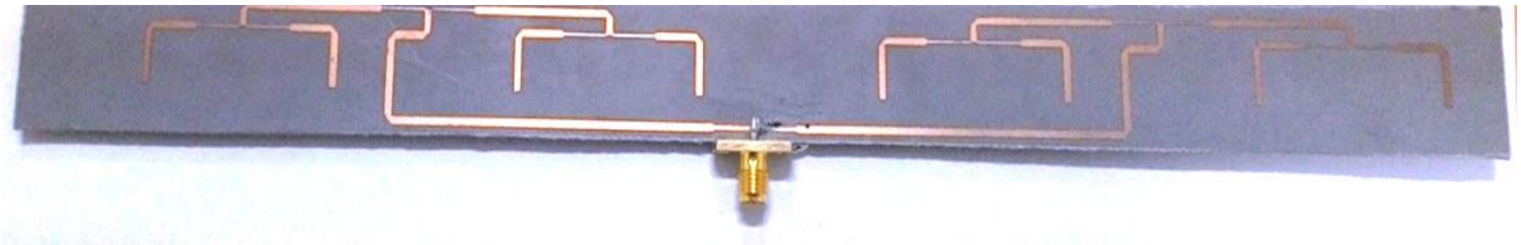


Top View



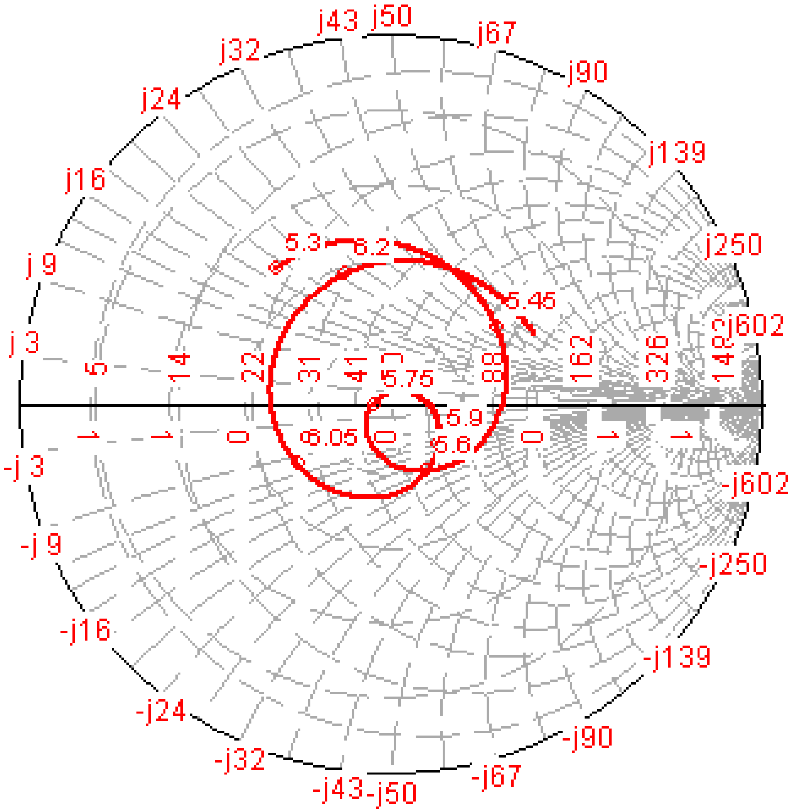
Bottom View

Integrated Cavity Backed Antenna

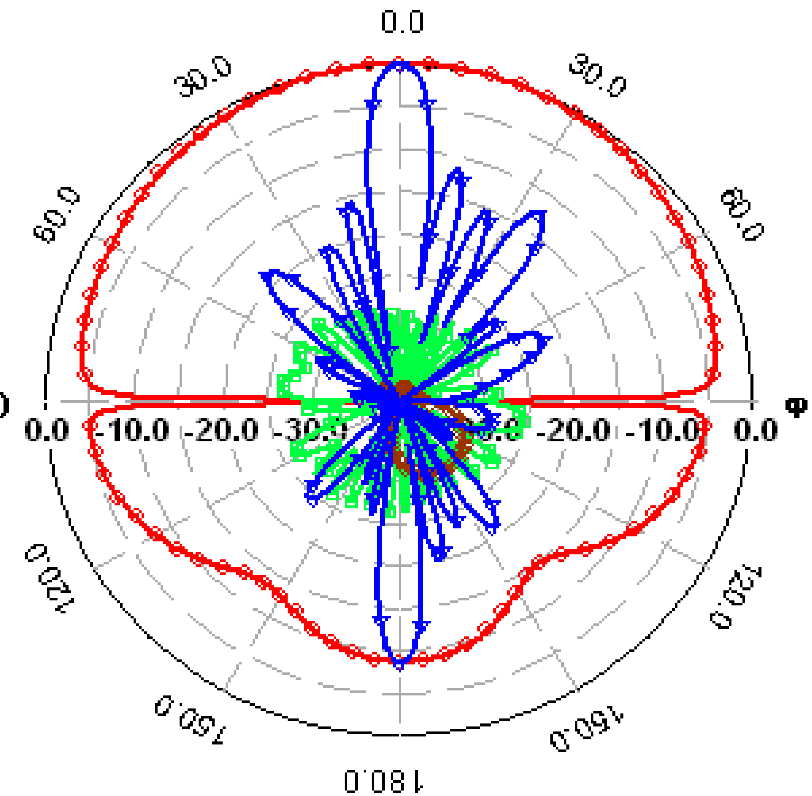


Bottom Feed Network

Results of 8x1 Cavity Backed Slot Antenna Array



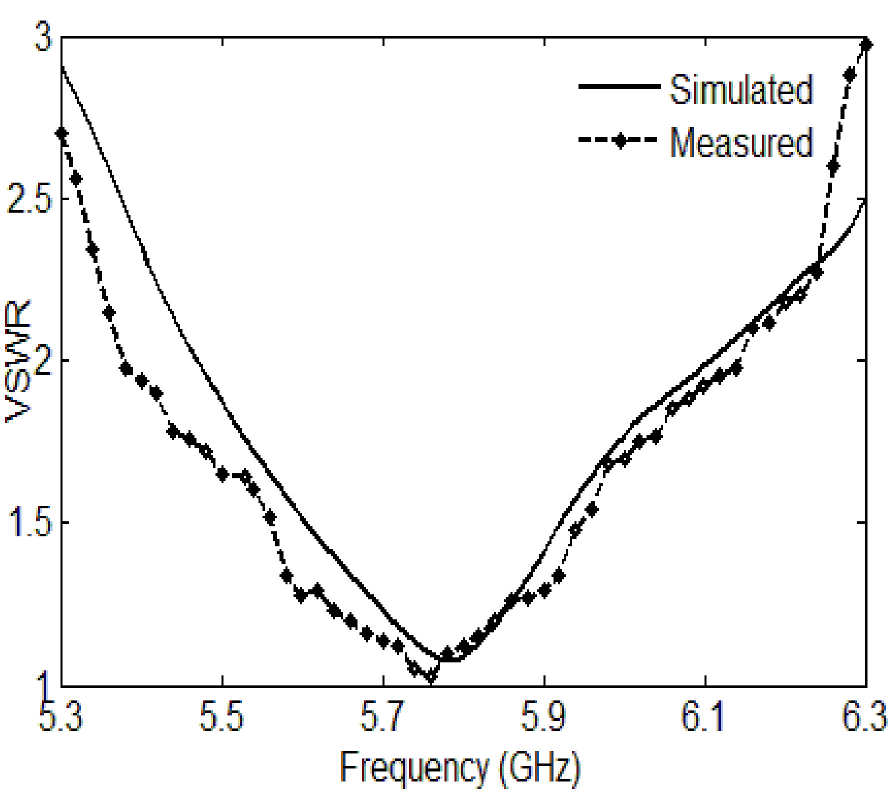
(Z$_{11}$)

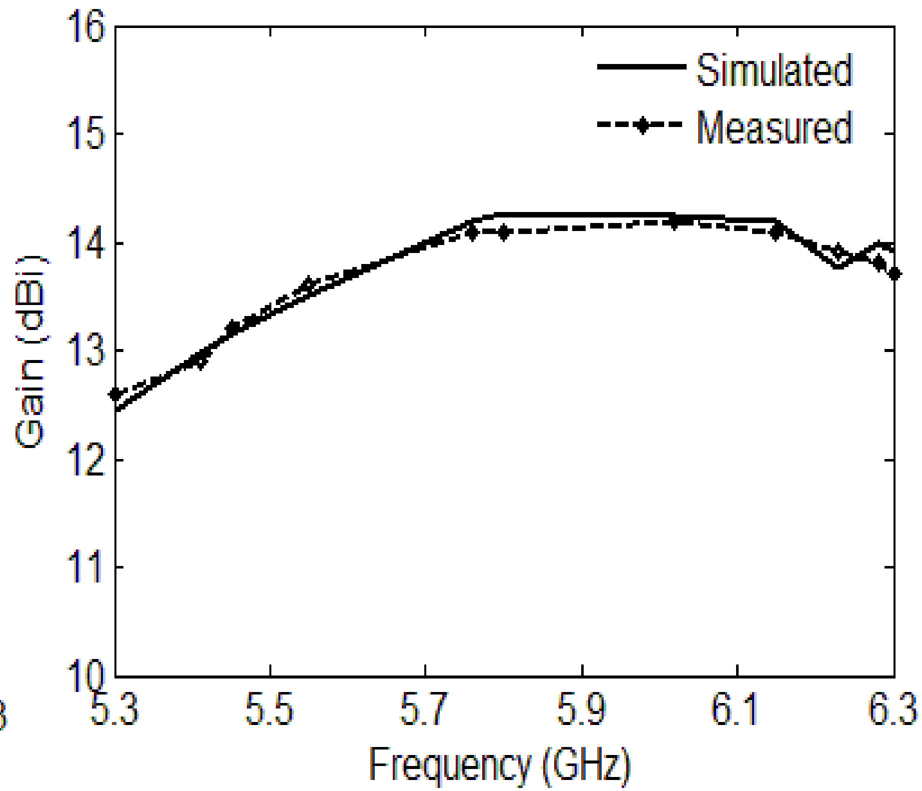


(E_Θ, E_Φ at Φ =0 degree and E_Θ, E_Φ at Φ =90 degree)

Input Impedance vs. Frequency **Radiation Pattern at 5.8 GHz**

Results of 8x1 Cavity Backed Slot Antenna Array



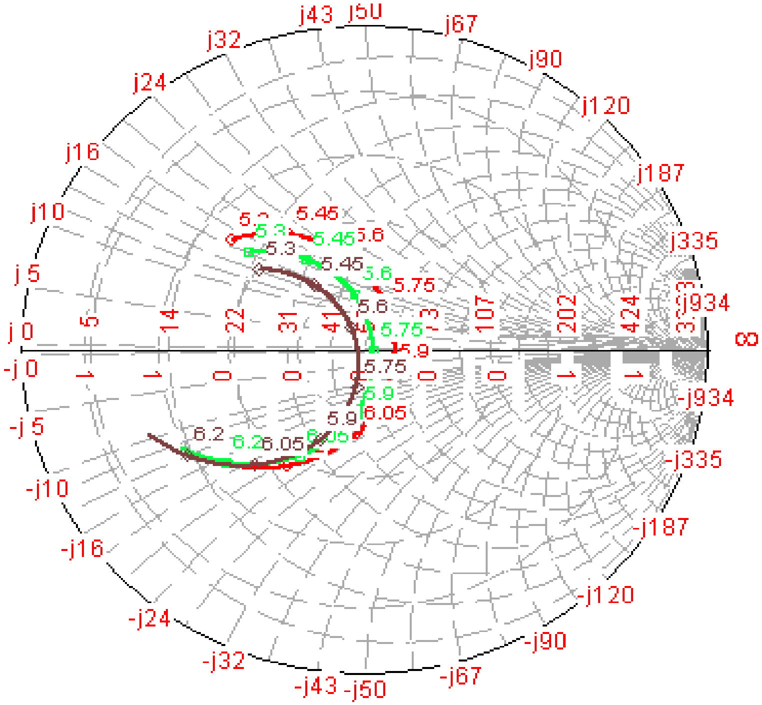


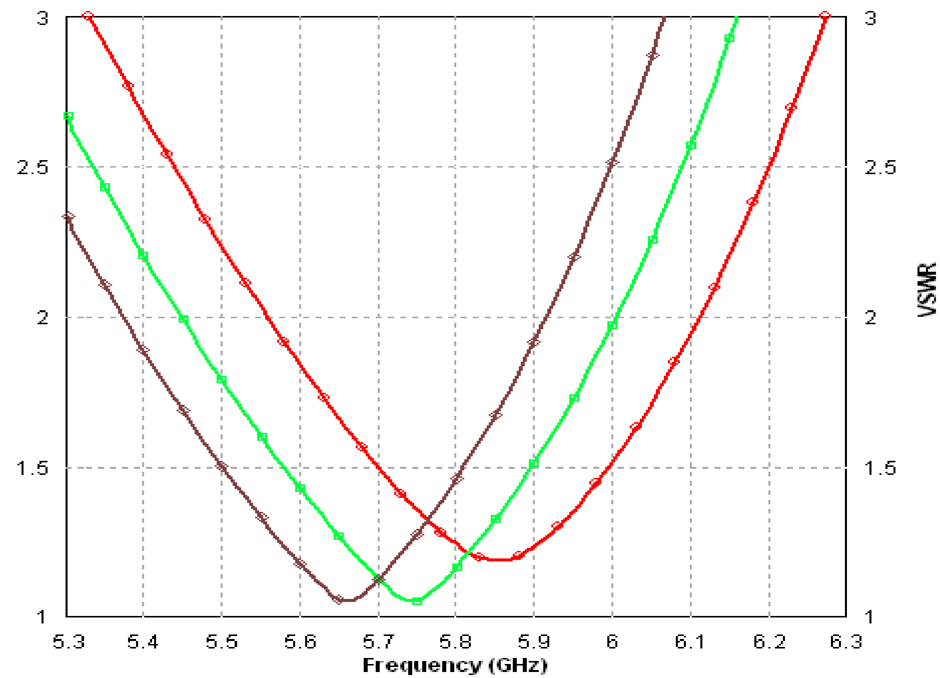
VSWR vs. Frequency Plot

BW for VSWR ≤2 is ~600 MHz

Gain vs. Frequency Plot

Feed Length Variation in Offset-fed Cavity Backed slot Antenna



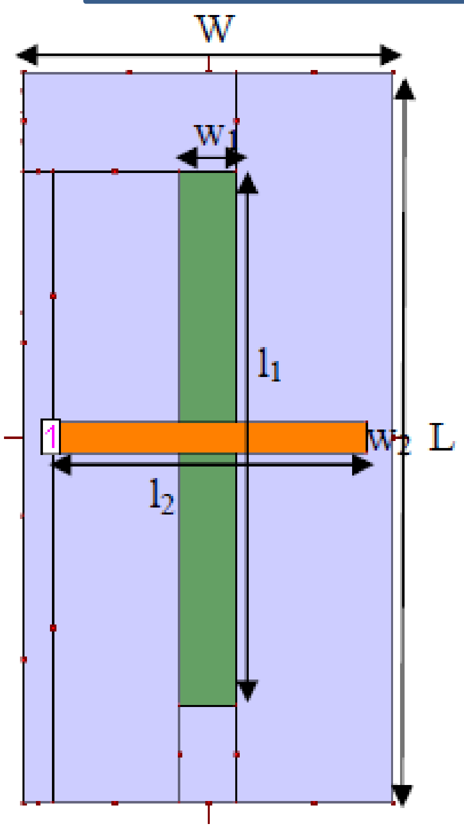


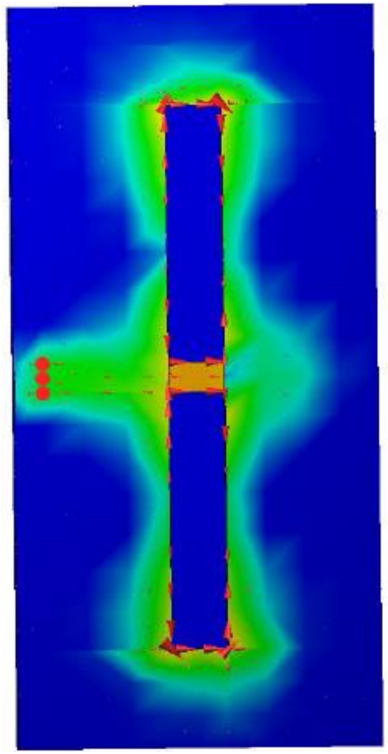
(16.5, 17.5, 18.5mm)

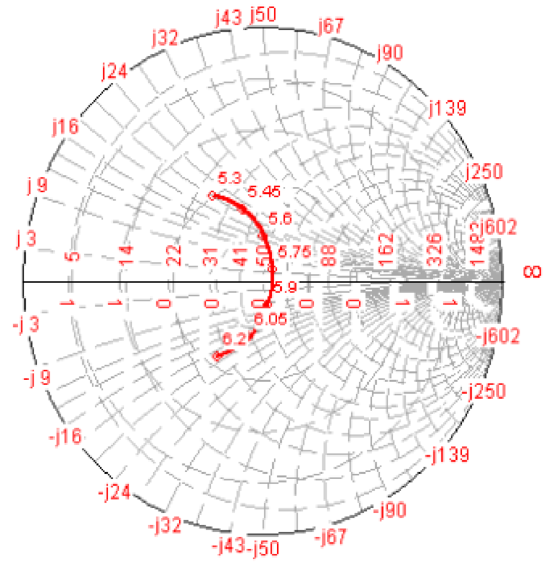
Input Impedance and VSWR vs. Frequency Plots for Three Values of Microstrip Feed Line Length (l_2 =16.5, 17.5, and 18.5mm)

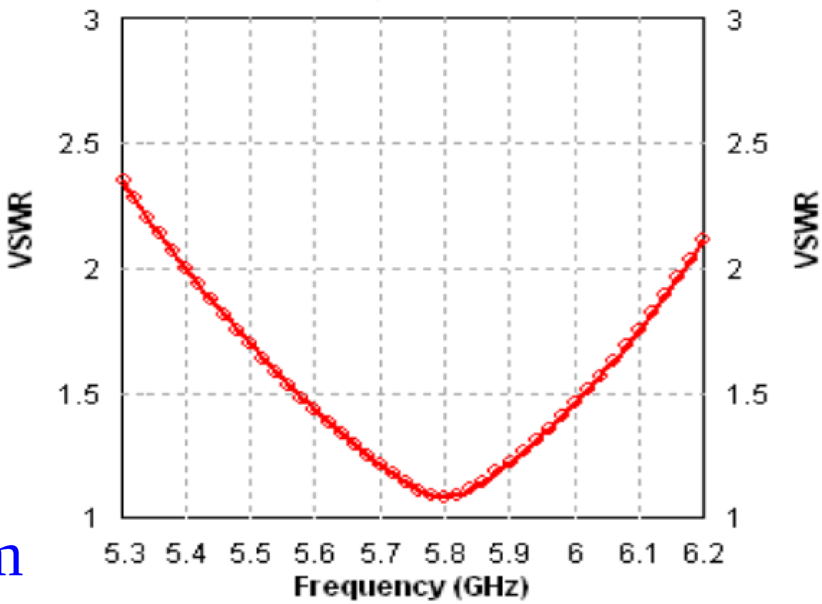
With increase in Microstrip Feed Line Length, frequency decreases and input impedance locus shifts to lower impedance value

Centre Fed Cavity Backed Slot Antenna









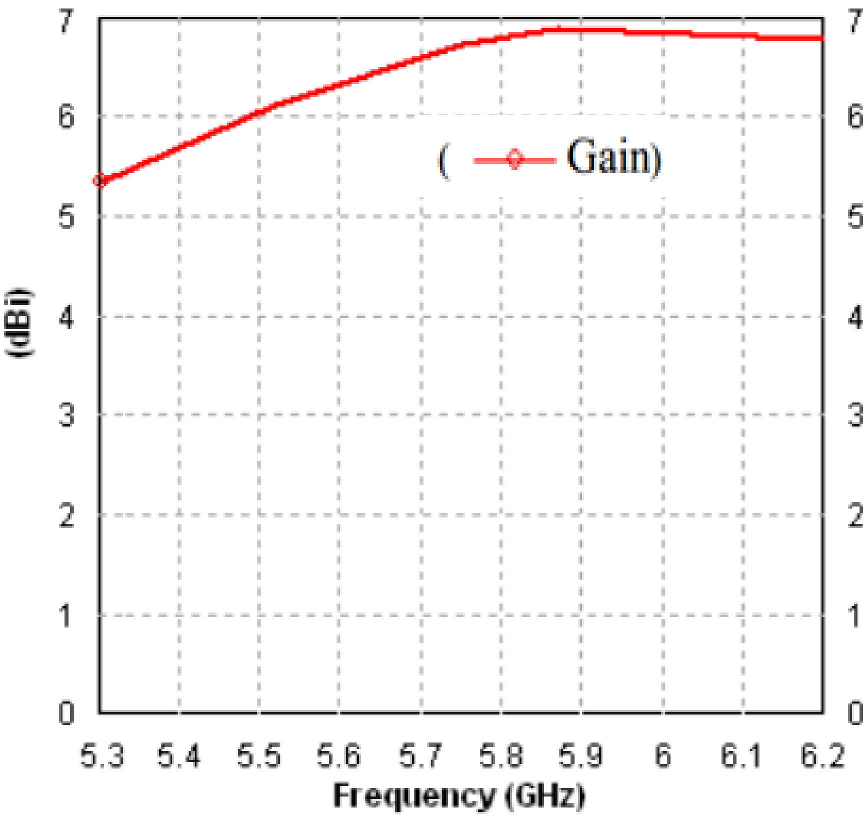
l_1 = 41 mm and w_1 = 4 mm

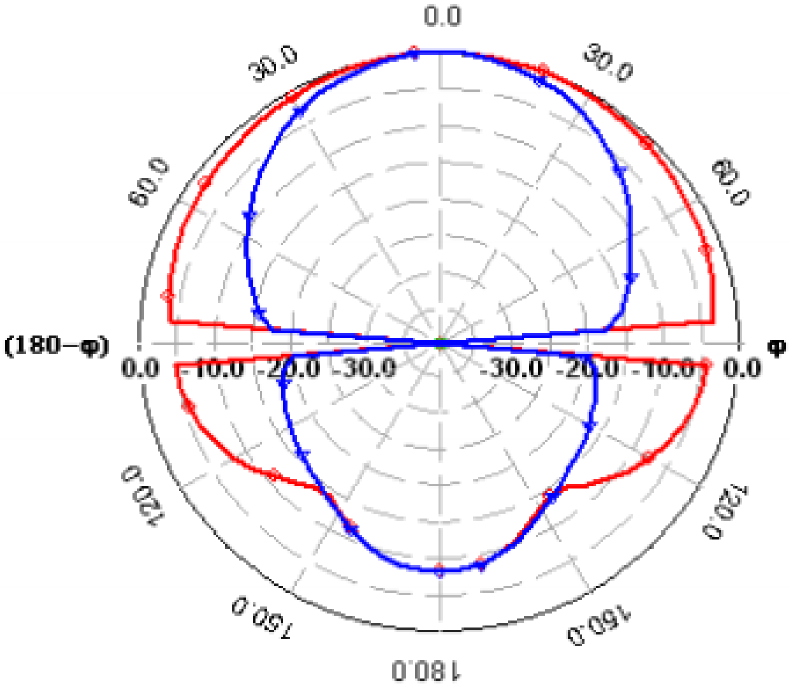
l_2 = 21.1 mm and w_2 = 2.1 mm

L = 56 mm and W = 26 mm.

Metallic cavity at distance d = 13 mm

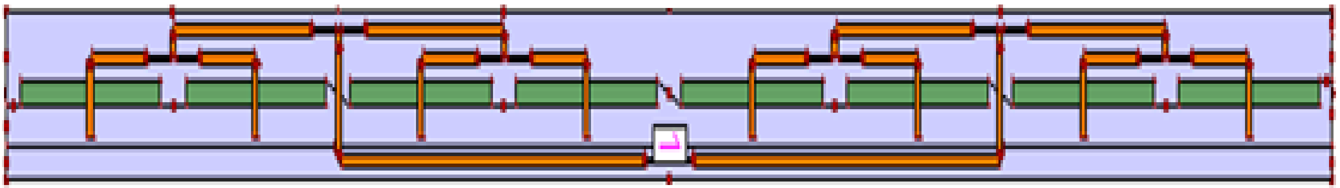
Results of Centre Fed Cavity Backed Slot Antenna



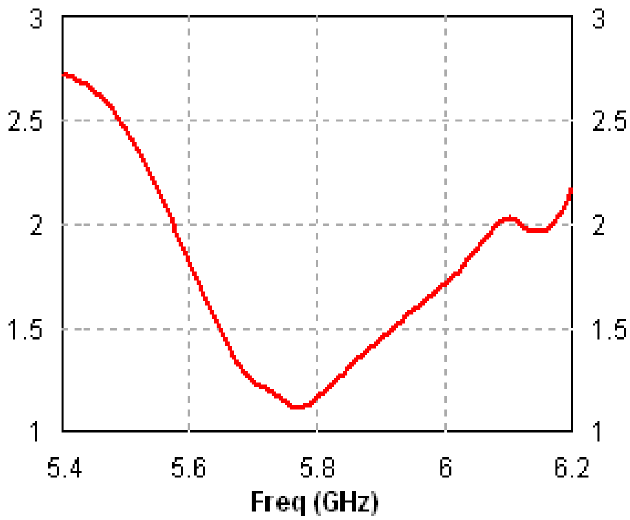


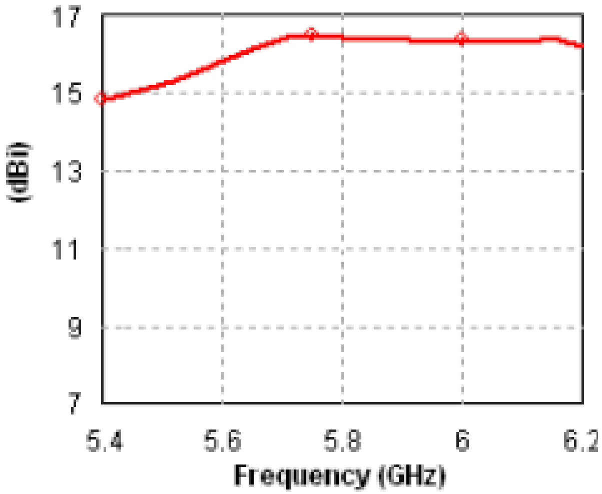
(E_Θ, E_Φ at Φ =0 degree and E_Θ, E_Φ at Φ =90 degree)

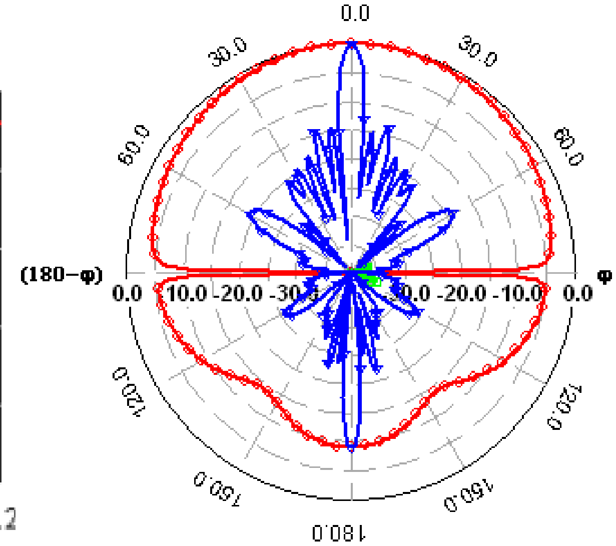
8x1 Centre fed Cavity Backed Slot Antenna Array



8x1 Centre fed Cavity Backed Slot Antenna Array







VSWR vs. Frequency

BW = 5.58 to 6.08 GHz

Gain vs. Frequency

Radiation Pattern at 5.8 GHz