Microstrip Antennas

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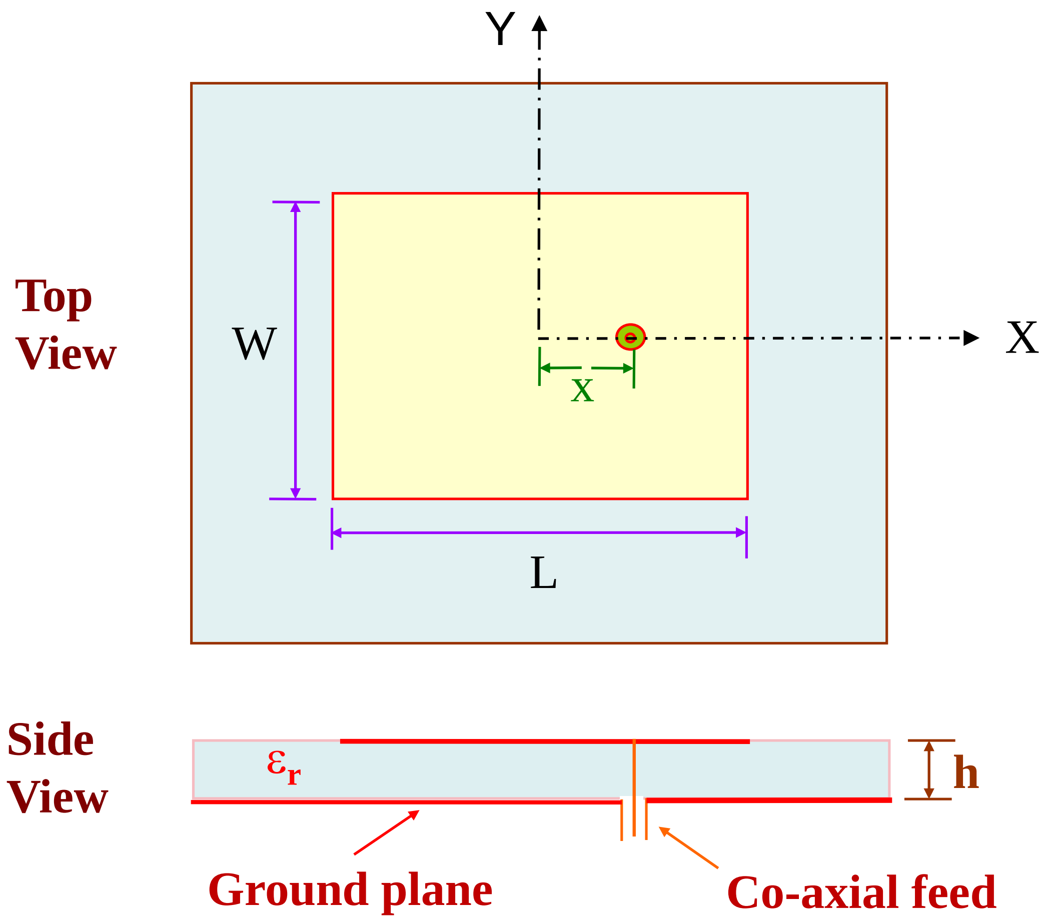
Rectangular Microstrip Antenna (RMSA)



Microwave Integrated Circuits (MIC) vs MSA

Parameters	MIC	MSA
Dielectric Constant (ε_r)	Large	Small
Thickness (h)	Small	Large
Width (W)	Generally Small (impedance dependent)	Generally Large
Radiation	Minimum (small fringing fields)	Maximum (large fringing fields)
Examples	Filters, power dividers, couplers, amplifiers, etc.	Antennas

Substrates for MSA

Substrate	Dielectric Constant (ε_r)	Loss tangent (tanδ)	Cost
Alumina	9.8	0.001	Very High
Glass Epoxy	4.4	0.02	Low
Duroid / Arlon	2.2	0.0009	Very High
Foam	1.05	0.0001	Low/ Medium
Air	1	0	NA

Advantages

- Light weight, low volume, low profile, planar configuration, which can be made conformal
- Low fabrication cost and ease of mass production
- Linear and circular polarizations are possible
- Dual frequency antennas can be easily realized
- Feed lines and matching network can be easily integrated with antenna structure

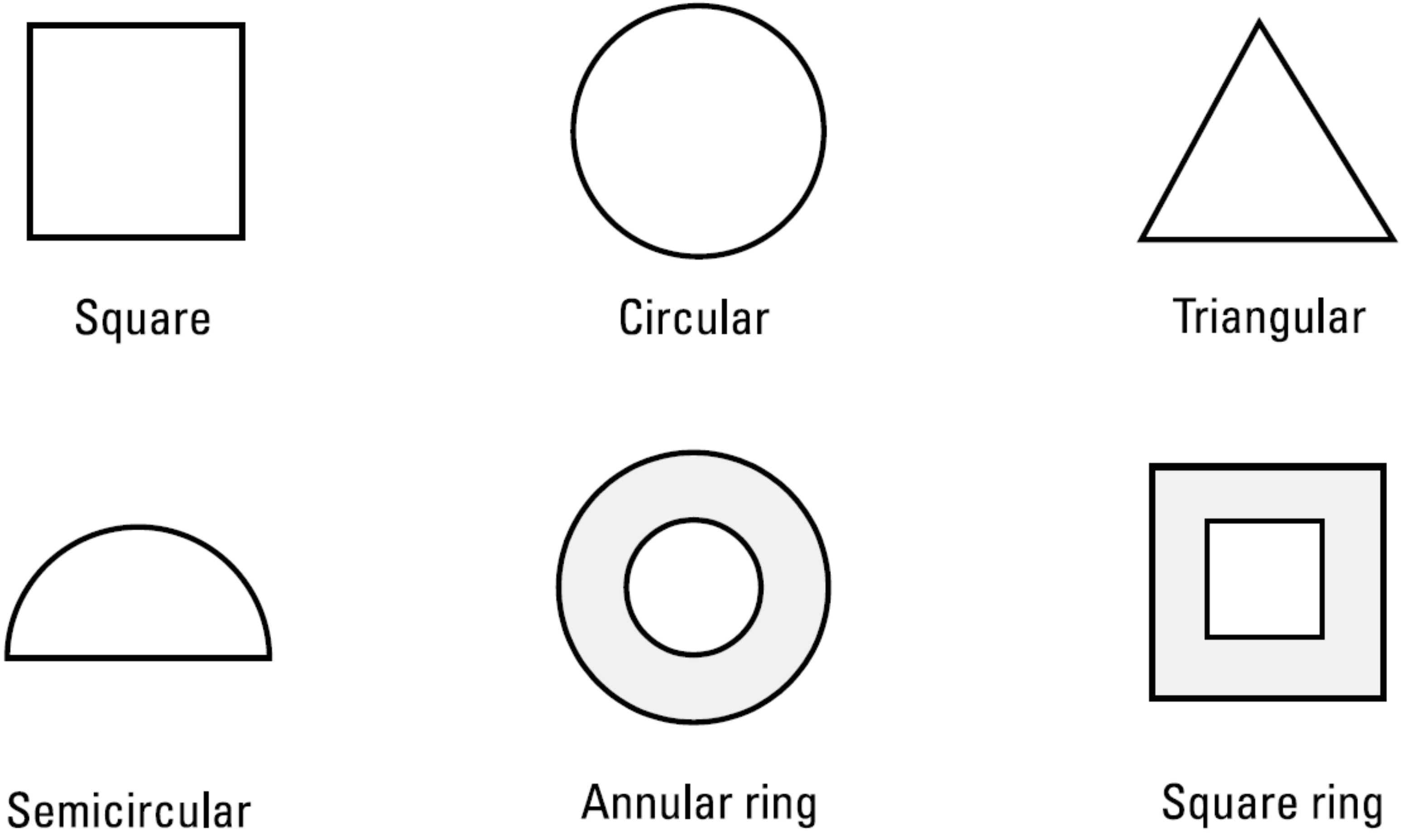
Disadvantages

- Narrow bandwidth (1 to 5%)
- Low power handling capacity
- Practical limitation on Gain (around 30 dB)
- Poor isolation between the feed and radiating elements
- Excitation of surface waves
- Tolerance problem requires good quality substrate, which are expensive
- Polarization purity is difficult to achieve
- Size is large at lower frequency

Applications

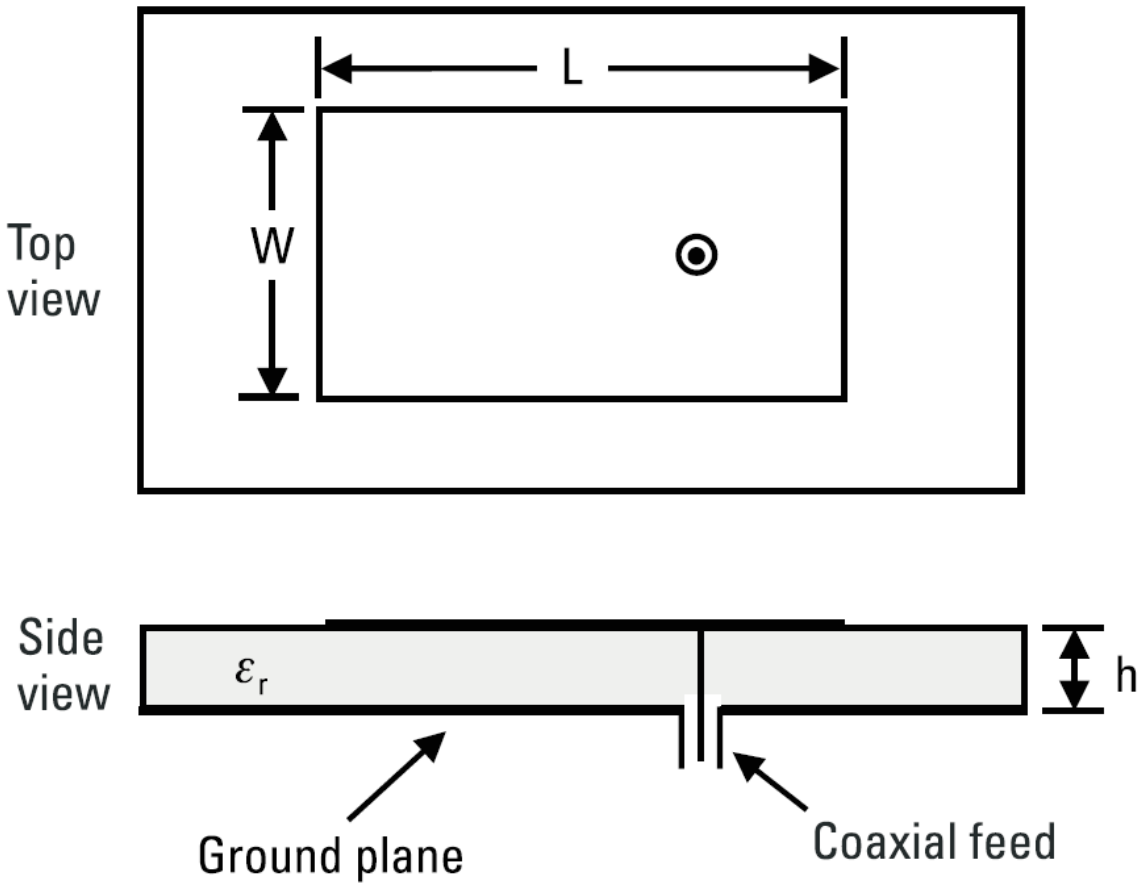
- Pagers and mobile phones
- Doppler and other radars
- Satellite communication
- Radio altimeter
- Command guidance and telemetry in missiles
- Feed elements in complex antennas
- Satellite navigation receiver
- Biomedical radiator

Various Microstrip Antenna Shapes

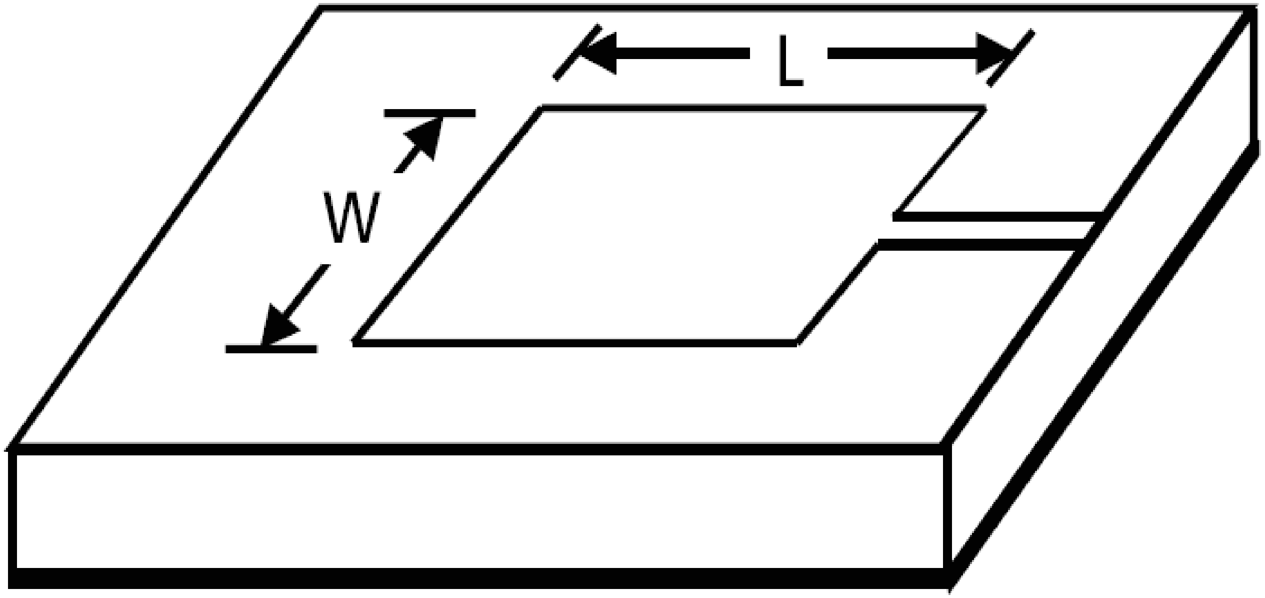


MSA Feeding Techniques

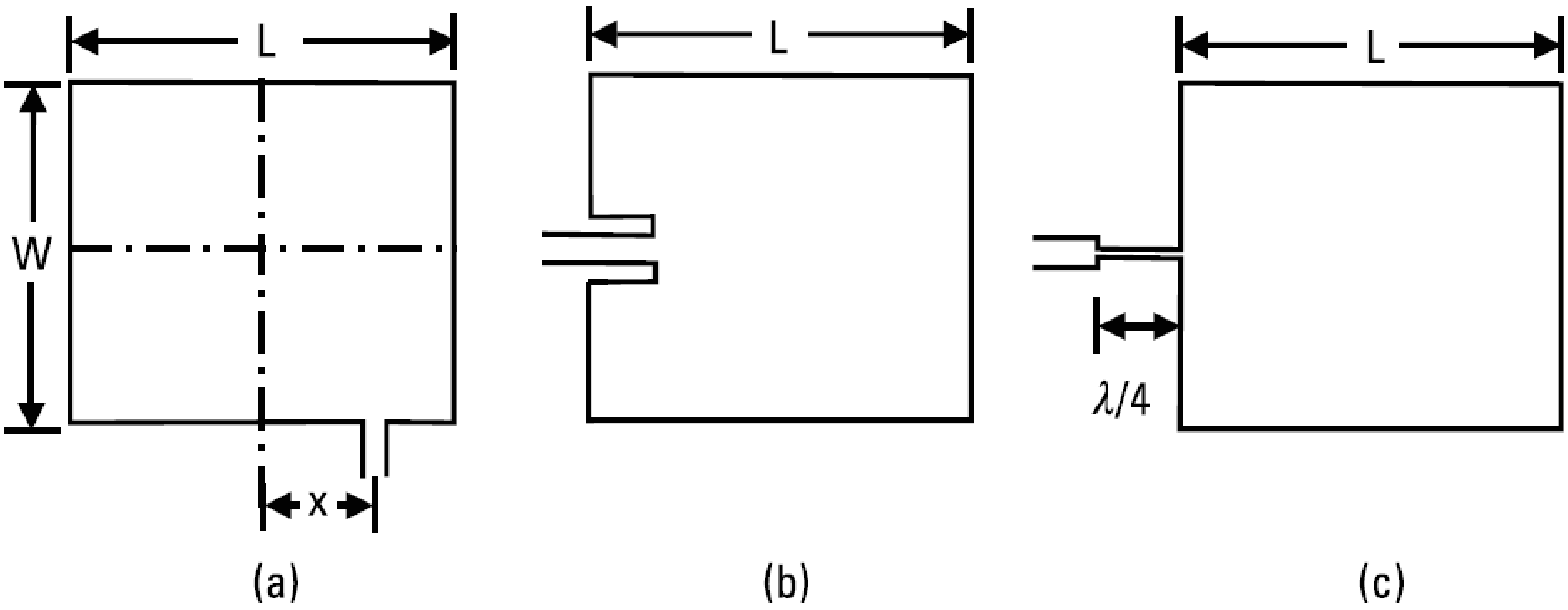
Coaxial Feed



Microstrip Line Feed

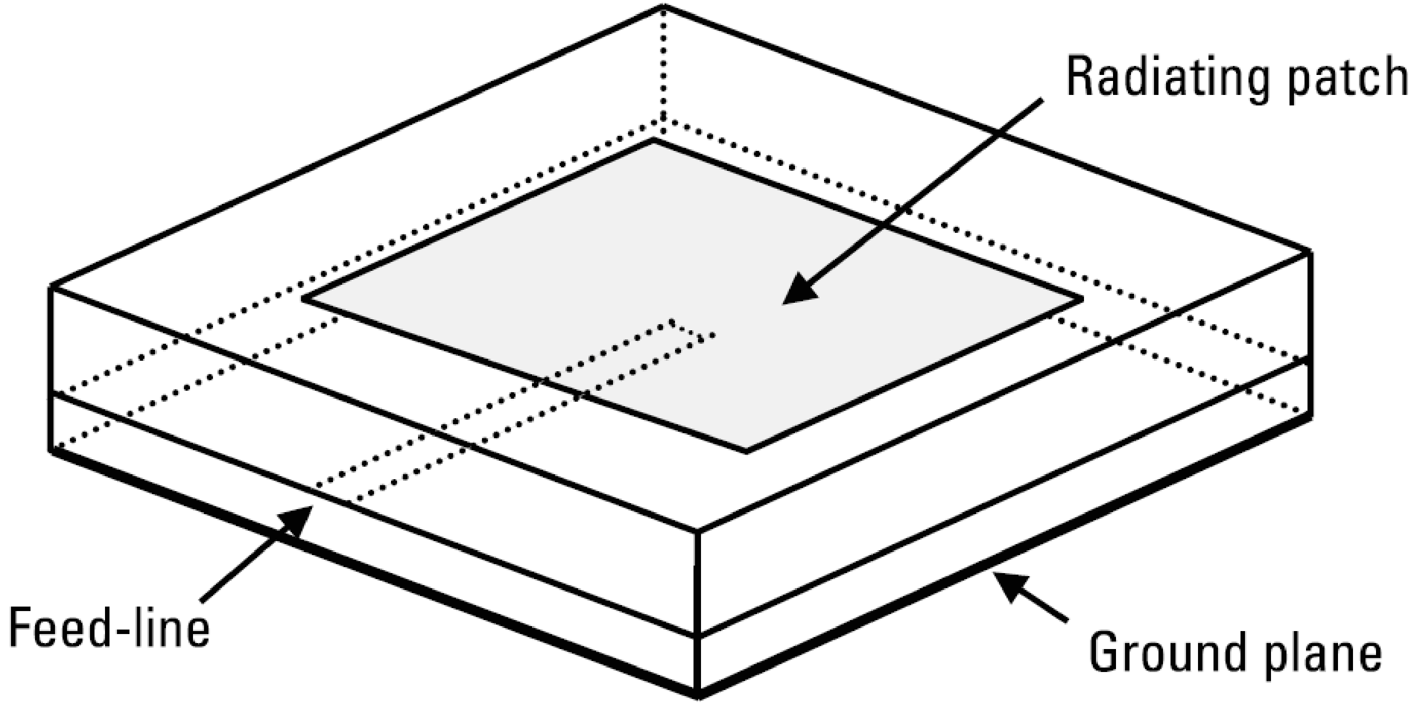


Microstrip Feed (contd.)

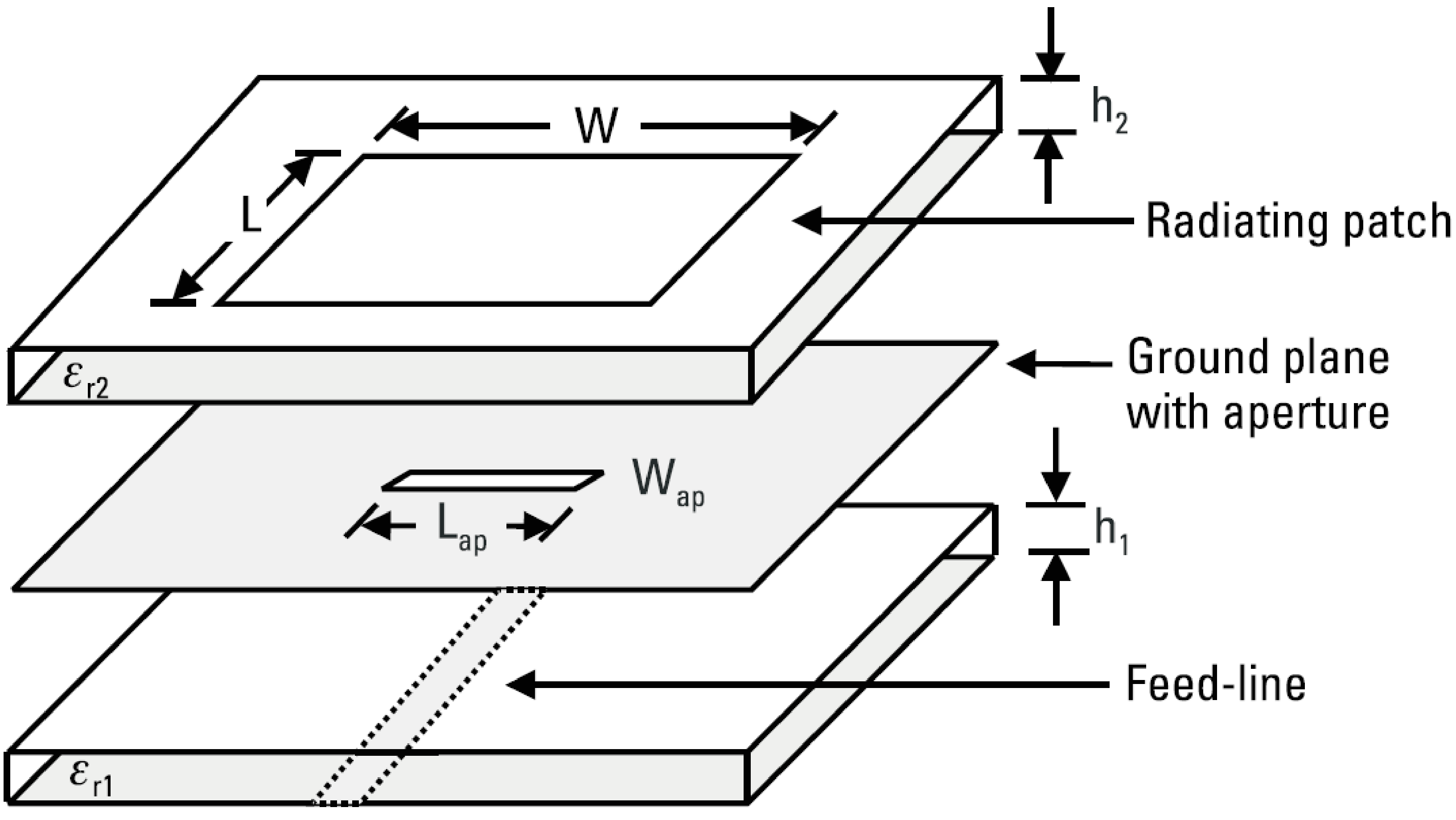


RMSA with microstrip line feed along its (a) nonradiating edge, (b) radiating edge with inset feed, and (c) radiating edge with quarter-wave transformer.

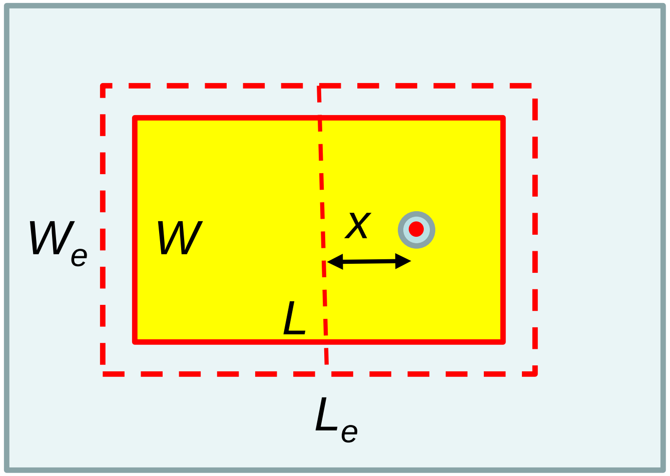
Electromagnetically Coupled Feed



Aperture Coupled Feed



RMSA: Resonance Frequency



$$L_e = L + 2\Delta L$$

$$W_e = W + 2\Delta W$$

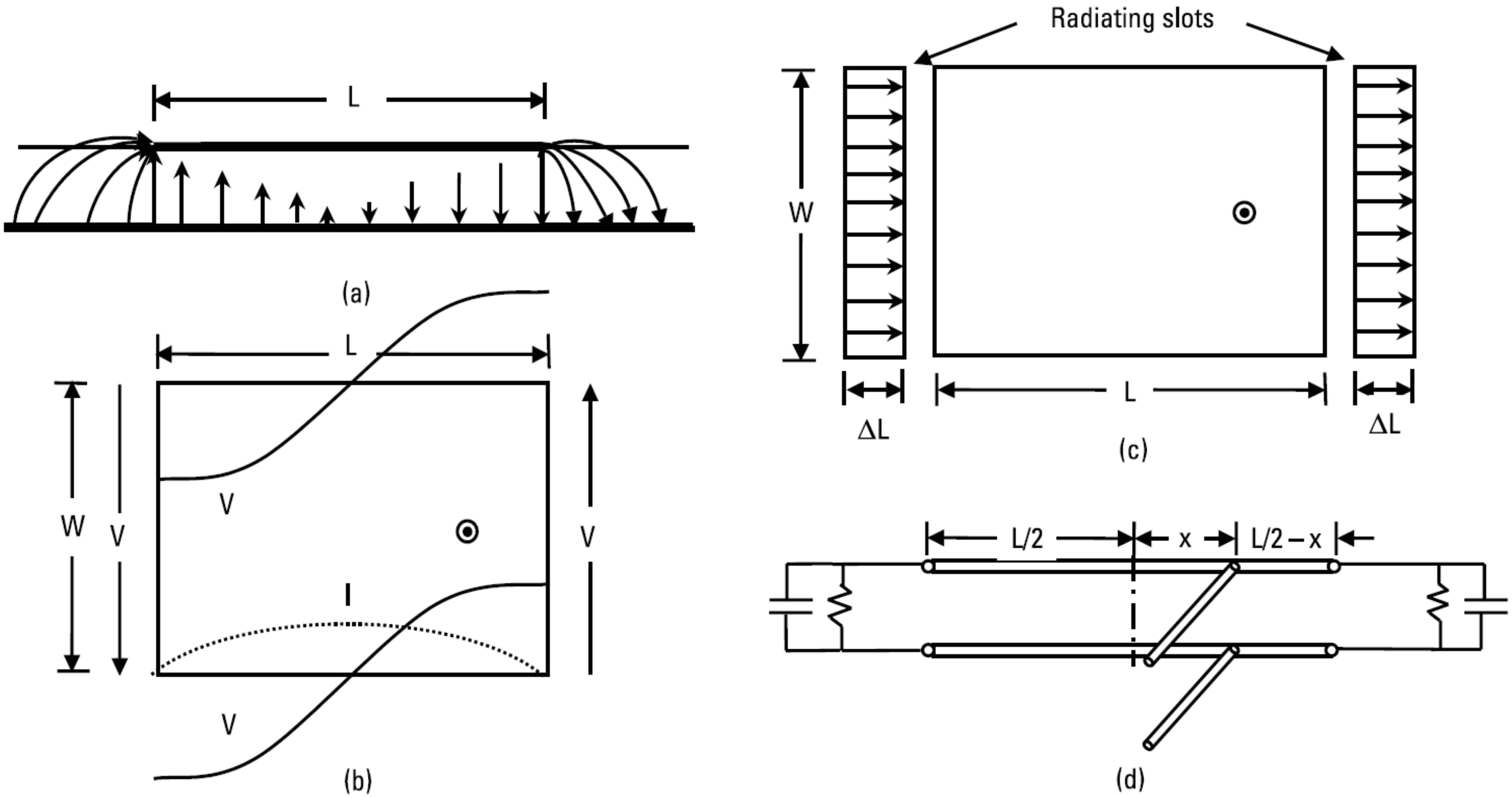
$$\Delta L \simeq \frac{h}{\sqrt{\epsilon_e}}$$

$$f_0 = \frac{c}{2\sqrt{\epsilon_e}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{1/2}$$

where m and n are orthogonal modes of excitation.

Fundamental mode is TM_{10} mode, where m =1 and n = 0.

RMSA – Characterization



Fundamental TM_{10} mode of RMSA: (a) E-field distribution, (b) (——) voltage and (· · ·) current variation, (c) two radiating slots, and (d) equivalent transmission line model.

RMSA: Design Equations

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

$$W = \frac{c}{2f_0\sqrt{\frac{(\epsilon_r + 1)}{2}}}$$

Smaller or larger W can be taken than the W obtained from this expression.

BW α W and Gain α W

$$\boxed{L_e = L + 2\Delta L = \frac{\lambda_0}{2\sqrt{\epsilon_e}} = \frac{c}{2f_0\sqrt{\epsilon_e}}}$$

Choose feed-point *x* between *L*/6 to *L*/4.

RMSA: Design Example

Design a RMSA for Wi-Fi application (2.400 to 2.483 GHz)

Chose Substrate: $\varepsilon_r = 2.32$, h = 0.16 cm and tan $\delta = 0.001$

$$W = \frac{c}{2f_0\sqrt{\frac{(\epsilon_r + 1)}{2}}}$$

$= 3 \times 10^{10} / (2 \times 2.4415 \times 10^9 \times \sqrt{1.66})$

$= 4.77$ cm. **W = 4.7 cm is taken**

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

= 2.23

$$L_e = \frac{c}{2f_0\sqrt{\epsilon_e}}$$

$= 3 \times 10^{10} / (2 \times 2.4415 \times 10^9 \times \sqrt{2.23})$ cm

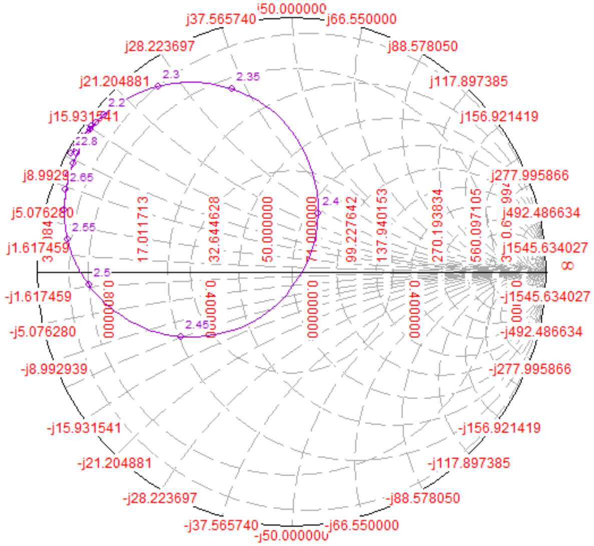
$= 4.11$ cm

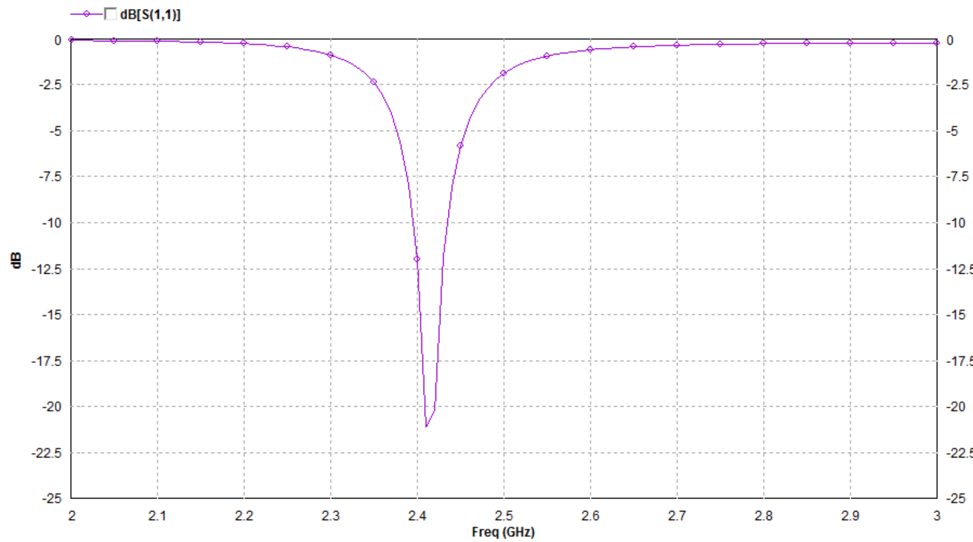
$L = L_e - 2\,\Delta L = 4.11 - 2 \times 0.16 / \sqrt{2.23} =$ **3.9 cm**

RMSA: Design Example – Simulation using IE3D

L = 3.9 cm, W = 4.7 cm, x = 0.7 cm

ε_r = 2.32, h = 0.16 cm and tan δ = 0.001





Z_{in} = 54Ω at f = 2.414 GHz

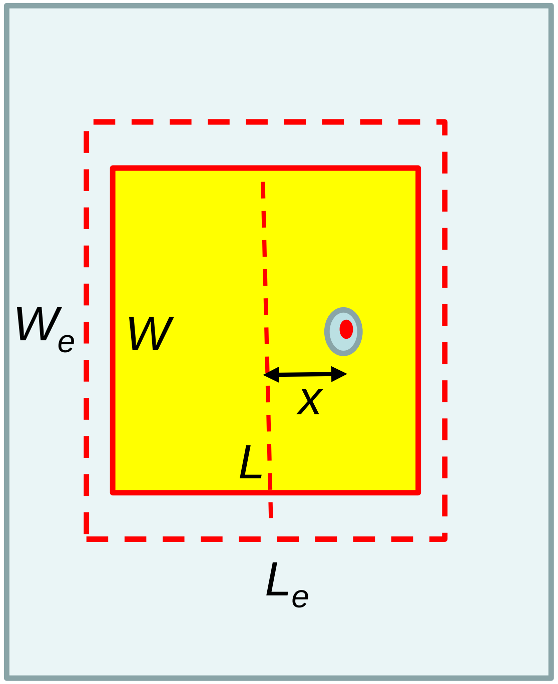
BW for |S11| ≤ -10 dB is from 2.395 to 2.435 GHz = 40 MHz

Designed f = 2.4415 and Simulated f = 2.414 GHz

% error = 1.1%. Also, BW is small.

SOLUTION: Increase h and reduce L

Effect of Various Parameters on Performance of RMSA



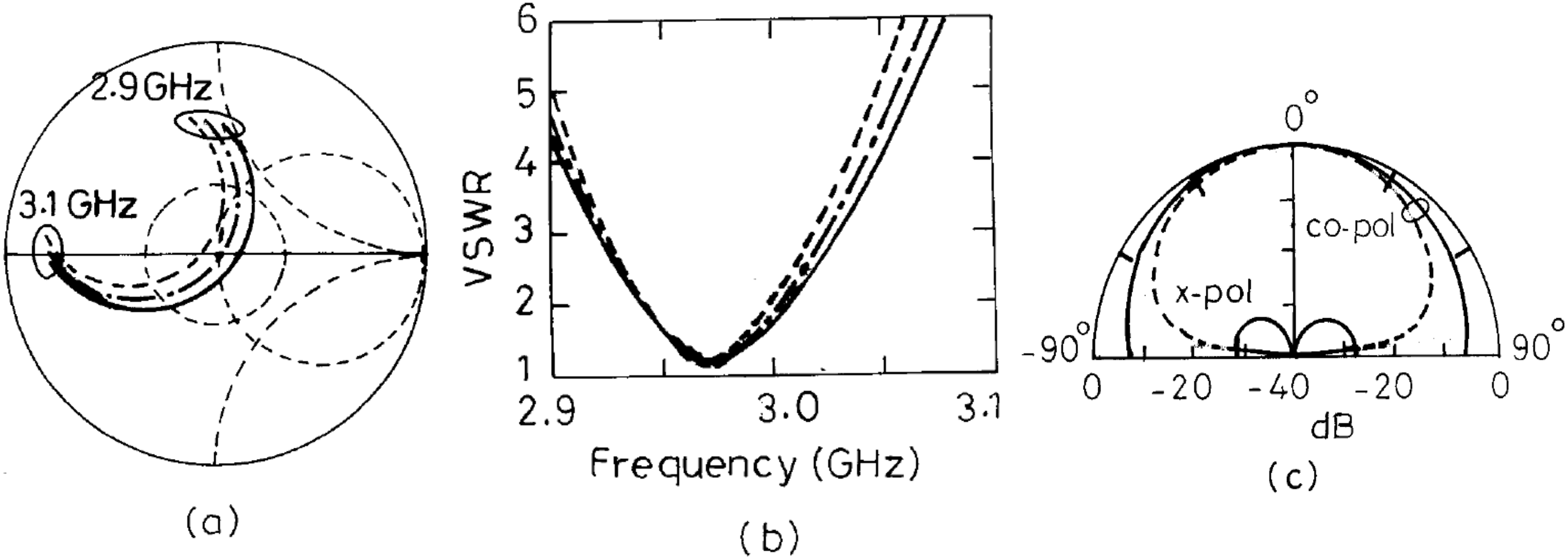
L = 3 cm and W = 4 cm

Substrate parameters: ε_r = *2.55*, *h* = *0.159 cm*, *and tan* δ = *0.001*

*P*robe diameter = 0.12 cm for SMA connector.

RMSA is analyzed using commercially available IE3D software.

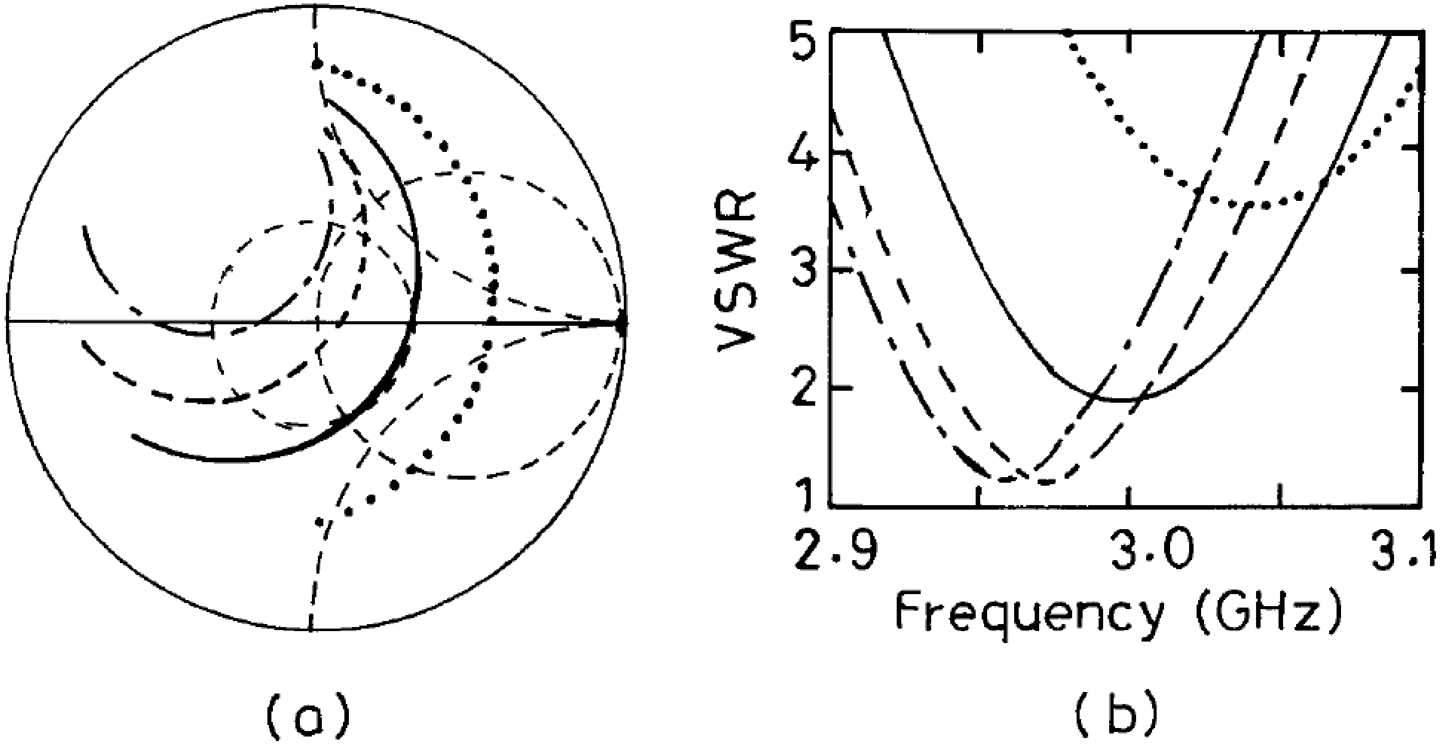
Effect of Feed Point Location (x)



(a) Input impedance and (b) VSWR plots of the RMSA for three different values of x, (- - -) 0.55, (– - –) 0.60, and (——) 0.65 cm, and (c) its radiation pattern at 2.975 GHz for x = 0.65 cm; (——) E-plane copolar and cross-polar and (- - -) H-plane copolar. For Infinite Ground Plane

With increase in x, input impedance plot shifts right towards higher impedance values.

Effect of Width (*W*)

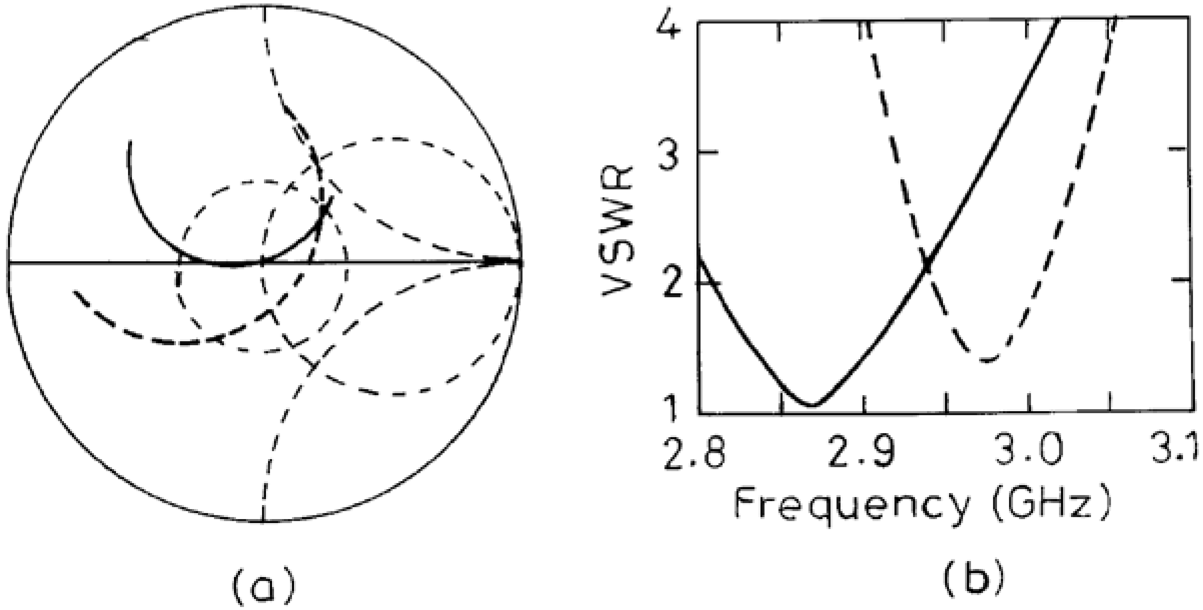


(a) Input impedance and (b) VSWR plots of the RMSA for four different *W*:
(· · ·) 2, (——) 3, (- - -) 4, (– - –), 5 cm.

With increase in *W*, aperture area, ε_e and fringing fields increase, hence frequency decreases and input impedance plot shifts towards lower impedance values.

BW α *W* and Gain α *W*

Effect of Thickness (h)



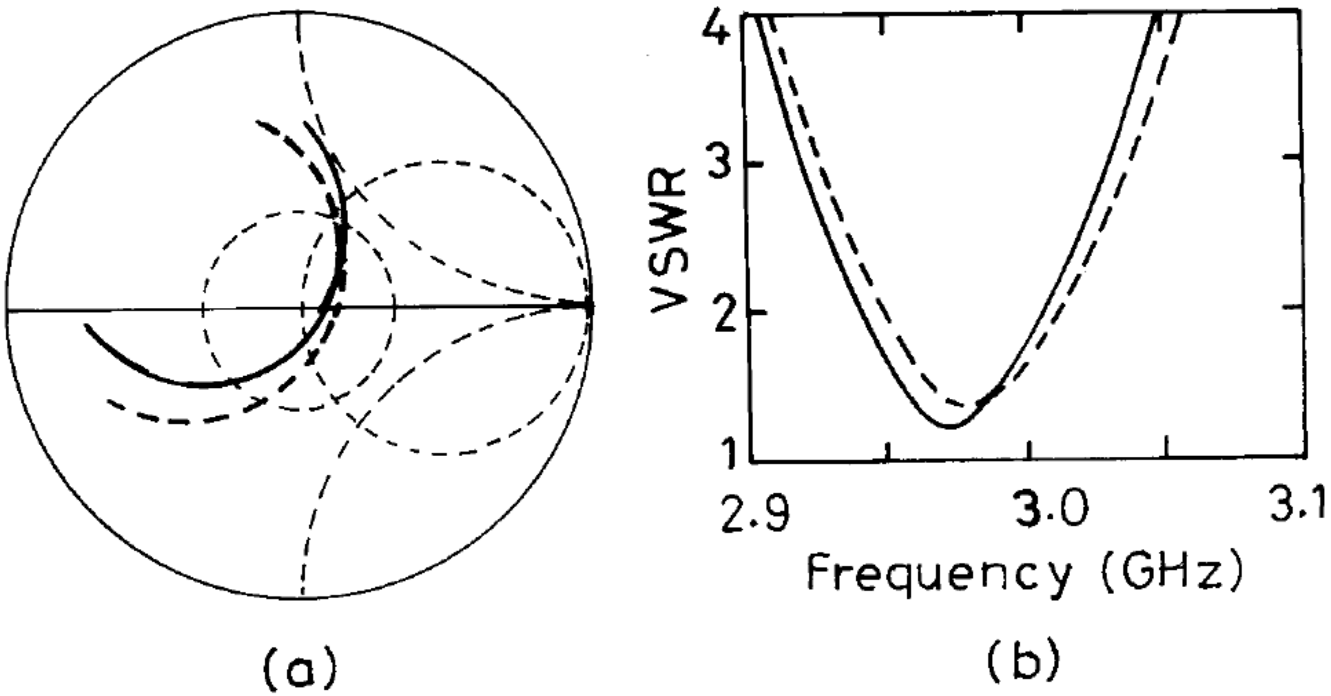
BW α h/λ_0

(a) Input impedance and (b) VSWR plots of the RMSA for two different values of h: (- - -) 0.159 and (——) 0.318 cm.

As h increases, fringing fields and probe inductance increase, frequency decreases and input impedance plot shifts upward.

However, $\frac{h}{\lambda_0} \leq \frac{0.3}{2\pi\sqrt{\epsilon_r}}$ to reduce surface waves

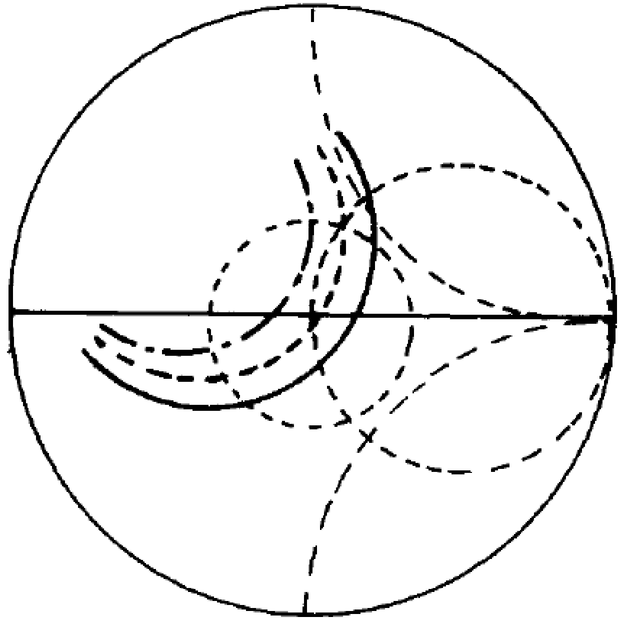
Effect of Probe Diameter

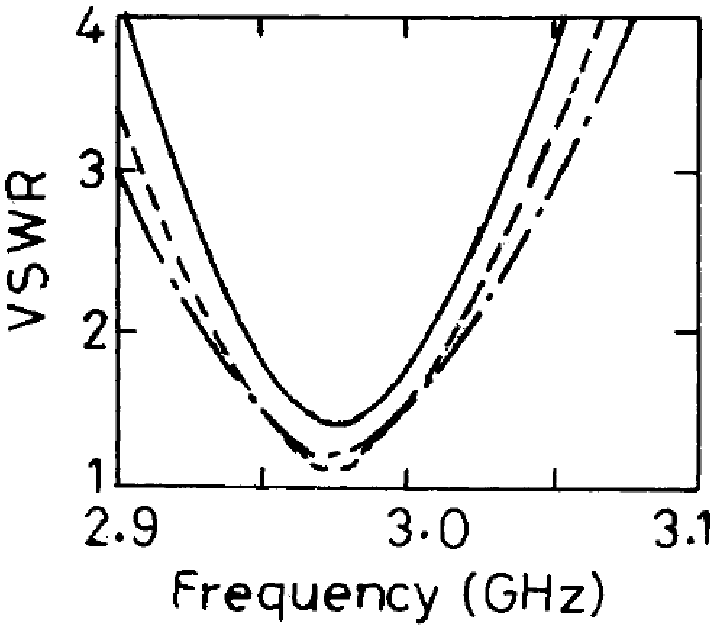


(a) Input impedance and (b) VSWR plots of the RMSA for two different connectors: (——) SMA and (- - -) N-type.

As probe diameter decreases, its inductance increases, so resonance frequency decreases and input impedance locus moves upward to the inductive region.

Effect of Loss Tangent (tanδ)





(a) Input impedance and (b) VSWR plots of the RMSA for different values of tan δ: (——) 0.001, (- - -) 0.01, and (– - –) 0.02.

With increase in tan δ, dielectric losses increase, so input impedance locus moves left towards lower impedance value. BW increases but efficiency and gain decrease.

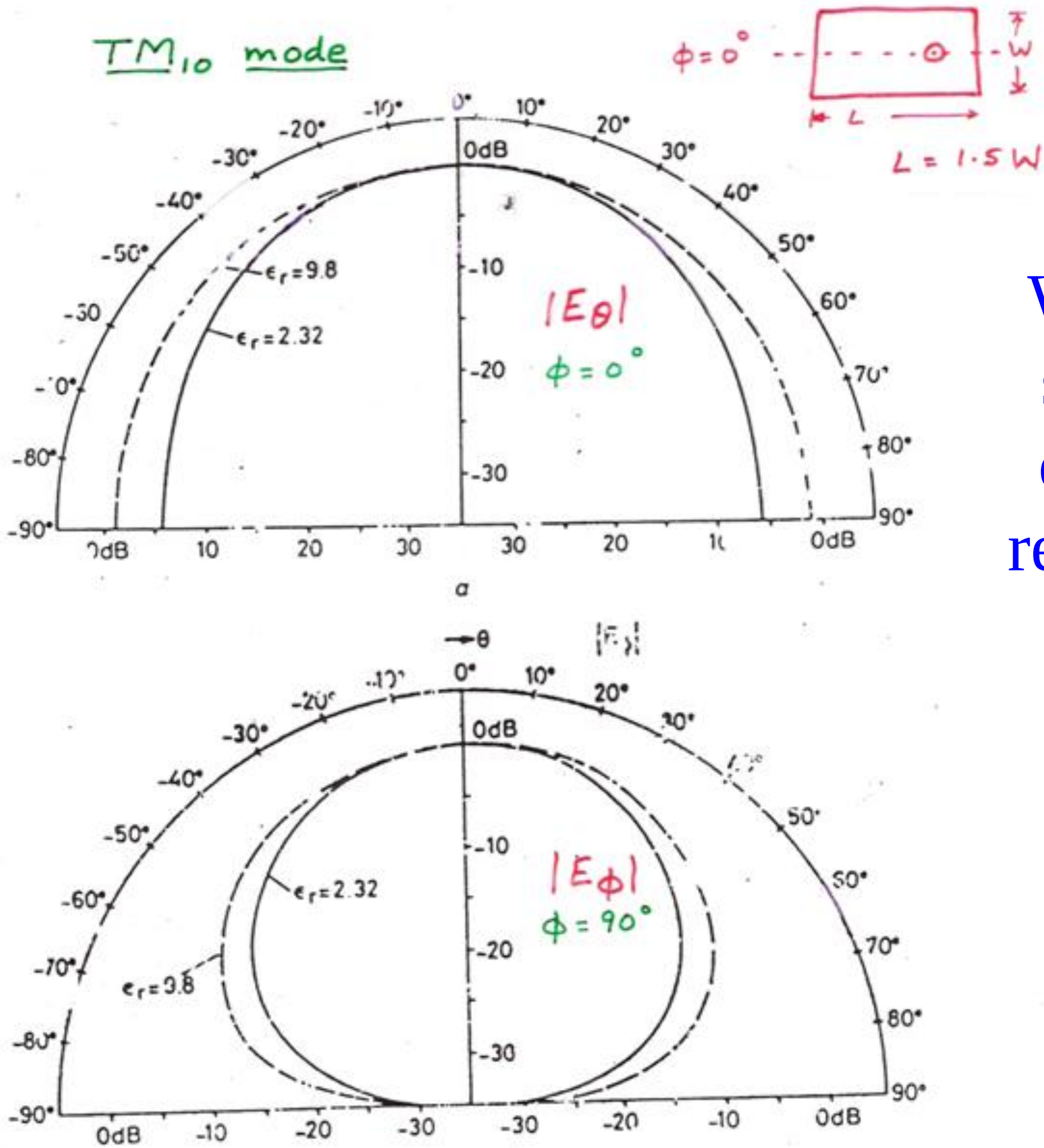
Effect of Dielectric Constant (ε_r)

Effect of ϵ_r on the Performance of RMSA
(h = 0.159 cm and tan δ = 0.001)

ϵ_r	L (cm)	W (cm)	x (cm)	f_0 (GHz)	R_{in} (Ω)	BW (MHz)	Gain (dB)
1	4.65	6.2	1.00	2.997	54	74	10.0
2.55	3.0	4.0	0.65	2.974	62	64	6.8
4.3	2.3	3.1	0.40	2.986	52	49	5.6
9.8	1.51	2.0	0.20	3.002	51	30	4.4

With decrease in ε_r, both L and W increase, which increases fringing fields and aperture area, hence both BW and Gain increase.

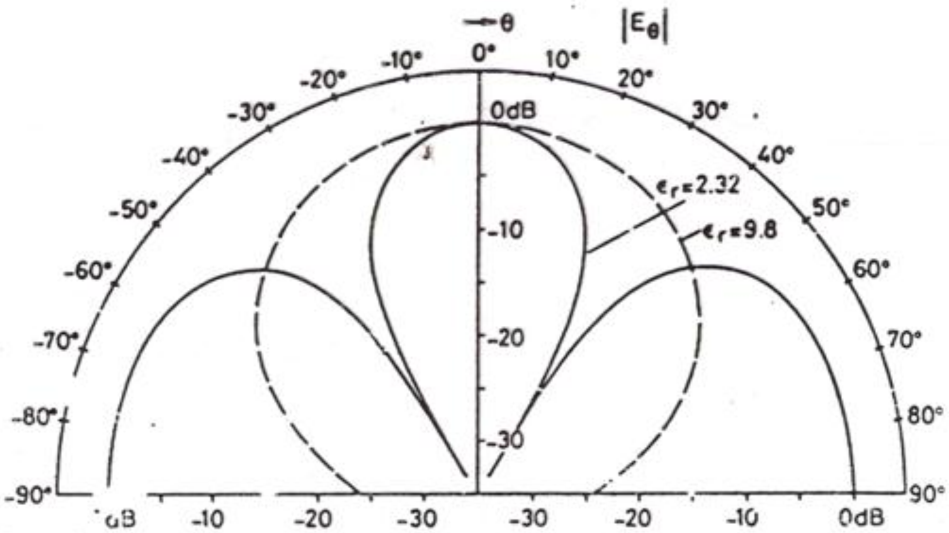
RMSA – Pattern for Different ε_r (TM$_{10}$ mode)

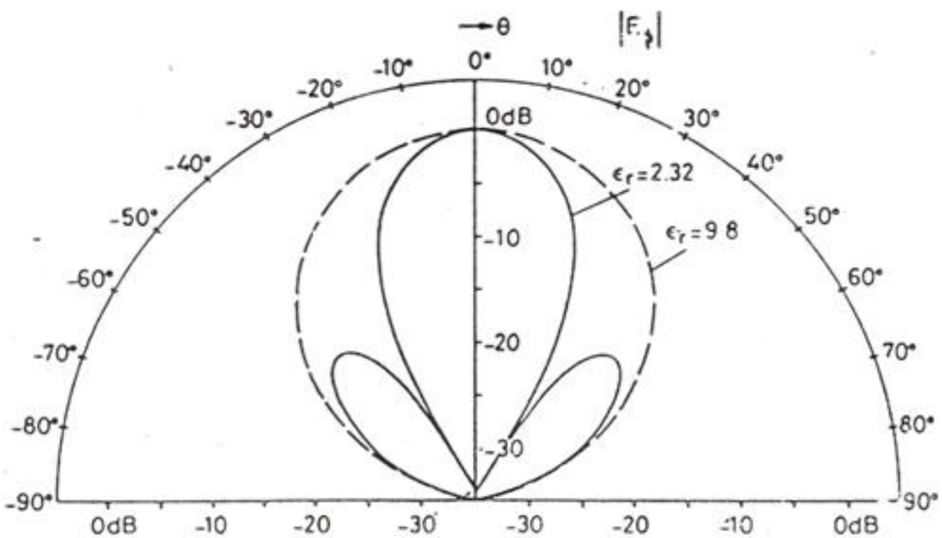


With increase in ε_r , size of the antenna decreases for same resonance frequency.

Hence, gain decreases and HPBW increases.

RMSA – Pattern for Different ε_r (TM_{30} mode)

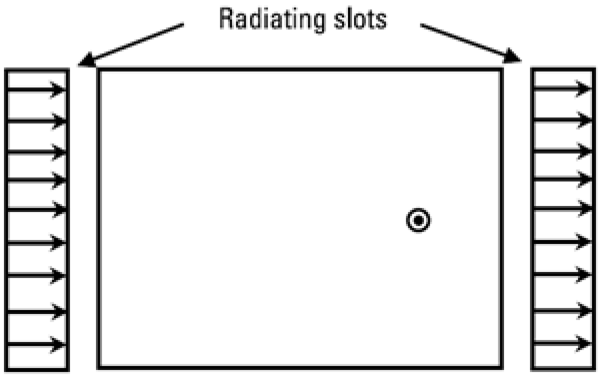




For TM_{30} mode,

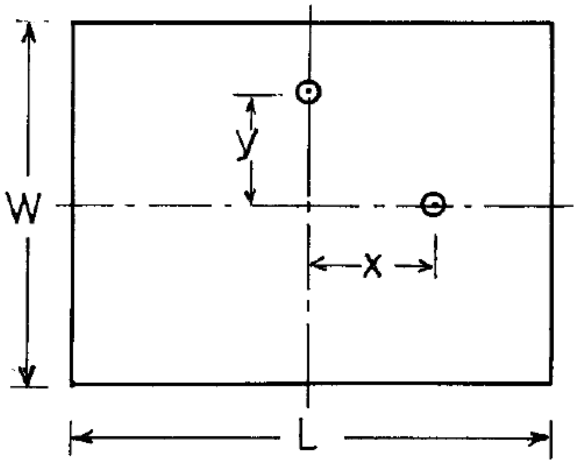
$L_e = 3\,\lambda_0 / (2\sqrt{\varepsilon_e})$

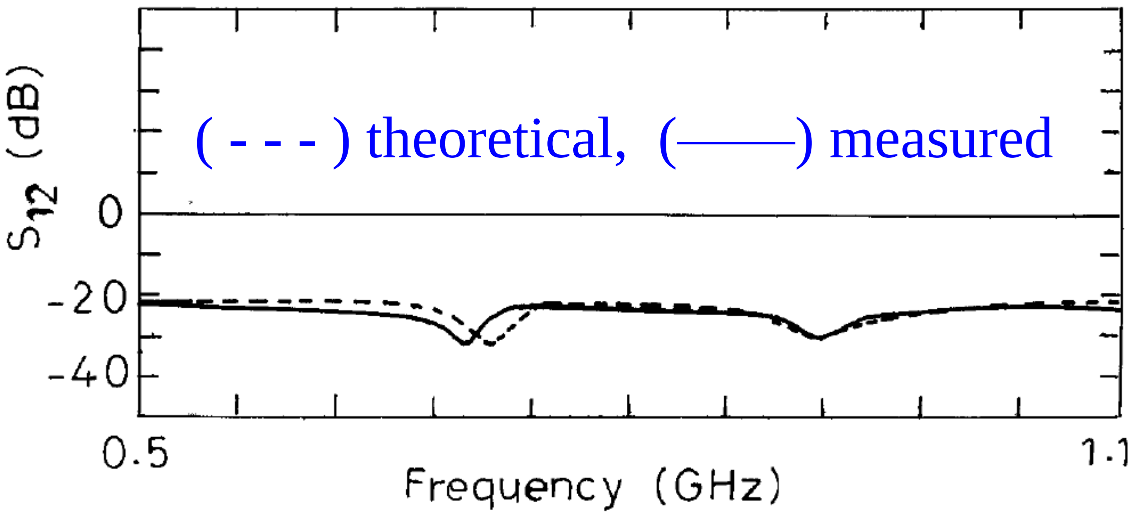
For $\varepsilon_r = 2.32$, $L_e \simeq \lambda_0$



So, two radiating slots will be at a distance of λ_0 yielding grating lobe in E-plane.

RMSA – Dual Polarization (TM_{10} and TM_{01} modes)





L = 10.1 cm and W = 7.9 cm

Orthogonal Feeds at:

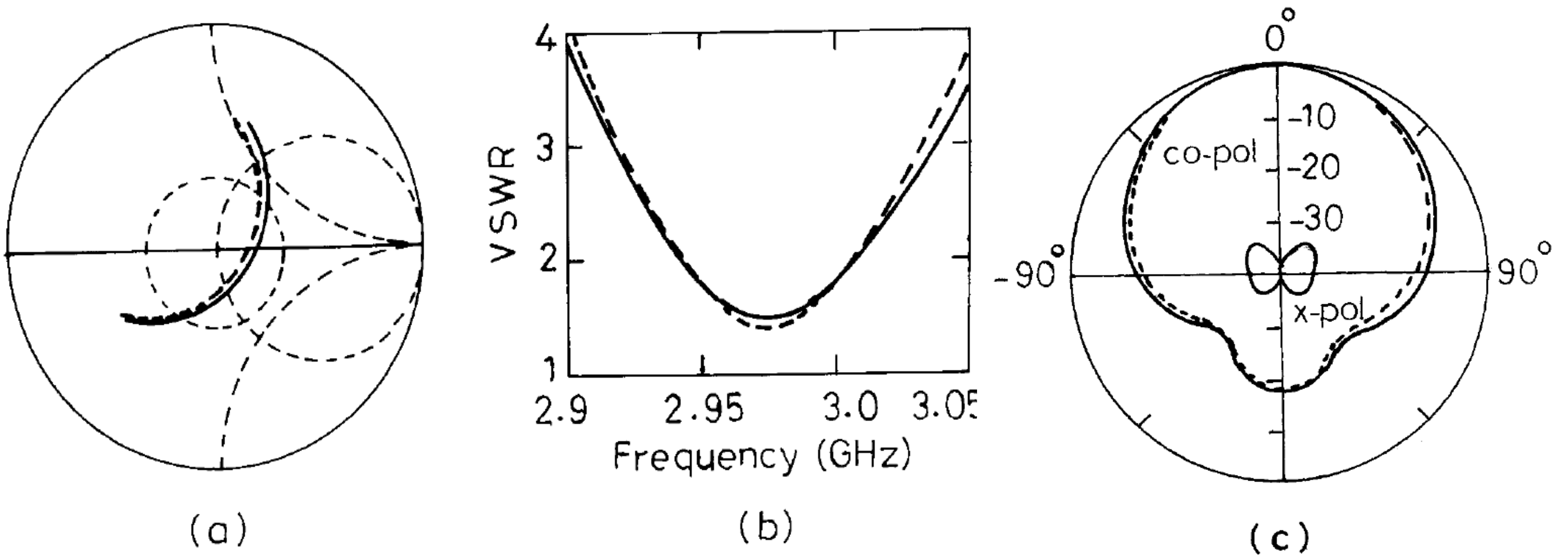
x = 3.8 cm and y = 2.9 cm

Substrate Parameters:

$\varepsilon_r = 4.3$, $h = 0.16$ cm, $\tan\delta = 0.02$

Measured resonance frequencies are 712 MHz and 913 MHz for two orthogonal modes

Effect of Finite Ground Plane

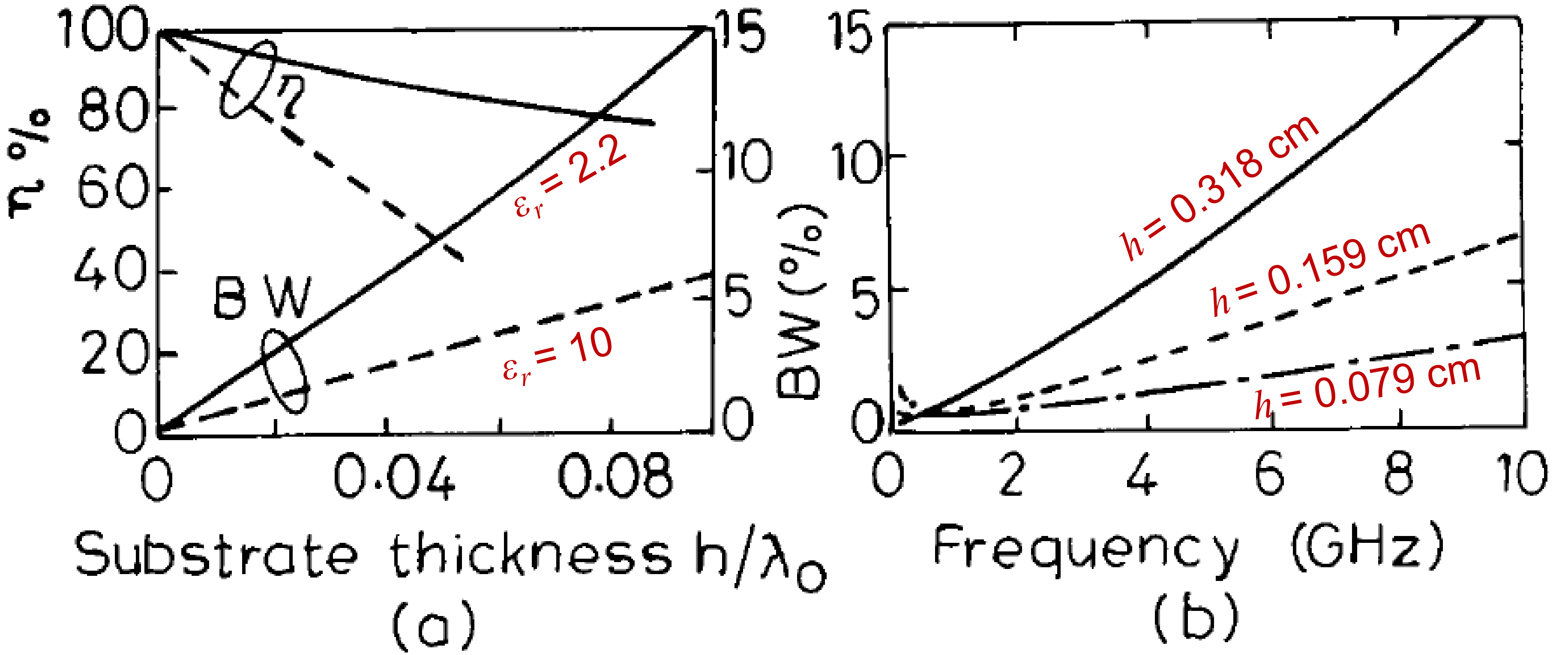


(a) Input impedance and (b) VSWR plots of the RMSA for (——) finite and (- - -) infinite ground planes, and (c) its radiation pattern on the finite ground plane: (——) E-plane copolar and cross-polar and (- - -) H-plane copolar.

Finite Ground Plane Size is taken as

$L_g = L + 6h + 6h$ and $W_g = W + 6h + 6h$

MSA – BW Variation with h and f



(a) Variation of percentage BW and efficiency of a square MSA versus h/λ_0. (——) ϵ_r = 2.2, (- - -) ϵ_r = 10 and (b) variation of percentage BW with frequency for three values of h and ϵ_r = 2.32: (——) 0.318, (- - -) 0.159, (– - –) 0.079 cm.

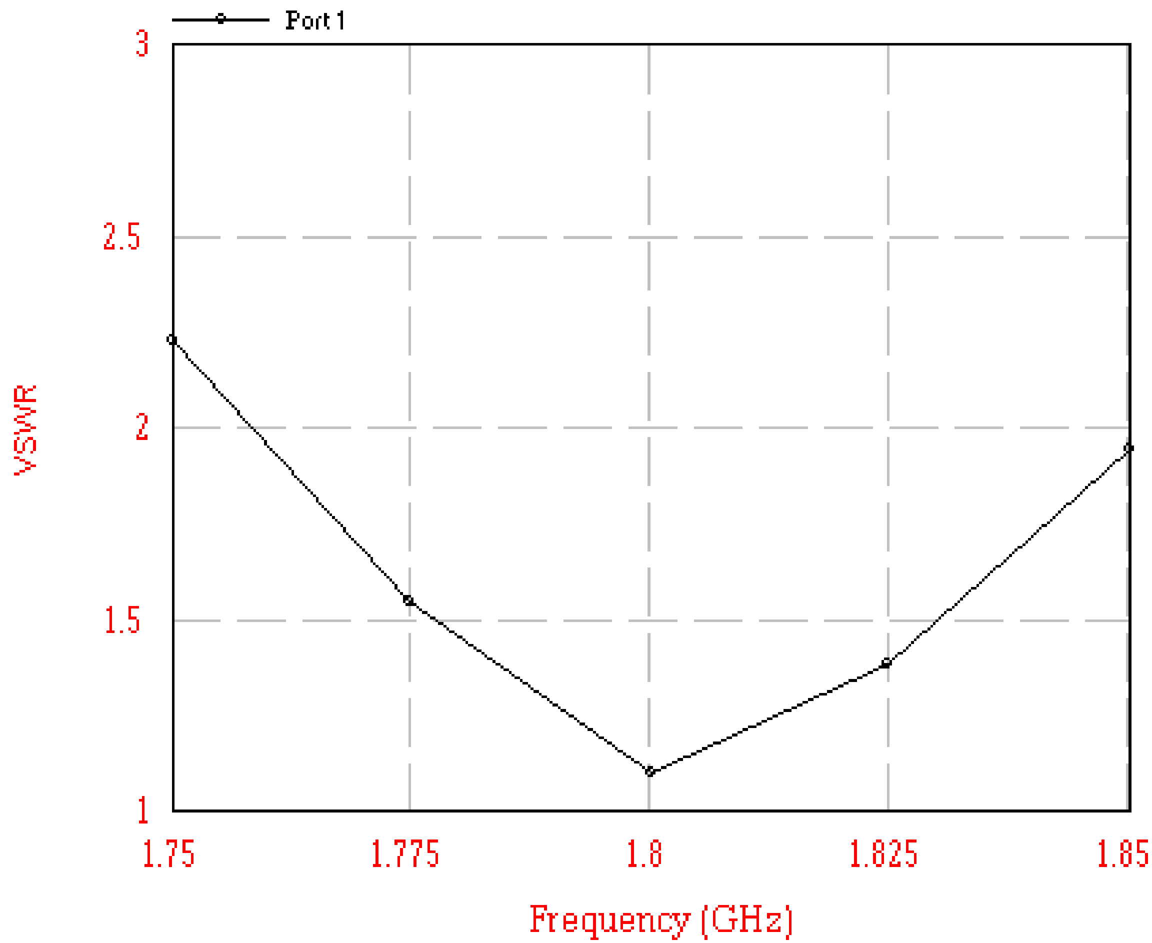
Square MSA in Air – VSWR Plot

Square MSA on a finite ground plane.

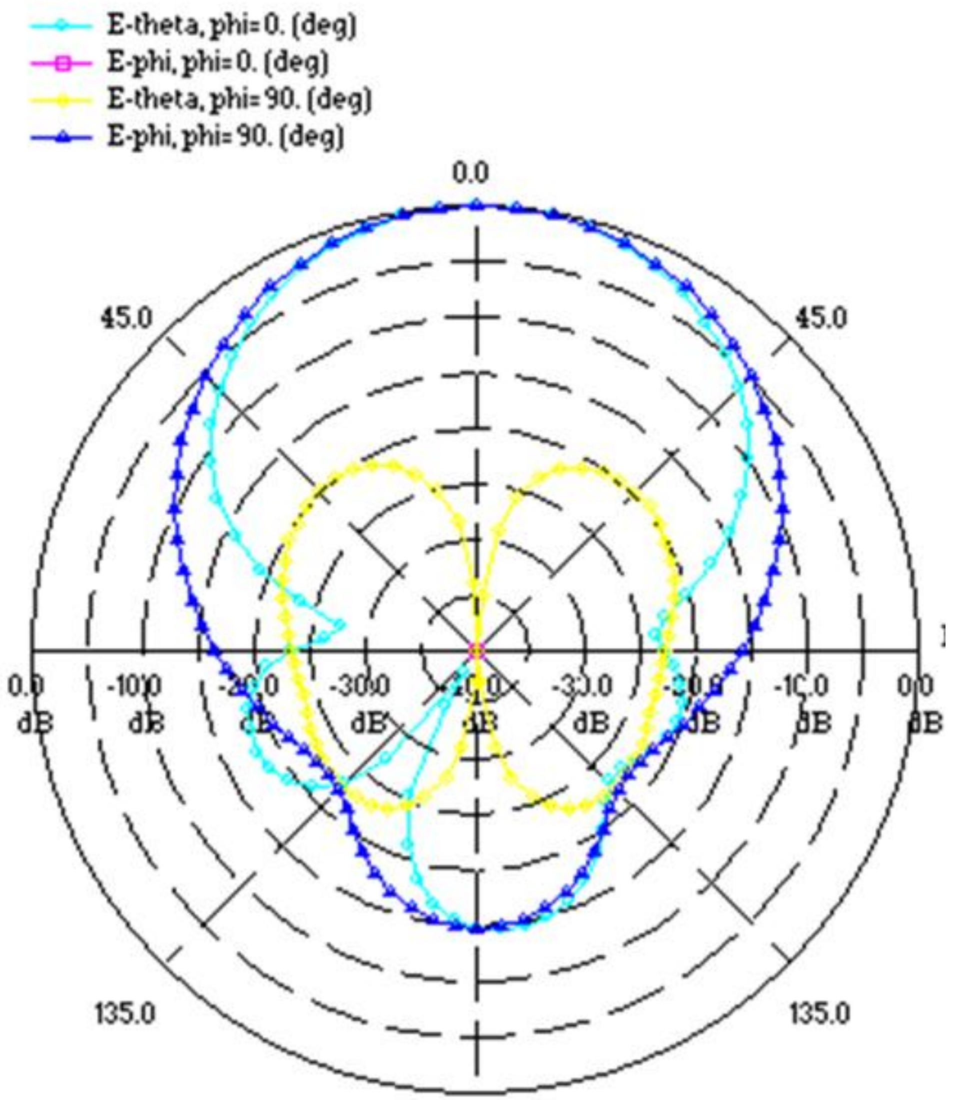
Low cost - Metallic plate suspended in air and fed by a co-axial feed.

BW for VSWR $\leq$ 2 is 95 MHz at 1.8 GHz

(% BW $\simeq$ 5%)



Square MSA in Air – Radiation Pattern

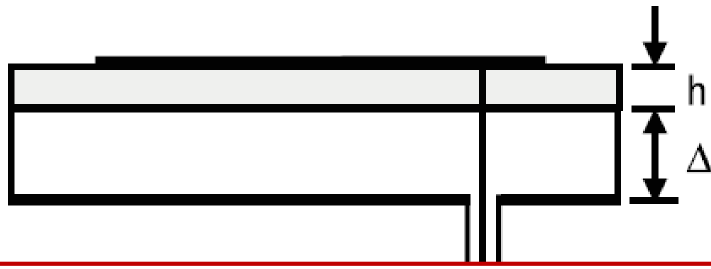


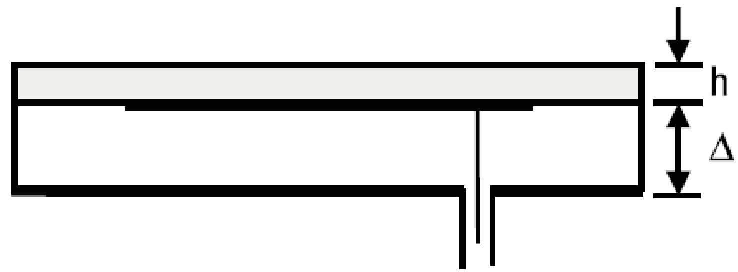
Radiation Pattern at 1.8 GHz

F/B = 15 dB

Cross Polar $\leq$ 20 dB

MSA – Suspended Configurations





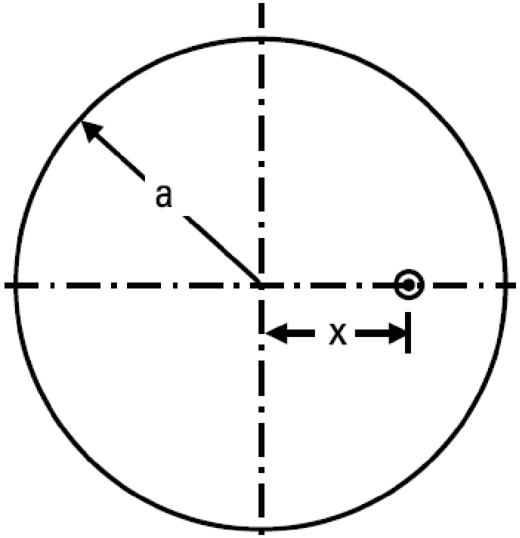
$$C_{eq} = \frac{\epsilon_o \epsilon_{eq} WL}{h + \Delta} = \frac{\frac{\epsilon_o \epsilon_r WL}{h} \frac{\epsilon_o WL}{\Delta}}{\frac{\epsilon_o \epsilon_r WL}{h} + \frac{\epsilon_o WL}{\Delta}}$$

$$\epsilon_{eq} = \frac{\epsilon_r (h + \Delta)}{\epsilon_r \Delta + h}$$

Comparison of Suspended Configurations of Square MSA
(L = 14 cm, Δ = 2 cm, h = 0.159 cm, x = 6.5 cm)

Configuration	Frequency Range for VSWR $\leq$ 2 (MHz)	BW (MHz)	Gain (dB)
Suspended with $\epsilon_r = 1$	935 to 1,019	84	9.5
Suspended with $\epsilon_r = 2.3$	889 to 970	81	9.3
Suspended with $\epsilon_r = 4.3$	858 to 934	76	9.2
Inverted with $\epsilon_r = 2.3$	909 to 988	79	9.5
Inverted with $\epsilon_r = 4.3$	880 to 955	75	9.4

CMSA: Resonance Frequency



Mode	K_{nm}
TM_{11}	1.84118
TM_{21}	3.05424
TM_{02}	3.83171
TM_{12}	5.33140

$$f_0 = \frac{K_{nm}\, c}{2\pi a_e \sqrt{\epsilon_e}}$$

where K_{nm} is the mth root of the derivative of the Bessel function of order n

For Fundamental TM_{11} Mode:

$f_0 \simeq 8.791 / [(a + h/\sqrt{\varepsilon_r})\sqrt{\varepsilon_e}\,]$ GHz

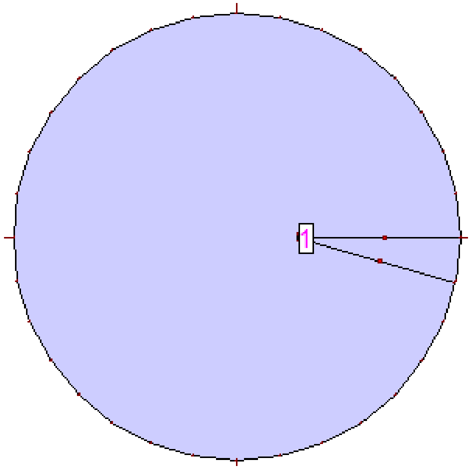
where a and h are in cm and $\varepsilon_e \leq \varepsilon_r$

Design Equation:

$a \simeq 8.791 / (f_0 \sqrt{\varepsilon_e}) - h / \sqrt{\varepsilon_r}$

Choose feed-point x between 0.3a to 0.5a

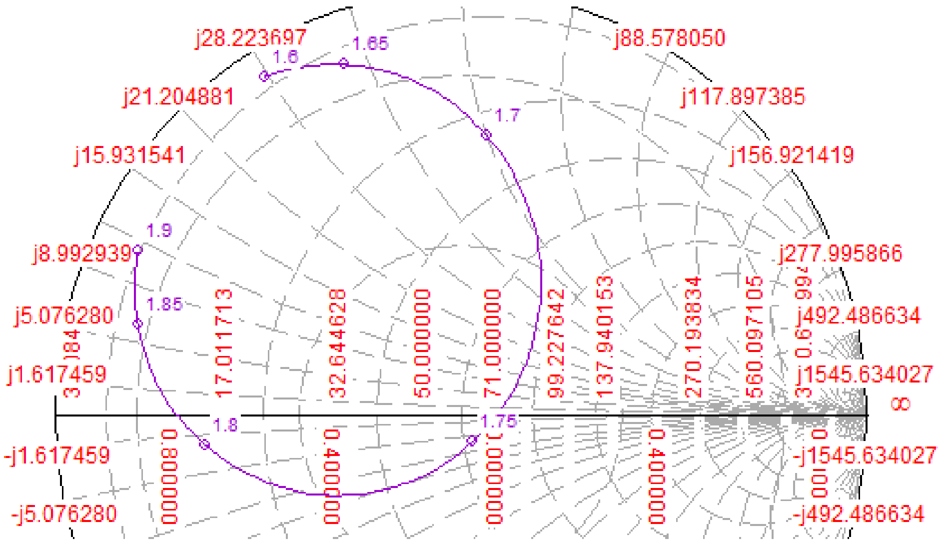
CMSA: Simulation using IE3D

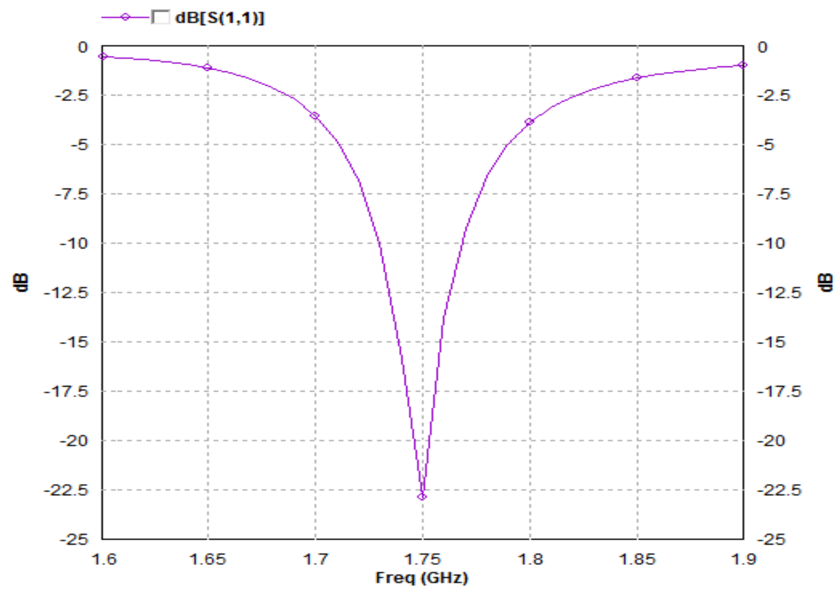


a = 3 cm, *h* = 0.318 cm, ε_r = 2.55, *tan* δ= 0.001. Take *x* = 0.3 *a* = 0.9 *cm*

For Fundamental TM_{11} Mode:

$f_0 \simeq 8.791 / [(3 + 0.318/\sqrt{2.55})\sqrt{2.45}]$
= 1.756 GHz





Calculated f_0 = 1.756, Simulated f_0 = 1.750 GHz, % error = 0.3%.

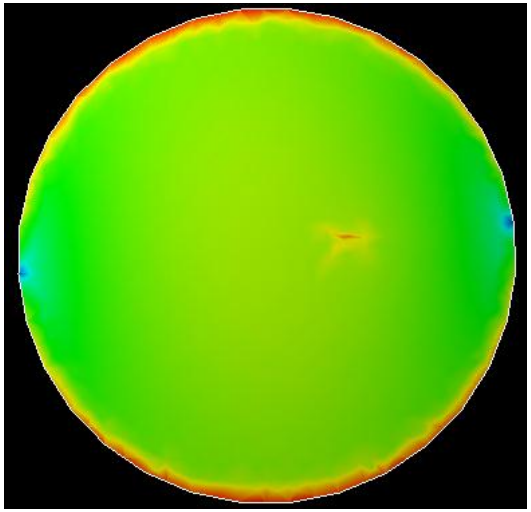
Simulated BW = 1.730 to 1.768 GHz = 38 MHz ($\simeq$ 2%)

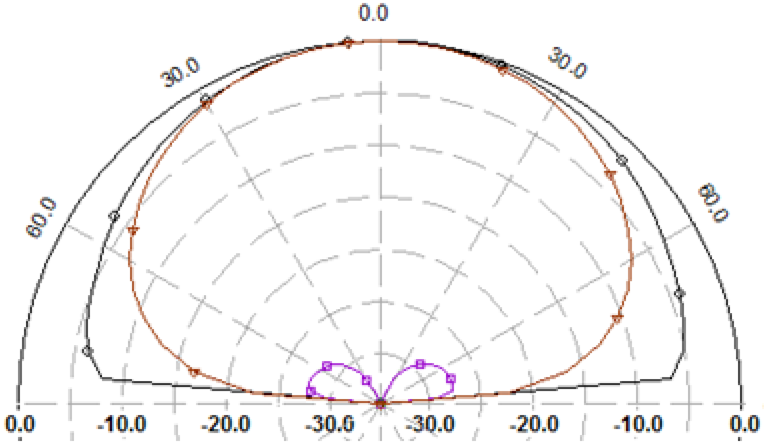
CMSA: Radiation Pattern

$$E_\theta = [J_{n+1}(k_0 a \sin\theta) - J_{n-1}(k_0 a \sin\theta)] \cos n\phi$$

$$E_\phi = [J_{n+1}(k_0 a \sin\theta) + J_{n-1}(k_0 a \sin\theta)] \cos\theta \sin n\phi$$

where J_{n+1} *and* J_{n-1} *are the Bessel functions of order* $n + 1$ *and* $n - 1$, respectively





Gain = 6.5 dB

$HPBW_E = 102^0$

$HPBW_H = 81^0$

X-pol < 27 dB

Current Distribution and Radiation Pattern at 1.75 GHz

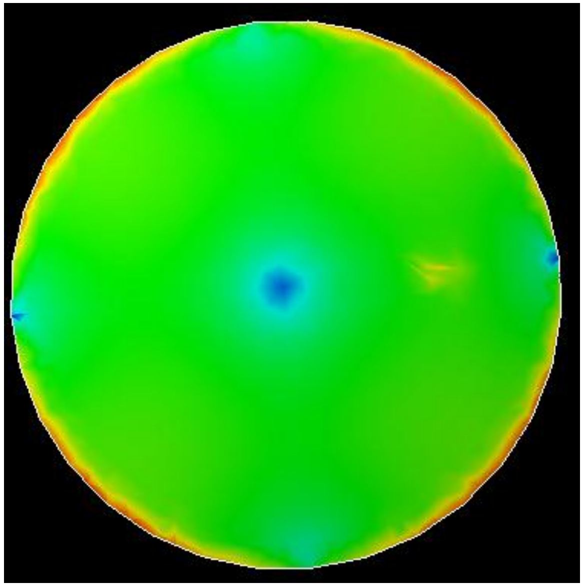
CMSA: Higher Order TM_{21} Mode

a = 3 cm, h = 0.318 cm, ε_r *= 2.55, tan* δ*= 0.001, x = 1.6 cm*

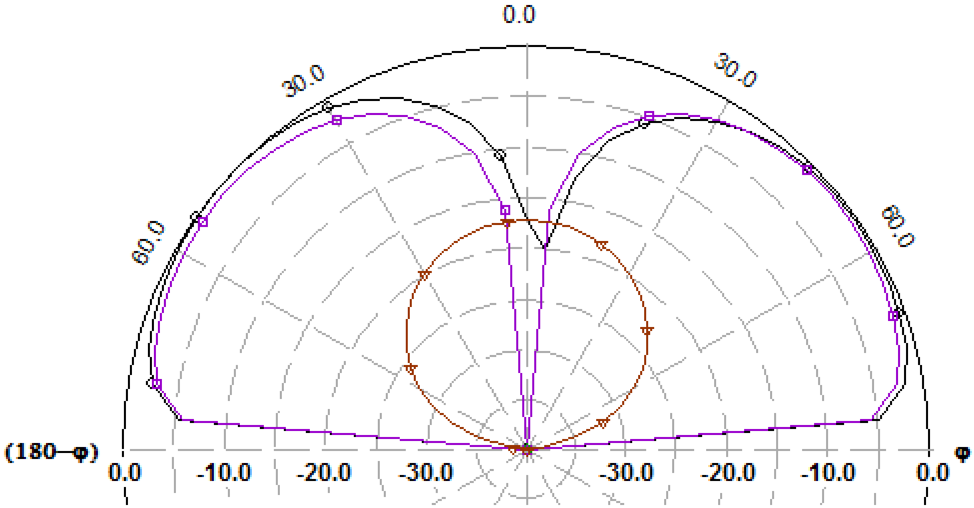
For TM_{21} Mode:

$f_0 \simeq 3.05424 \times 30 / [2\pi (3 + 0.318/\sqrt{2.55}) \sqrt{2.45}\,] = 2.912$ GHz

Simulated f_0 =2.94 GHz

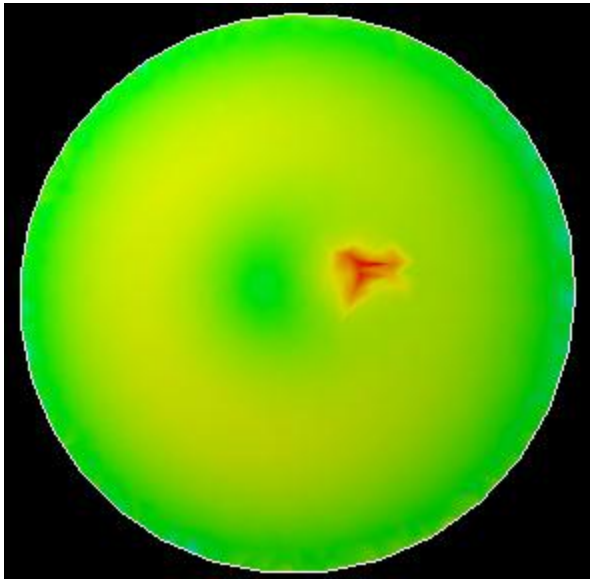


Mode	K_{nm}
TM_{11}	1.84118
TM_{21}	3.05424
TM_{02}	3.83171
TM_{12}	5.33140



Radiation Pattern at 2.94 GHz

CMSA: Higher Order TM_{02} Mode



$a = 3$ cm, $h = 0.318$ cm, $\varepsilon_r = 2.55$, $\tan\delta = 0.001$, $x = 0.9$ cm

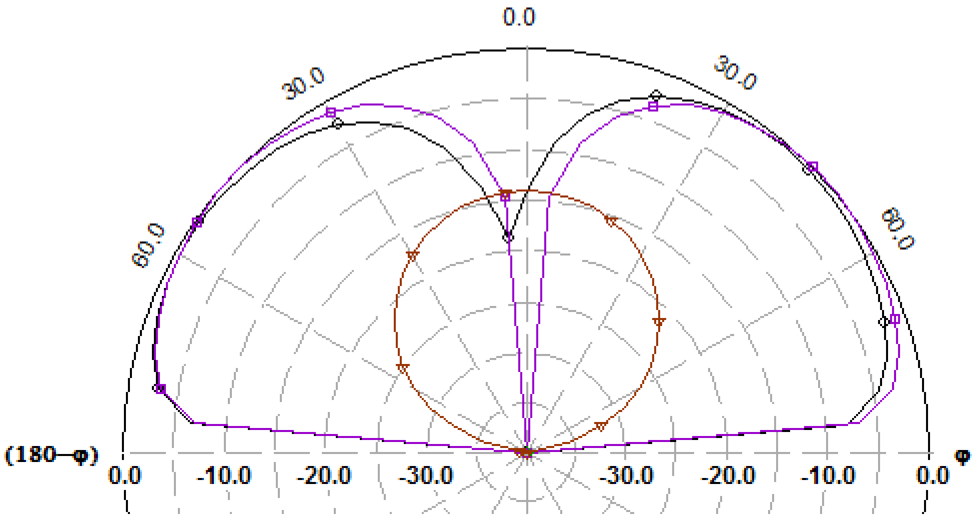
For TM_{02} Mode:

$f_0 \simeq 3.83171 \times 30 / [2\pi (3 + 0.318/\sqrt{2.55}) \sqrt{2.45}\,] = 3.654$ GHz

Simulated Results:

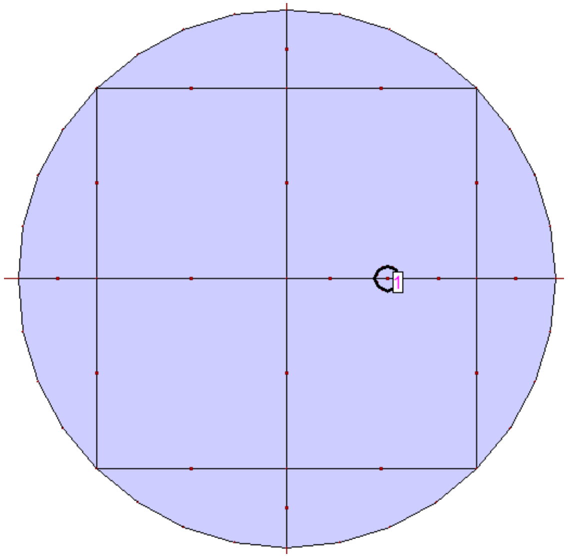
Good impedance match at 3.63 GHz

Mode	K_{nm}
TM_{11}	1.84118
TM_{21}	3.05424
TM_{02}	3.83171
TM_{12}	5.33140



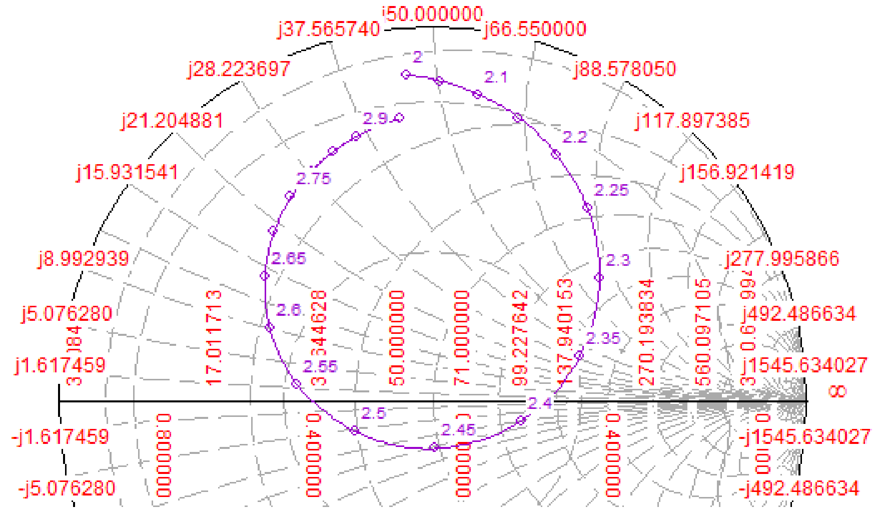
Used as N-way Power Divider with input at the center.

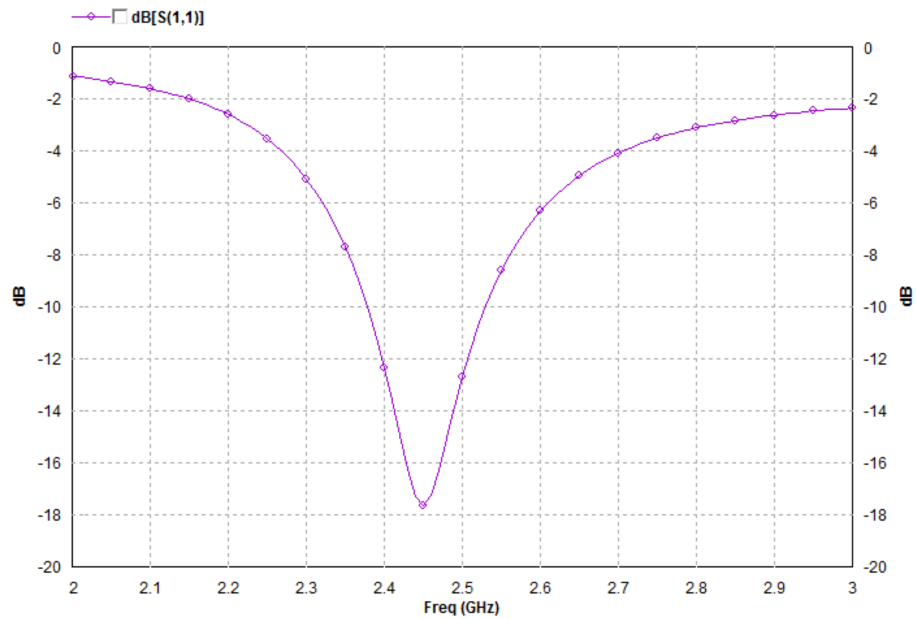
Broadband CMSA – Metallic Plate in Air



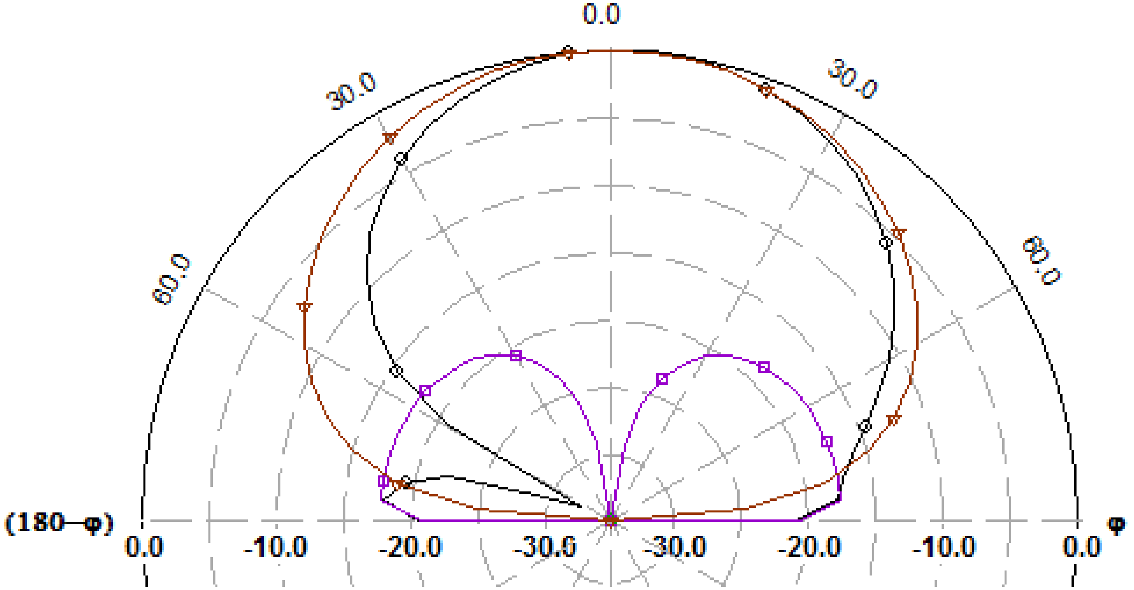
a = 3.2 cm, h = 0.5 cm, ε_r = 1
Probe Dia. = 0.3 cm
(N-type Connector)
Taken x = 1.2 cm

BW = 2.378 to 2.529 GHz
= 151 MHz ($\simeq$ 6%)





Broadband CMSA – Radiation Pattern



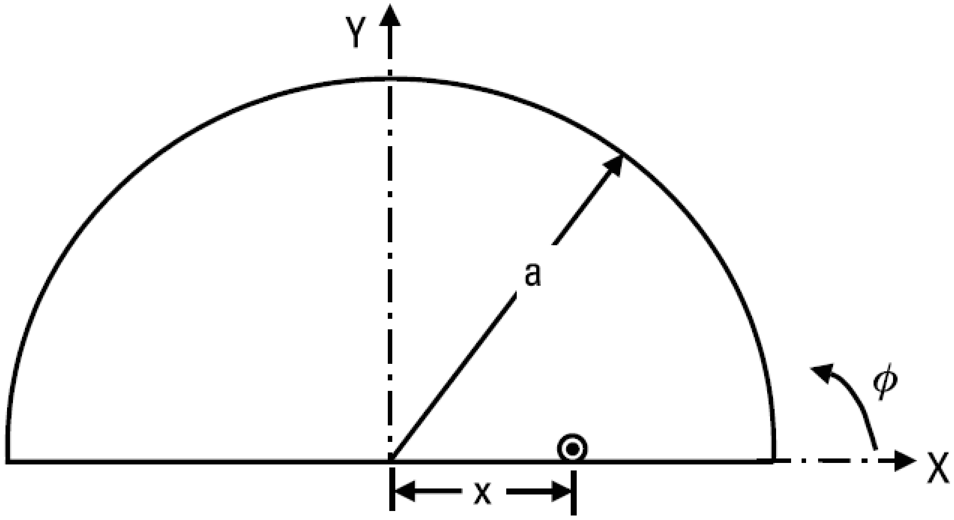
Radiation Pattern at 2.45 GHz

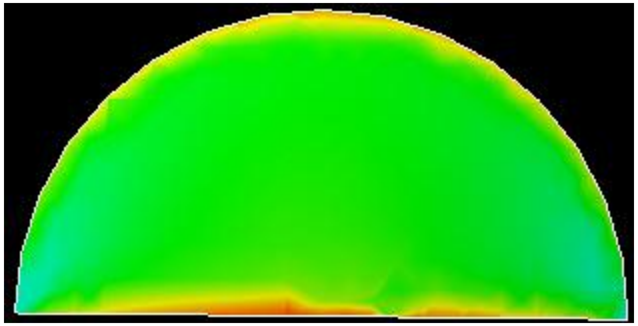
$HPBW_E = 58^0$, $HPBW_H = 71^0$

Gain = 9.5 dB at 2.45 GHz

X-pol < 17 dB

Semi-Circular MSA

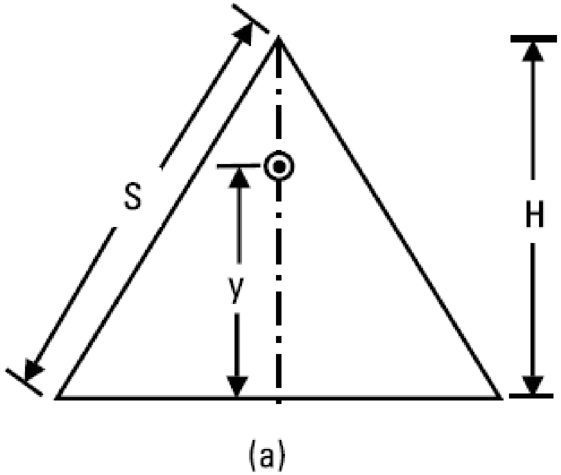




For *a* = *3* cm, ε_r = 1, and *h* = 0.65 cm,
N-type Connector at *x* = 1.0 cm
BW = 2.525 to 2.640 GHz =115 MHz (4.4%), Gain = 9.0 dB

In comparison: CMSA of *a* = 3 cm and *x* = 1.1 cm
BW = 2.514 to 2.699 GHz = 185 MHz (7.1%), Gain = 9.5 dB

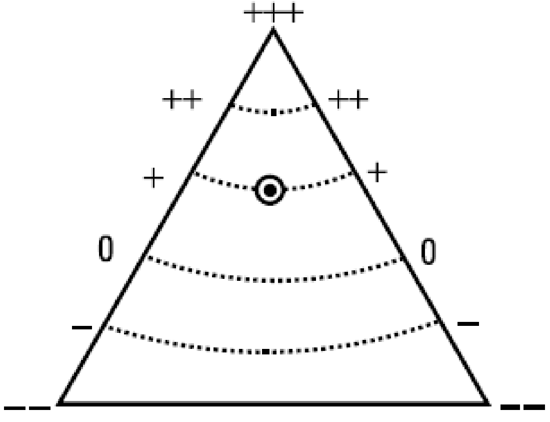
Equilateral Triangular MSA (ETMSA)

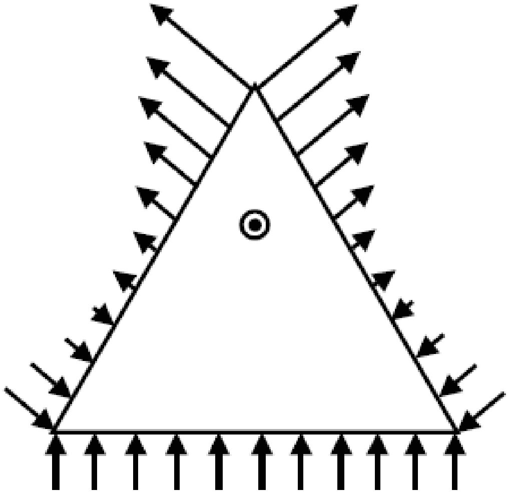


For Fundamental TM_{10} Mode:

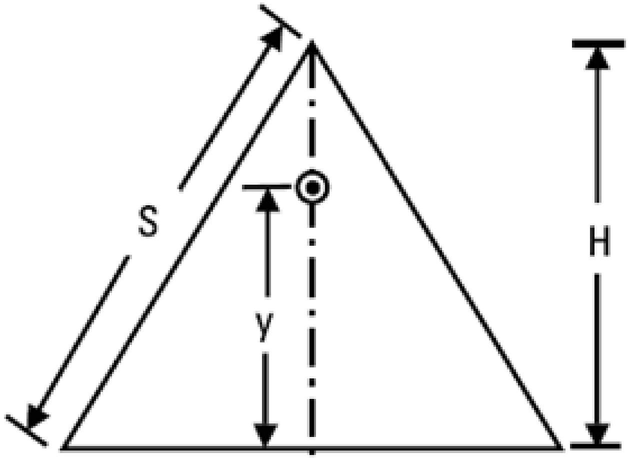
$$f_0 = \frac{2\ c}{3\ S_e \sqrt{\epsilon_e}}$$

where $S_e \simeq S + 4h/\sqrt{\varepsilon_r}$





ETMSA Design - TM_{10} Mode



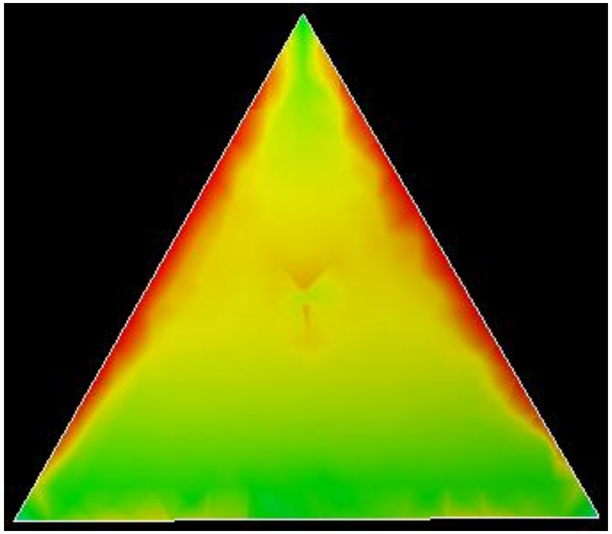
For f_0 = 3 GHz, ε_r = 2.55, h = 0.159 cm

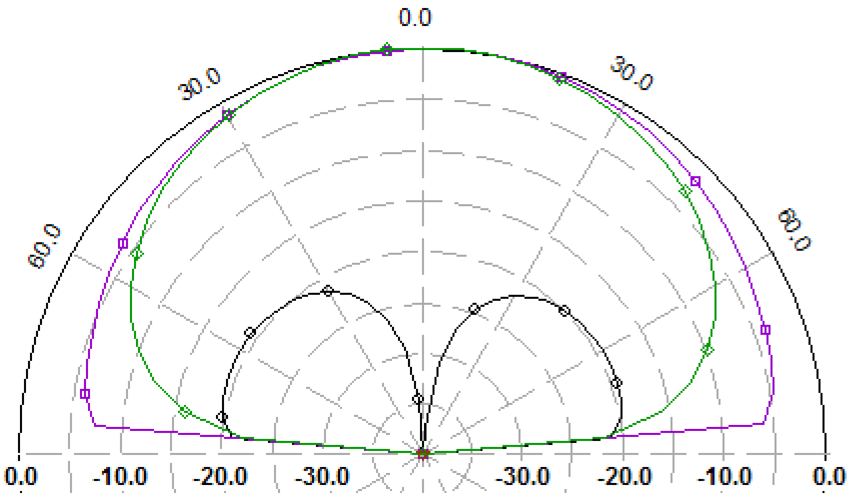
$S_e \simeq (2 \times 30 / (3 \times 3 \times \sqrt{2.35}) = 4.35$ cm

$S = S_e - 4 \times 0.159/\sqrt{2.55} = 3.95$ cm

Taken S = 4 cm, H =3.46 cm, y = 1.52 cm

f_0 = 3 GHz, BW = 40 MHz, Gain = 6.26 dB





Current Distribution and Radiation Pattern at 3.0 GHz