Seminar

# Introduction to Planar Antennas

2010.7.26@E-JUST

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# Contents

# Yoshitomi Lab

Students (Research)

- D2 Yang (Small UWB antenna)
- M2 Zhao (Small UWB antenna)
  Kuramoto (Design of antenna using ANN)
  Umekida (Scattering from decoupling capacitor, EMI)
- M1 Yoshioka (Miniaturization of antenna)
- B4 Fukumoto (Design of antenna using ANN)

Tools

- Antenna simulator (HFSS)
- Fortran software（FDTD program, ANN program)
- Measurement facilities (VNA, anechoic chamber, etc.)

# Proposal of Research Subjects for PhD or Master’s degree

- Development of antennas using HFSS simulator or FDTD program
- Design of antennas using ANN (artificial neural network)

    Small planar UWB antennas

    Multiband patch antennas

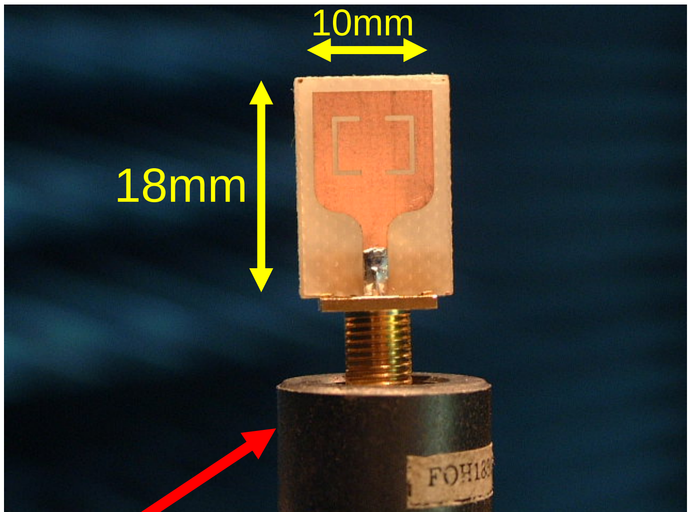
    One-sided directional antennas

    Matching circuits for antennas

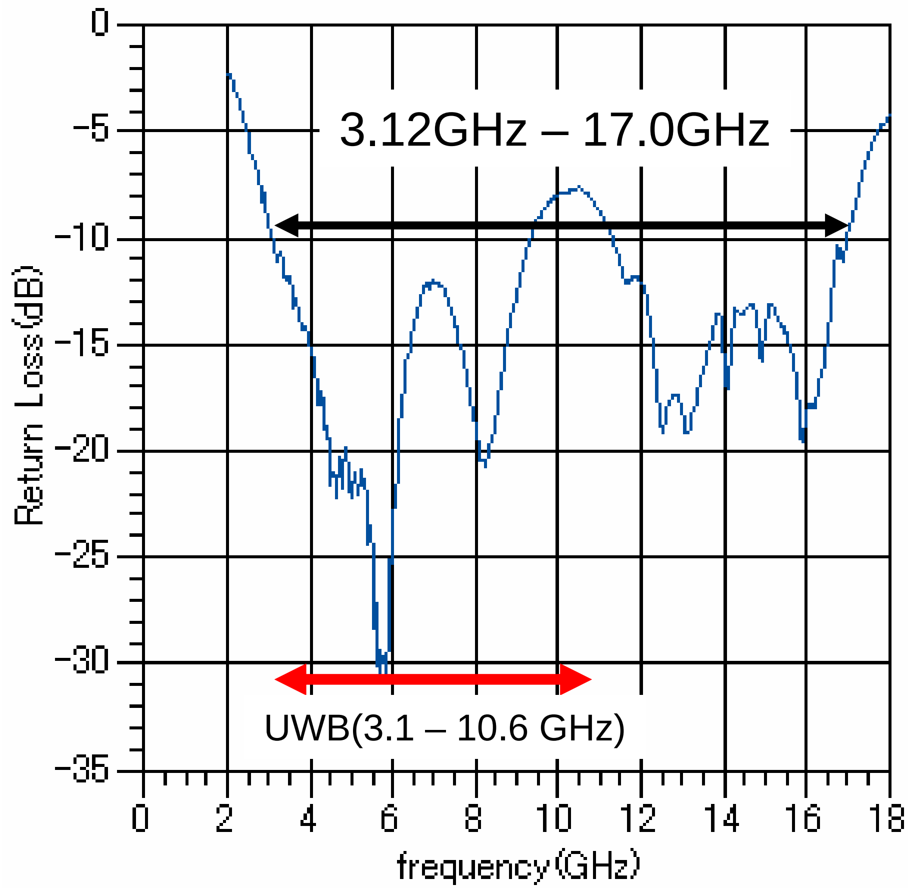
    etc.

We will study antenna designs with various radiator shapes, feeding structures, and matching circuits for better performance.

# Example1: Small planar UWB antenna



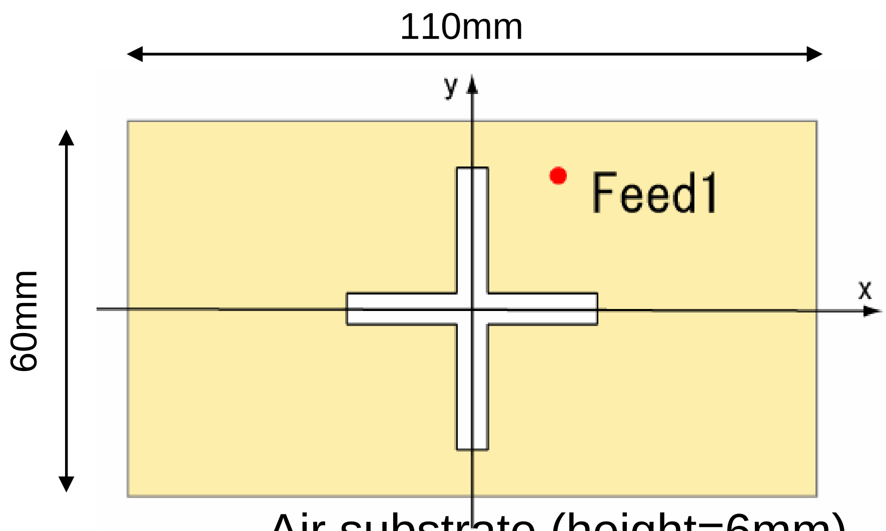

Ferrite core

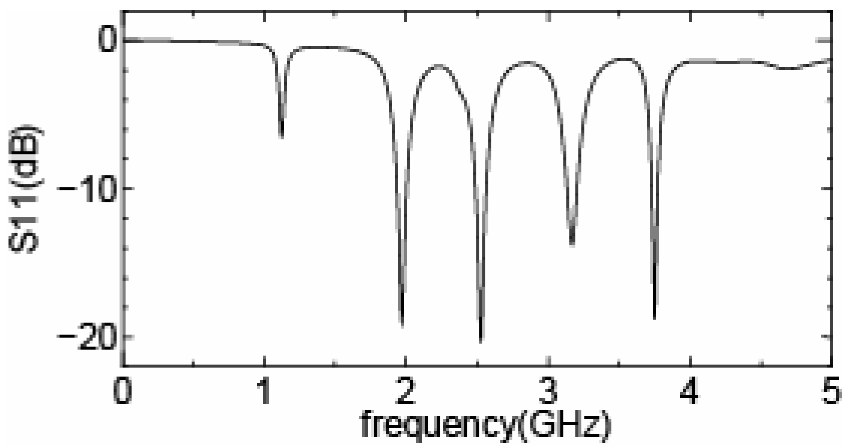


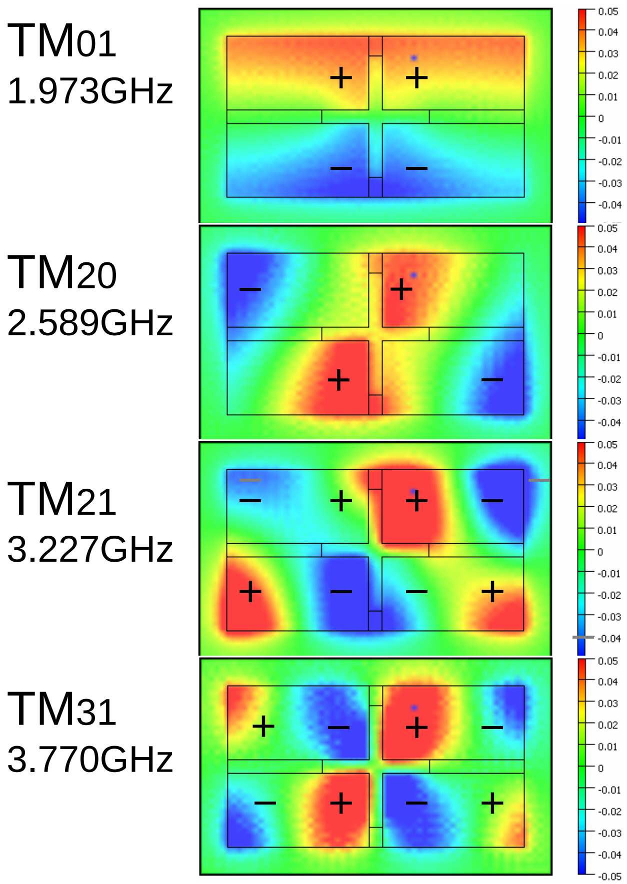

Simulation Result
-10dB Return Loss Bandwidth
3.1GHz – 14.9GHz

Various antenna shapes and feeding structures
for better performance should be studied.

# Example2: Multiband patch antenna



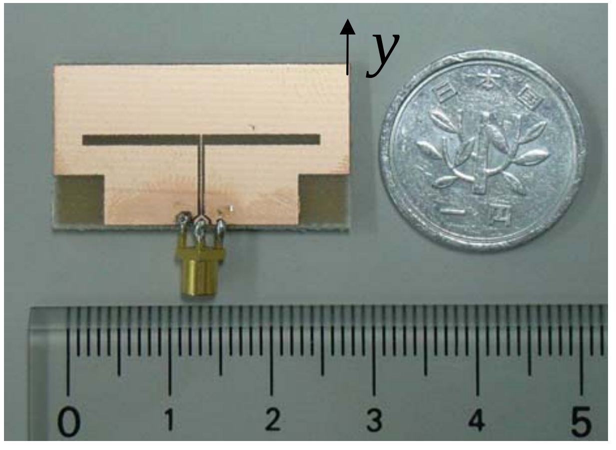



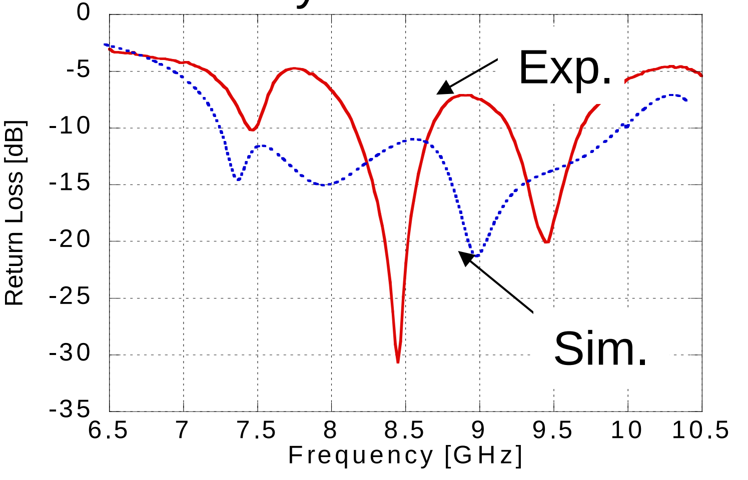

Relation among slot size, feeding point location, and resonant frequencies has not been studied yet.

# Example3: One-sided directional antenna

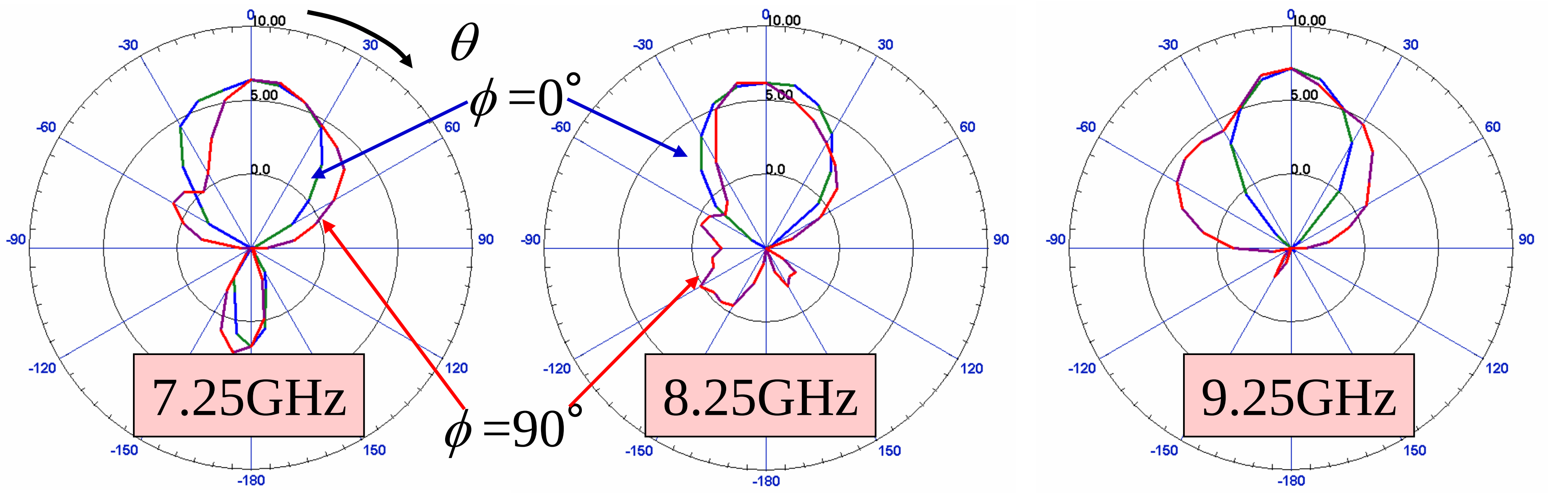
* Developed by Prof. Yoshida's lab




The mechanism of one-sided radiation has not been studied yet.



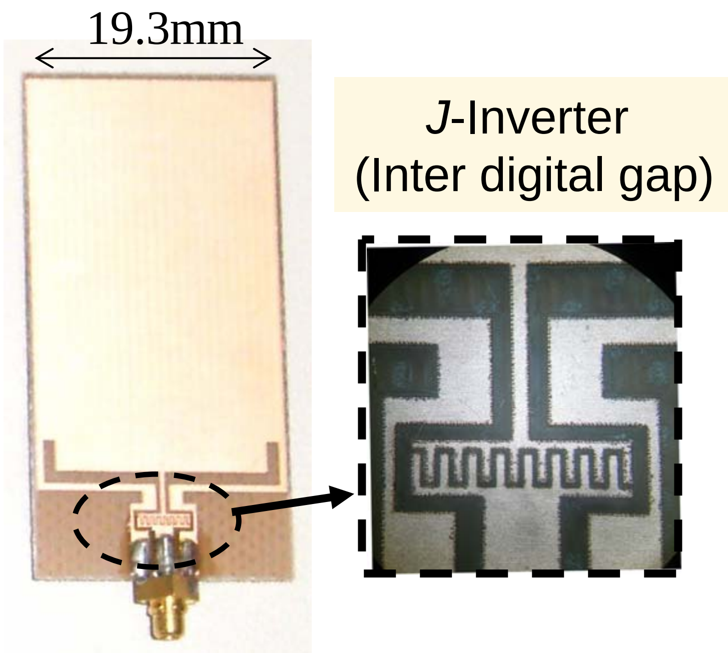

Three resonance—broad band

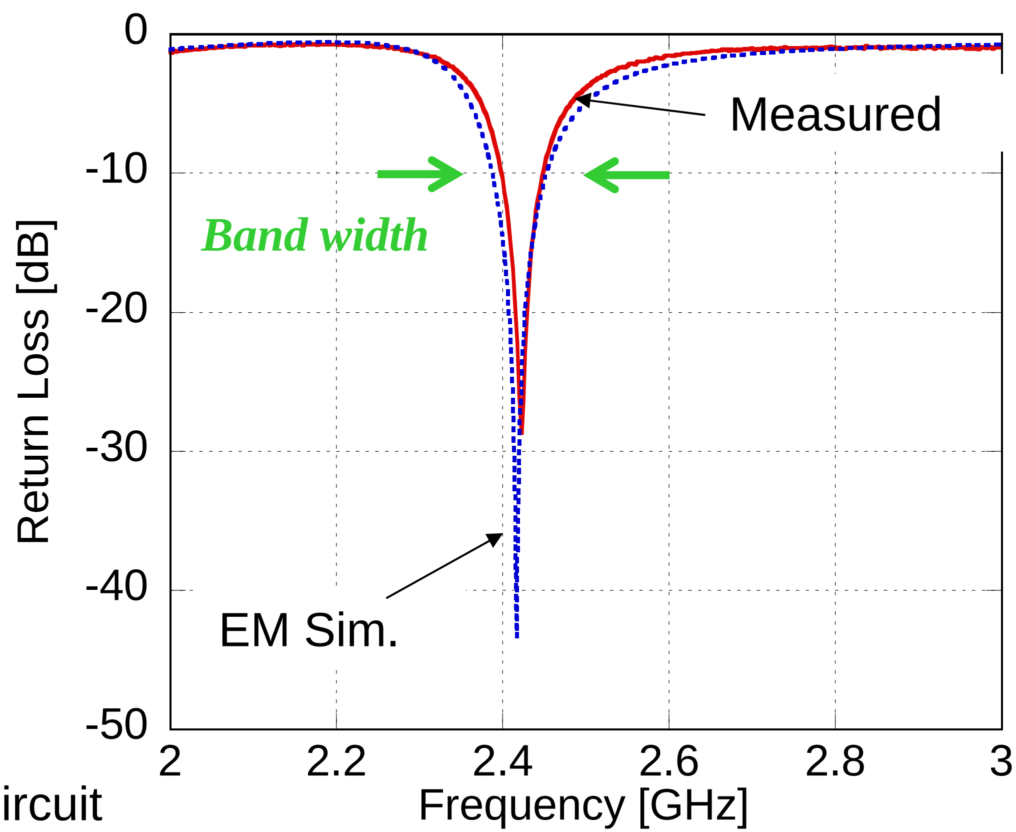


# Example4: A matching circuit for one-sided directional antenna

* Developed by Prof. Yoshida's lab

Photographs of the antenna



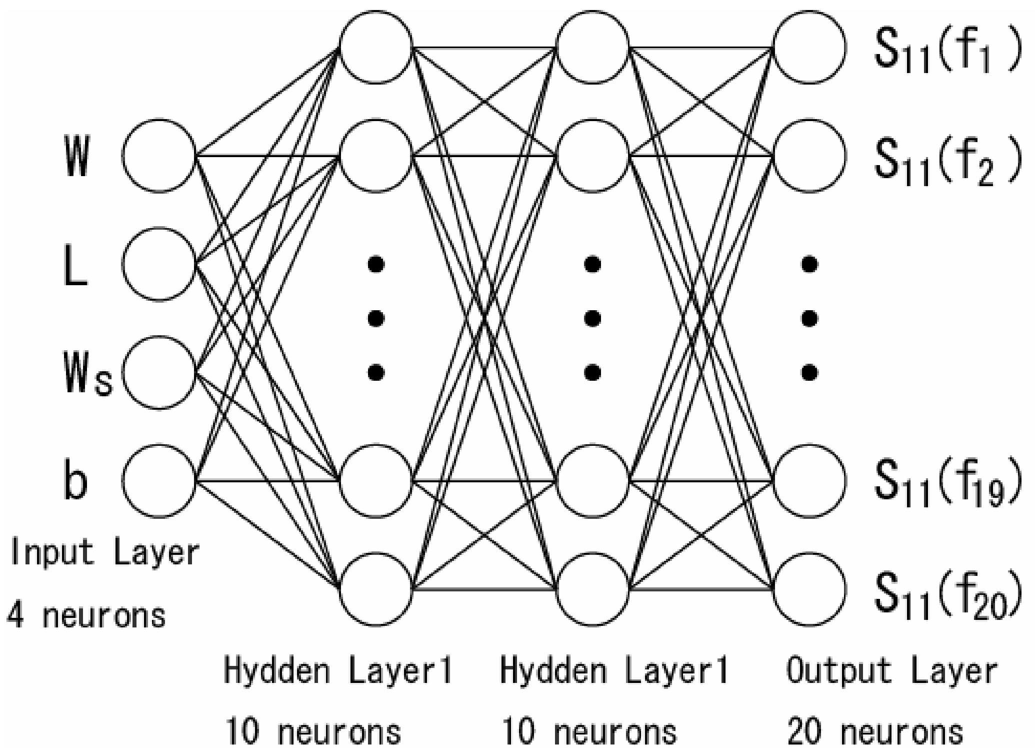



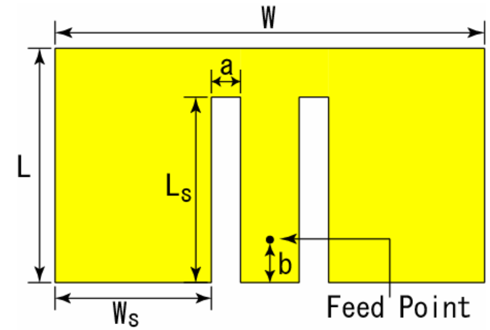

Antennas with this kind of matching circuit have not been studied so much.

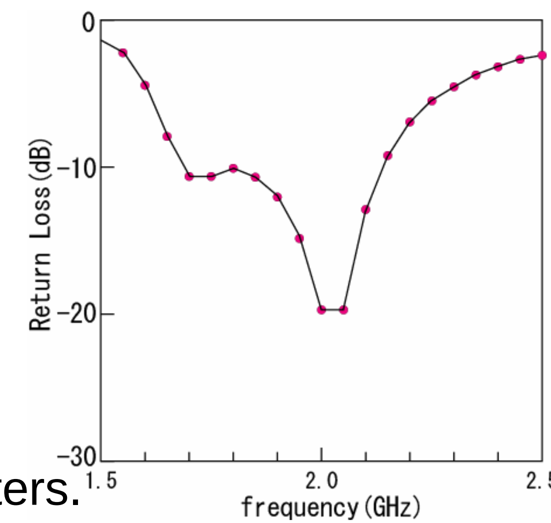
# Example5: Design of the antenna using an artificial neural network (ANN)

An artificial neural network (ANN) for computing the return losses

(Training method: Back propagation)



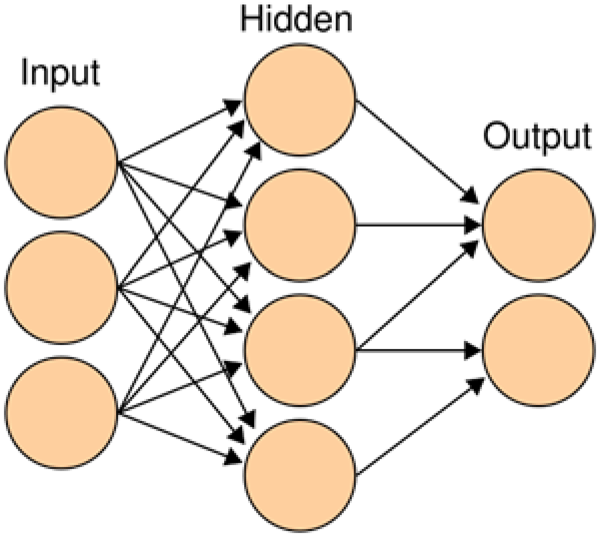




ANNs might be useful to optimize the antenna parameters.

# An **artificial neural network(ANN)**

- An **artificial neural network (ANN)**, usually called "neural network" (NN), is a mathematical model or computational model that tries to simulate the structure and/or functional aspects of biological neural networks. It consists of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. Modern neural networks are non-linear statistical data modeling tools. They are usually used to model complex relationships between inputs and outputs or to find patterns in data. --- “Wikipedia”

Input:
Antenna parameters




Output:
Return Loss

# Publication List（Journal）


[1] L.Lolit Kumar Singh, Bhaskar Gupta, Partha P Sarkar, K. Yoshitomi, and K. Yasumoto, “A Novel Versatile Multiband Rectangular Patch Antenna,” *Microwave and Optical Technology Letters*, Vol.52, No.6, pp.1348–1353, June, 2010.

[2] L.Lolit Kumar Singh, Bhaskar Gupta, Kuniaki Yoshitomi, and Kiyotoshi Yasumoto, “New Single Layer Wideband Rectangular Patch Antenna,” *The Special Issue of Asian Journal of Physics*, Vol. 19, No.2、2009.（accepted）

[3] Kuniaki Yoshitomi, “A Study on the Excitation and the Input Impedance of an Antenna,” *The Special Issue of Asian Journal of Physics*, Vol. 19, No.2, 2009 .(accepted).

[5] Kuniaki Yoshitomi, “Radiation from a Slot Aperture in a Lossy Ground Plane,” *Telecommunications and Radio Engineering*, Vol.7, No.4–5, pp.85–92, 2002.

[6] Kuniaki Yoshitomi, “Radiation from a Slot in an Impedance Surface,” *IEEE Transactions on Antennas and Propagation*, Vol.49, No.10, pp.1370–1376, October 2001.

[7] Kiyotoshi Yasumoto and Kuniaki Yoshitomi, “Efficient Calculation of Lattice Sums for Free-Space Periodic Green’s Function,” *IEEE Transactions on Antennas and Propagation*, Vol.47, No.6, pp.1050–1055, June 1999.

[8] Hongting.Jia, Kiyotoshi Yasumoto, and Kuniaki Yoshitomi, “Rigorous Analysis of E-/H-Plane Junctions in Rectangular Waveguide Using Fourier Transform Technique,” *Progress In Electromagnetics Research*, Vol. PIER 21, pp.273–292, 1999.

[9] Hongting.Jia, Kiyotoshi Yasumoto, and Kuniaki Yoshitomi, “Rigorous Analysis of Rectangular Waveguide Junctions by Fourier Transform Technique,” *Progress In Electromagnetics Research*, Vol. PIER 20, pp.263–282, 1998.

[10] Kuniaki Yoshitomi, “Polarization Characteristics of the Radiation Field from an Aperture in an Impedance Surface,” *IEEE Transactions on Antennas and Propagation*, Vol.44, No.11, pp.1464–1466, November 1995.

[11] Youn S. Kim, Hyo J. Eom, Jae W. Lee, and Kuniaki Yoshitomi, “Scattering from Multiple Slits in a Thick Conducting Plane,” *Radio Science*, Vol.30, No.5, pp.1341–1347, September–October 1995.

# Publication List (Conference)

[1] L.Lolit Kumar Singh, Bhaskar Gupta, Kiyotoshi Yasumoto, and Kuniaki Yoshitomi, “New Single Layer Wideband Rectangular Patch Antennas,” *Proceedings of 12th International Symposium on Microwave and Optical technology*, ISMOT-2009, December 2009.

[2] L.Lolit Kumar Singh, Bhaskar Gupta, Kiyotoshi Yasumoto, and Kuniaki Yoshitomi, “L-Shaped Slot Broadband Single Layer Rectangular Patch Antennas,” *Proceedings of 12th International Symposium on Microwave and Optical technology*, ISMOT-2009, December 2009.

[3] Kuniaki Yoshitomi, Bhaskar Gupta, and L.Lolit Kumar Singh, “A Study on Cross Slot Rectangular Patch Antenna,” *Proceedings of International Symposium on Antennas and Propagation*, ISAP2008, October 2008.

[4] Kuniaki Yoshitomi, “Transmission through an Aperture in a Plate with Surface Impedance in a Rectangular Waveguide,” *Proceedings of 10th International Symposium on Microwave and Optical technology*, ISMOT-2005, pp.87-90, August 2005.

[5] Kuniaki Yoshitomi, “Radiation from a Slot Aperture in a Lossy Ground Plane,” *Proceedings and Abstracts of 2001 far-Eastern School-Seminar on Mathematical Modeling and Numerical Analysis*, FESS-MMNA’01, pp.227-232, August 2001.

[6] Hongting Jia, Kiyotoshi Yasumoto, and Kuniaki Yoshitomi, “Modified Perfectly Matched Boundary Conditions for Open Waveguide Structures,” *Proceedings of 2000 International Conference on Microwave and Millimeter Wave Technology*, pp.287-290, September 2000.

# Definition of Antenna

*An antenna is a transition device, or transducer, between a guided wave and a free-space wave, or vice-versa.*

*J. D. Kraus and R. J. Marhefka,"Antennas," McGraw-Hill. 2002.*

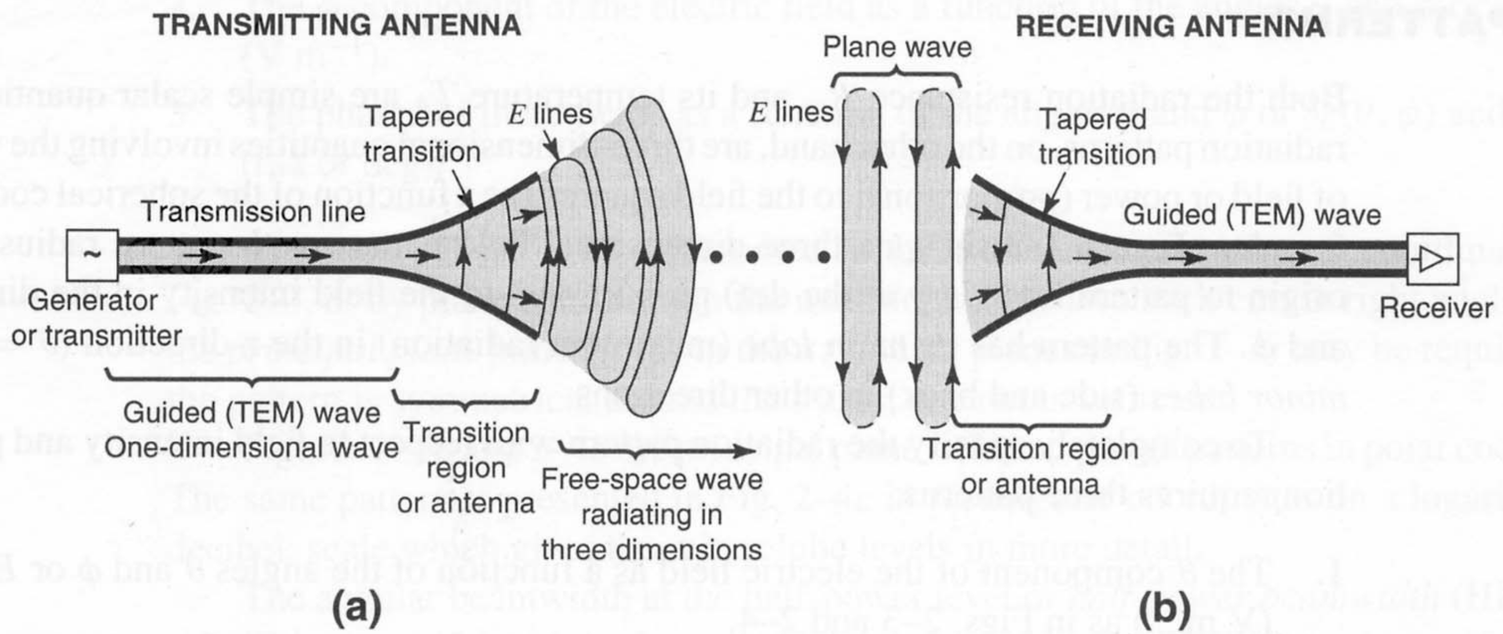
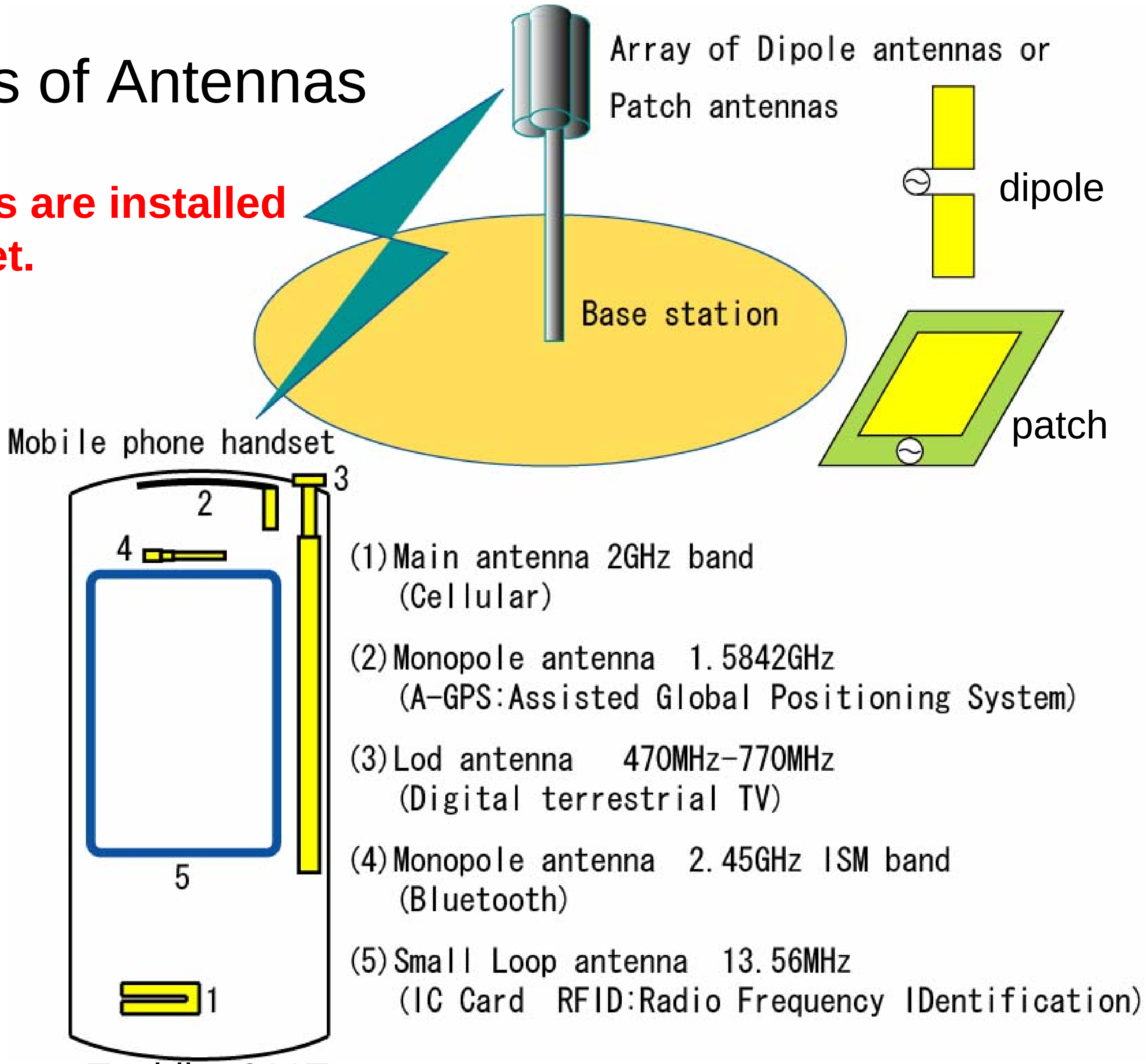



**Figure 2–1**
(*a*) Radio (or wireless) communication link with transmitting antenna and (*b*) receiving antenna. The receiving antenna is remote from the transmitting antenna so that the spherical wave radiated by the transmitting antenna arrives as an essentially plane wave at the receiving antenna.

# Examples of Antennas

**Five antennas are installed in the handset.**




Toshiba 911T

# Basic Antenna Parameters

## Antenna Performance Parameters

- Radiation Pattern
- Directivity
- Gain
- Polarization
- Input Impedance
- Bandwidth
- Scanning :Movement of the radiation pattern in space
- System Consideration :Size, weight, power handling, etc.

*There are trade-offs between parameter values.*

*Performance cannot be improved significantly for one parameter without sacrificing one or more of other parameter levels.*

*W.L.Stutzman and G.A.Thiele, "Antenna Theory and Design," John Wiley & Sons, Inc. 1998.*

# Antenna Types

*W.L.Stutzman and G.A.Thiele, "Antenna Theory and Design," John Wiley & Sons, Inc. 1998.*

*Antenna can be divided into four basic types by their performance as a function of frequency.*

## 1. Electrically small antennas

The extent of the antenna structure is much smaller than a wavelength $\lambda$ .

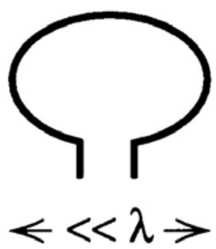
Properties:

- Very low directivity
- Low input resistance
- High input reactance
- Low radiation efficiency

Examples:


Short dipole

(the most basic antenna)




Small loop

(dual of a short dipole)

# Antenna Types

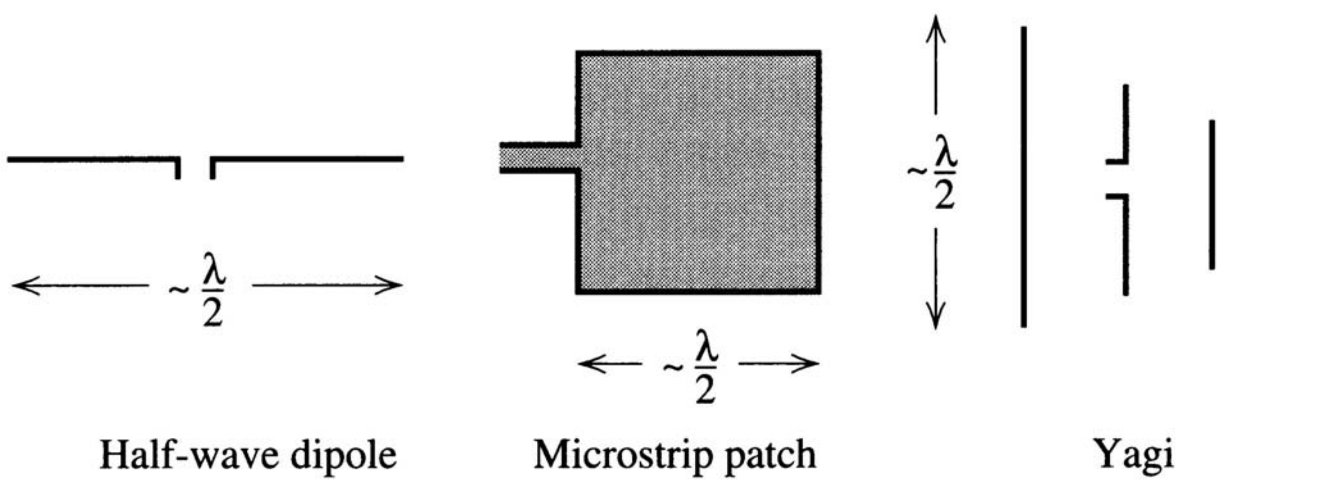
## 2. Resonant antennas

The antenna operates well at a single or selected narrow frequency bands.

Properties:

- Low to moderate gain (a few dB)
- Real input impedance
- Narrow bandwidth

Examples:




(a very widely used antenna) (printed antenna)

# Antenna Types

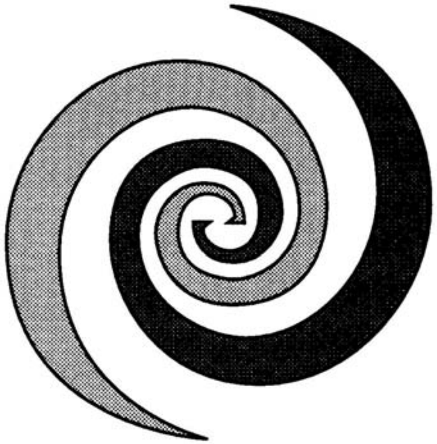
## 3. Broadband antennas

The pattern, gain, and impedance remain acceptable and are nearly constant over a wide frequency range.

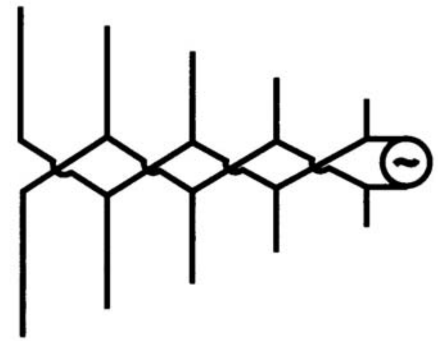
Properties:

- Low to moderate gain
- Constant gain
- Real input impedance
- Wide bandwidth

Examples:



Spiral



Log periodic dipole array

# Antenna Types

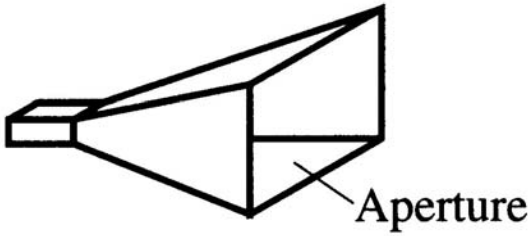
## 4. Aperture antennas

The antenna has a physical aperture (opening) through which waves flow.

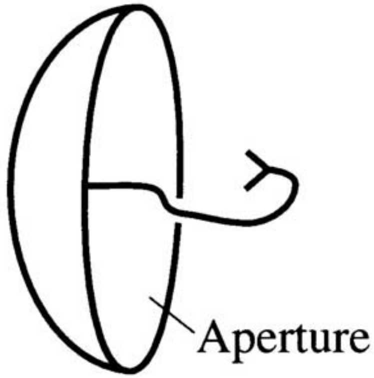
Properties:

- High gain (narrow main beam)
- Gain increases with frequency
- Moderate bandwidth

Examples:

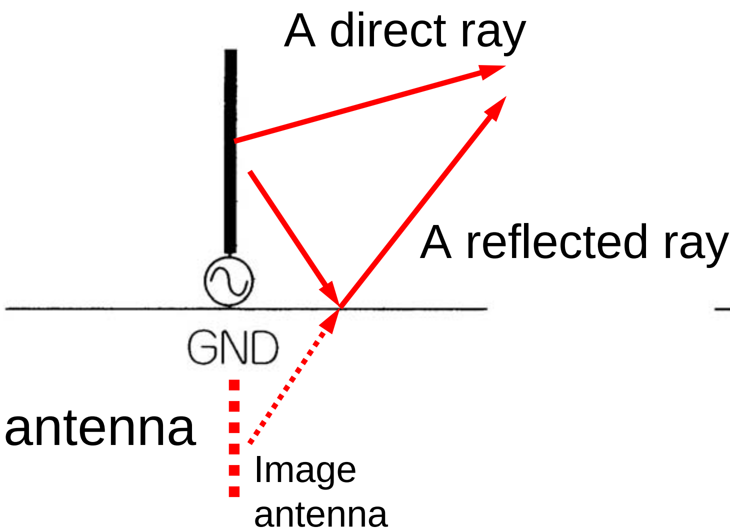



Horn

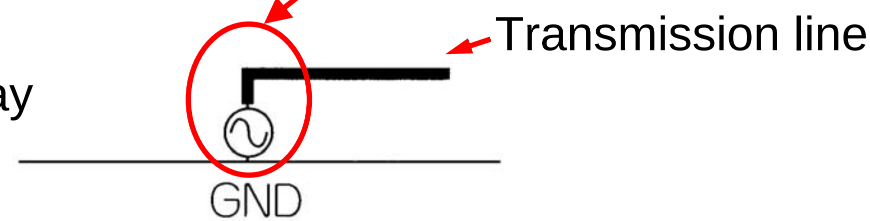



Reflector

# Antennas above a perfect ground plane




Monopole antenna




Inverted-L antenna

Monopole antenna:

A monopole is a dipole that has been divided in half at its center feed point and fed against a ground plane.

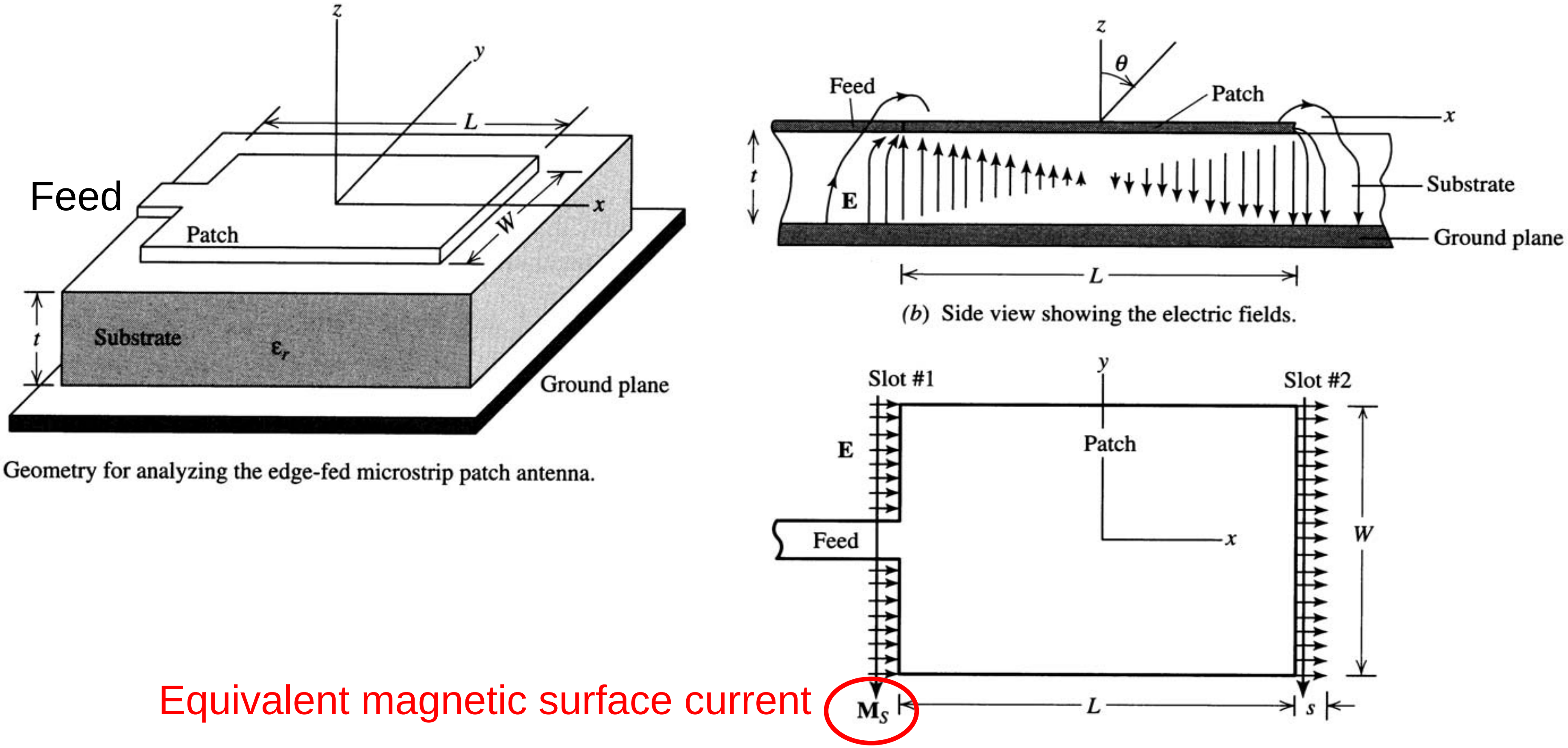
(The image antenna acts as an equivalent source for the reflected ray.)

Inverted-L antenna:

An inverted-L antenna is a transmission line loaded dipole.

(Low profile antenna)

# Microstrip Patch Antennas




(*a*) Geometry for analyzing the edge-fed microstrip patch antenna.

(*b*) Side view showing the electric fields.

(*c*) Top view showing the fringing electric fields that are responsible for radiation. The equivalent magnetic surface $\mathbf{M}_S$ currents are also shown.

**Figure 5-54** The half-wavelength rectangular patch microstrip antenna; $L \approx 0.49\lambda_d$, $\lambda_d$ the wavelength in the dielectric.

# Advantages of Microstrip Patch Antennas

- Low profile *(The thickness is usually less than* $0.03\lambda_0$ *.*
  $\lambda_0$ *is the operating wavelength in free space.)*
- Light weight
- Conformability to surface of substrates
- Low cost
- Integration with other circuits
- Versatility *(A microstrip patch antenna is very versatile in terms of impedance, resonant frequency, radiation pattern, polarization, and operating mode, by choice of shape and feeding arrangement.)*

*Z.N.Chen and M.Y.W.Chia,"Broadband Planar Antennas," Wiley, 2006.*

# Drawbacks of Microstrip Patch Antennas in their basic forms

- Narrow impedance bandwidth *(typically of around 1%)*
- Poor polarization purity
- Low radiation efficiency
- Poor power capability
- Poor scan performance
- Excitation of surface waves

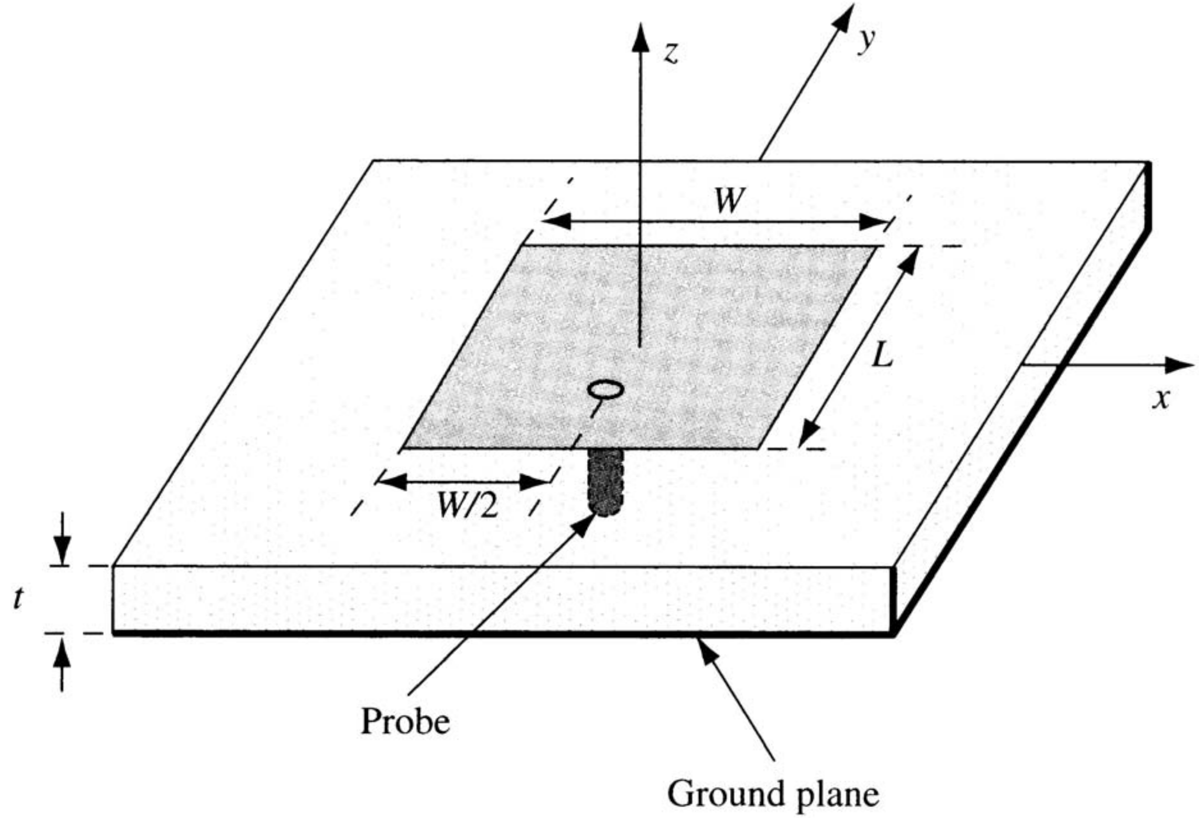
*Much effort has been devoted to the development of broadband techniques.*

# Broadband techniques for microstrip patch antennas

| Approach | Techniques |
| --- | --- |
| (1)Lower the Q | Select the radiator shape |
| | Thicken the substrate |
| | Lower the dielectric constant |
| | Increase the losses |
| (2)Use impedance matching | Insert a matching network |
| | Add tuning elements |
| | Use slotting and notching patches |
| (3)Introduce multiple resonances | Use parasitic elements |
| | Use slotting patches |
| | Insert impedance networks |
| | Use an aperture, proximity coupling |

*Z.N.Chen and M.Y.W.Chia,"Broadband Planar Antennas," Wiley, 2006.*

# A probe-fed rectangular microstrip patch antenna




Resonant frequency of $TM_{mn}$ mode

$$f_{mn} = \frac{c}{2\sqrt{\varepsilon_{eff}(L,W)}}\sqrt{\left(\frac{m}{L+2\Delta L(W)}\right)^2 + \left(\frac{n}{W+2\Delta W(L)}\right)^2}$$

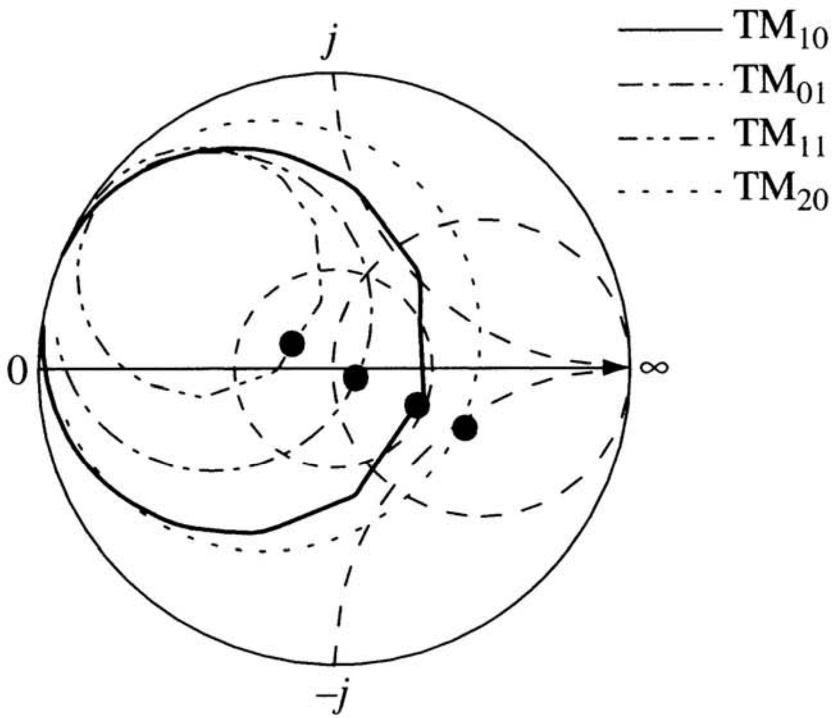
$\varepsilon_{eff}$ : effective relative dielectric constant

$c = 2.998\times 10^8\,\mathrm{m/s}$ : velocity of light

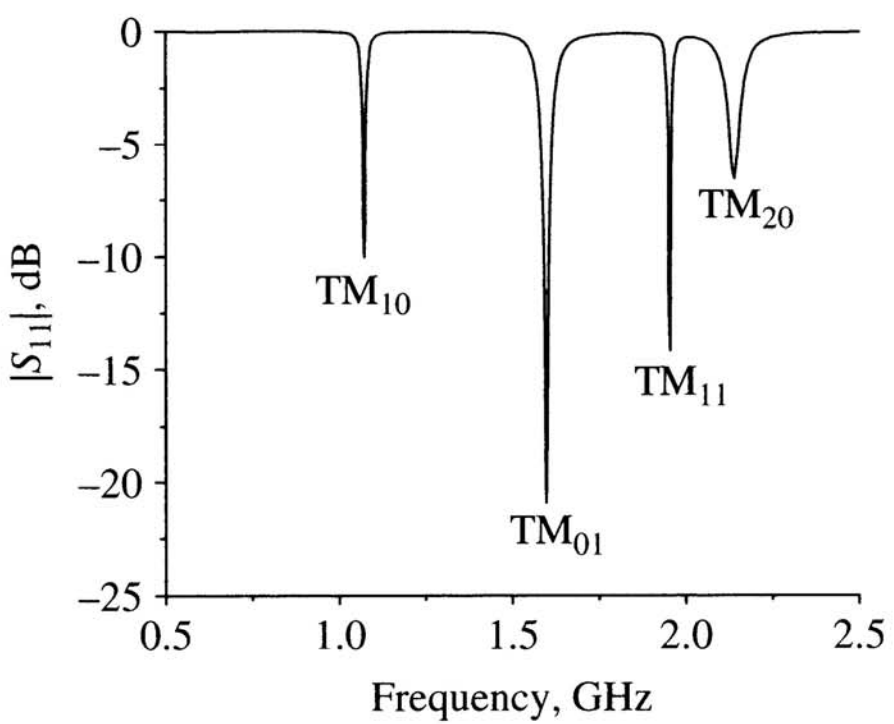
$\Delta L,\ \Delta W$ : lengths of fringing effect

*Z.N.Chen and M.Y.W.Chia,"Broadband Planar Antennas," Wiley, 2006.*

# The input impedance and return loss of a rectangular microstrip patch antenna




(a) Input impedance

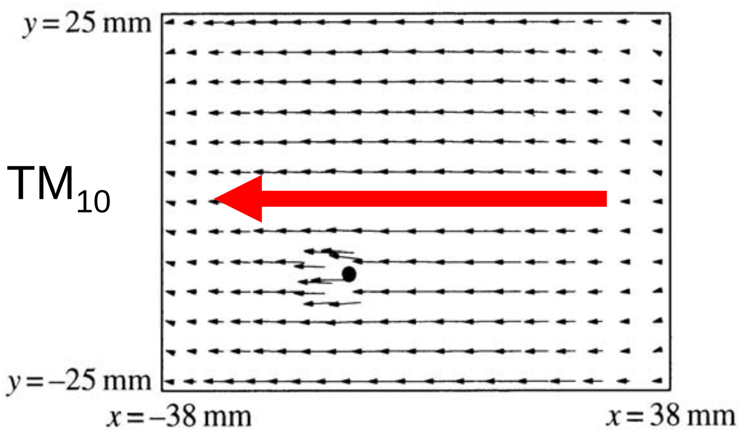



(b) Return loss

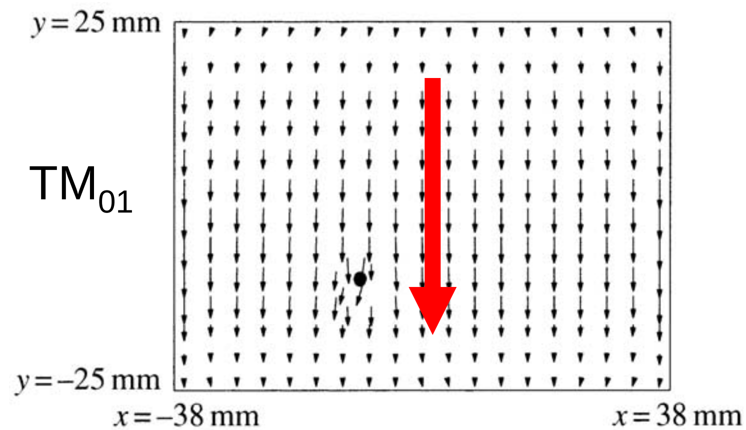
**Figure 2.10** The input impedance and return loss $|S_{11}|$.

$W = 76\text{mm}, L = 54\text{mm}, t = 1.5\text{mm}, \varepsilon_r = 3.38$

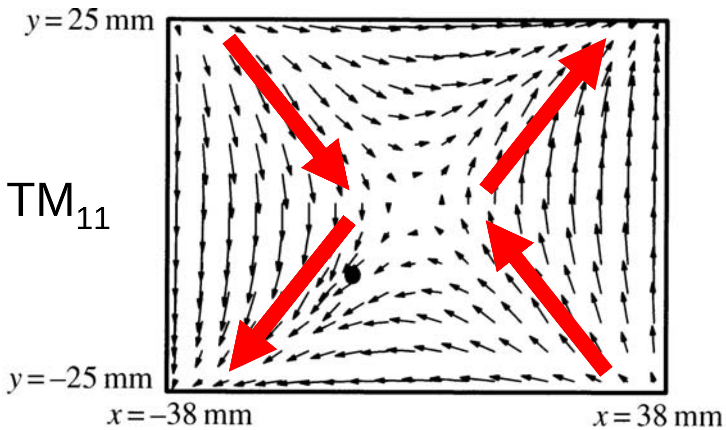
# Current distributions of the rectangular microstrip patch antenna



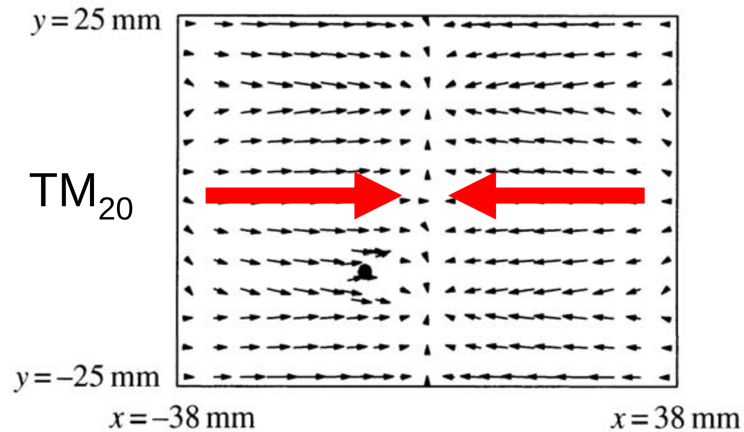

(a) TM$_{10}$ imaginary part




(a) TM$_{01}$ imaginary part




(a) TM$_{11}$ imaginary part




(a) TM$_{20}$ imaginary part

# Bandwidth of the rectangular patch antenna

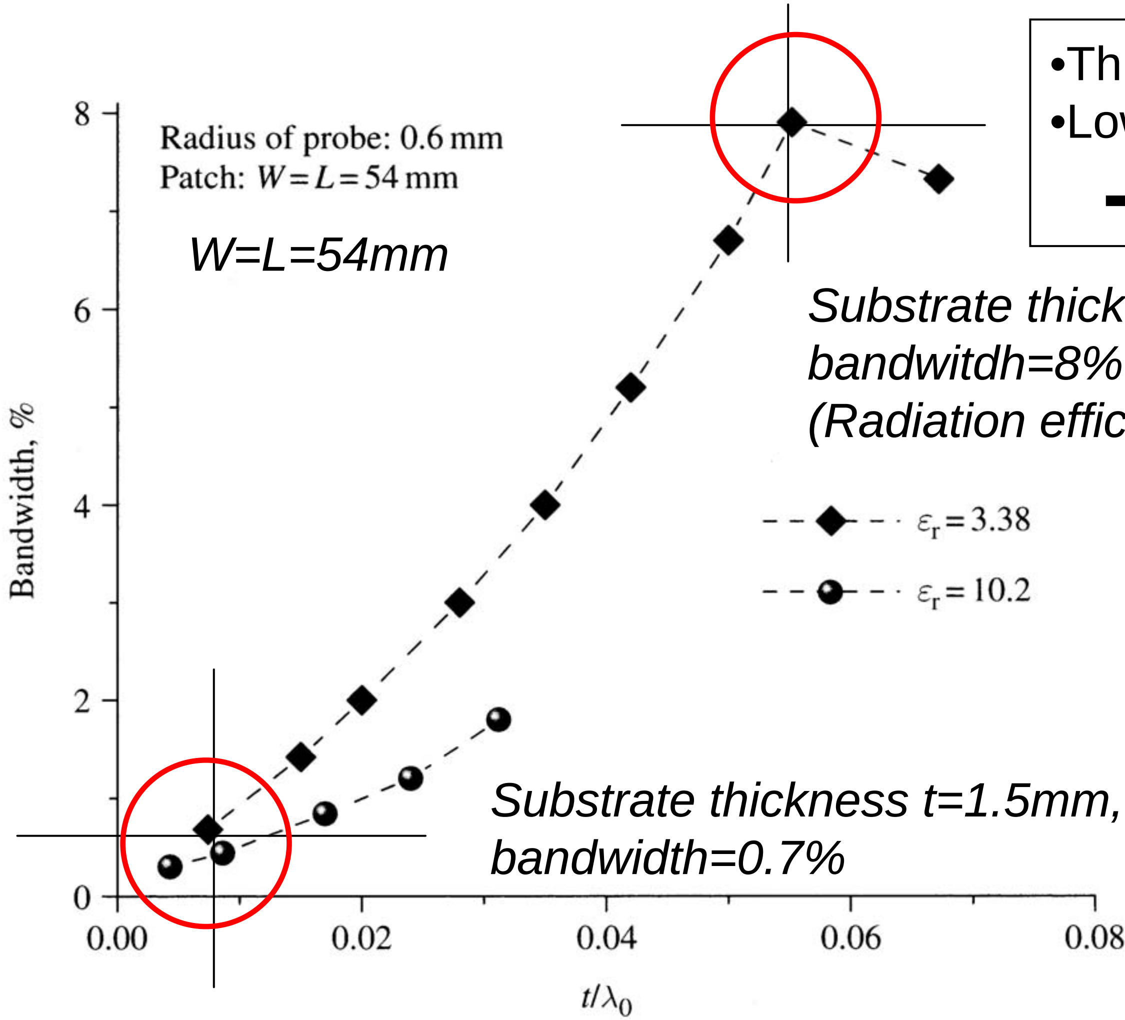
- Thicker substrate
- Lower dielectric constant

→ Broader bandwidth

W=L=54mm

*Substrate thickness t=11.6mm, bandwitdh=8%*
*(Radiation efficiency decreases.)*

*Substrate thickness t=1.5mm, bandwidth=0.7%*



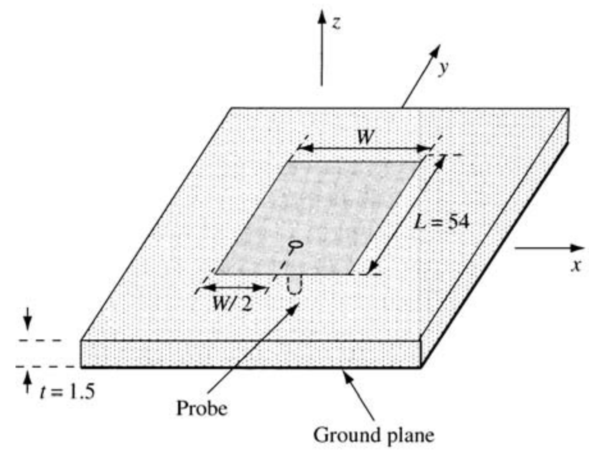
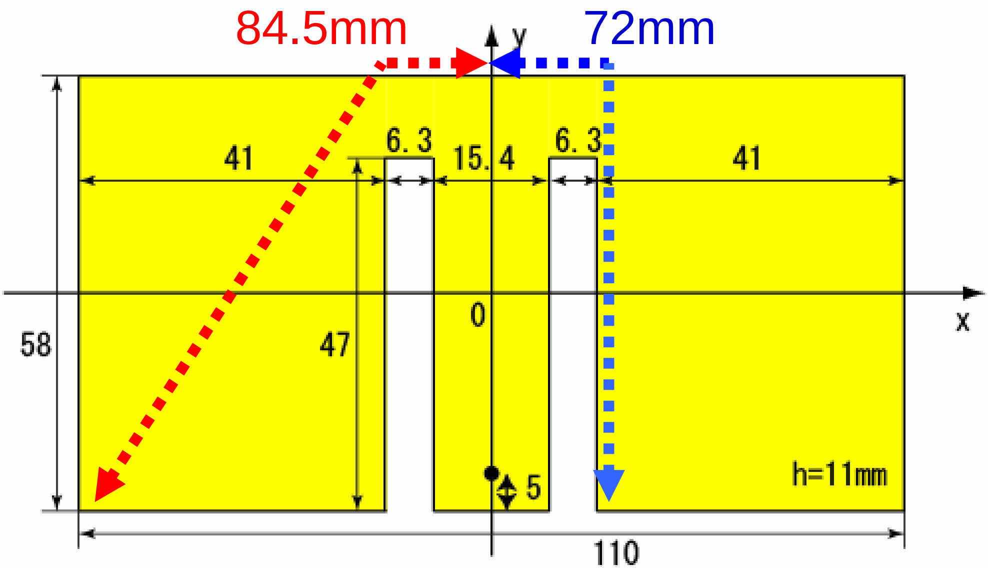
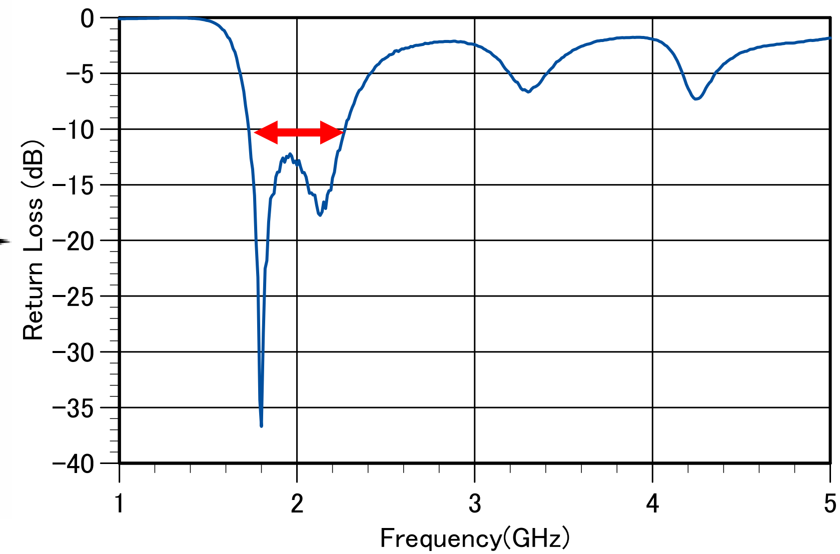




**Figure 2.16** Bandwidth versus substrate thickness ratio.

# A probe-fed rectangular patch antenna
## (Introducing multiple resonances)




- Air substrate
- Height h=11mm
- Double slot → Two resonances → Broadband

$$f_{r1} = 1.8GHz \quad \lambda_{r1}/2 = 83.3mm$$

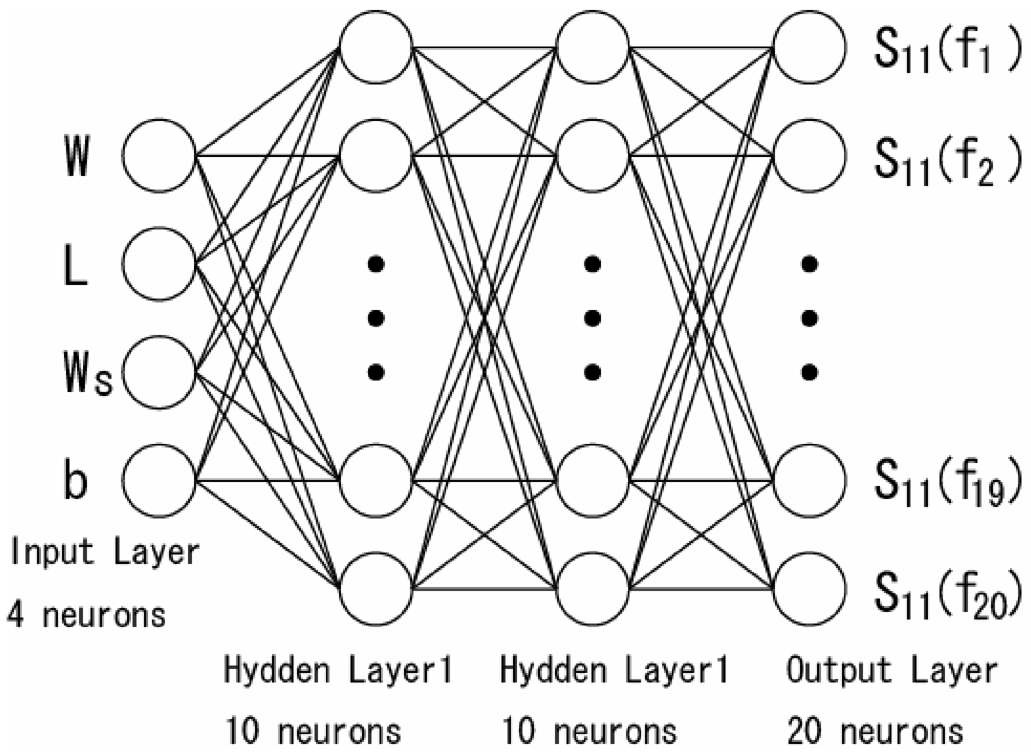
$$f_{r2} = 2.2GHz \quad \lambda_{r2}/2 = 68.2mm$$

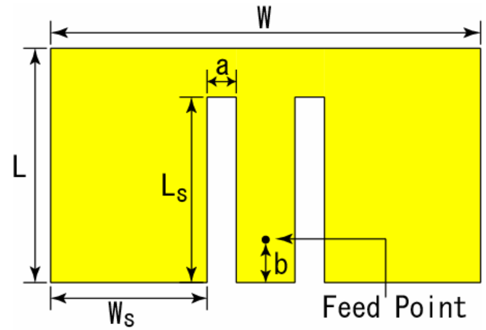
1.73GHz - 2.26GHz
fc=1.995GHz
-10dB bandwidth=26.6%

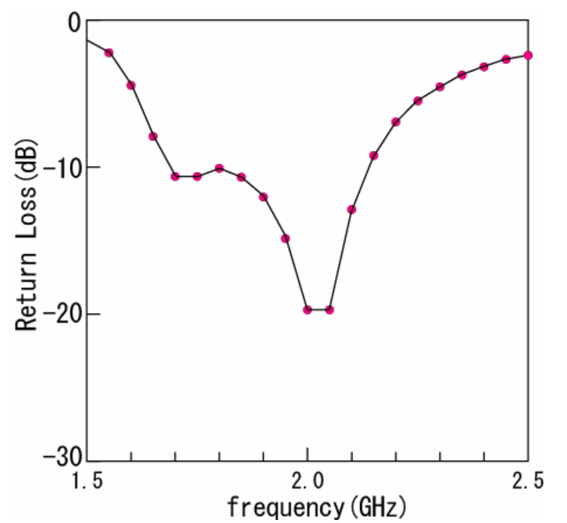
L.L.K.Singh, B.Gupta, K.Yasumoto, K.Yoshitomi, "Development of Novel Compact Broadband and Multifrequency Patch Antennas on Air Substrate," 4th Research Forum of Japan-Indo Collaboration Project, 2008.

# Design of the antenna using an artificial neural network (ANN)

An artificial neural network (ANN) for computing the return losses

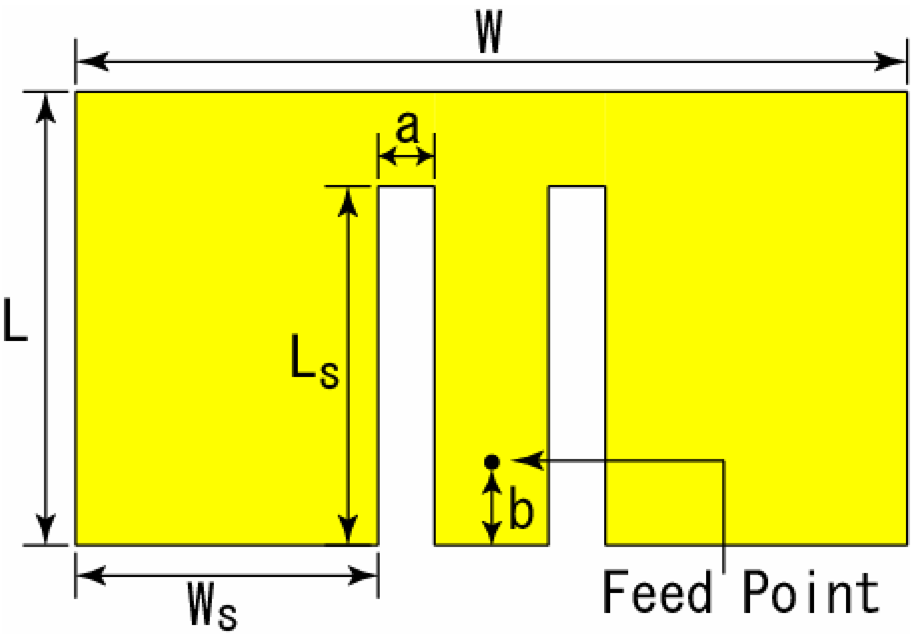



Training method: Back propagation

# A probe-fed rectangular patch antenna
## (Introducing multiple resonances)




*Double I-slot patch antenna*

Substrate (air dielectric) $\varepsilon_r = 1$

Thickness $h = 7\text{mm}$ *(fixed)*

$W = 105\text{mm},\ 110\text{mm}$

$L = 55\text{mm},\ 60\text{mm}$

$L_s = 47.5\text{mm}$ *(fixed)*

$W_s = 30\text{mm},\ 35\text{mm},\ 40\text{mm}$

$a = 7.5\text{mm}$ *(fixed)*

$b = 2.5\text{mm},\ 5.0\text{mm},\ 7.5\text{mm},$
$10.0\text{mm},\ 12.5\text{mm}, 15.0\text{mm}$

Training Data:
72 different sets of parameters and S11

# Result of ANN

Input:

$$105\text{mm} \le W \le 110\text{mm}$$

$$55\text{mm} \le L \le 60\text{mm}$$

$$30\text{mm} \le W_s \le 40\text{mm}$$

$$2.5\text{mm} \le b \le 15\text{mm}$$

Output: $S_{11}(f_n)$

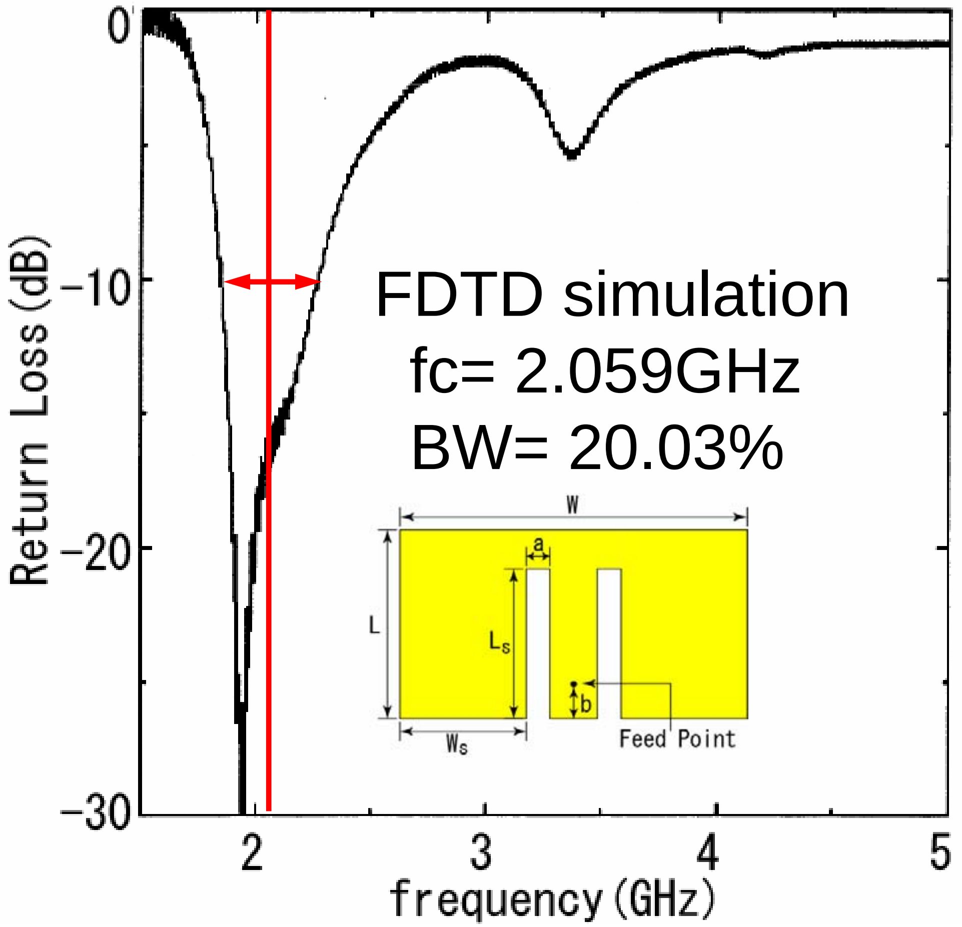
For

center frequency 2.0GHz

bandwidth 20%

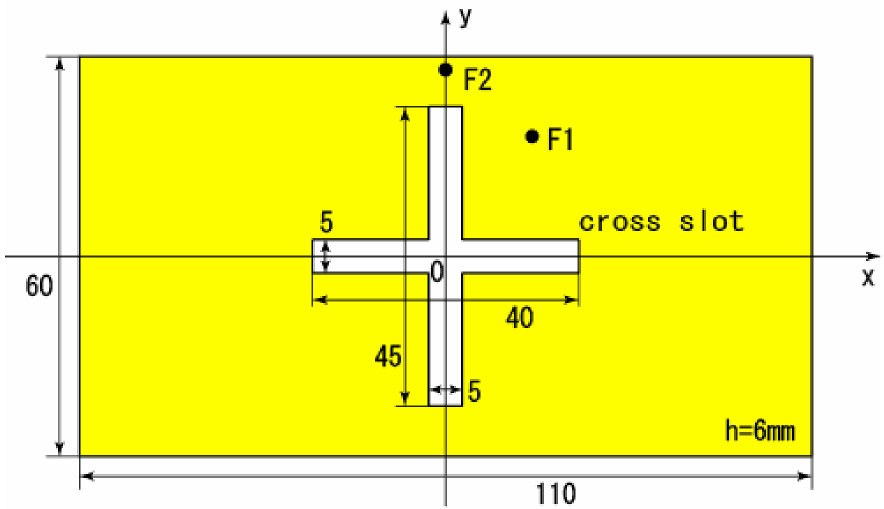
$$W = 105.5\text{mm}, L = 55.5\text{mm}$$

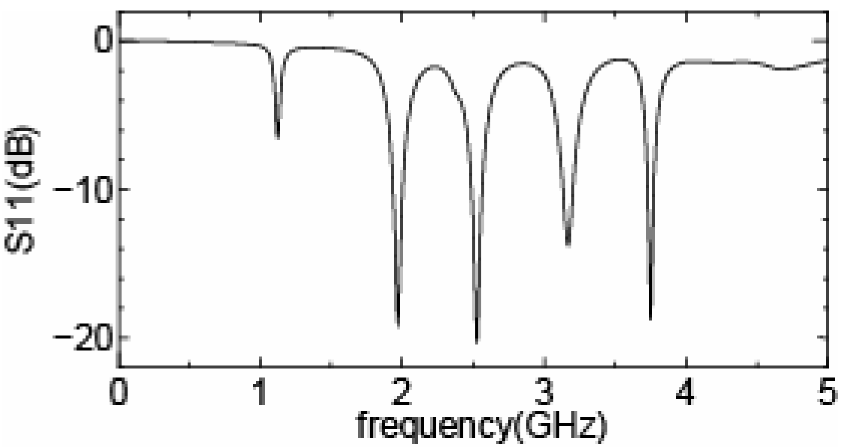
$$W_s = 39\text{mm}, \ b = 11.25\text{mm}$$



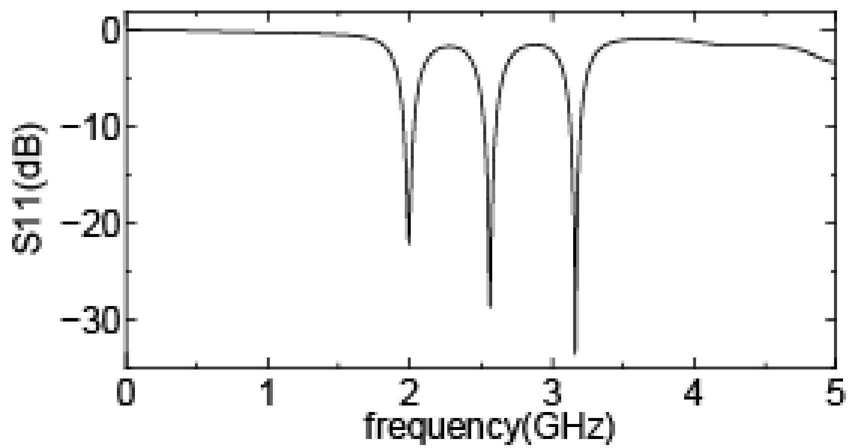
# Quad or tri frequency bands antennas

(Introducing multiple resonances by using slot)




Quad frequency bands fed at F1

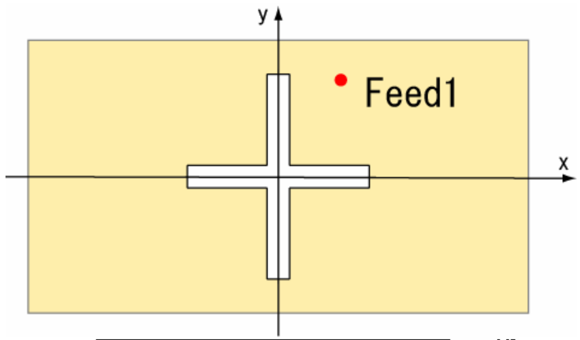



Tri frequency bands fed at F2

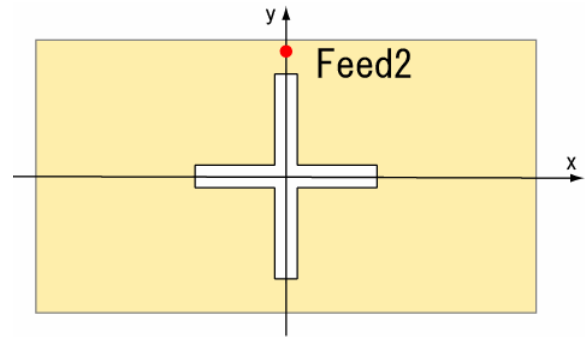
L.L.K.Singh, B.Gupta, K.Yasumoto, K.Yoshitomi, "Development of Novel Compact Broadband and Multifrequency Patch Antennas on Air Substrate," 4th Research Forum of Japan-Indo Collaboration Project, 2008.

# Simulation of Electric Field $E_z$ Distribution

Case1




Case2

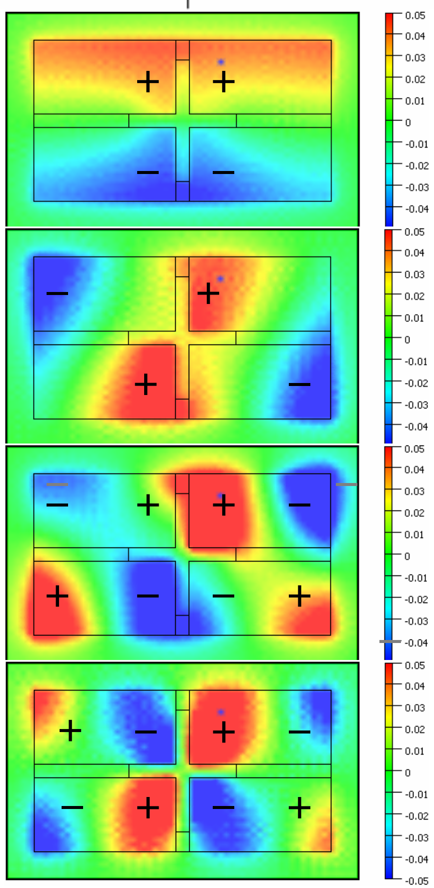



TM01
1.973GHz

TM20
2.589GHz

TM21
3.227GHz

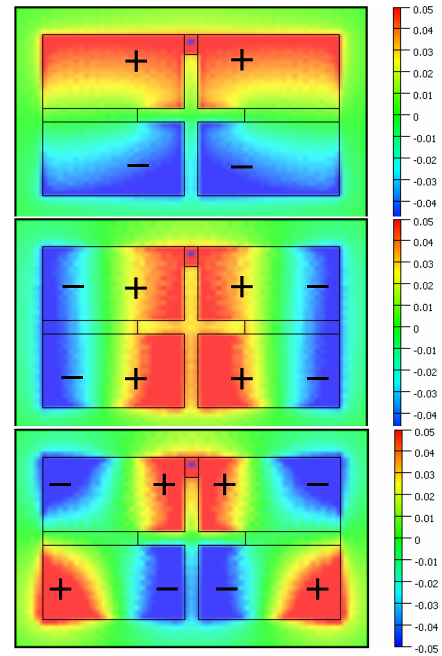
TM31
3.770GHz




TM01
2.020GHz

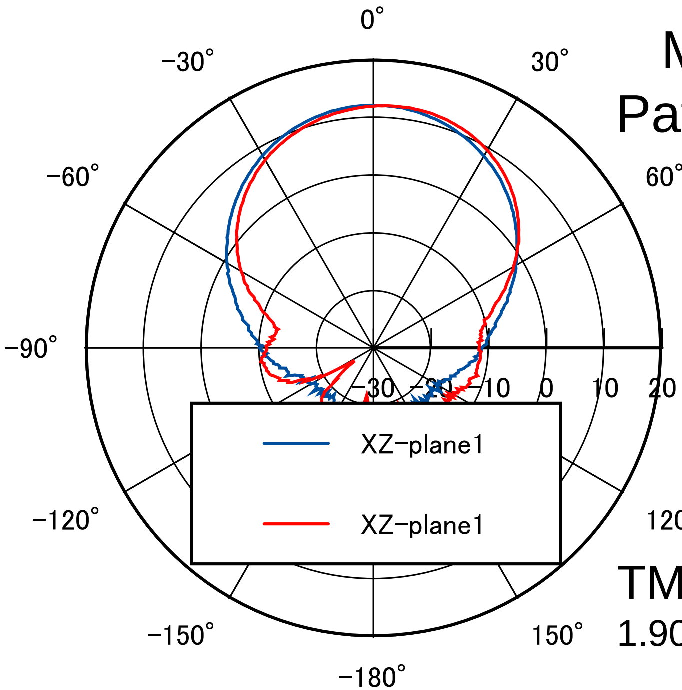
TM20
2.640GHz

TM21
3.220GHz

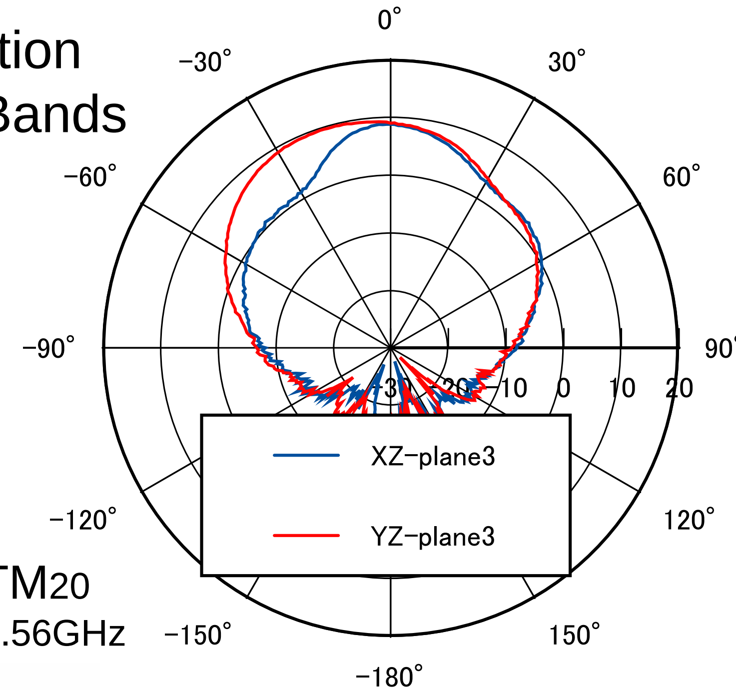



Resonance modes and frequencies

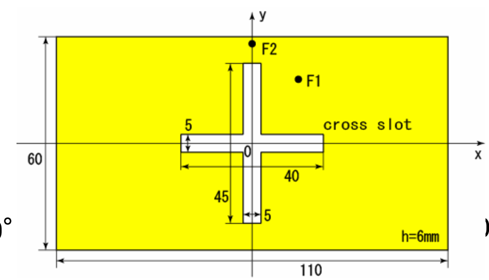
# Measured Radiation Patterns of Quad Bands Antenna

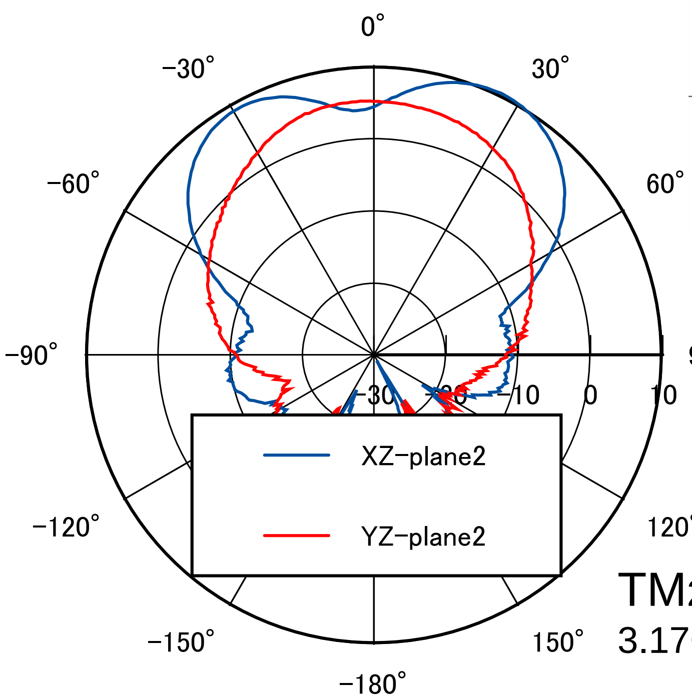



TM01
1.90GHz

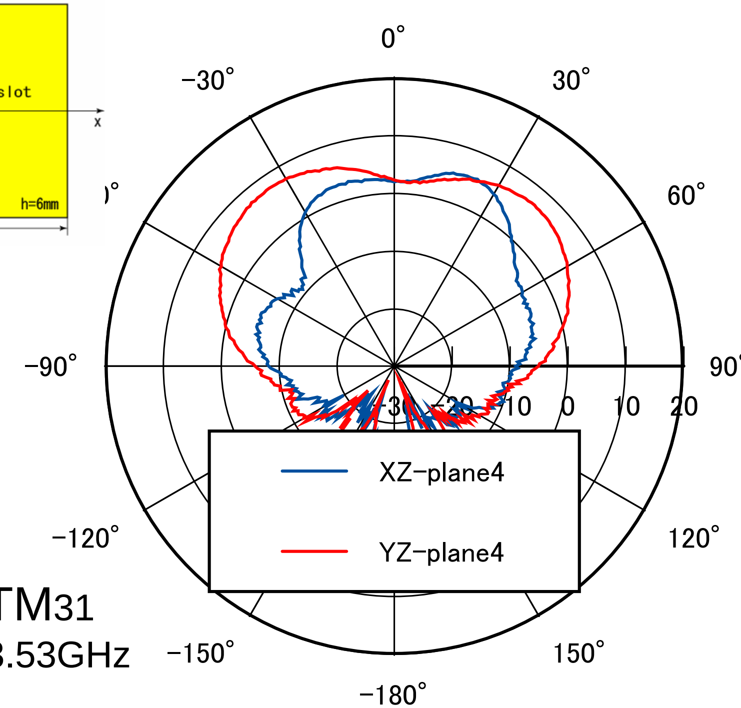



TM20
2.56GHz



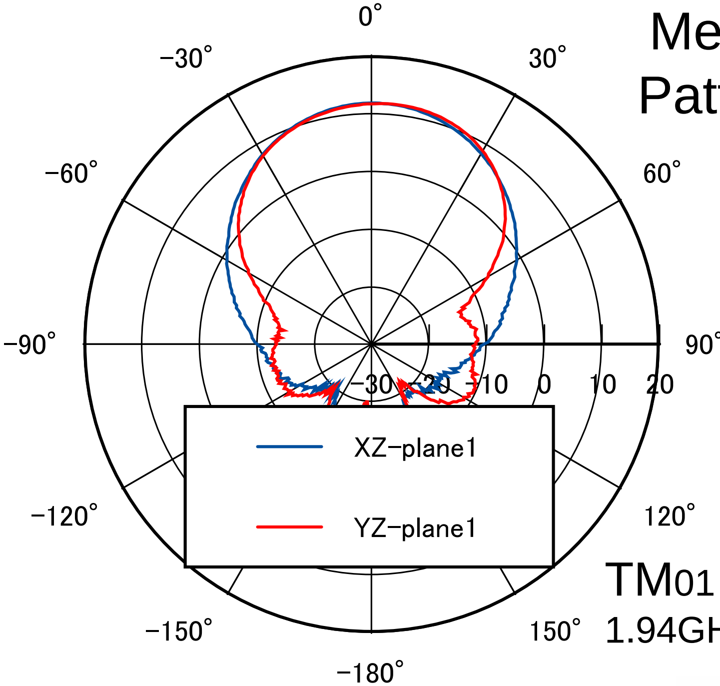




TM21
3.17GHz

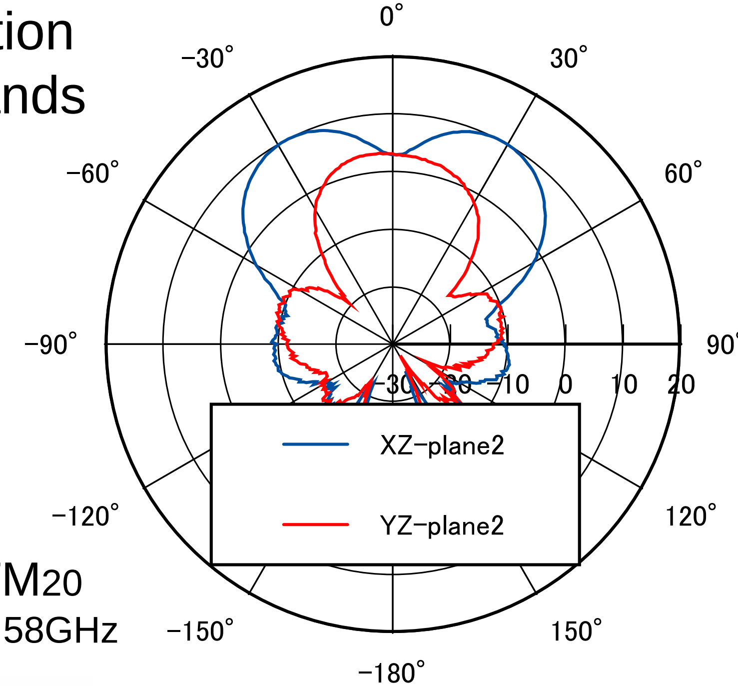



TM31
3.53GHz

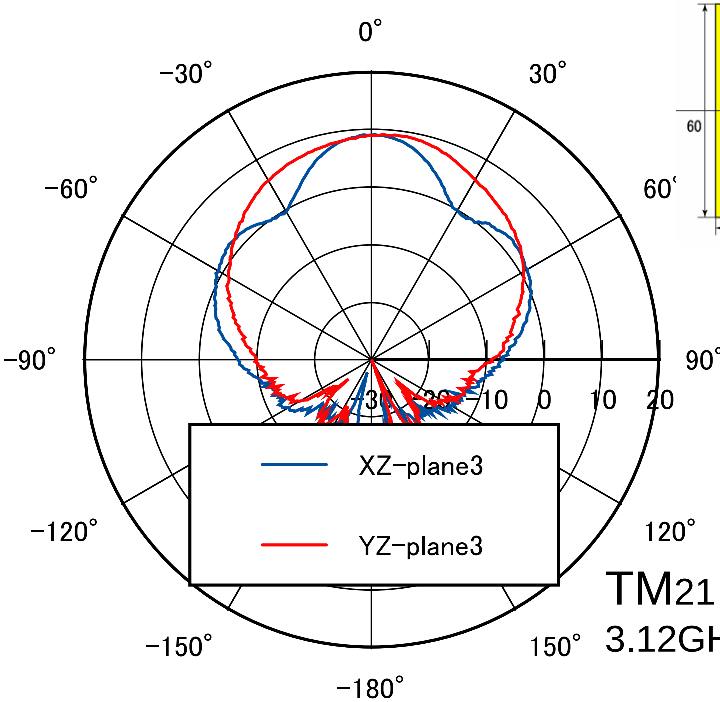
# Measured Radiation Patterns of Tri Bands Antenna



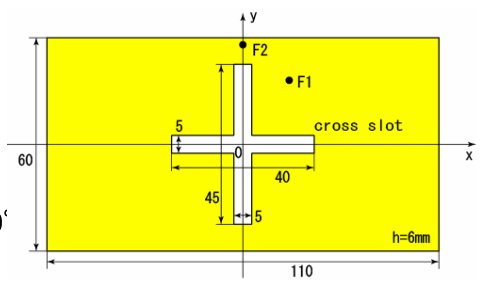

TM01
1.94GHz



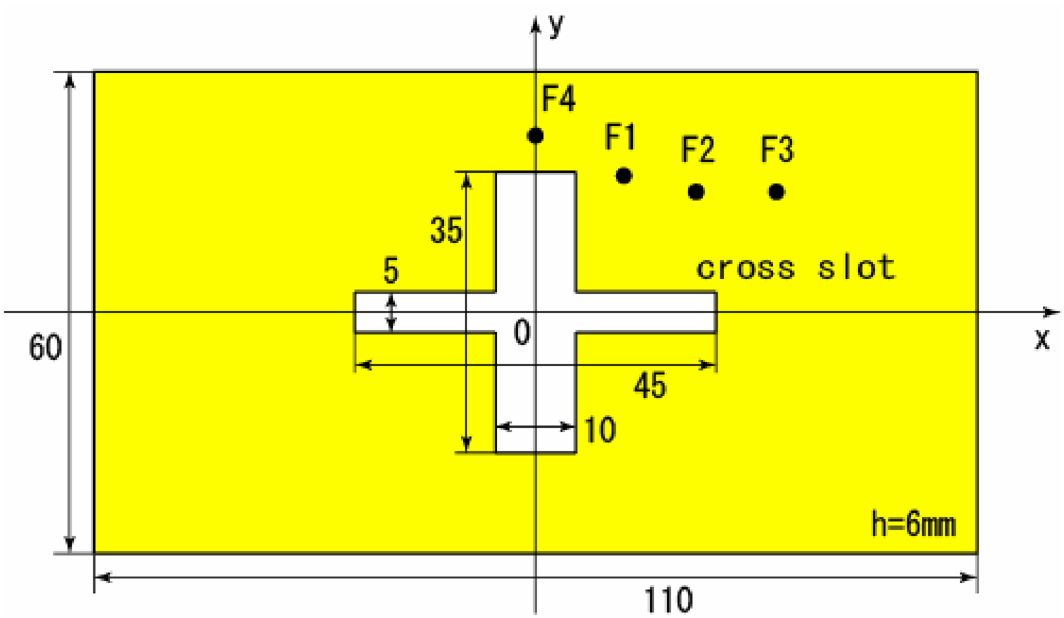

TM20
2.58GHz




TM21
3.12GHz



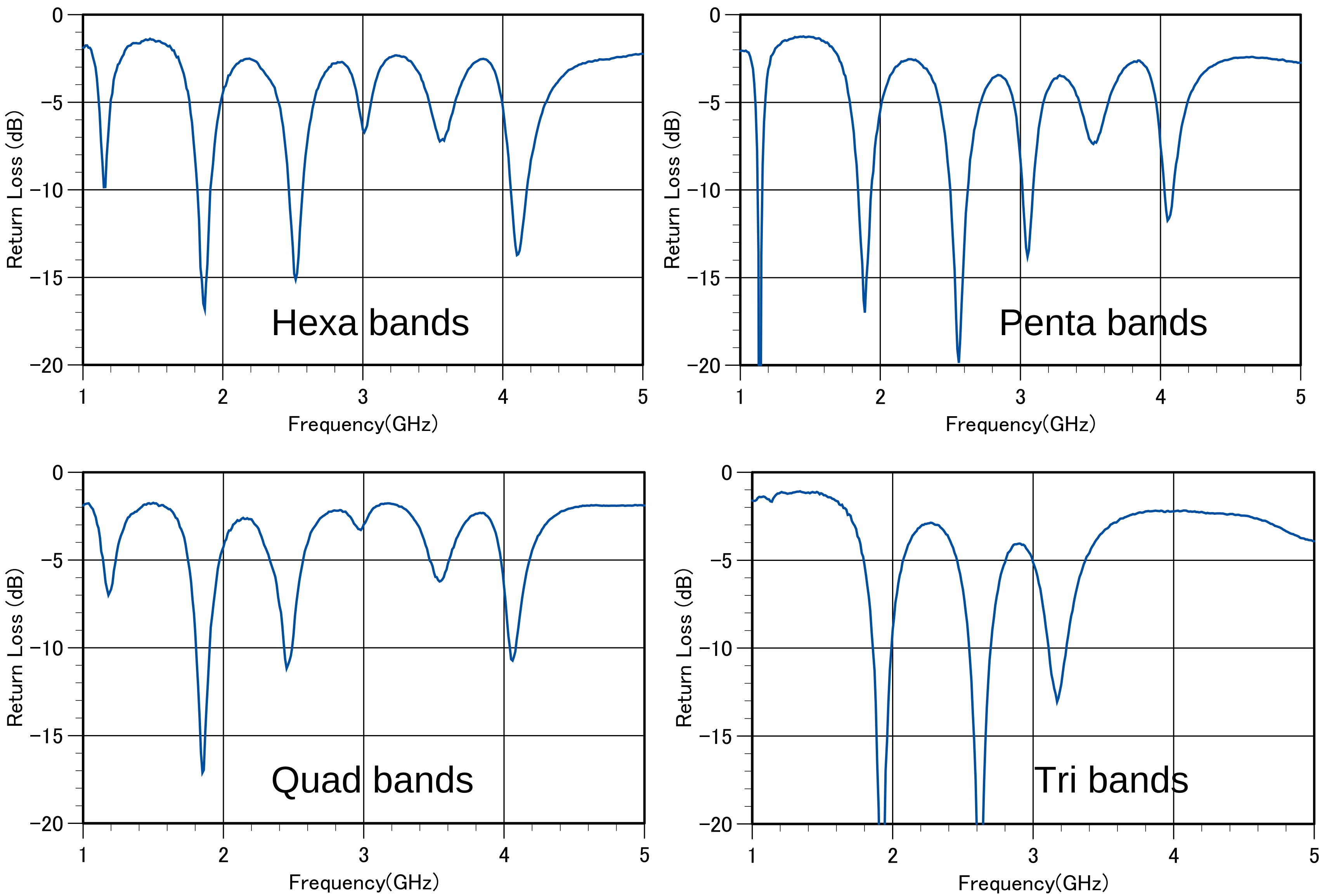
# Hexa, penta, quad or tri frequency bands antennas



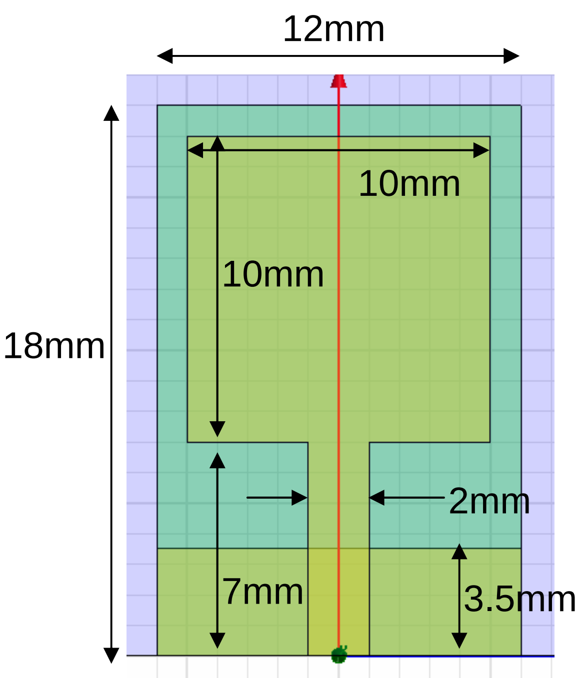

| Frequency bands | Feed point |
|---|---|
| Hexa bands | F1 |
| Penta bands | F2 |
| Quad bands | F3 |
| Tri bands | F4 |

L.L.K.Singh, B.Gupta, K.Yasumoto, K.Yoshitomi, “Development of Novel Compact Broadband and Multifrequency Patch Antennas on Air Substrate,” 4th Research Forum of Japan-Indo Collaboration Project, 2008.

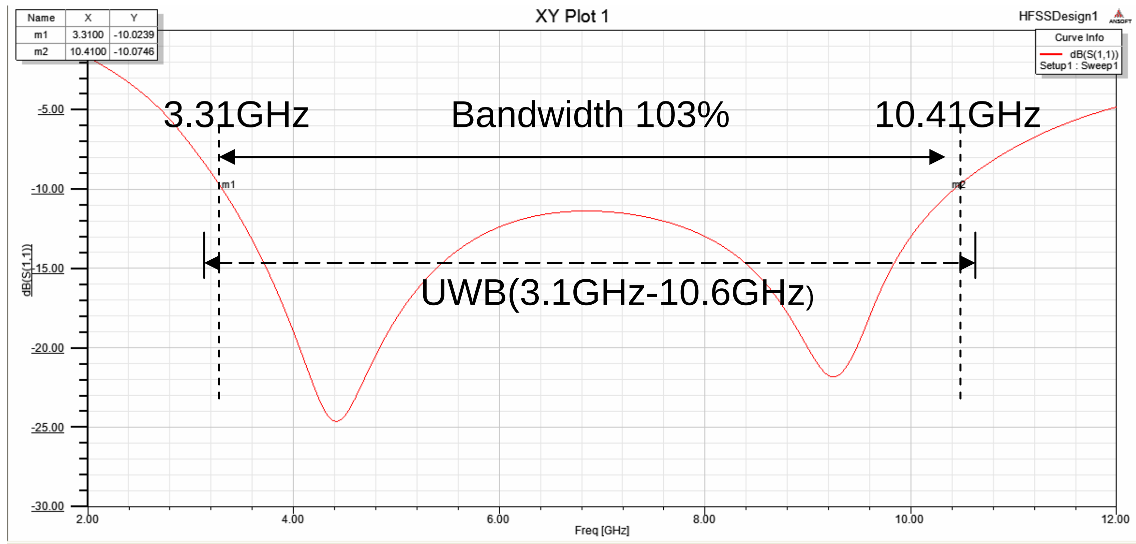
# Measured return losses of hexa, penta, quad or tri frequency bands antennas

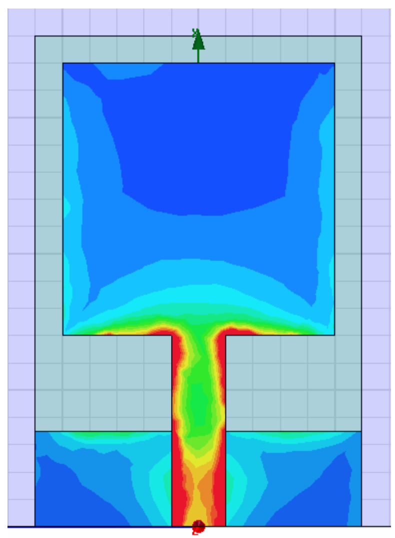


# Planar monopole antenna 1

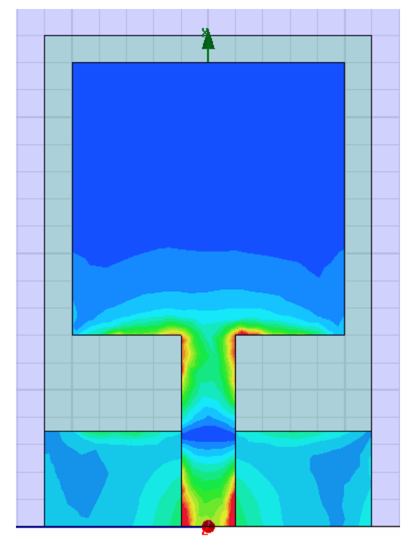



FR4 ($\varepsilon_r = 4.4$ )
thickness=1.6mm



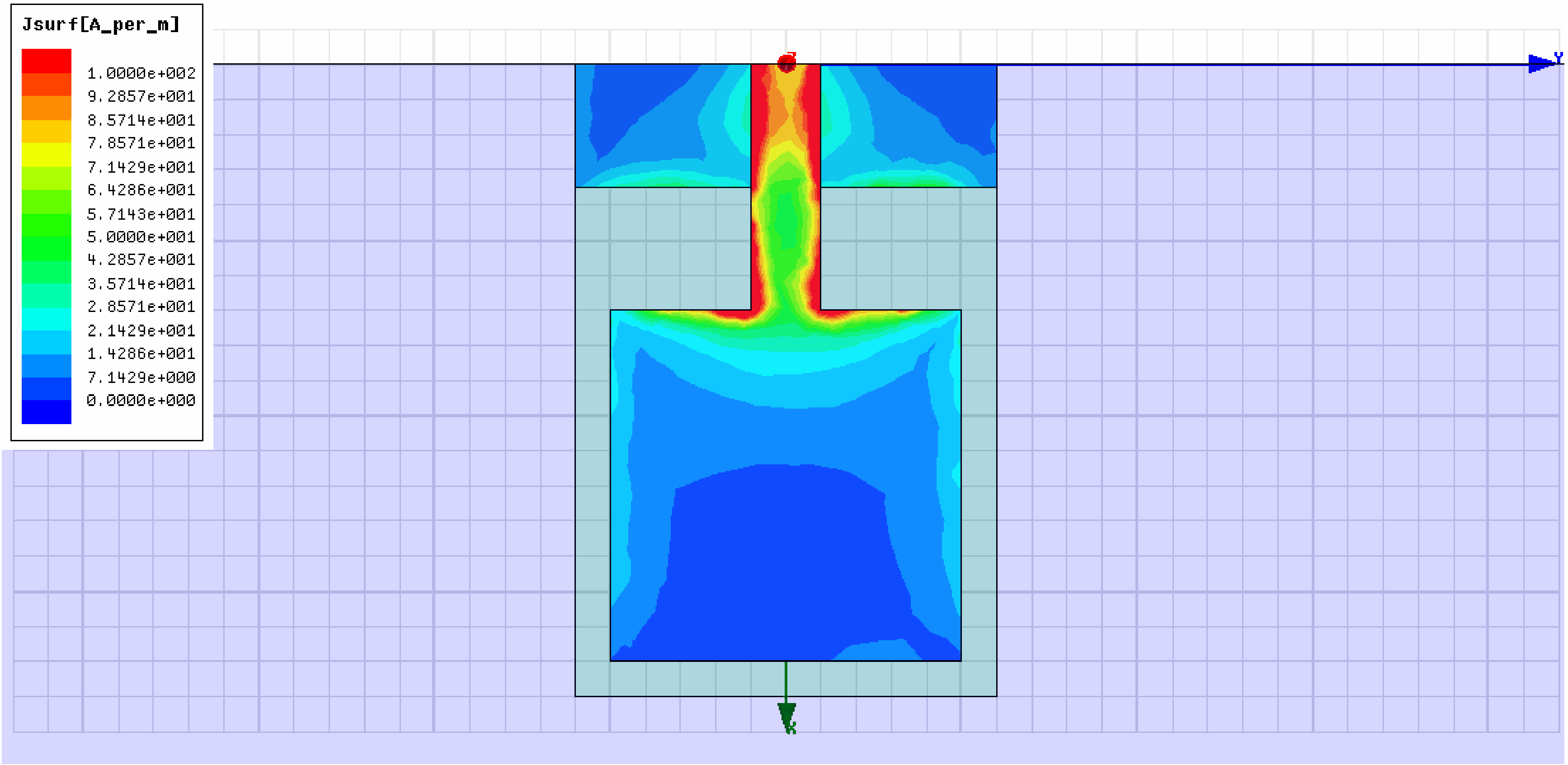



3GHz

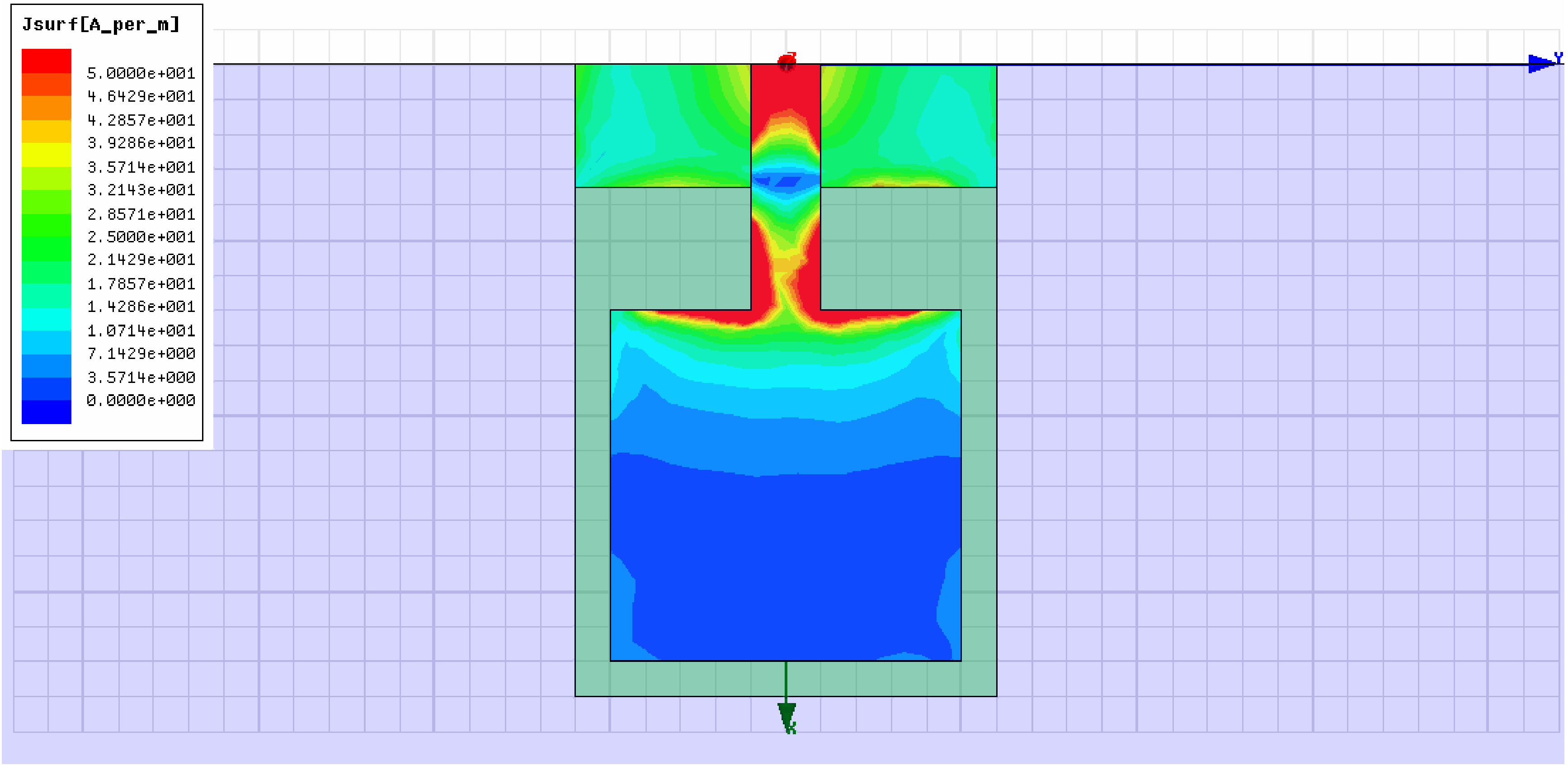


10GHz

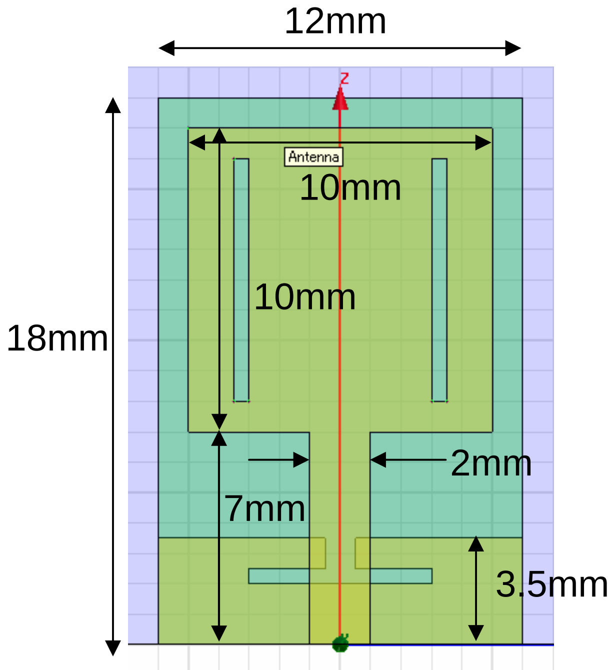
# Planar monopole antenna 1
# 3GHz



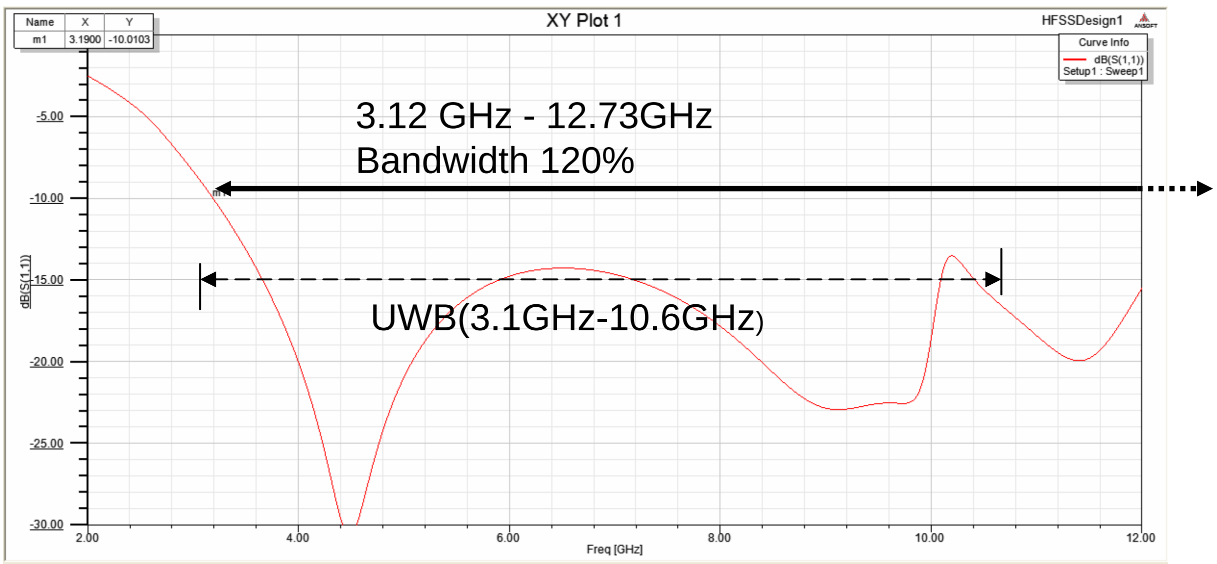
# Planar monopole antenna 1
# 10GHz



# Planar monopole antenna 2

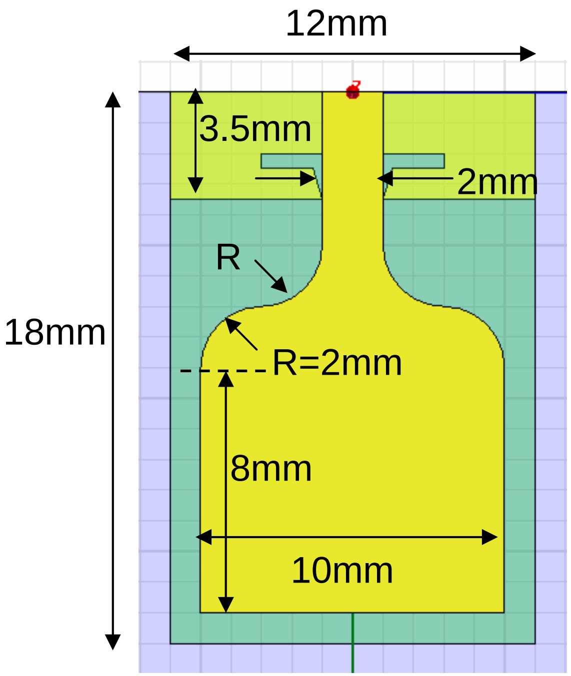



FR4 ($\varepsilon_r = 4.4$)
thickness=1.6mm

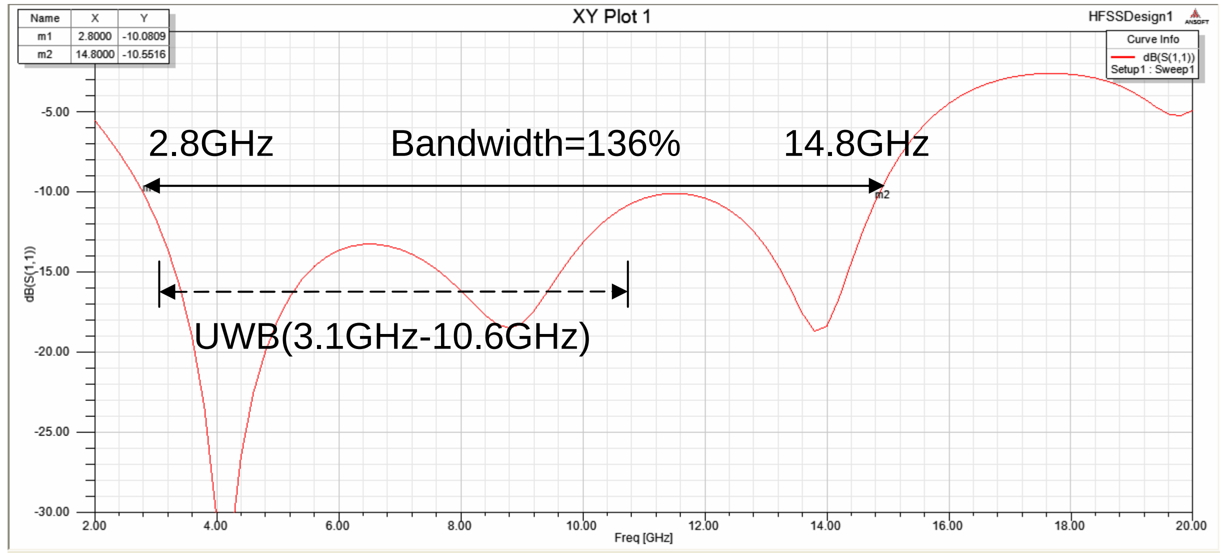


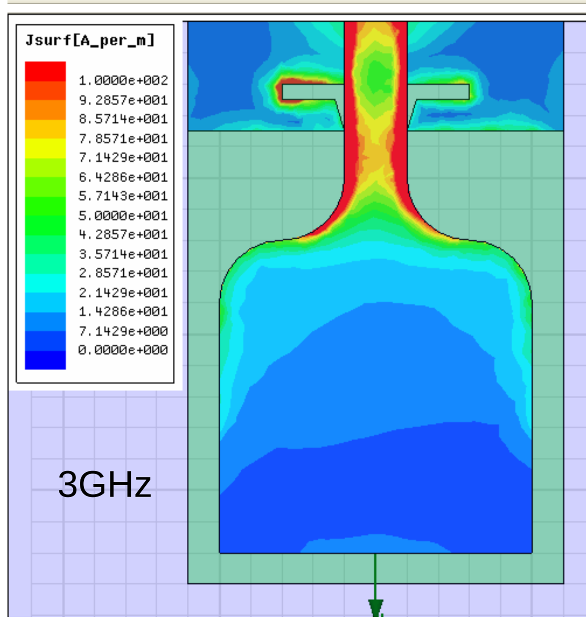

M. Ojaroudi, C. Ghobadi, and J. Nourinia,"Small Square Monopole Antenna With Inverted T-Shaped Notch in the Ground Plane for UWB Application," IEEE Antennas and Wireless Propagation Letters, Vol.8, pp.728-731, 2009

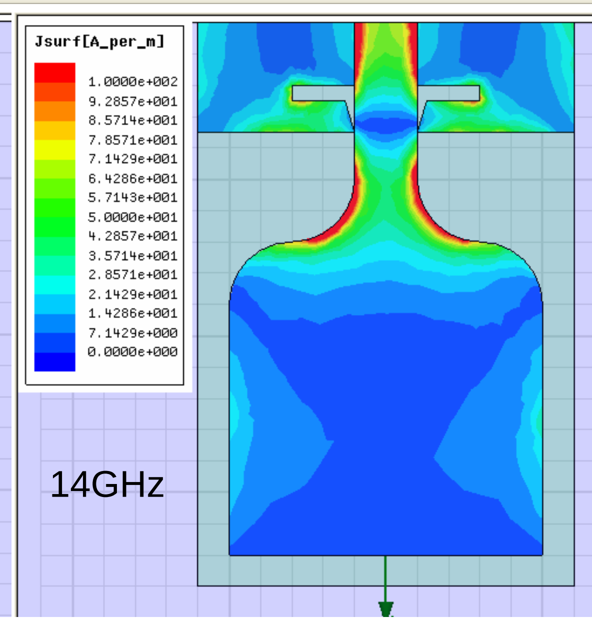
# Planar monopole antenna 3



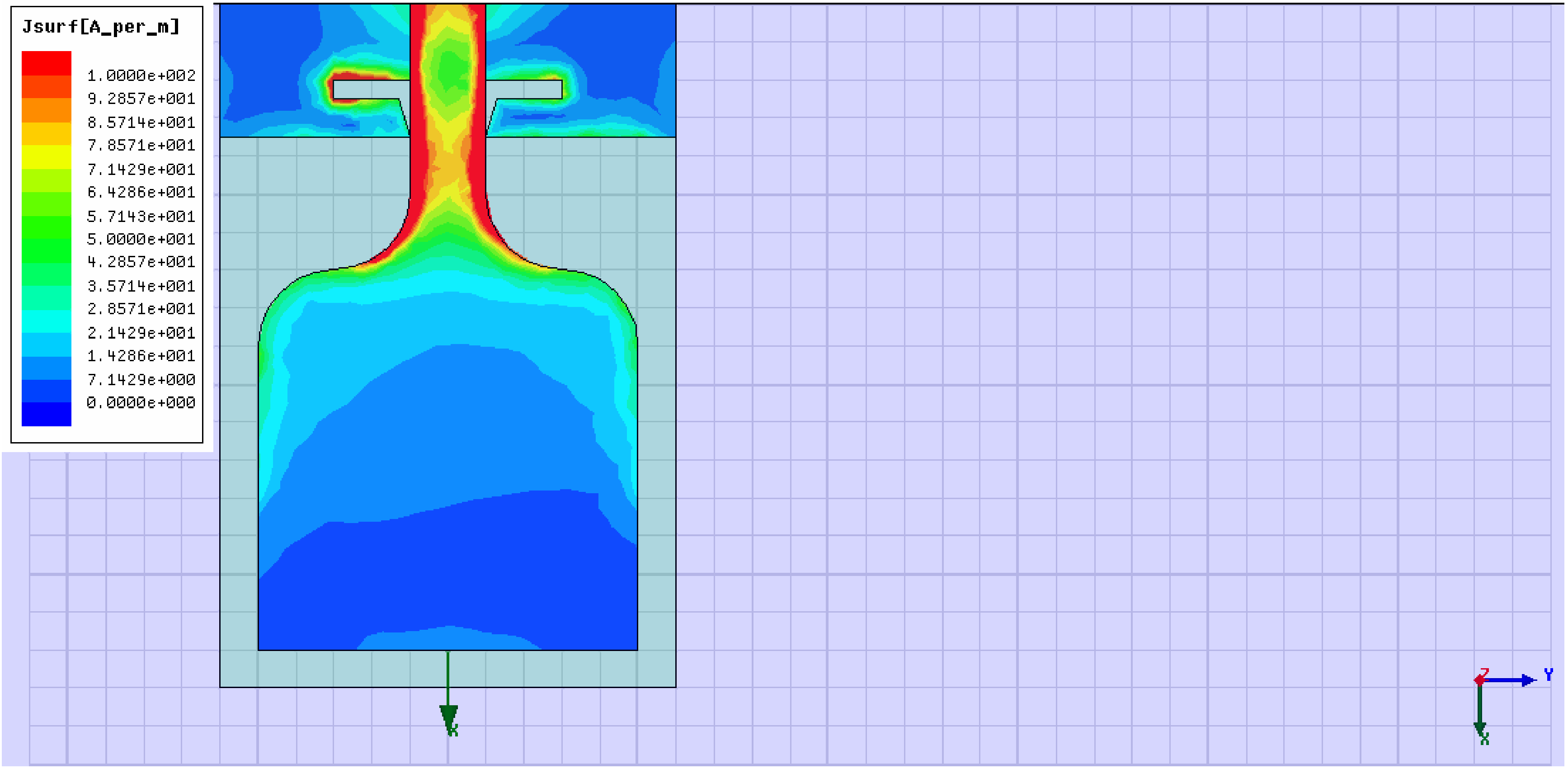

FR4 ($\varepsilon_r = 4.4$)
thickness=1.6mm



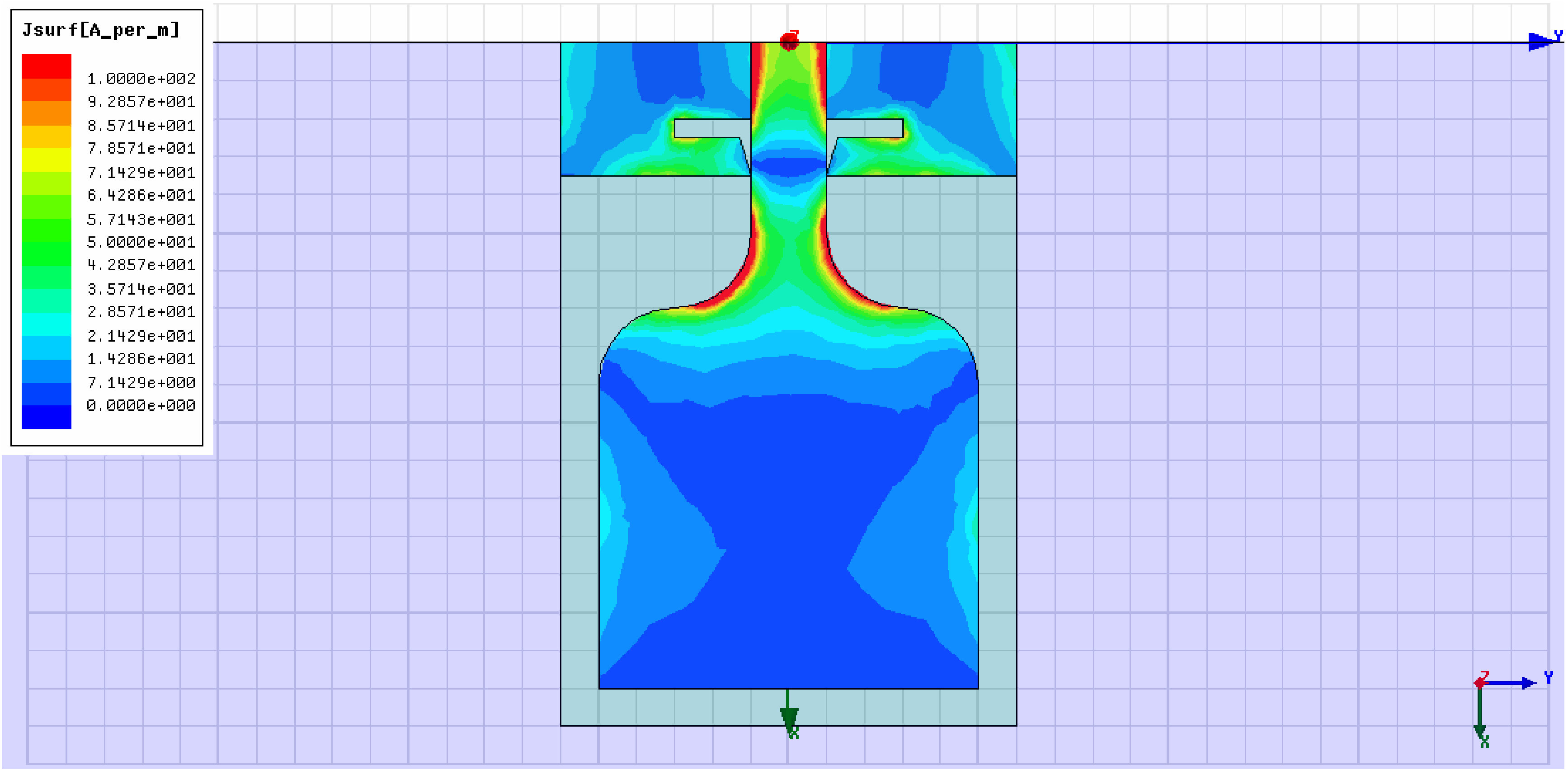



# Planar monopole antenna 3
# 3GHz

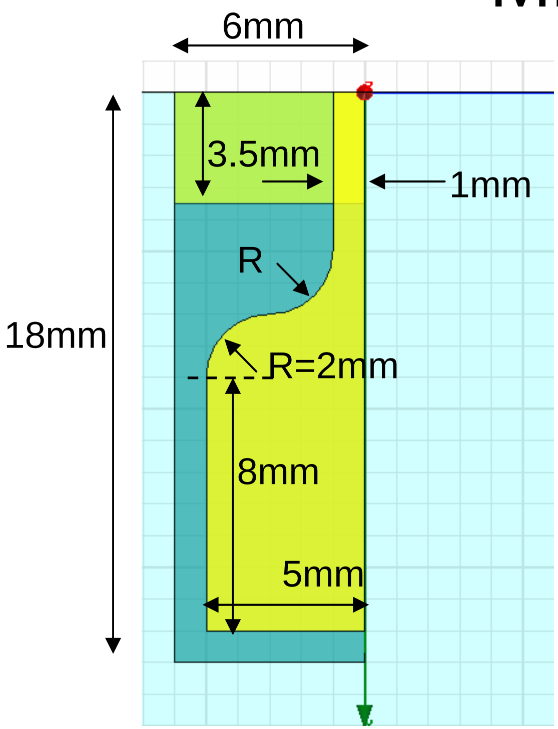


# Planar monopole antenna 3
# 14GHz

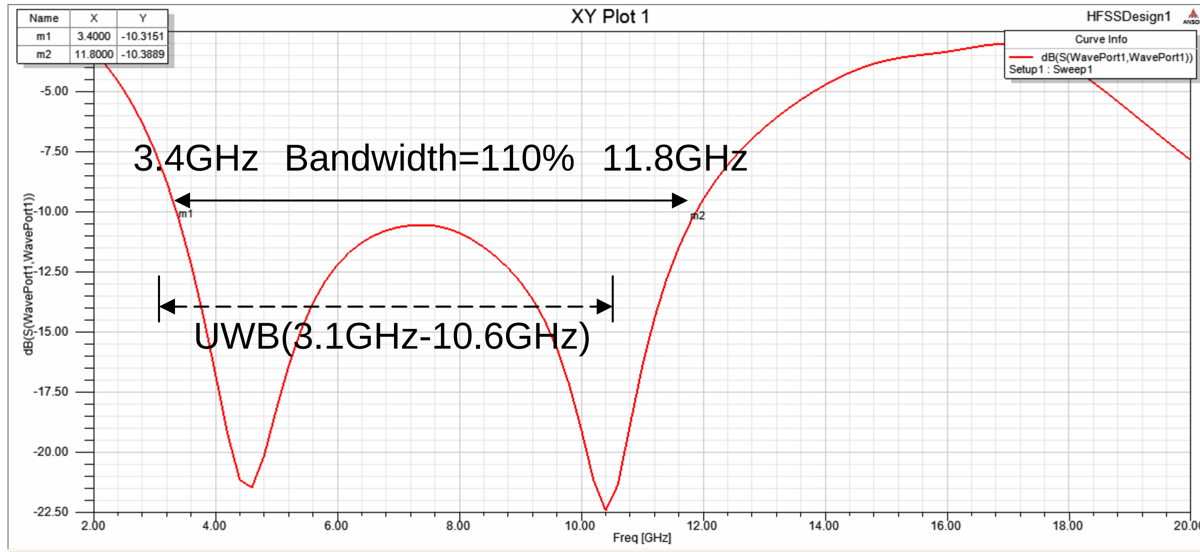


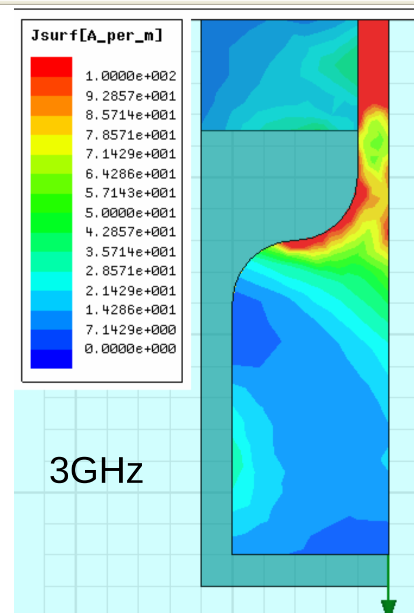
# Planar monopole antenna 4

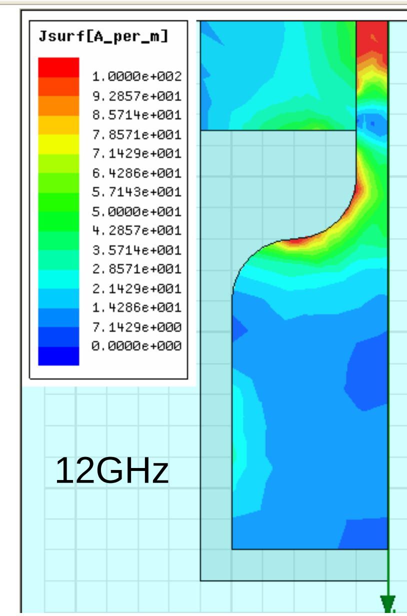
## Miniaturization by half-cut



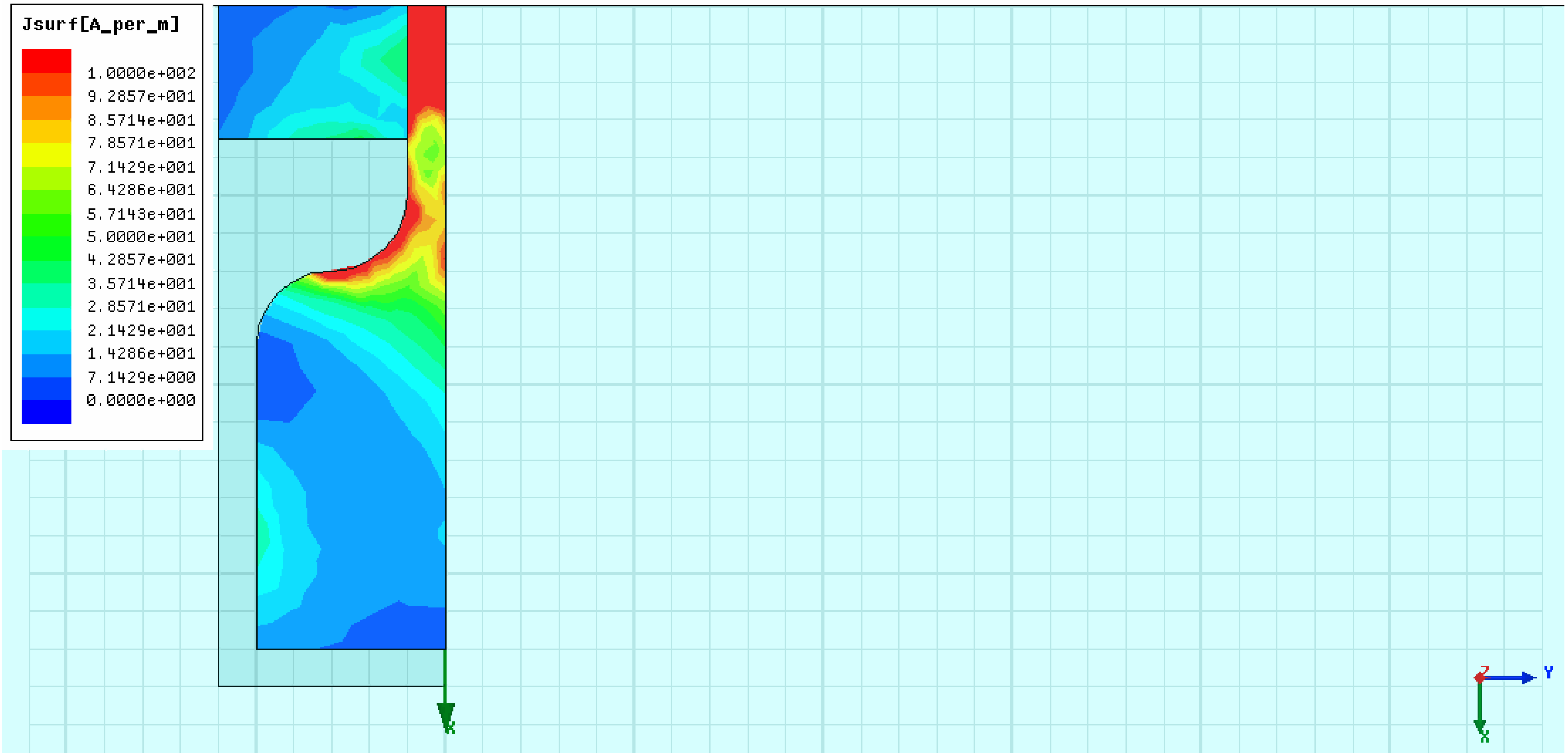

FR4 ($\varepsilon_r = 4.4$)
thickness=1.6mm



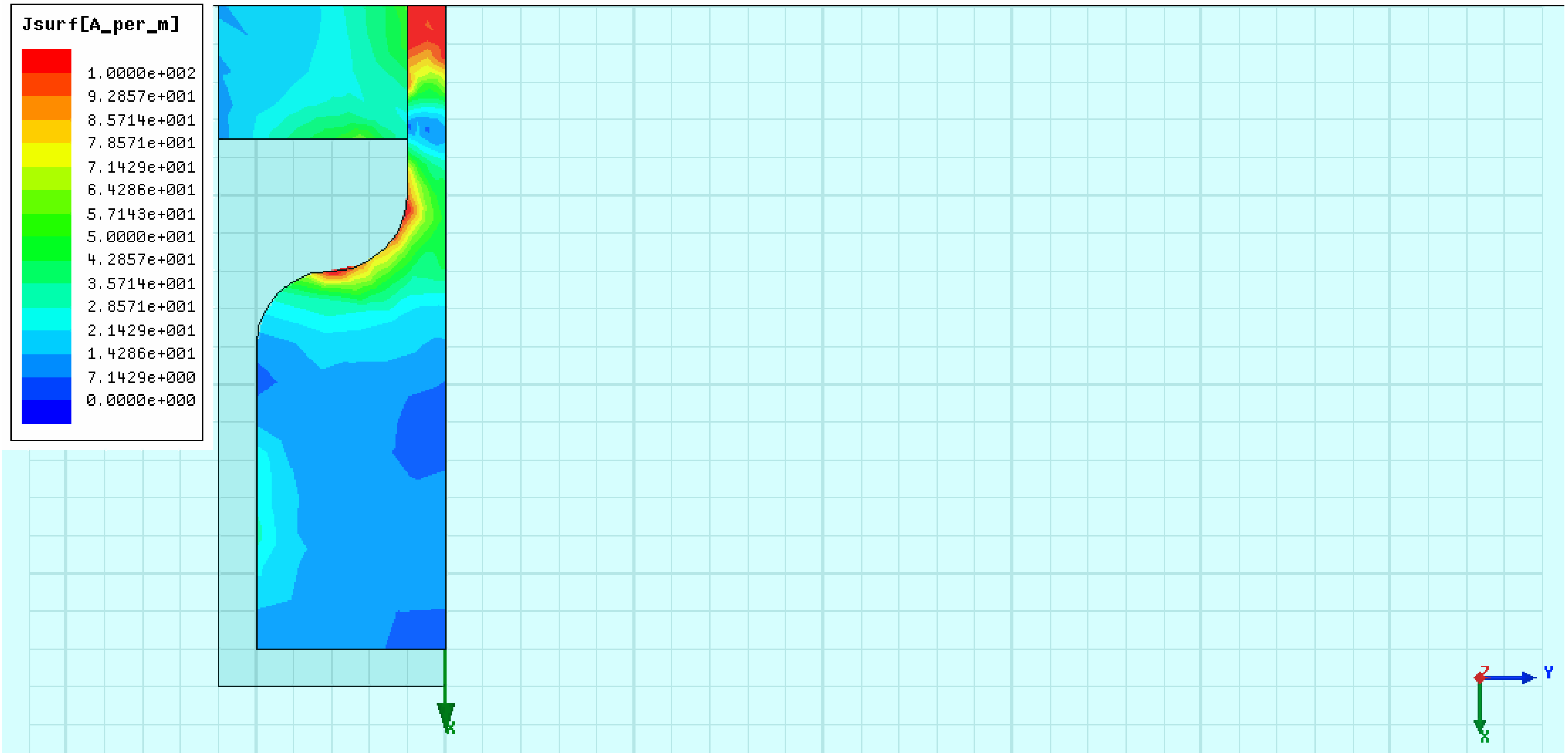



# Planar monopole antenna 4
# 3GHz

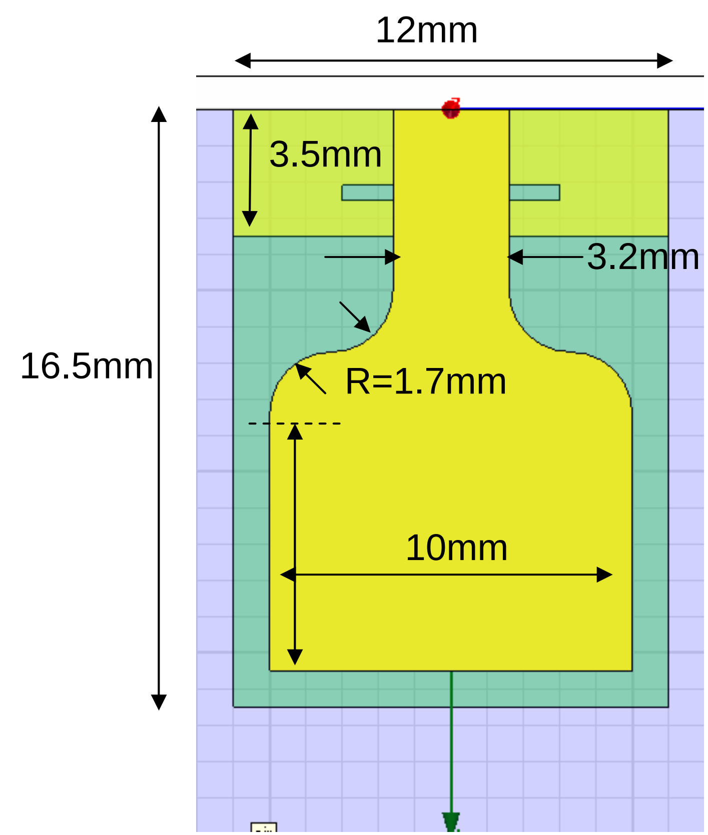


# Planar monopole antenna 4
# 12GHz

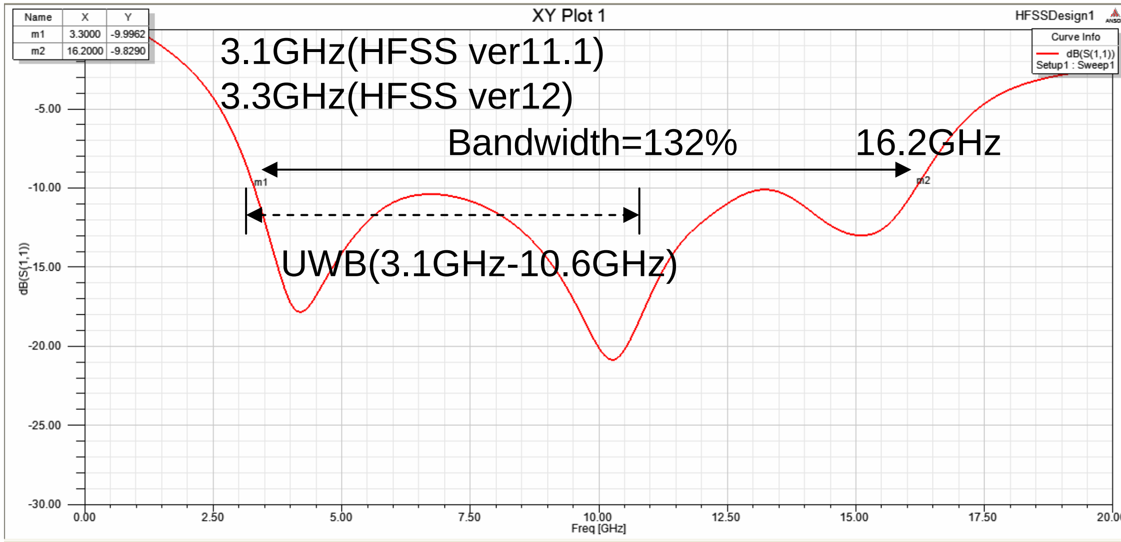


# Planar monopole antenna 5

(Prototype1)

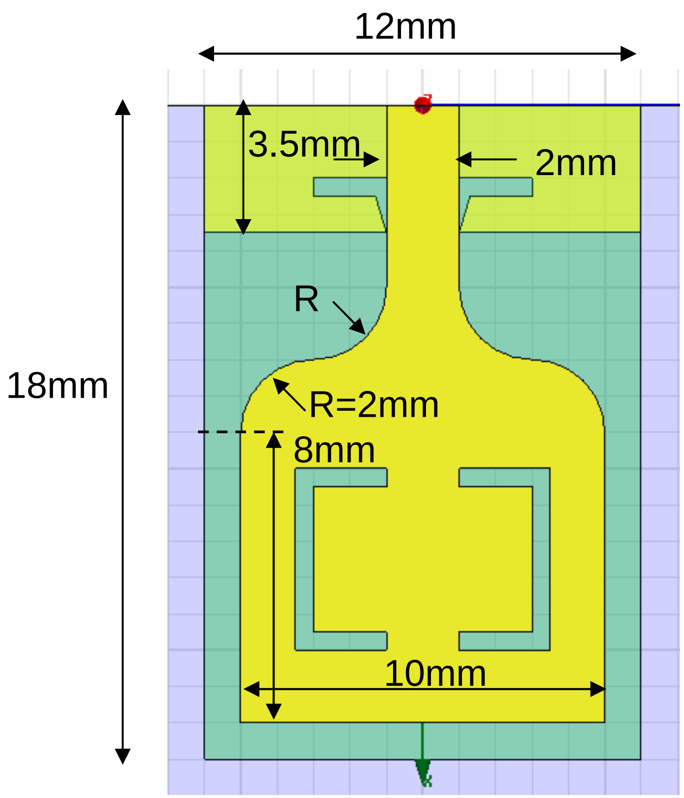


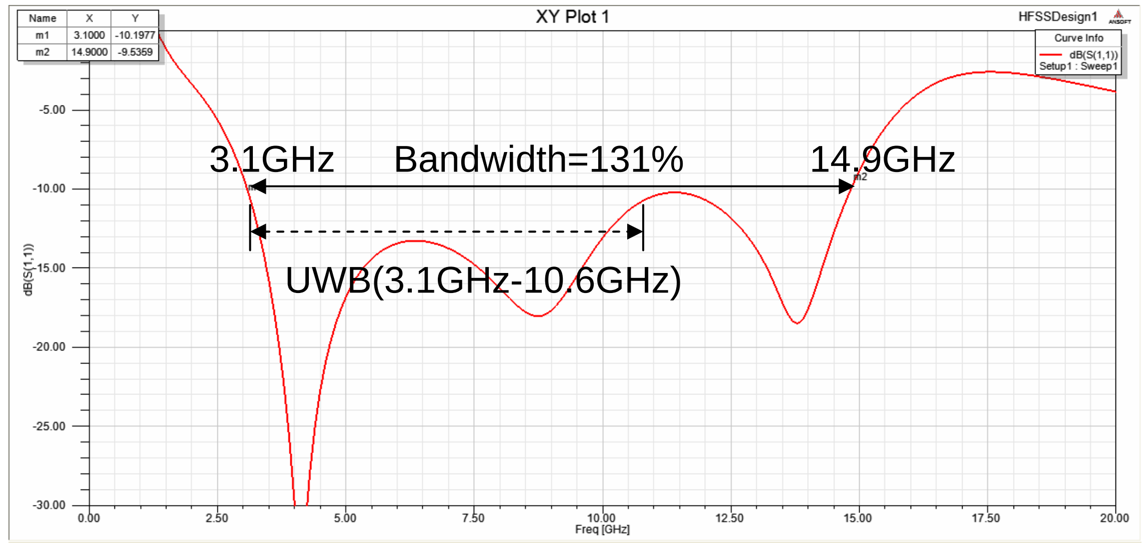

FR4 ( $\varepsilon_r = 4.4$ )
thickness=1.6mm



# Planar monopole antenna 6

(Prototype 2)

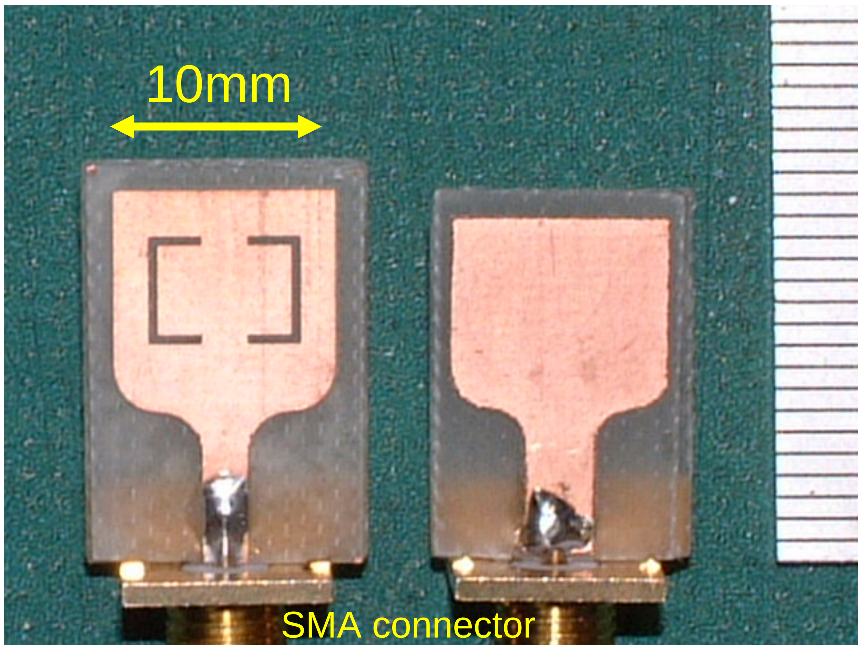



FR4 ($\varepsilon_r = 4.4$)
thickness=1.6mm

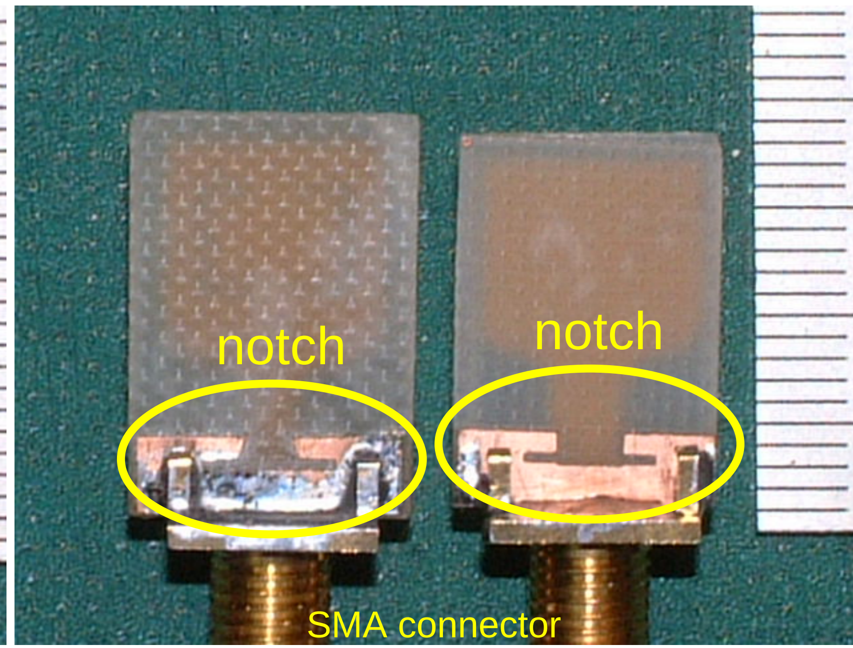
# Measurement

Top Layer



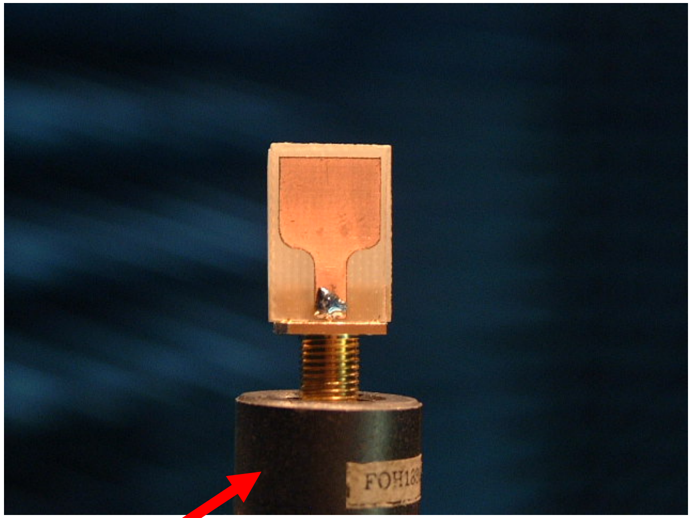

antenna6 antenna5

Bottom Layer



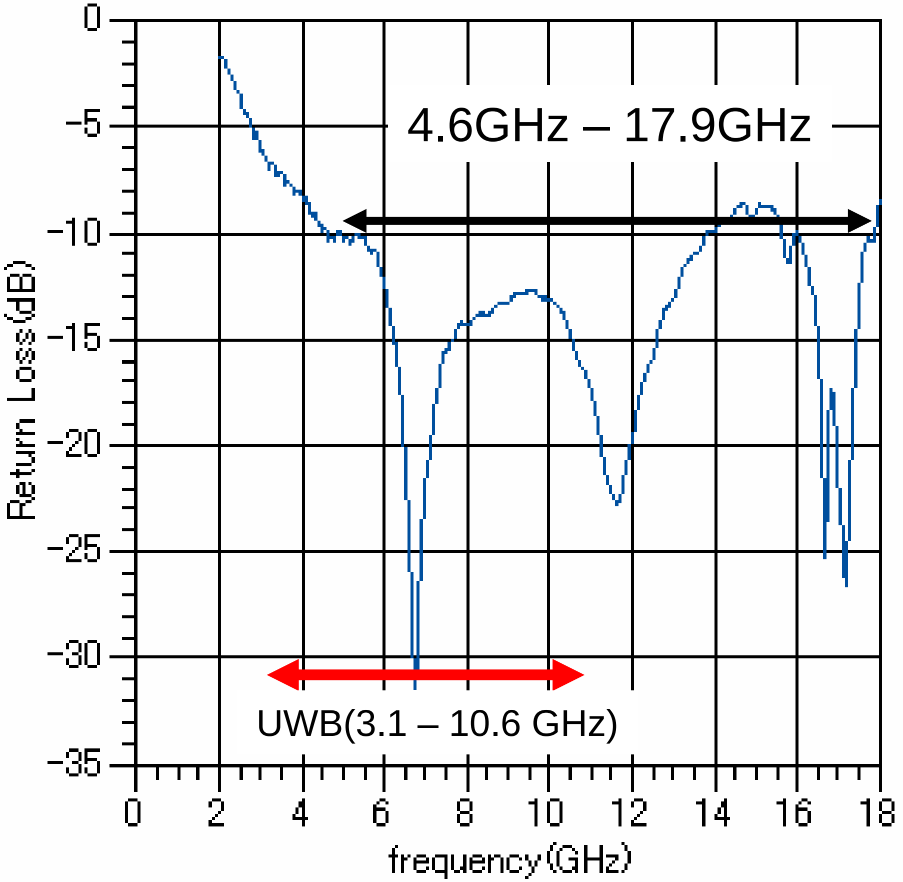

antenna6 antenna5

# Return loss of antenna 5

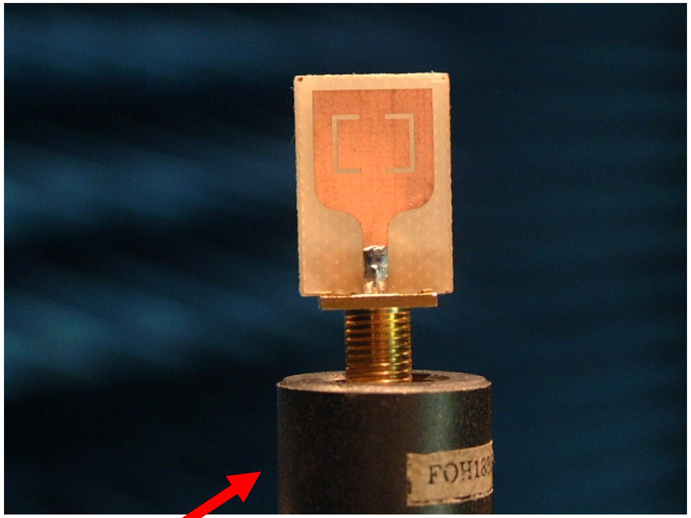



Ferrite core

Simulation Result
-10dB Return Loss Bandwidth
3.3GHz – 16.2GHz

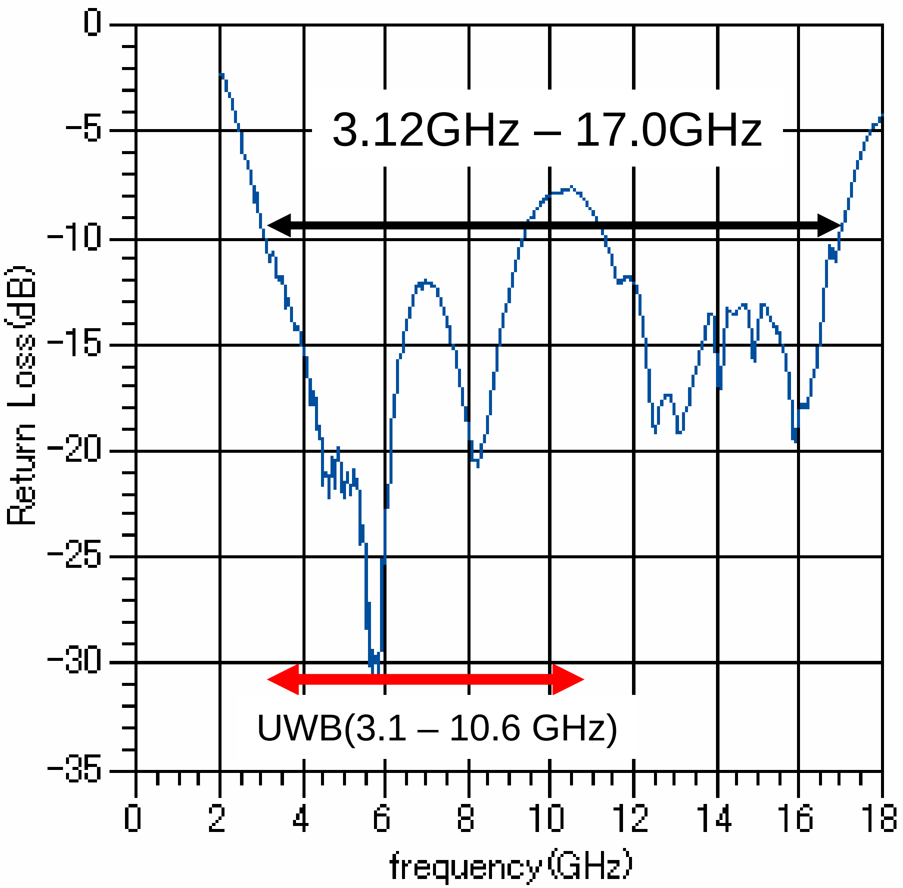


# Return loss of antenna 6




Ferrite core

Simulation Result
-10dB Return Loss Bandwidth
3.1GHz – 14.9GHz



# Conclusion

*Proposal of Research Subjects for PhD or Master's degree*

*Presented study*

- Basics of Antennas
- Microstrip Patch Antennas
  - Basic Rectangular Patch Antenna
  - Slotted Patch Antenna (Broad Bandwidth)
  - Slotted Patch Antenna (Multifrequencies)
- Monopole Antennas
  - Basic Square Monopole Antenna
  - Monopole Antenna with Notched Ground
  - Rounded Square Monopole Antenna
- Measurement

*Future study*

- Miniaturization of antennas
- Metamaterial antennas, etc.

*Thank you for your attention!*