

# Interesting Findings in the Research of Antennas

**22 Jan. 2015**

**Professor Yoshihide Yamada**

**MJIIT of UTM (KL)**

# **Contents of today's talk**

- Self introduction**
- Aperture antenna**
- Array antenna**
- Very small antenna**
- Radar Cross Section**
- Notes for simulations and measurements**

# Self introduction

**1973 to 1993; NTT comm. research lab.**

**Aperture antennas (Reflectors and Lens)**

**1994 to 1997; NTT DoCoMo research laboratory**

**Array antenna for mobile base station**

**1998 to 2014; National Defense Academy**

**Very small antennas, Aperture antennas,  
Radar cross sections**

**2011 ~ ; Co-supervisor of PhD students at UKM**

**2015 ; Malaysia-Japan International Institute of  
Technology in UTM at KL**

**Co-supervisor of PhD students at UTM WCC  
and Le Quy Don Tech. Univ.(Vietnam)**

# **Aperture antennas**

- 1. Parabolic reflector antenna**
- 2. Dual reflector antenna**
- 3. Lens antenna**



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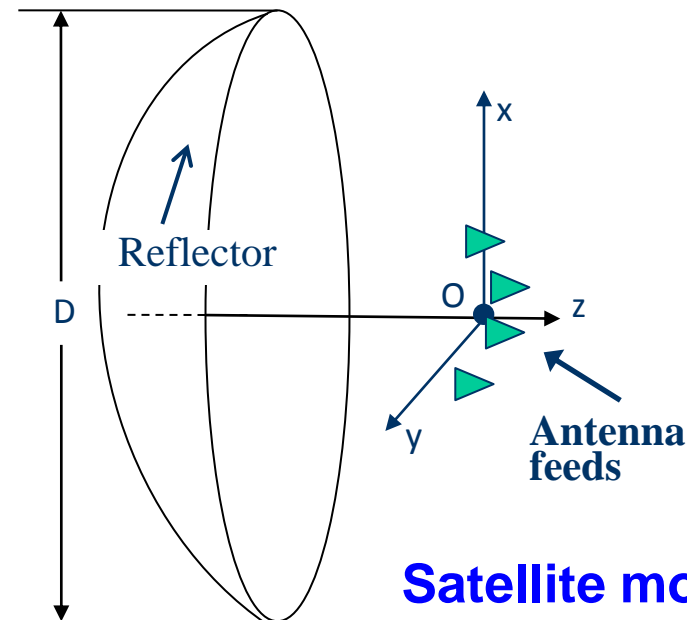
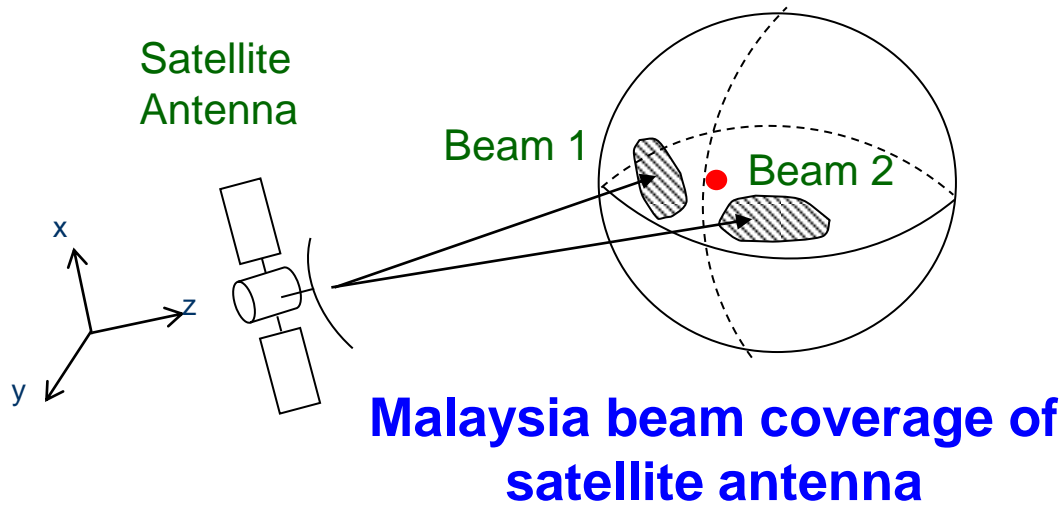
# **Design and Analysis of a Satellite-mount Parabolic Reflector Antenna for Malaysia Beam Coverage by Adopting Ray Tracing Method**

(Published in IEEE antenna magazine Dec. 2014)

Nurul Huda Abd Rahman, Ph.D (2015)

Faculty of Engineering and Built Environment of UKM

# Antenna application



- **Broadcasting** application
- To optimize transmission of signal to **desired areas** and to avoid disruption from unwanted region
- Separated **two beams**
- **Precise beam shaping** is requested



- **What are adequate feed positions?**
- **How to achieve beam shaping?**

# Design Procedure of the Malaysia beam antenna

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## ① Rough design (Previous approximate equations)

- Beam width and antenna diameter ← simple equation
- Feed positions ← beam deviation factor (BDF)

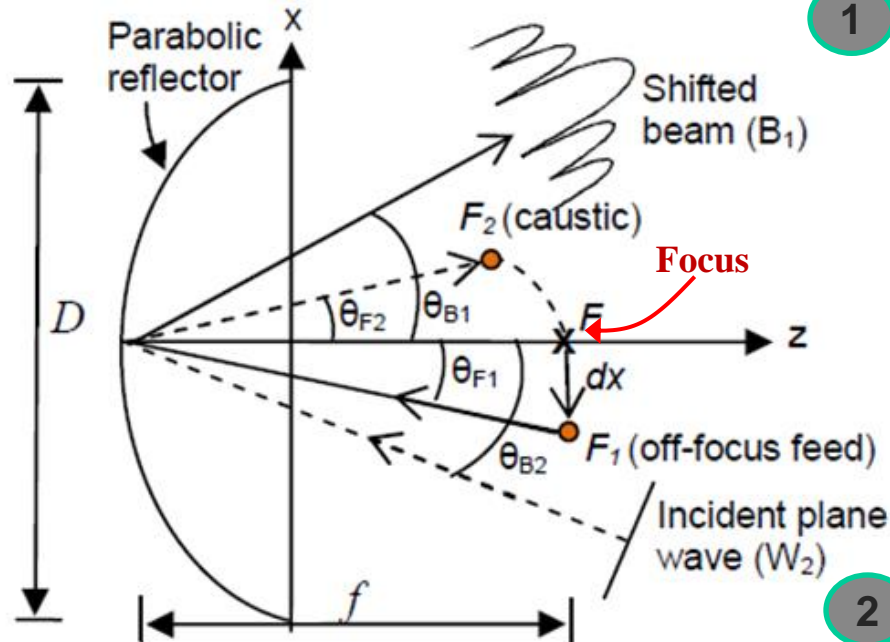
## ② Detailed design (Newly performed by ray tracing method)

- Reflector shape ( $F/D$ ), radiation pattern ← radiation mode ray tracing
- Feed position ← focal region ray tracing  
(Total Rays, Scanning Plane & Transverse Plane analysis)
- Radiation pattern shaping ← contribution of antenna feeds

## ③ Performance estimations (EM simulation)

- Exact radiation patterns of an antenna and a feed

# Previous works for feed position calculation



- 1 **Method 1 (1D) by Y. T. Lo:** To evaluate the *aperture phase aberration* based on the feed displacement of  $\Delta x$

$$\Rightarrow BDF = \frac{\sin \theta_B}{\tan \theta_F} = \frac{1 + k(D/4f)^2}{1 + (D/4f)^2} \quad \text{Eq. (2.1)}$$

$$\Rightarrow \Delta x = F \sin\left(\frac{\theta_{B1}}{BDF}\right) \quad \text{Eq. (5.1)}$$

- 2 **Method 2 (2D):** To find *caustics* ( $\Delta x$  and  $\Delta z$ ) produced by incoming beams

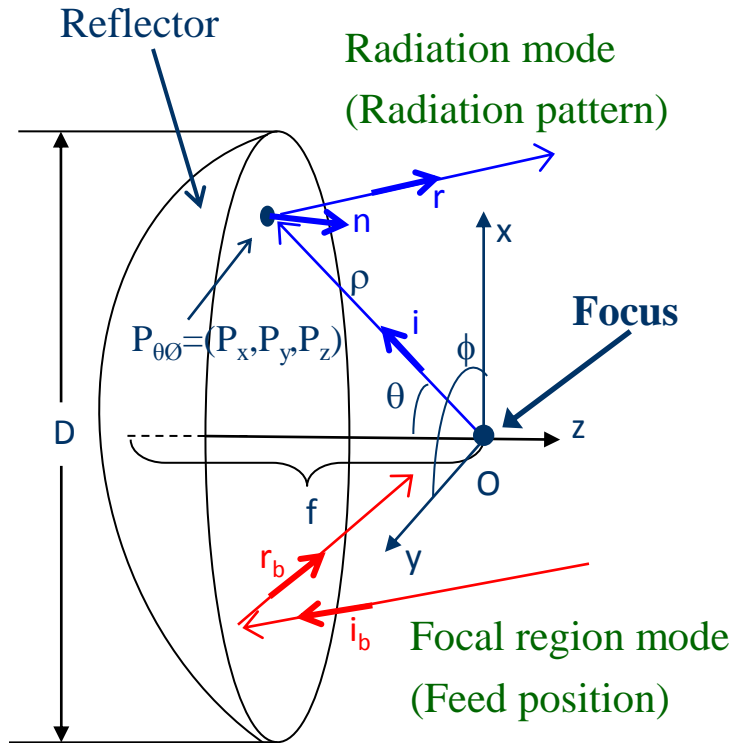
$$x^2 = -4F_L z \quad \text{Insufficient}$$



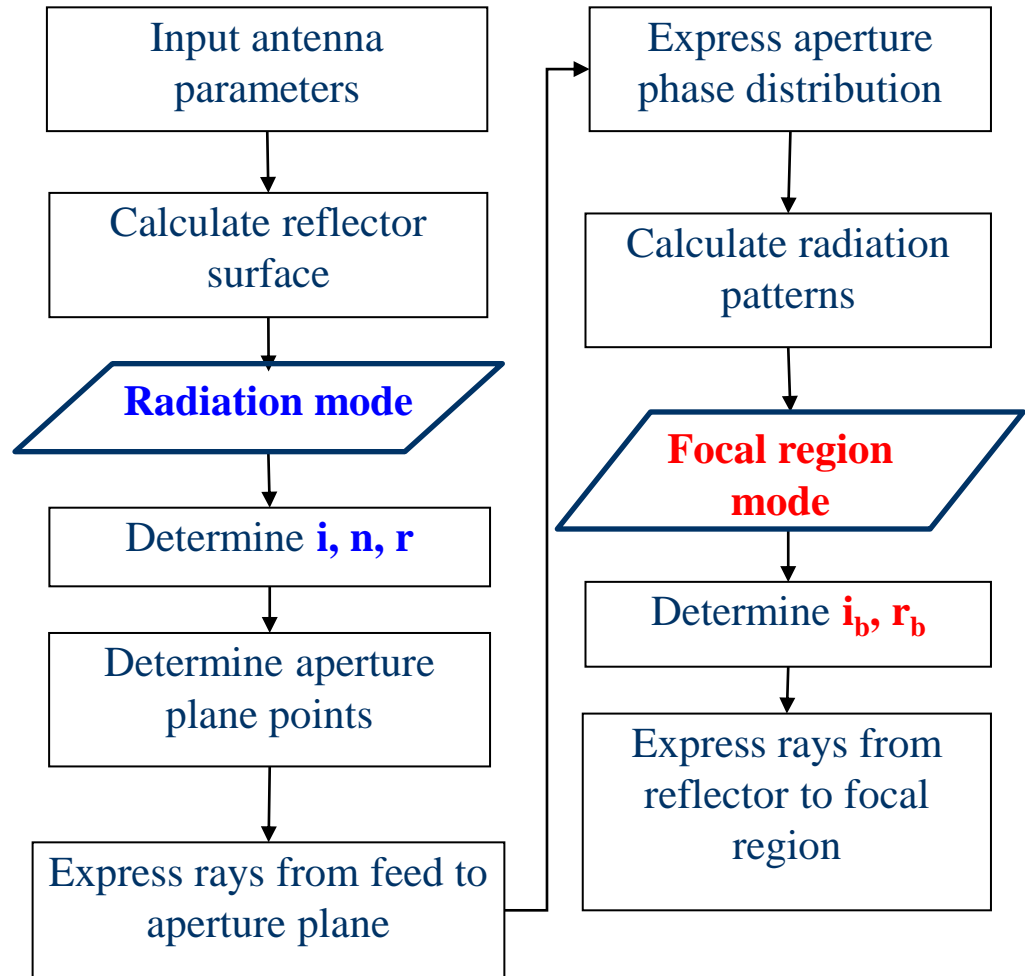
Graphical Design Tool is developed!



# Developed Ray Tracing Program

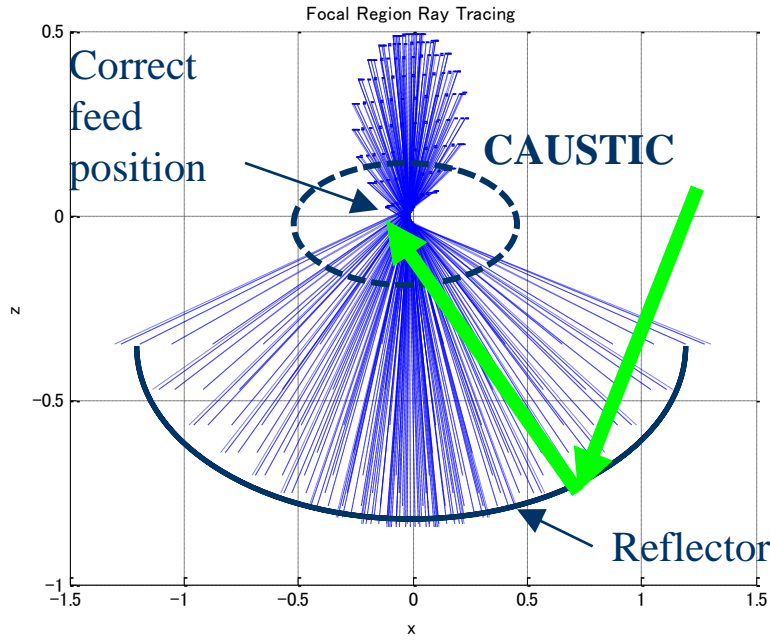


Antenna parameters



(MATLAB software)

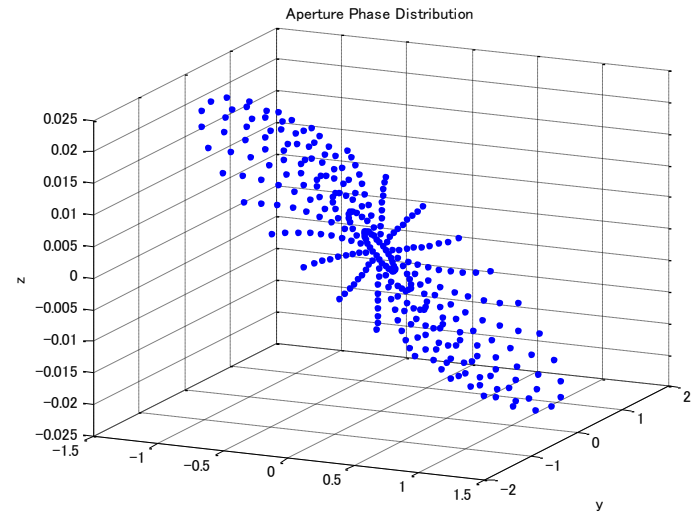
# Ray Tracing typical results



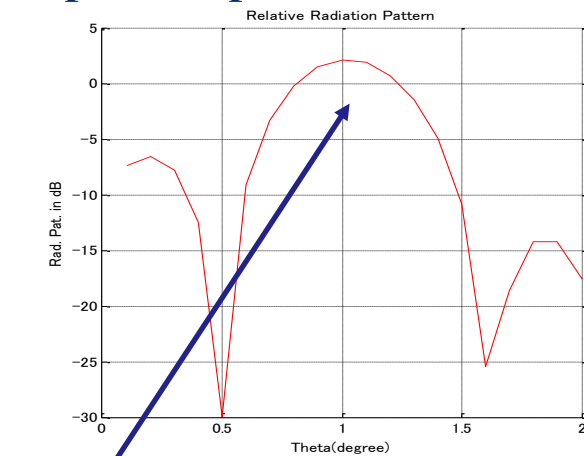
Rays from a reflector to a focal region

- Feed position for  $1^\circ$  beam shift is obtained

The feed position is adequate for the  $1^\circ$  beam shift

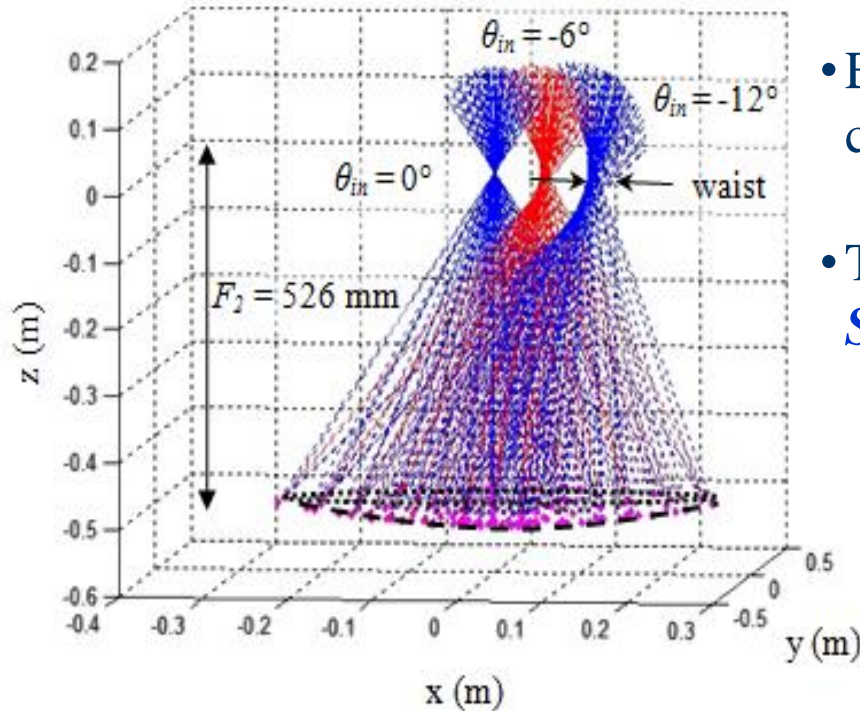


Aperture phase distribution



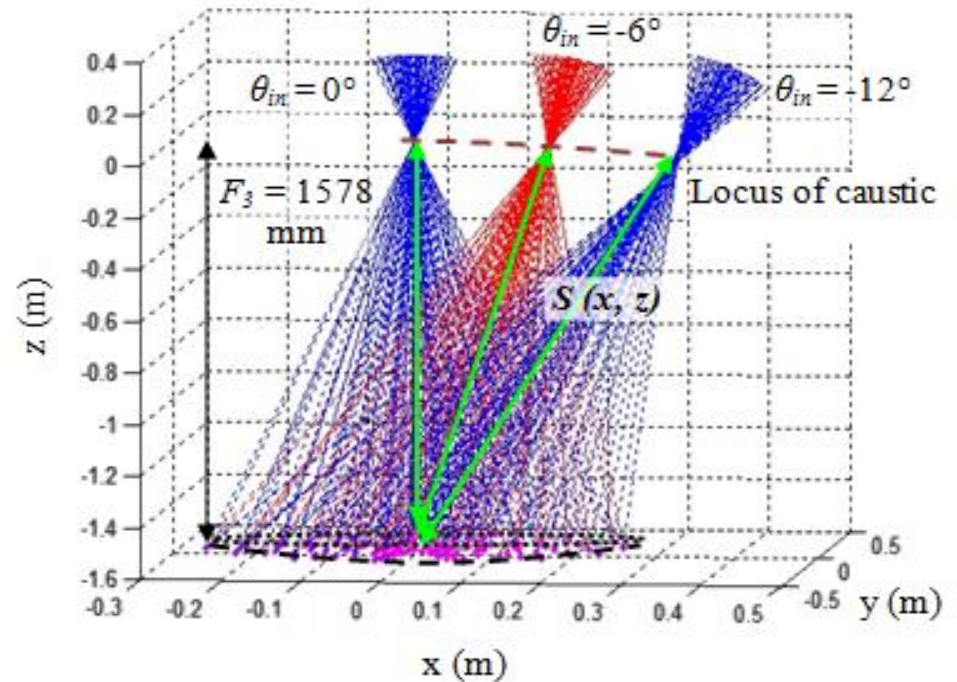
Radiation pattern

# Rays' concentration



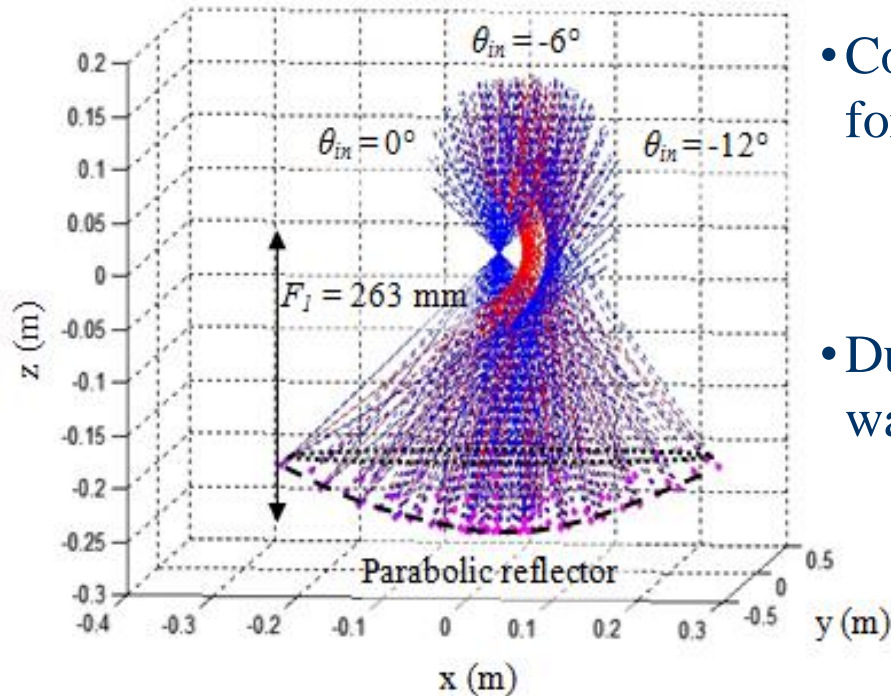
$F/D = 1$

- Excellent caustics are formed for  $F/D > 1$  configurations, especially at  $F/D = 3$ .
- The trajectories of caustics are represented by  $S(x,z) = F \cos \theta_{in}$  (Eq. 5.2)



$F/D = 3$

# Caustic divergence (spread)

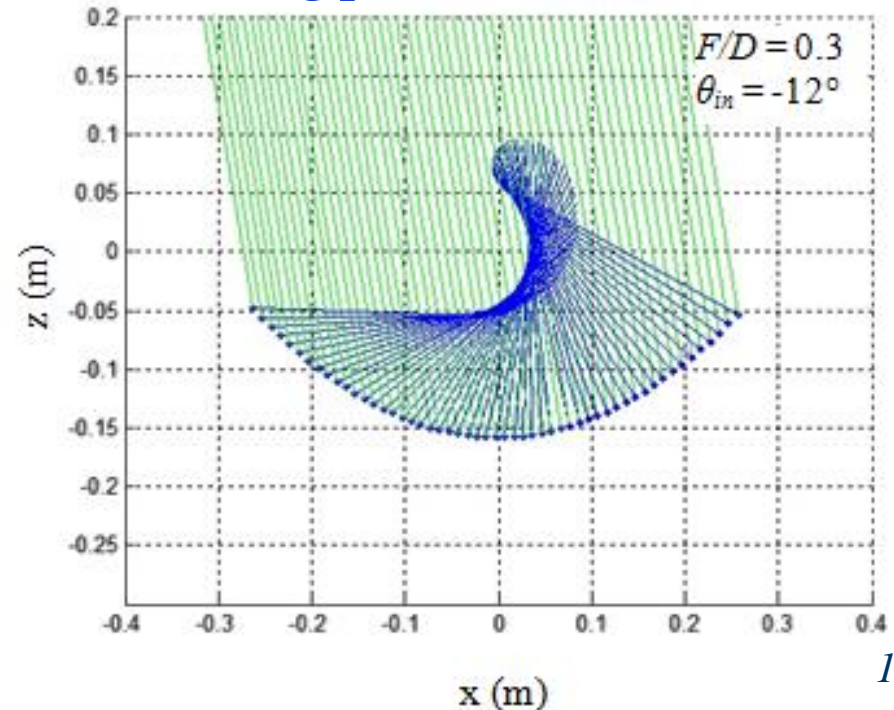


$F/D = 0.5$

- Considerable amount of caustic spread is formed for  $F/D < 1$  configurations.

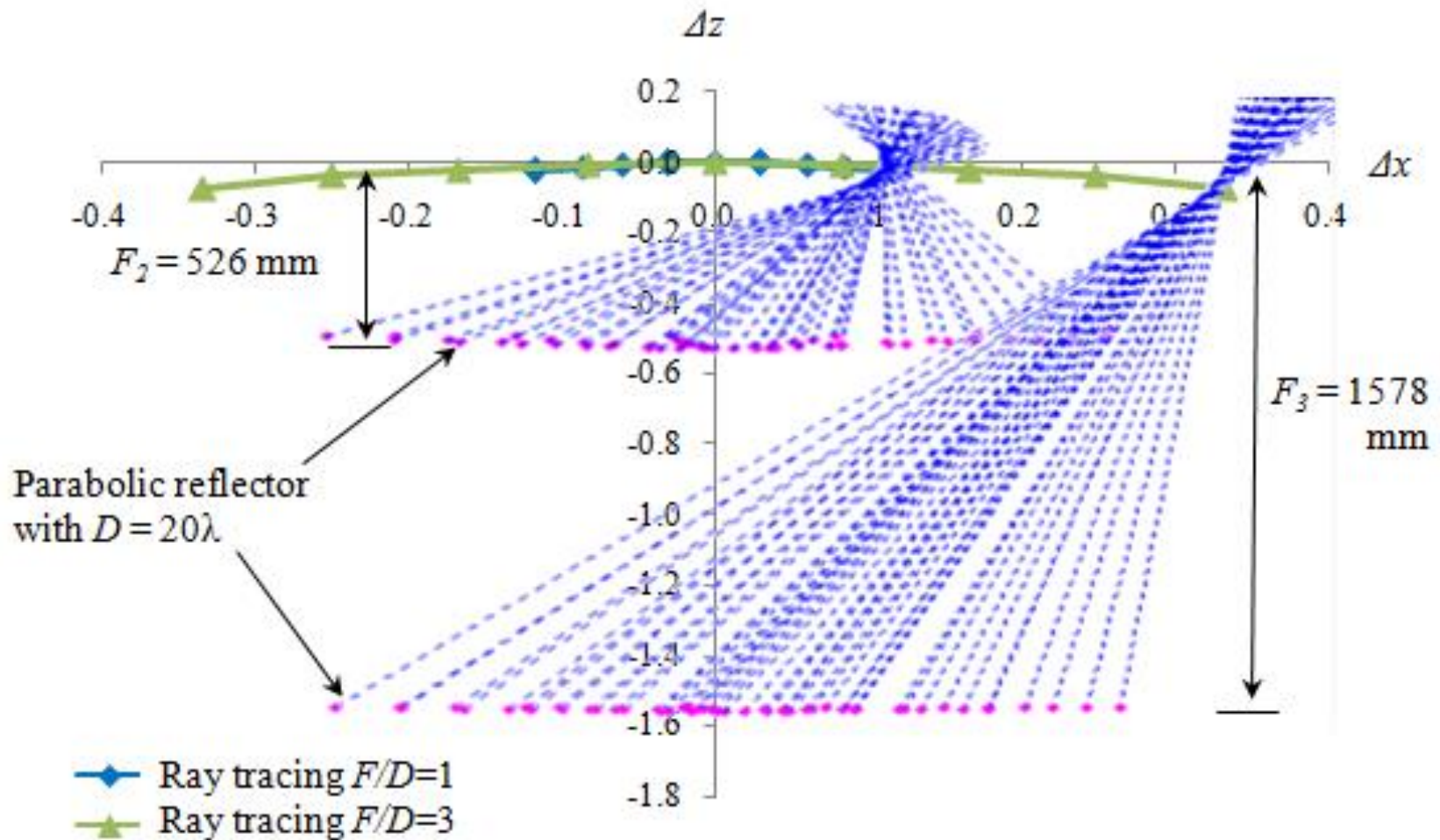


- Due to spreading of rays caused by incident waves on **scanning plane**

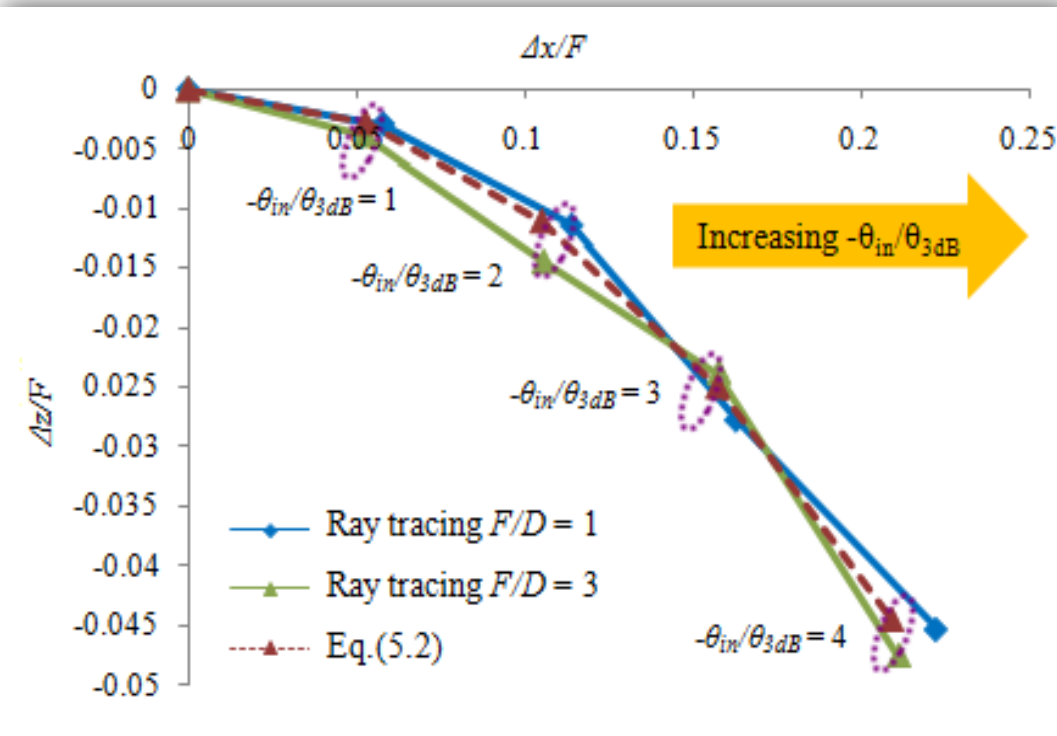




# Illustration of rays in XZ plane

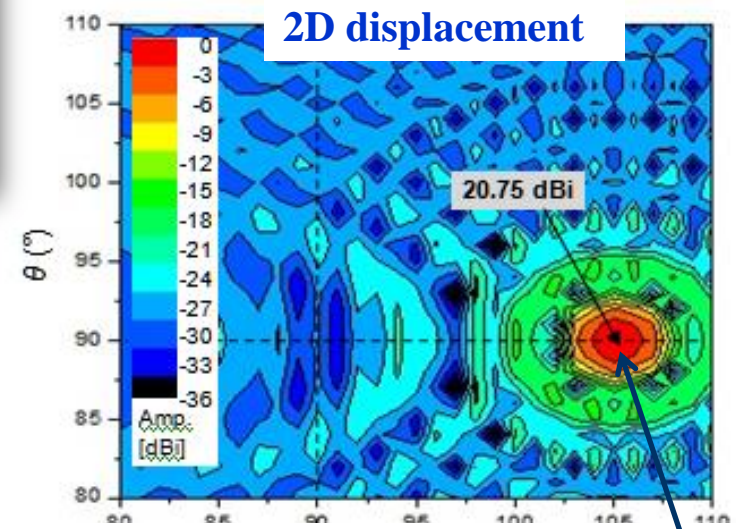
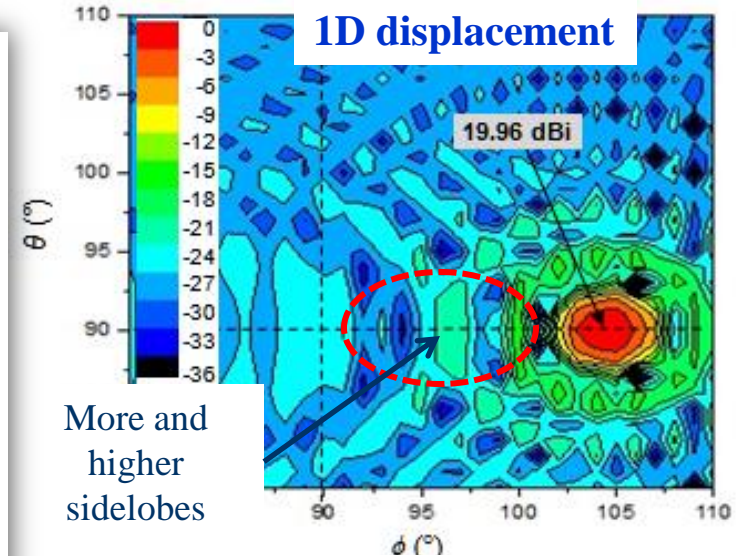


# Universal graph of caustic locus



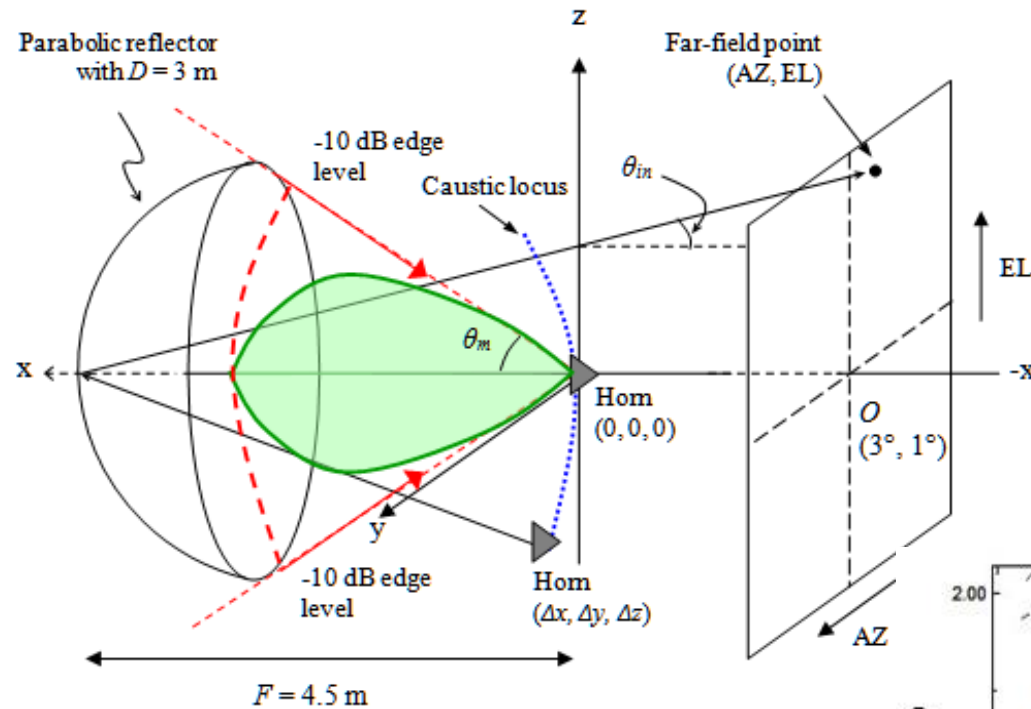
Normalized 2D caustic positions, and comparison with Equation (5.2)

Feed positions  $(x,z) = F \cos \theta_{in}$  Eq. (5.2)



Smaller main lobe, higher gain 14

# Malaysia beam design



## 1 Antenna Diameter (D)

$$D = (1.2 \pm 0.2) \frac{\lambda}{\theta_{3dB}}$$

$$\theta_{3dB} = 0.5^\circ$$

$$\rightarrow D = 3\text{ m}$$

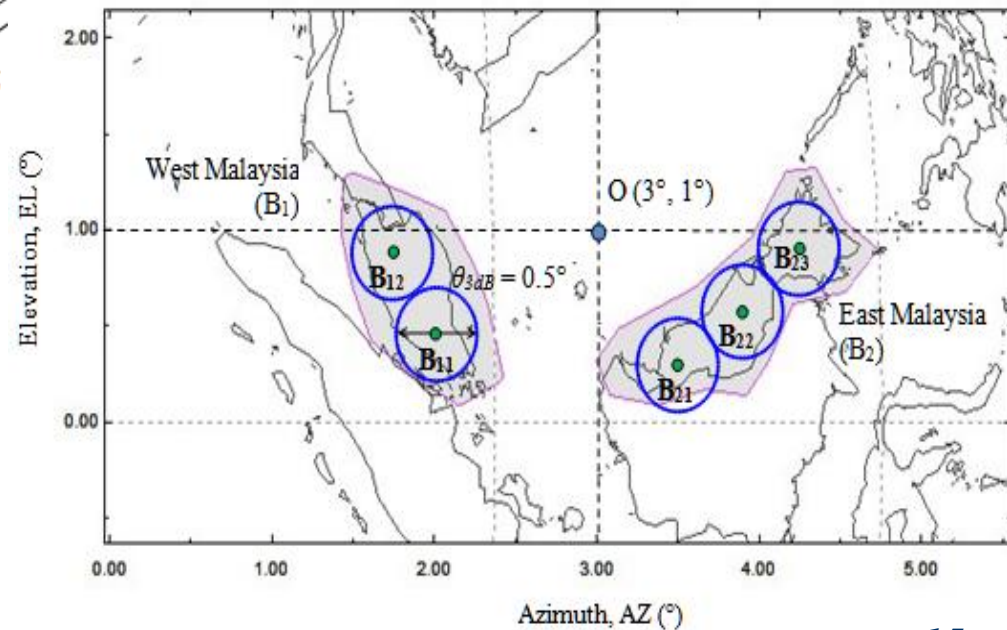
## 2 Antenna F/D

$$\rightarrow F/D = 1.5$$

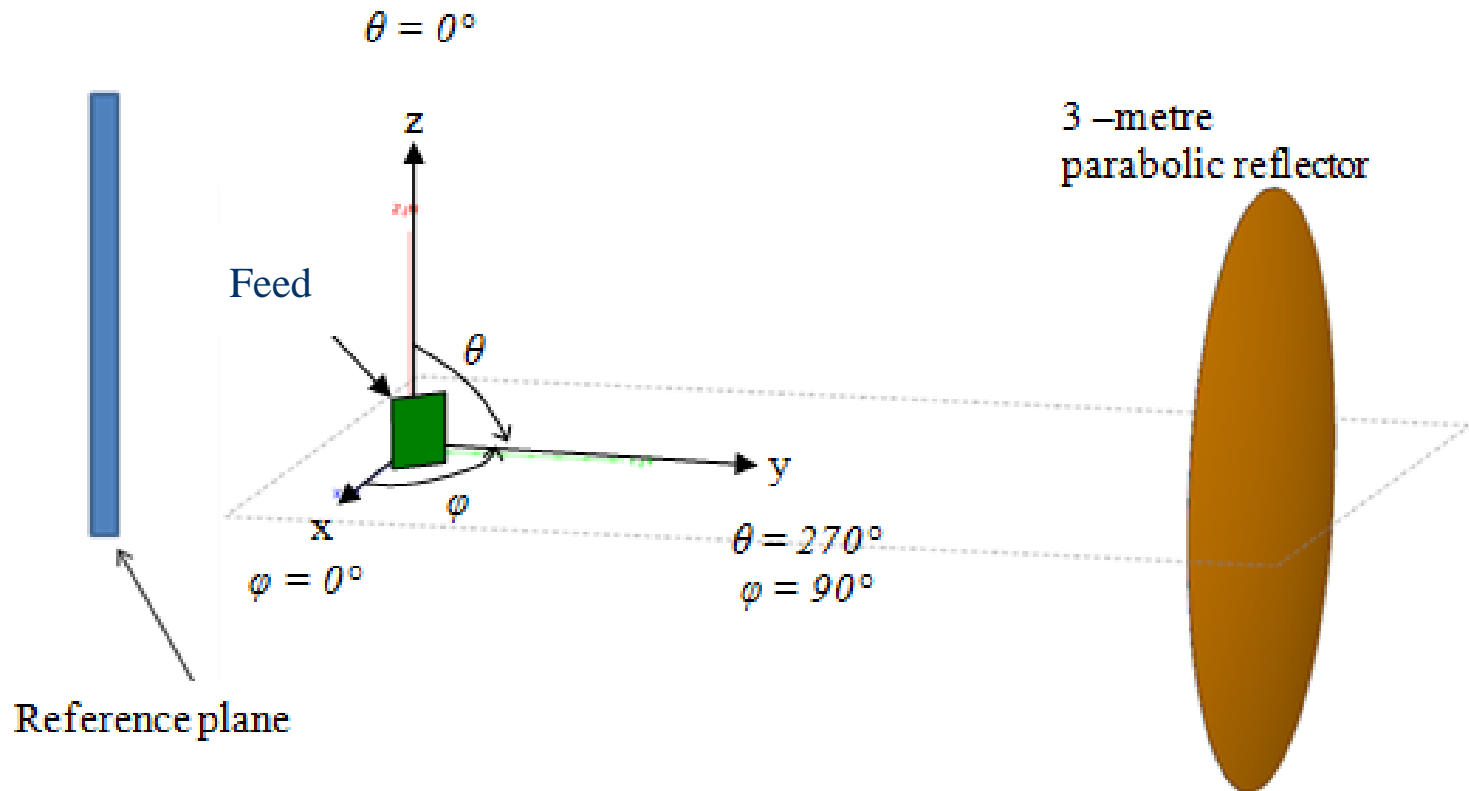
## 3 Feed position

$$\rightarrow \text{Eq. (5.2)}$$

## 4 Feed design?

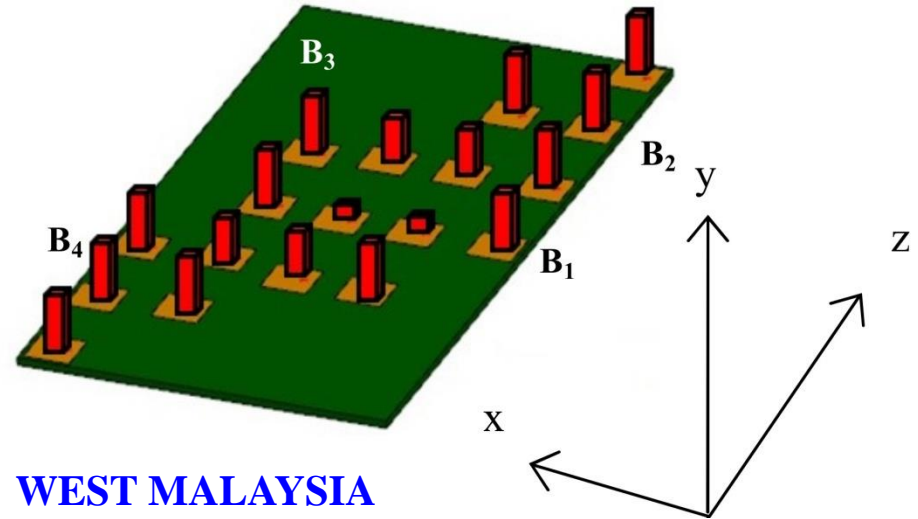
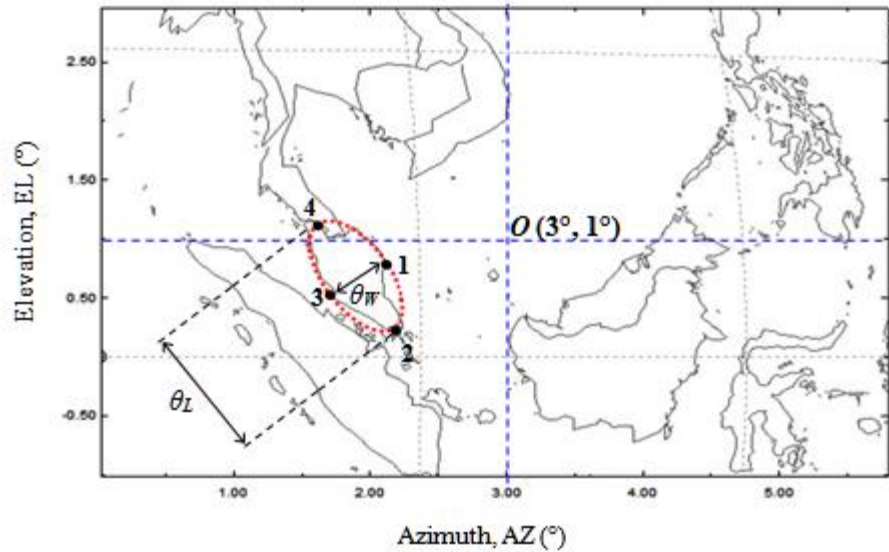


# Antenna configuration

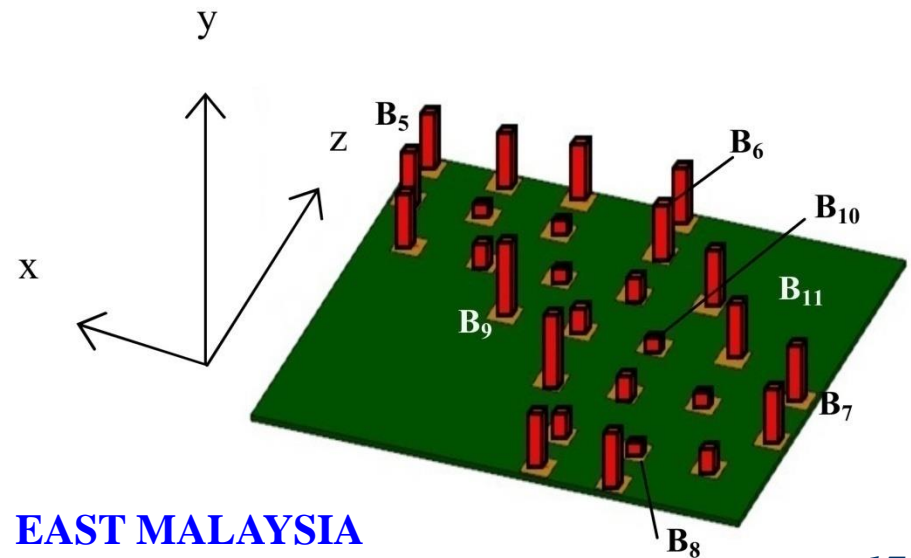
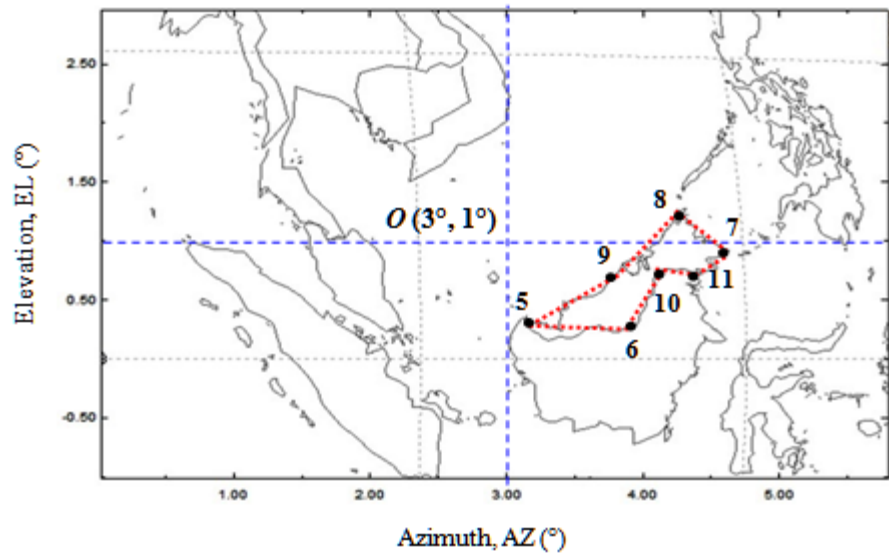




# Array feed design

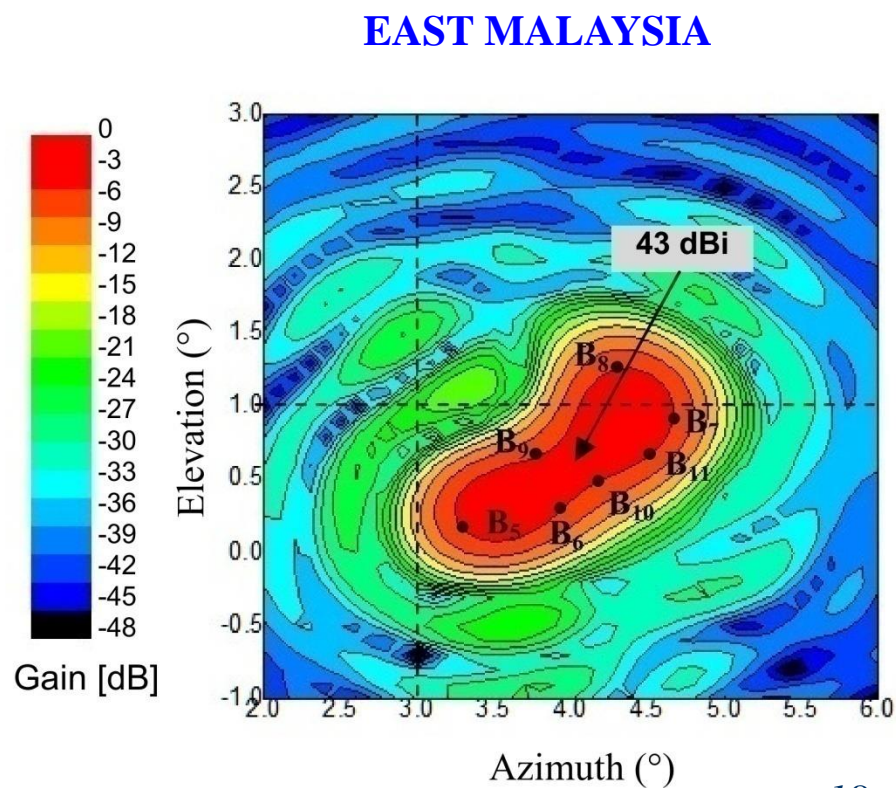
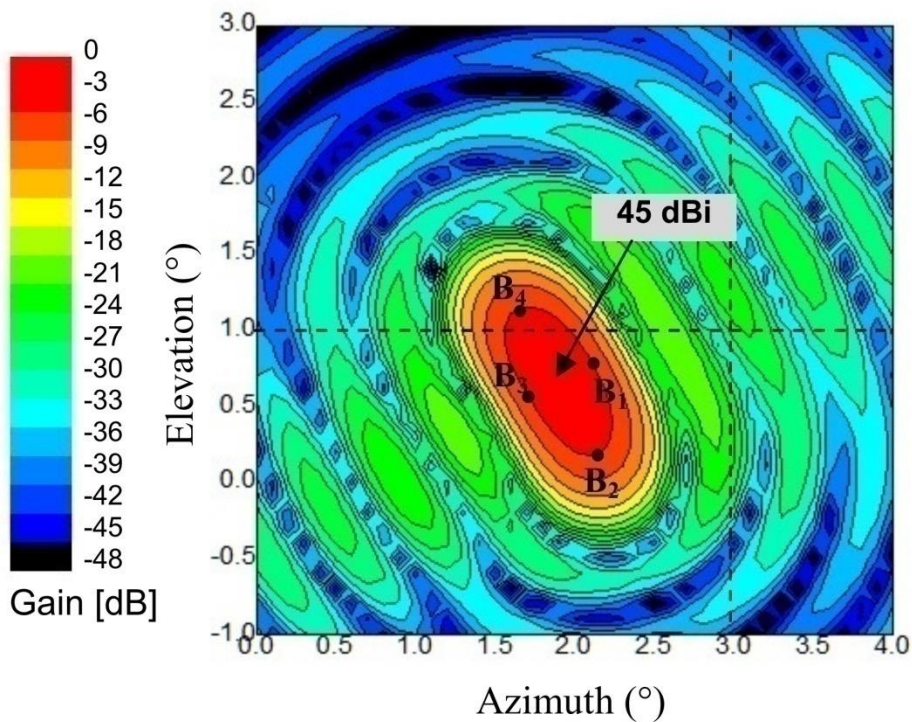


**WEST MALAYSIA**



**EAST MALAYSIA**

# Final contoured beam



# Summaries

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- High performance **contoured beam** for Malaysia is designed (-3dB EOC gain, precise shaped-beam)
- **Accurate design method** for feed positioning is proposed and developed (portrays ray-movement in 3D)
- New **equation model** for fast calculation of **exact caustic** is derived (universal graph)
- Analysis on **caustic behaviors** is performed. (caustic shape, position, reason of spreading)



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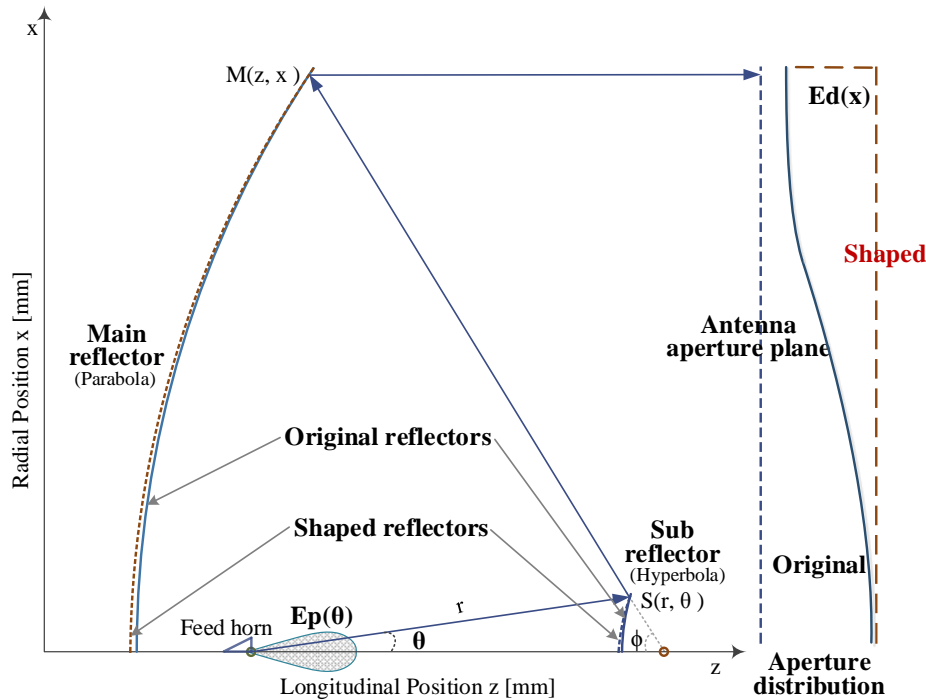
# Designing Shaped Dual Reflector Antenna System by Ray Tracing Method

**M. Rezwanul Ahsan** (D3, 2015)

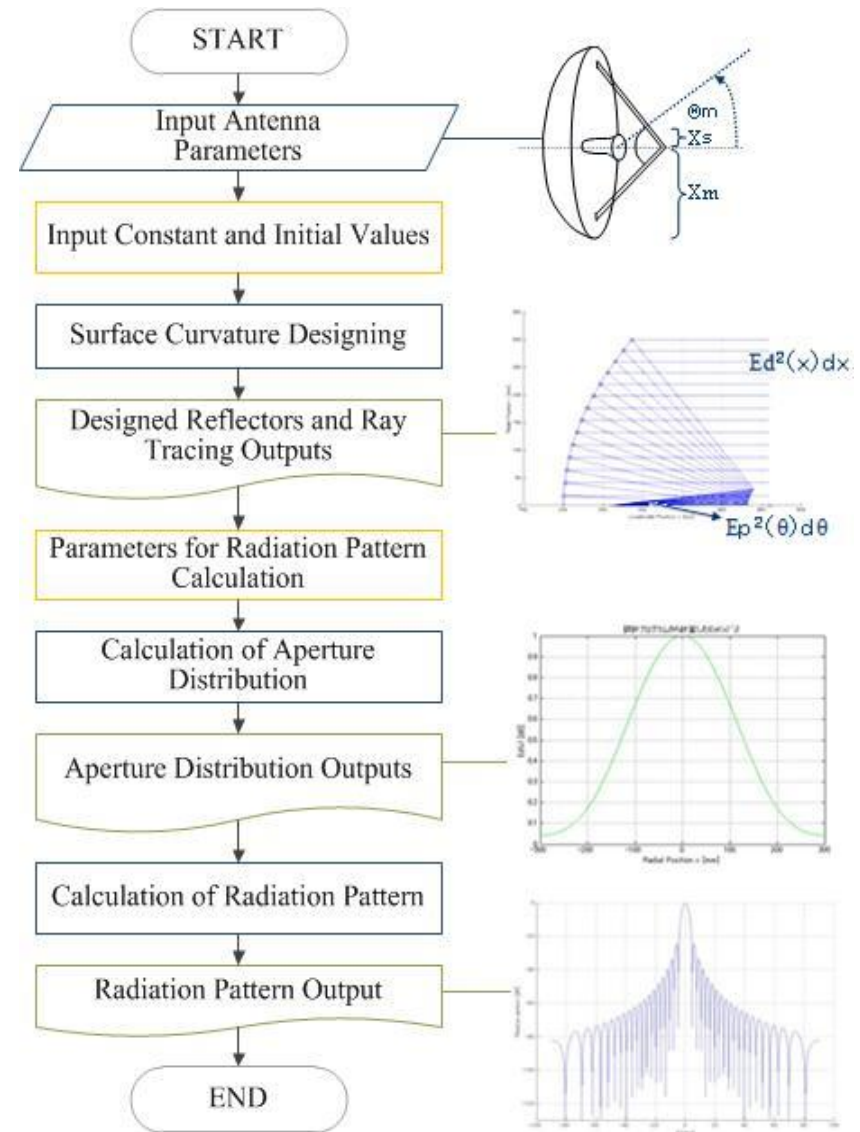
Faculty of Engineering and Built Environment of UKM



# Design method of reflector shaping

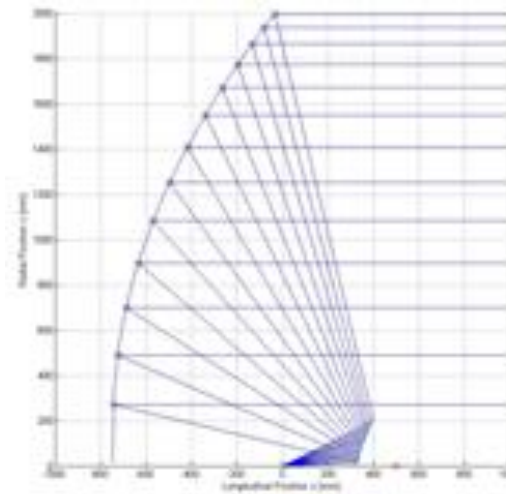
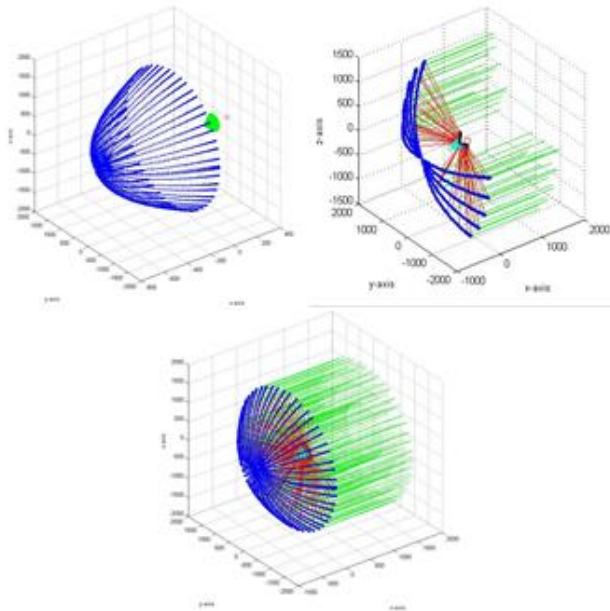


Antenna configuration

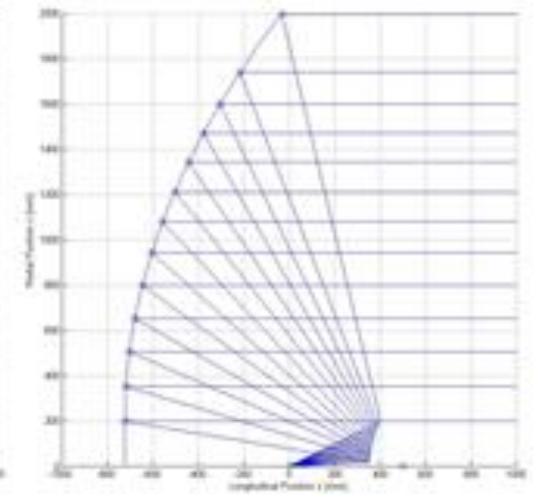


(MATLAB software)

# Ray tracing results

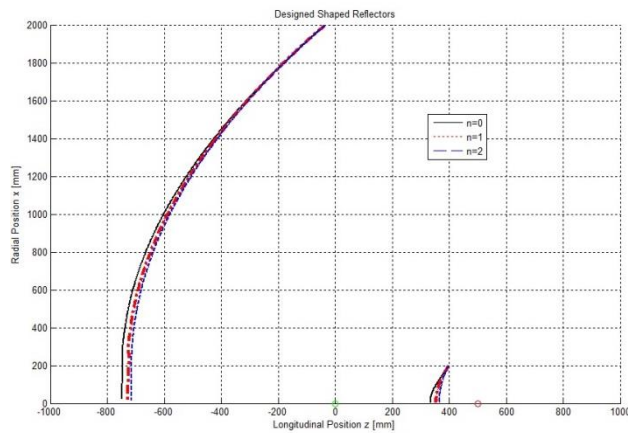


(a)  $n = 0$

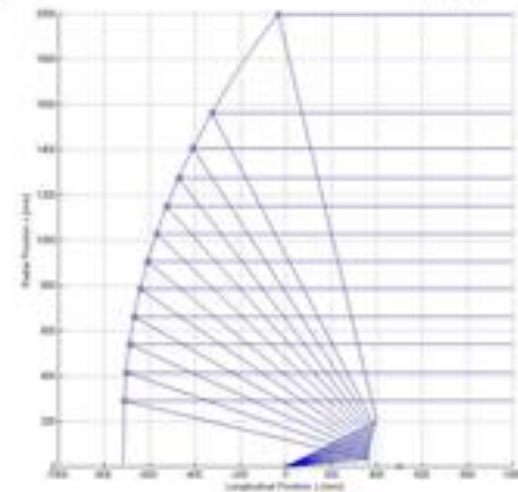


(b)  $n = 1$

## Examples of ray tracing



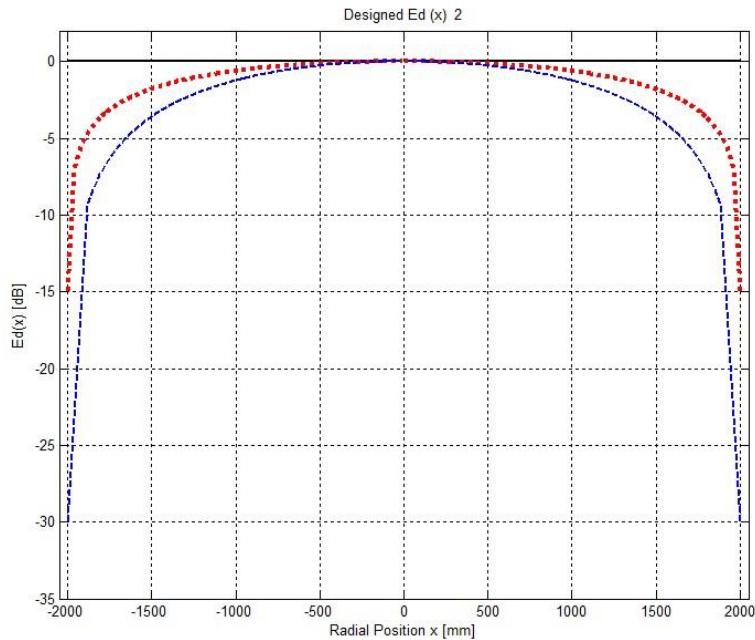
Shaped reflectors



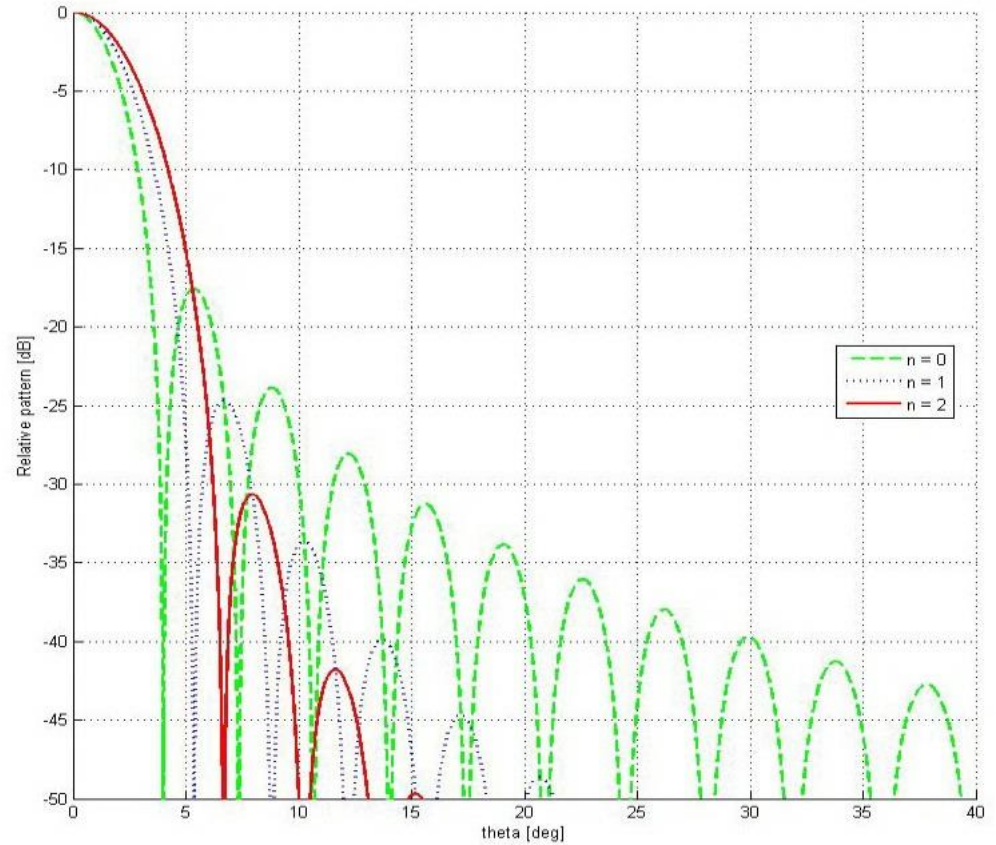
(c)  $n = 2$

Reflected rays

# Ray tracing results



Achieved aperture  
distribution



Radiation patterns

# Summaries

- 1. Achievement of antenna design programs by ray tracing method**
- 2. Focal region analysis of a parabolic reflector antenna**
- 3. Reflector shaping of a dual reflector antenna**
- 4. By the results of ray tracing, useful antenna characteristics will be shown**



# **Lens antenna**

**Designing of dielectric lens antenna  
for wide angle beam scanning**

**National Defense Academy**

**Yosuke Tajima (Dr. at 2008)**

Yosuke Tajima et al., "Electrical Performance Estimations for Shaped Dielectric Lens Antenna with Array Feed", 2010 ACES Journal

# Design method of lens surface shaping

## Fundamental design equations

Snell's law

**Surface-1** 
$$\frac{dr}{d\theta} = \frac{nr \sin(\theta - \theta')}{n \cos(\theta - \theta') - 1} \quad (1)$$

**Surface-2** 
$$\frac{dz}{d\theta} = \frac{n \sin(\theta')}{1 - n \cos(\theta - \theta')} \frac{dx}{d\theta} \quad (2)$$

Energy conservation law

$$\frac{dx}{d\theta} = \frac{E_p^2(\theta) \sin(\theta) D_t}{E_d^2(x) x P_t} \quad (3)$$

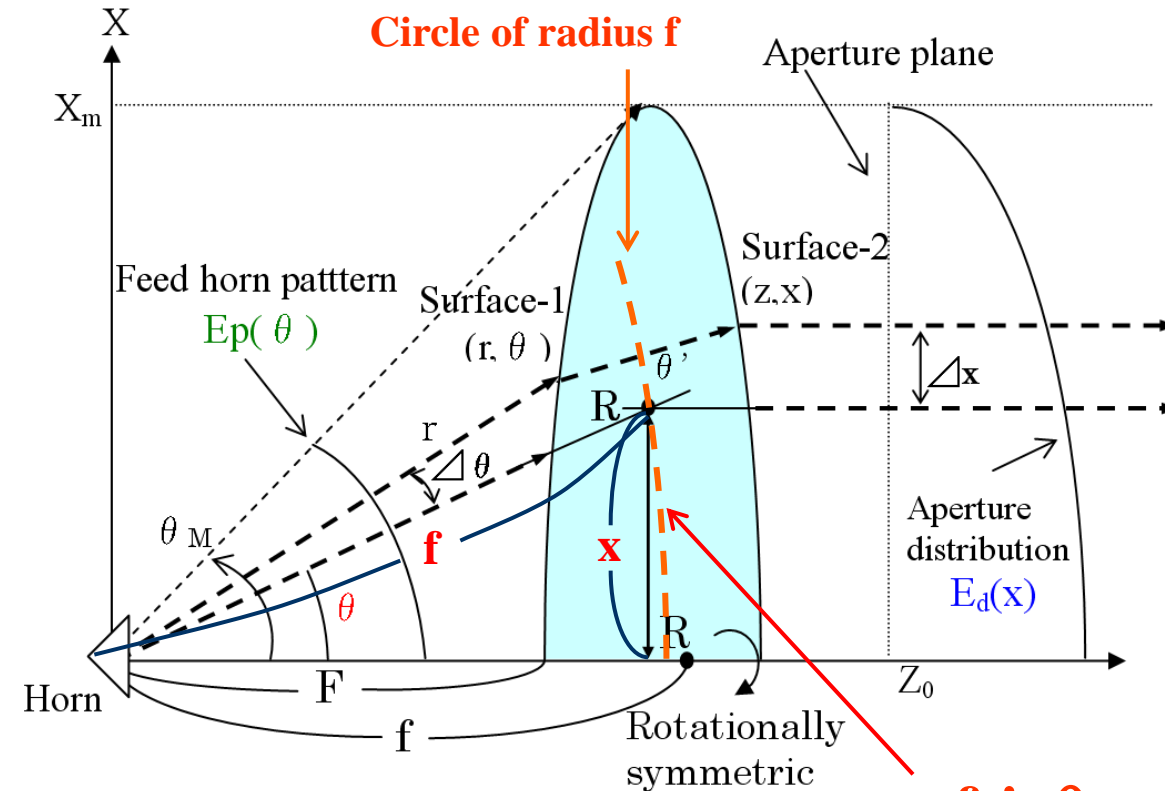
Wide angle scanning

$$x = f \sin \theta, \quad \frac{dx}{d\theta} = f \cos \theta$$

Change of energy equation

$$E_d^2(x) = E_p^2(\theta) / f^2 \cos \theta \quad (3')$$

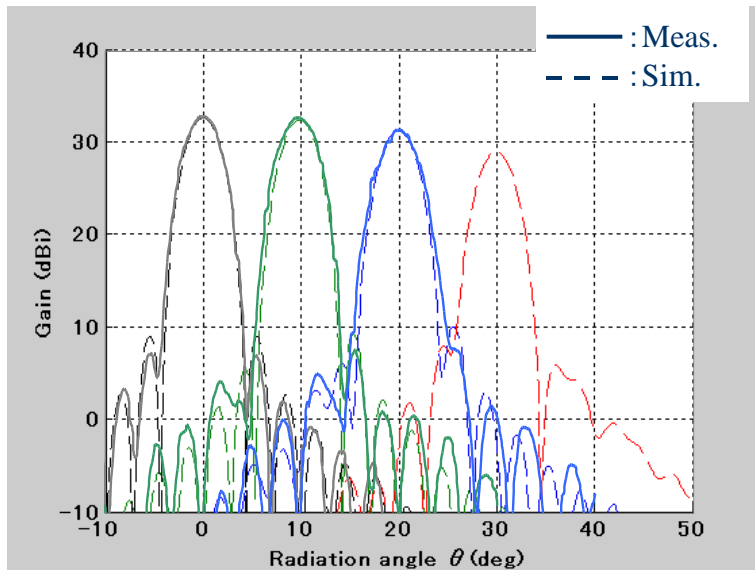
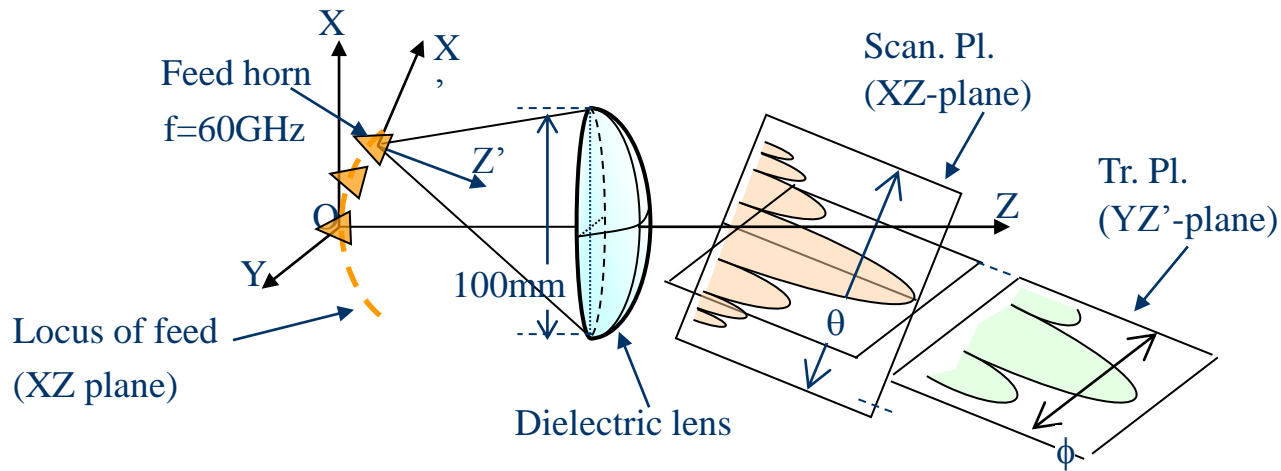
$$\theta = \arcsin(x/f)$$



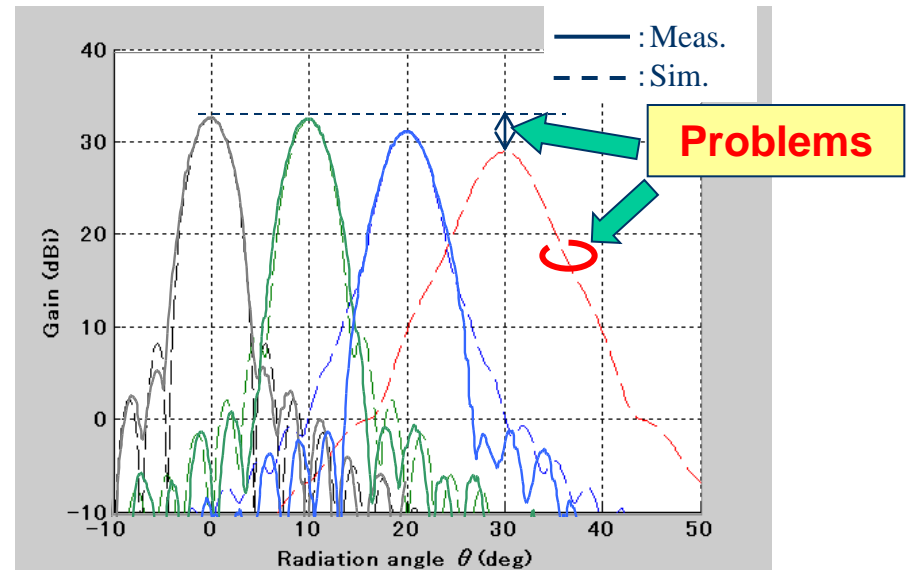
$$x = f \sin \theta$$

Abbe's sine condition

# Problems of the designed wide scan. lens



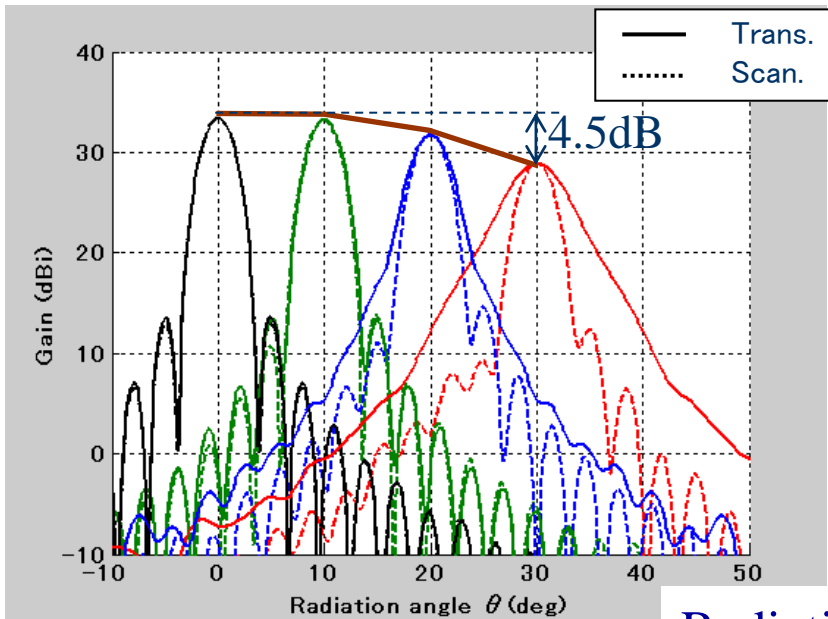
Scanning plane



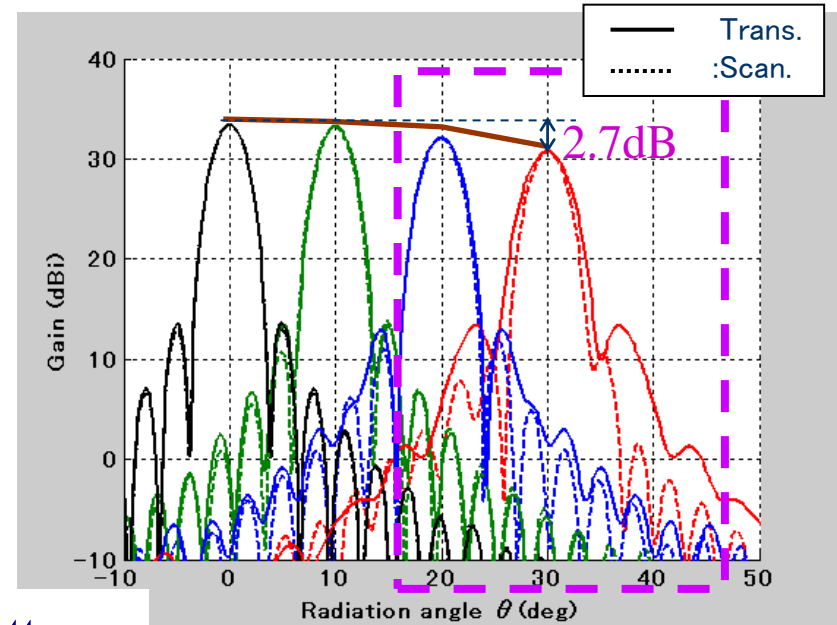
Transverse plane

Radiation patterns

# Radiation improvement by array feed

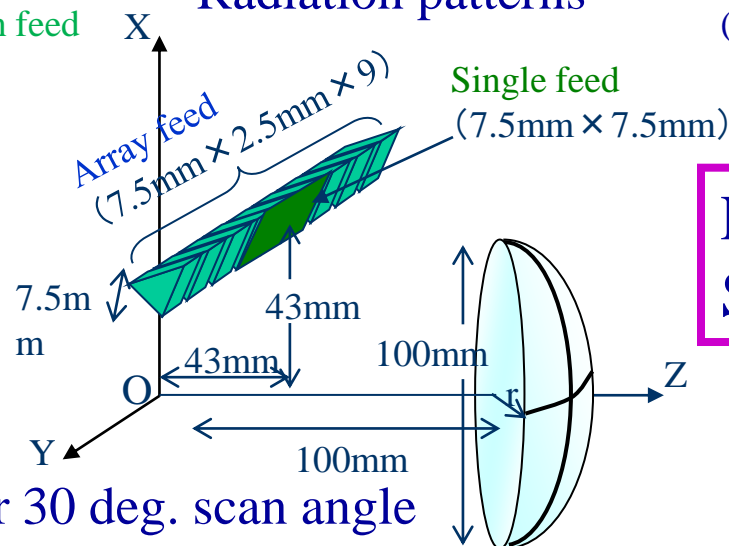


(a) Single horn feed



(b) Array feed

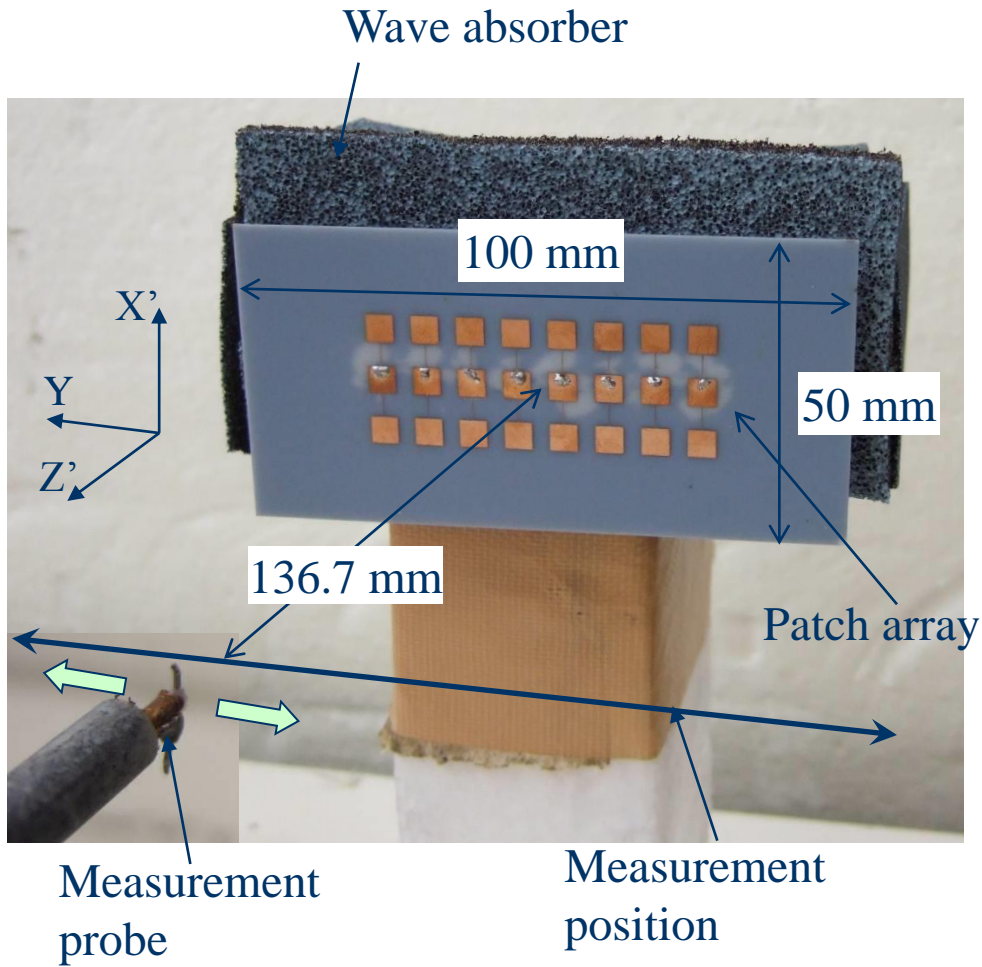
## Radiation patterns



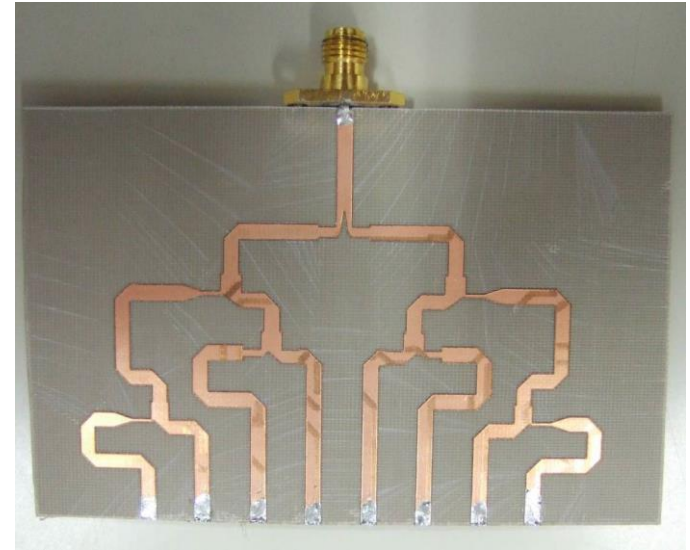
Array position for 30 deg. scan angle

Fine Radiation patterns  
Small gain reduction

# Fabricated array feed

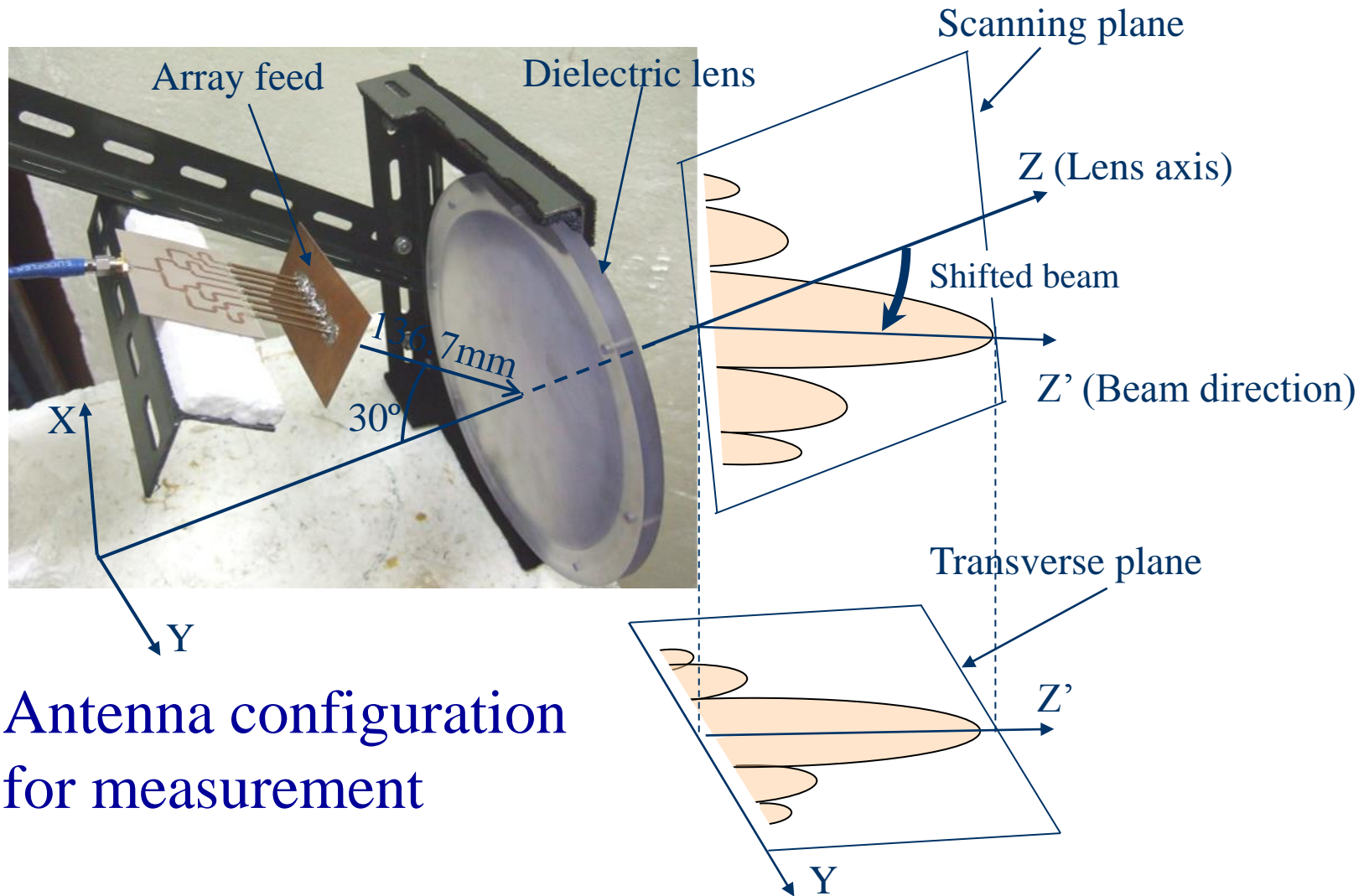


Array configuration



Array feeding network

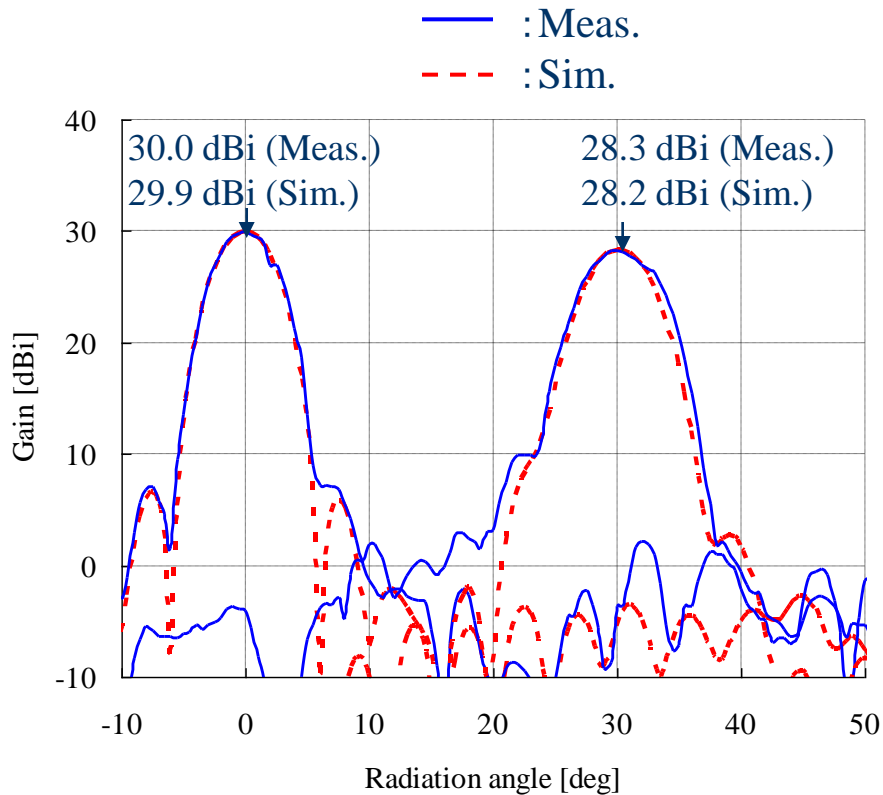
# Fabricated array feed lens antenna



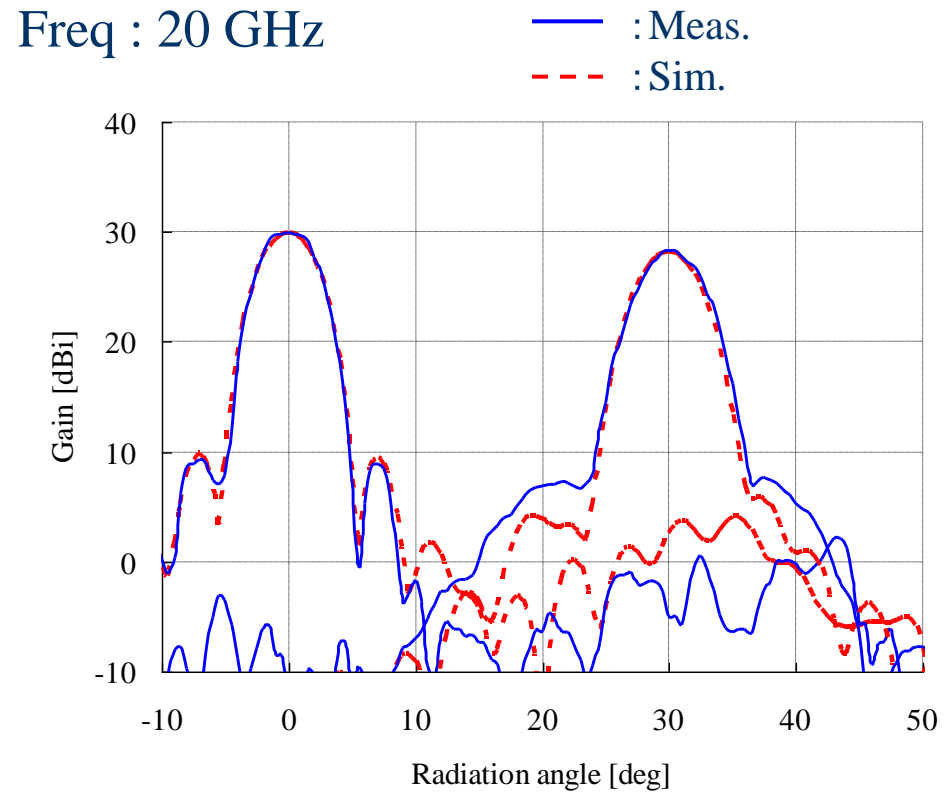
Antenna configuration  
for measurement

Radiation patterns

# Measured results



(a) Scanning plane



(b) Transverse plane

Comparisons of measured and calculated results

# Summaries

- 1. Achievement of antenna design program by ray tracing method**
- 2. Wide angle beam scanning lens antenna is designed**
- 3. Antenna performance are ensured through calculated and measured results**
- 4. Application to a collision avoidance car radar at mm-wave is expected**



# **Array antenna**

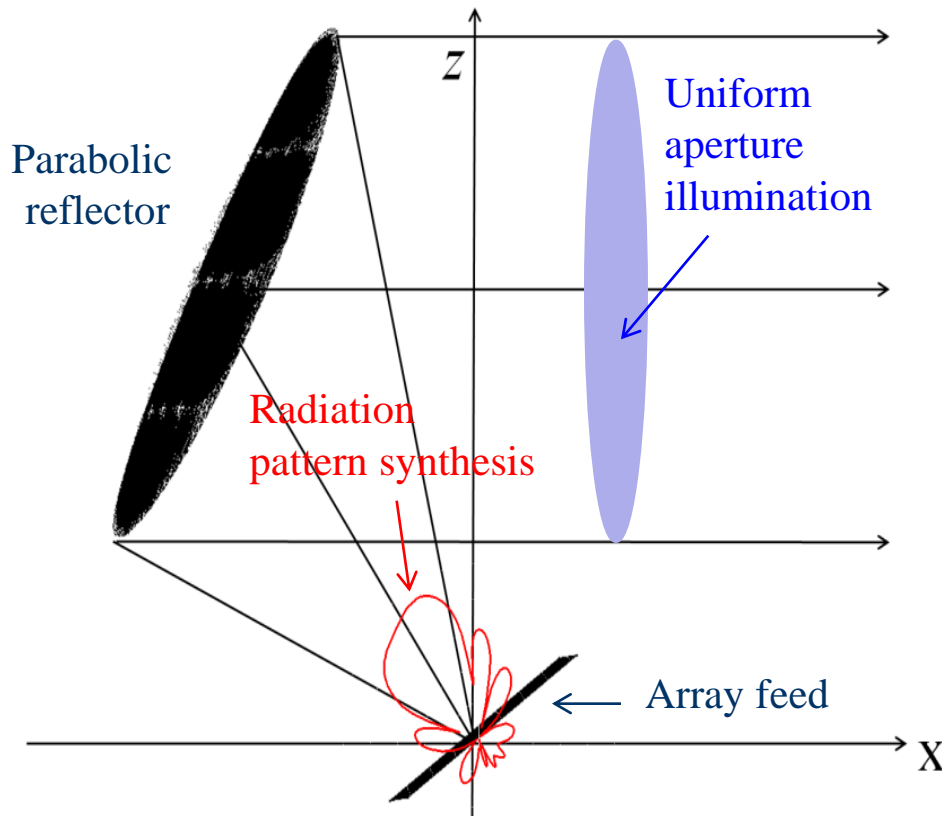
## **Array antenna for a parabolic reflector antenna**

### **National Defense Academy**

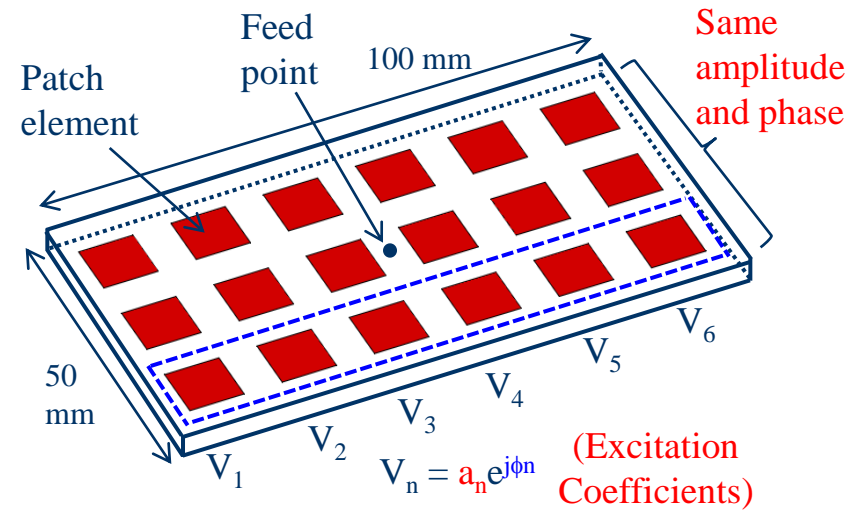
### **Junichi Shinohara (Ms. at 2012 )**

Shinohara et al., ” Design of an array feed offset parabolic reflector antenna by using electromagnetic simulations and measured results ”, 2014 ACES Journal

# Configuration of array feed



Antenna configuration



Array feed

## Purpose

Radiation pattern synthesis is accomplished to achieve **high antenna gain**.

# Radiation Pattern Synthesis Method

Synthesis objective

- Designing  $[F]$  similar to  $[A]$ .



- The difference between  $[F]$  and  $[A]$  is defined as the **error function  $[\varepsilon]$** .
- Find the minimum  $[\varepsilon]$  by the least mean square method (LMS).

$$\begin{aligned}\varepsilon &= ([T][F] - [T][A])^H ([T][F] - [T][A]) \\ &= ([T][B][V] - [T][A])^H ([T][B][V] - [T][A])\end{aligned}$$

$[T]$ : weighting diagonal matrix  
(Emphasize the important direction  
in the synthesis)

Radiation pattern given by  $[V]$

$$[F] = [B] \times [V]$$

Reaction matrix

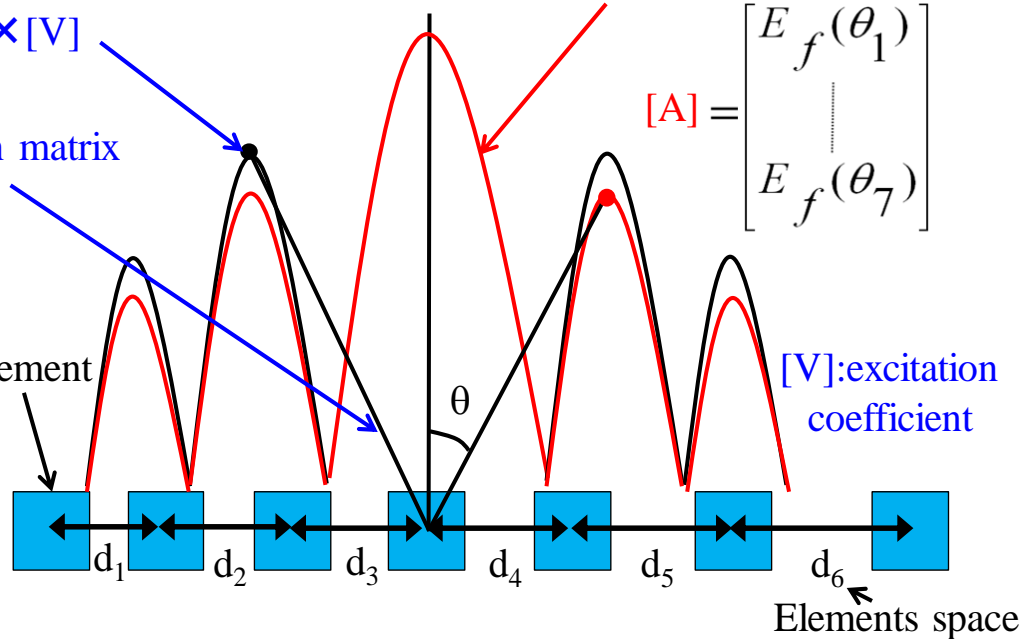
$$[B] = [b_{ij}]$$

Objective radiation pattern

$$[A] = \begin{bmatrix} E_f(\theta_1) \\ \vdots \\ E_f(\theta_7) \end{bmatrix}$$

Array element

$[V]$ : excitation coefficient

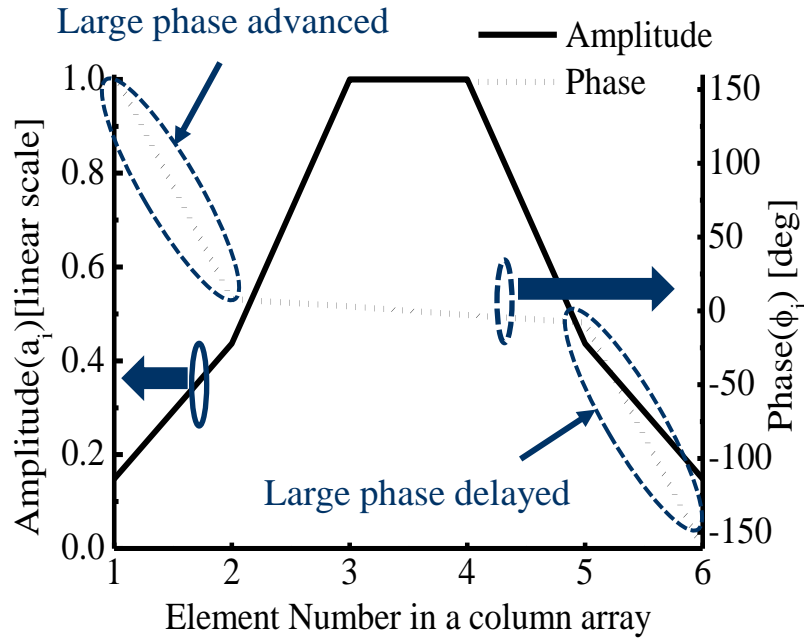


Configuration and radiation patterns of an array

Excitation coefficients of  
array elements are obtained  
as a result of minimum  $\varepsilon$ .

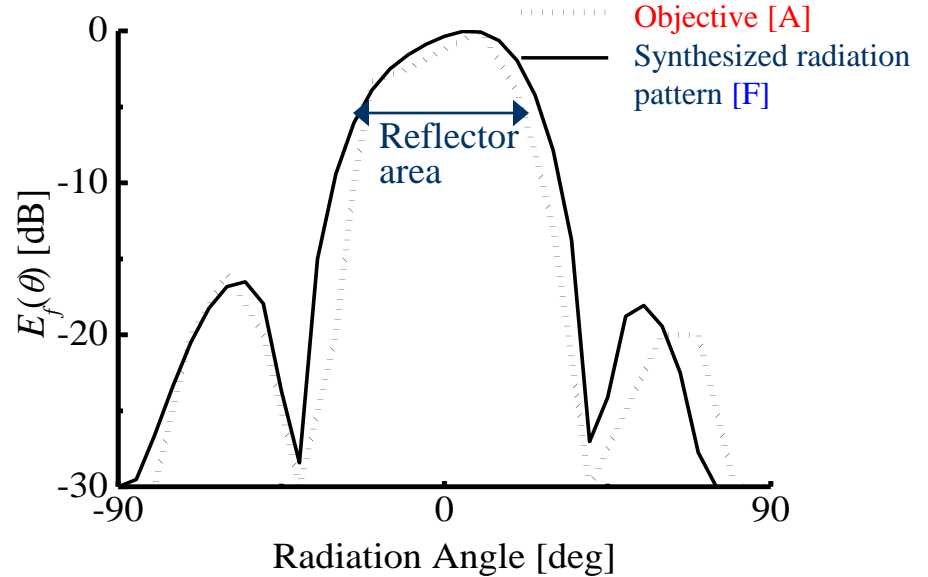
$$\begin{aligned}[V_0] &= ([B]^H [T_0] [B])^{-1} [B]^H [T_0] [A] \\ &\quad (T_0 = [T]^H [T])\end{aligned}$$

# Radiation pattern synthesis results



Designed excitation coefficients

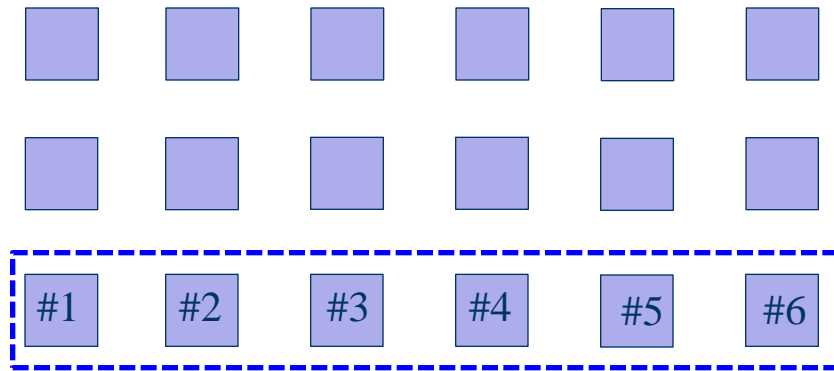
Excitation coefficients are requested in radiation pattern synthesis .



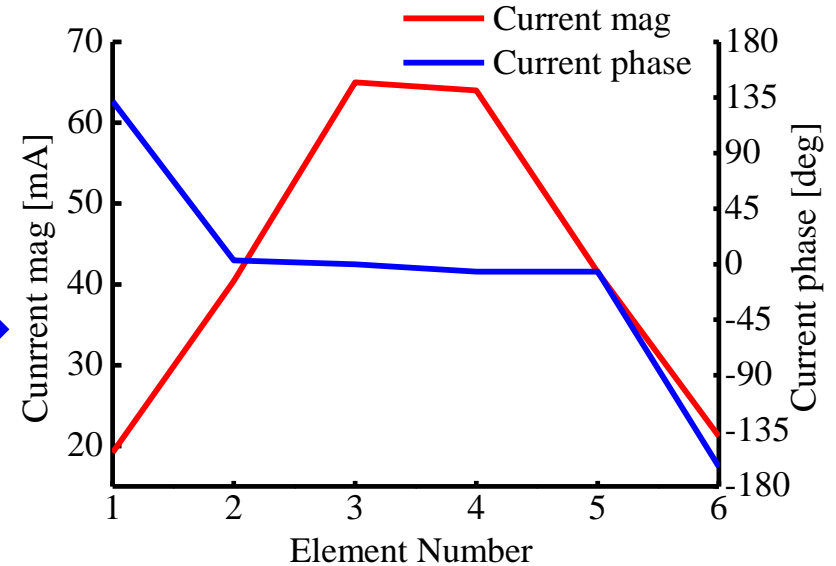
Synthesized radiation pattern

Radiation pattern synthesis is successfully achieve.

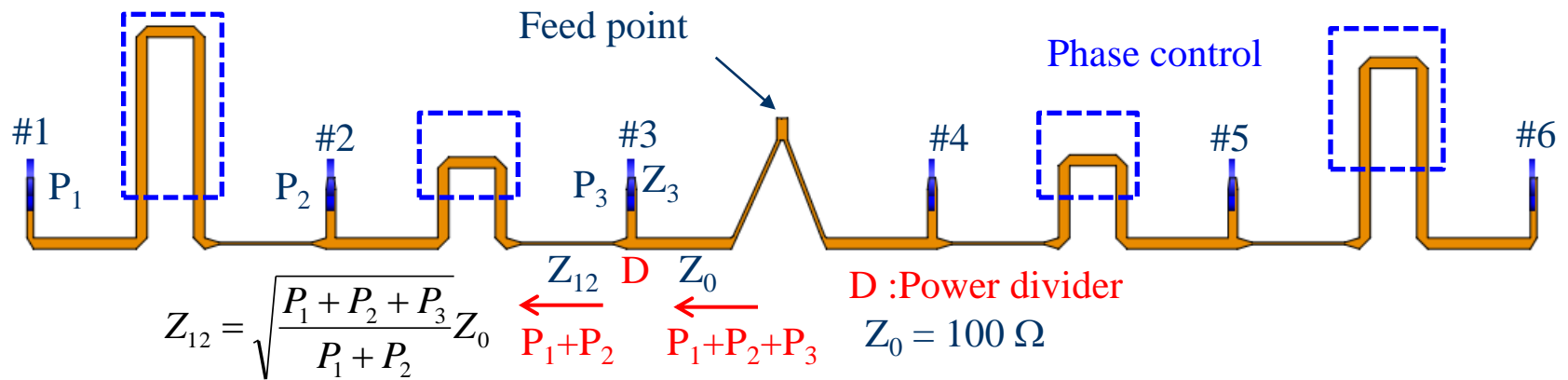
# Design method of feed network-1



Configuration of the feed array

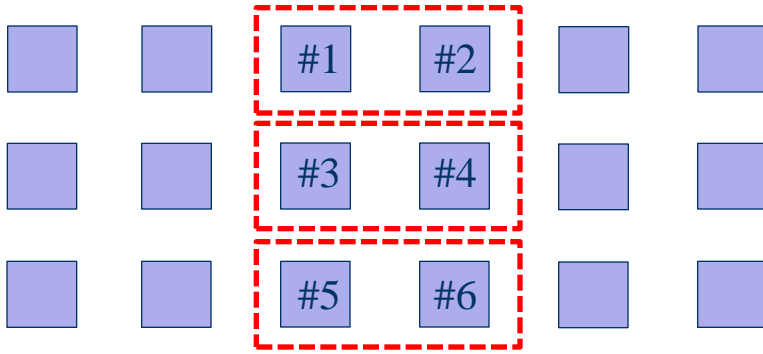


Achieved excitation condition

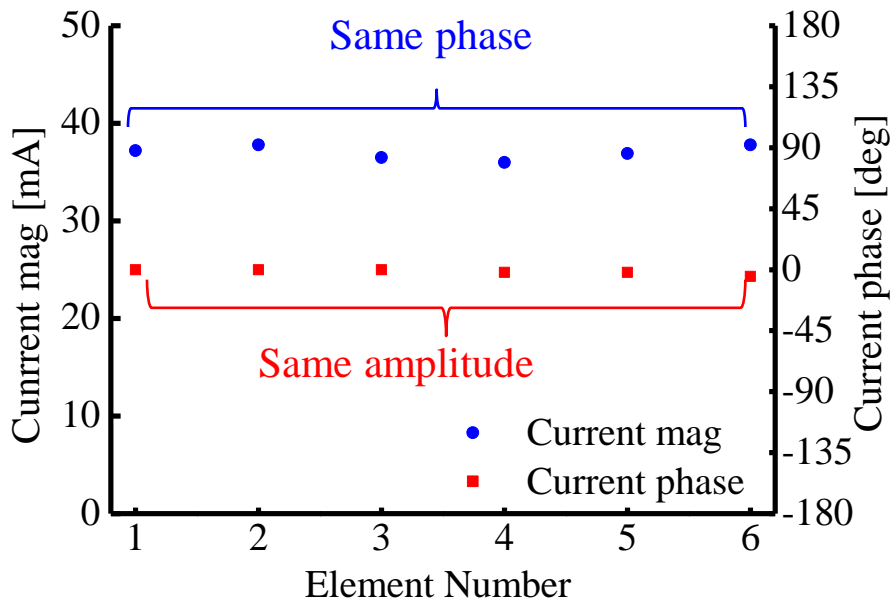


Circuit configuration

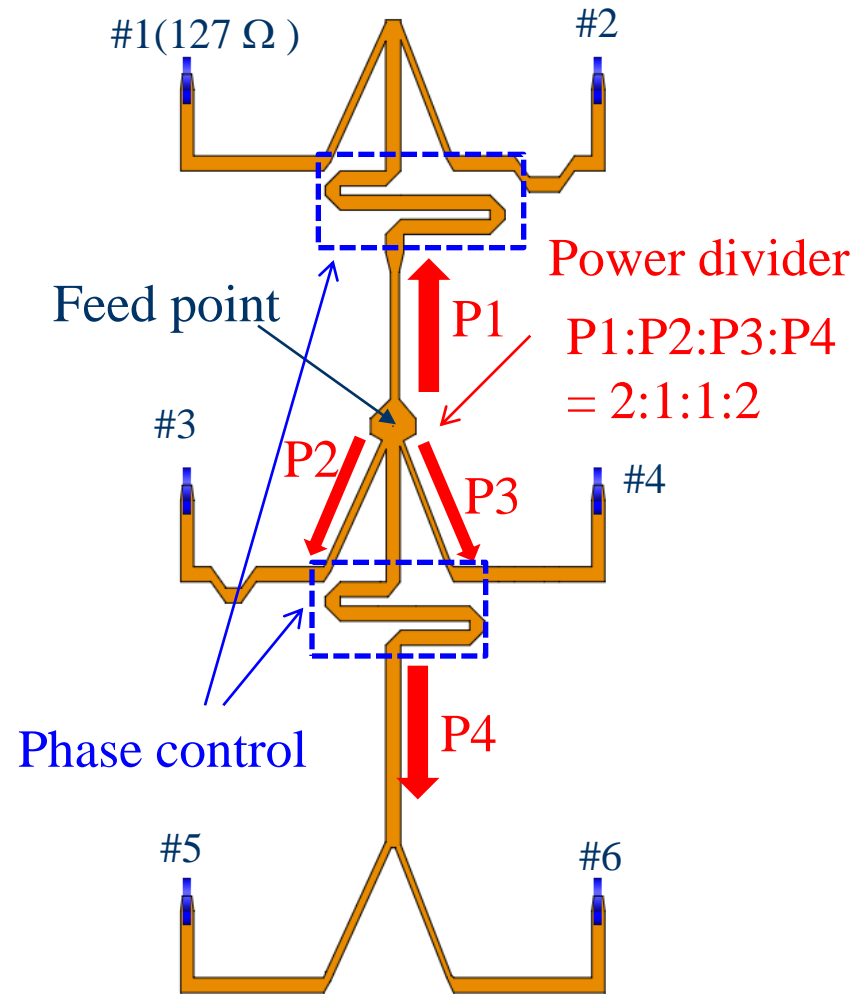
# Design method of feed network-2



Configuration of the feed array

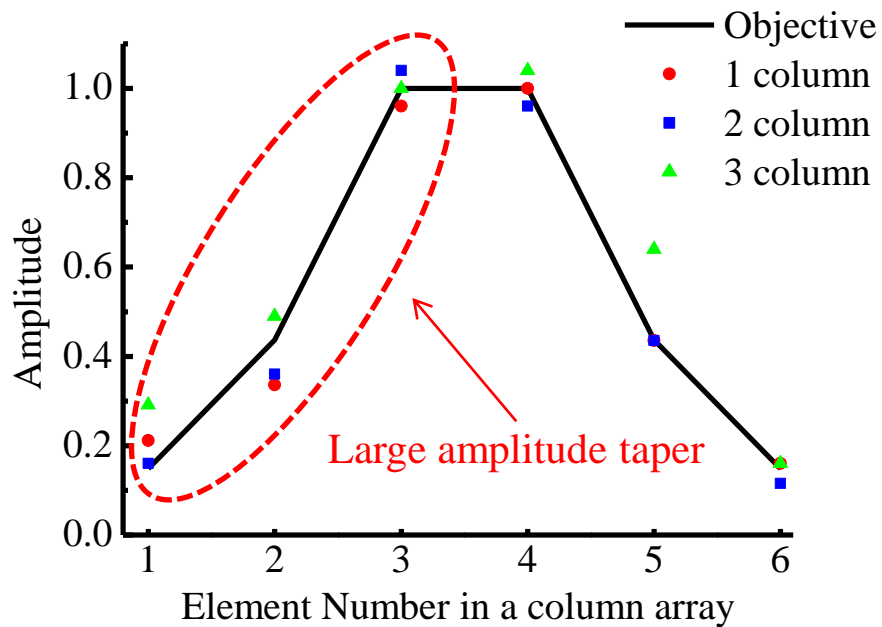
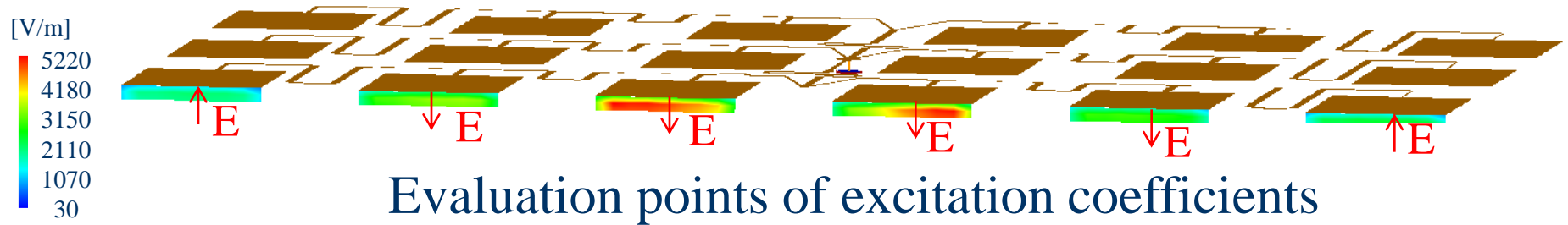


Achieved excitation condition

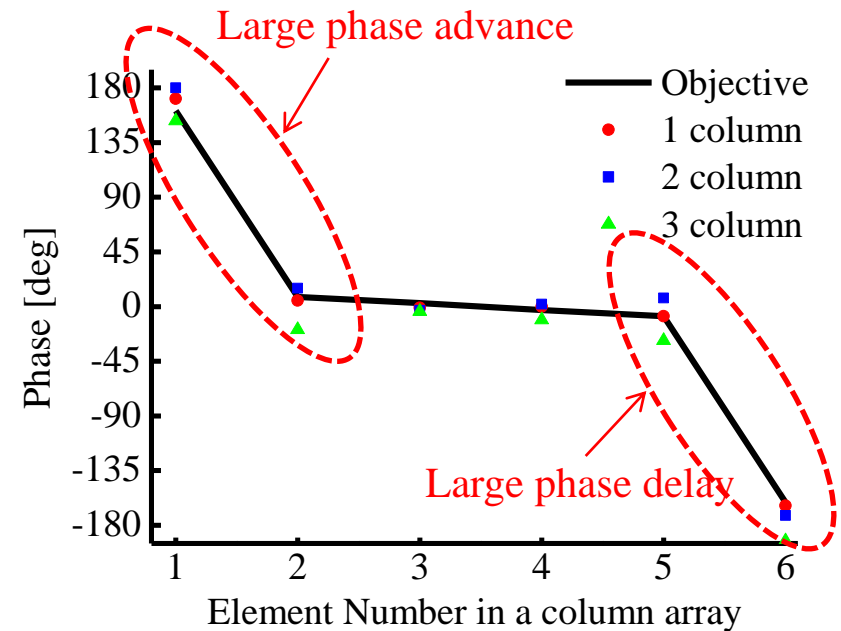


Circuit configuration

# Excitation coefficients of designed feed

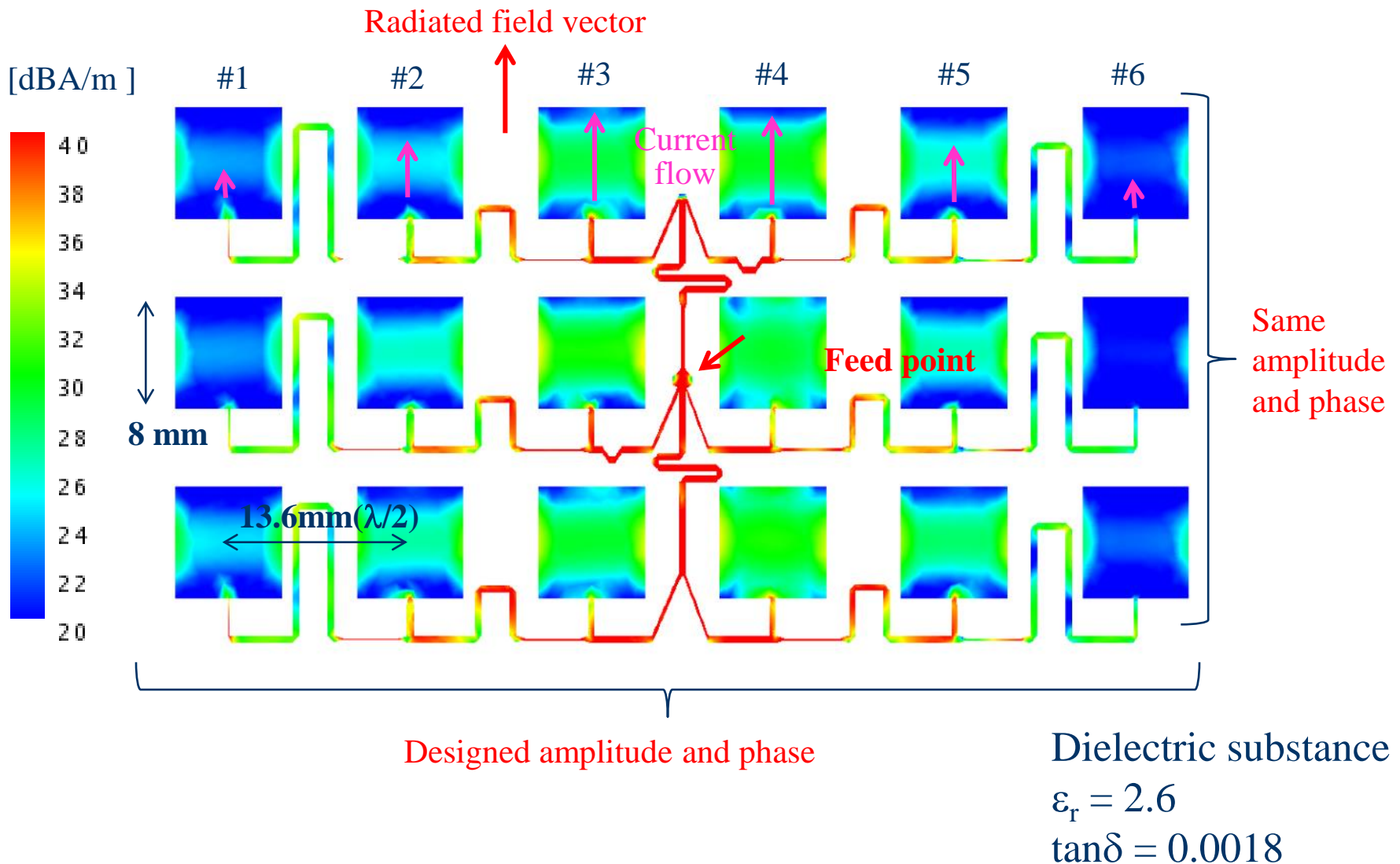


Amplitude distribution



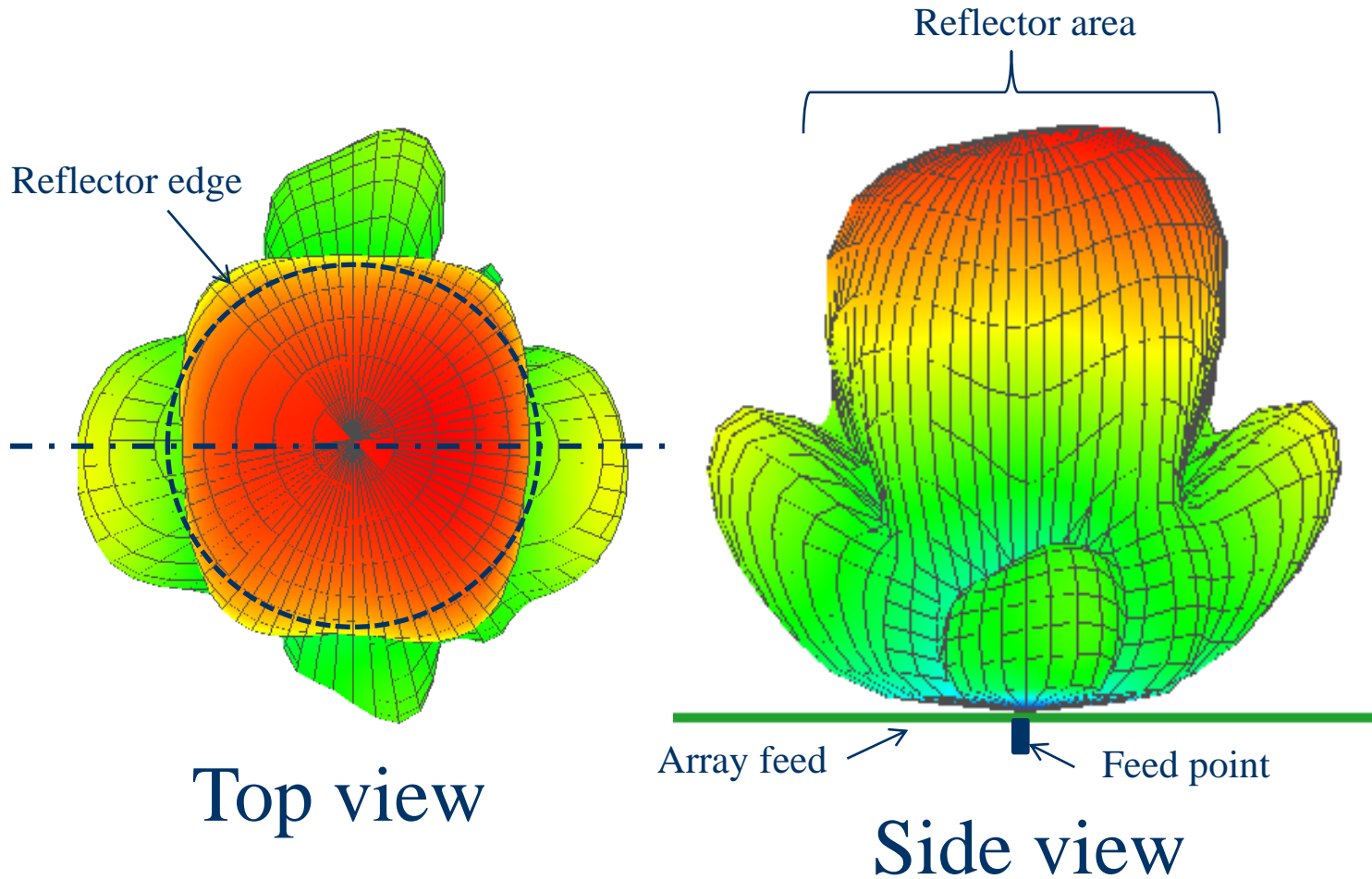
Phase distribution

# Current distributions of designed feed

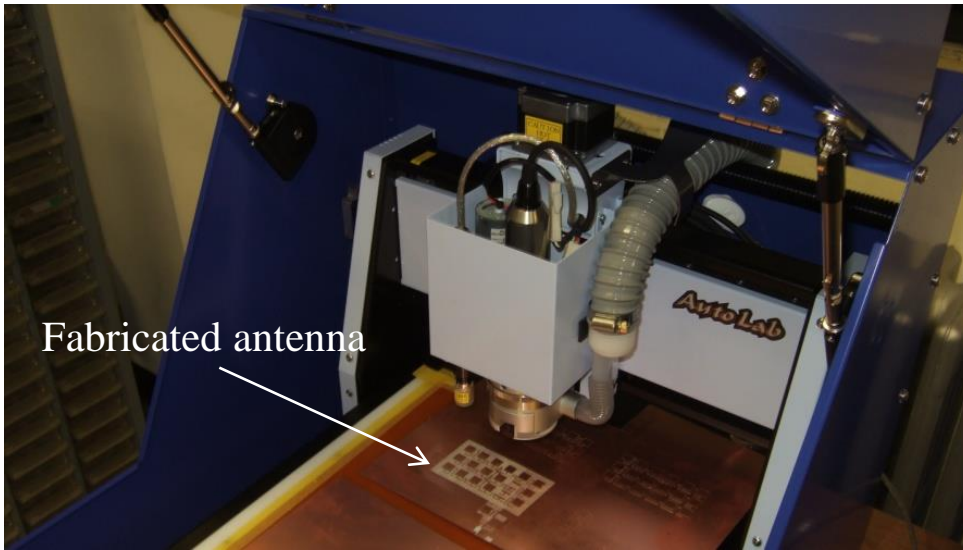




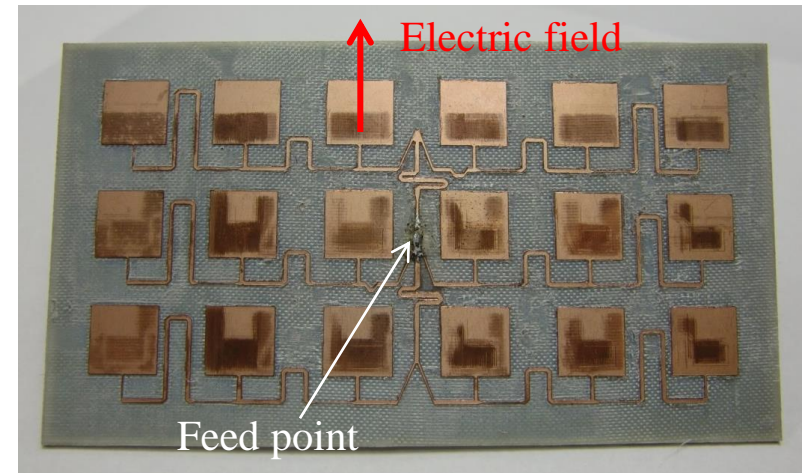
# Calculated 3D radiation patterns of the array feed



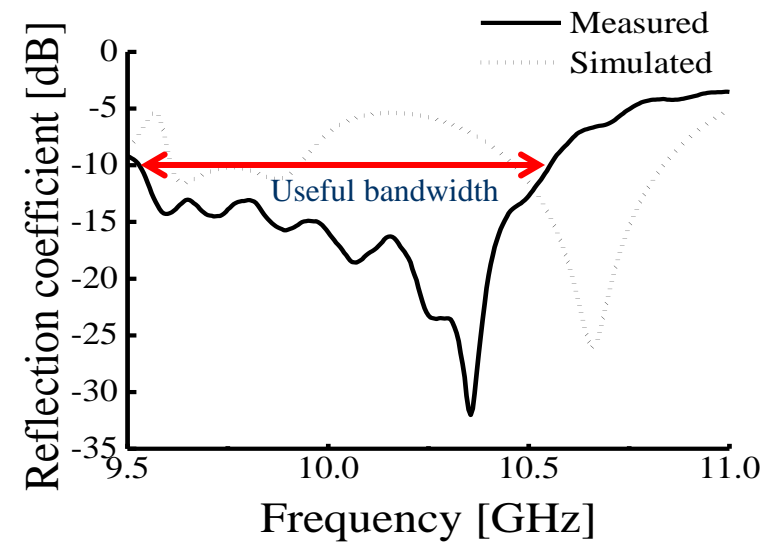
# Fabrication of the array feed



Cutting machine

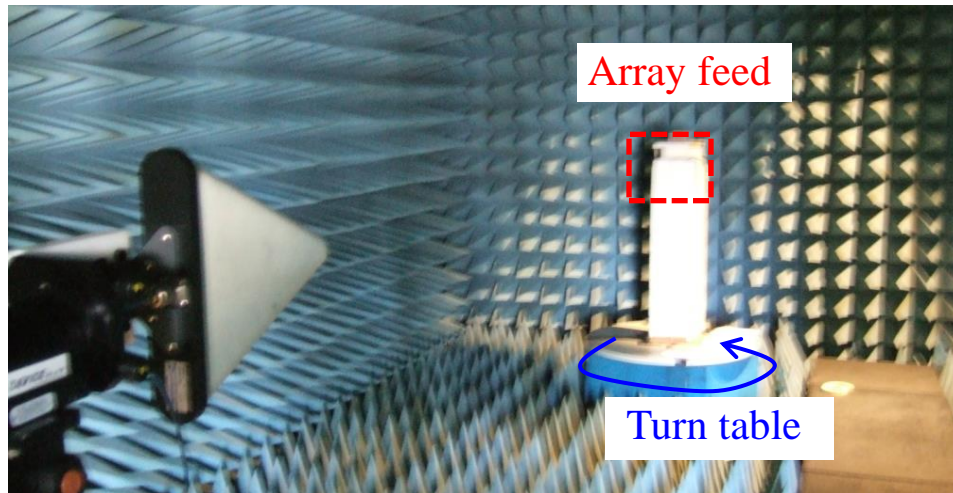


Fabricated array feed

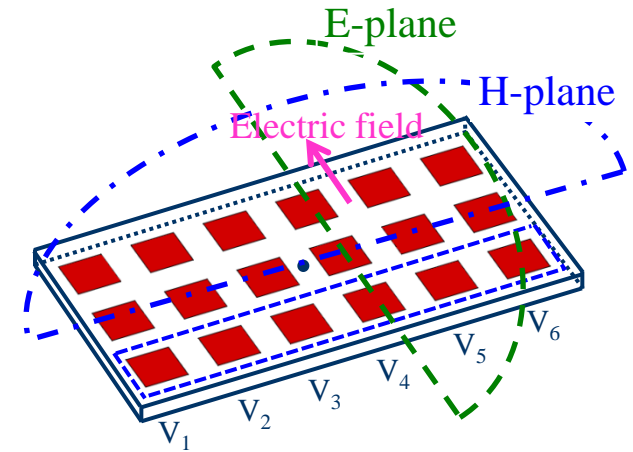


Reflection coefficient at the feed point

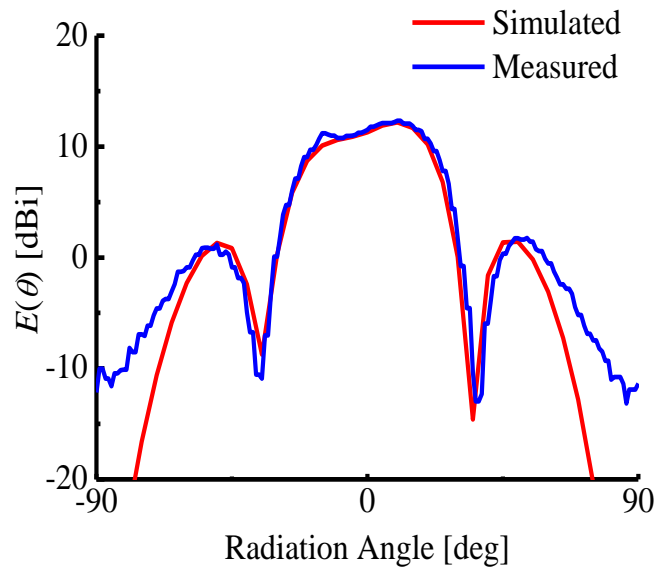
# Radiation pattern of array feed



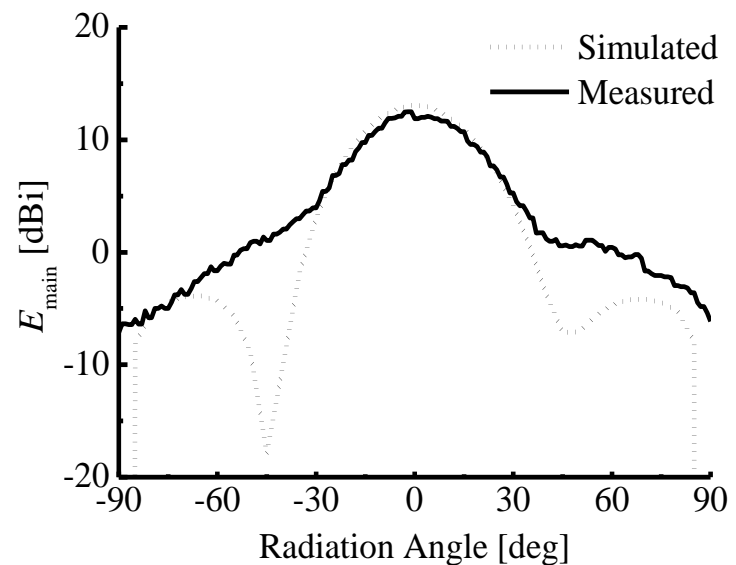
Measurement set up



Measured planes

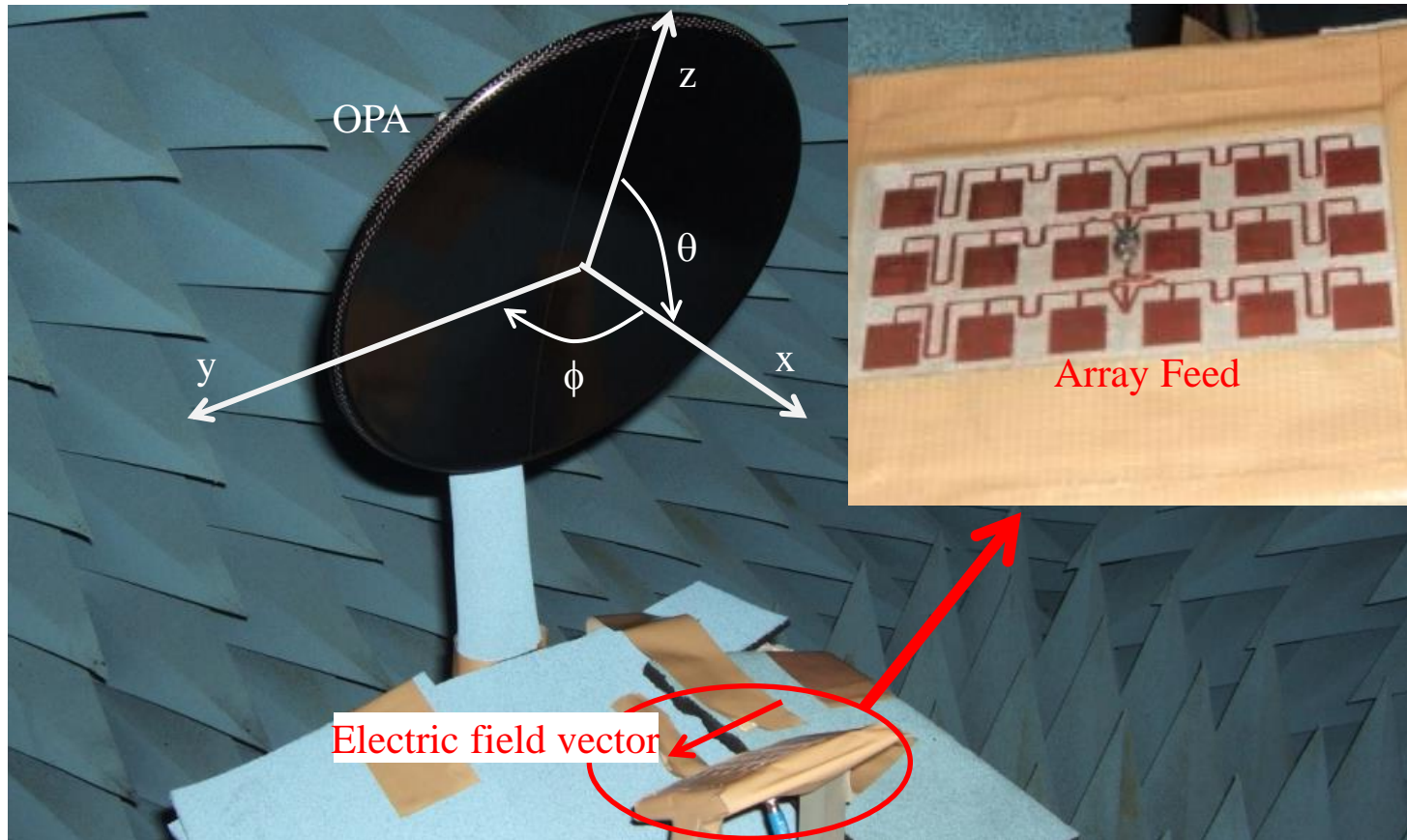


Radiation pattern in the H-plane



Radiation pattern in the E-plane

# Radiation pattern of antenna

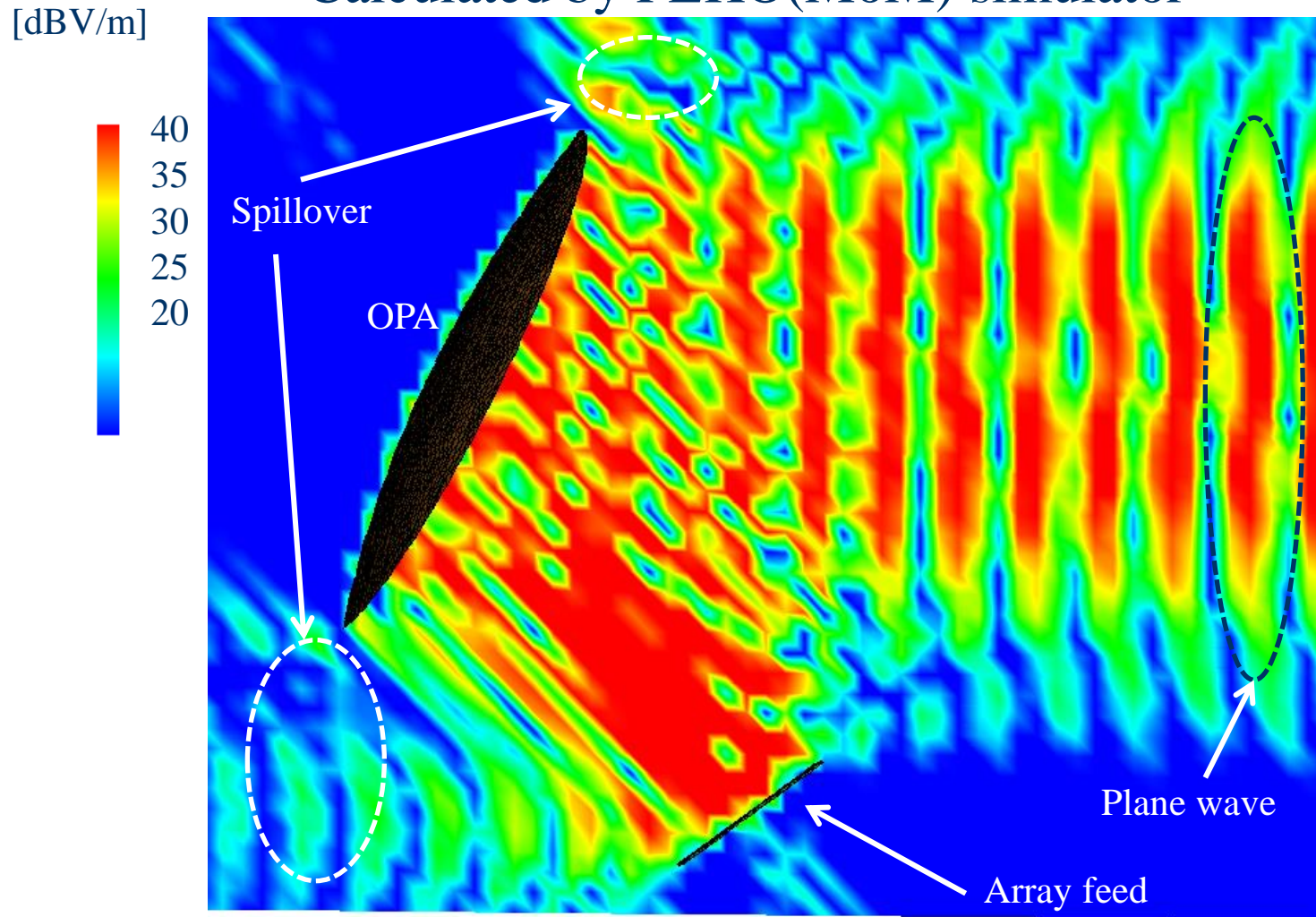


Fabricated OPA with array feed



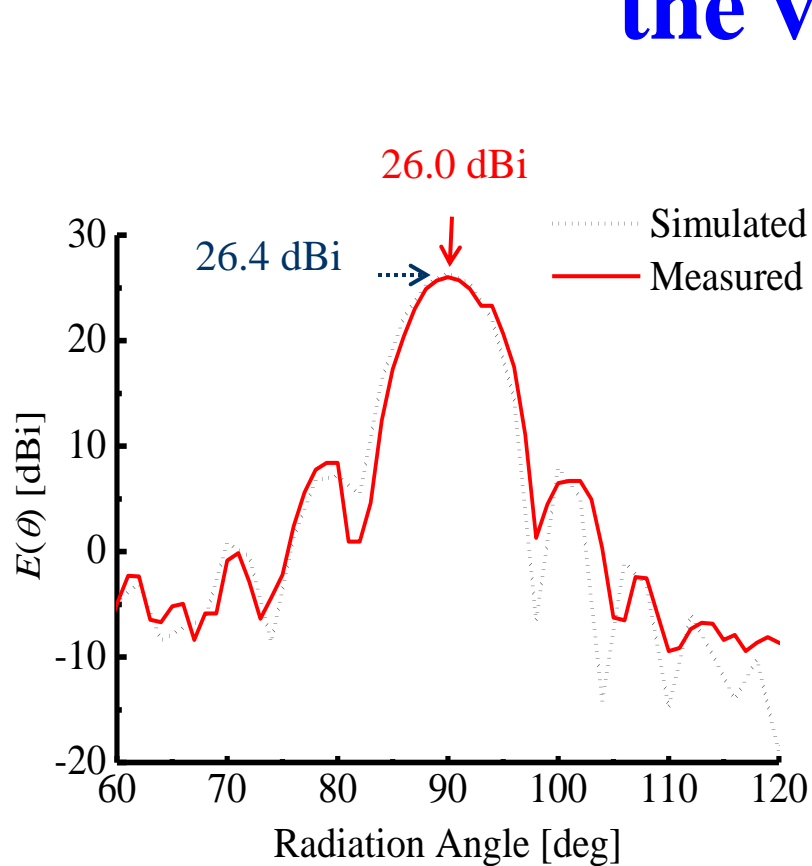
# Calculated antenna near fields

Calculated by FEKO(MoM) simulator

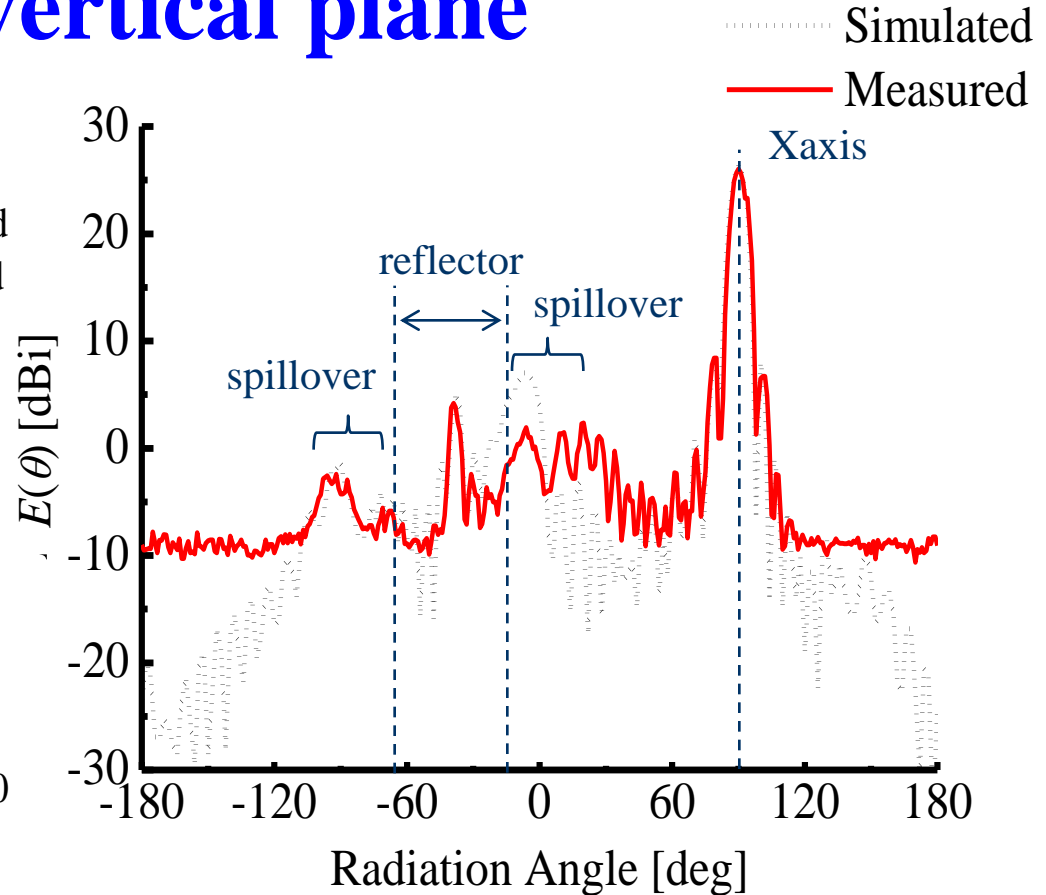


Electric field distribution (Vertical plane)

# Radiation patterns in the vertical plane



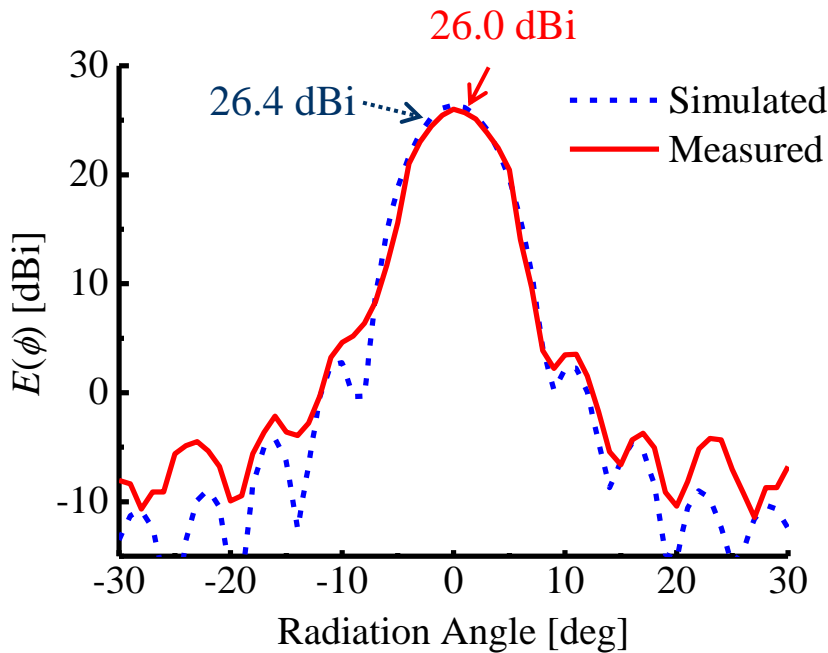
Near axis radiation pattern  
(Vertical plane)



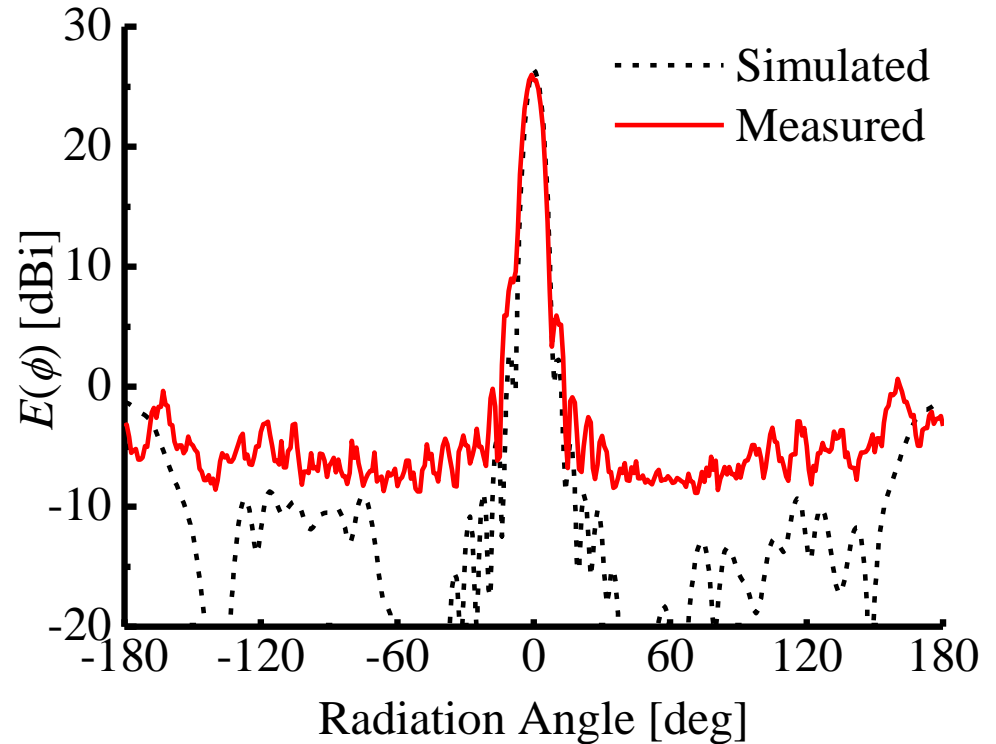
Wide angle radiation pattern  
(Vertical plane)



# Radiation patterns in the horizontal plane



Near axis radiation pattern  
(Horizontal plane)



Wide angle radiation pattern  
(Horizontal plane)

# Summaries

- 1. Achievement of an array radiation pattern synthesis program**
- 2. High gain offset parabola is designed**
- 3. Antenna performance are ensured through calculated and measured results**
- 4. Array design method is useful in many applications**

# **Very small antenna**

## **Very small normal-mode helical antenna**

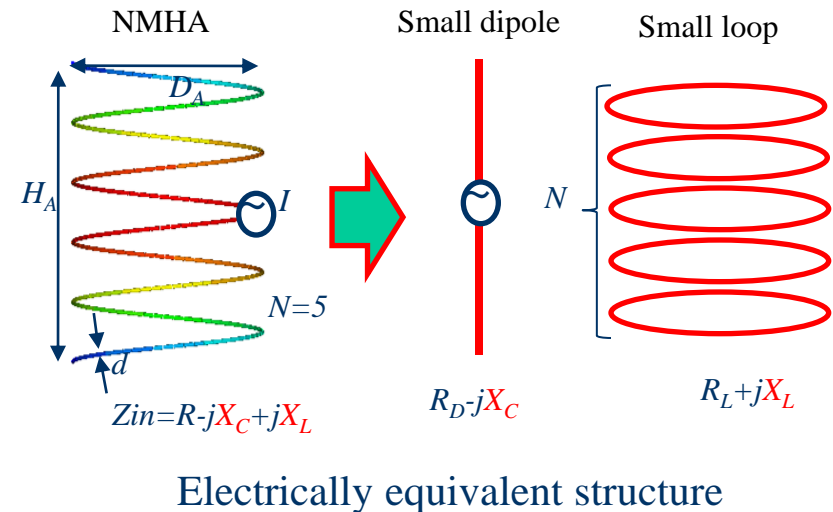
National Defense Academy

**Nguyen Quoc Dinh (Dr. at 2010)**

N.Q.Dinh, et.al, “Deterministic equation for self-resonant structures of very small normal-mode helical antenna”, IEICE Trns., Commn., 2011

# Normal-mode helical antenna

- (1) Normal-mode helical antenna (NMHA) is famous for achieving high performances in a very small size.
- (2) NMHA works in a resonant condition ( $X_C = X_L$ ).  
However, structure for resonance was not clear.
- (3) In a very small size, input resistance becomes very small. Effective impedance matching structure is requested.



Electrically equivalent structure

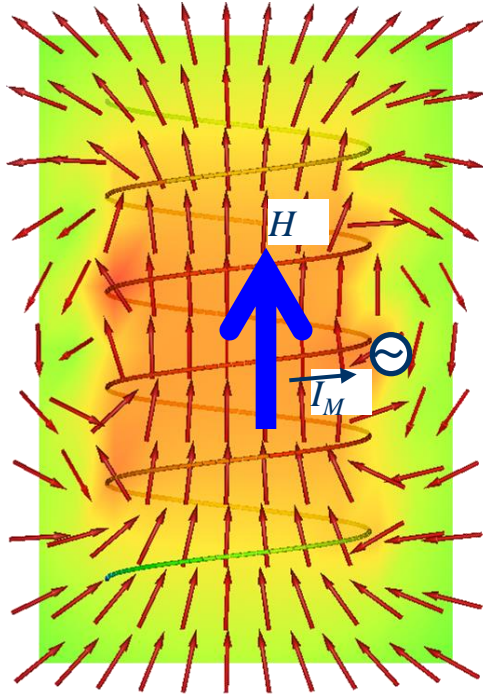
## (2) And (3) are solved by Dr. Dinh

- [1] Quoc Dinh Nguyen et.al. "Design Method of a Tap Feed for a Very Small Normal Mode Helical Antenna", IEICE Transactions on Comm., Vol.J-94B, No.2, pp.164-175, Feb. 2011
- [2] Quoc Dinh Nguyen et.al. "Deterministic Equation for Self-Resonant Structures of Very Small Normal-Mode Helical Antennas", IEICE Transactions on Comm., Vol.E94-B, No.5, pp.1276-1279, May 2011
- [3] Quoc Dinh Nguyen et.al. "Deterministic Equation for Self-Resonant Structures of Very Small Normal-Mode Helical Antennas Placed on a Metal Plate", IEICE Transactions on Comm., Vol.J94-B, No.9, pp.1214-1217, Sept. 2011
- [4] Quoc Dinh Nguyen et.al. "FEKO-Based Method for Electromagnetic Simulation of Carcass Wires Embedded in Vehicle Tires", ACES Journal, Vol.26, No.3, pp.217-224, March 2011

# Inductance( $X_L$ )

□ H.A.Wheeler\*

$$L_w = \frac{19.7ND_A^2}{9D_A + 20H_A} \times 10^{-6}$$



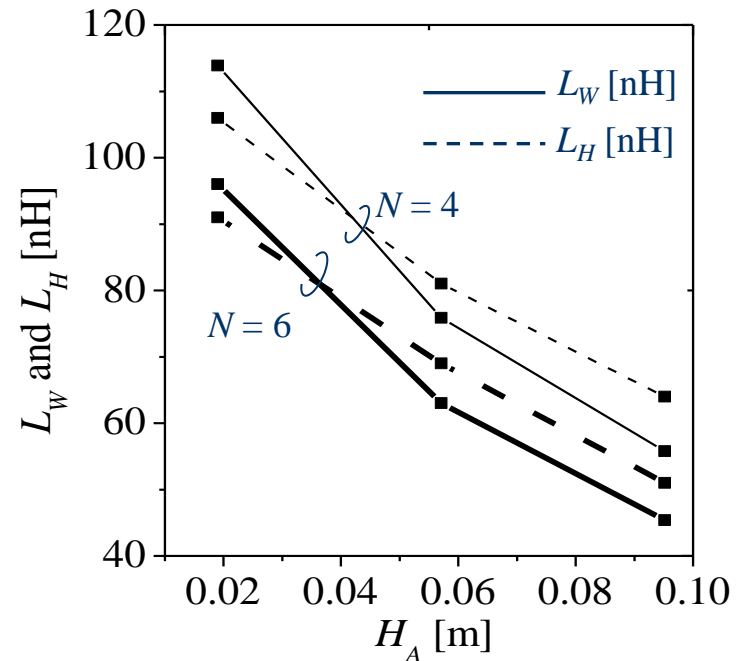
Magnetic field distribution

( $N=5$ ,  $H_A=57.14\text{mm}$ ,  $D_A=31.43\text{mm}$ )

**Wheeler's empirical equation is useful.**

□ Calculation equation

$$L_H = \frac{\Phi}{I_M} = \frac{\mu \oint H dS}{I_M}$$

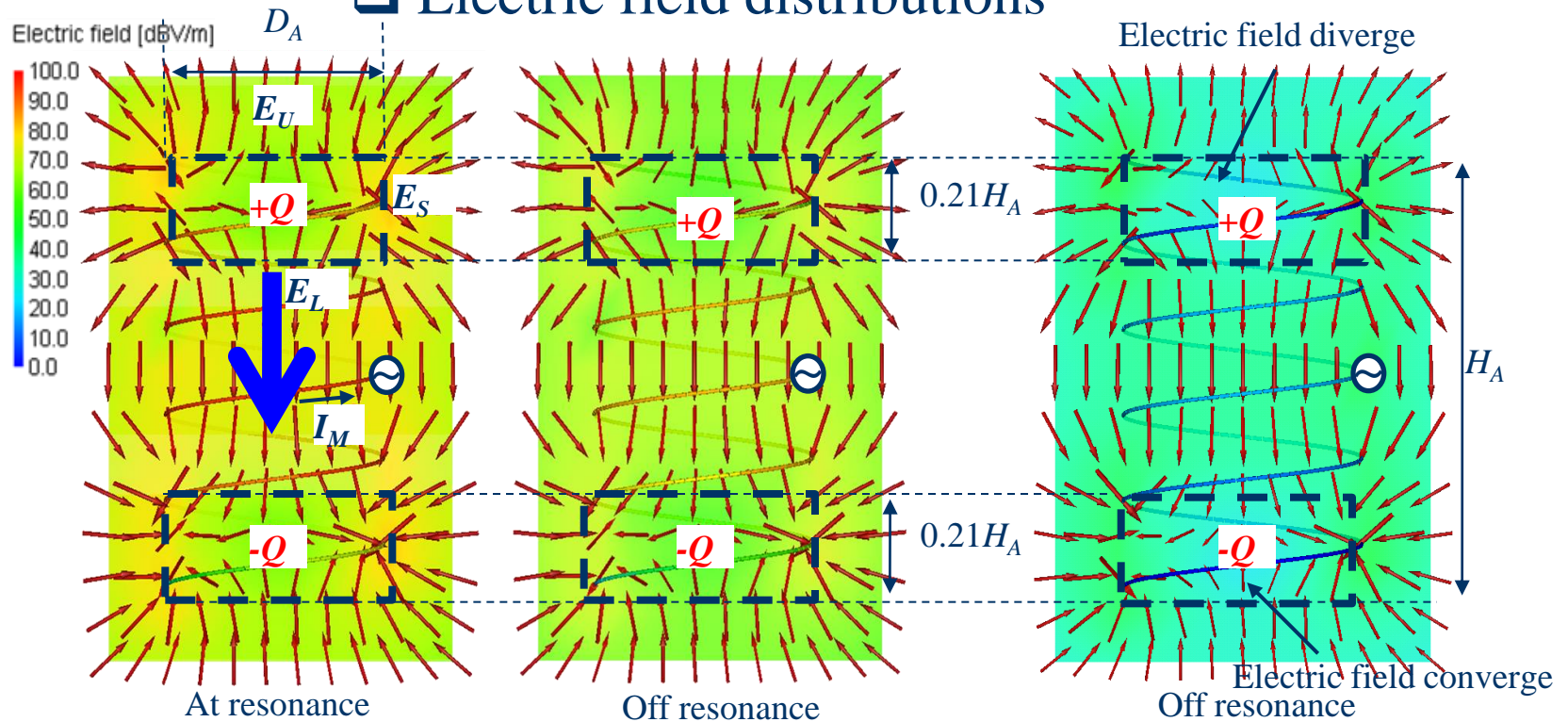


Comparisons of calculated and Wheeler's results

\*H.A.Wheeler, "Simple Inductance formulas for Radio Coils," Proc.IRE, Vol.16, pp.1398- 1400, 1928.

# Capacitance ( $X_C$ )

## □ Electric field distributions



**Charge areas (Q) are discovered at the both end of antenna**

## □ Expression of charge

$$Q_E = \varepsilon \iint E dS = \varepsilon \left\{ \iint E_S dS + \iint E_U dS + \iint E_L dS \right\} = \frac{\varepsilon \pi D_A}{4} \{ 0.84 H_A E_S + D_A (E_L + E_U) \}$$

**From the charge area, expression for charge is derived.**

# Equation for self-resonant structure

□ Expression for  $X_C$

$$X_C = \frac{279\lambda H_A}{N\pi(0.92H_A + D_A)^2}$$

□ Expression for  $X_L$

$$X_L = \omega L_w = \omega \frac{19.7ND_A^2}{9D_A + 20H_A} \times 10^{-6}$$

$X_C = X_L$  Deterministic equation for the self-resonant structure

Normalized with  $\lambda$

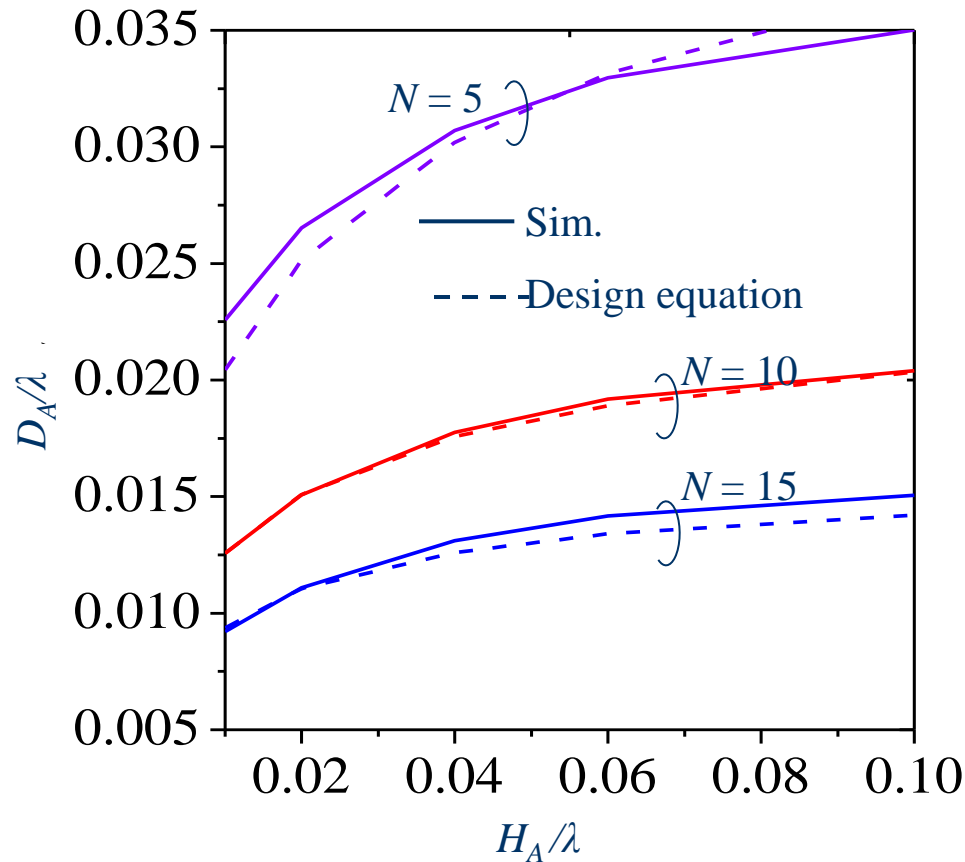
Final design equation

$$\frac{279 \frac{H_A}{\lambda}}{N\pi(0.92 \frac{H_A}{\lambda} + \frac{D_A}{\lambda})^2} = \frac{600\pi \times 19.7N(\frac{D_A}{\lambda})^2}{9 \frac{D_A}{\lambda} + 20 \frac{H_A}{\lambda}}$$

□ Universal design equation considering frequency factor is established.



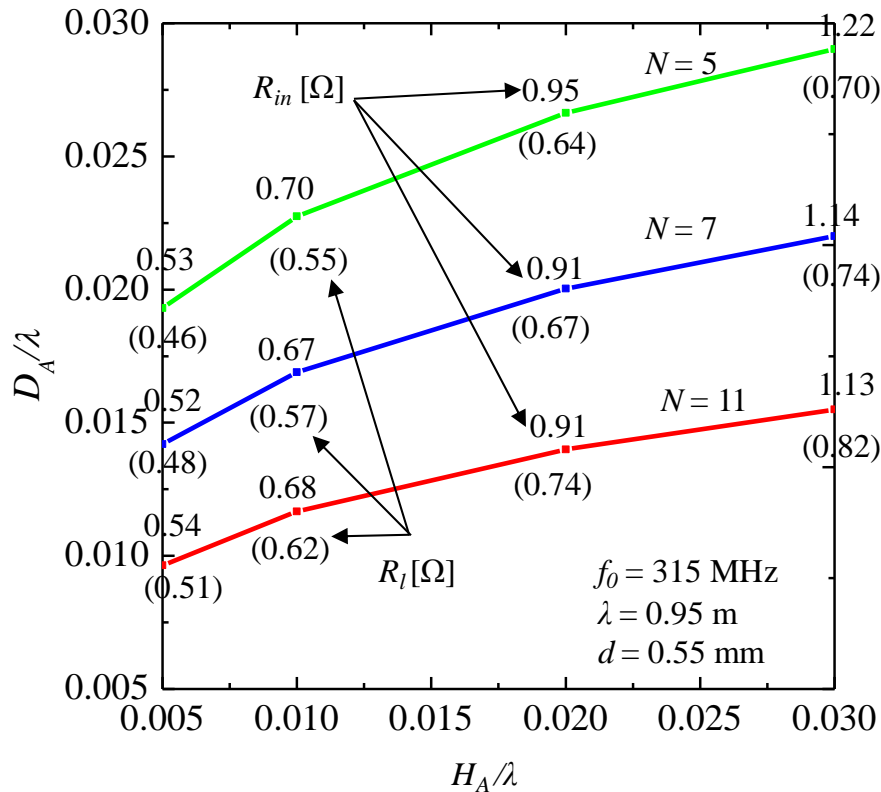
# Adequateness of the design equation



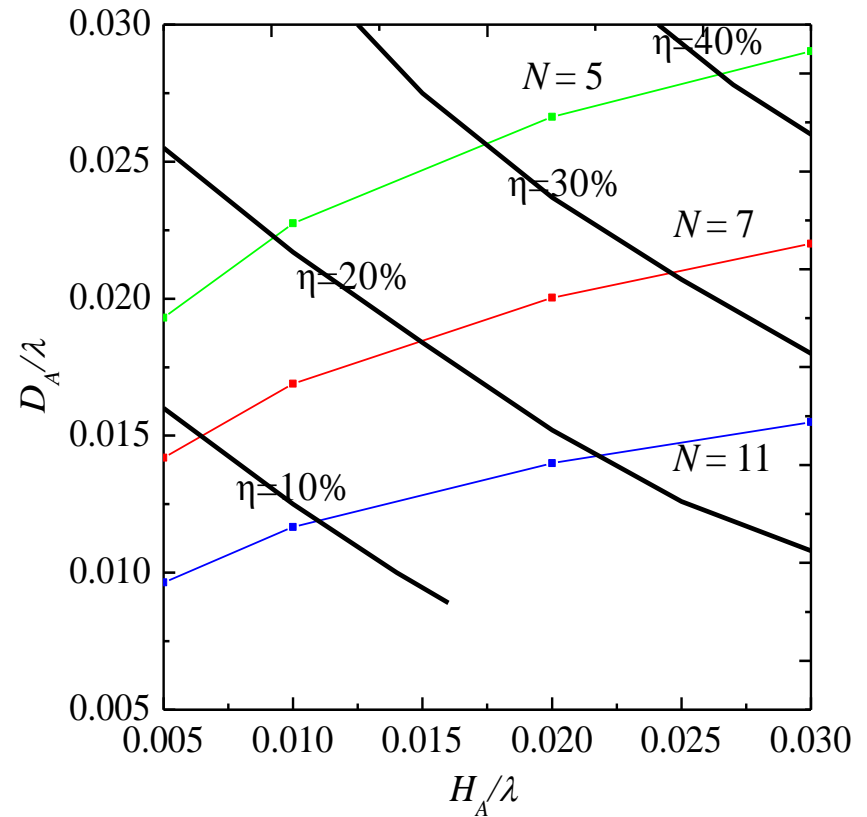
Self-resonant structure of NMHA

- Structures by design equation agree very well with simulated results.
- Adequateness of the design equation is ensured.

# Input resistance and radiation efficiency



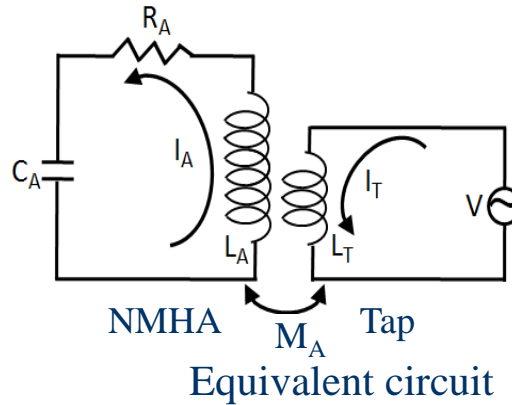
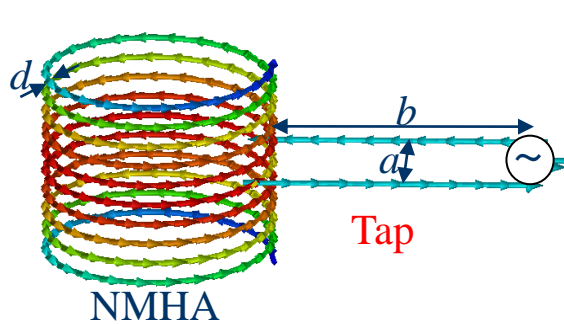
Input resistance( $R_{in}$ ) and ohmic resistance( $R_l$ )



Radiation efficiency

**Because of very small input resistance, impedance matching is needed.**

# Design method for impedance matching



$M_A$  : Mutual inductance  
 $R_A$  : Resistance of NMHA  
 $C_A$  : Capacitance of NMHA  
 $L_A$  : Inductance of NMHA  
 $L_T$  : Inductance of a tap

## ● Circuit equation

$$\left\{ \frac{1}{j\omega C_A} + R_A + j\omega(L_A - M_A) \right\} I_A + j\omega M_A (I_A - I_T) = 0$$

$$j\omega(L_T - M_A) I_T + j\omega M_A (I_T - I_A) = V$$

## ● Input impedance ( $Z_{in} = V/I_T$ )

$$Z_{in} = \frac{R_A (\omega M_A)^2}{R_A^2 + (\omega L_A - \frac{1}{\omega C_A})^2} + j \frac{R_A^2 (\omega L_T) - (\omega M_A)^2 (\omega L_A - \frac{1}{\omega C_A}) + \omega L_T (\omega L_A - \frac{1}{\omega C_A})^2}{R_A^2 + (\omega L_A - \frac{1}{\omega C_A})^2}$$

## ● At self-resonance $R_s \cong R_A \left( \frac{L_T}{M_A} \right)^2$ ( $R_A$ is very small)

## ● Step up ratio $\gamma = \left( \frac{L_T}{M_A} \right)^2$

A simple step up expression at self-resonance is obtained.

# Design equation of step up ratio ( $\gamma$ )

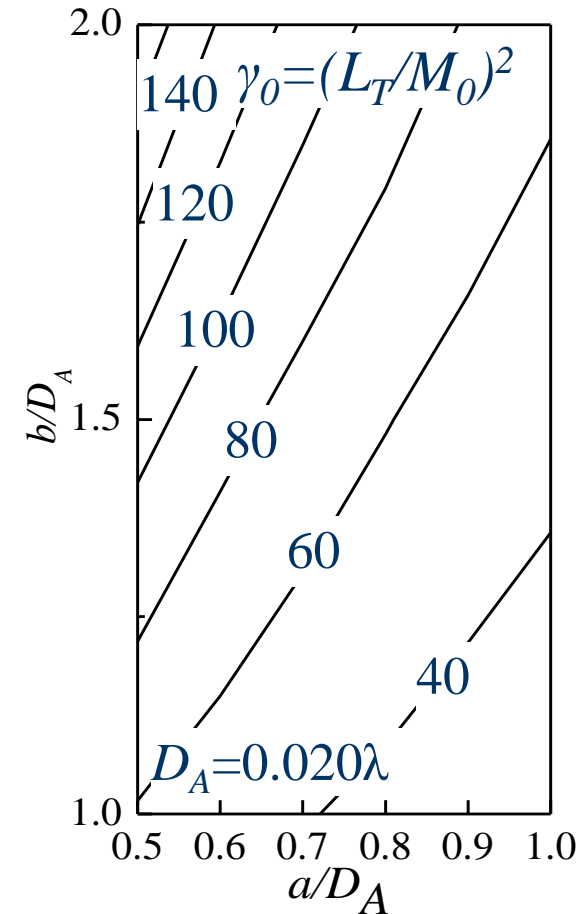
- Design equation of  $\gamma$

$$\gamma = \left(\frac{L_T}{M_A}\right)^2 = \left(\frac{L_0}{M_A}\right)^2 \left(\frac{L_T}{L_0}\right)^2 = \left(\frac{H_A}{\alpha_A D_A N}\right)^2 \gamma_0$$

- $\gamma_0$  is given as a graphical data

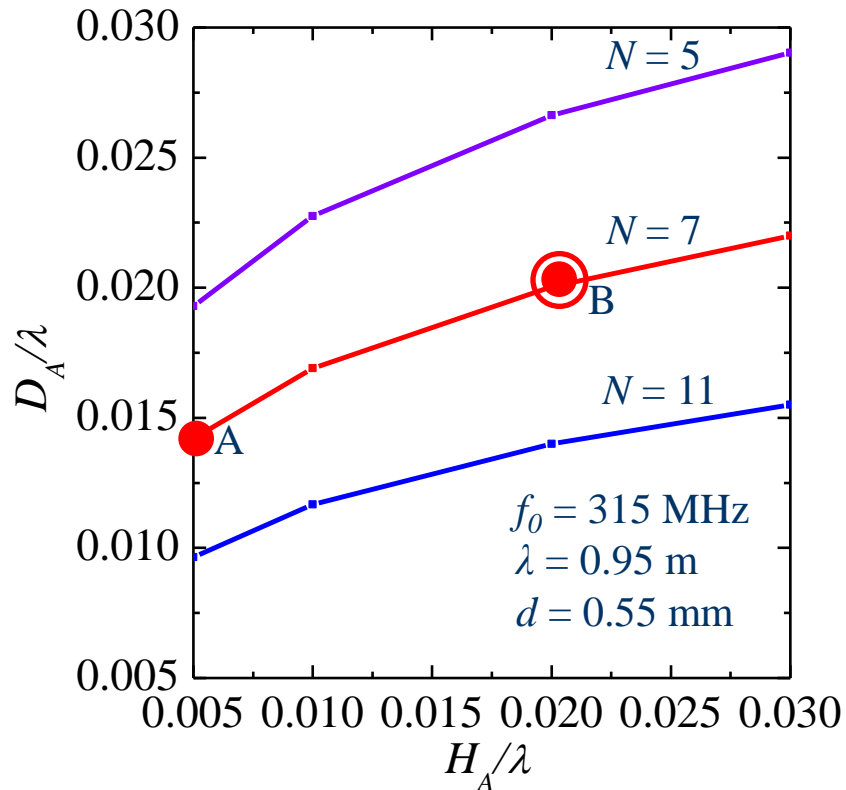
$$\gamma_0 = \left(\frac{L_T}{M_0}\right)^2$$

Based on the graphical data of  $\gamma_0$ , step up ratio ( $\gamma$ ) can be calculated for antenna structure ( $H_A, N, D_A$ ).

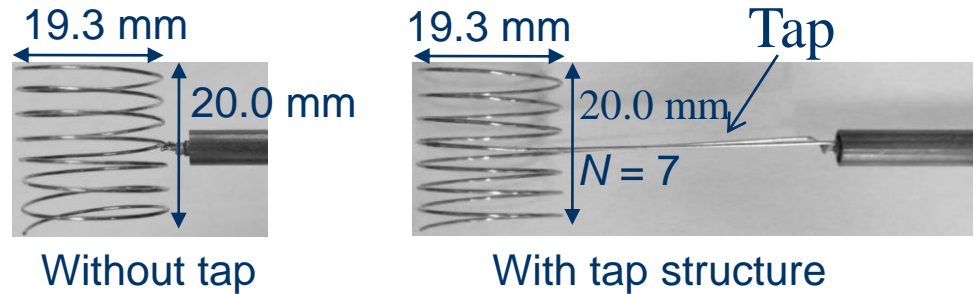


$\gamma_0$  data

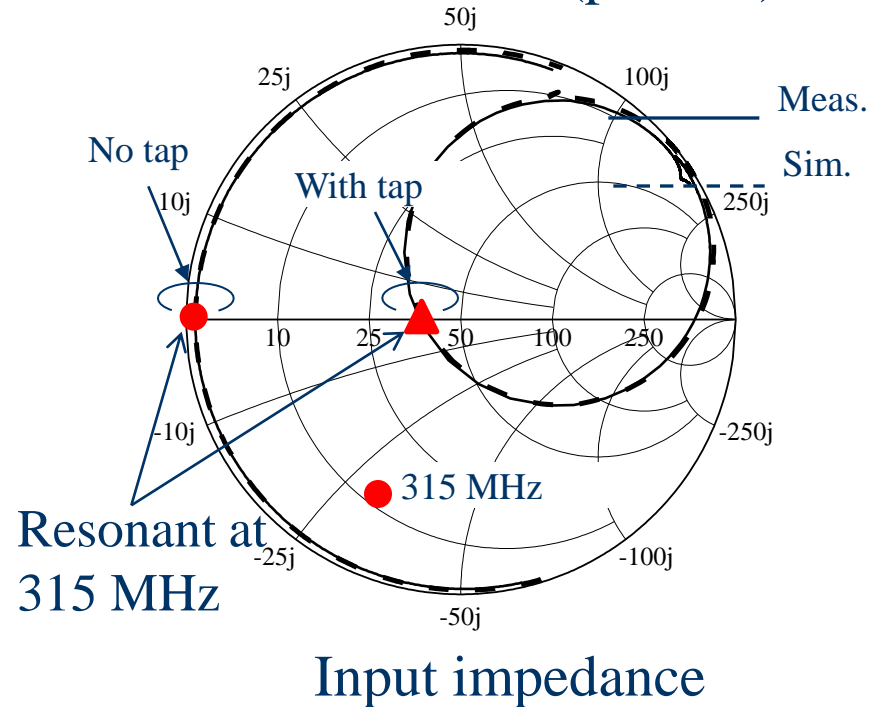
# Experimental results



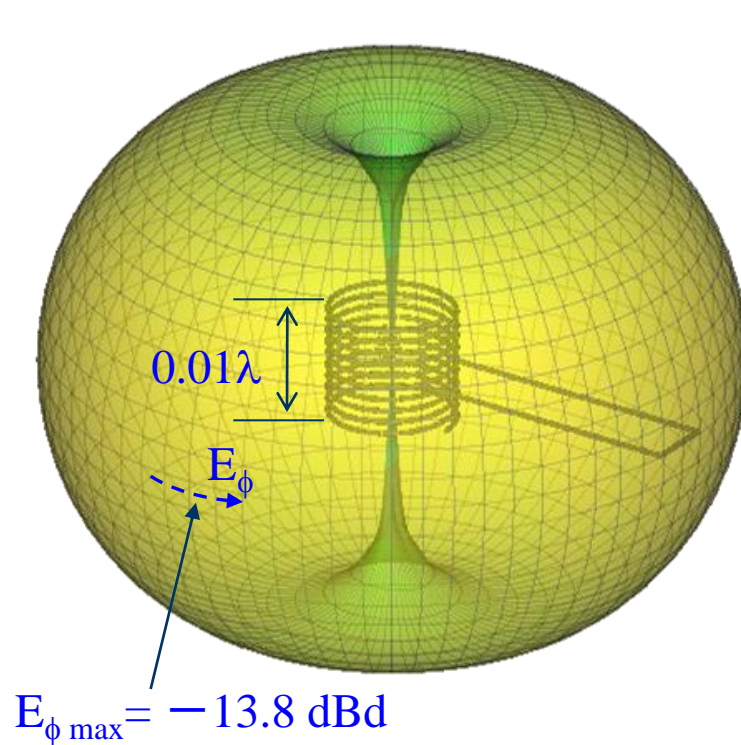
Fabricated antenna structure  
(Point B)



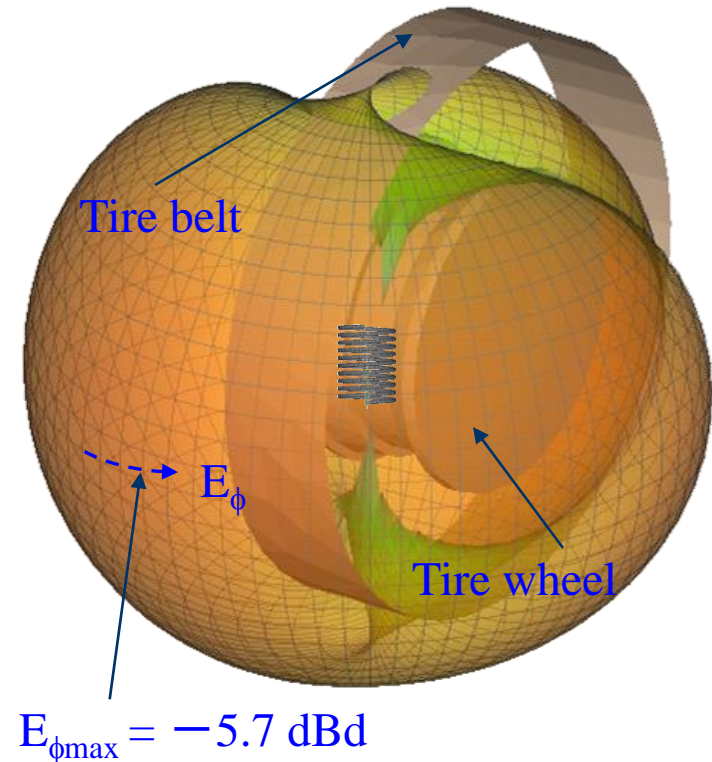
Fabricated antenna (point B)



# Application for the tire pressure monitoring system



Radiation characteristic of NMHA



In tire placement

**Antenna gain is increased 8.1dB by metal proximity effects.**

# Summaries

- 1. Achievement of the self-resonant equation through electromagnetic simulation results**
- 2. Impedance matching method is developed**
- 3. Antenna performance are ensured through calculated and measured results**
- 4. Calculations of stored electric and magnetic energies are future works**



# Calculation and Measurement Methods for RCS of a Scale Model Airplane

15 October 2014

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<sup>1</sup> Malaysia-Japan International Institute of Technology,  
Universiti Teknologi Malaysia

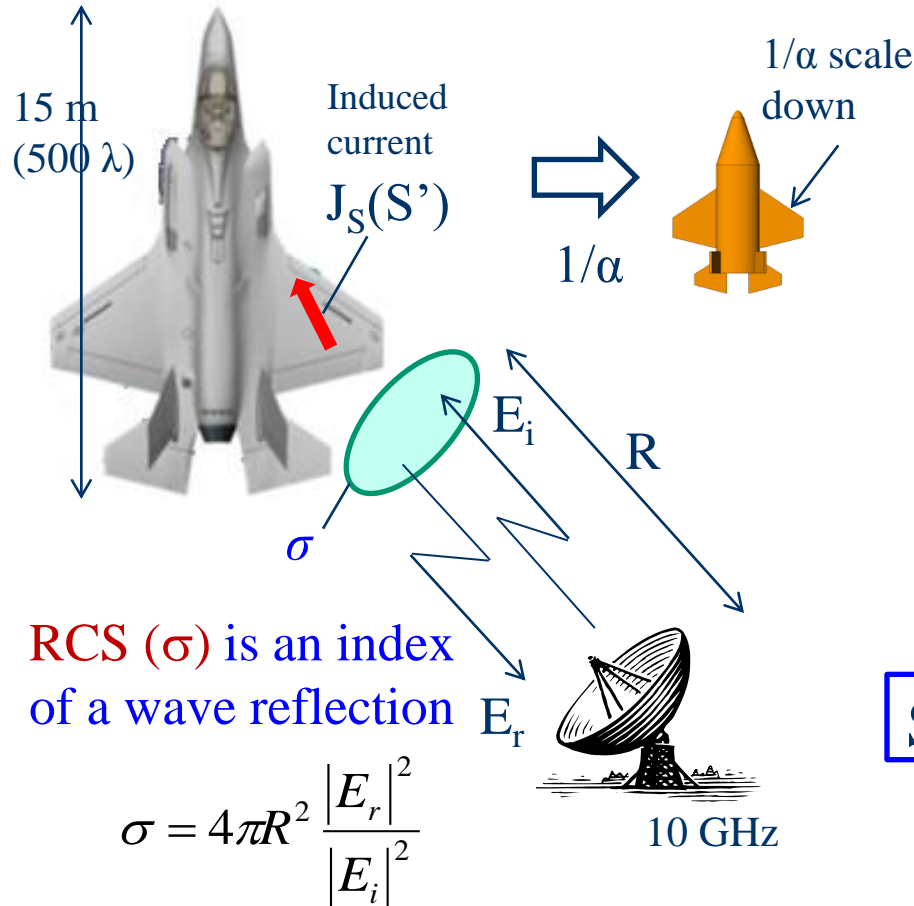
<sup>2</sup> Electrical & Electronic Eng., National Defense Academy

<sup>3</sup> Department of Fundamental of Radio and Electronic Eng.,  
Le Quy Don Technical University

# Outline of Presentation

1. Explanations of RCS
2. RCS calculation employing a scale model
3. Comparisons of calculation methods
4. Comparisons of calculated and measured values
5. Calculation methods for higher frequencies
6. Conclusion

# What is Radar Cross Section (RCS)



**RCS ( $\sigma$ )** is an index of a wave reflection

$$\sigma = 4\pi R^2 \frac{|E_r|^2}{|E_i|^2}$$

RCS expression with target current distribution( $J_S(S')$ )

$$\sigma = \frac{k^2 \eta^2}{4\pi} \frac{\left| \iint_s J_S(S') e^{jkr'} ds' \right|^2}{|E_i|^2}$$

## Scale model conditions

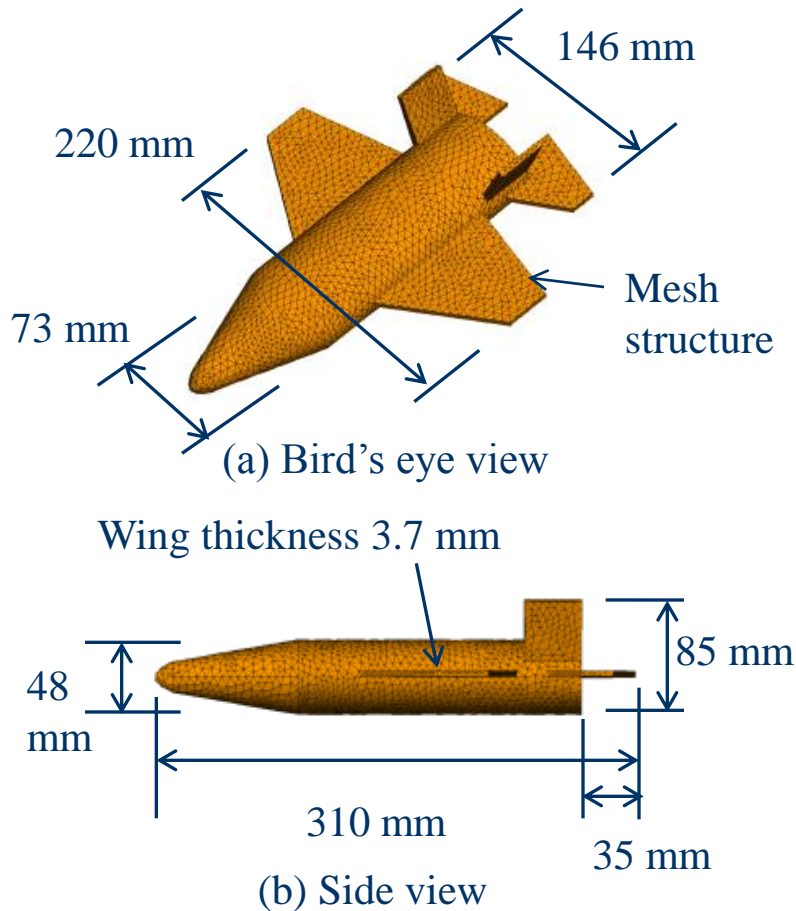
	Real object*	Scale model
Size	1	$1/\alpha$
Frequency	$f_0$	$\alpha f_0$
RCS pattern	$\sigma(\theta)/\sigma_{\max}$	Same value
RCS value	$\sigma$	$\sigma/\alpha^2$

## Study subjects

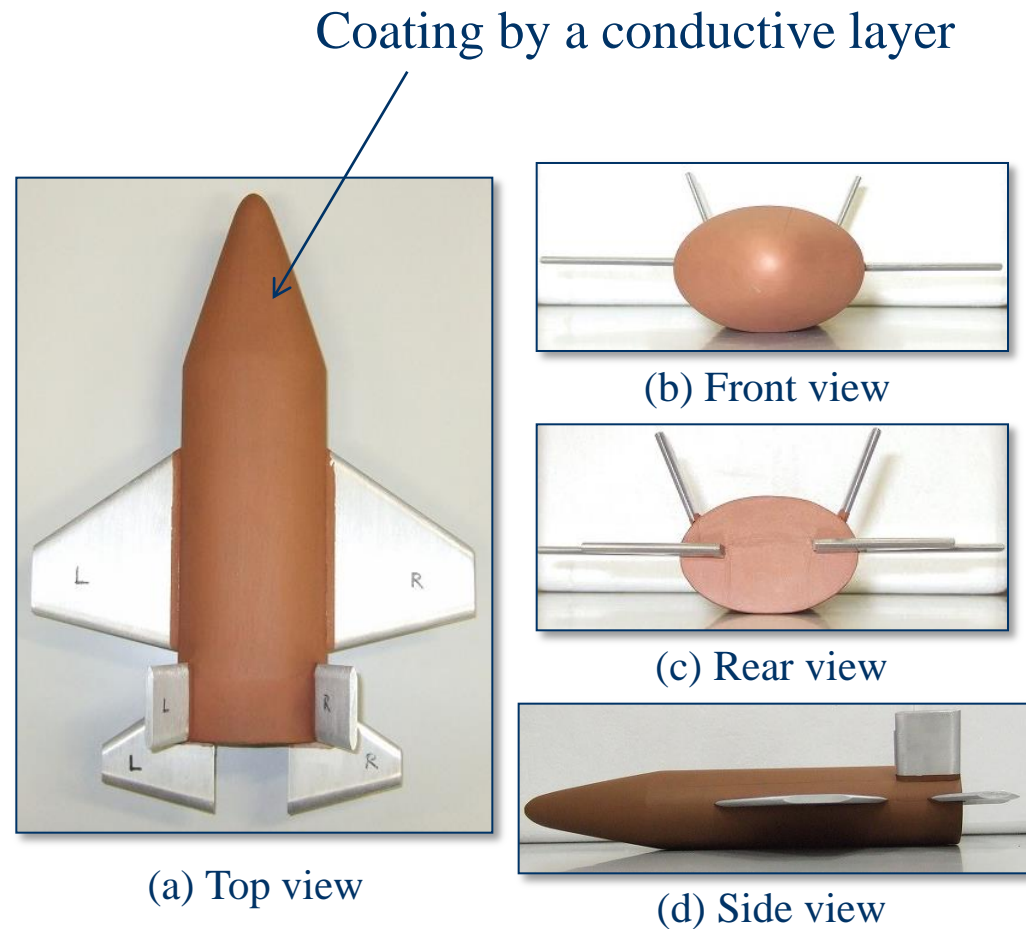
- How to calculate RCS values exactly
- How to measure RCS values exactly
- Comparisons of measured and calculated results

# Structure of a scale model airplane

Scale factor : 1/48



Calculation structure



Experimental structure

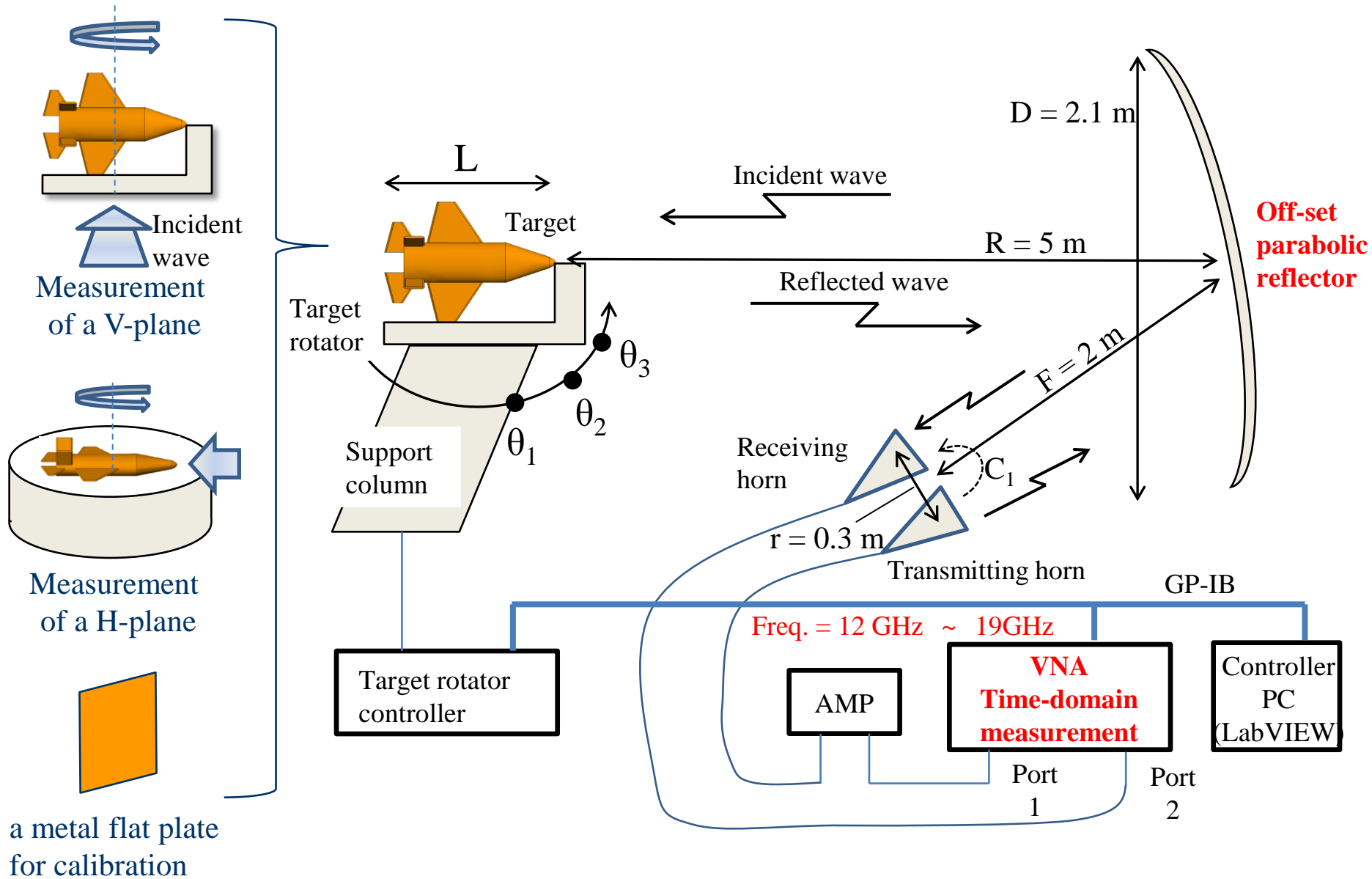
# Calculation methods at 18 GHz

Algorithm	Mesh size	Mesh number	Unknown number	Memory amount	Calculation time
MoM	$0.1 \lambda$	83,160	124,740	116.336 GB	282,293 seconds (78 hours)
MLFMM	$0.1 \lambda$	83,160	124,740	5.430 GB	19,999 seconds (5.6 hours)
HOBF	$\lambda$	790	14,207	1.527 GB	4,168 seconds (1.2 hours)

PC SPEC	CPU Xeon E5-2687W 3.1 GHz, Memory 256 GB
Simulation tool	FEKO Suite 6.3

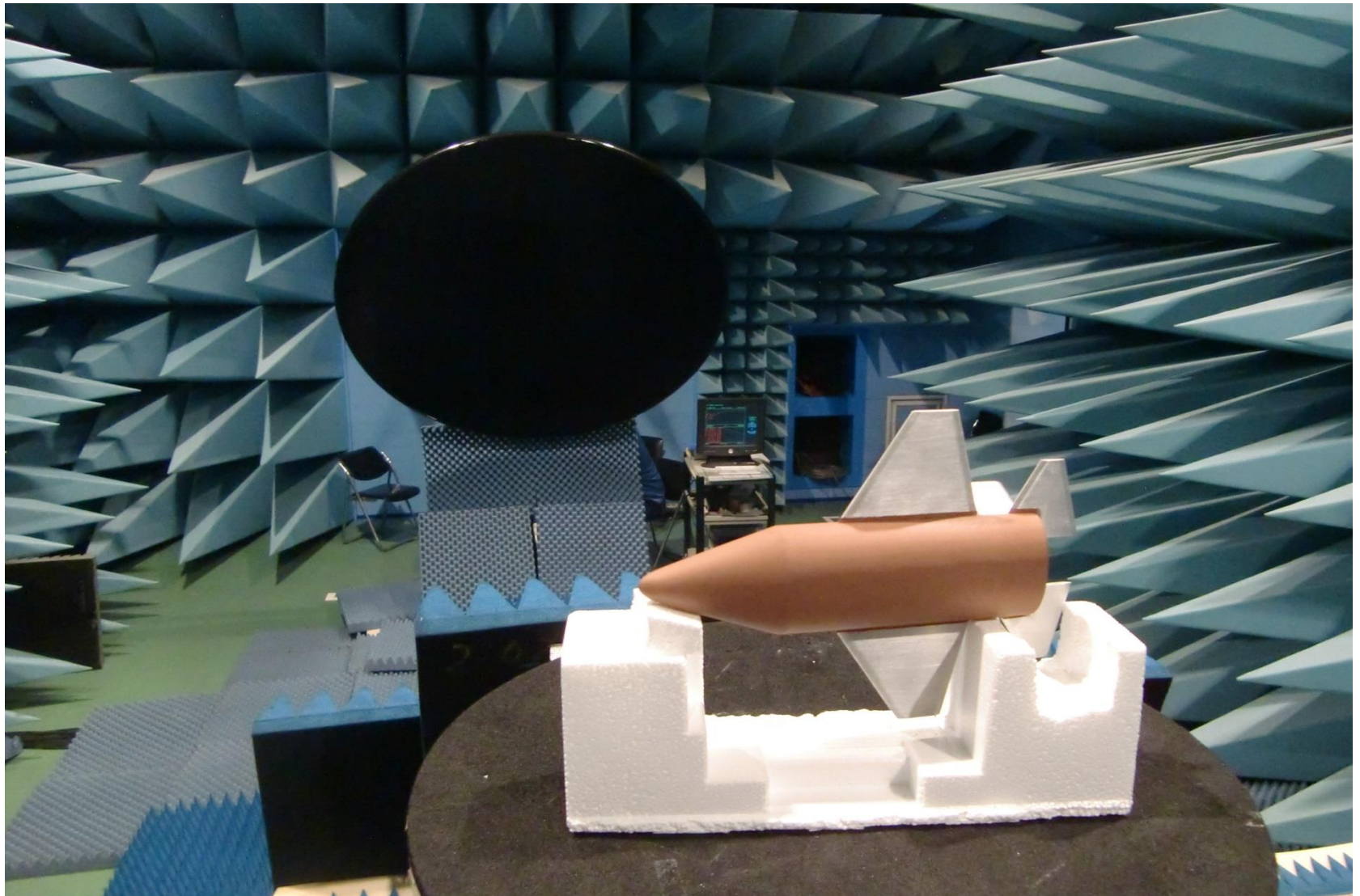
MoM (Method of moment); Exact calculation of surface currents  
 MLFMM(Multi Level Fast Multipole Method); Approximate calculation  
 HOBF(Higher Order Basis Function) ; Approximate calculation

# Measurement method (Compact range)



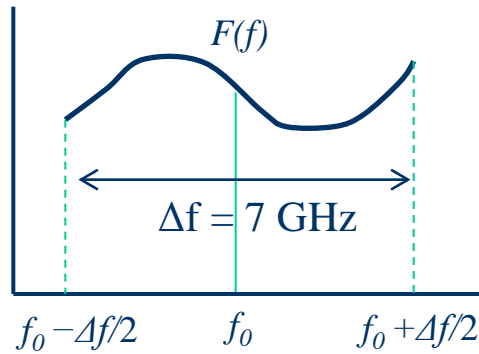


# Actual measurement setup

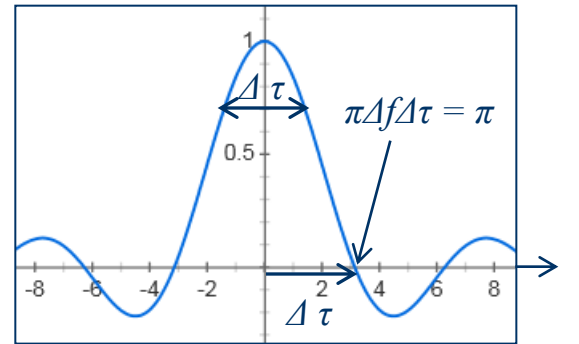




# Effects of time-domain measurements



(a) Frequency sweep transmission



(b) Time-domain signal at reception

Production of time-domain signal by Fourier transformation

$$A(t) = \int_{-\infty}^{\infty} F(f) e^{j2\pi ft} df \quad (1)$$

$$A(t) = F_C \int_{f_0 - \frac{\Delta f}{2}}^{f_0 + \frac{\Delta f}{2}} e^{j2\pi ft} df$$

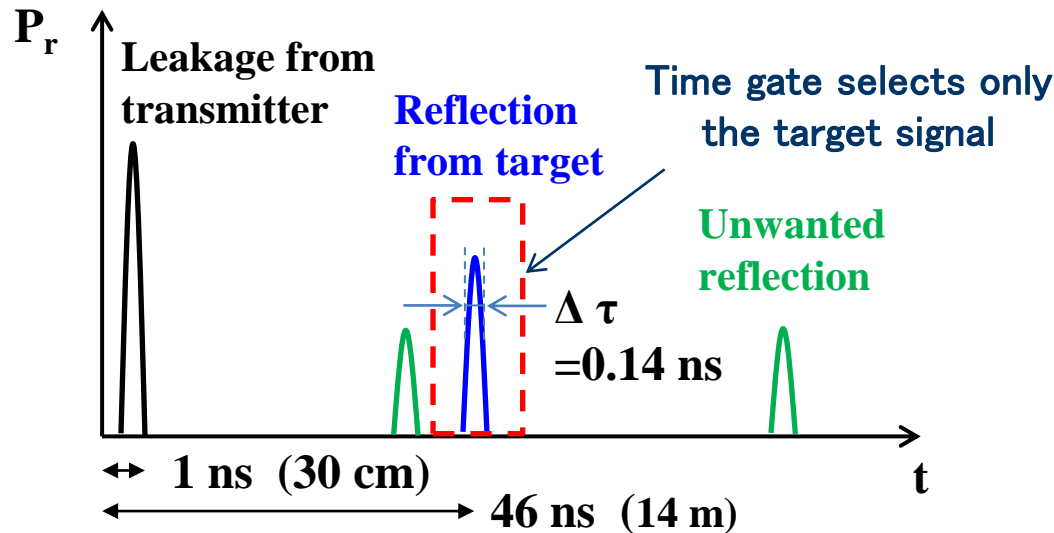
$$= F_C e^{j2\pi f_0 t} \Delta f \frac{\sin(\pi \Delta f t)}{\pi \Delta f t} \quad (2)$$

Here, in Eq.(2)  $\pi \Delta f \Delta \tau = \pi$

$$\text{Then, } \therefore \Delta \tau = \frac{1}{\Delta f} \quad (3)$$

In Eq. (3) Insert,  $\Delta f = 7 \text{ GHz}$   
Then,  $\Delta \tau = 0.14 \text{ ns}$

Pulse width of 0.14 ns  
corresponds to distance 4.2 cm



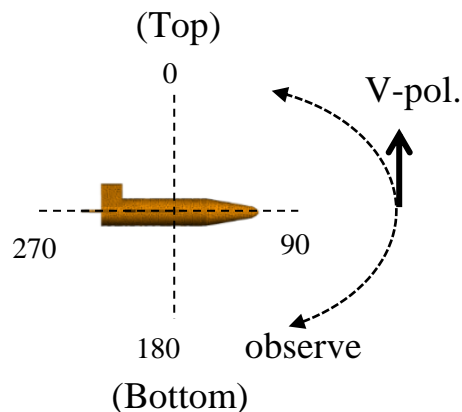
(c) Actual time-domain signals

Reflected signals of approximately 10 cm can be distinguished

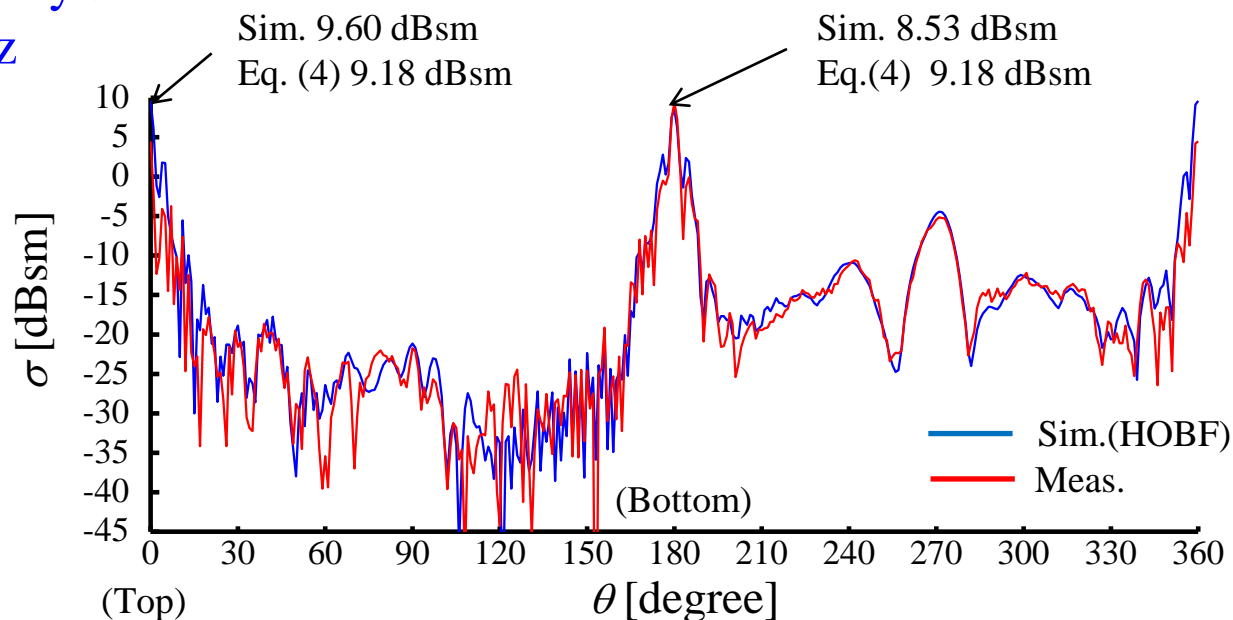
# Calculated and measured results

Vertical plane  
V-pol.

Frequency :  
18 GHz



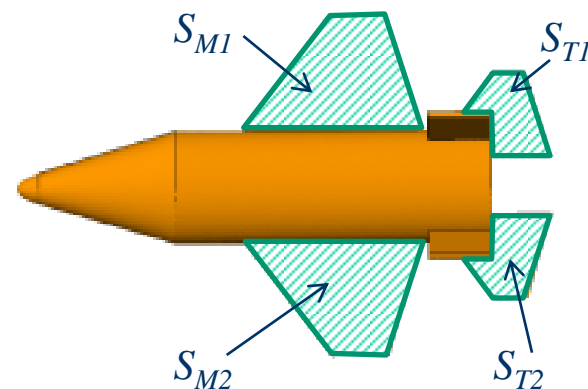
Measurement coordinates



Theoretical  $\sigma$  values

Theoretical equation  
(a flat plate)  $\sigma = \frac{4\pi S^2}{\lambda^2}$  (4)

Position	Symbol	Area [m <sup>2</sup> ]	$\sigma$ [dBsm]
Main wing + Tail wing	$S_{M1} + S_{M2}$ + $S_{T1} + S_{T2}$	0.01352	9.18

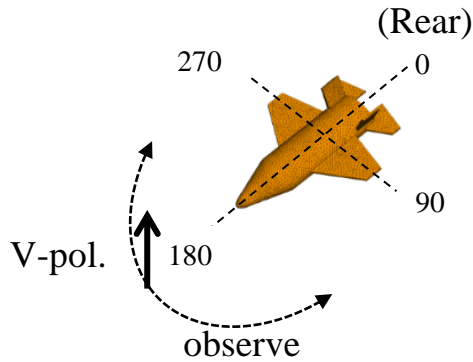


Main wing and tail wing are  
almost equal to a flat plate.

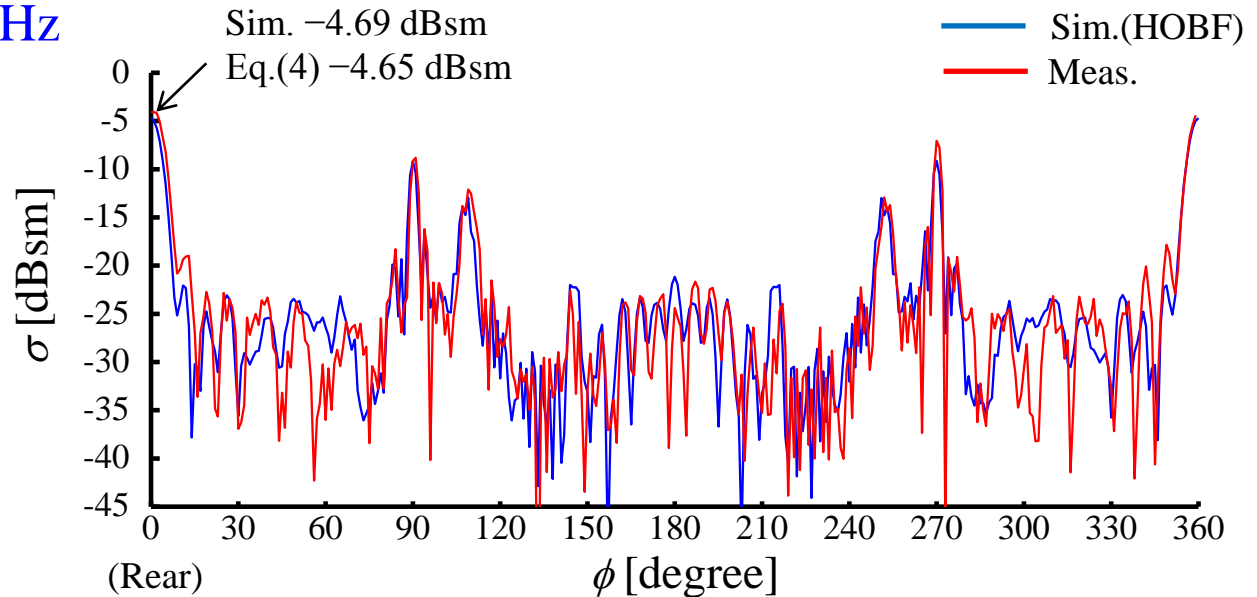
In very large dynamic range, RCS can  
be correctly estimated.

# Calculated and measured results

Horizontal plane  
V-pol. Frequency :  
18 GHz



Measurement coordinates

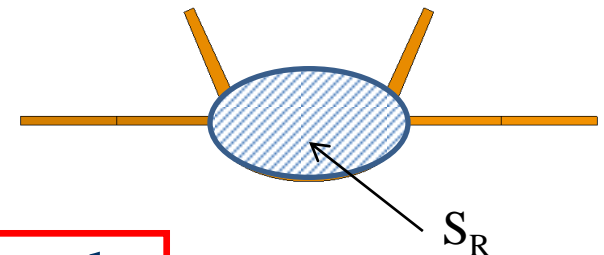


Theoretical  $\sigma$  values

Theoretical equation  
(a flat plate)

$$\sigma = \frac{4\pi S^2}{\lambda^2} \quad (4)$$

Position	Symbol	Area [m <sup>2</sup> ]	$\sigma$ [dBsm]
Rear end	$S_R$	0.00275	-4.65



Rear end is almost equal to a flat plate.

In very large dynamic range, RCS can be correctly estimated. 18 GHz corresponds to 380 MHz at the real object.

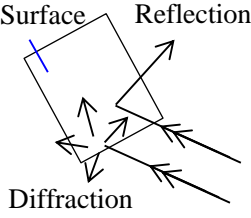
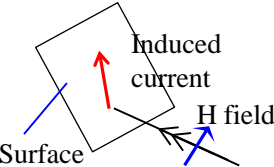
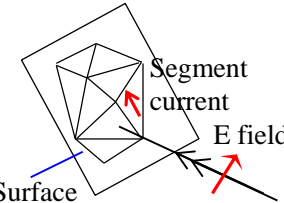
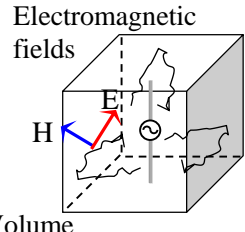
# Summaries

1. Actual calculation abilities were compared between MLFMM, HOBf and GO.
2. Calculated and measured values agree very well. Calculated RCS values are reliable.
3. GO method is suitable for calculation in higher frequency.
4. GO attained RCS calculation at 144 GHz that corresponds to 3 GHz at a real airplane.

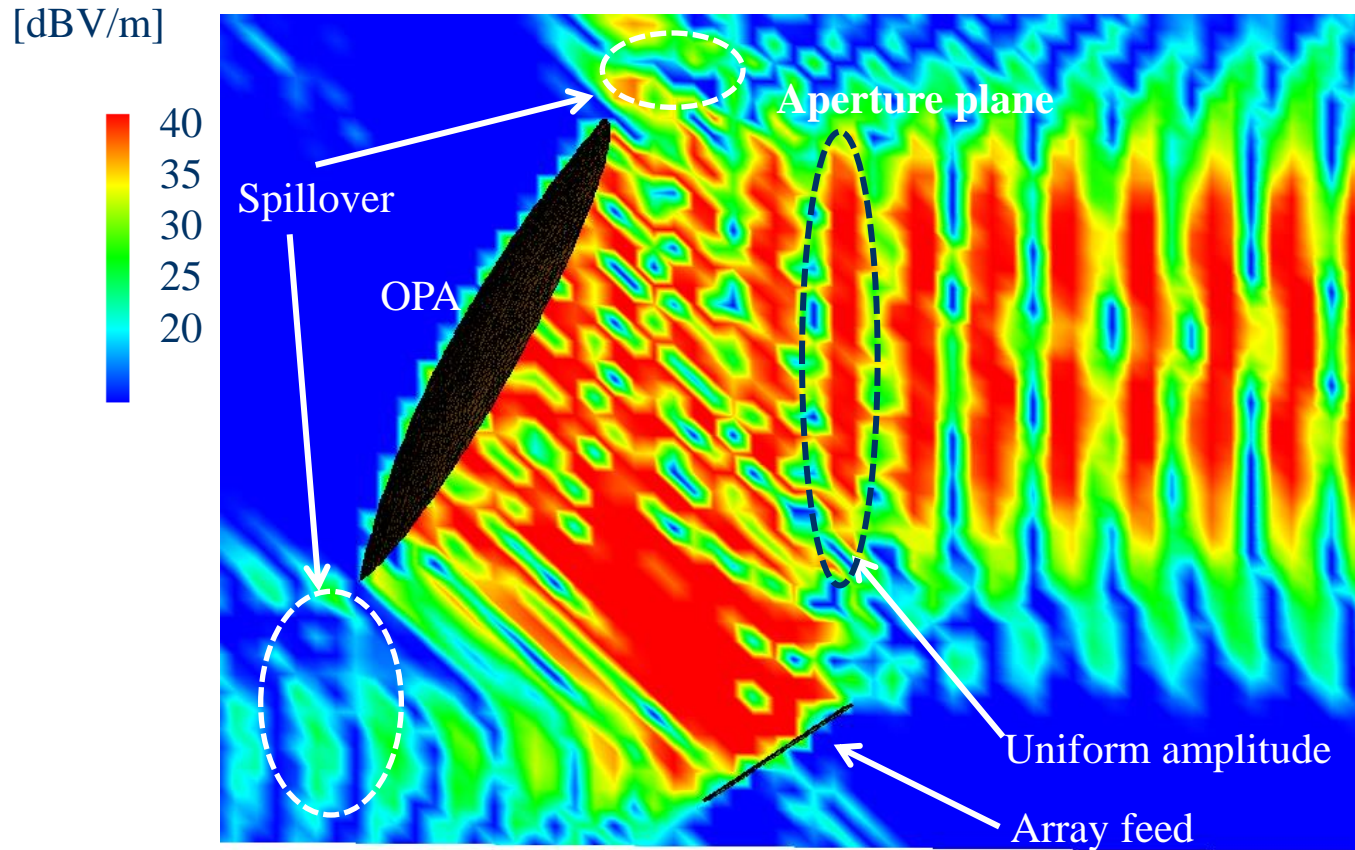
# **Notes for simulations and measurements**

- 1. Overview of simulation methods**
- 2. Simulation examples and notes**
- 3. Antenna measurement items**
- 4. Explanations of how to measure**
- 5. Notes for measurements**

# Overview of simulation methods

Method	Concept		Feature	Applicable objects	Examples
Geometrical optics (GO)		<ul style="list-style-type: none"> <li>▪ Reflection law</li> <li>▪ Diffraction law</li> <li>▪ Simple geometrical equations are used</li> </ul>	<ul style="list-style-type: none"> <li>▪ Calculation is very fast</li> <li>▪ Accuracies are not sufficient</li> </ul>	<ul style="list-style-type: none"> <li>▪ Smooth surfaces</li> <li>▪ Large objects</li> </ul>	<ul style="list-style-type: none"> <li>▪ Aperture antennas</li> </ul>
Physical optics (PO)		<ul style="list-style-type: none"> <li>▪ Induced currents of incident waves</li> <li>▪ Integral calculation give radiation characteristics</li> </ul>	<ul style="list-style-type: none"> <li>▪ Calculation is rather fast</li> <li>▪ Easily used by personal computers</li> </ul>	<ul style="list-style-type: none"> <li>▪ Smooth surfaces</li> <li>▪ Large objects</li> </ul>	<ul style="list-style-type: none"> <li>▪ Aperture antennas</li> <li>▪ Radar cross section</li> </ul>
Method of Moment (MoM)		<ul style="list-style-type: none"> <li>▪ Exact segment currents are calculated</li> <li>▪ Matrix equation should be solved</li> </ul>	<ul style="list-style-type: none"> <li>▪ High class personal computers</li> <li>▪ Large computer memory</li> <li>▪ Long calculation time</li> </ul>	<ul style="list-style-type: none"> <li>▪ All surface shapes</li> <li>▪ Very small objects</li> <li>Large objects</li> </ul>	<ul style="list-style-type: none"> <li>▪ All antenna structures</li> <li>▪ Radar cross section</li> </ul>
Finite Difference Time Domain (FDTD)		<ul style="list-style-type: none"> <li>▪ Maxwell's equations are directly solved</li> <li>▪ Exact electric and magnetic fields are calculated</li> </ul>	<ul style="list-style-type: none"> <li>▪ Very large computer memory</li> <li>▪ Long calculation time for convergence results</li> </ul>	<ul style="list-style-type: none"> <li>▪ Any volume structure</li> <li>▪ Not so large objects</li> </ul>	<ul style="list-style-type: none"> <li>▪ Complex structures</li> <li>▪ Human body</li> </ul>

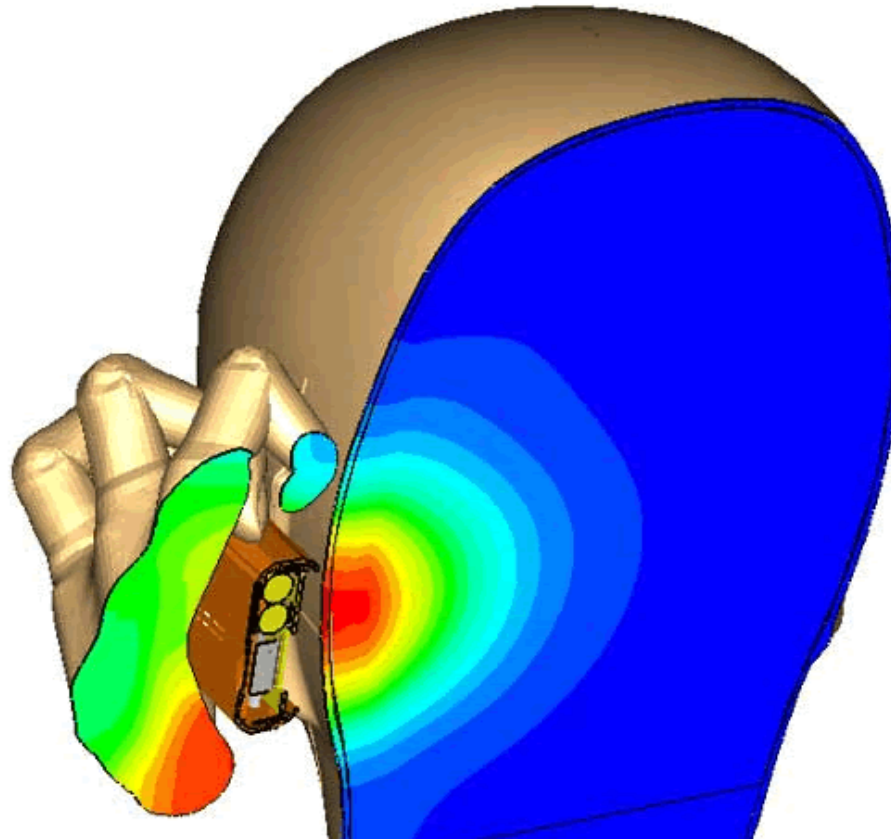
# An example of MoM simulation



- Electric field distributions of a reflector antenna with an array feed
- By radiation pattern synthesis of the array feed, a uniform electric field distribution is achieved on the antenna aperture



# An example of FDTD simulation



- Electric field penetration into a human head

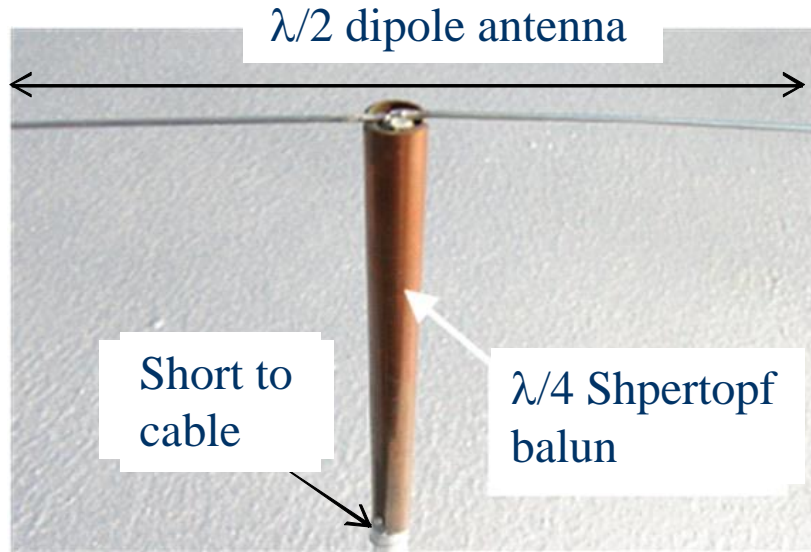
# Important notes for simulations

- Calculated results are **not necessarily correct**.
- Take care the adequateness of **calculation parameters**.
- Many **electrical components** should be calculated
- After **many corrections**, correct results are obtained.
- Electromagnetic simulations **reveal new antenna physics**.

# **Main items in antenna measurement**

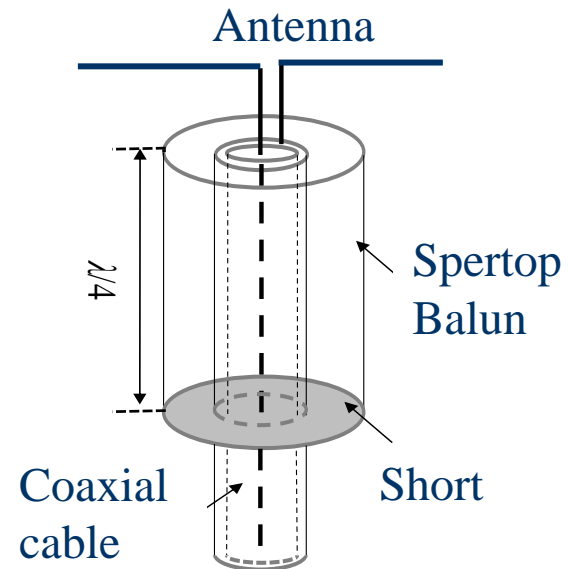
- 1. Antenna feed**
- 2. Input impedance**
- 3. Transmission parameters**
- 4. Radiation and ohmic resistances**
- 5. Directivity**
- 6. Antenna gain**
- 7. Axial ratio**

# Antenna feed structure



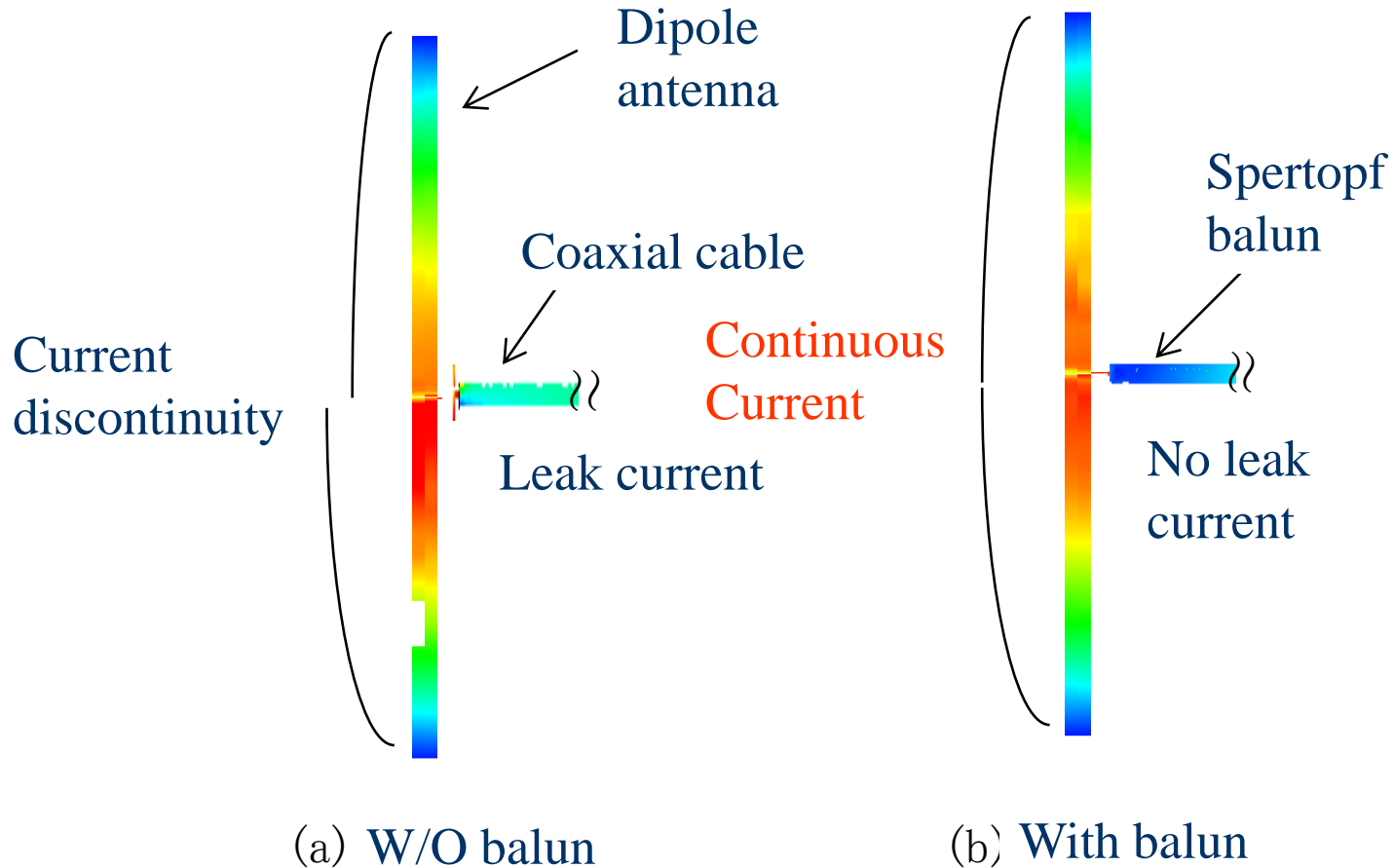
## Coaxial cable feed

$\lambda/2$  dipole antenna is important antenna. This is used as a standard gain antenna.



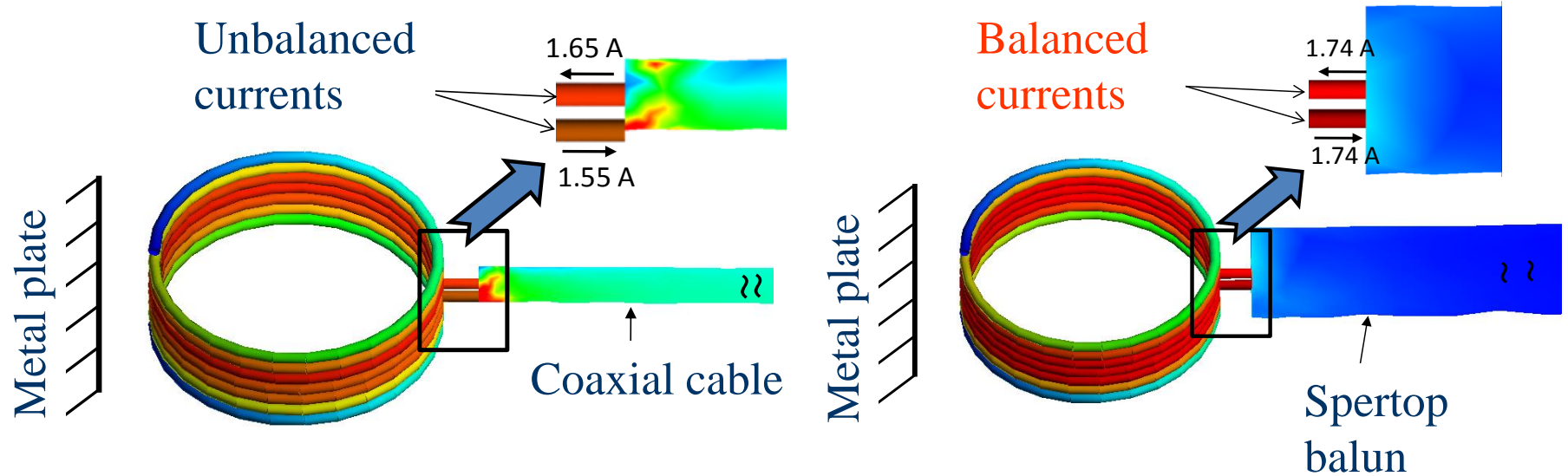
## Structure of Spertop balun

# Effects of Spertop balun



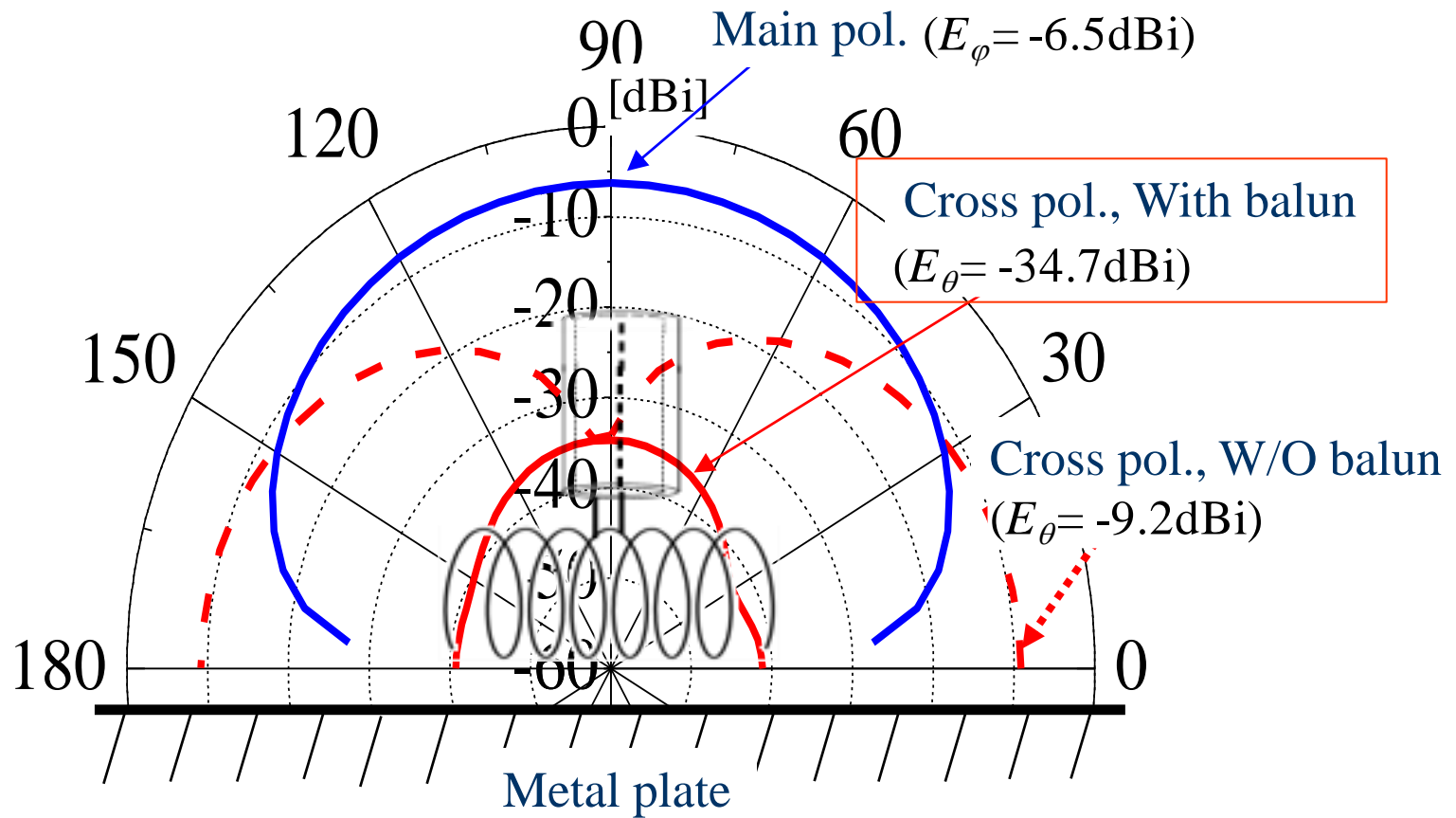
Purpose of spertop balun is to **suppress leakage currents** on a feed cable.

# Effects of Spertop balun



To suppress leakage currents on a feed cable is especially important in a very small antenna.

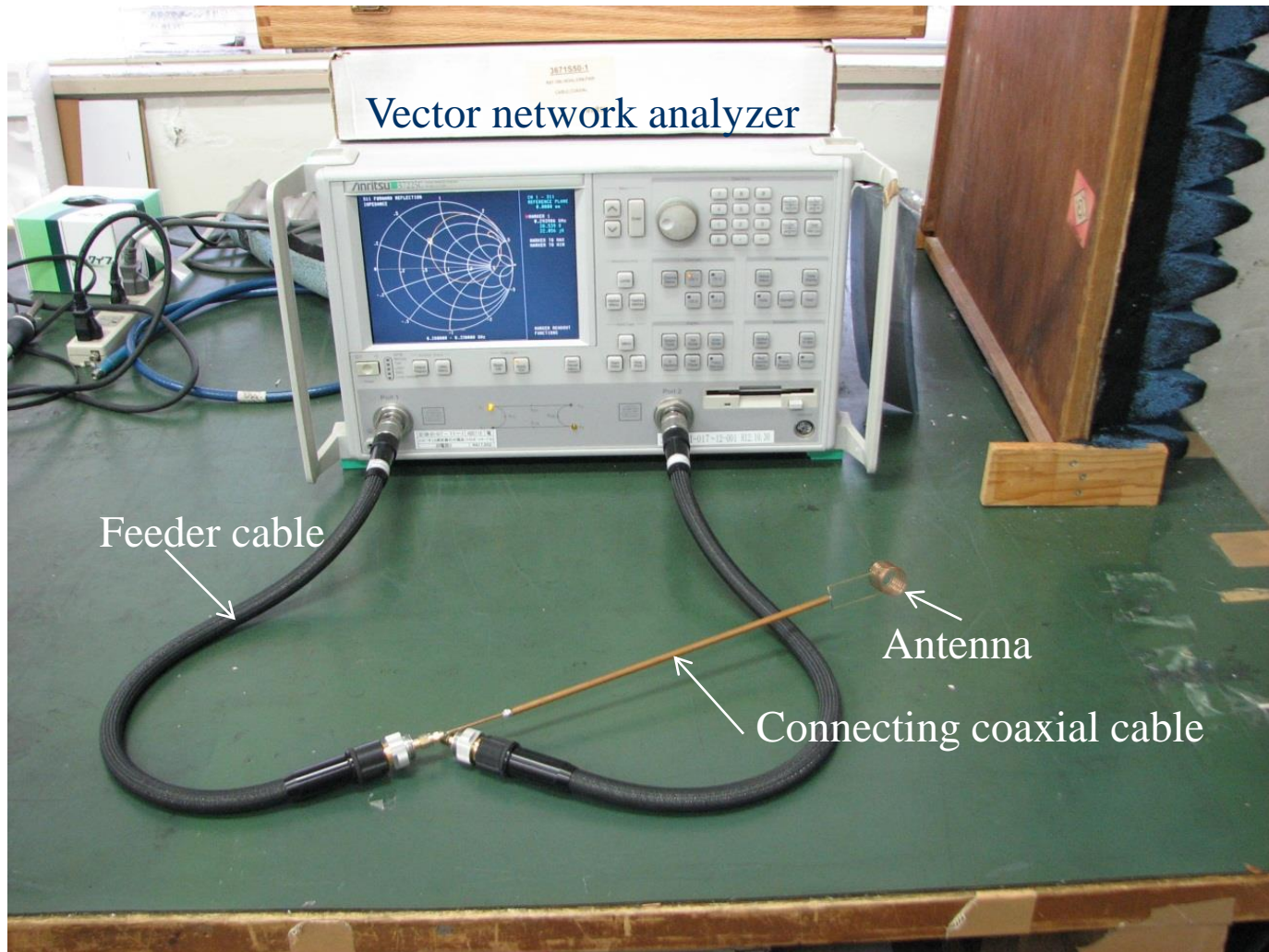
# Effects of Spertop balun



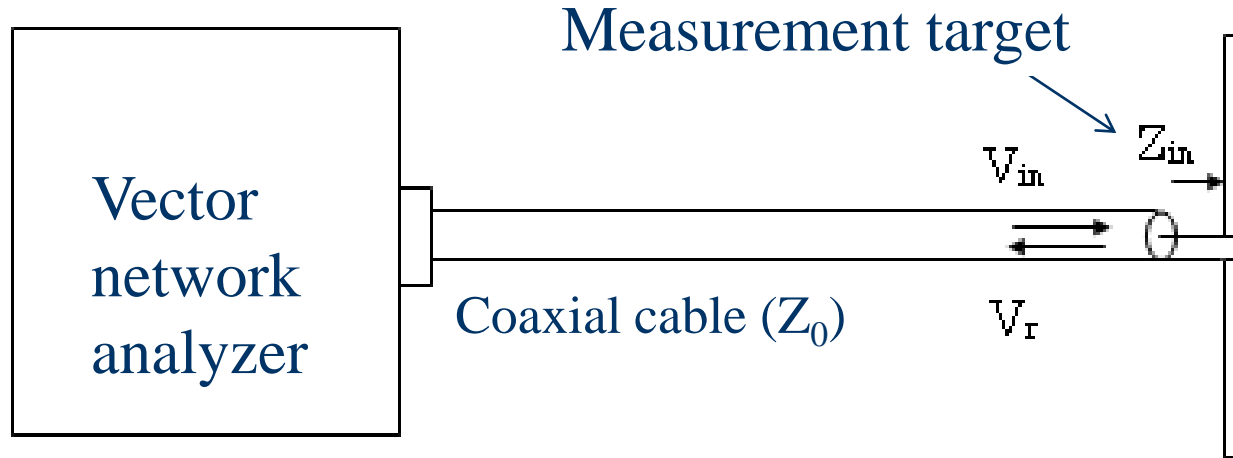
Radiation pattern change



# Impedance measurement system



# Measurement principle

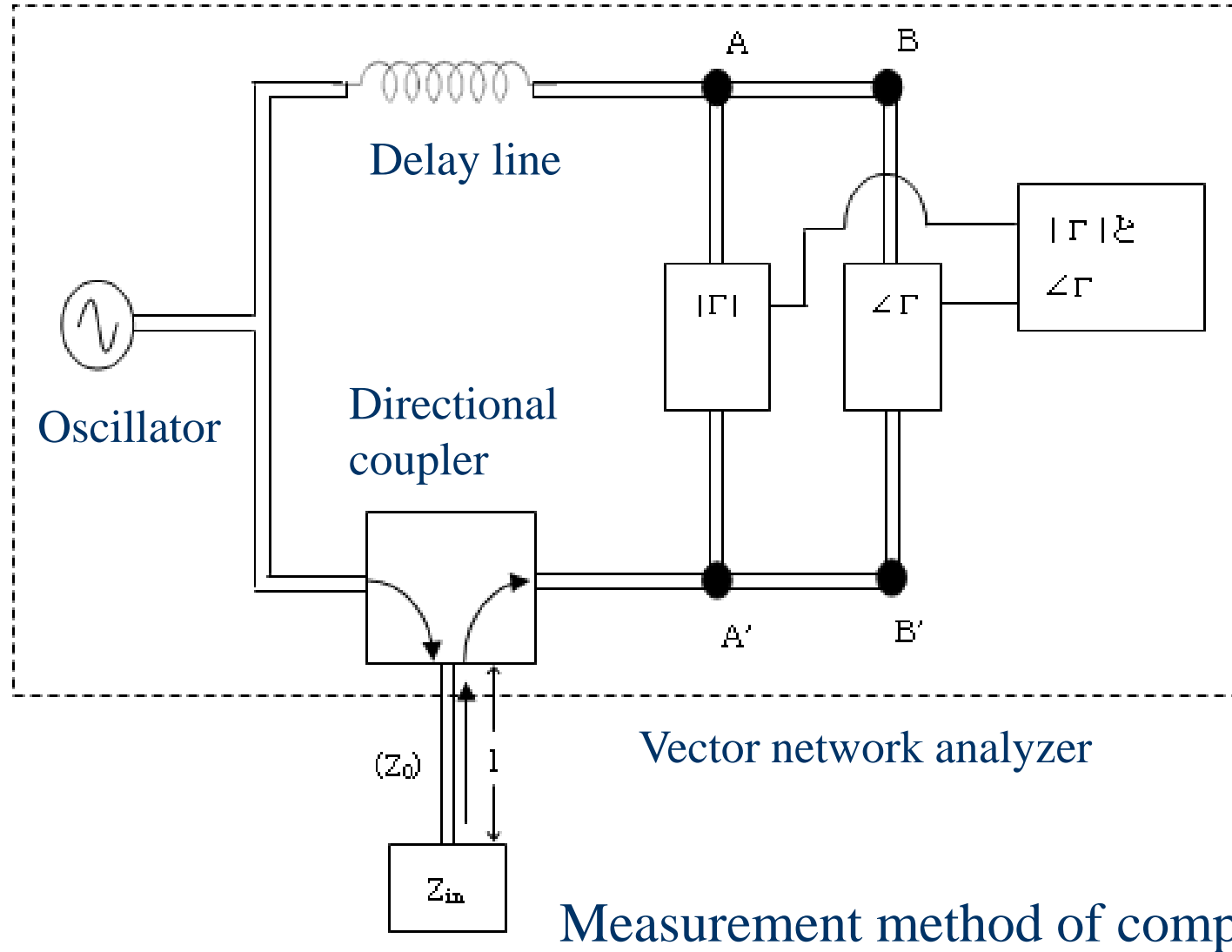


## Test antenna and VNA

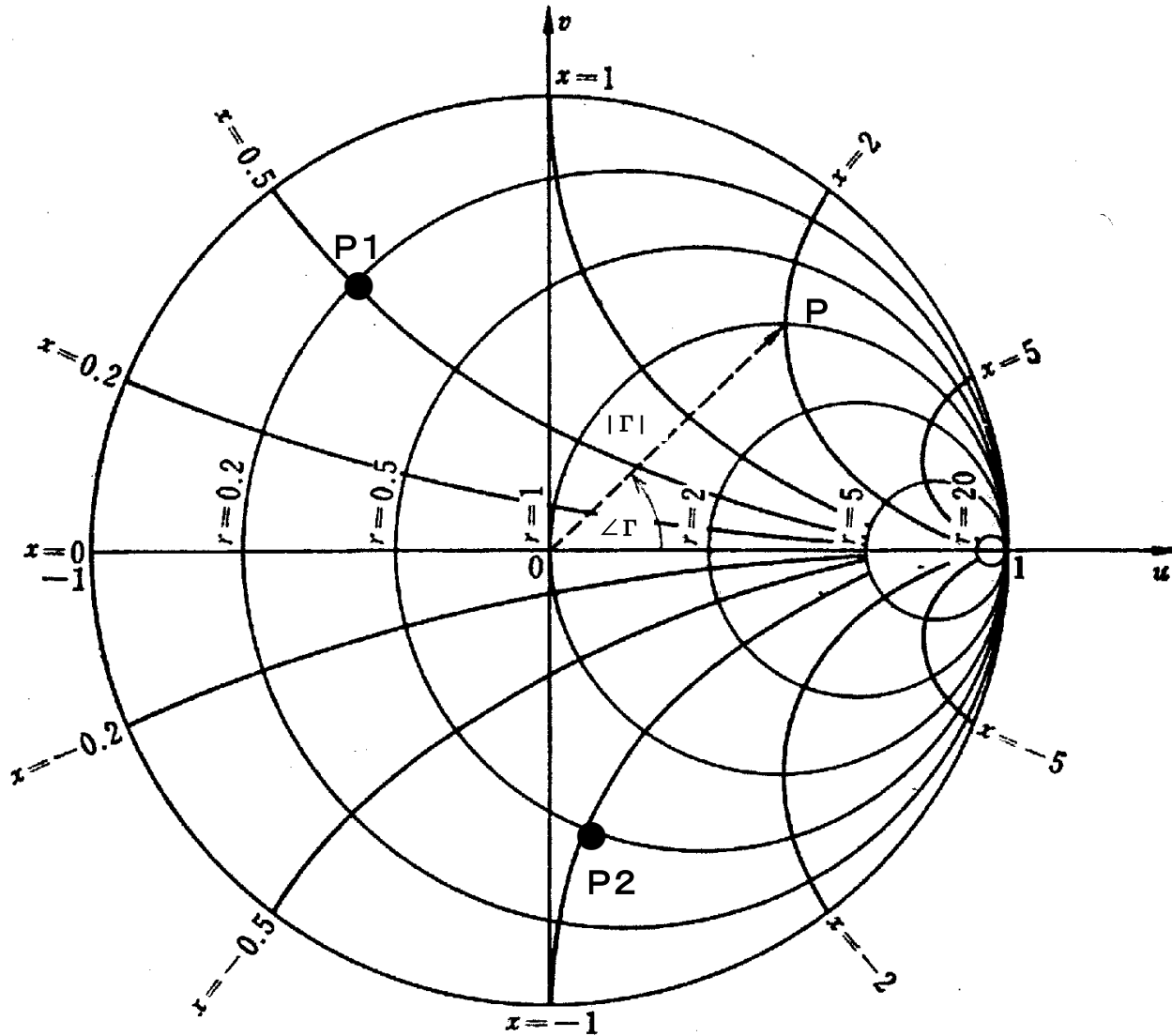
Measure the complex reflection coefficient ( $\Gamma$ )

$$\Gamma = \frac{V_r}{V_{in}} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

# Principle of Vector Network Analyzer



# Smith chart

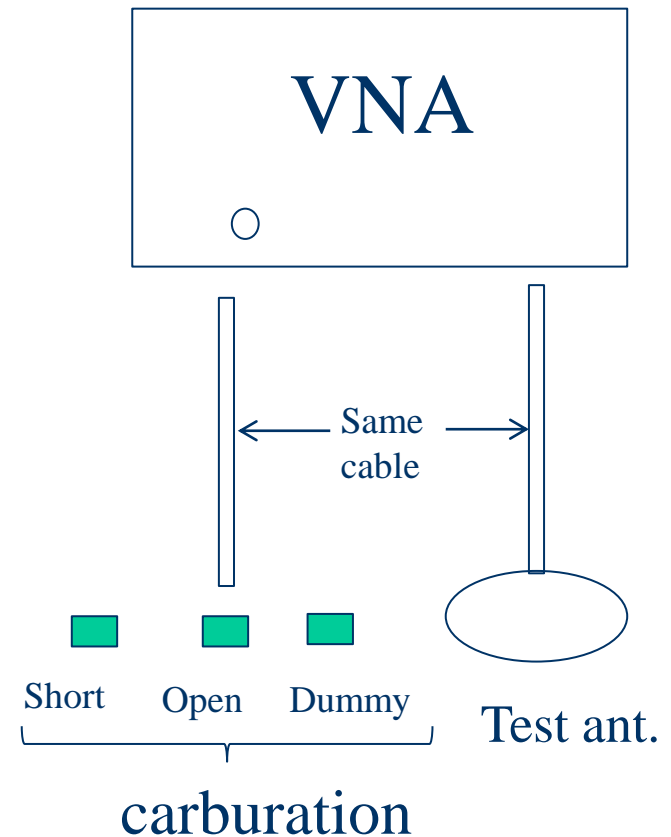


$Z_{in}$  is expressed  
by  $r$  and  $x$

$$Z_{in}/Z_0 = r + jx$$

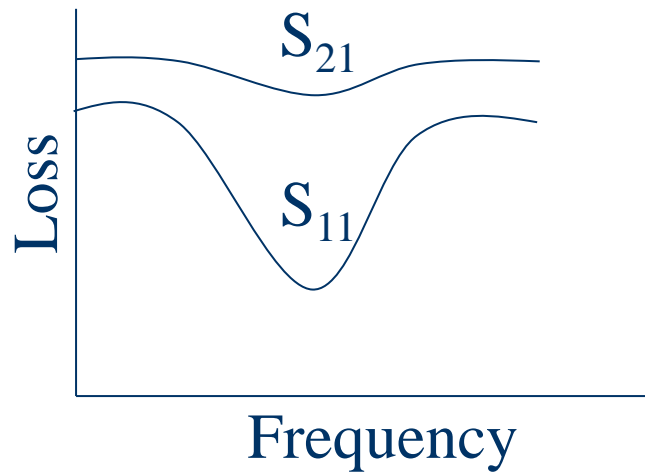
# Impedance measurement

- (1) At the calibration, the same coaxial cable should be used.
- (2) Touch antenna to ensure activation.
- (3) Impedance matching may be made to different parts from antenna.

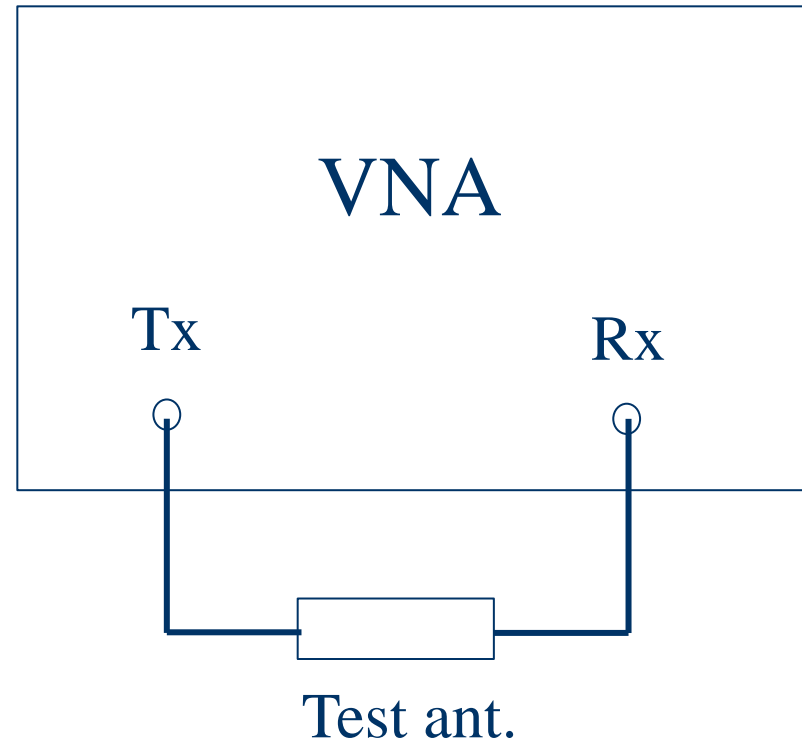


# Transmission parameters

$S_{21}$  is measured



Measured results



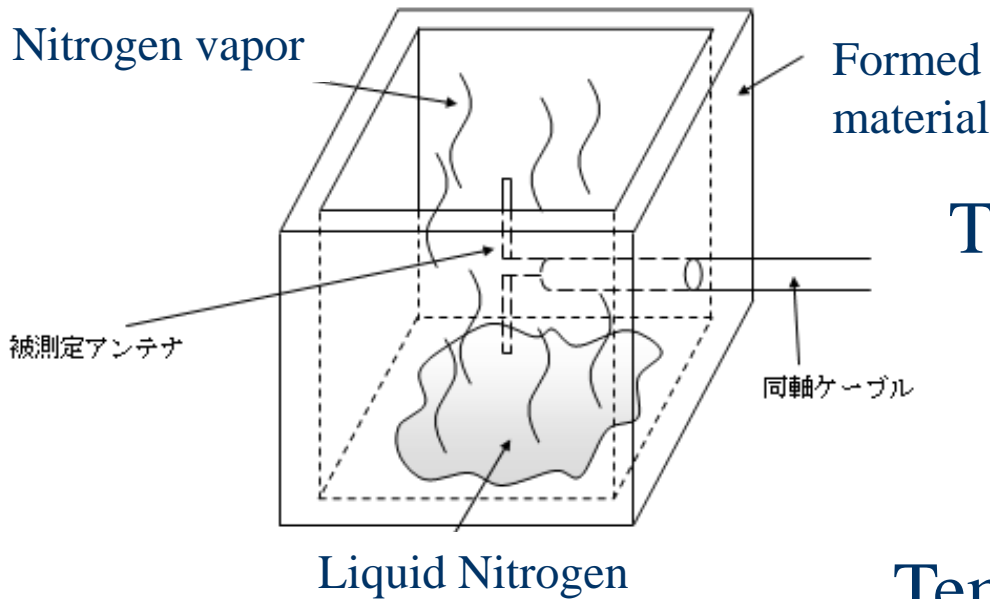
Measurement setup

# Resistance measurement

Input resistance ( $R_{in}$ )

$$R_{in} = R_r + R_l$$

$\nwarrow$  Radiation resistance       $\swarrow$  Ohmic resistance



Measured setup of  $R_1$

Temperature dependence

$$R_{in}(T) = R_r + R_l(T)$$

$$R_{in}(T_R) - R_{in}(T_C) = R_l(T_R) - R_l(T_C)$$

Room                  Cooled

Temperature dependence of  $R_l$

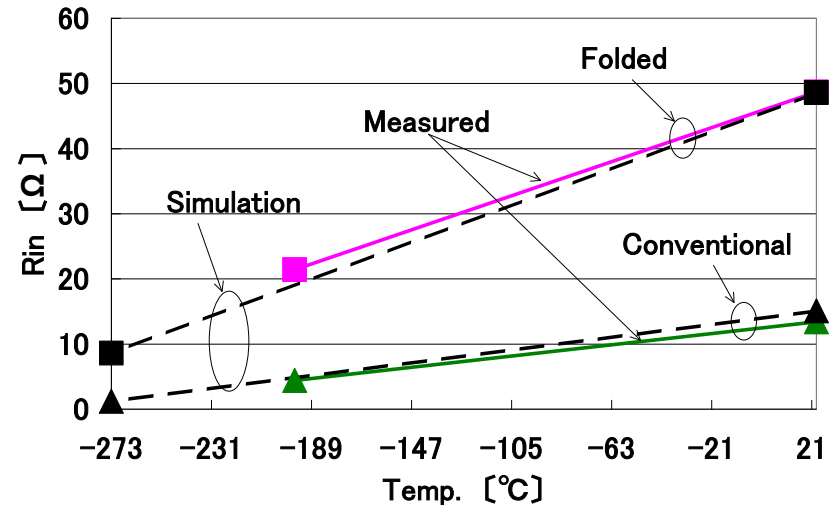
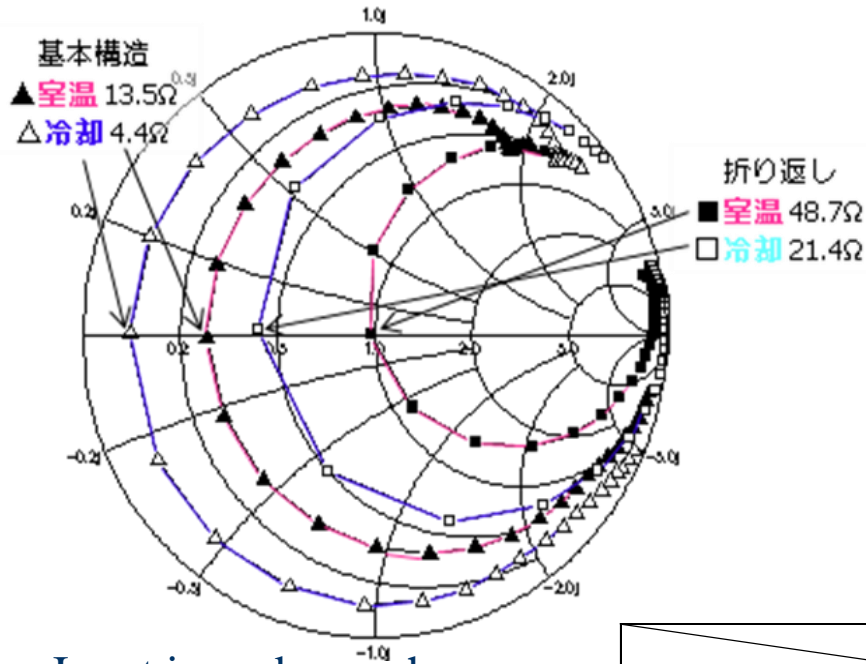
$$R_l(T_C) = \alpha R_l(T_R)$$

Measured result of  $R_l$

$$R_l(T_R) = \frac{R_{in}(T_R) - R_{in}(T_C)}{1 - \alpha}$$

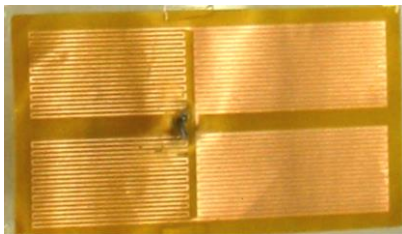


# Resistance measurement



Measured temperature

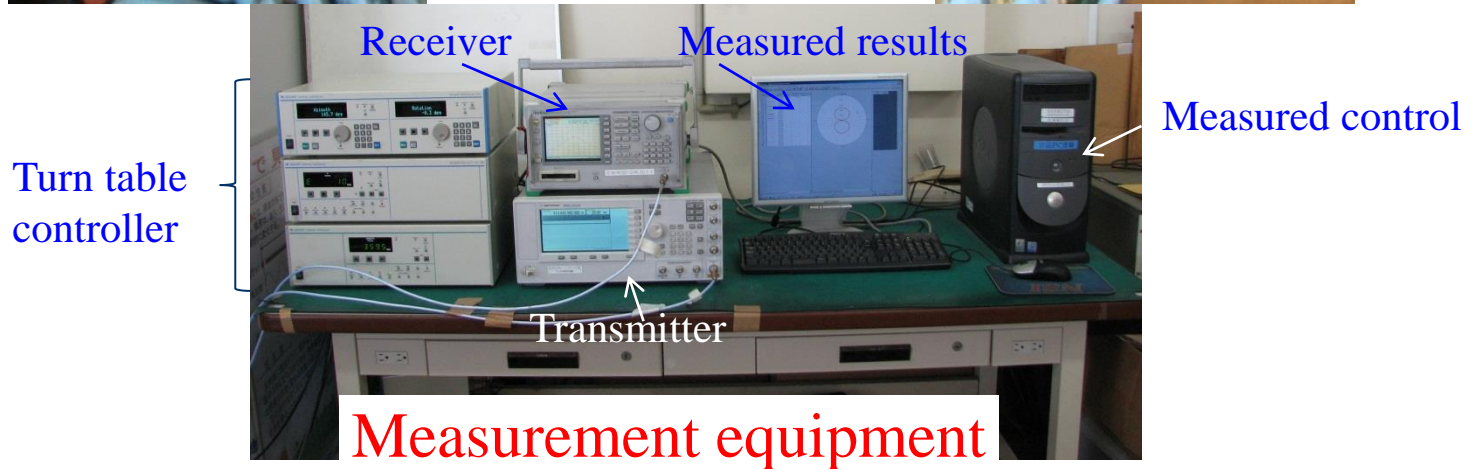
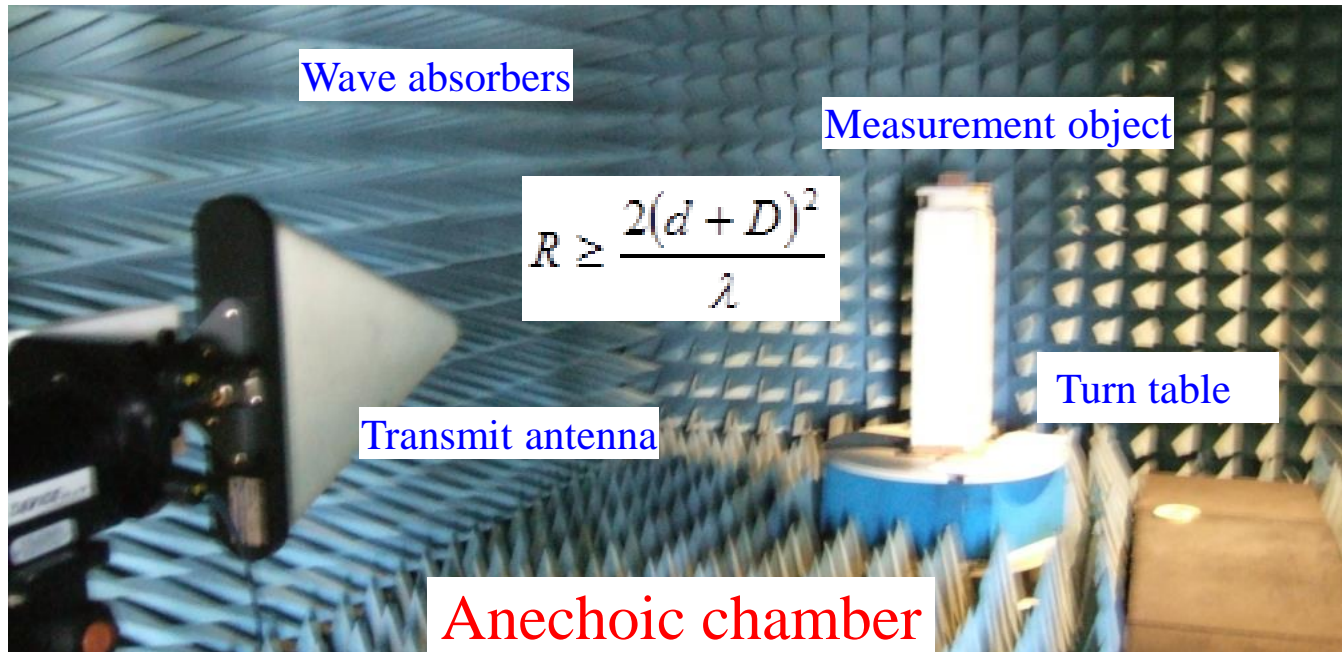
Input impedance changes



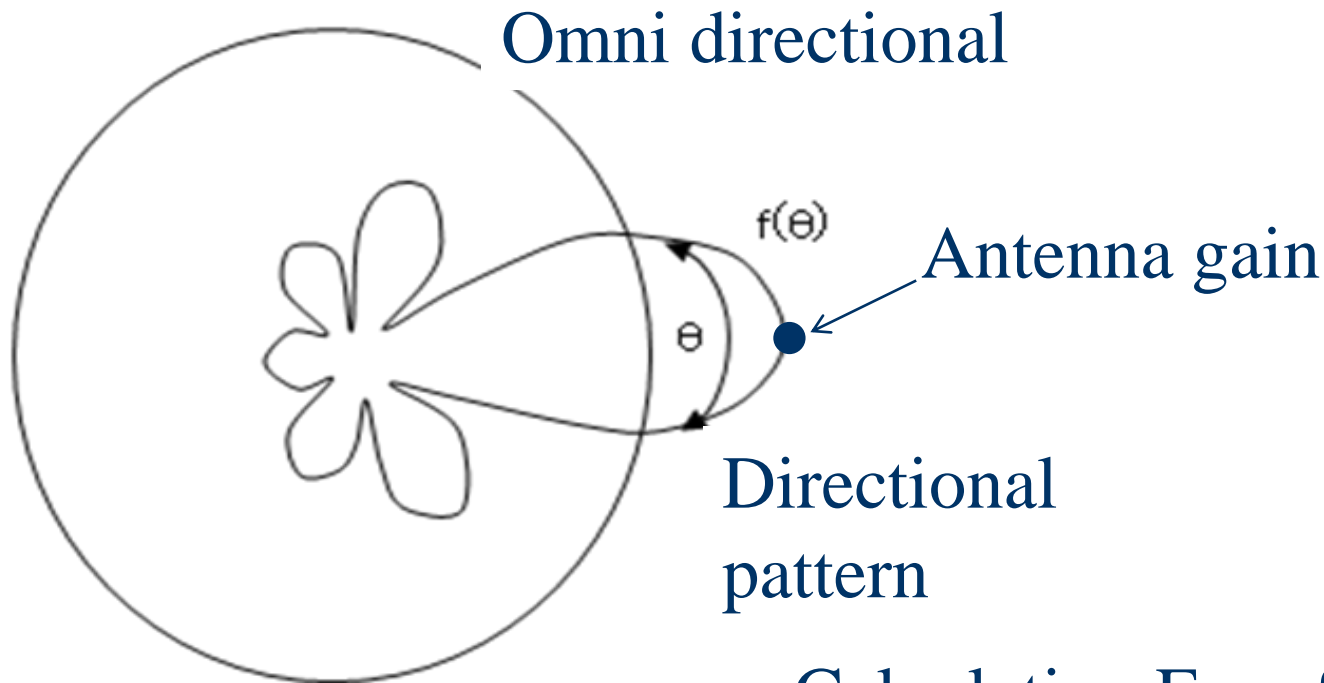
Test antenna

			Measurement	Simulation
			$R_{in} (R_r + R_l) [\Omega]$	
Input resistances	Conventional	Room Temp.	13.5(3.3+ 10.2)	15.1 (1.2+ 13.9)
		Cooled	5.0	
	Folded	Room Temp.	48.7(15.8+ 32.9)	48.6 (8.6+ 40.0)
		Cooled	21.4	

# Radiation pattern measurement system



# Directivity measurement



Calculation Eq. of antenna gain

$$G_D = \frac{|f(\theta_0, \phi_0)|^2}{\frac{1}{4\pi} \int_0^{2\pi} d\phi \int_0^\pi |f(\theta, \phi)|^2 \sin \theta d\theta}$$

# Antenna gain

## Three antenna method

Use three antennas and measure three times

$$\begin{cases} Pr1 = Pt + Gt1 + Gr2 + Ls + La \\ Pr2 = Pt + Gt2 + Gr3 + Ls + La \\ Pr3 = Pt + Gt3 + Gr1 + Ls + La \end{cases}$$

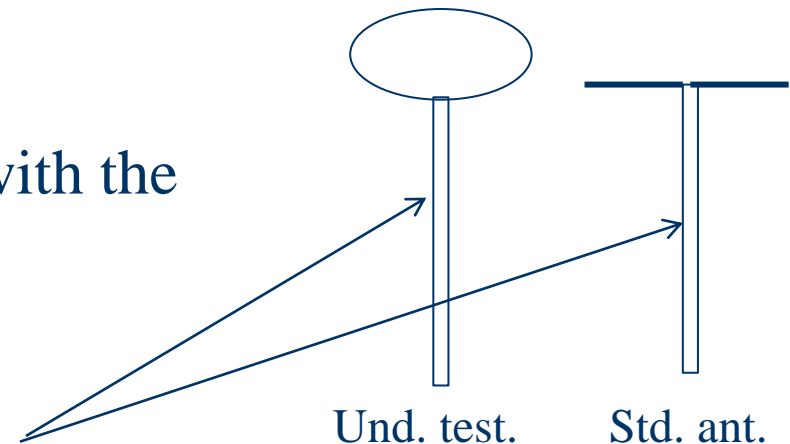
To make three antennas is not realistic.

## Comparison method

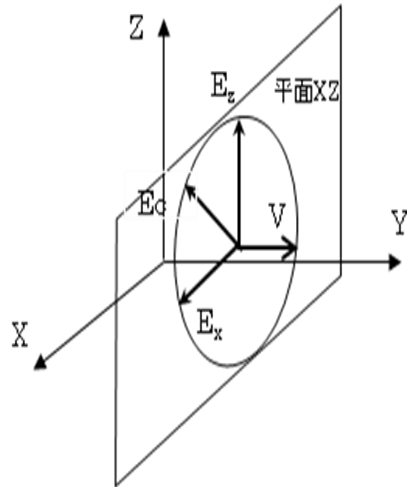
Compare the received level with the  
**standard gain antenna.**

The most convenient method

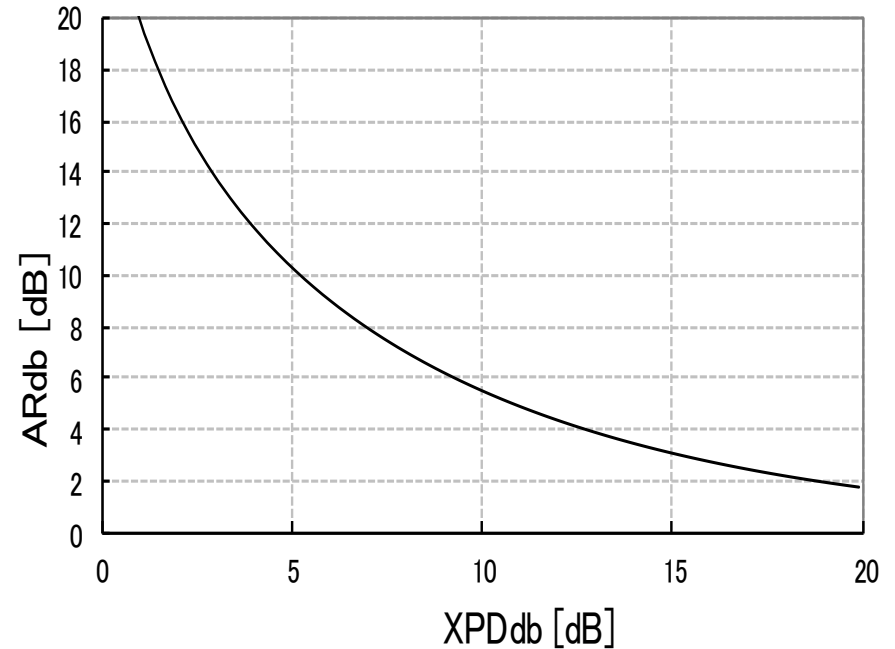
Use the same coaxial cable.



# Axial ratio concept

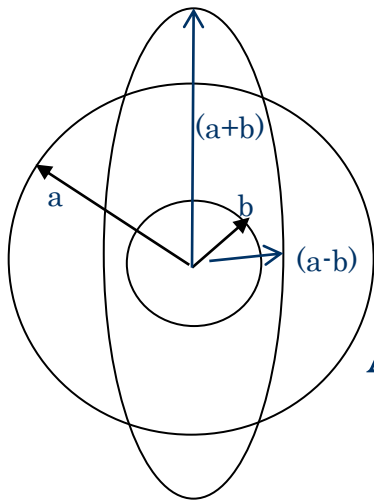


Circular polarization



Axial ratio and cross rotation ratio

$$\text{XPD} = a / b$$



Long axis

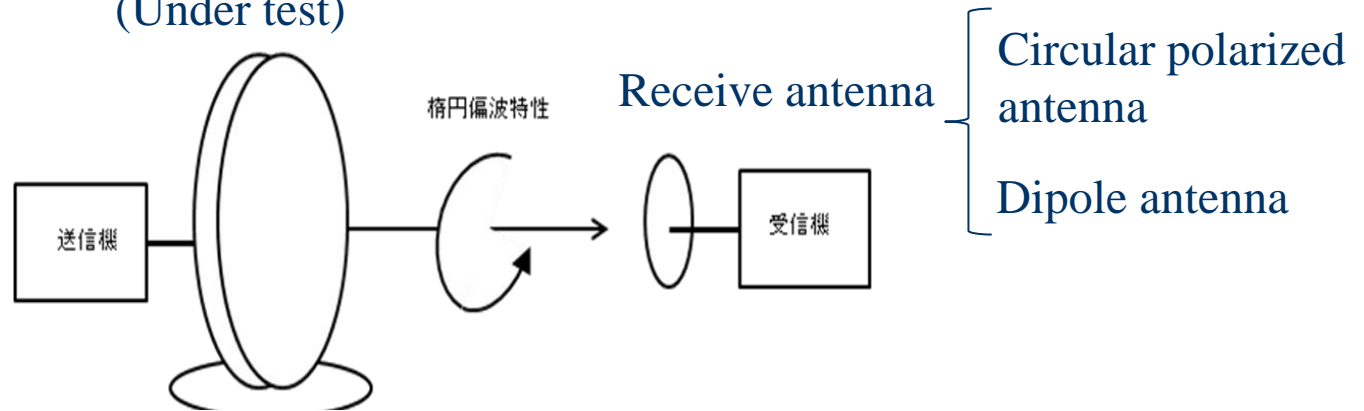
$$\text{Axial ratio} = (a+b)/(a-b)$$

Short axis

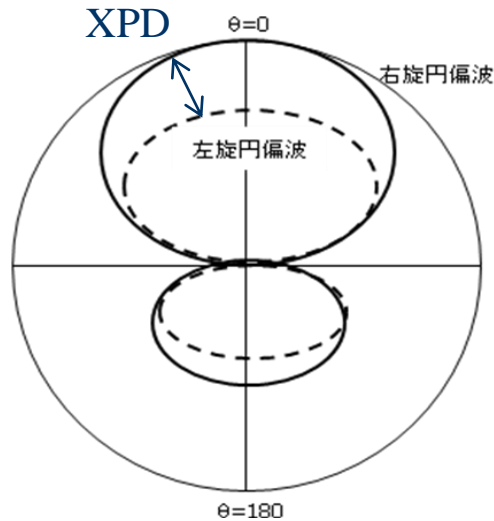
Expression by two rotational polarizations

# Axial ratio measurements

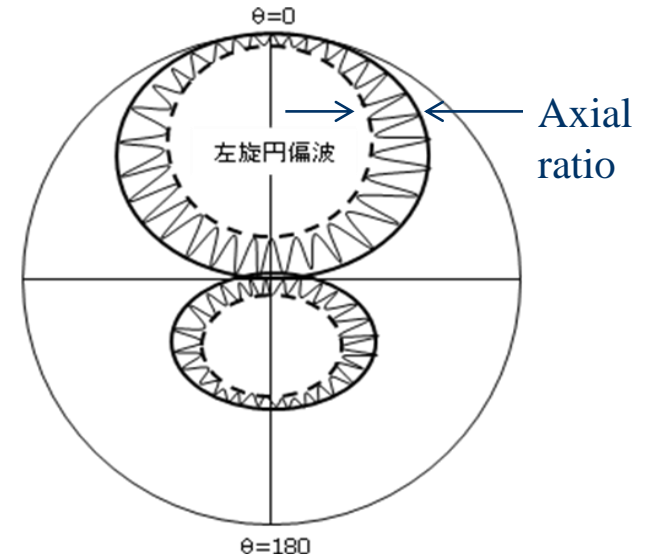
Circular polarized antenna  
(Under test)



Measurement setup



Right and left rotation polarizations



Dipole antenna rotation

# Notes for measurements

- Be very careful for **reliability** of measured results.
- Compare with **calculated** results.
- **Check** whether measured data is that of the **objective target**.
- **Touch** the target and watch data change.
- **Differences** of measured and calculated results may give a hint of **new phenomena**.



# Conclusion

- Many interesting **subjects are buried in the antenna fields.**
- In order to find out the treasure, we must **make efforts by ourselves.**
- In antenna researches, simulation and measurement **abilities** are requested.
- I'm expecting that many person **feel interest in antenna researches.**