International Summer School in Wireless Power Transmission for Space Applications

23-26 June 2014, Aveiro Portugal

Wireless Power Transmission for Sustainable Electronics

WIPE COST IC1301

Directing and Focusing Electromagnetic Waves using Leaky and Travelling Wave concepts for Wireless Power Transmission

José Luis Gómez-Tornero[1] and George Goussetis[2]

Technical University of Cartagena (Spain)

HERIOT WATT UNIVERSITY

Wednesday, June 25th, 11:30-13:00

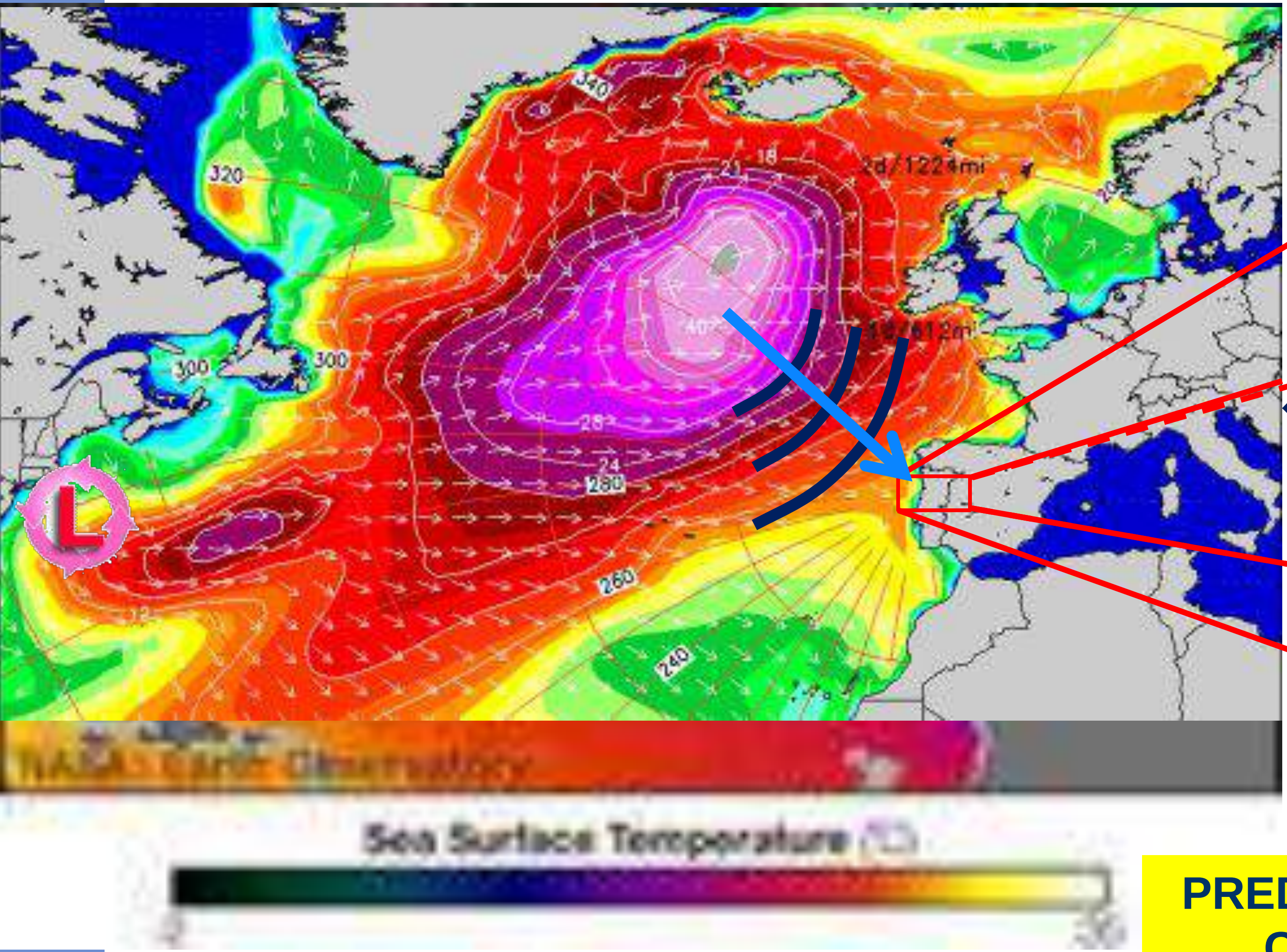
UPCT- Cartagena (Carthago-nova)

HERIOT WATT UNIVERSITY

Technical University of Cartagena (Spain)

AVEIRO AND THE WAVES...

PREDOMINATING NORTH ATLANTIC LOW PRESSURE



PREDOMINATING SWELLS COMING FROM NW

AVEIRO AND THE WAVES...

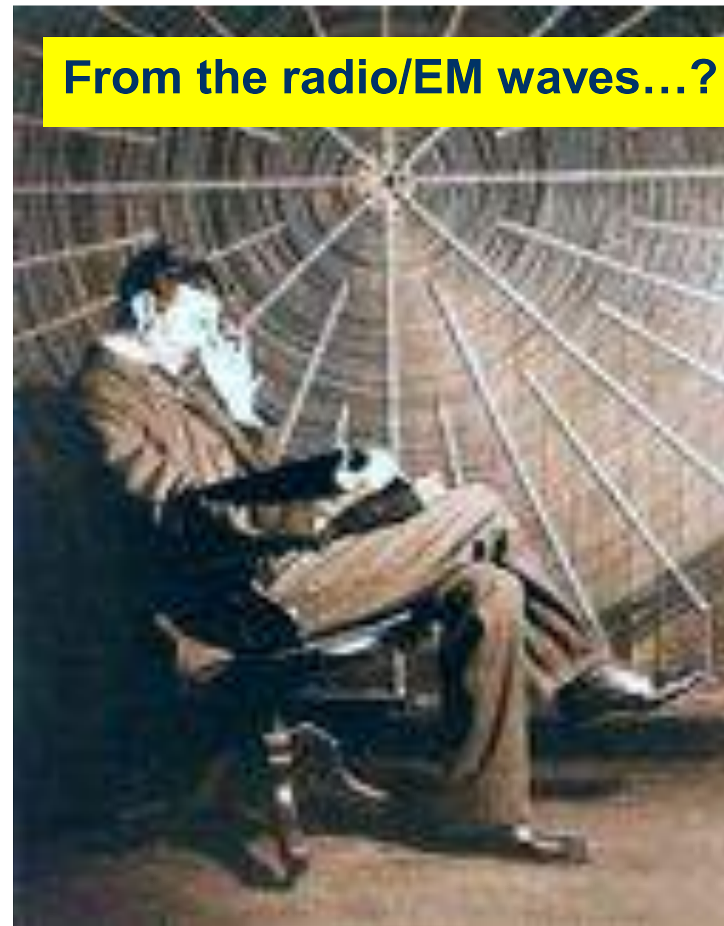
AVEIRO AND THE WAVES...

AVEIRO AND THE WAVES...

From the ocean waves…?

How to harvest the energy from the waves…?

From the radio/EM waves…?



From the wind waves…? light waves… ?

Directing and Focusing Electromagnetic Waves using **Leaky and Travelling Wave concepts** for **Wireless Power Transmission**

1- Wireless Power Transmission.

2- Travelling-Wave and Leaky-Wave (LW) Concepts.

3- LW Radiation Control and Far/Near-field focusing.

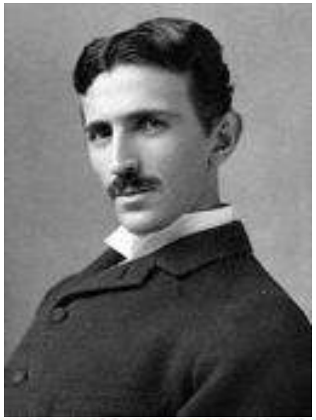
OUTLINE

1- Wireless Power Transmission.

2- Travelling-Wave and Leaky-Wave (LW) Concepts.

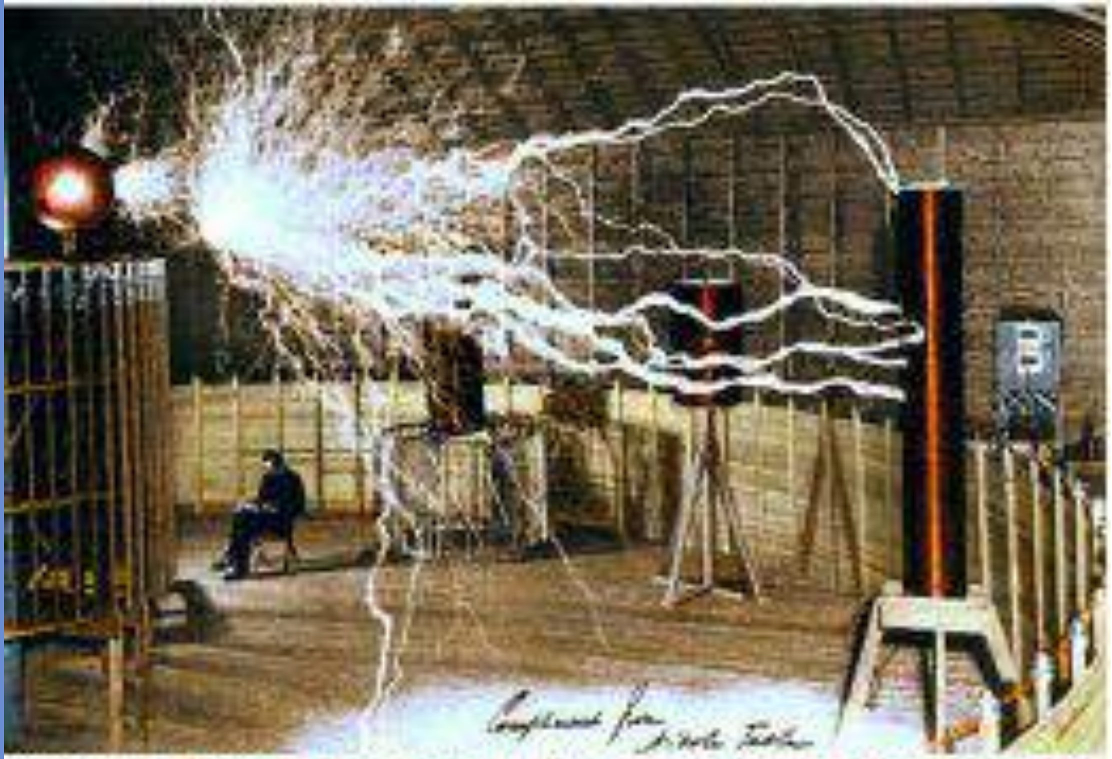
3- LW Radiation Control and Far/Near-field focusing.

1- Wireless Power Transmission.



“Wireless Power Transmission” Especial Issue of IEEE Microwave Magazine vol.14, no.2 March 2013

Nikola Tesla, 1856 –1943



Nikola Tesla sitting in his laboratory in Colorado Springs in December 1899

Nikola Tesla's Wardenclyffe lab building, seen in 1904

1- Wireless Power Transmission.

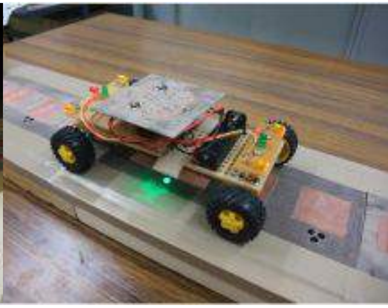
Three different mechanisms for WPT:

1- Conduction :
(plasma arcs – conducting current "breaking" the air)

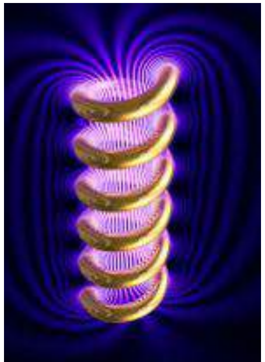
Tesla coils **:**

2- Induction :
(reactive near field coupling)

2.1- Capacitive



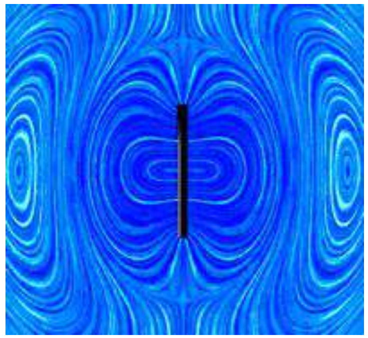
2.2- Inductive
- **"direct" coupling**
- **resonance-based**

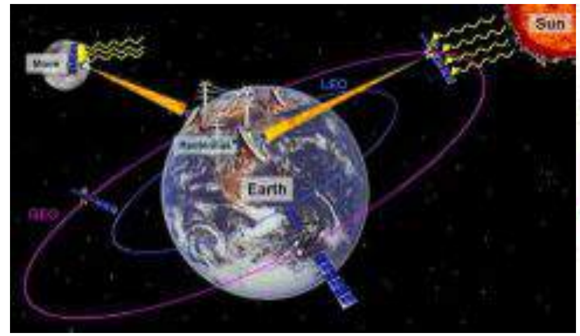


1- Wireless Power Transmission.

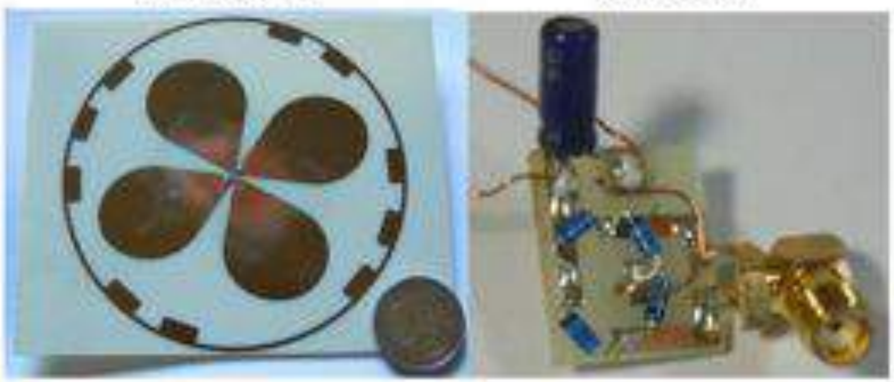
Three different mechanisms for WPT:

3- Radiation :
(radiative coupling)

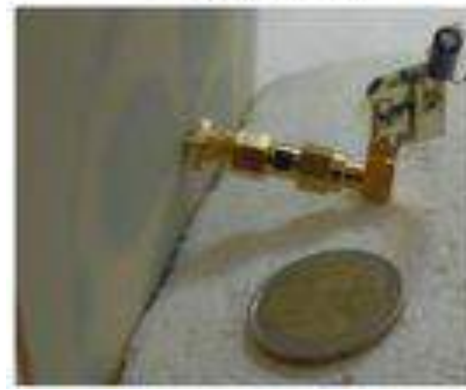




Antenna Rectifier



Rectenna



3.1- Far-field focusing

3.2- Near-field focusing

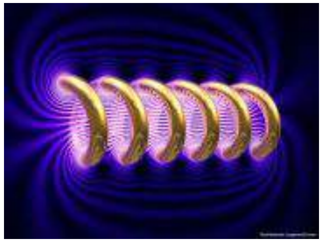
DO NOT CONFUSE !
- **REACTIVE NEAR-FIELD COUPLING / RESONANCE**
- **RADIATIVE MICROWAVE TRANSMISSION USING NEAR-FIELD FOCUSING TECHNIQUES**

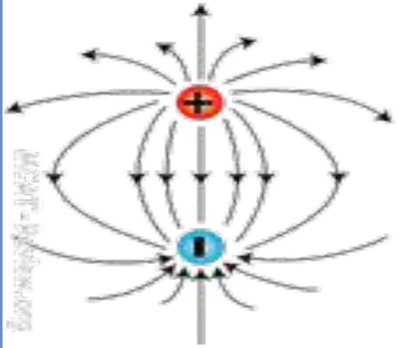
1- Wireless Power Transmission.

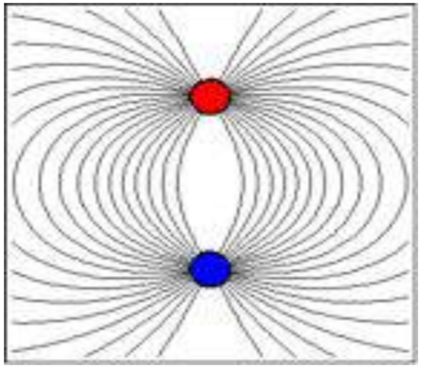
DO NOT CONFUSE !

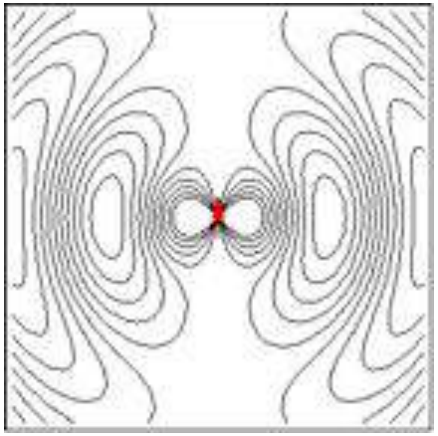
REACTIVE NEAR-FIELDS (STORED ENERGY)

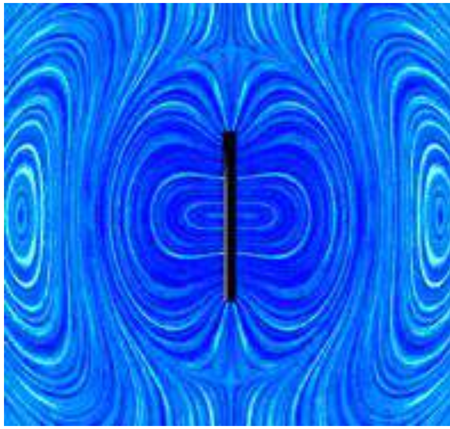
RADIATIVE FIELDS (RADIATED ENERGY)











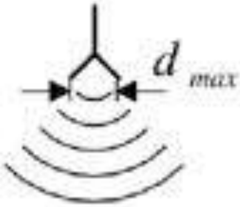
radiated fields exists even if the source disappears…
(we can see stars which do no exist since they disappeared M years ago)

1- Wireless Power Transmission.

DO NOT CONFUSE !

REACTIVE NEAR-FIELDS (STORED ENERGY)	**RADIATIVE FIELDS (RADIATED ENERGY)**

Radiation Regions



- **Reactive Near Field / Rayleigh Region**

  Reactive components of the EM field are dominating,
  strong radial dependency

$$r = 0.62\sqrt{\frac{d_{max}^3}{\lambda}}$$

- **Radiating Near Field / Fresnel Region**

  Still strong reactive components, radiated field is dominating,
  strong radial dependency (transition zone)

$$r = 2\frac{d_{max}^2}{\lambda}$$

- **Far Field / Fraunhofer Region**

  E- and H-field components are in phase (Plane Wave)

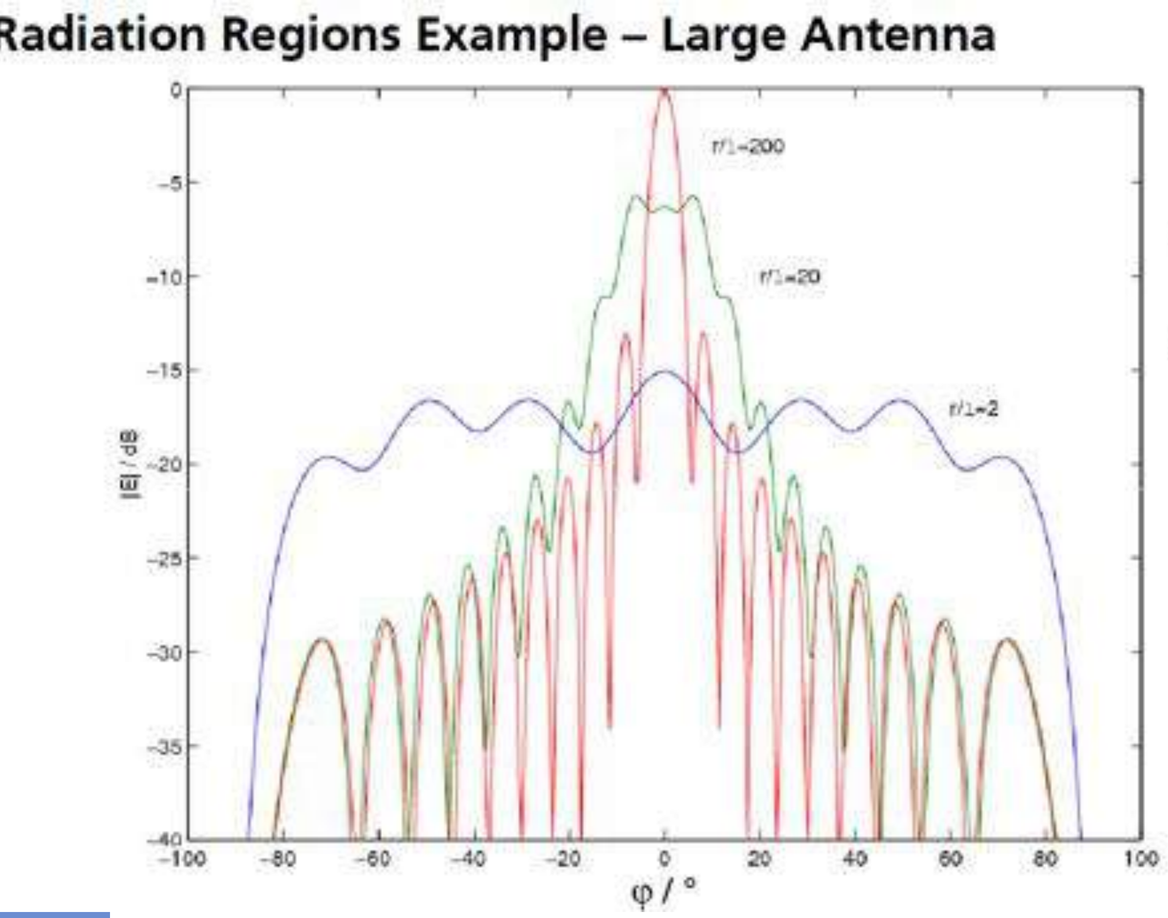
  Effective components of the EM field are dominating (Real Power),
  small radial dependency

max. extension of the antenna: d_{max}

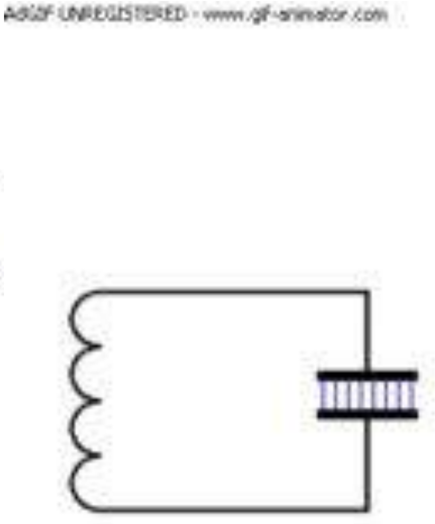
1- Wireless Power Transmission.

DO NOT CONFUSE !

REACTIVE NEAR-FIELDS (STORED ENERGY)	RADIATIVE FIELDS (RADIATED ENERGY)



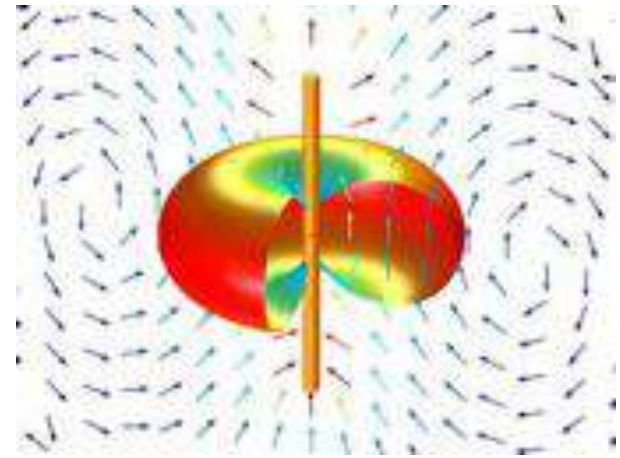
Antenna with $d_{max} = 10\lambda$

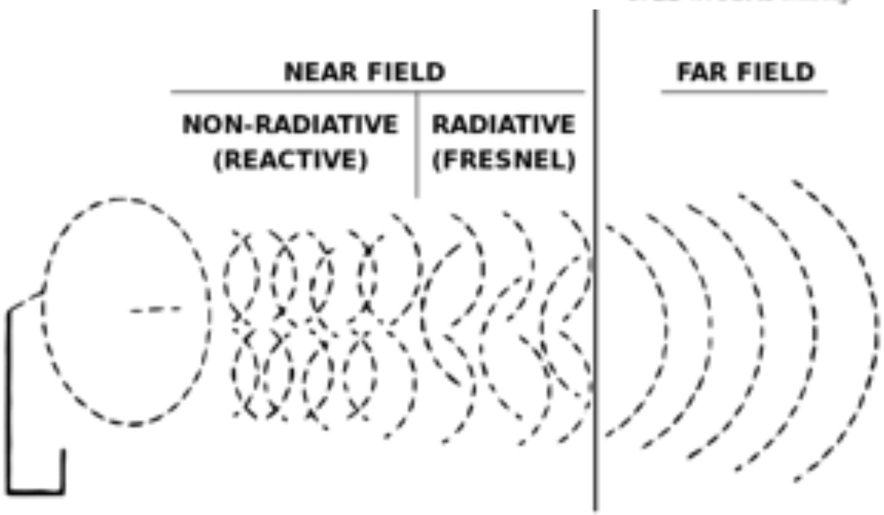


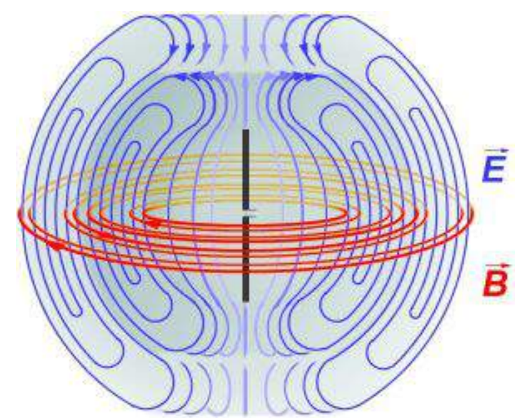
1- Wireless Power Transmission.

DO NOT CONFUSE !

REACTIVE NEAR-FIELDS | **RADIATIVE FIELDS**







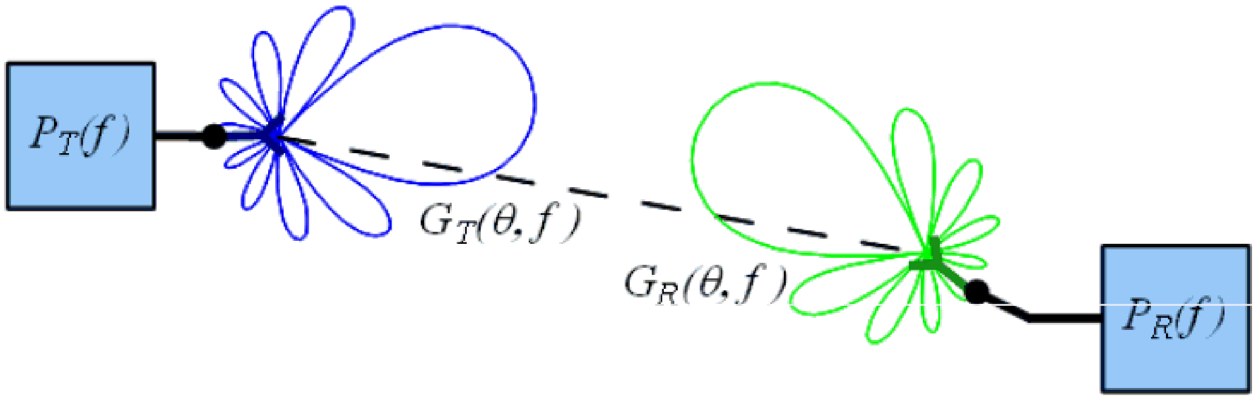
John David Jackson, *Classical Electrodynamics*, 3rd edition (Wiley: New York, 1998)

1- Wireless Power Transmission.

Gain in Wireless Links

Transmission Equation (Friis)

Power balance between transmitting and receiving antenna

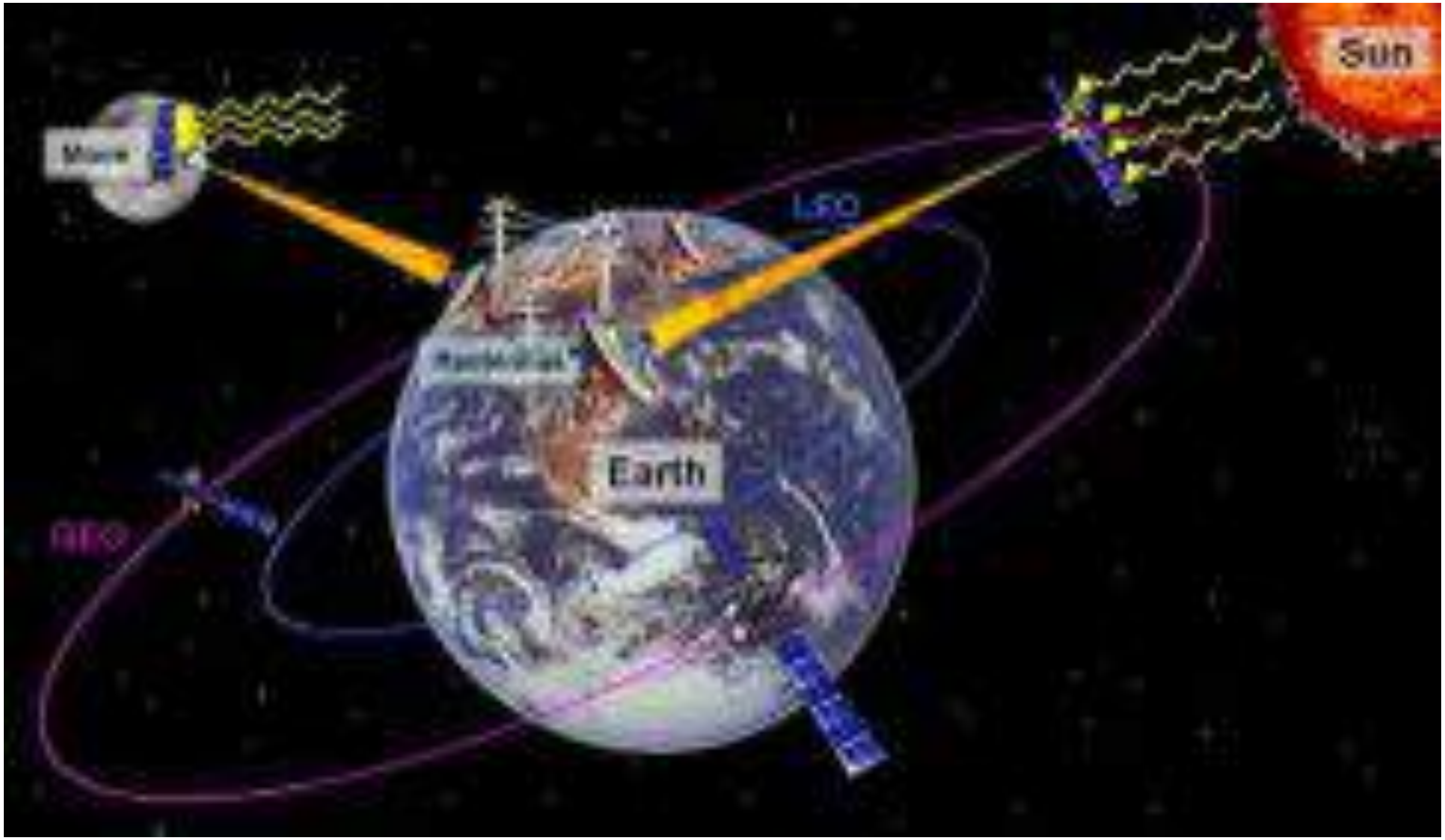


Available power at receiving antenna

$$P_R(\vec{r}, f) = P_T(f) \cdot G_T(\vartheta, f) \cdot \left(\frac{\lambda}{4\pi r} \right)^2 \cdot G_R(\vartheta, f)$$

1- Wireless Power Transmission.

THIS WORK IS ON WPT USING BEAMING TECHNIQUES



1- Wireless Power Transmission.

I am a bit overwhelmed with the impressive level of speakers and their respective works.

I believe I am the youngest (37), and for sure the less experienced in research/development…

How can I contribute in this interesting Summer School ?

Let me talk you a bit about me:

- **Worked for 1 year at Alcatel Space Industries, Madrid.**
- **Associate professor at UPCT.**
- **Teach microwaves, antennas and circuits.**
- **Vocation for learning, teaching and research**

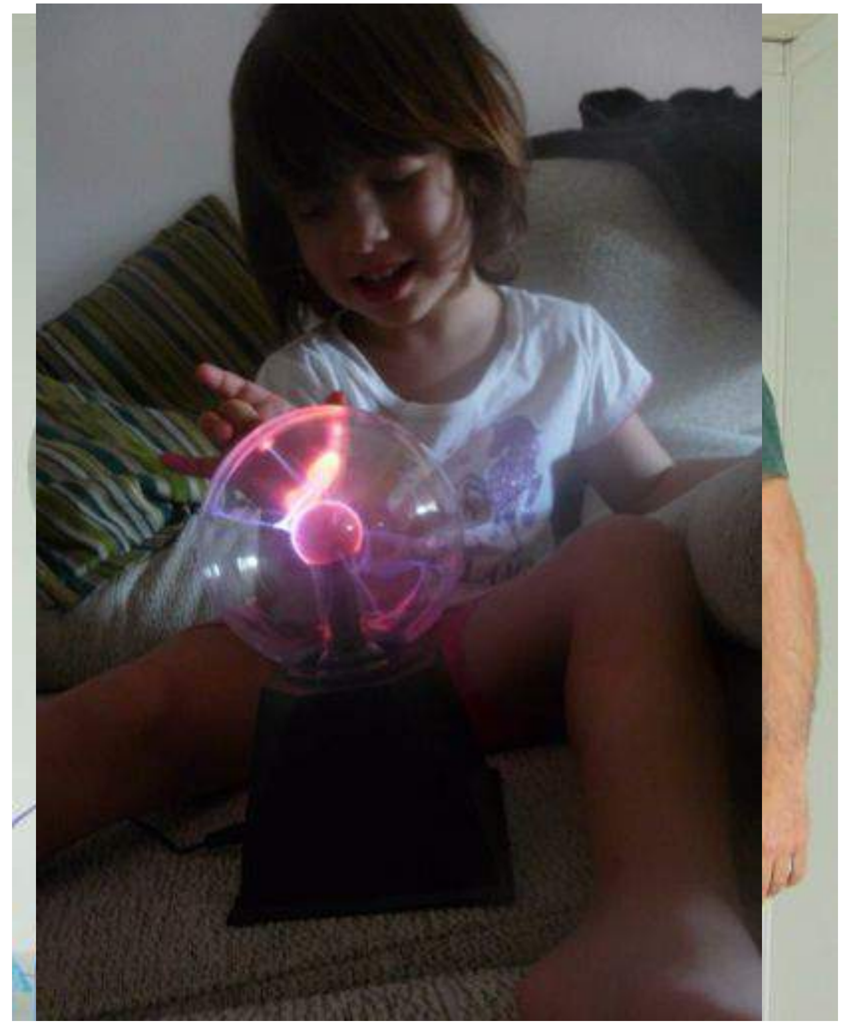
I WILL GIVE 3 FACTS TO SUPPORT MYSELF

1- Wireless Power Transmission.

FACT #1- I am a man interested in contributing to WPT and understanding from insight.

My daughter Mar too….

And also my son Héctor…



1- Wireless Power Transmission.

FACT #1: We are a WPT family…

1- Wireless Power Transmission.

FACT #2- Also I love surfing because I can feel the power of the ocean waves …

1- Wireless Power Transmission.

FACT #2- it is all about getting / providing energy from waves , isn't it ?

AVEIRO AND THE WAVES...

Now it comes FACT #3, which is the most intriguing and revealing one…

JOSE LUIS GOMEZ TORNERO

1- Wireless Power Transmission.

My field of expertise is on the efficient EM analysis and design of novel leaky-wave devices.

I come from Technical University of Cartagena, SE Spain.

I have worked in Alcatel Space Industries, now Thales-Alenia Space, Madrid.

I have made research stays in many countries, and I collaborate with:

- **Heriot-Watt University , Dr. Goussetis and colleagues.**
- **CSIRO ICT Center, Sydney, Dr. Jay Guo and colleagues.**

All my research is focused on leaky-wave devices modelling and applications, which can be too specialized (Andrea Neto calls me the leaky-man), but on the other side I am not that intelligent to work on much more different topics.

I am very devoted to learning and teaching !

OUTLINE

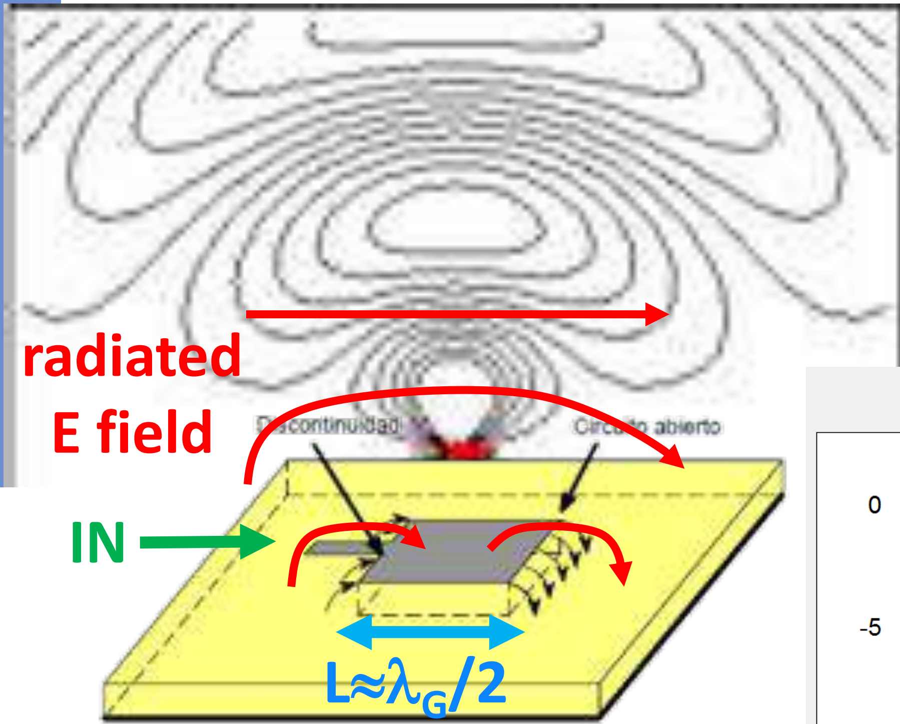
1- Wireless Power Transmission.

2- Travelling-Wave and Leaky-Wave (LW) Concepts.

3- LW Radiation Control and Far/Near-field focusing.

2- Travelling-Wave and Leaky-Wave

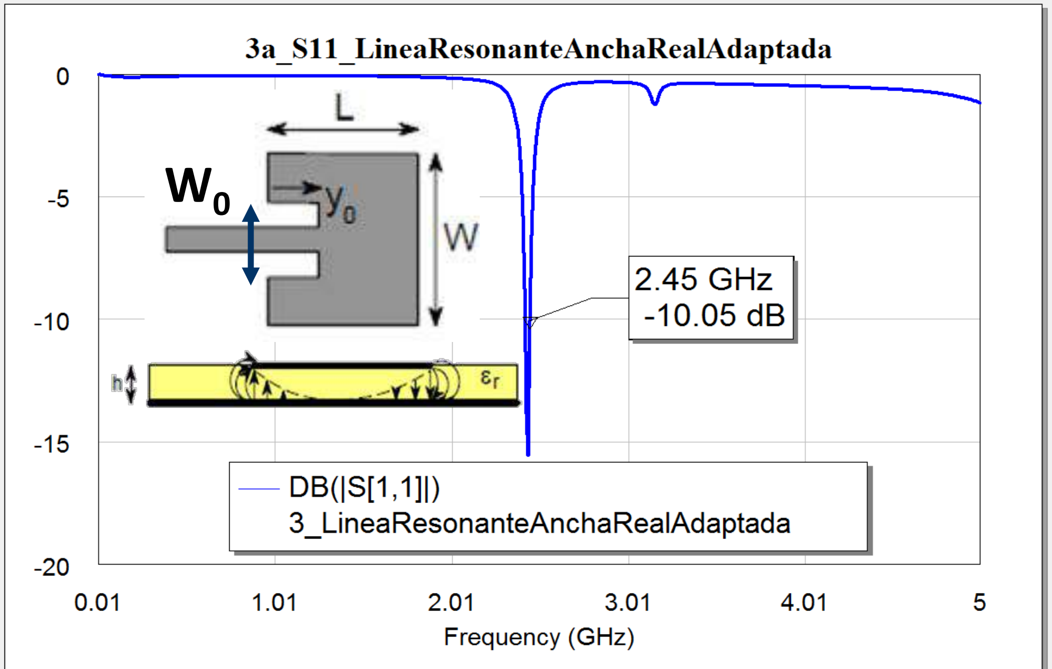
2.1- Radiation mechanisms of resonant antenna (i.e, patch / slot antenna)



- **Typical input matching / rad. efficiency due to resonance:**

f_0=2.45GHz
BW=50MHz=2% (S_{11}<-10dB)
η_{RAD}=30% (losses↑↑ resonance)

Resonant Impedance Matching S11

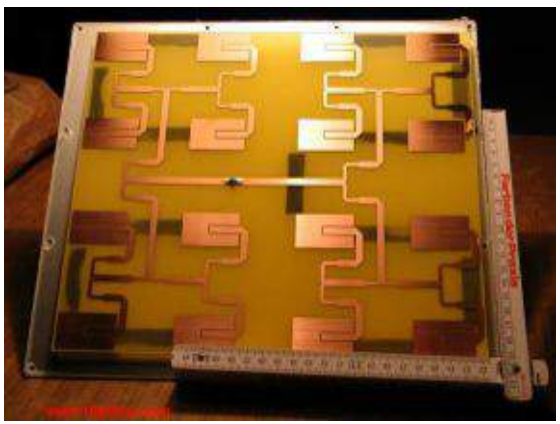


2- Travelling-Wave and Leaky-Wave

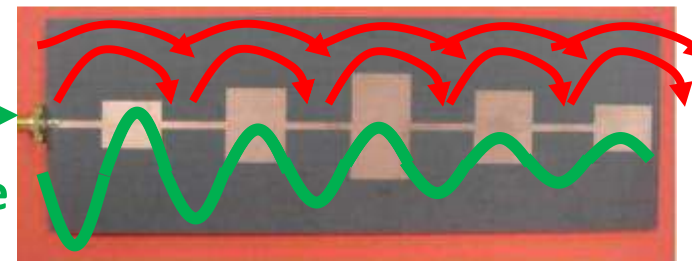
2.2- Radiation mechanisms of series-patch / slotted travelling-wave antenna

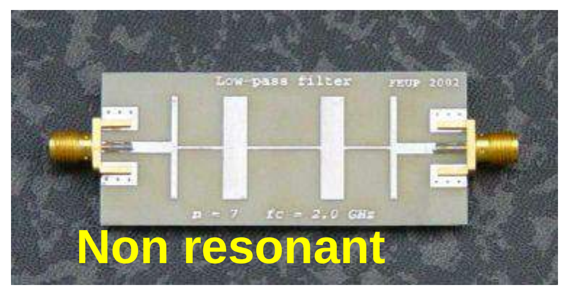
- The periodic strips / slots are resonant !
- But they are distributely fed by a travelling / propagating wave instead of a discrete distributed network:

- Phased array (shunt feeding):



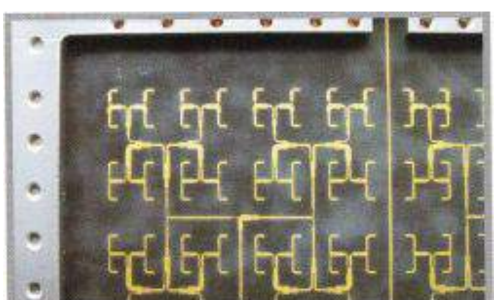
- Phased array (series feeding):



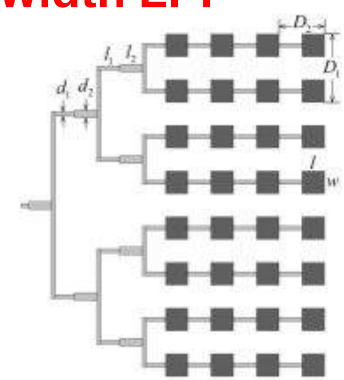


Do not confuse with stepped width LPF

Complex distribution / feeding network

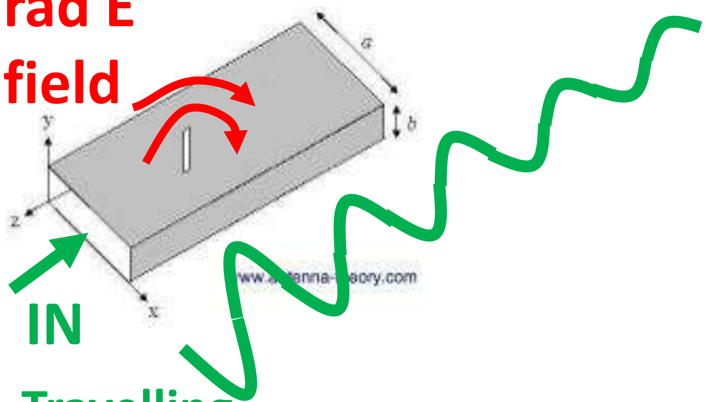


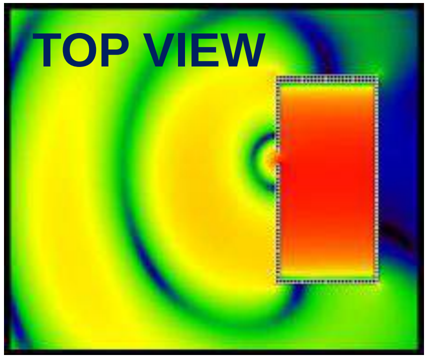
- Shunt & series feeding:



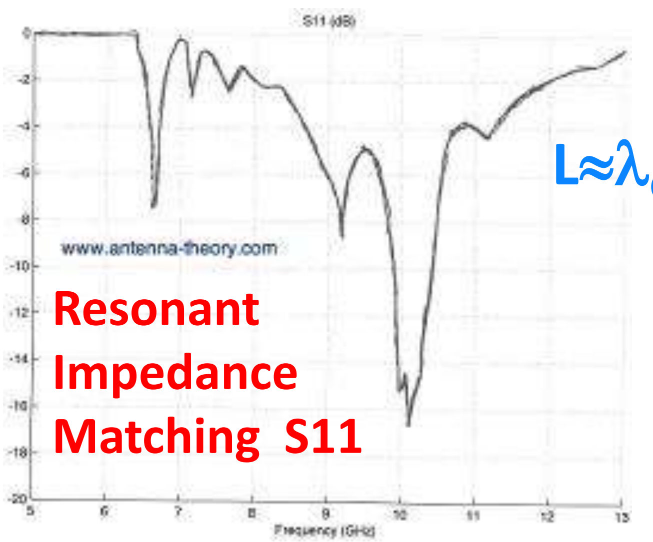
2- Travelling-Wave and Leaky-Wave

- **Slotted waveguide TWA (Series feeding):**

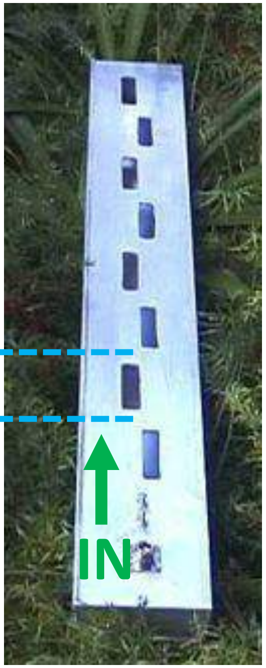


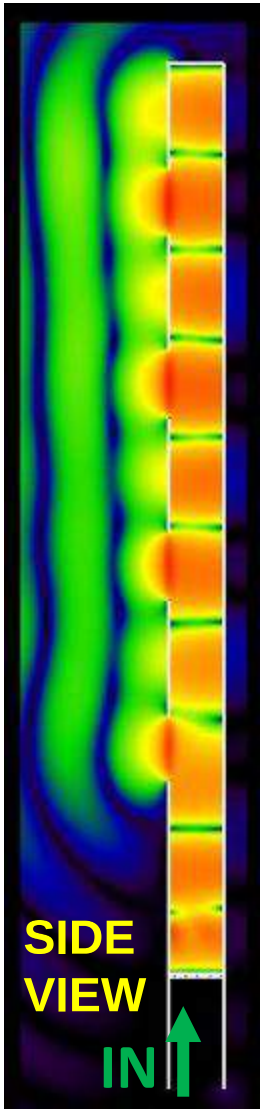


- **If resonant slots → TWA Travelling-Wave Antenna**



$L \approx \lambda_G/2$



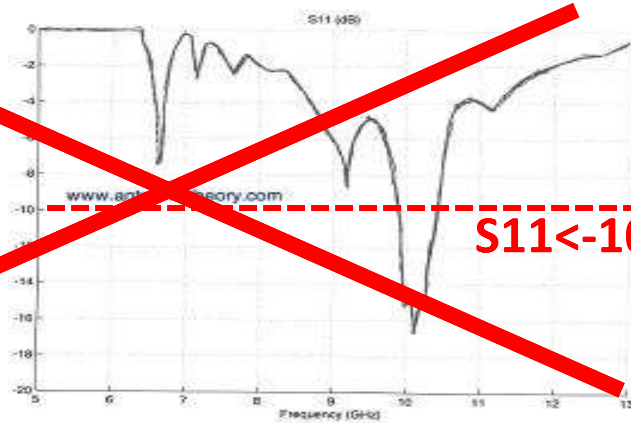


2- Travelling-Wave and Leaky-Wave

- If NON resonant slots → LWA Leaky-Wave Antenna

Resonant Impedance Matching S11

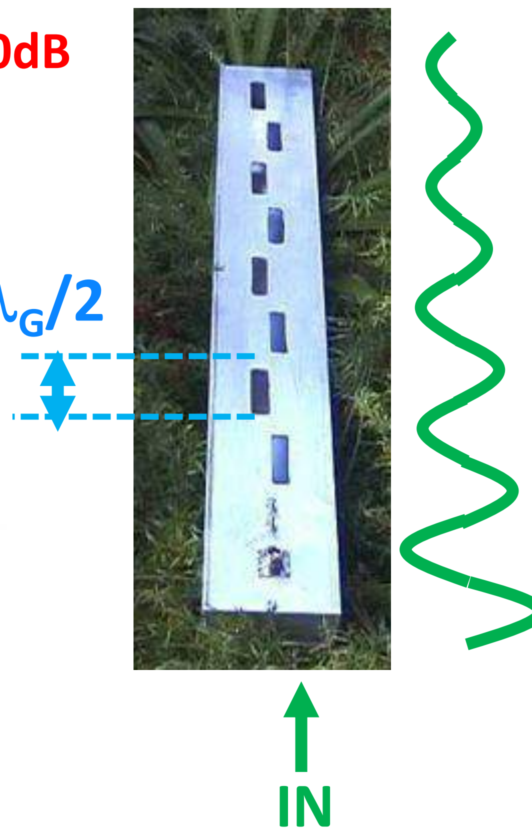
f_0=10GHz
BW=0.2GHz=2%



S11<-10dB

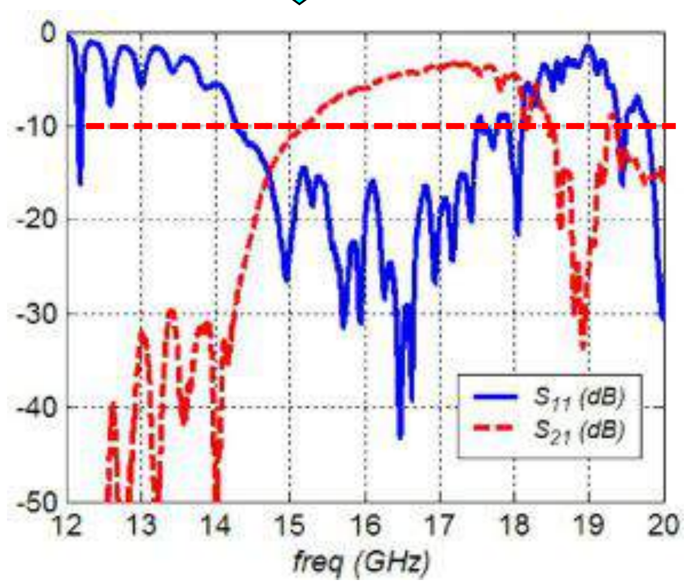
Matched load at the LWA end to absorb non-radiated energy

L<λ_G/2



Non-resonant Impedance Matching S11

f_0=16GHz
BW=4GHz=25%
η_{RAD}=90% (no resonance)



2- Travelling-Wave and Leaky-Wave

2.3- Radiation mechanisms of series-patch / slotted leaky-wave antenna

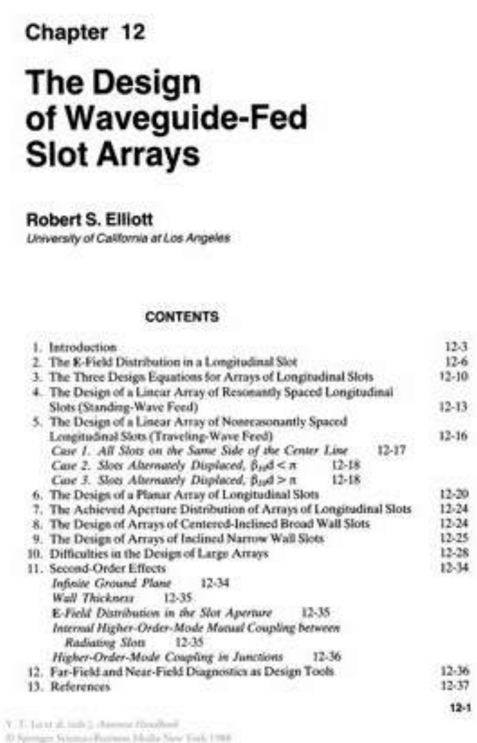
- LWAs fall in the type of travelling-wave antennas
- The periodic strips / slots are non resonant !
- They are discontinuities which create each one low-efficiency radiation, but due to the high number of them the total efficiency can be large.
- As a result the illuminated length is large

  → long antennas / high directivity / narrow beam
- And with a simple single feeding.
- Wide input matching bandwith >25 % → with frequency beam scanning
- High radiation efficiency / possibility to control the complex aperture fields → high aperture efficiency / beam shaping
- The problem is how to deal with complex leaky modes…

2- Travelling-Wave and Leaky-Wave

2.4- Leaky-wave antennas (LWA) and leaky modes (LM)

"Antenna Handbook , Theory, Applications, and Design"
Y. T. Lo, S. W. Lee (Springer, 1988)
Ch.12, pp 805-842:
"The Design of Waveguide-Fed Slot Arrays",
By Robert S. Elliot.

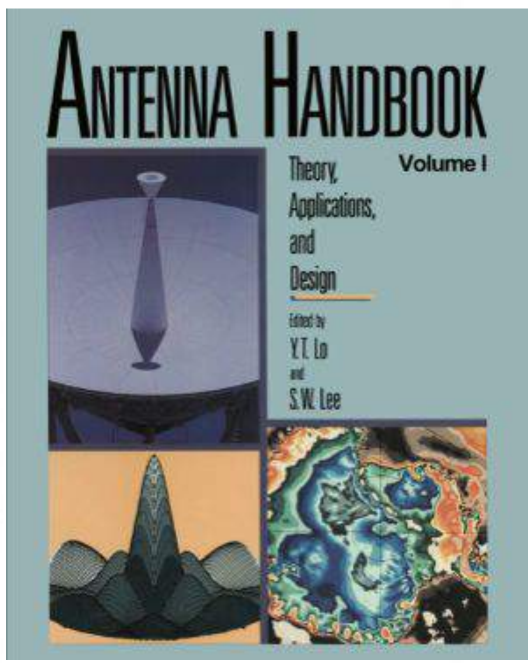


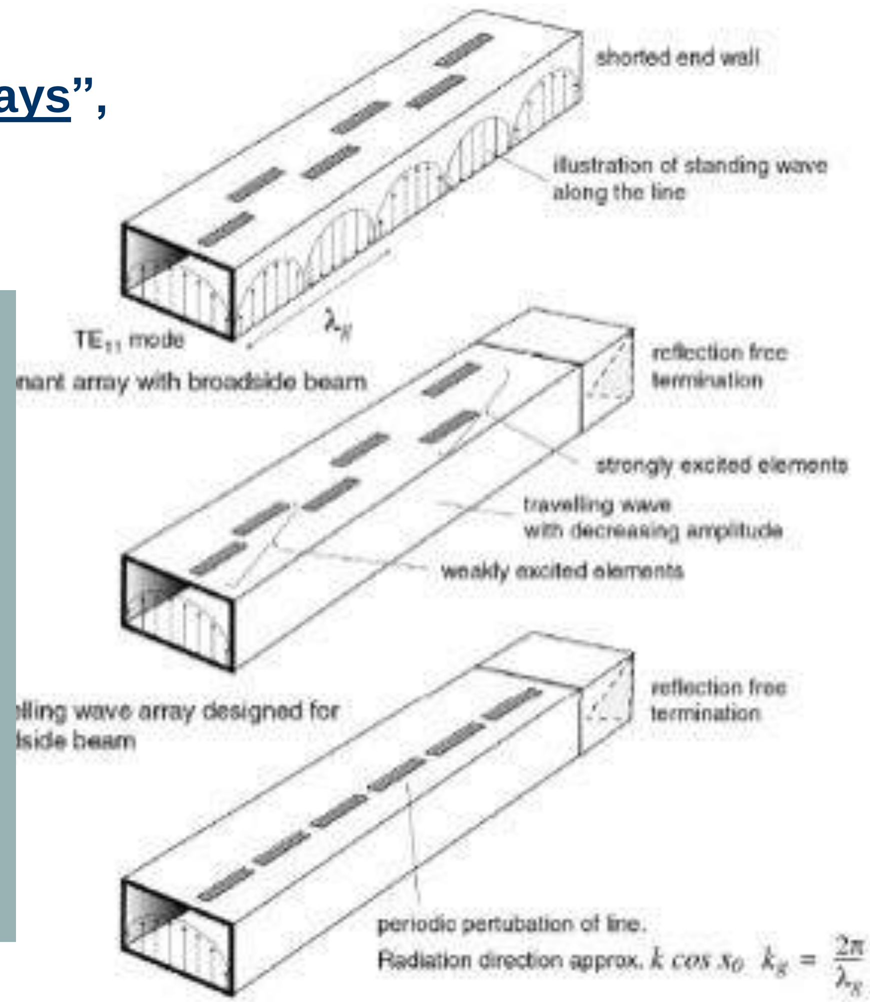
Chapter 12

The Design of Waveguide-Fed Slot Arrays

Robert S. Elliott
University of California at Los Angeles

CONTENTS





2- Travelling-Wave and Leaky-Wave

2.4- Leaky-wave antennas (LWA) and leaky modes (LM)

"Antenna Engineering Handbook",
R.C. Johnson, Ed., (3rd ed. McGraw-Hill, 1993)
Ch.10, 59pages, "Leaky-wave antennas",
By A. A. Oliner.

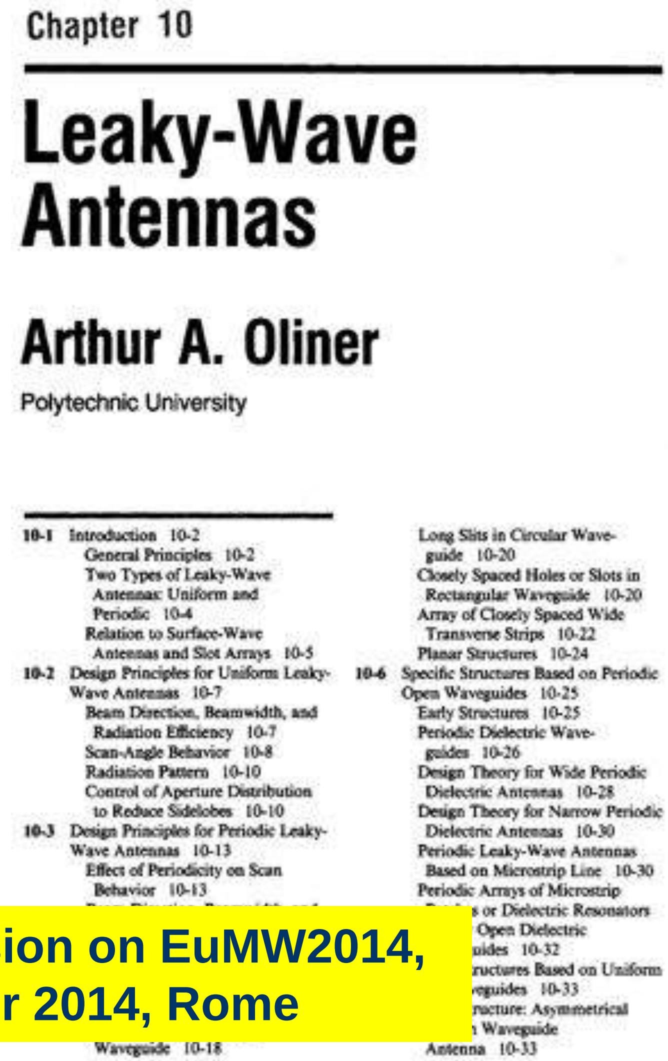

Antenna Engineering Handbook

THIRD EDITION

Richard C. Johnson Editor
Georgia Institute of Technology
Atlanta, Georgia

Henry Jasik Editor of First Edition

McGraw-Hill, Inc.
New York St. Louis San Francisco Auckland Bogotá
Caracas Lisbon London Madrid Mexico Milan
Montreal New Delhi Paris San Juan São Paulo
Singapore Sydney Tokyo Toronto


Chapter 10

Leaky-Wave Antennas

Arthur A. Oliner
Polytechnic University

Prof. Arthur A. Oliner (1921-2013)
In memoriam D.E.P.
Polytechnic Institute of Brooklyn

Special Session on EuMW2014, October 2014, Rome

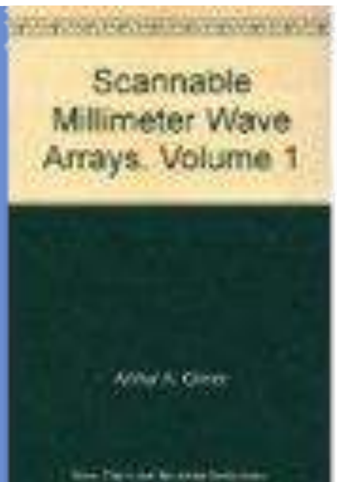
2- Travelling-Wave and Leaky-Wave

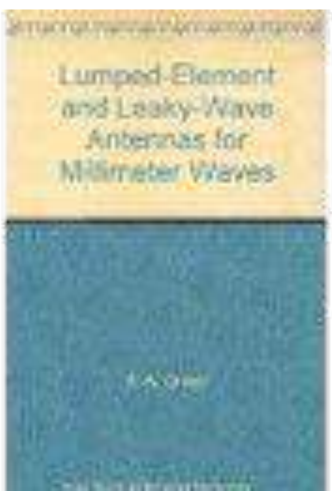
2.4- Leaky-wave antennas (LWA) and leaky modes (LM)

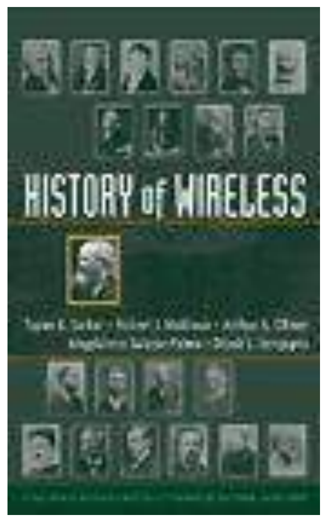
IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. MTT-32, NO. 9, SEPTEMBER 1984

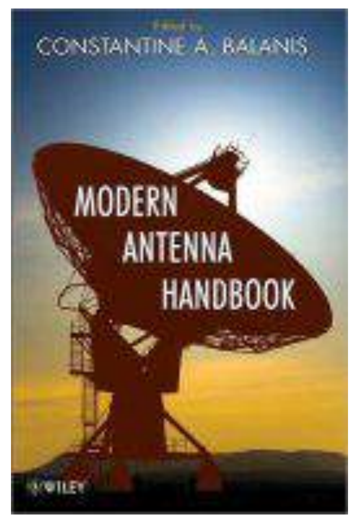
Historical Perspectives on Microwave Field Theory

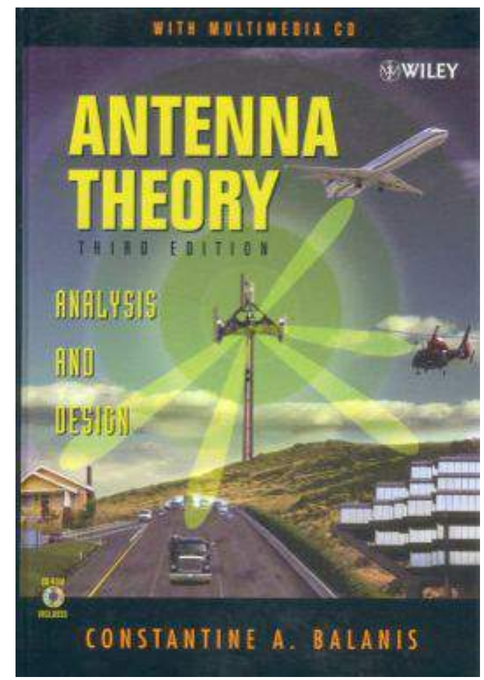
A. A. OLINER, FELLOW, IEEE





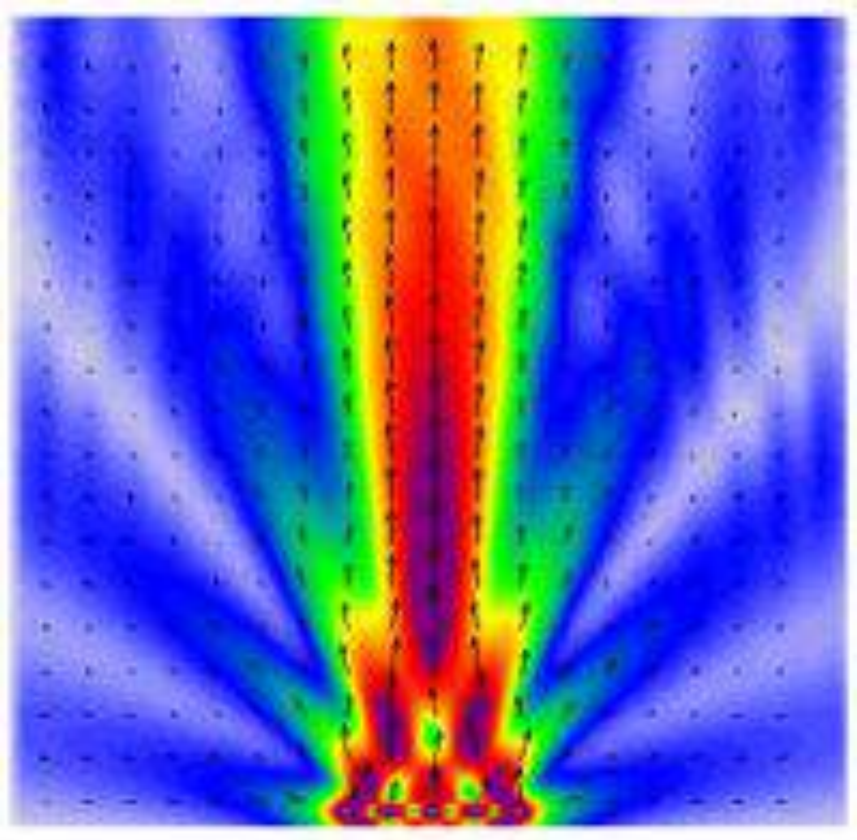






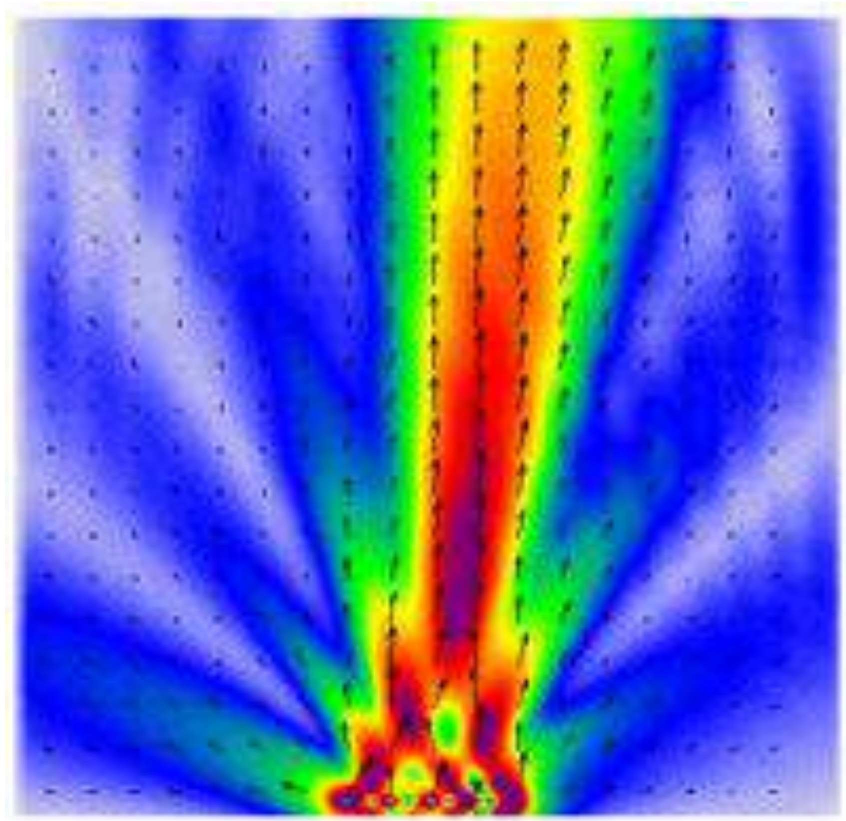
2- Travelling-Wave and Leaky-Wave

Phased array antenna – phase feed



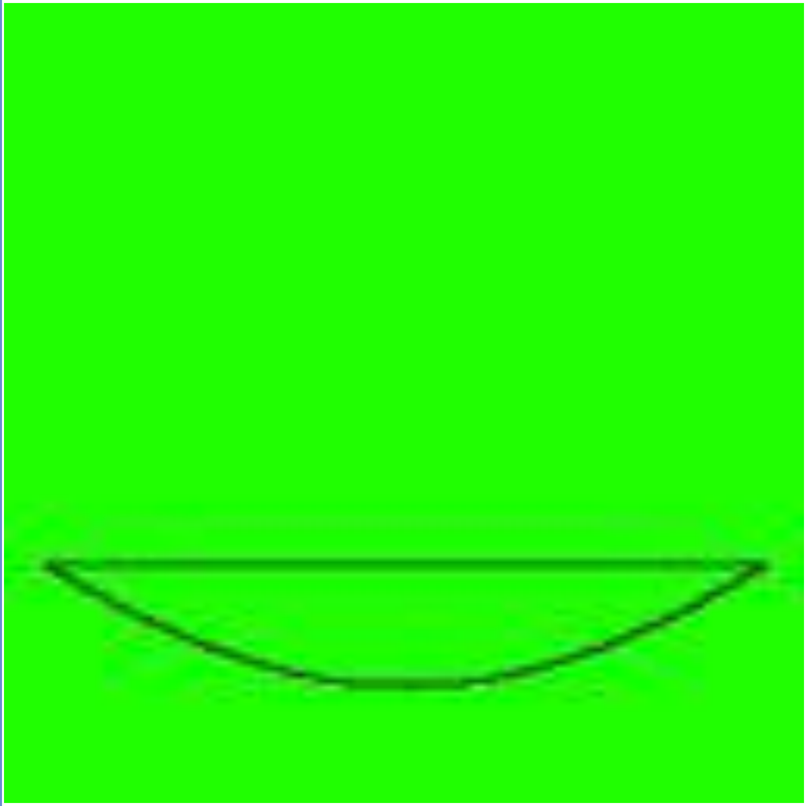
2- Travelling-Wave and Leaky-Wave

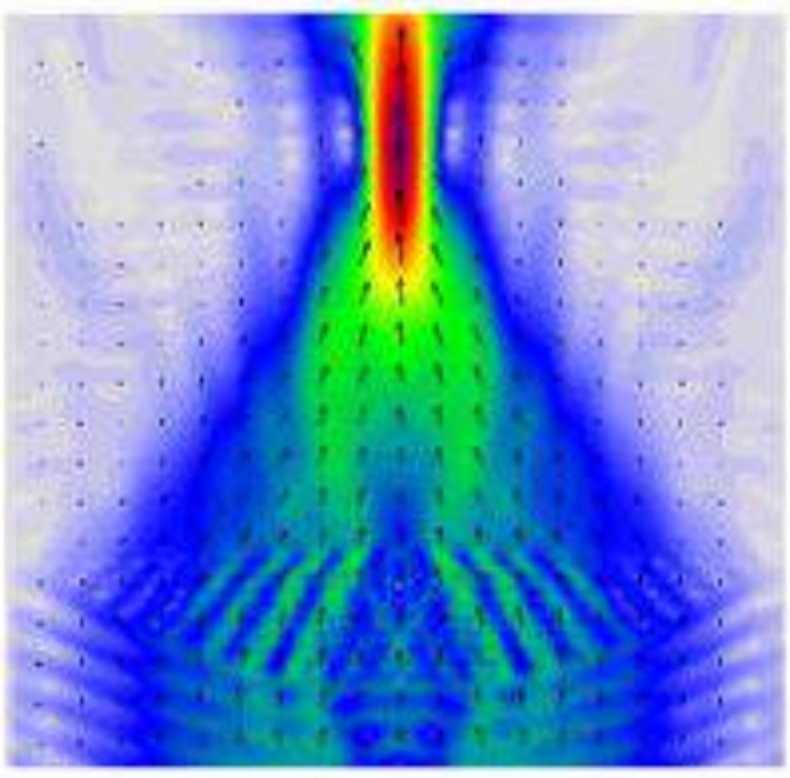
Phased array antenna – beam steering



2- Travelling-Wave and Leaky-Wave

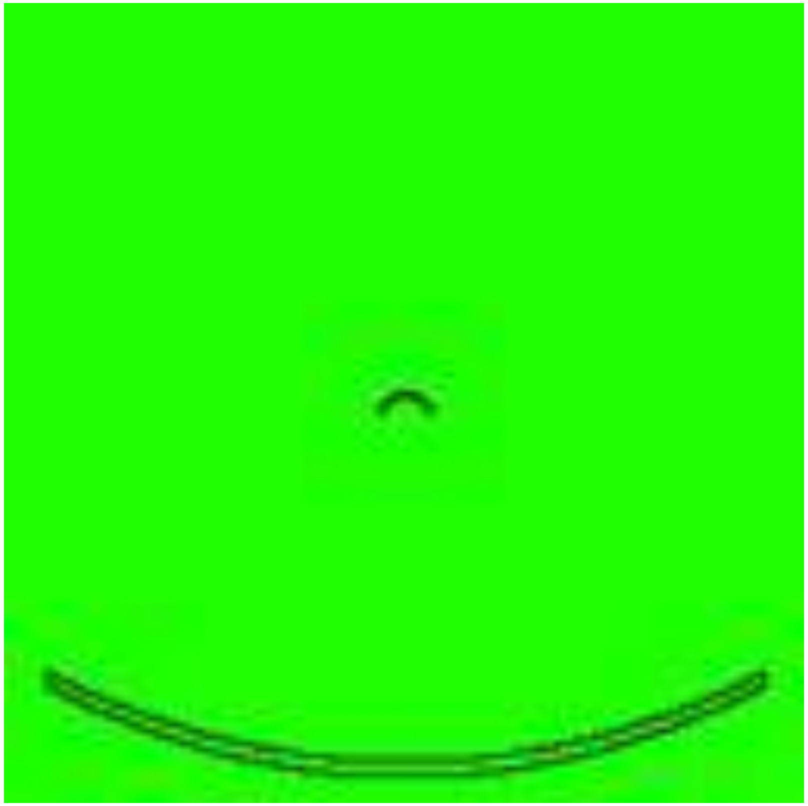
Convex lens antenna

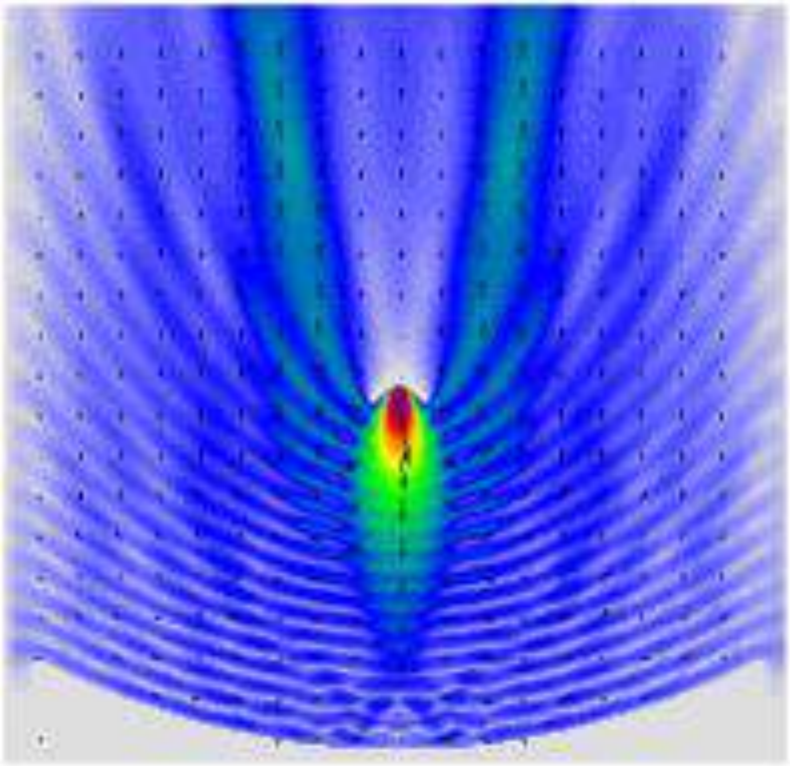




2- Travelling-Wave and Leaky-Wave

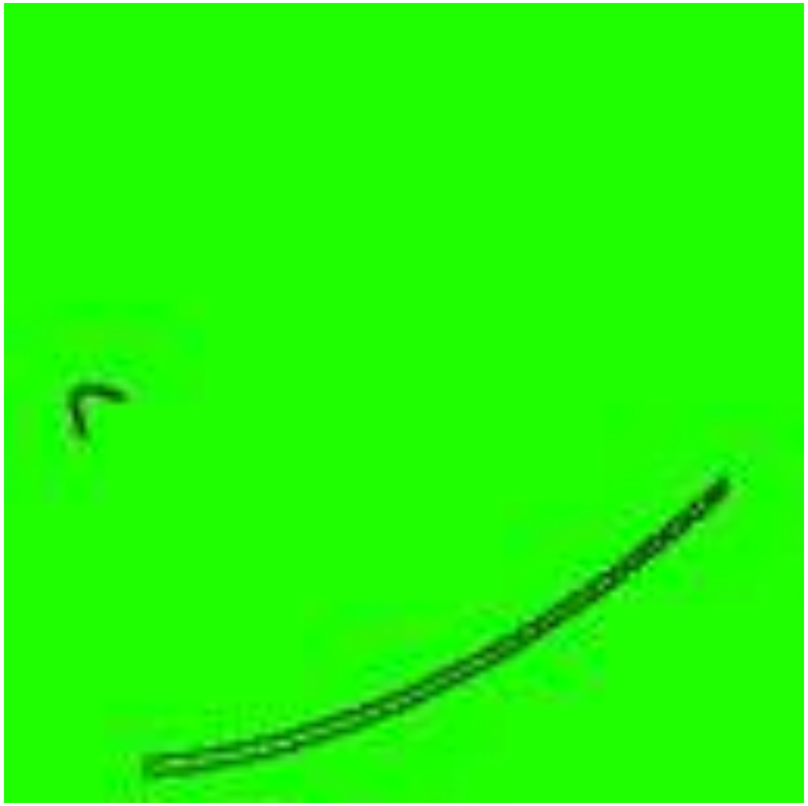
Parabolic dish antenna

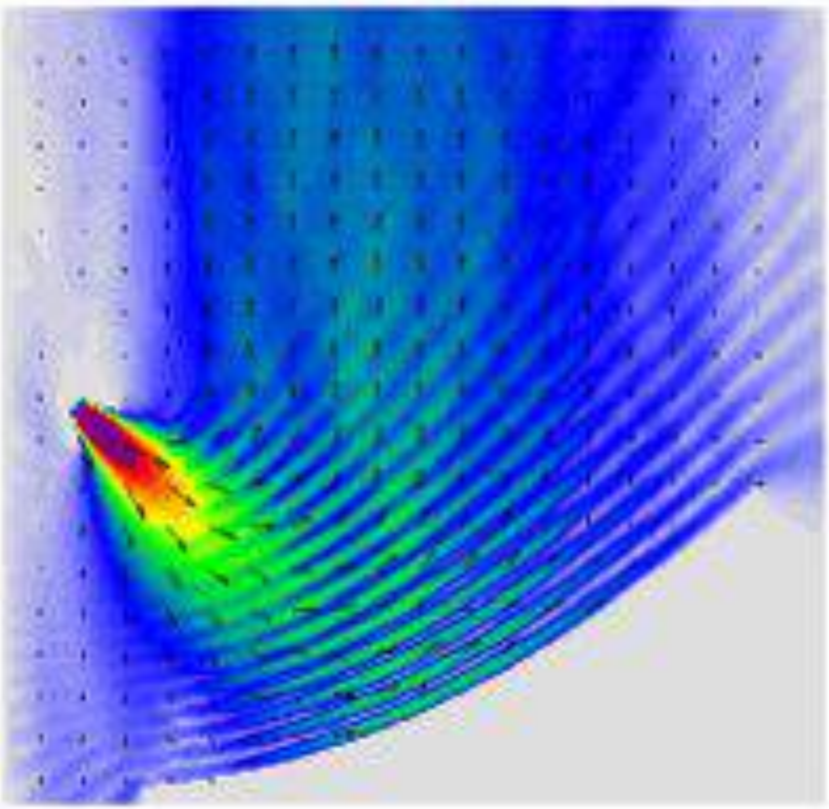




2- Travelling-Wave and Leaky-Wave

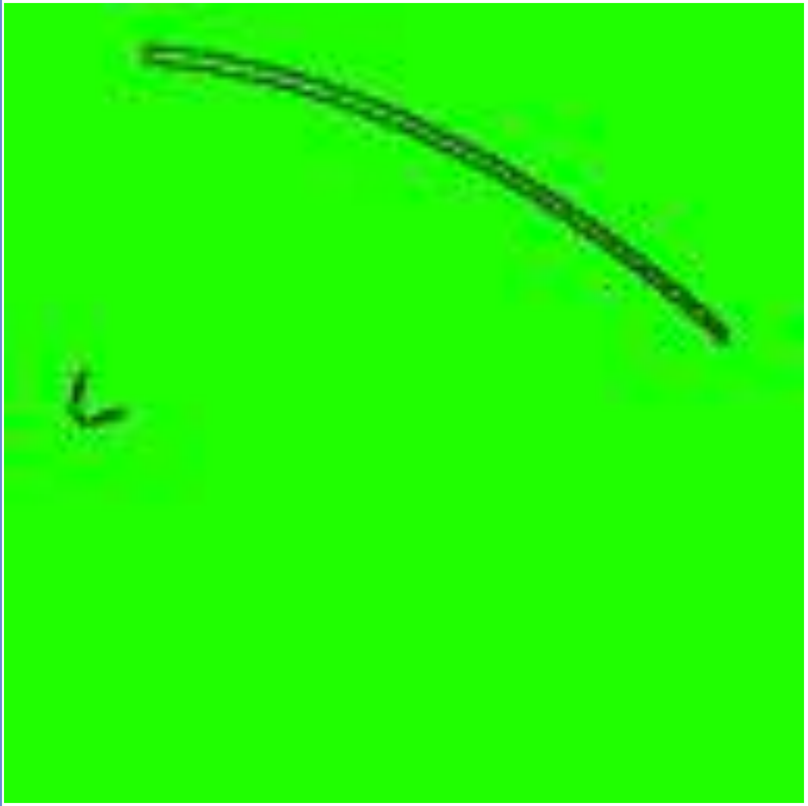
Offset Parabolic dish antenna - transmitting

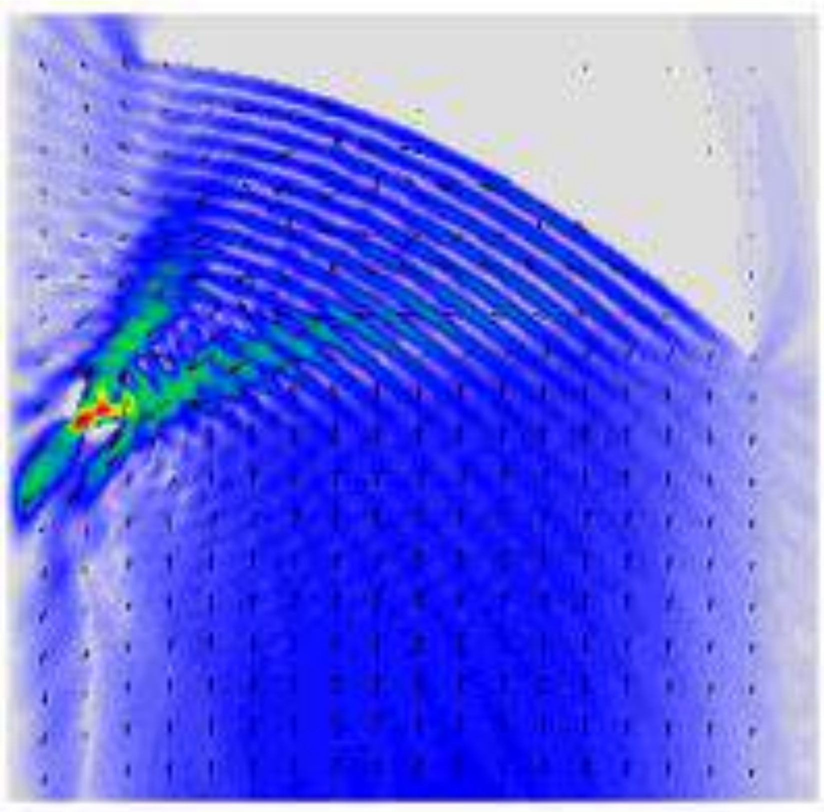




2- Travelling-Wave and Leaky-Wave

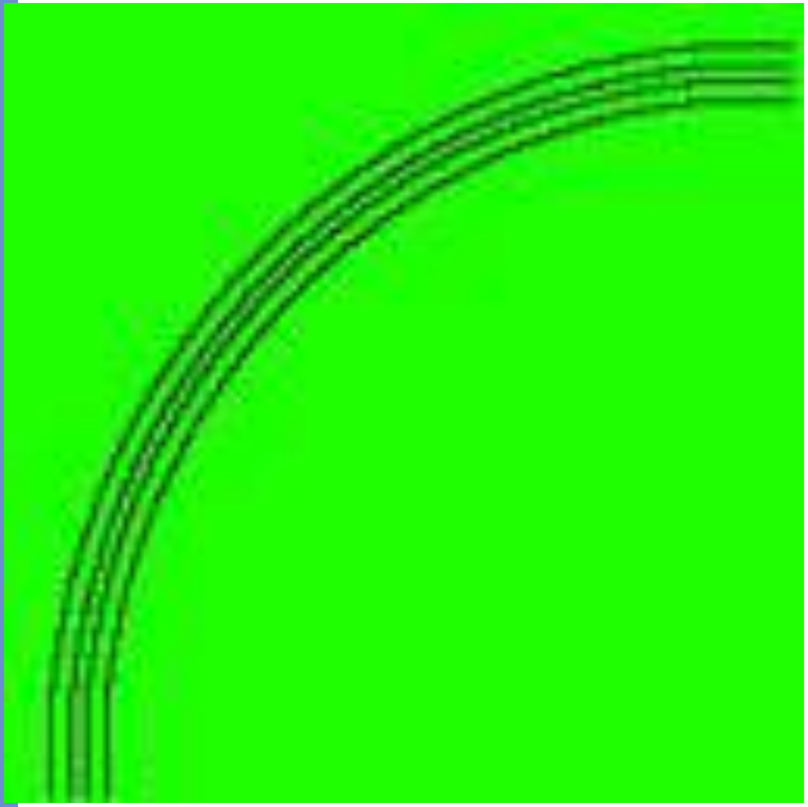
Offset Parabolic dish antenna - receiving

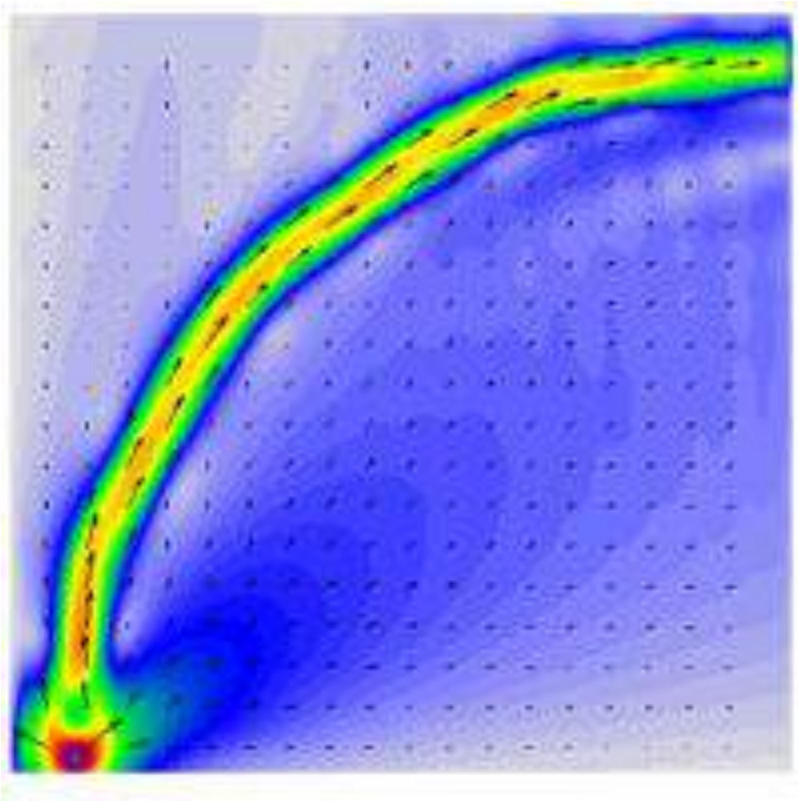




2- Travelling-Wave and Leaky-Wave

Waveguide – wave guiding and leakage

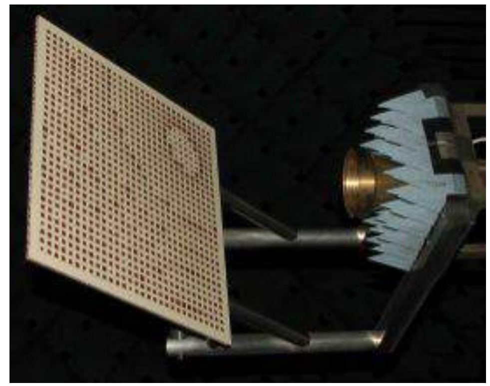




2- Travelling-Wave and Leaky-Wave

Phased array antenna

Reflect / transmit arrays



Reflector antennas

Lens antennas

2- Travelling-Wave and Leaky-Wave

2.3- Why can leaky-wave antennas be useful for WTP ??

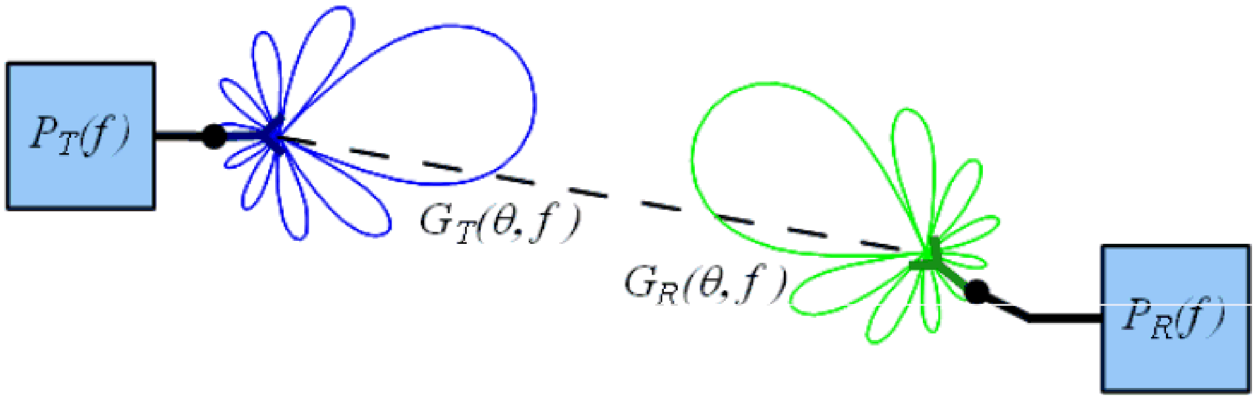
- **Simple, integrated single feeding.**
- **Low profile, low cost, PCB compatible, planar.**
- **Wide input matching bandwith >25 % → with frequency beam scanning**
- **High radiation efficiency / possibility to control the complex aperture fields → high aperture efficiency / beam shaping**
- **Near and far-field beaming**
- **Distributed radiation → Space power combining**
- **Frequency scanning.**
- **Electronic scanning.**
- **Analog Signal Processing**

1- Wireless Power Transmission.

Gain in Wireless Links

Transmission Equation (Friis)

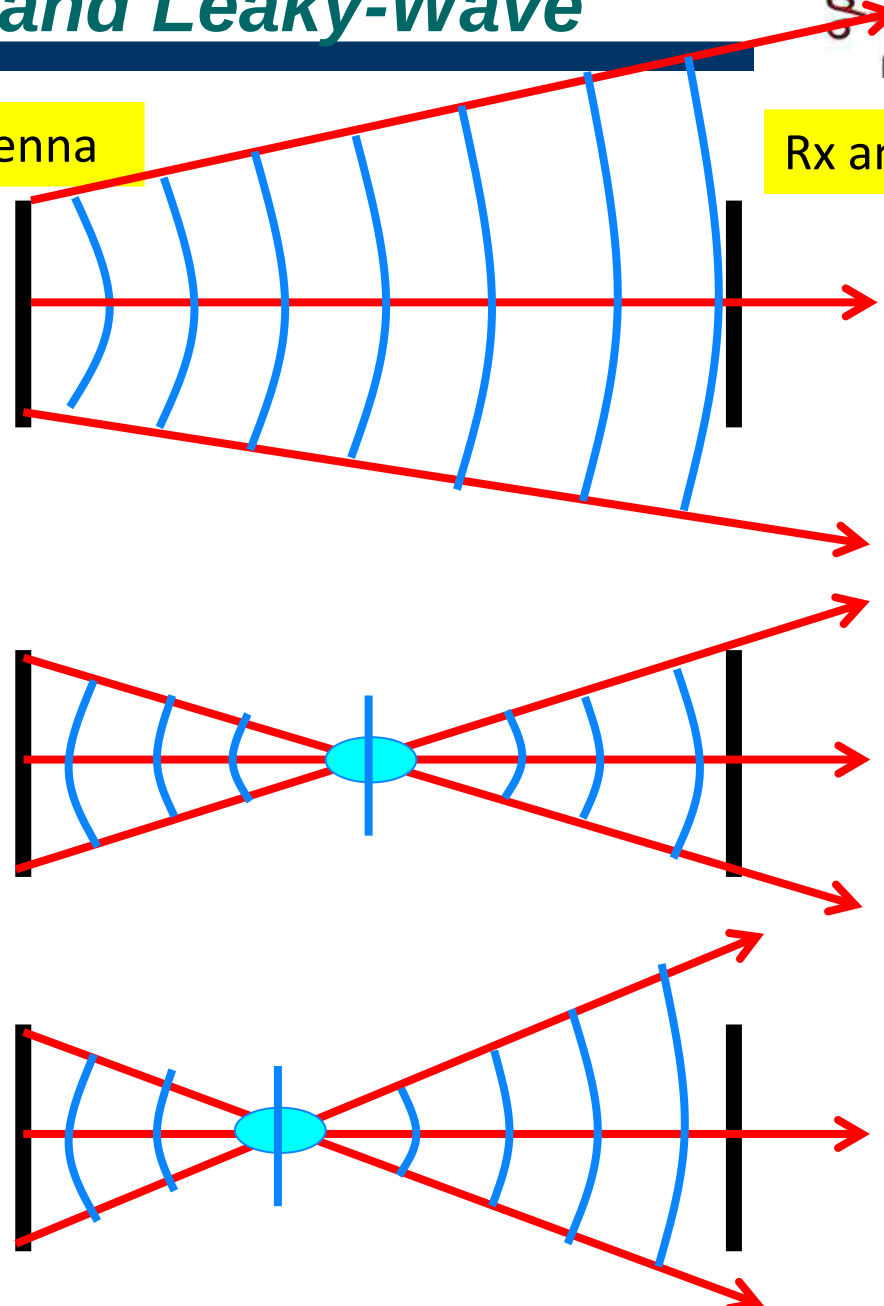
Power balance between transmitting and receiving antenna



Available power at receiving antenna

$$P_R(\vec{r}, f) = P_T(f) \cdot G_T(\vartheta, f) \cdot \left(\frac{\lambda}{4\pi r} \right)^2 \cdot G_R(\vartheta, f)$$

2- Travelling-Wave and Leaky-Wave



a) Far-field focused WPT

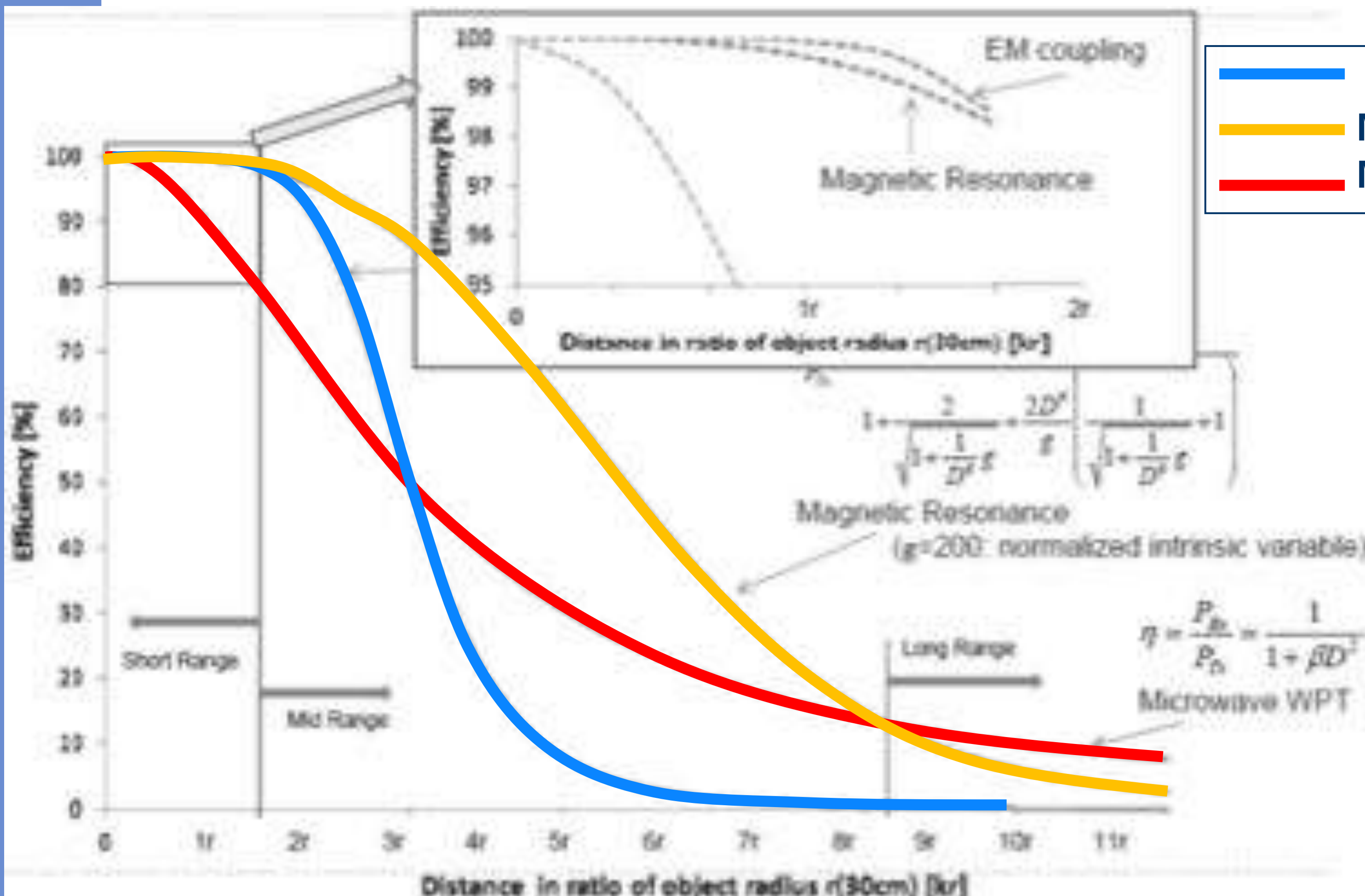
Prof. Zoya Popovic:
- High-power directive beaming
- Beaming efficiency

b) Near-field focused WPT
(common focus)

c) Near-field focused WPT
(non common focus)

2- Travelling-Wave and Leaky-Wave

Prof. Shigeo Kawazaki: Comparison of WPT techniques



EM coupling .
Magnetic resonance.
Microwave radiation.

D : Diameter(60cm) of Coil/Antenna (The normalized parameter)
f : operating Frequency (common)

OUTLINE

1- Wireless Power Transmission.

2- Travelling-Wave and Leaky-Wave (LW) Concepts.

3- LW Radiation Control and Far/Near-field focusing.

OUTLINE

1- Modulated SIW antenna.

2- Synthesis Design Examples.

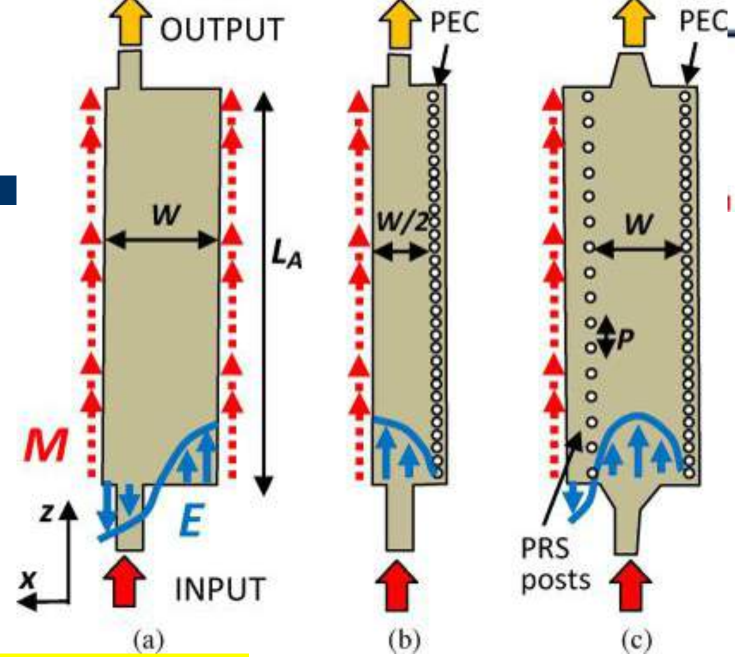
3- Conclusions.

1- Modulated SIW antenna.

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 60, NO. 3, MARCH 2012

Planar Leaky-Wave Antenna With Flexible Control of the Complex Propagation Constant

Alejandro Javier Martinez-Ros, José Luis Gómez-Tornero, and George Goussetis



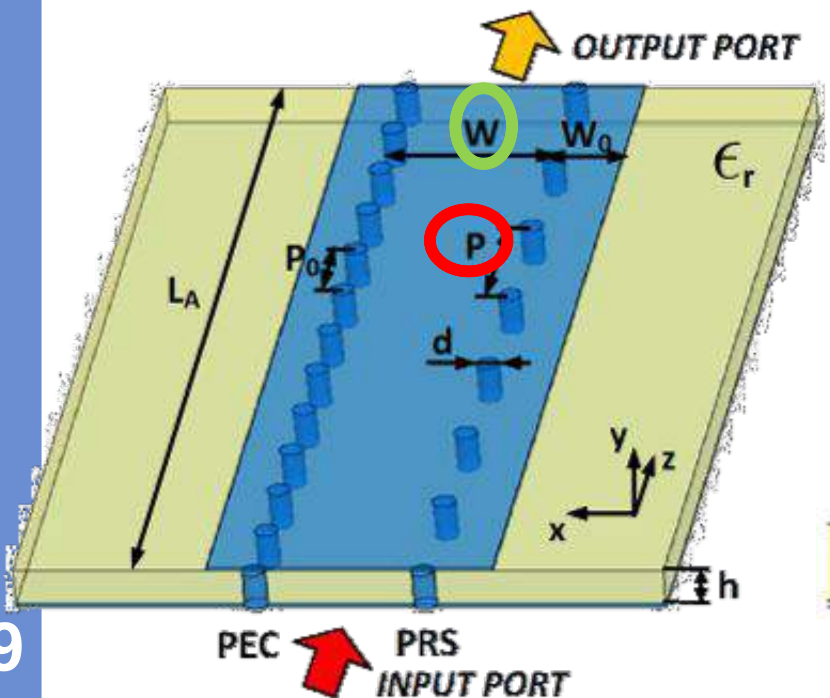
W → Controls the scanning angle (aperture phase)

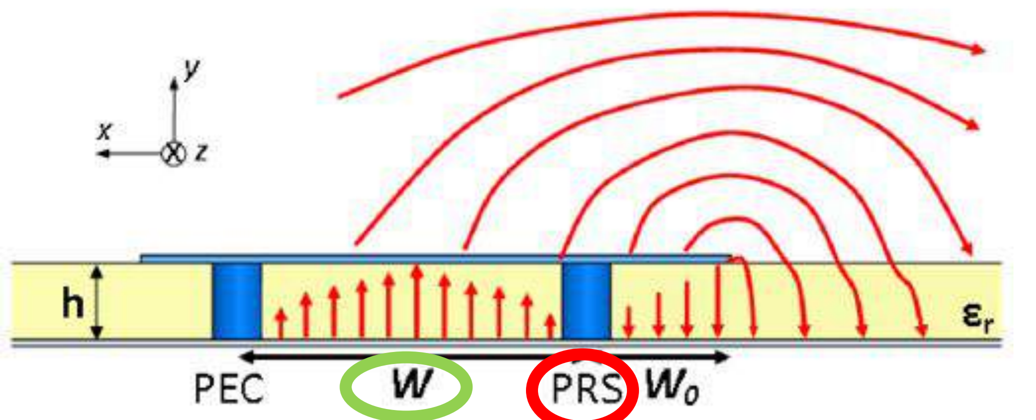
P → Controls the leakage rate (aperture amplitude)

Menzel LWA [1979]

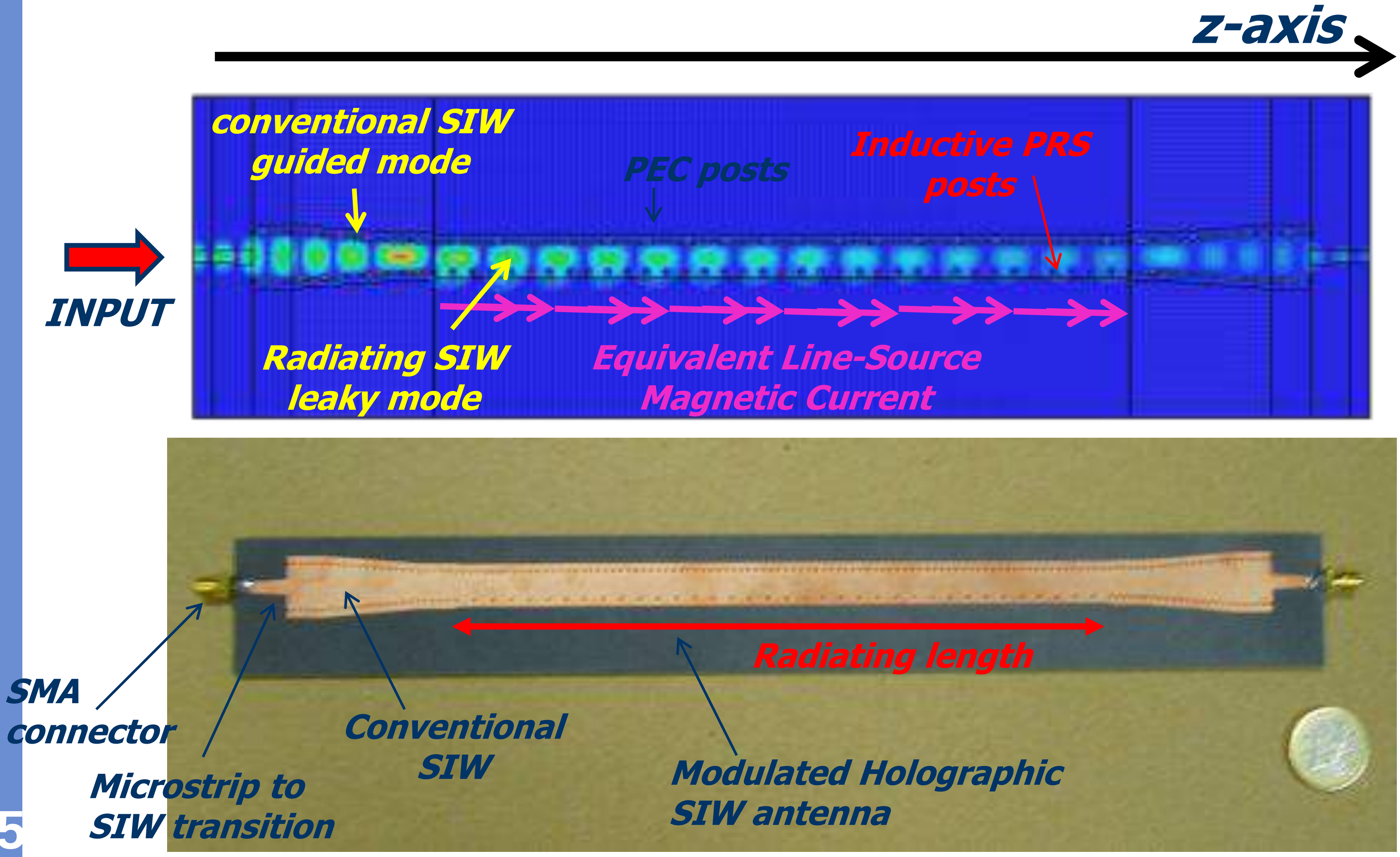
Half-width LWA Zelinski [2004]

SIW LWA lateral Deslandes [2005]





1- Modulated SIW antenna.



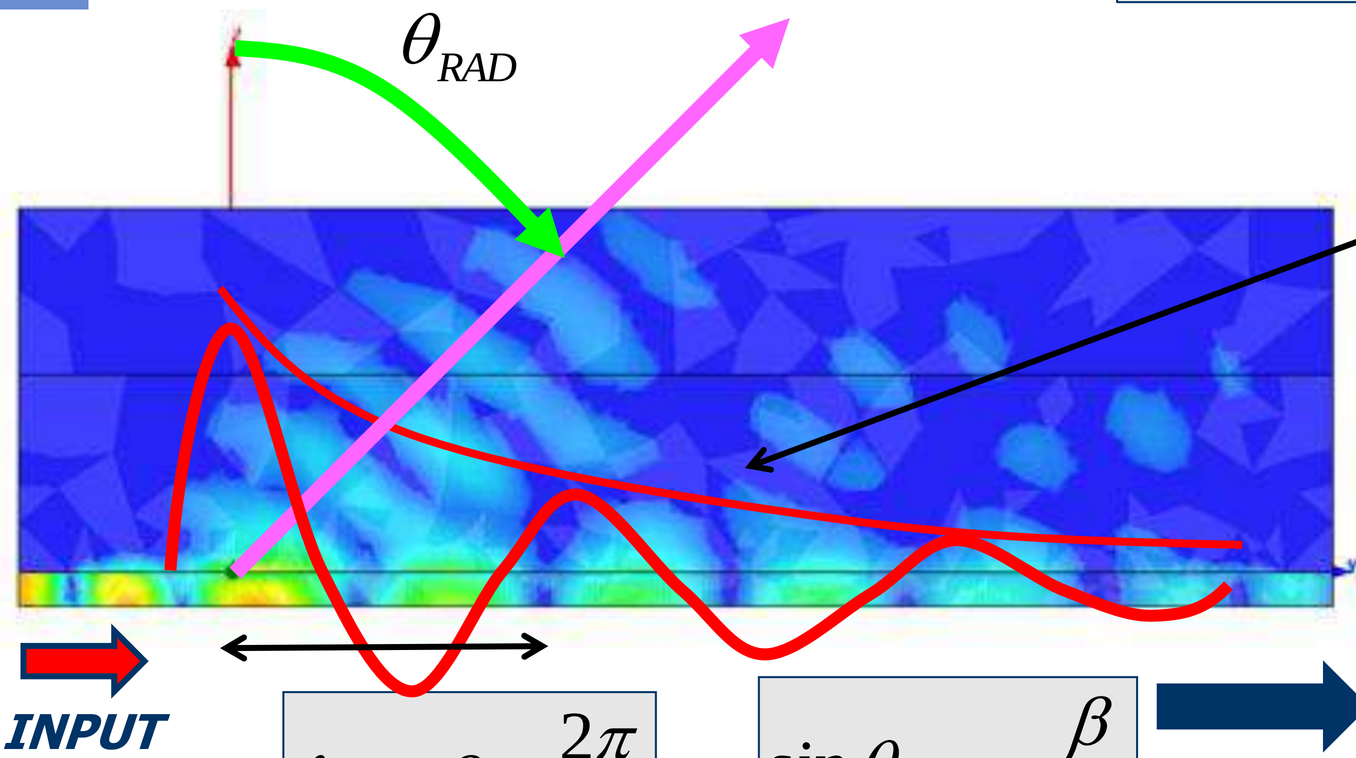
1- Modulated SIW antenna. Leaky Waves.

LEAKY-MODE COMPLEX PROPAGATION CONSTANT

$$k = \beta - j\alpha$$

β= phase constant

α=leakage rate



$$\frac{\alpha}{k_0}$$

Intensity of the radiation (amplitude)

$$\lambda \rightarrow \beta = \frac{2\pi}{\lambda}$$

$$\sin\theta_{RAD} \approx \frac{\beta}{k_0}$$

Direction of the radiation (phase)

1- Modulated SIW antenna.

Efficient synthesis technique for electrically-large line-sources

$$E_{RAD}^{APERT}(z) = M(z) \cdot e^{j\phi(z)}$$

Fields Radiated at the Holographic Antenna Aperture

$$k(z) = \beta(z) - j\alpha(z)$$

Leaky-Mode Modulated Complex Propagation Constant

$$\beta(z) = k_0 \sin\theta_{RAD}(z) = -\frac{\partial\phi(z)}{\partial z}$$

Leaky-Mode Modulated Phase Constant

$$\alpha(z) = \frac{1}{2}\frac{|M(z)|^2}{\frac{1}{\eta}\int_0^{L_A}|M(\tau)|^2\partial\tau - \int_0^z|M(\tau)|^2\partial\tau}$$

Leaky-Mode Modulated Leakage Rate

Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP)

Unusual Tapering of Leaky-Wave Radiators and Their Applications

Jose-Luis Gómez-Tornero

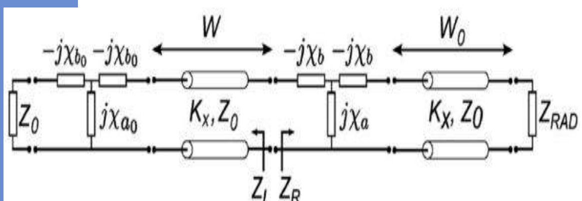
496 IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 12, 2013

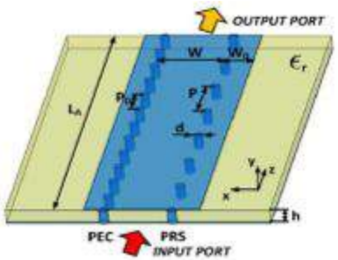
Efficient Analysis and Design of Novel SIW Leaky-Wave Antenna

Alejandro Javier Martinez-Ros, *Student Member, IEEE*, José Luis Gómez-Tornero, *Member, IEEE*, and Fernando Quesada-Pereira, *Member, IEEE*

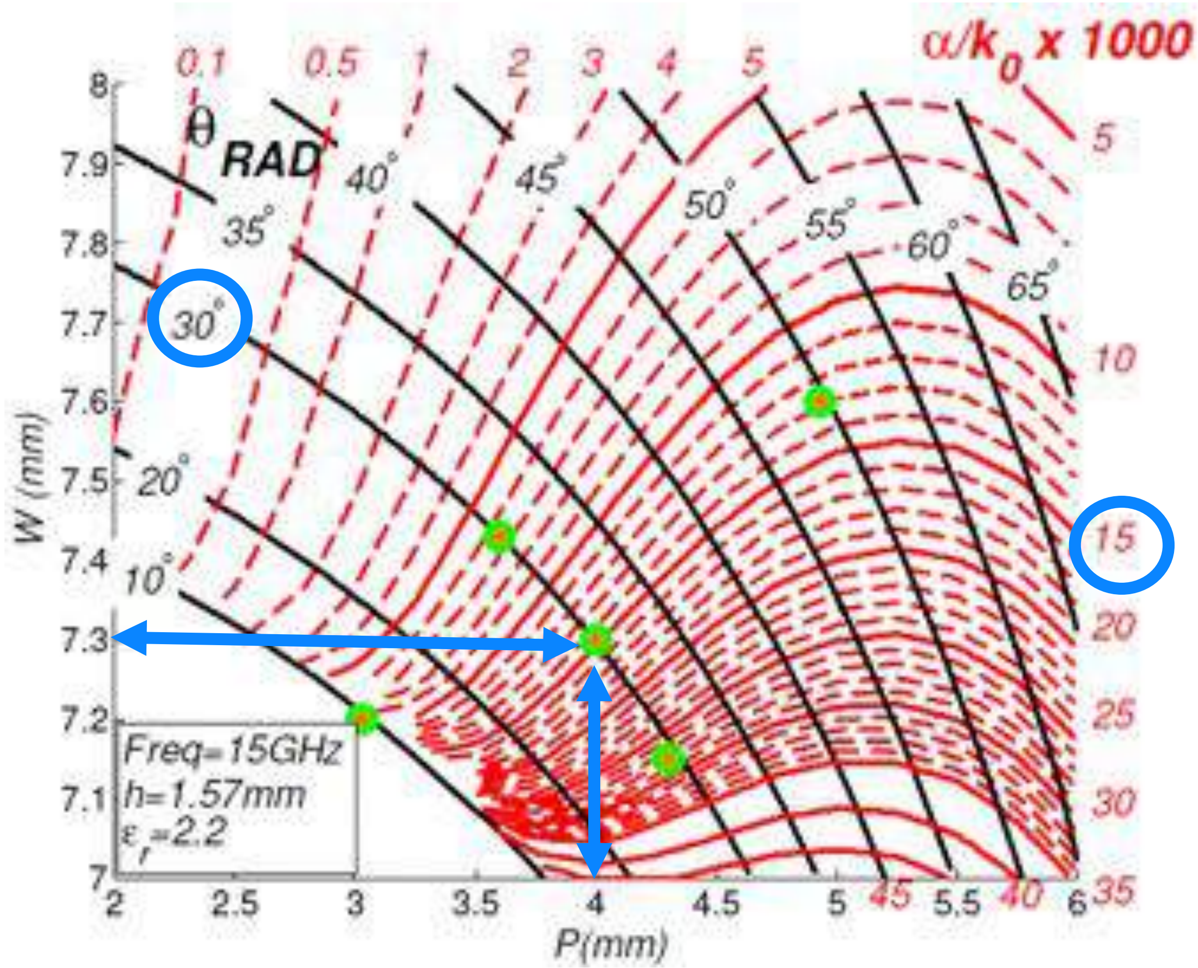
WIPE
COST IC1301

Efficient Analysis with Transverse Equivalent Network





Geometry design chart "look-up table"



Modulated leaky wave

Holographic antenna modulated dimensions

$$k(z) = \beta(z) - j\alpha(z)$$

P(z) *W(z)*

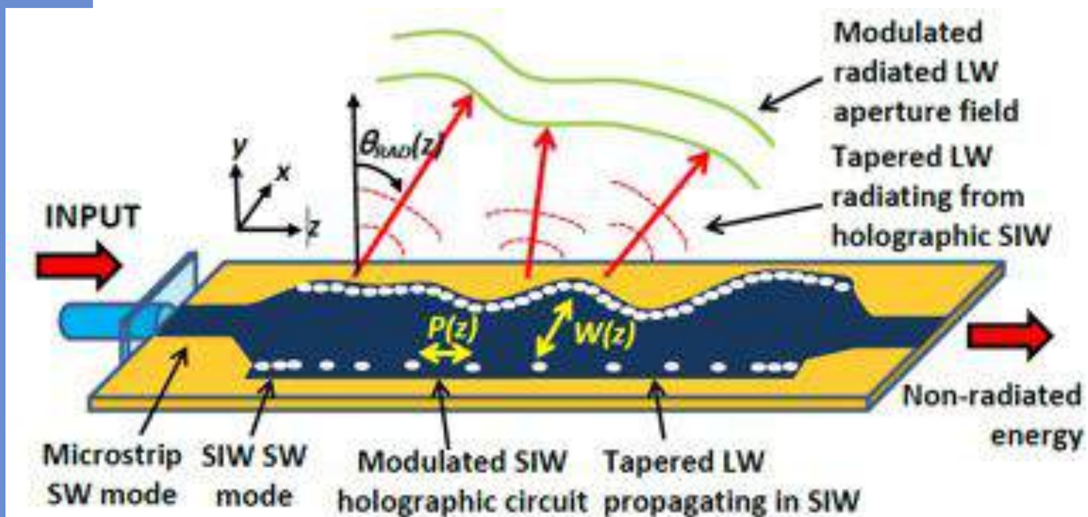
1- Modulated SIW antenna.

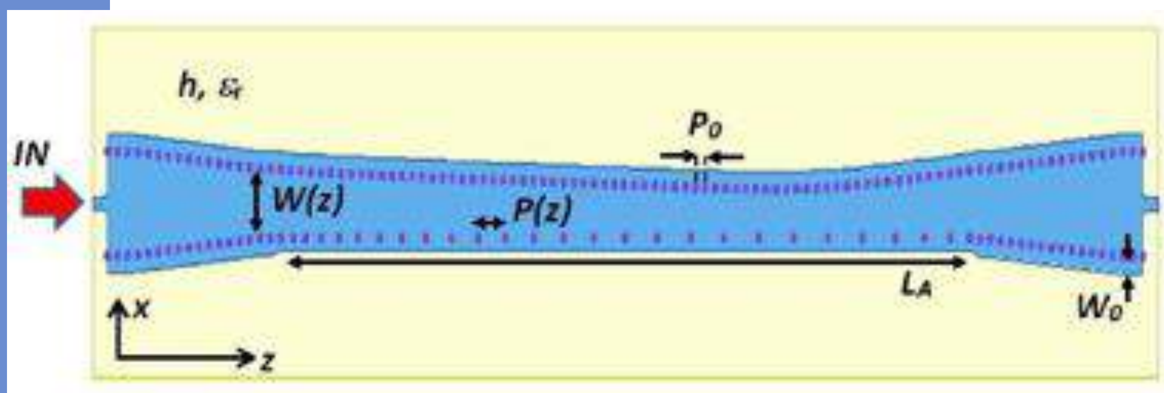
3466 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 61, NO. 7, JULY 2013

Holographic Pattern Synthesis With Modulated Substrate Integrated Waveguide Line-Source Leaky-Wave Antennas

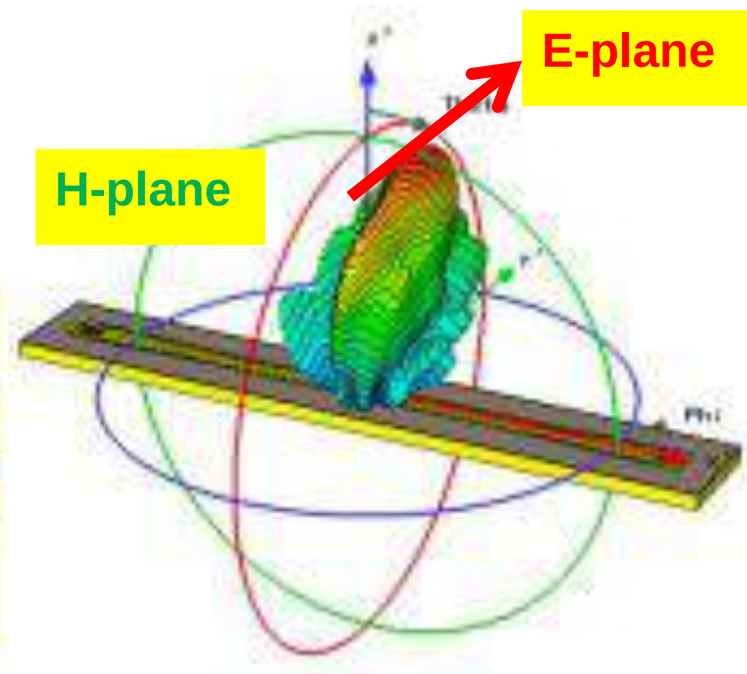
Alejandro Javier Martinez-Ros, *Student Member, IEEE*, José Luis Gómez-Tornero, *Member, IEEE*, and George Goussetis, *Senior Member, IEEE*

Scheme of holographic antenna in SIW technology:





Pencil beam with linear polarization:



1- Modulated SIW antenna.

Reference input signal (surface wave) SW: $\Psi_{IN} = \Psi_{SW}$ → **Holographic Surface with Electric Response:** $H = \Psi_{LW} \otimes \Psi_{SW}^{*}$ → Objective output radiated signal created by LW: $\Psi_{OUT} = \Psi_{LW}$

Holographic antenna → Guided to leaky-wave transformation

3212 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 58, NO. 10, OCTOBER 2010

Scalar and Tensor Holographic Artificial Impedance Surfaces

Bryan H. Fong, Joseph S. Colburn, *Member, IEEE*, John J. Ottusch, John L. Visher, and Daniel F. Sievenpiper, *Fellow, IEEE*

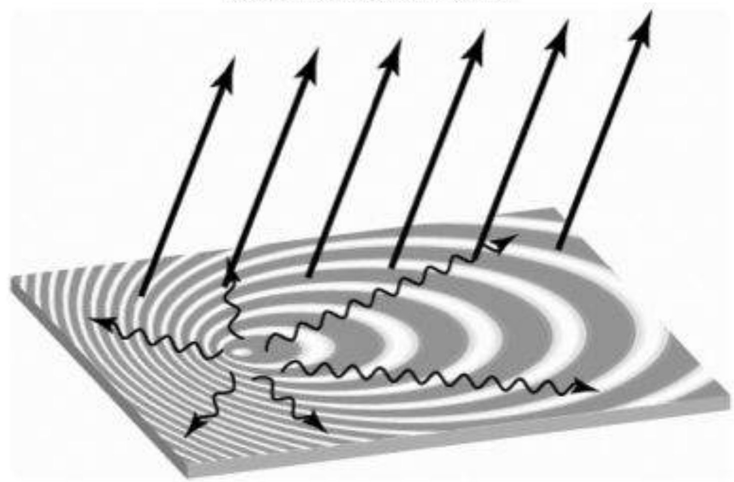
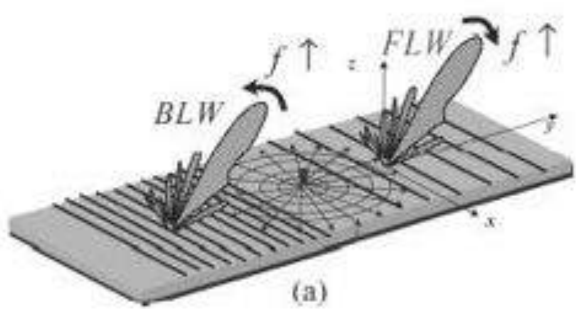


Fig. 1. Holographic leaky wave antenna concept. Surface waves (undulating arrows) are excited on an artificial impedance surface, and are scattered by variations in the surface impedance to produce the desired radiation (straight arrows).

4436 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 59, NO. 12, DECEMBER 2011

Spiral Leaky-Wave Antennas Based on Modulated Surface Impedance

Gabriele Minatti, Francesco Caminita, Massimiliano Casaletti, and Stefano Maci, *Fellow, IEEE*



Leaky-wave based interpretation of the radiation from holographic surfaces

M. Nannetti, F. Caminita, S. Maci(*)

1- Modulated SIW antenna.

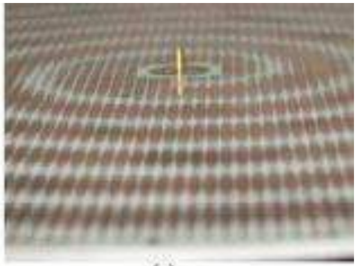
Critical point: design the modulation of the holographic surface / metasurface to obtain the desired radiated leaky fields…

IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 10, 2011 1499

Metasurfing: Addressing Waves on Impenetrable Metasurfaces

S. Maci, *Fellow, IEEE*, G. Minatti, M. Casaletti, and Marko Bosiljevac

(b)



(c)

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 59, NO. 6, JUNE 2011

A Printed Leaky-Wave Antenna Based on a Sinusoidally-Modulated Reactance Surface

Amit M. Patel, *Student Member, IEEE*, and Anthony Grbic, *Member, IEEE*

1959 *IRE TRANSACTIONS ON ANTENNAS AND PROPAGATION* S201

Guided Waves on Sinusoidally–Modulated Reactance Surfaces

A. A. OLINER† AND A. HESSEL†

OUTLINE

1- Modulated SIW antenna.

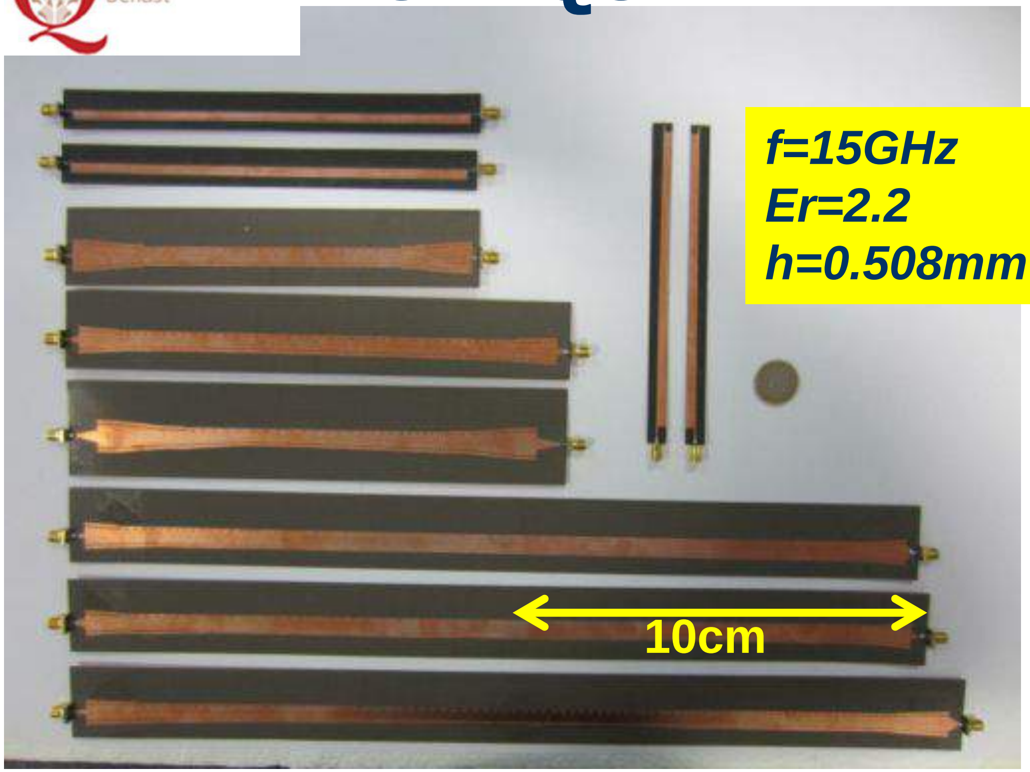
2- Synthesis Design Examples.

3- Conclusions.

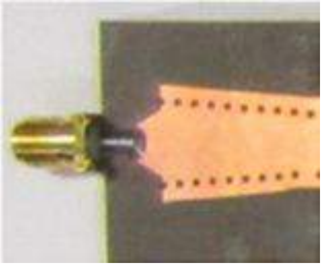
2- Manufactured prototypes.

Manufactured prototypes @15GHz:

ECIT-QUB

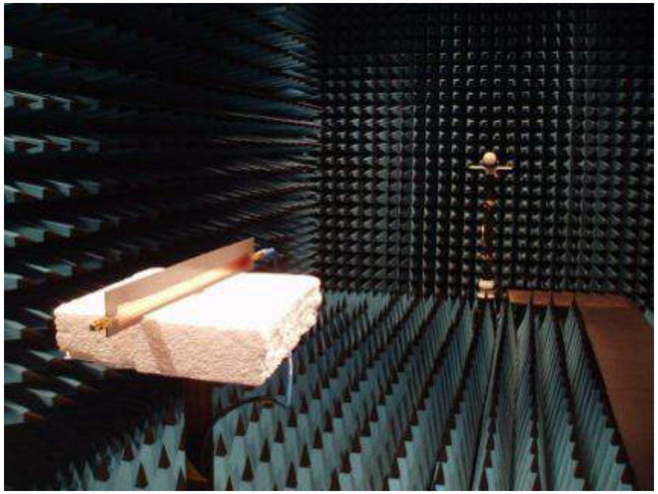


f=15GHz
Er=2.2
h=0.508mm



SMA-microstrip-SIW transition

Near and far field measurement set-up:

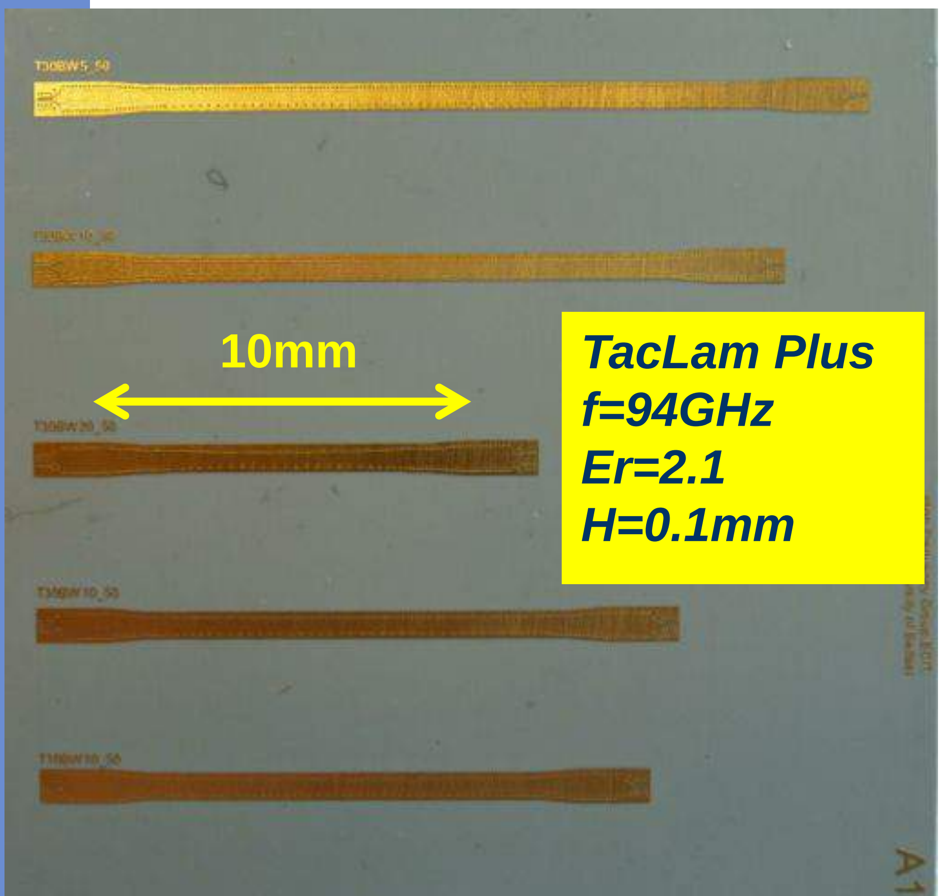


2- Manufactured prototypes.

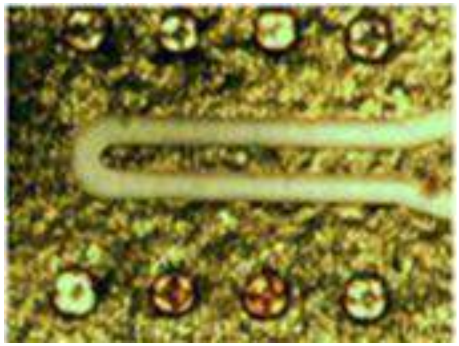
ECIT-QUB

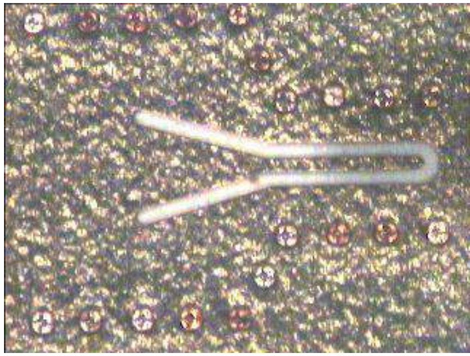
Queen's University Belfast

Manufactured prototypes @ 95GHz:



TacLam Plus
f=94GHz
Er=2.1
H=0.1mm





Coplanar CWG to SIW transition

OUTLINE

1- Modulated SIW antenna.

2- Synthesis Design Examples.

2.1- Scanning antenna with reduced SLL

2.2- Shaped beam synthesis.

2.3- Synthesis of radiation nulls.

2.4- Near-field focusing.

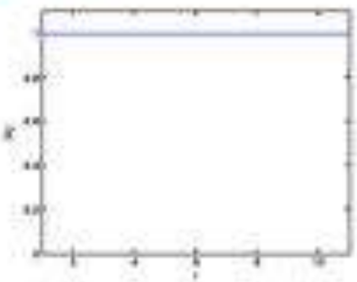
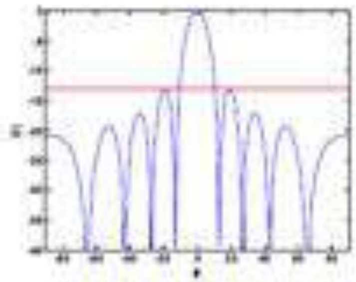
2.5- Conformal antennas.

3- Conclusions.

2.1- Scanning Antenna with Reduced SLL.

Aperture Distribution (Taper) Function and Far Field

- Uniform

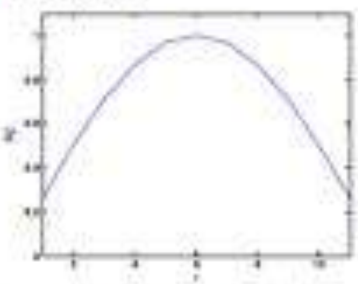
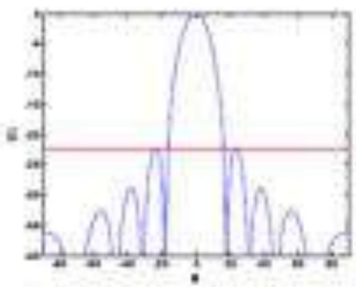



$SLL \approx -13\text{dB}$

$\Delta\phi_{3dB} \approx 11.6°$

$\eta_{\text{Taper}} = 100\%$

- Cosine

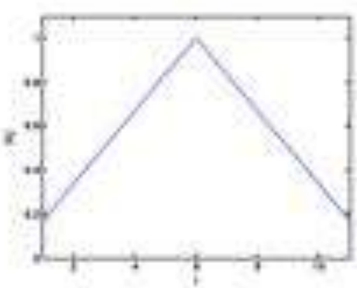
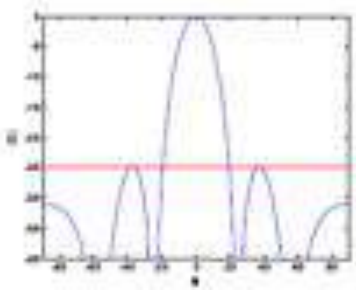



$SLL \approx -23\text{dB}$

$\Delta\phi_{3dB} \approx 14.3°$

$\eta_{\text{Taper}} = 81\%$

- Triangular

$SLL \approx -25\text{dB}$

$\Delta\phi_{3dB} \approx 15.3°$

$\eta_{\text{Taper}} = 50\%$

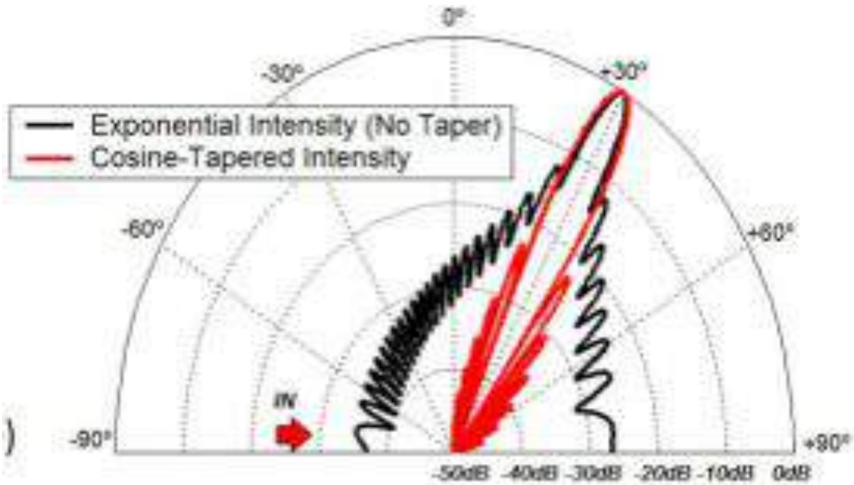
Array Geometry

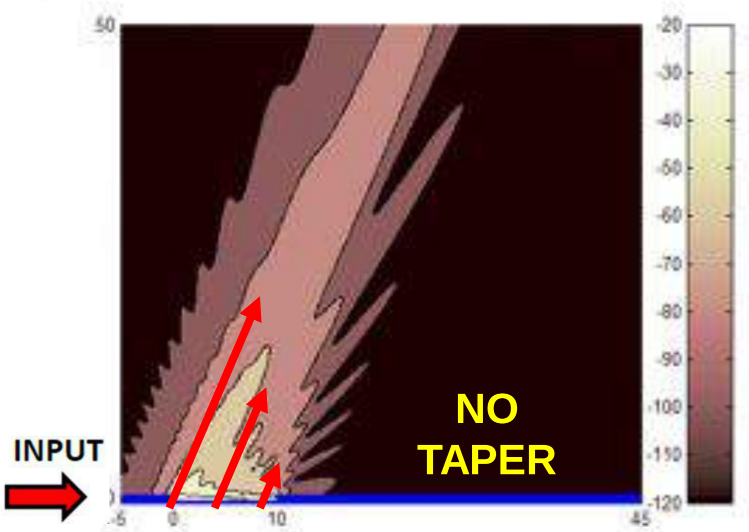
$N = 11$

$d = 0.4\,\lambda$

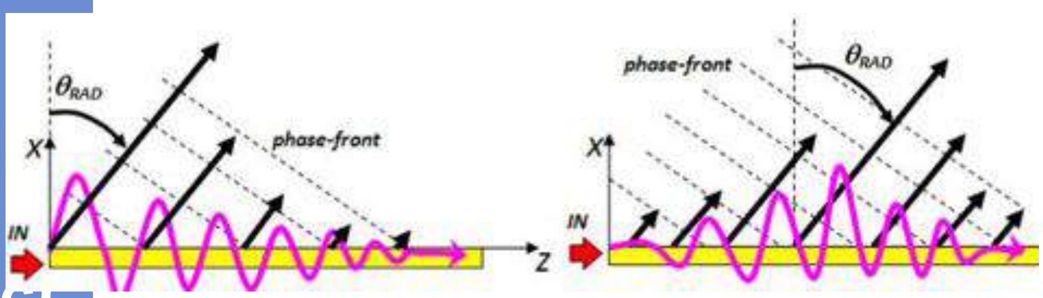
2.1- Scanning Antenna with Reduced SLL.

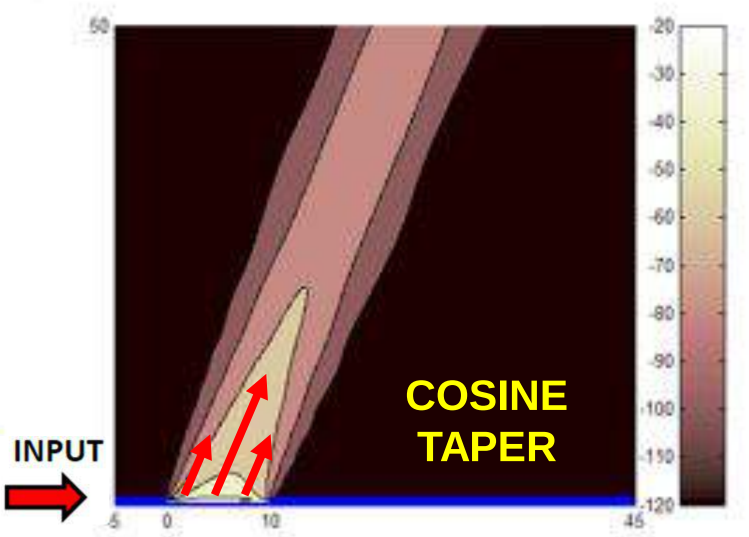
Objective:





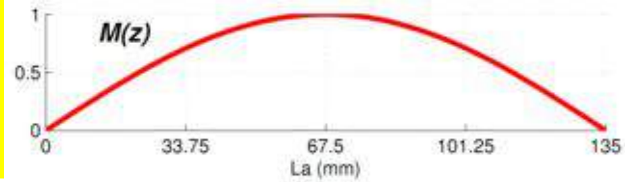
Scanned antenna with reduction of SLL



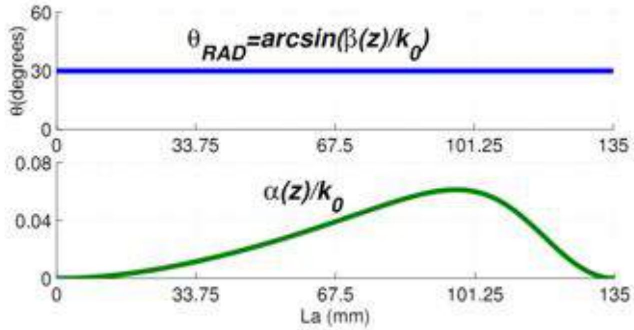


2.1- Scanning Antenna with Reduced SLL.

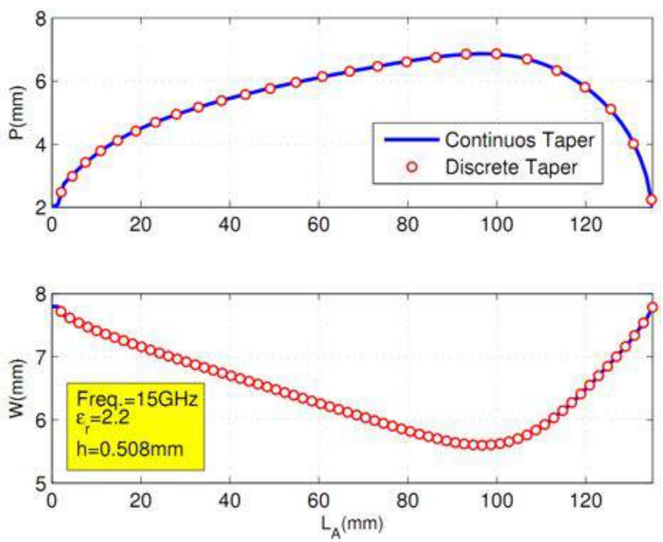
- Modulation of aperture fields and leaky wave:

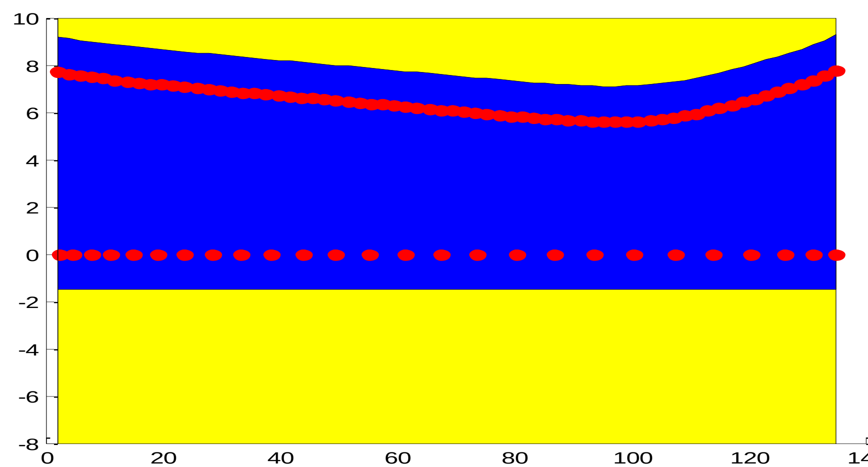


(a)



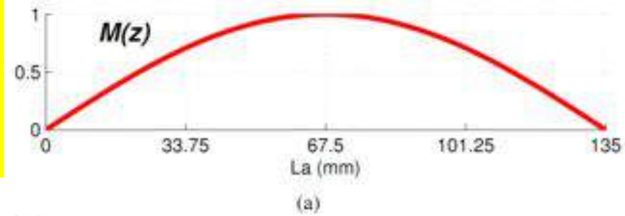
- Modulation of holographic antenna dimensions

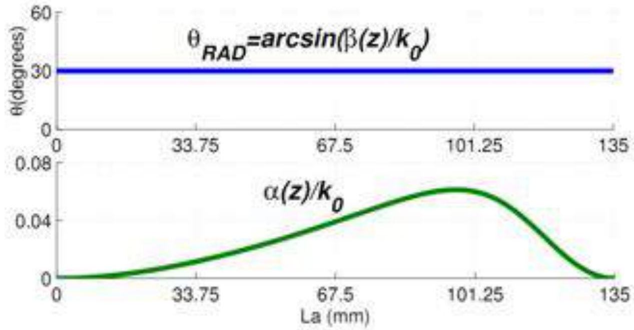


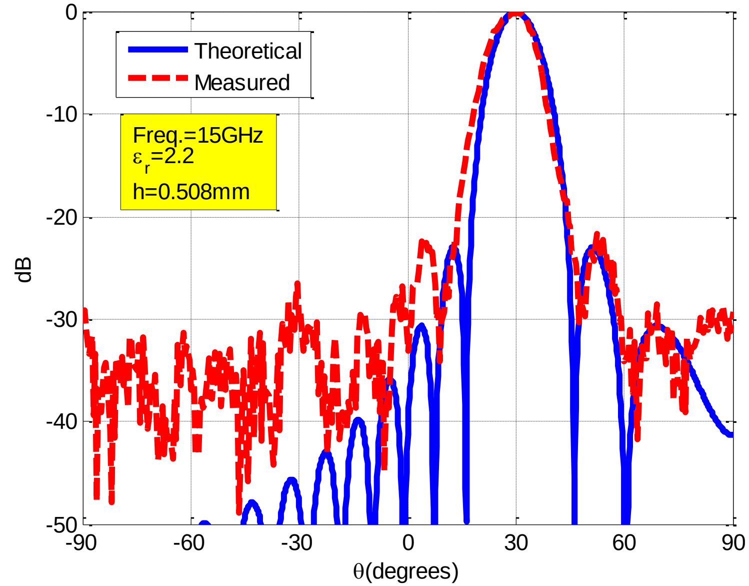


2.1- Scanning Antenna with Reduced SLL.

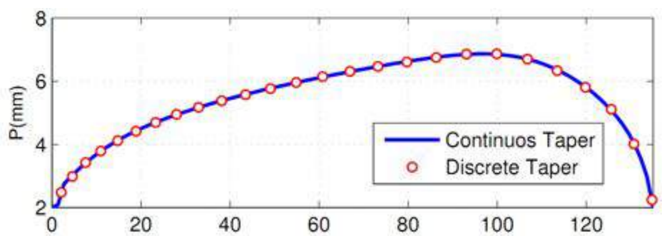
- Modulation of aperture fields and leaky wave:

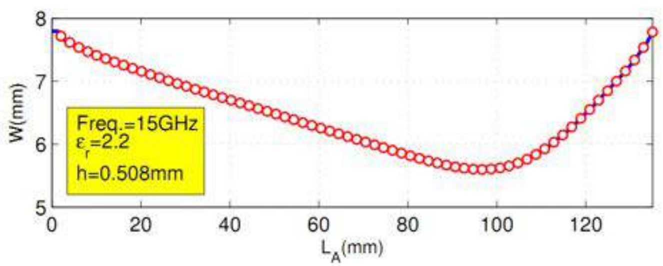


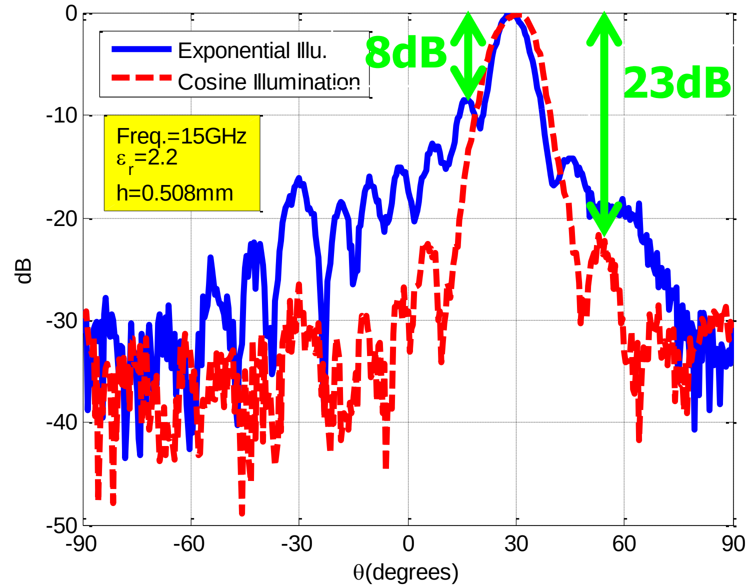




- Modulation of holographic antenna dimensions

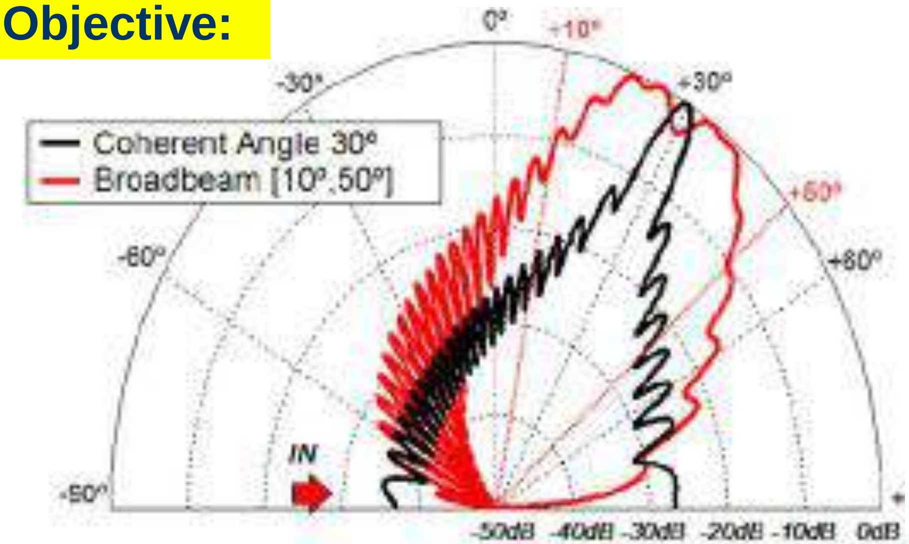


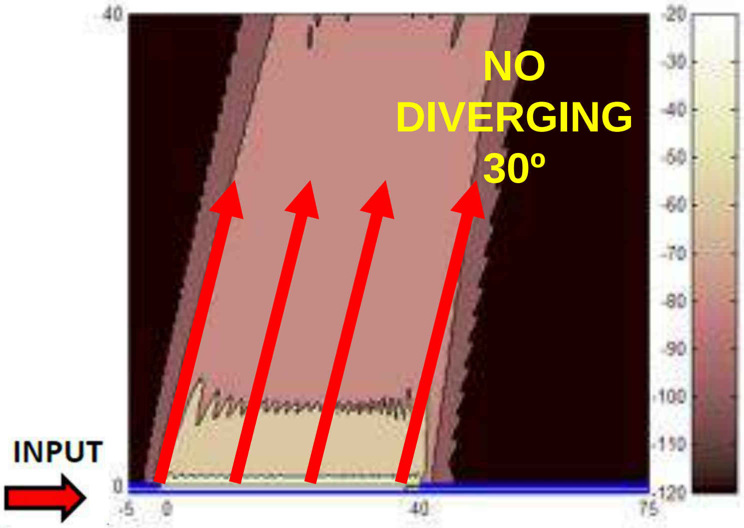




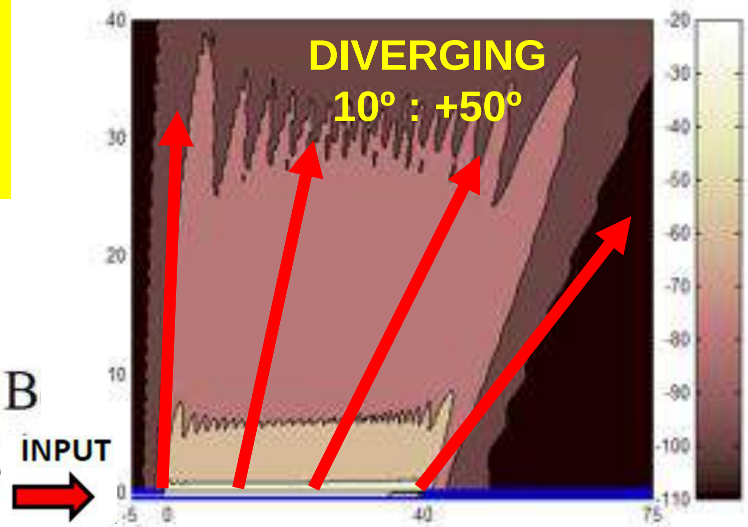
2.2- Shaped beam.

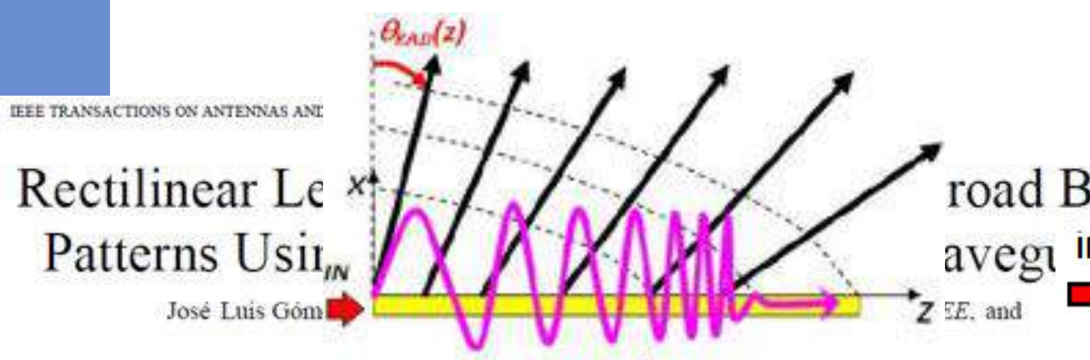
Objective:





Scanned broadbeam with high rejection out from the prescribed angular region



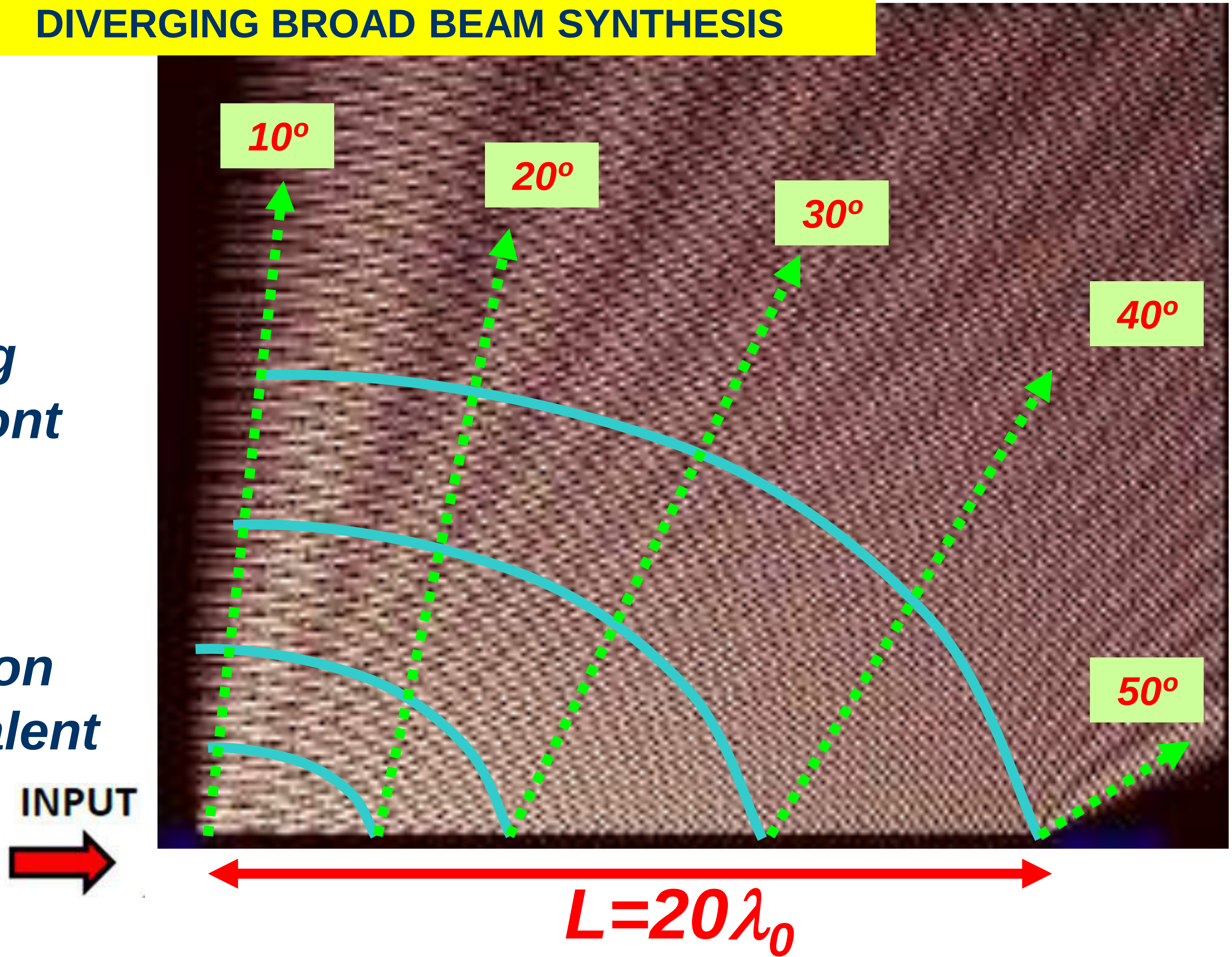


2.2- Shaped beam.

Holographic modulation OF POINTING FOR DIVERGING BROAD BEAM SYNTHESIS

Diverging phase front

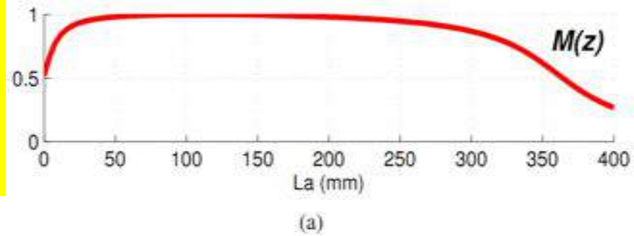
Local Modulation of equivalent radiation angle

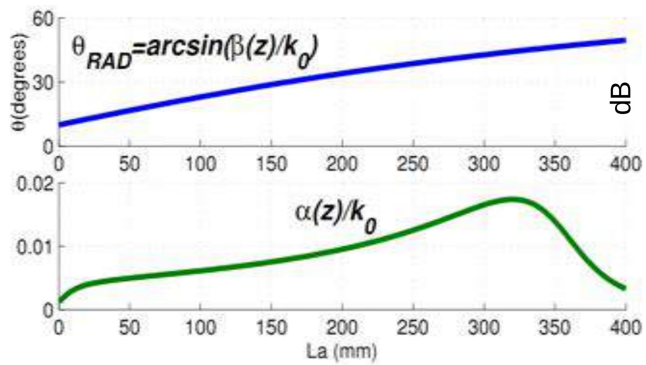


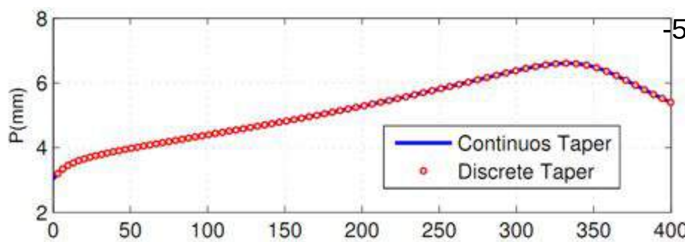
2.2- Shaped beam.

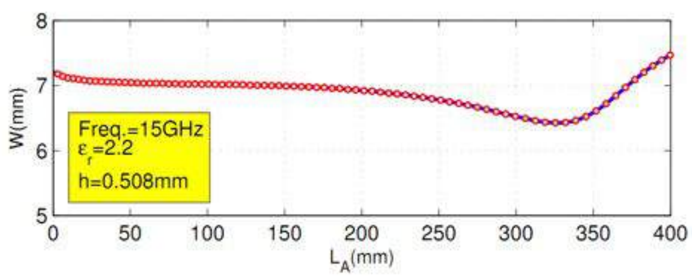
- Modulation of aperture fields and leaky wave:

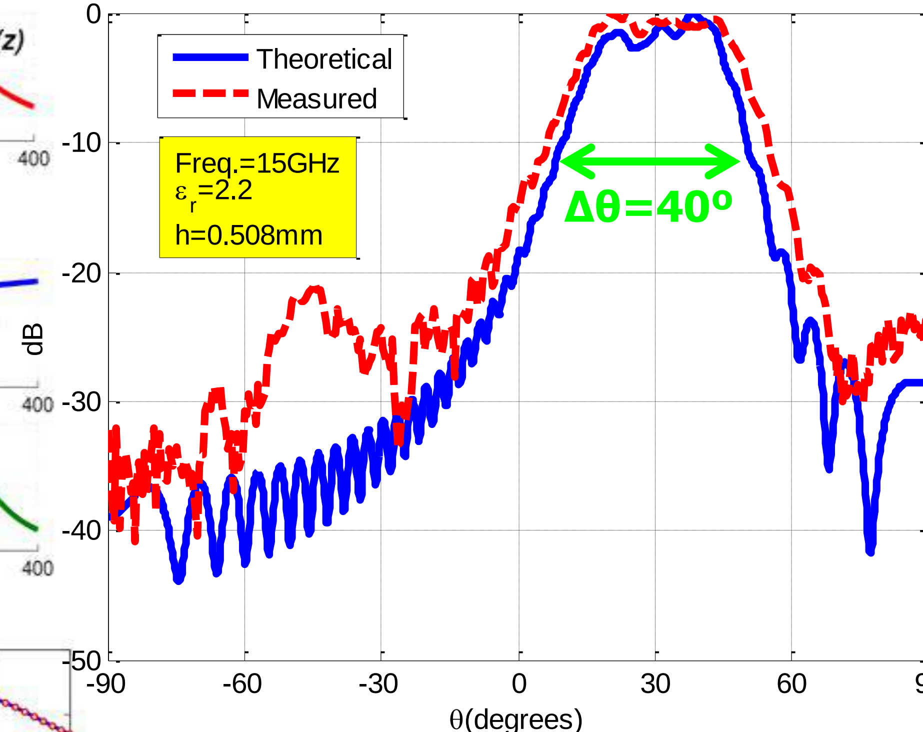
- Modulation of holographic antenna dimensions

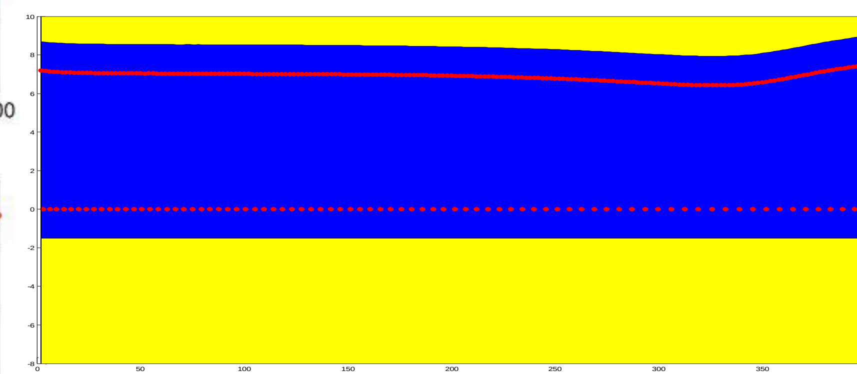






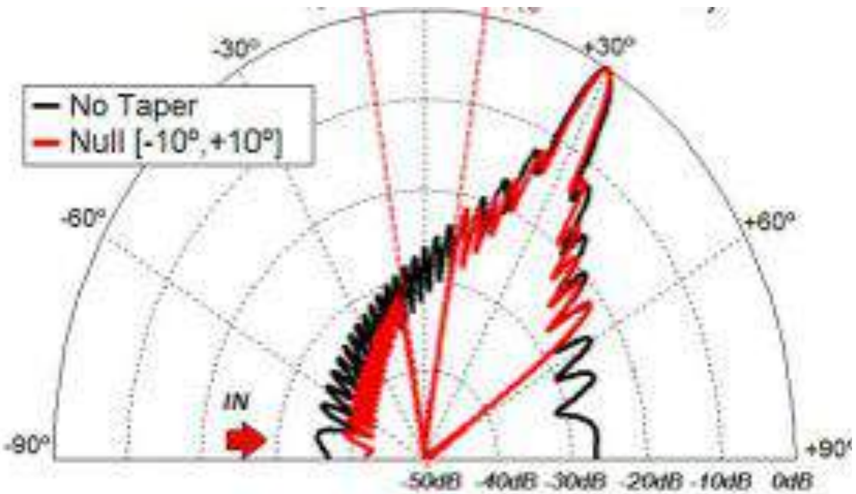


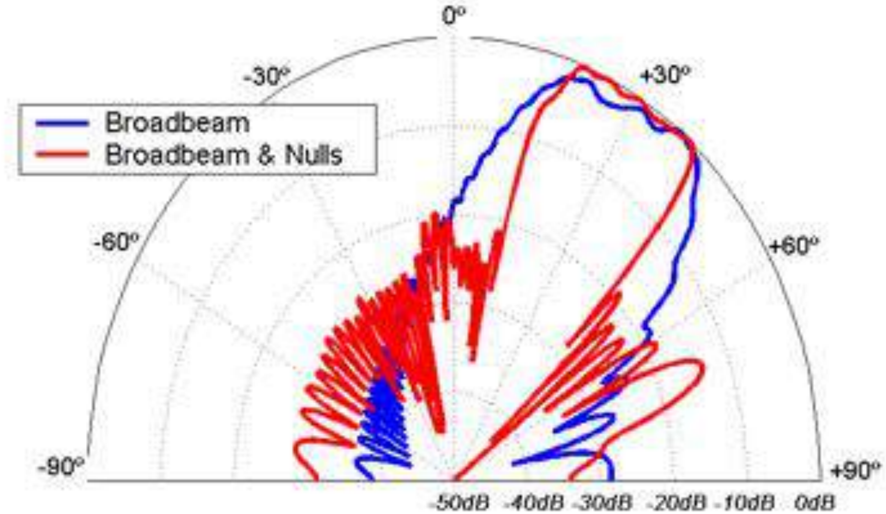




2.3- Synthesis of radiation nulls.

Objective:





Generation of radiation nulls in prescribed angular region to minimize interferences

Combination of broadbeam and radiation nulls to generate ultra-selective elliptic angular filters

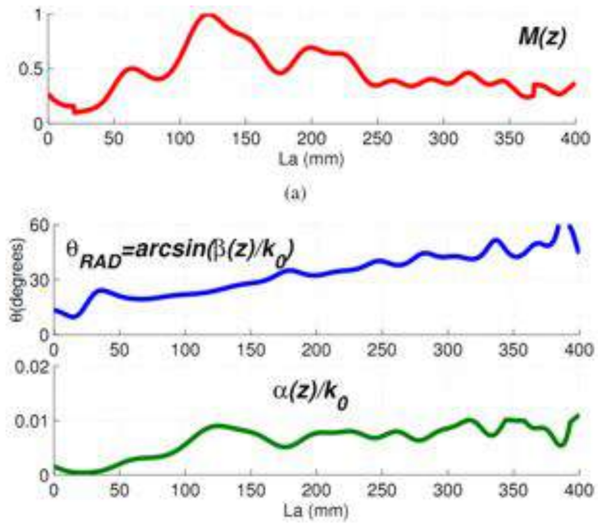
518 IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 9, 2010

FFT Synthesis of Radiation Patterns With Wide Nulls Using Tapered Leaky-Wave Antennas

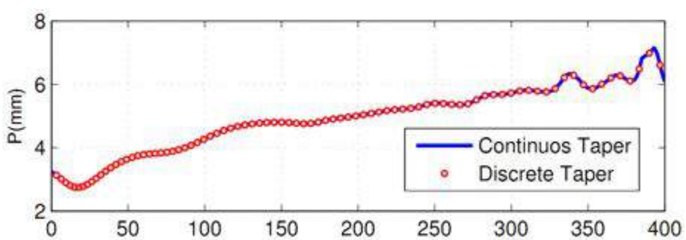
José Luis Gómez-Tornero, *Member, IEEE*, Alejandro Javier Martínez-Ros, and Rafael Verdú-Monedero

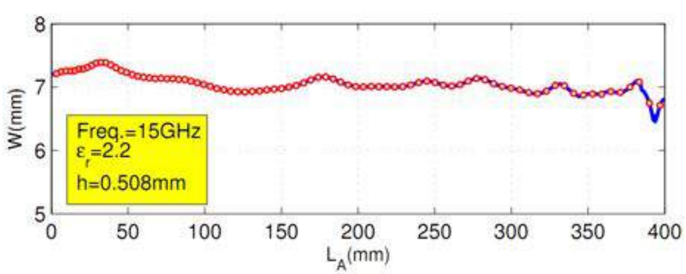
2.3- Synthesis of radiation nulls.

- Modulation of aperture fields and leaky wave:

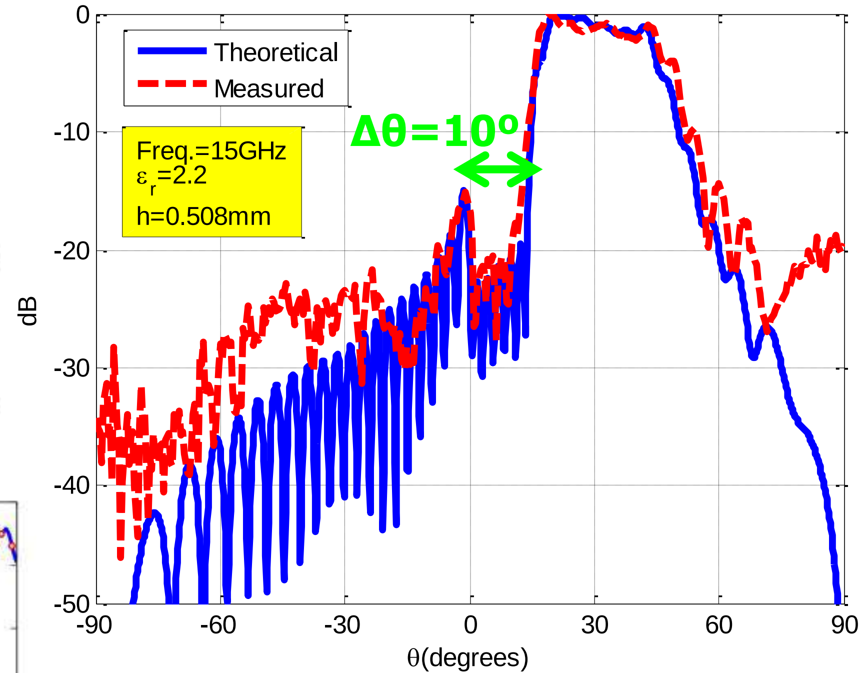


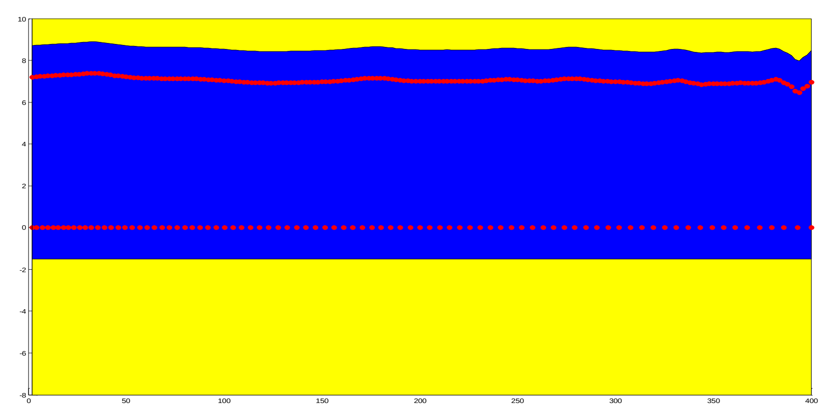
- Modulation of holographic antenna dimensions





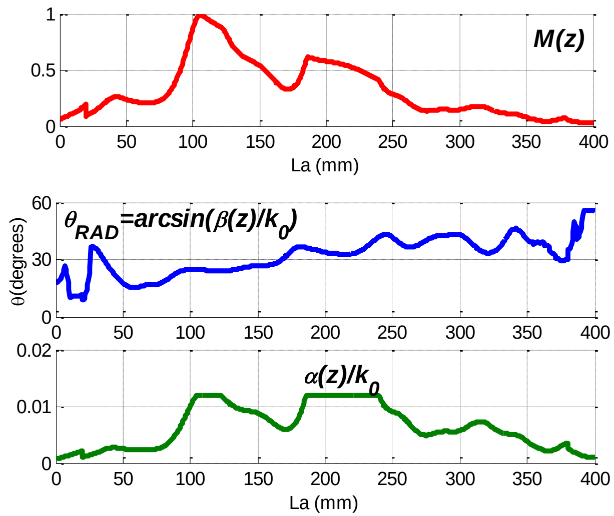
Broadbeam & One Null



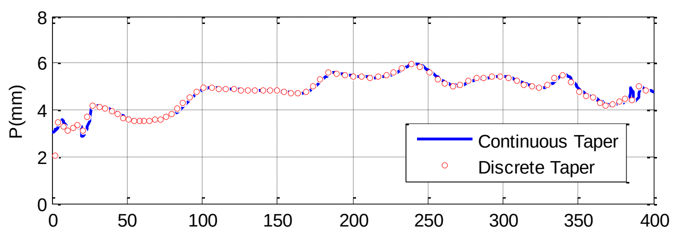


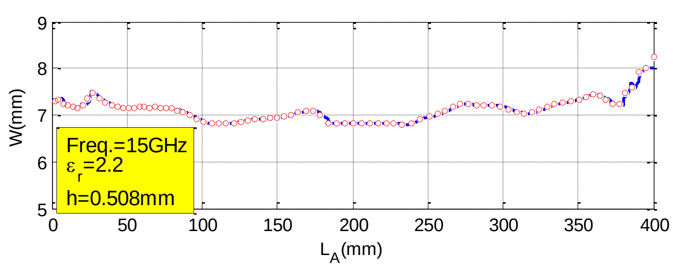
2.3- Synthesis of radiation nulls.

- Modulation of aperture fields and leaky wave:

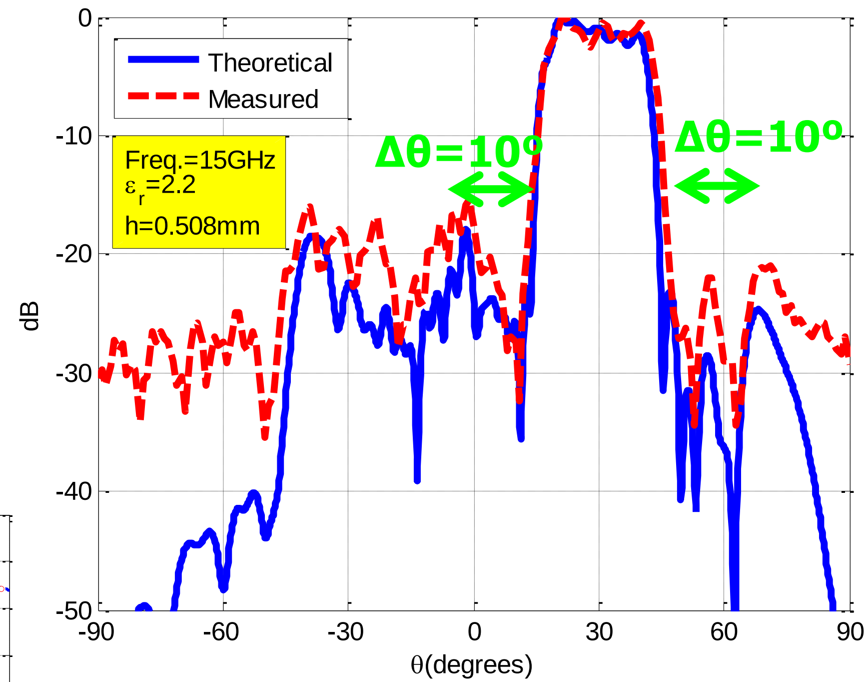


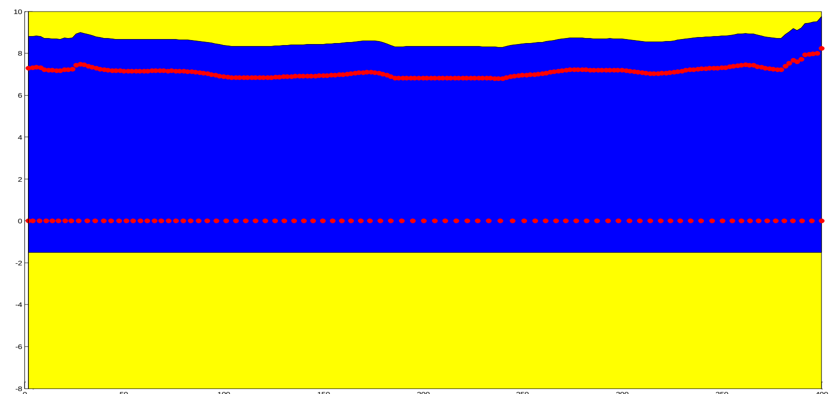
- Modulation of holographic antenna dimensions





Broadbeam & Two Nulls

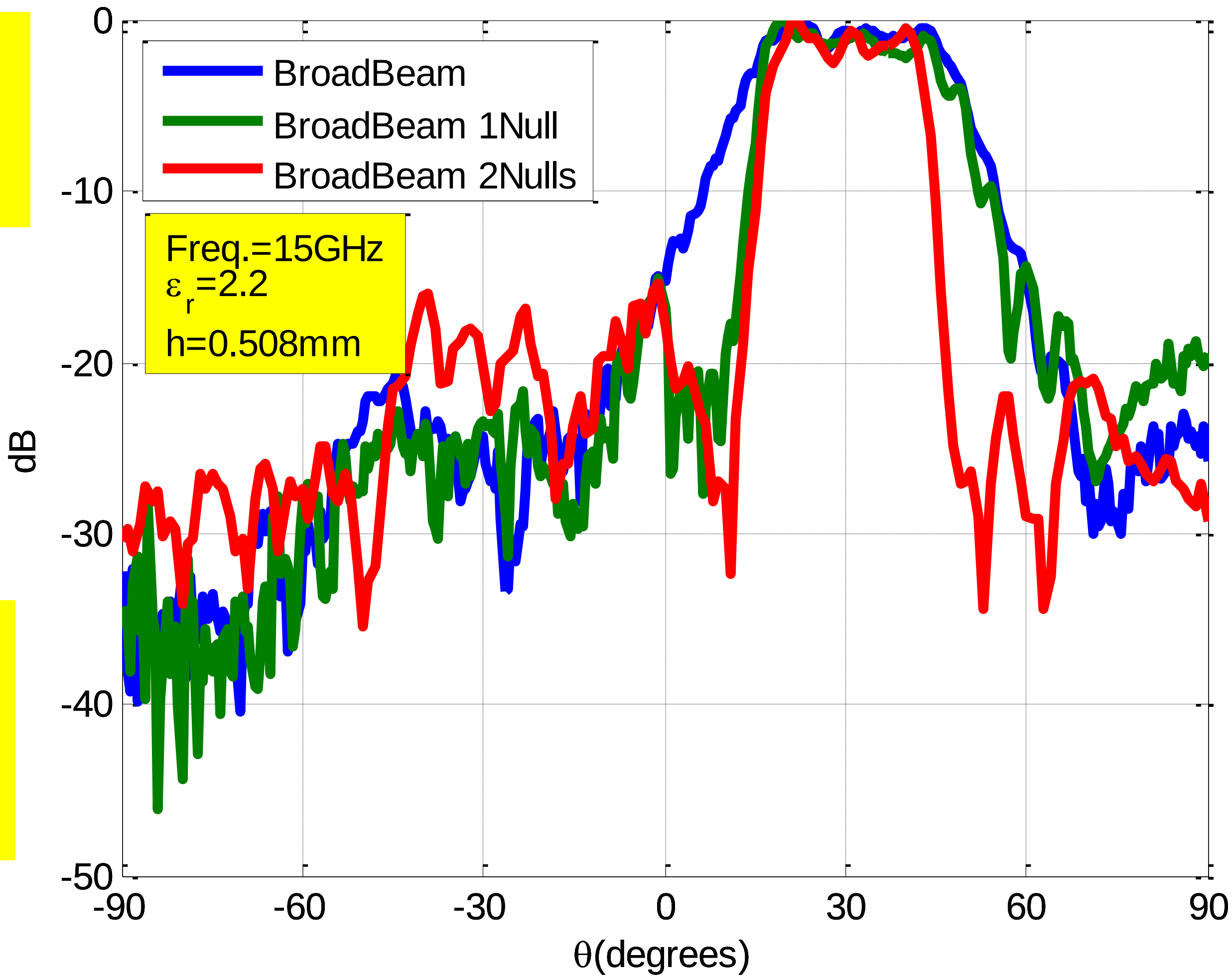




2.3- Synthesis of radiation nulls.

Holographic design of selective elliptic angular filters

From Chebyshev-type to Elliptic-type angular responses

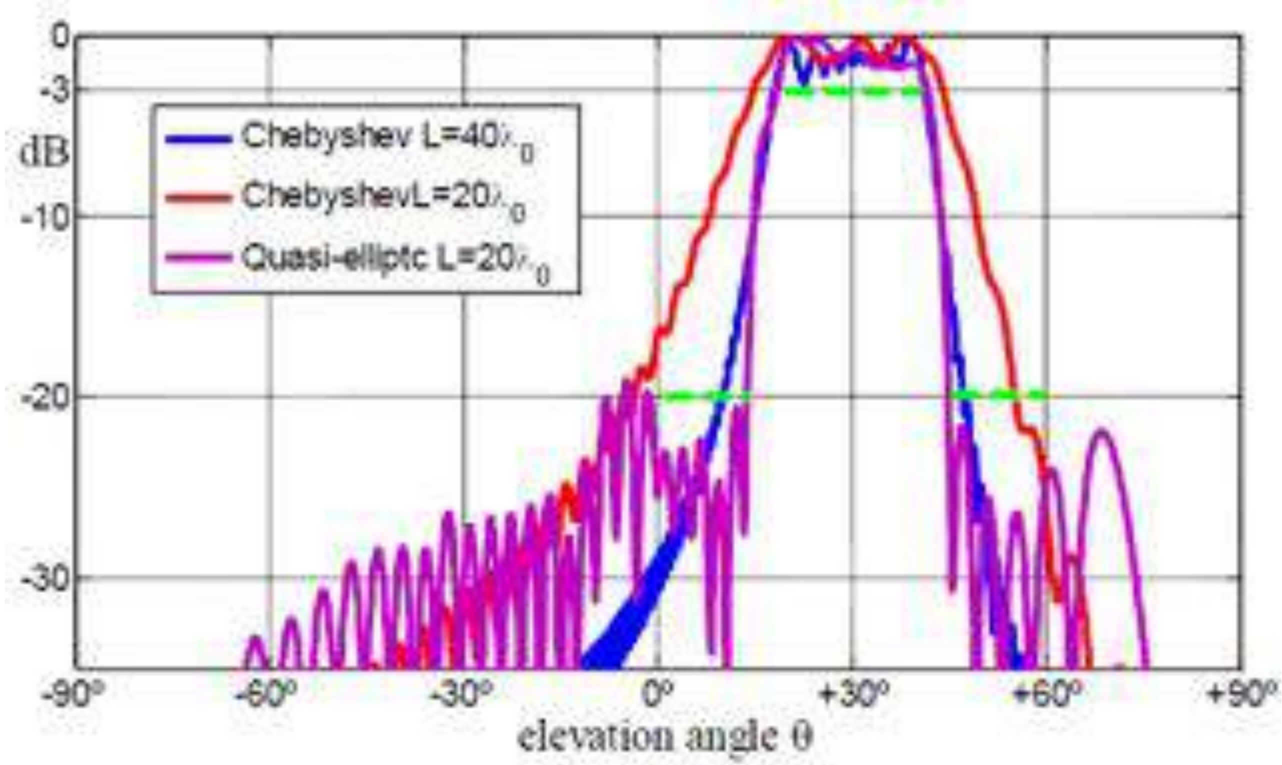


Measured Increase in the spatial filtering rejection (roll-off)

2.3- Synthesis of radiation nulls.

Holographic design of selective elliptic angular filters

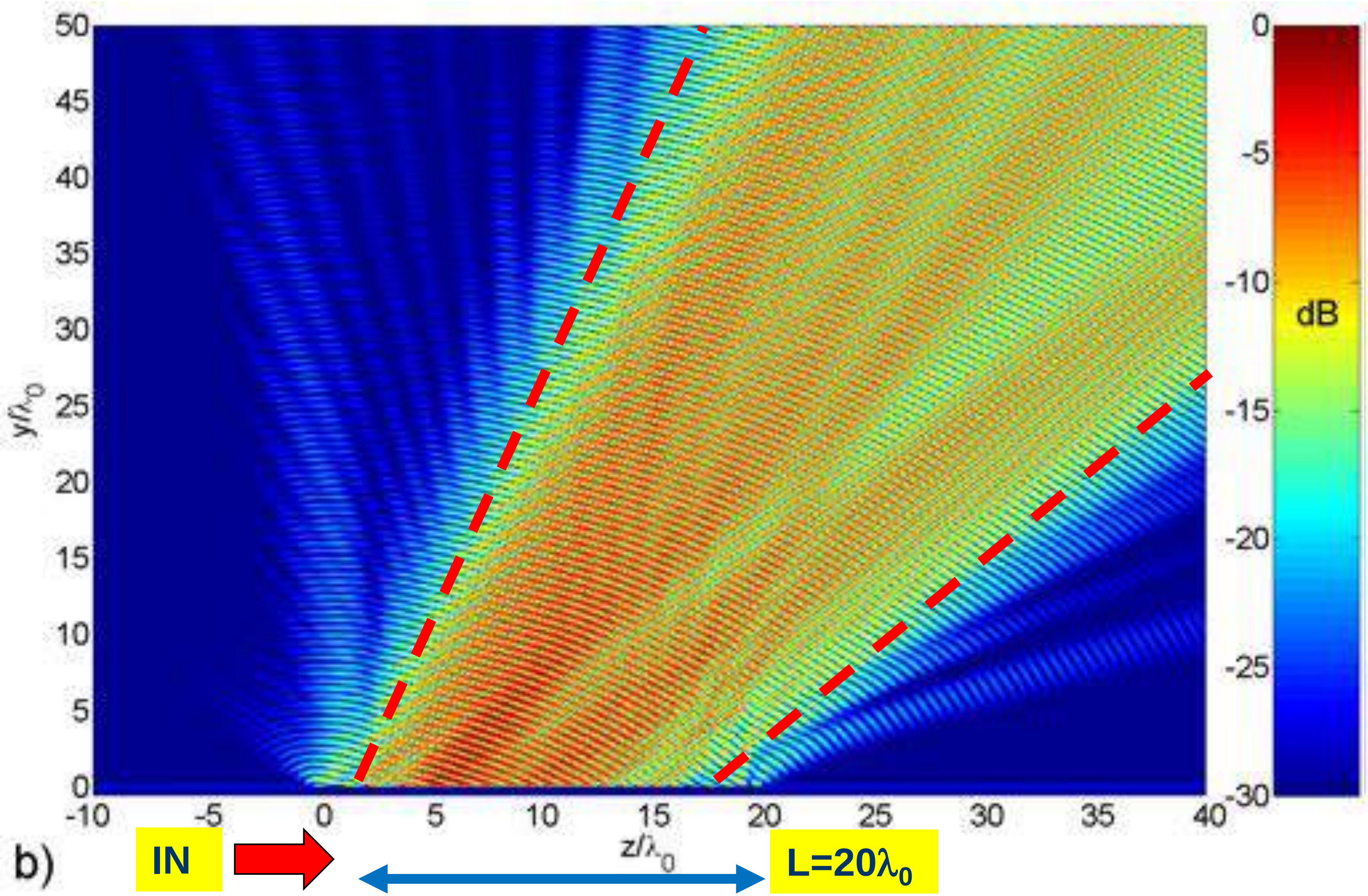
From Chebyshev-type to Elliptic-type angular responses



Length L	$5\lambda_0$	$10\lambda_0$	$20\lambda_0$	$30\lambda_0$	$40\lambda_0$
Rejection dB/º	0.5	0.7	1	1.5	2.4

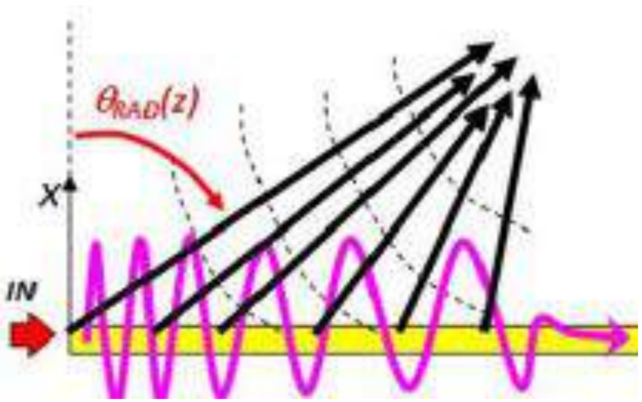
2.3- Synthesis of radiation nulls.

Holographic design of ultra selective ANGULAR BANDPASS filters



2.4- Near-field focusing synthesis.

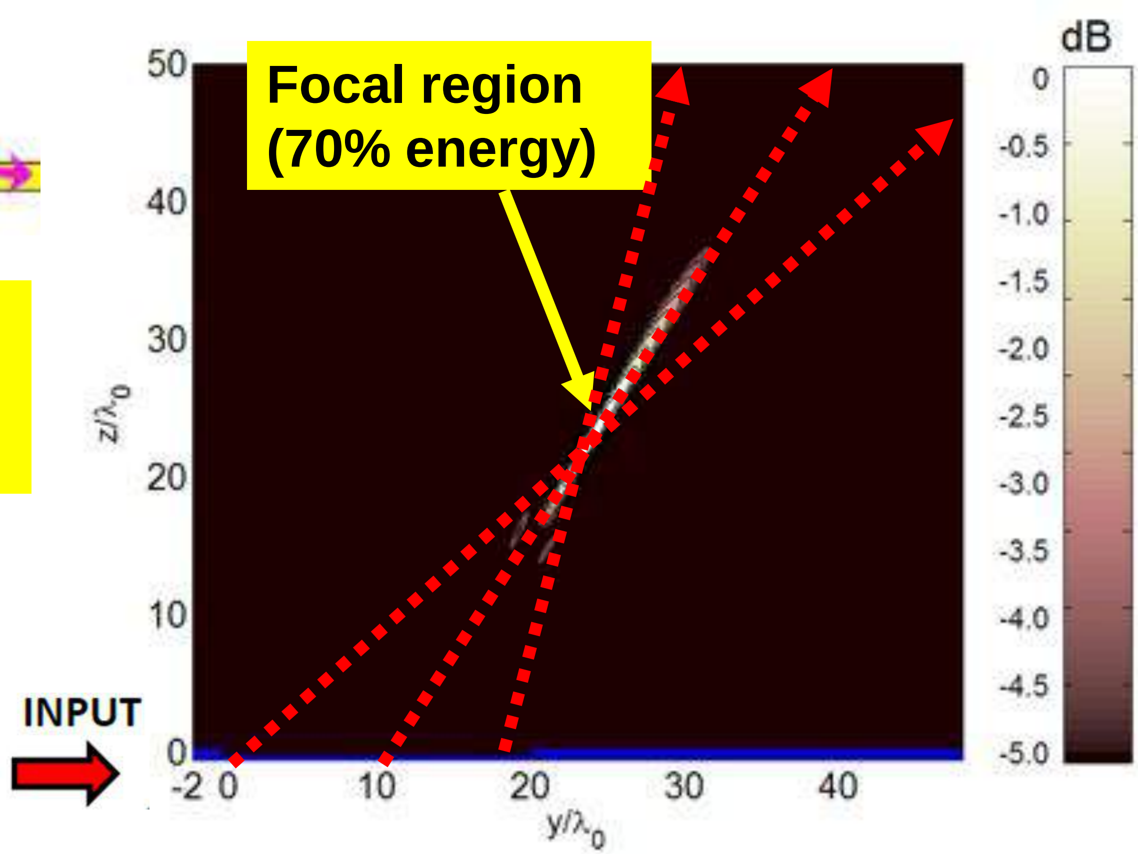
Objective:



Focusing of EM energy in the near-field (Fresnel) region

Power focusing pattern with -5dB scale.

Converging / Diverging pattern with -30dB scale

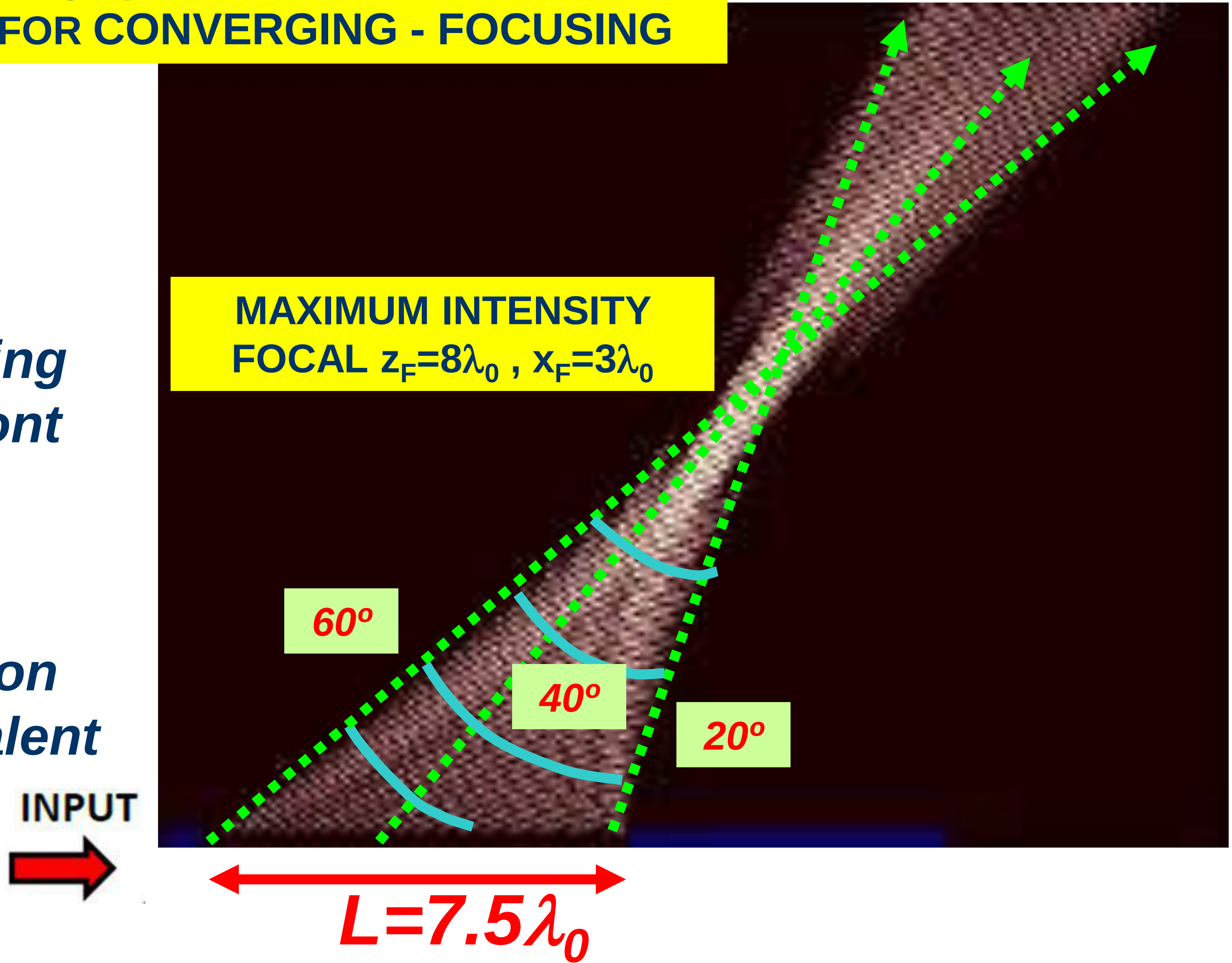


2.4- Near-field focusing synthesis.

Holographic Modulation OF POINTING FOR CONVERGING - FOCUSING

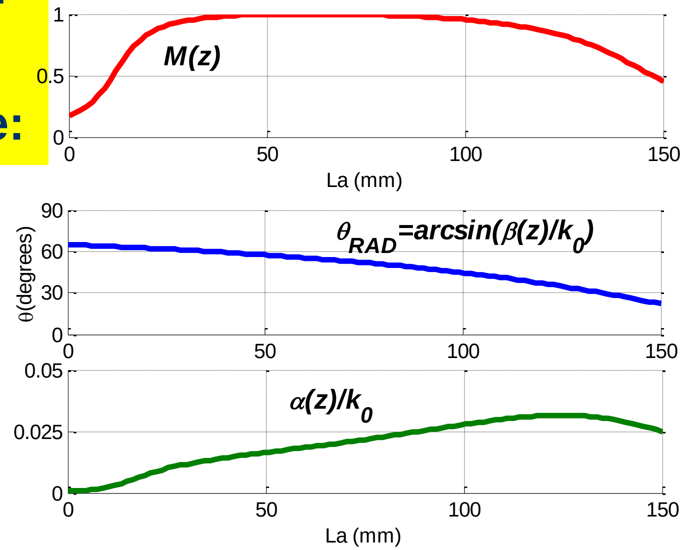
Converging phase front

Local modulation of equivalent radiation angle

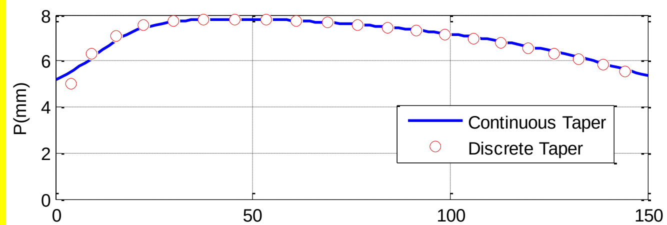


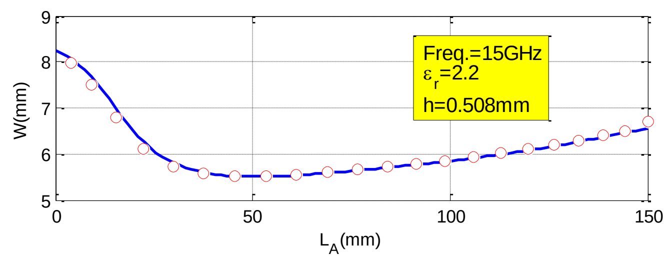
2.4- Near-field focusing synthesis.

- Modulation of aperture fields and leaky wave:

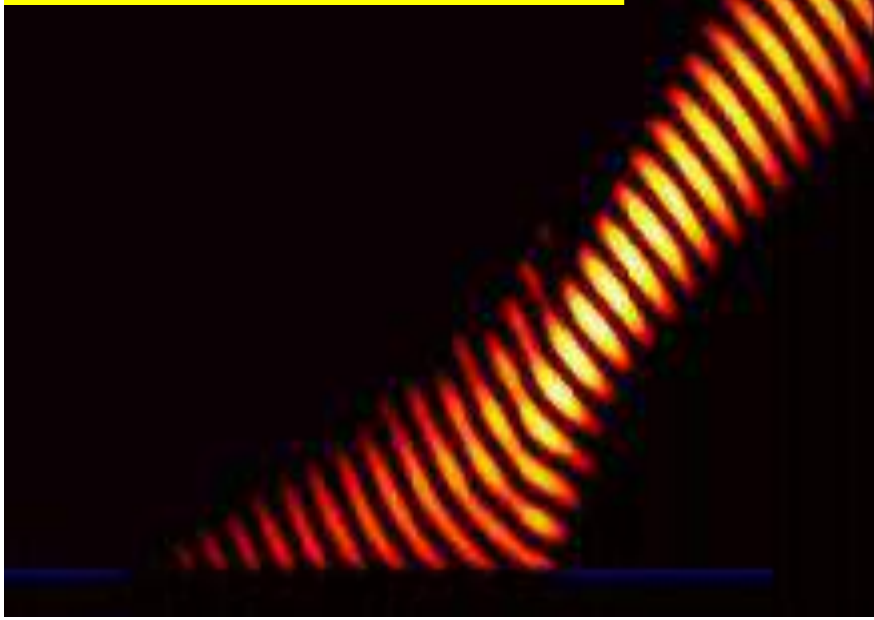


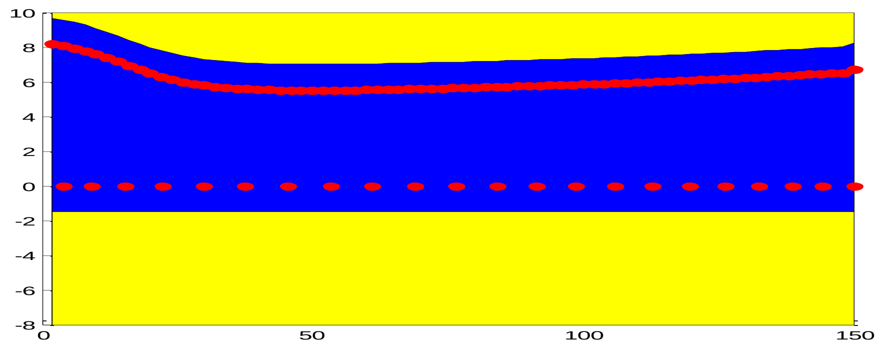
- Modulation of holographic antenna dimensions





Objective near fields

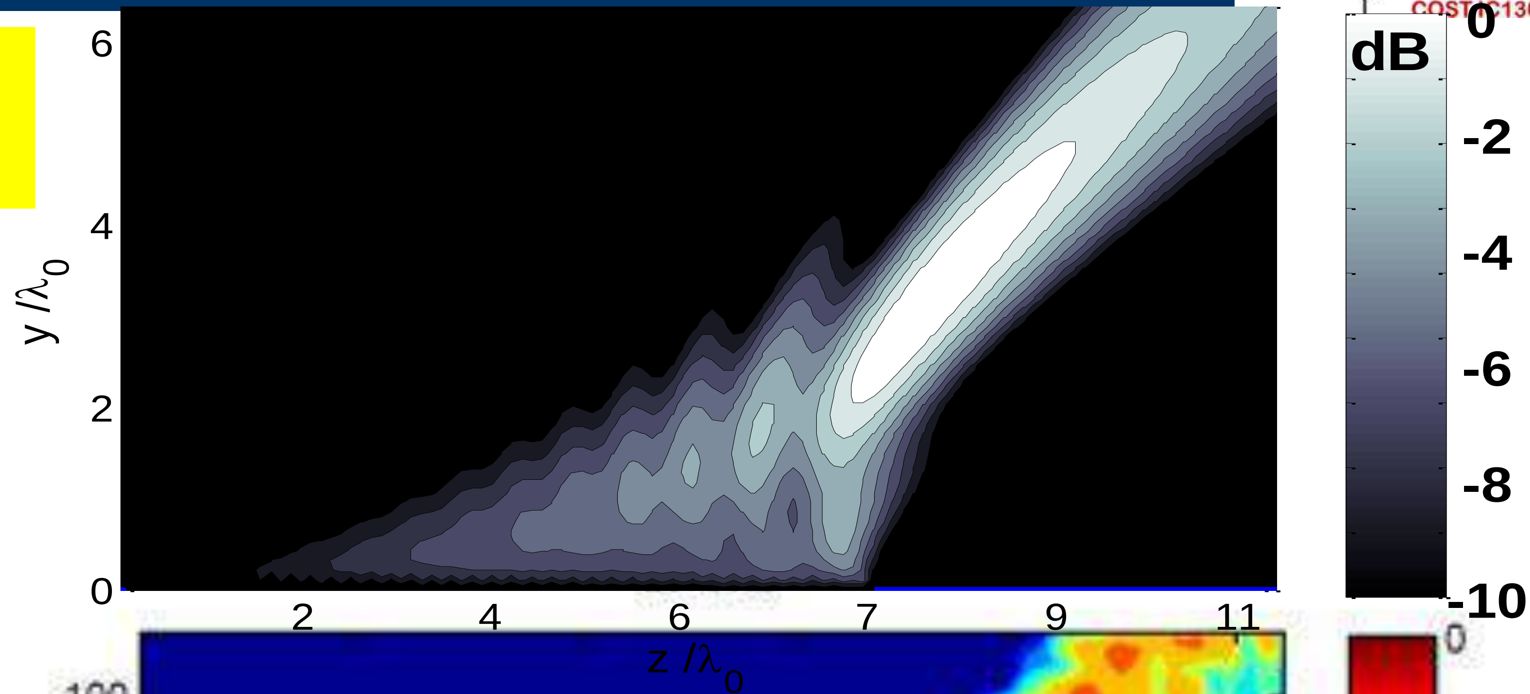




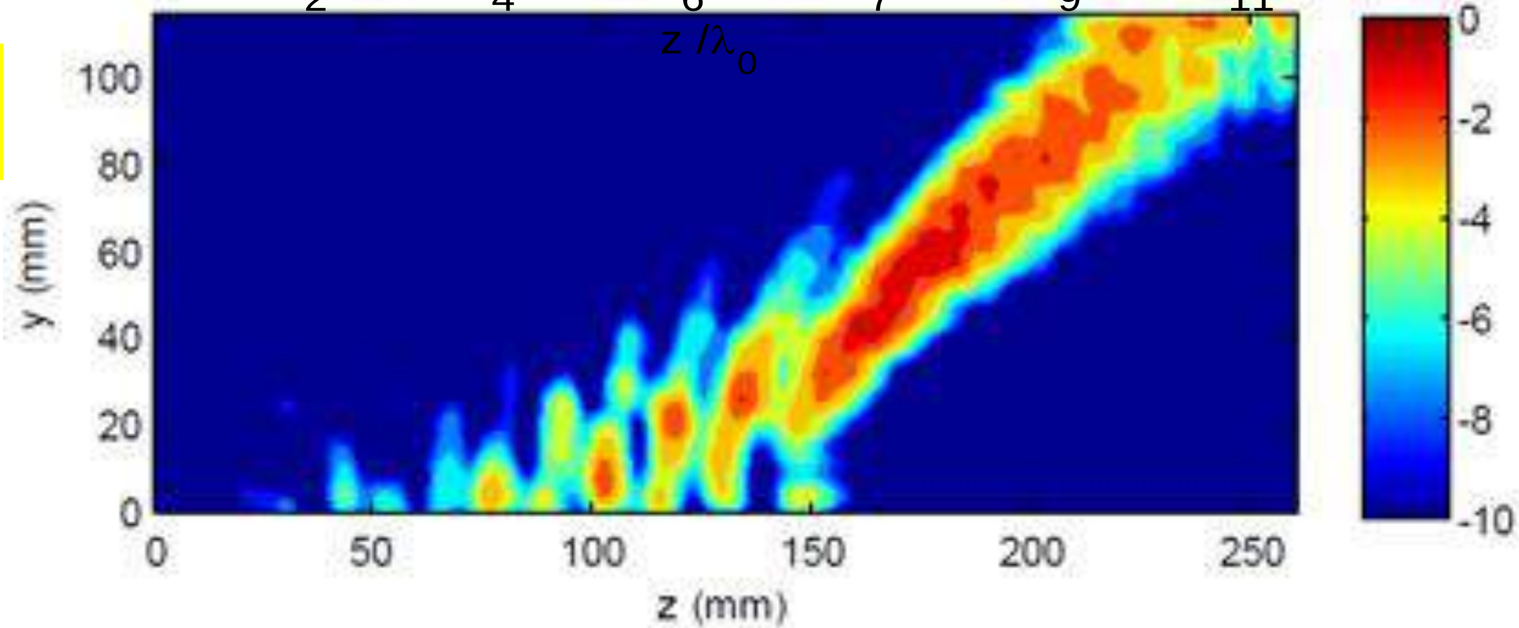
2.4- Near-field focusing synthesis.

Holographic design of leaky lenses

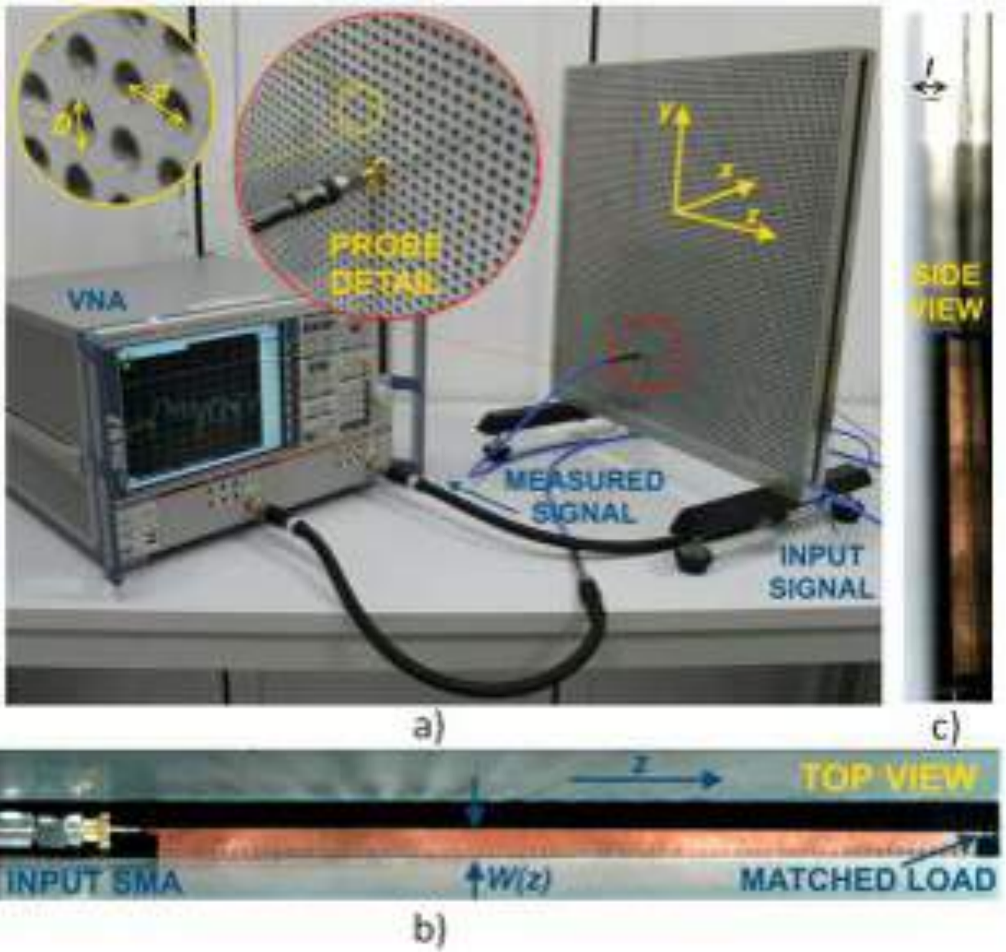
Objective near fields

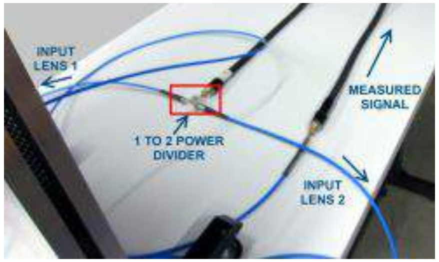


Measured near fields

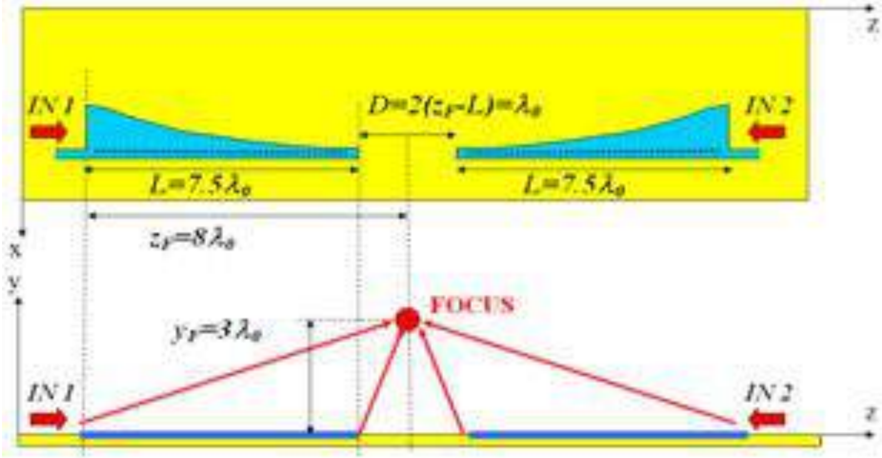


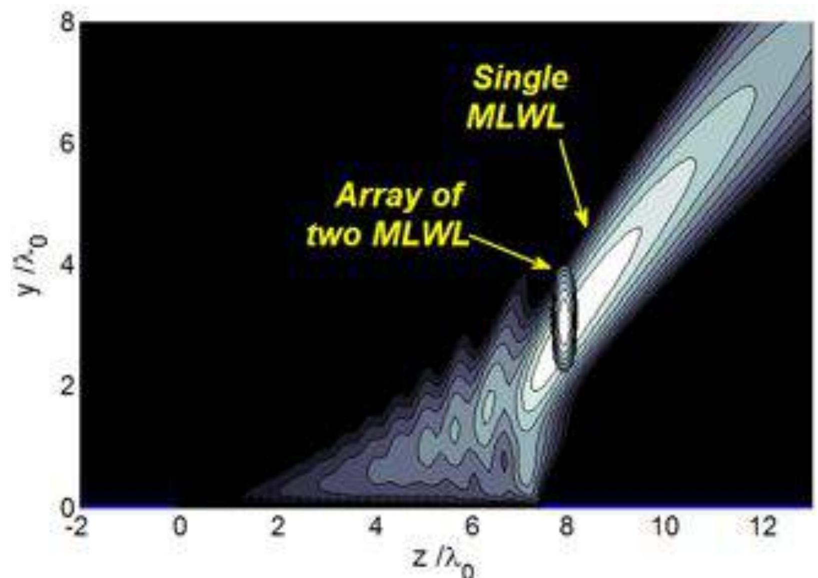
2.4- Near-field focusing synthesis.



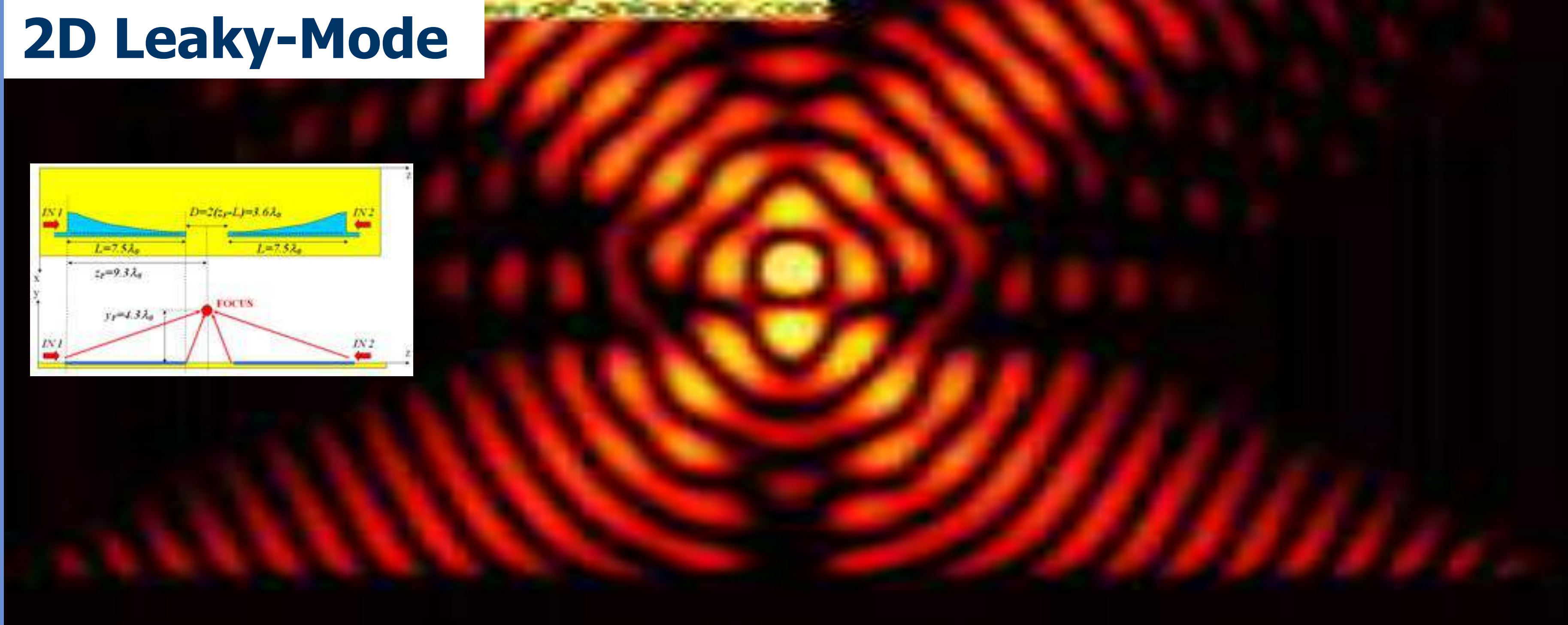


Array of two front-to-front leaky-wave lenses

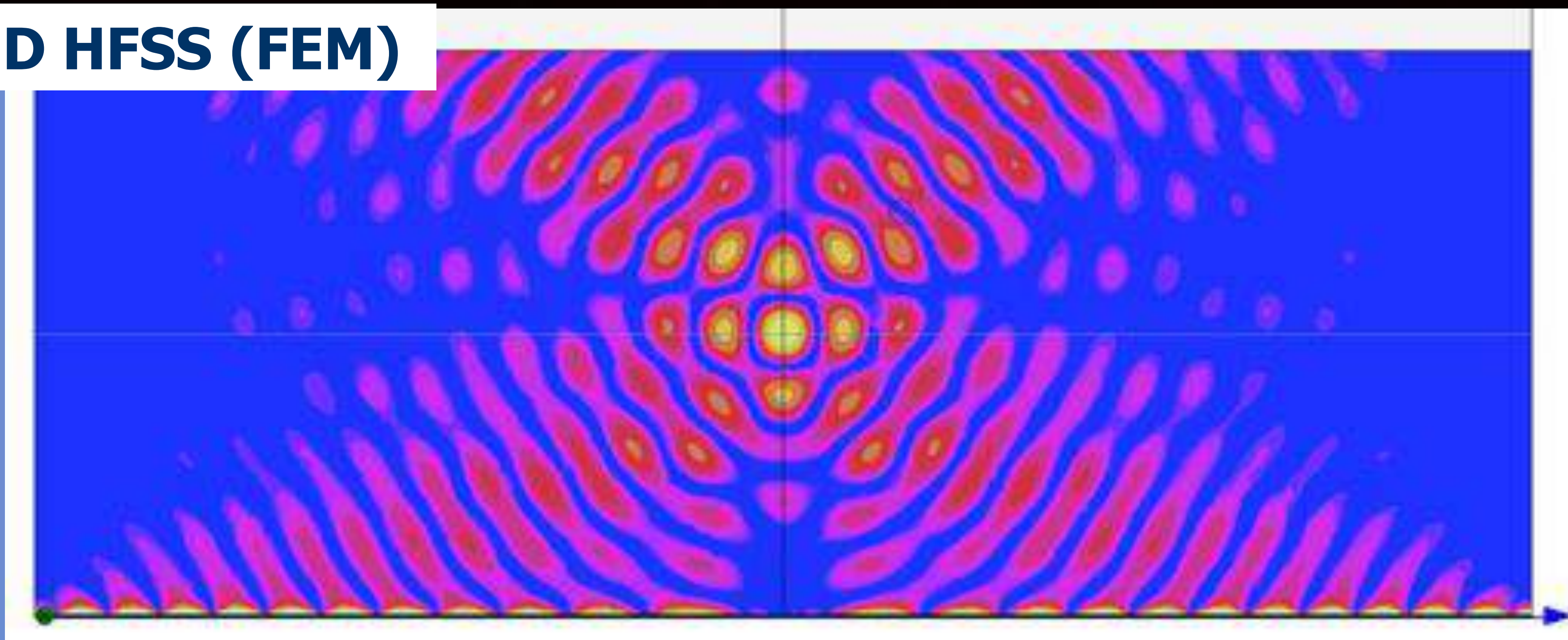




2D Leaky-Mode

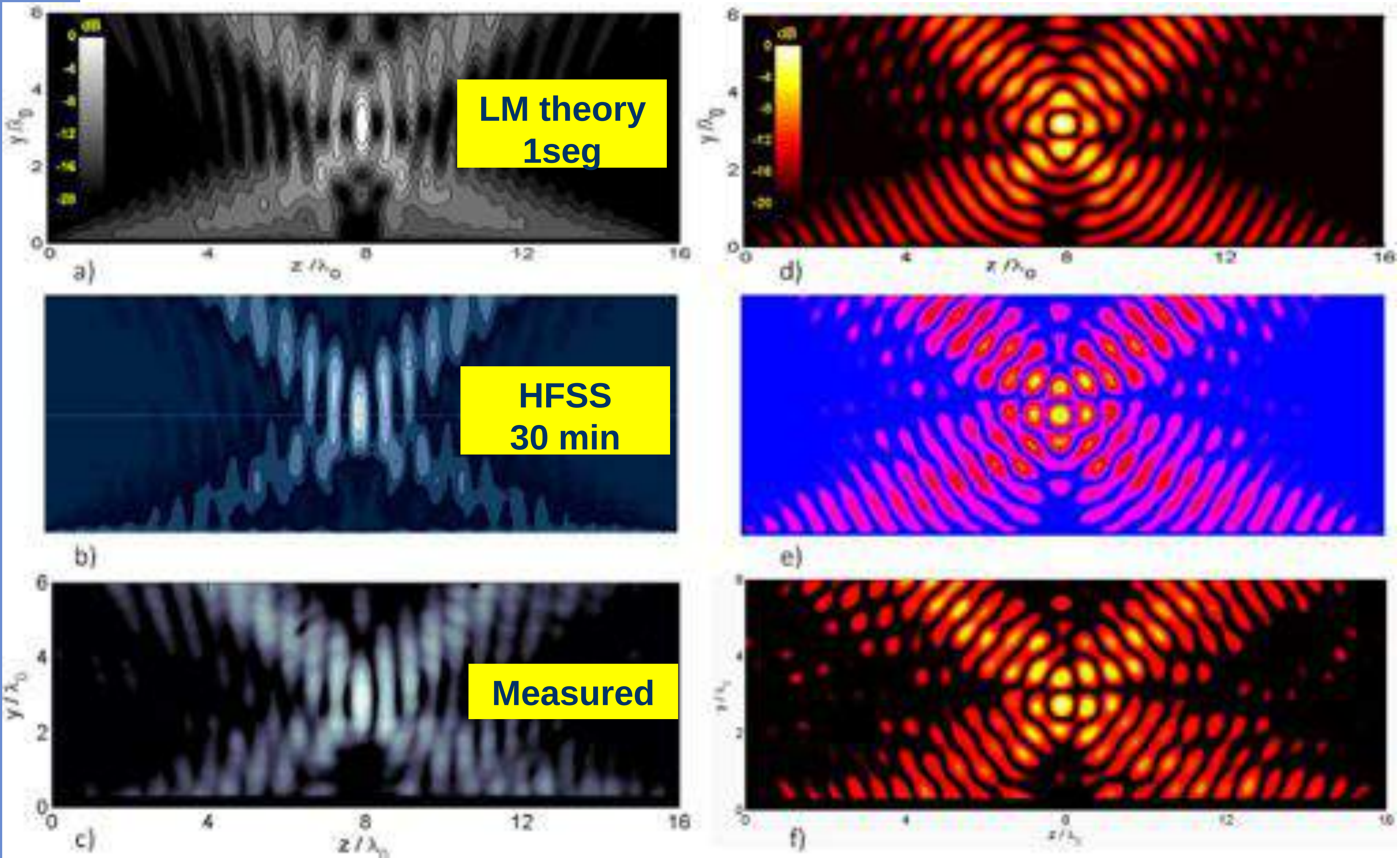


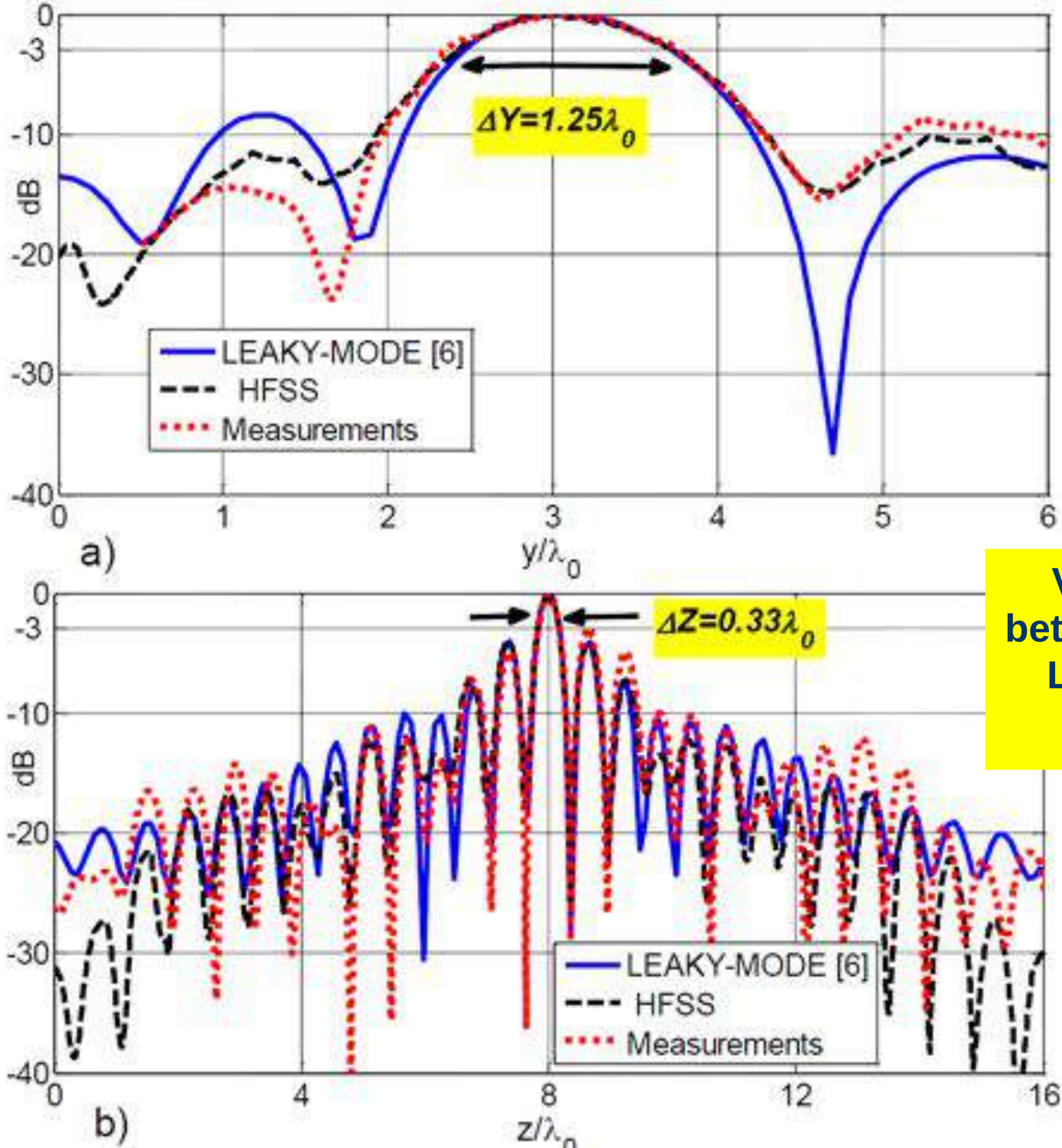
3D HFSS (FEM)



2.4- Near-field focusing.

Array of two front-to-front leaky-wave lenses $L=16\lambda_0$





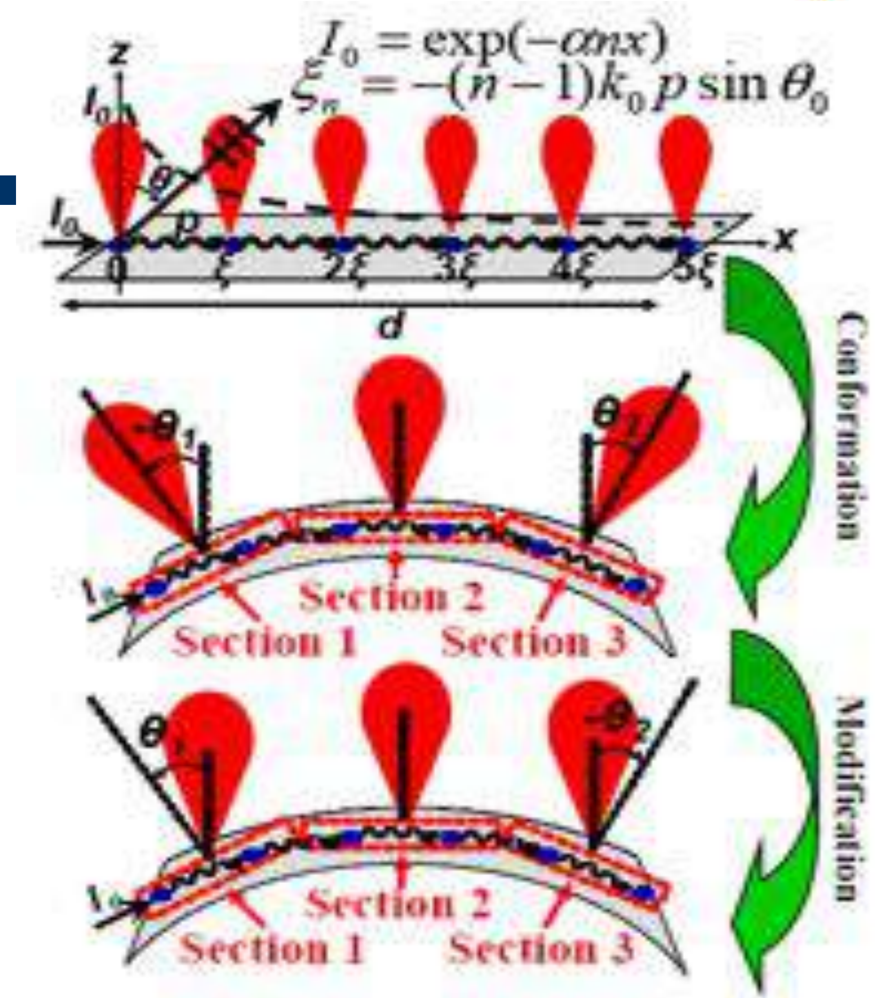
WIPE
COST IC1301

Very good agreement between: experiments and LM theory / HFSS full-wave simulations

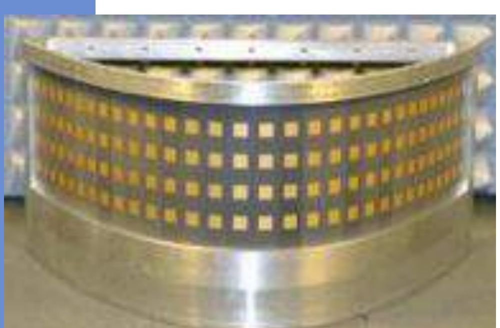
2.5- Conformal antenna



Aircrafts and vehicles telecomm.



M. R. Hashemi, and T. Itoh, "Dispersion Engineered Metamaterial-Based Transmission Line for Conformal Surface Application," *IEEE MTT-S Int. Microwave Symp*. Jun. 2008



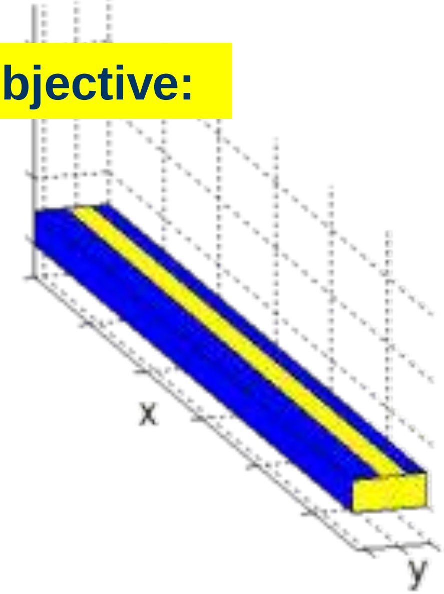
1068 IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 10, 2011

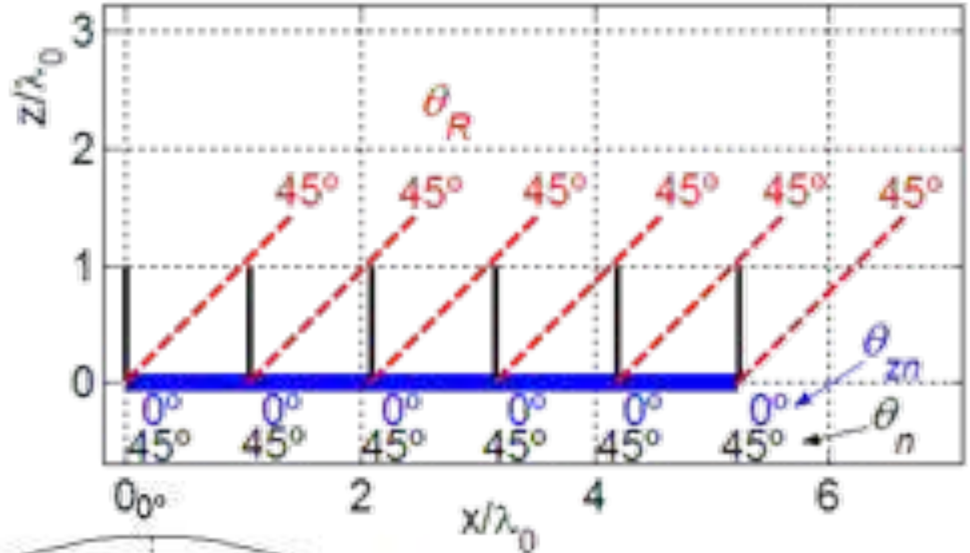
Analysis and Design of Conformal Tapered Leaky-Wave Antennas

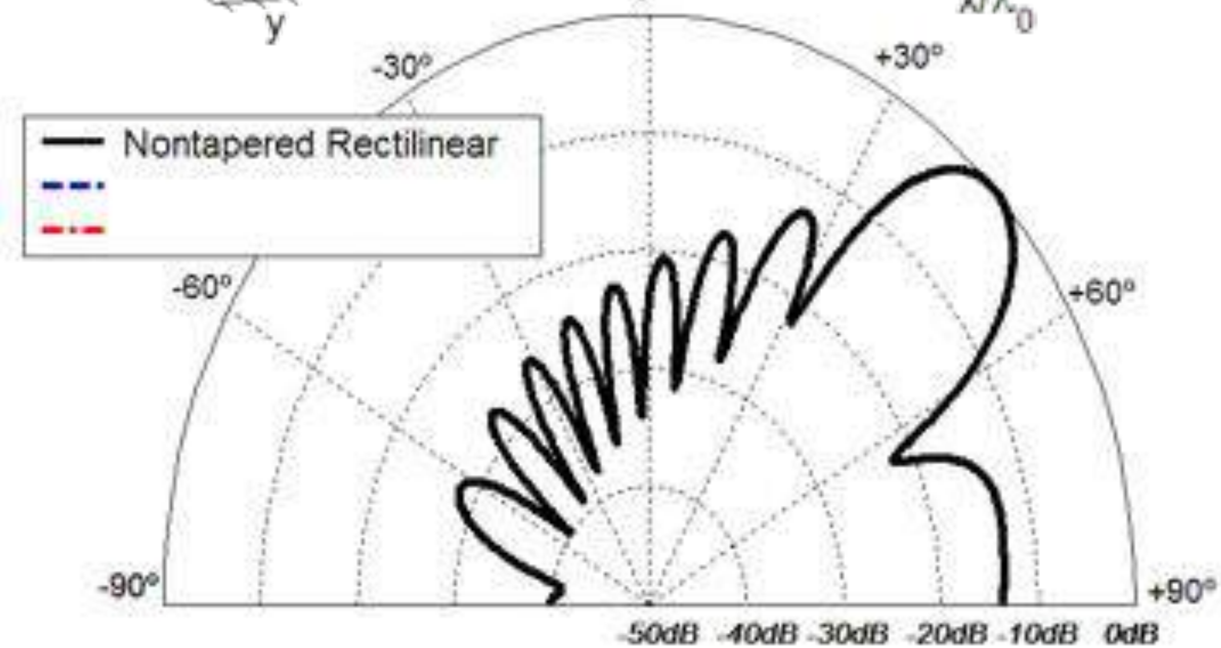
José Luis Gómez-Tornero, *Member, IEEE*

2.5- Conformal scanning antenna design.

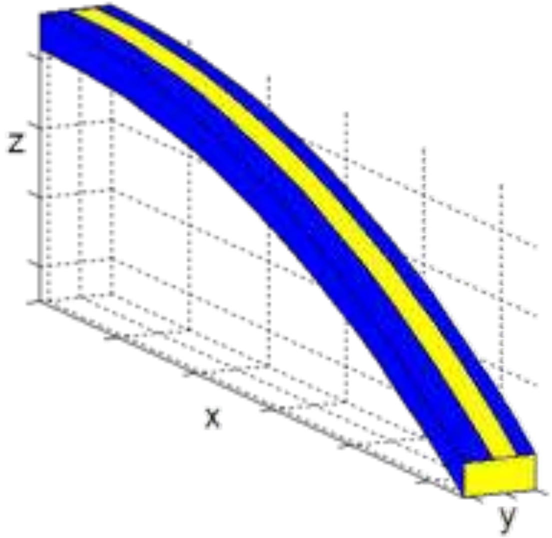
Objective:

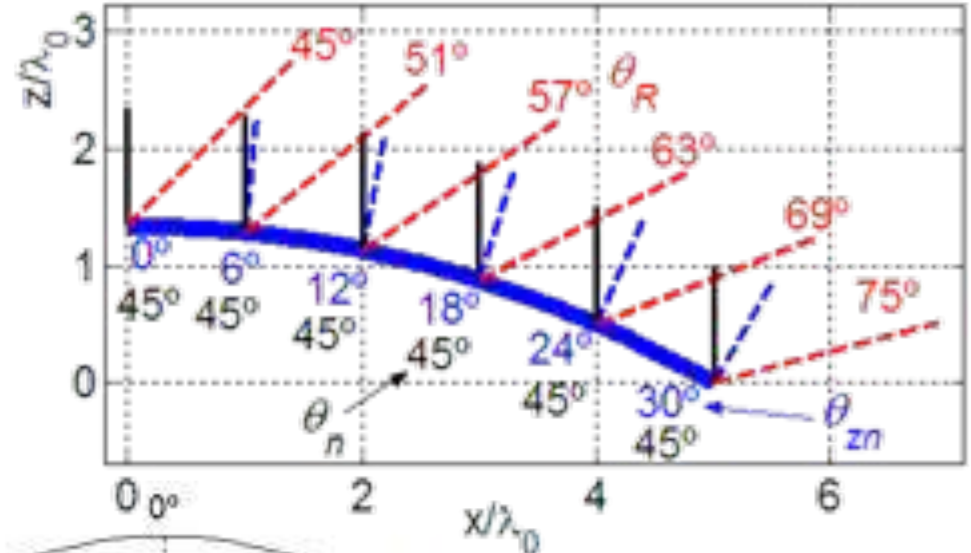


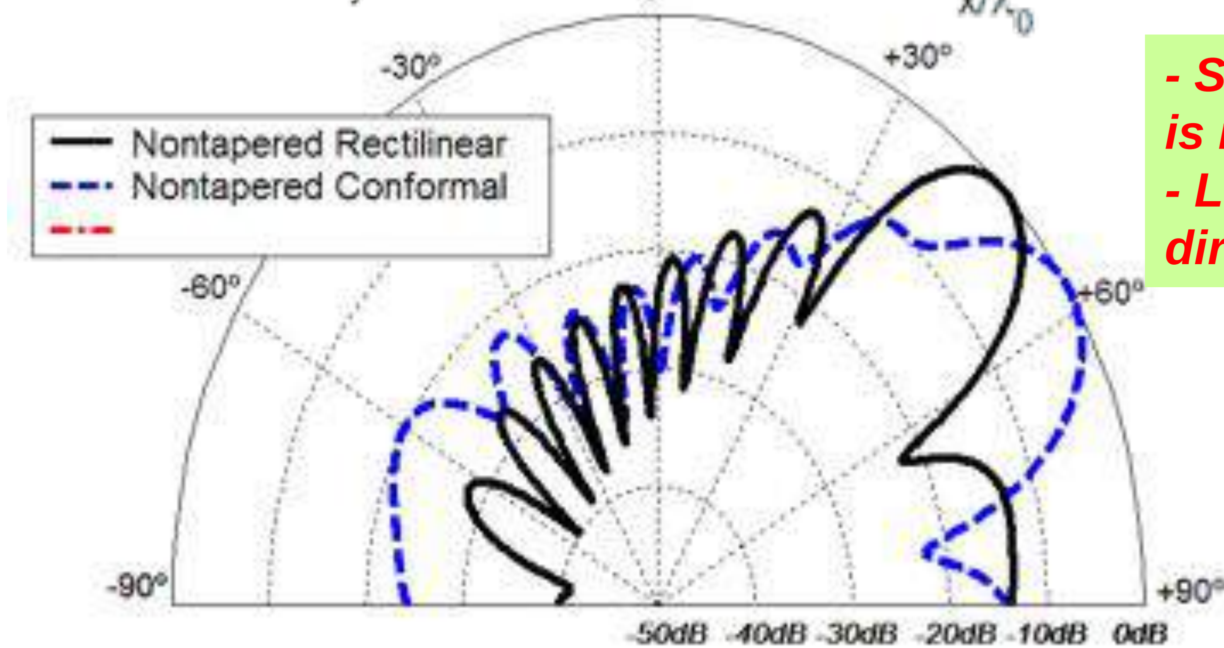




2.5- Conformal scanning antenna design.

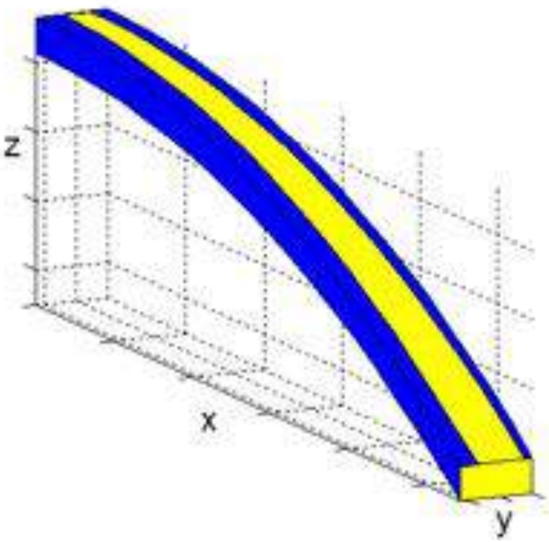


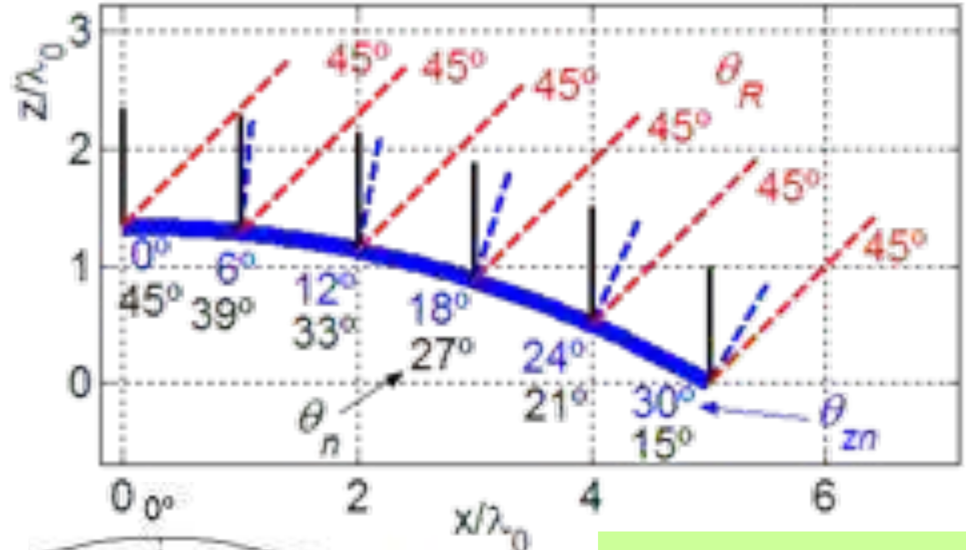


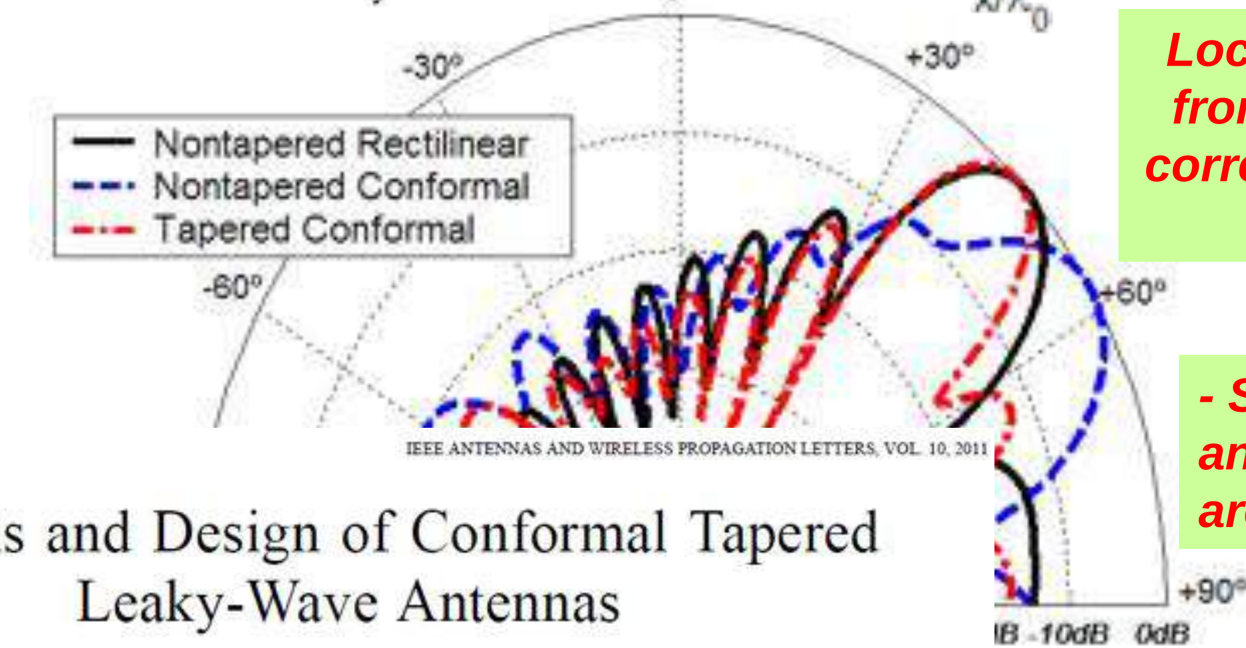


- Scanning angle is modified
- Loss of directivity

2.5- Conformal scanning antenna design.







Local θ_n is varied from 45º to 15º to correct the effect of curvature

- Scanning angle and directivity are restored

1068 IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 10, 2011

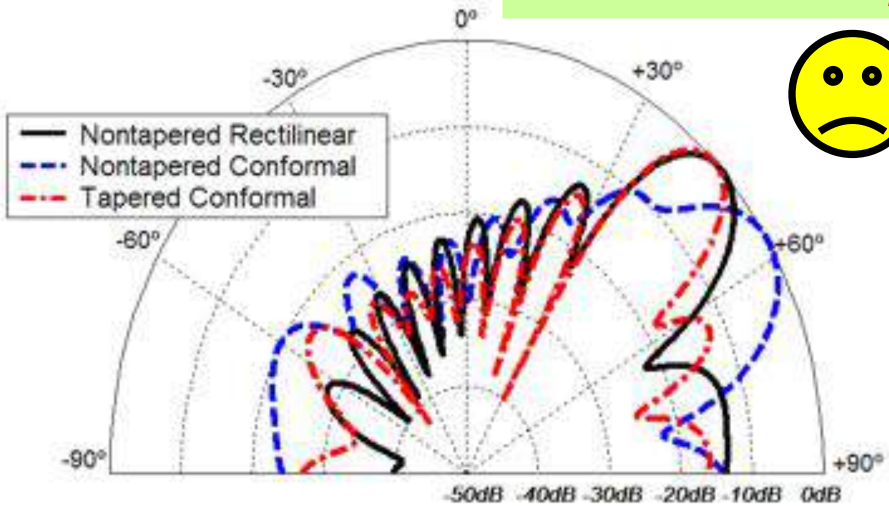
Analysis and Design of Conformal Tapered Leaky-Wave Antennas

José Luis Gómez-Tornero, *Member, IEEE*

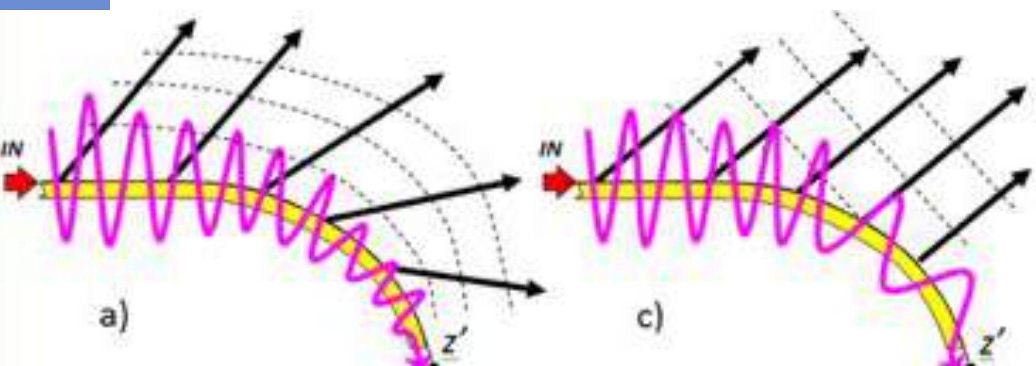
2.5- Conformal antenna

Objective:

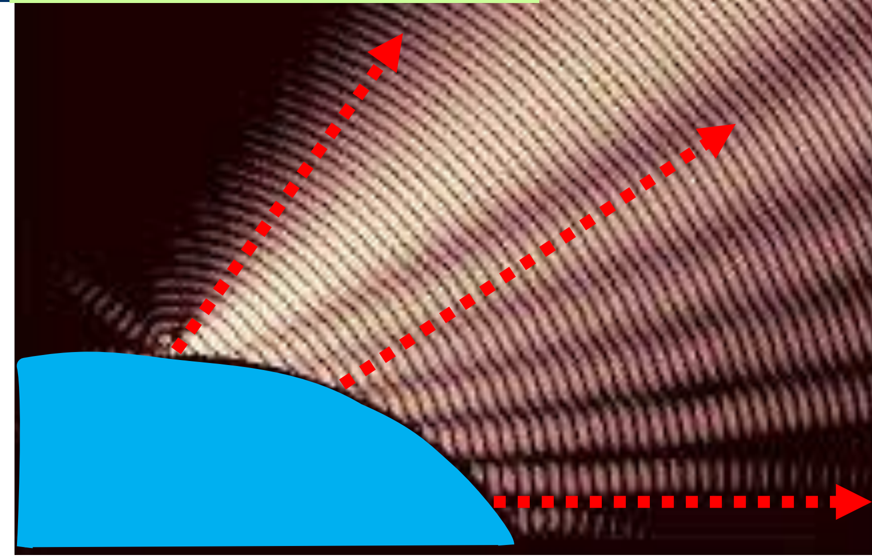
- Scanning angle is modified
- Loss of directivity



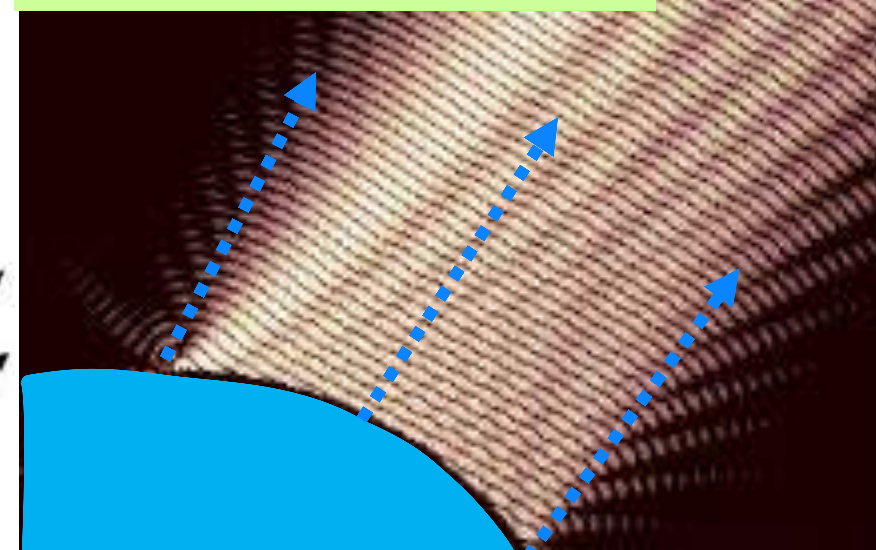
Correct for curvature to keep highly-directive scanning radiation



Non Modulated Conformal Antenna

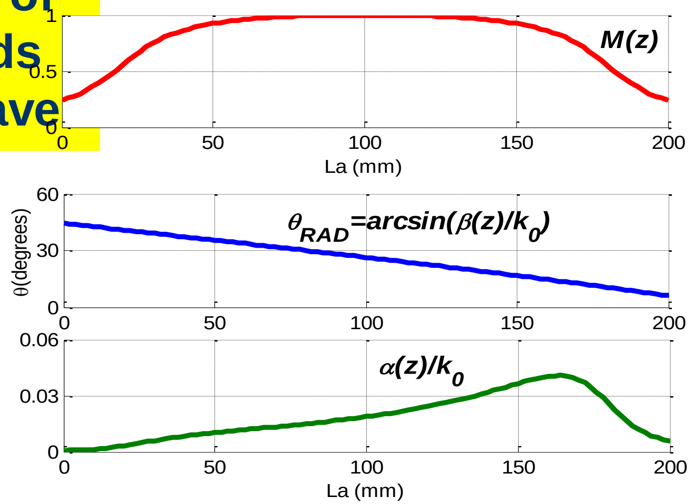


Modulated (holographic) Conformal Antenna

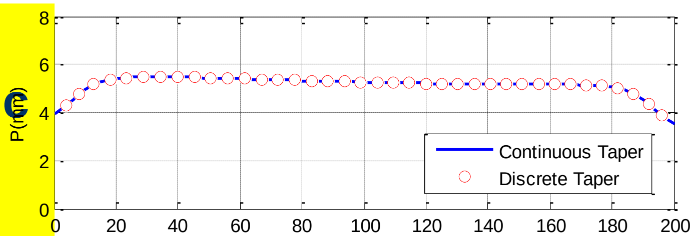


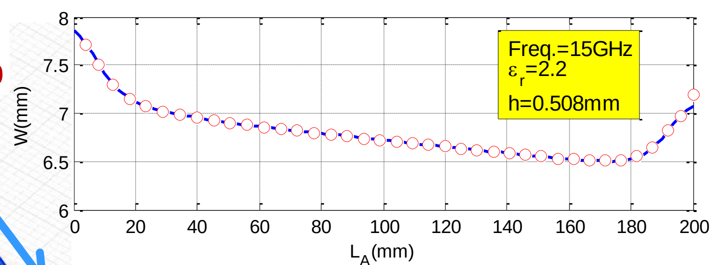
2.5- Conformal scanning antenna design.

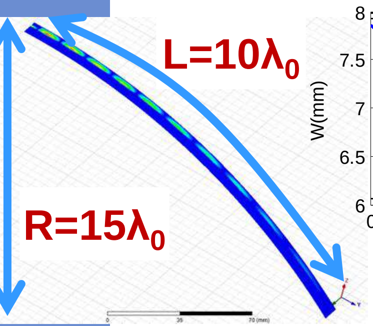
- Modulation of aperture fields and leaky wave

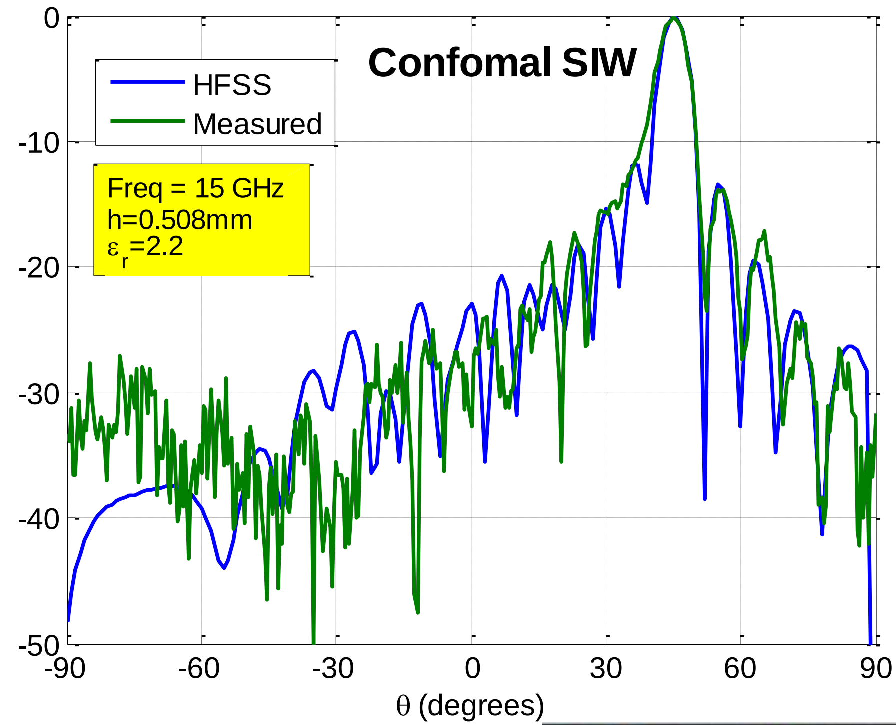


- Modulation of holographic antenna dimensions



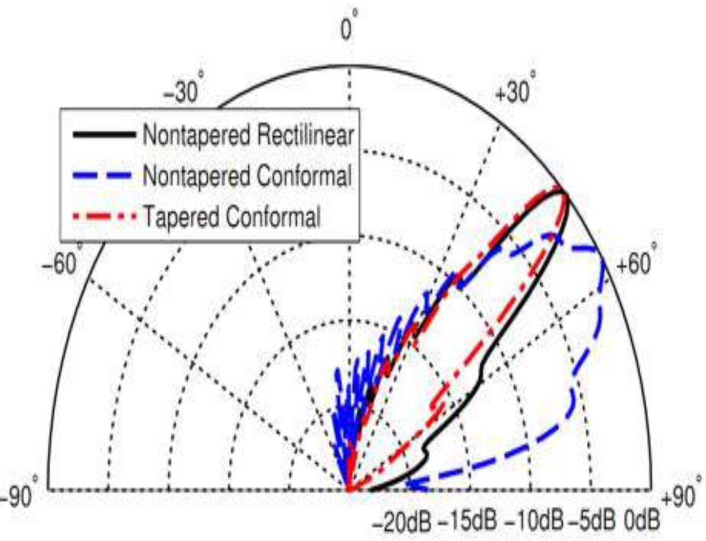


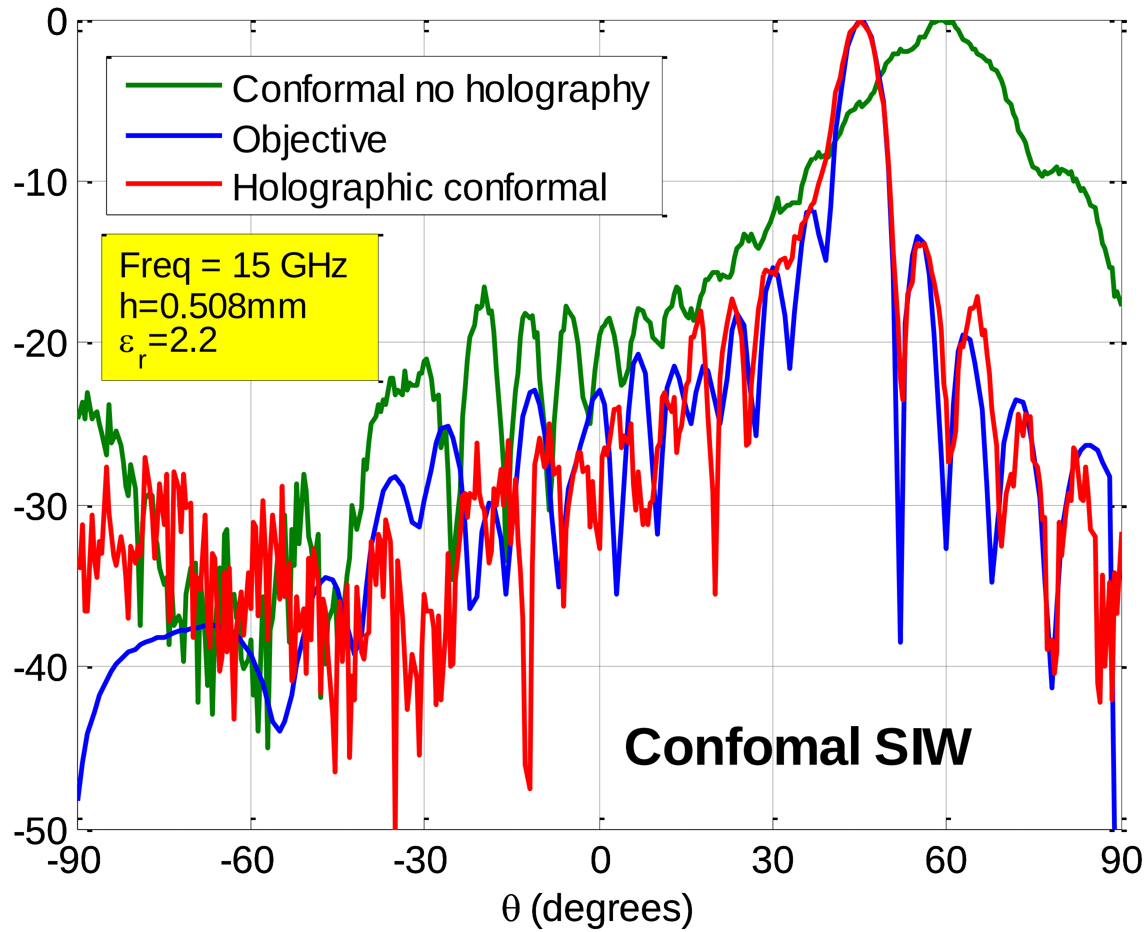




2.5- Conformal scanning antenna design.

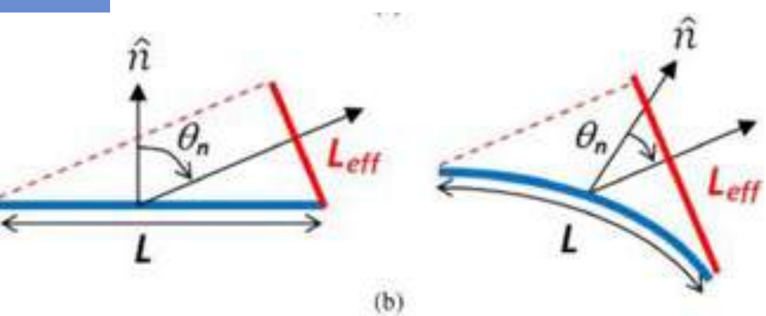
Measured radiation patterns

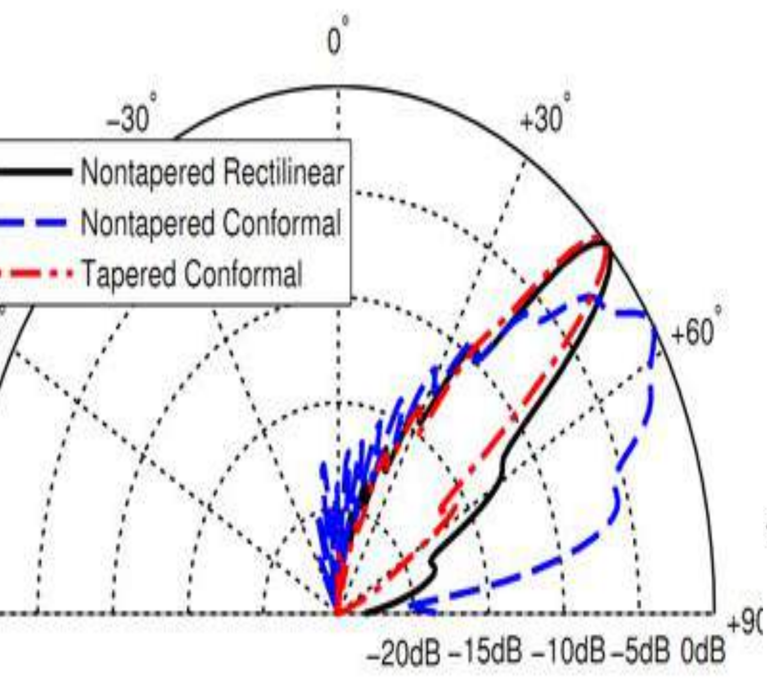


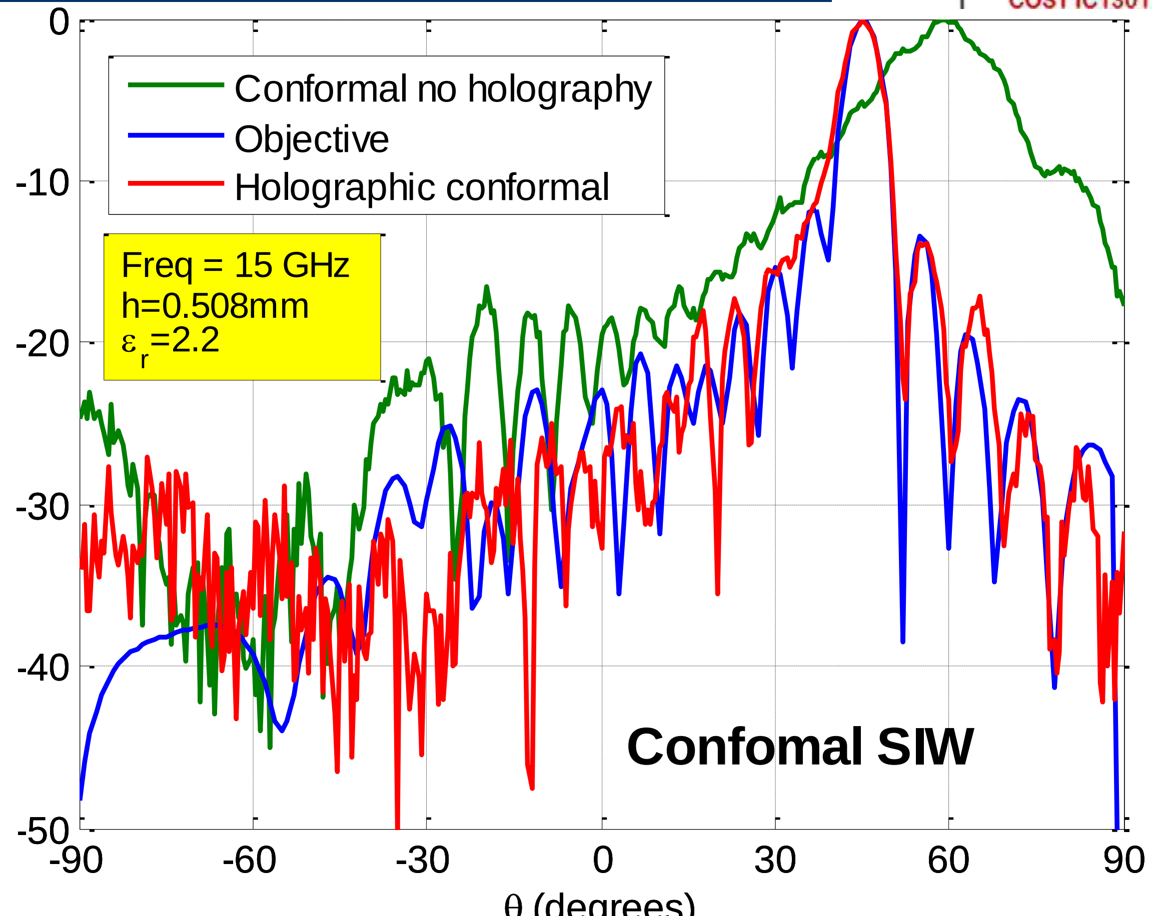


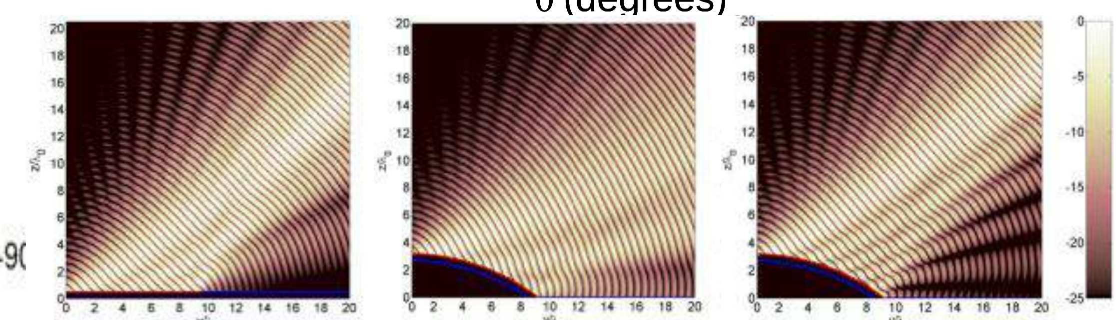
2.5- Conformal scanning antenna design.

Measured radiation patterns

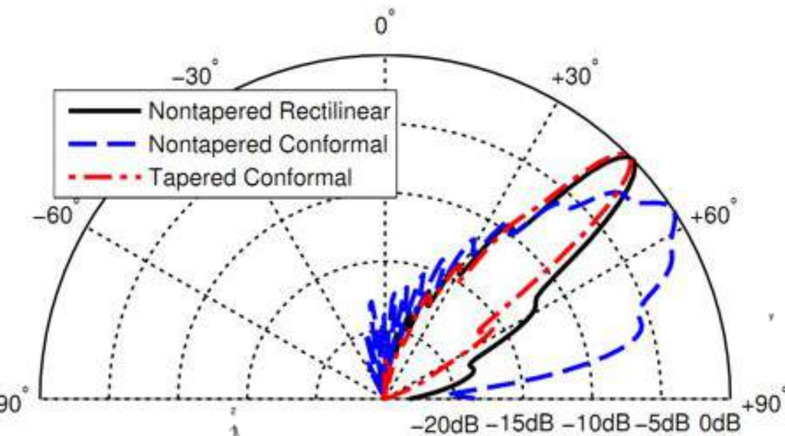


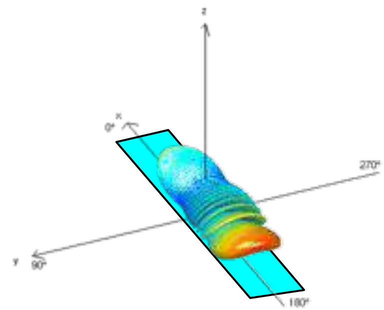


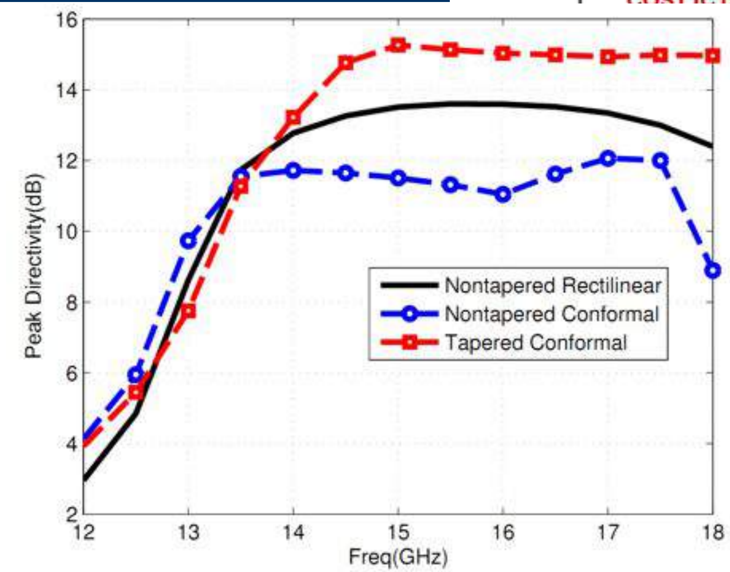


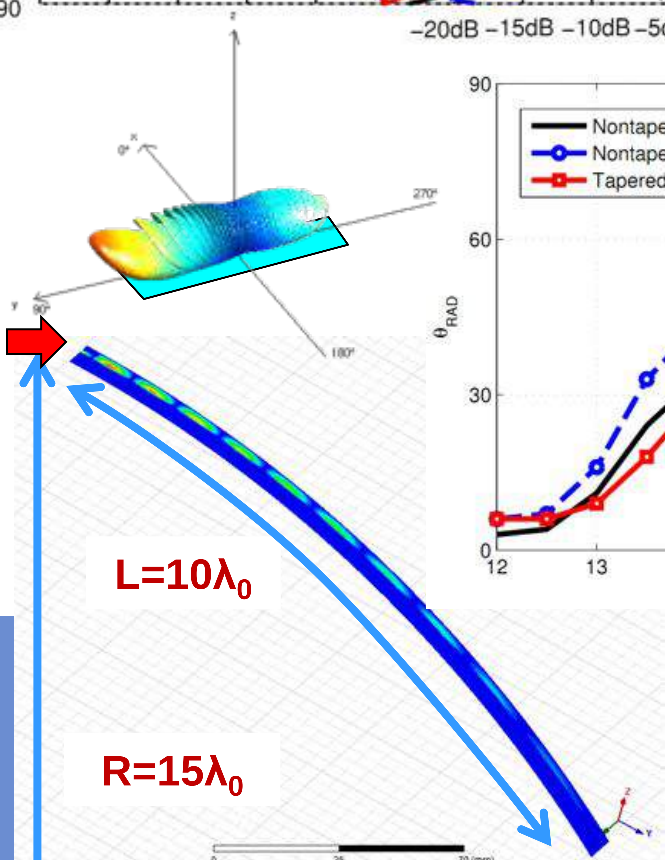


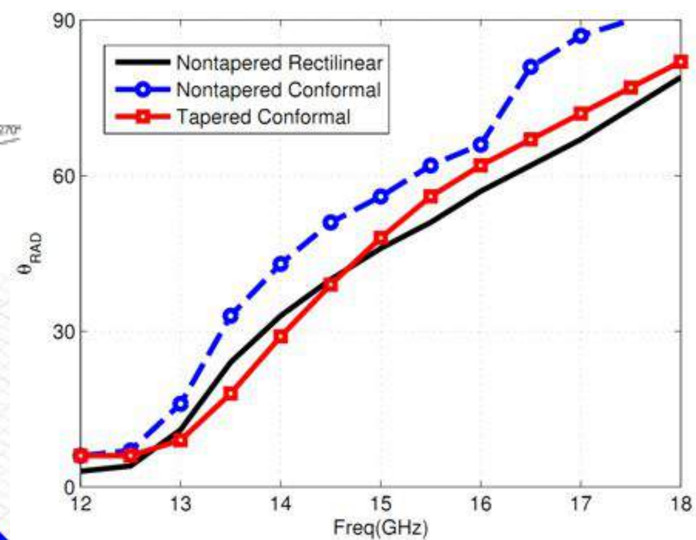
2.5- Conformal scanning antenna design.

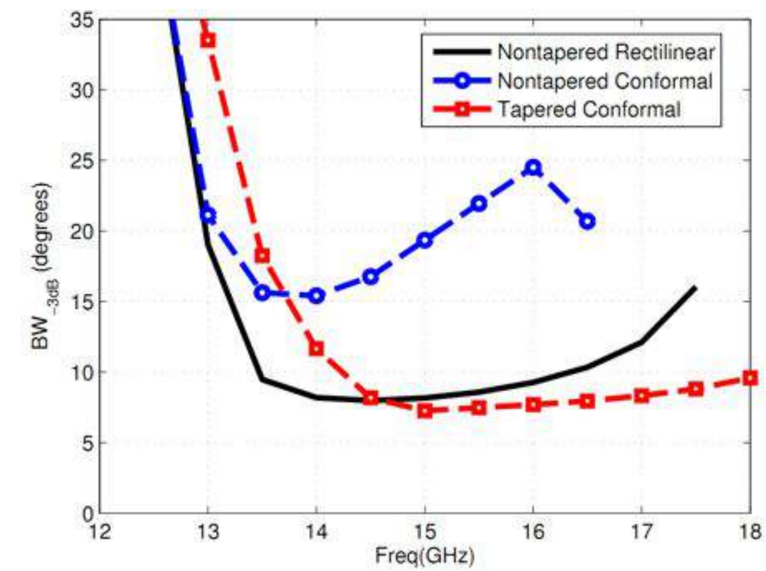






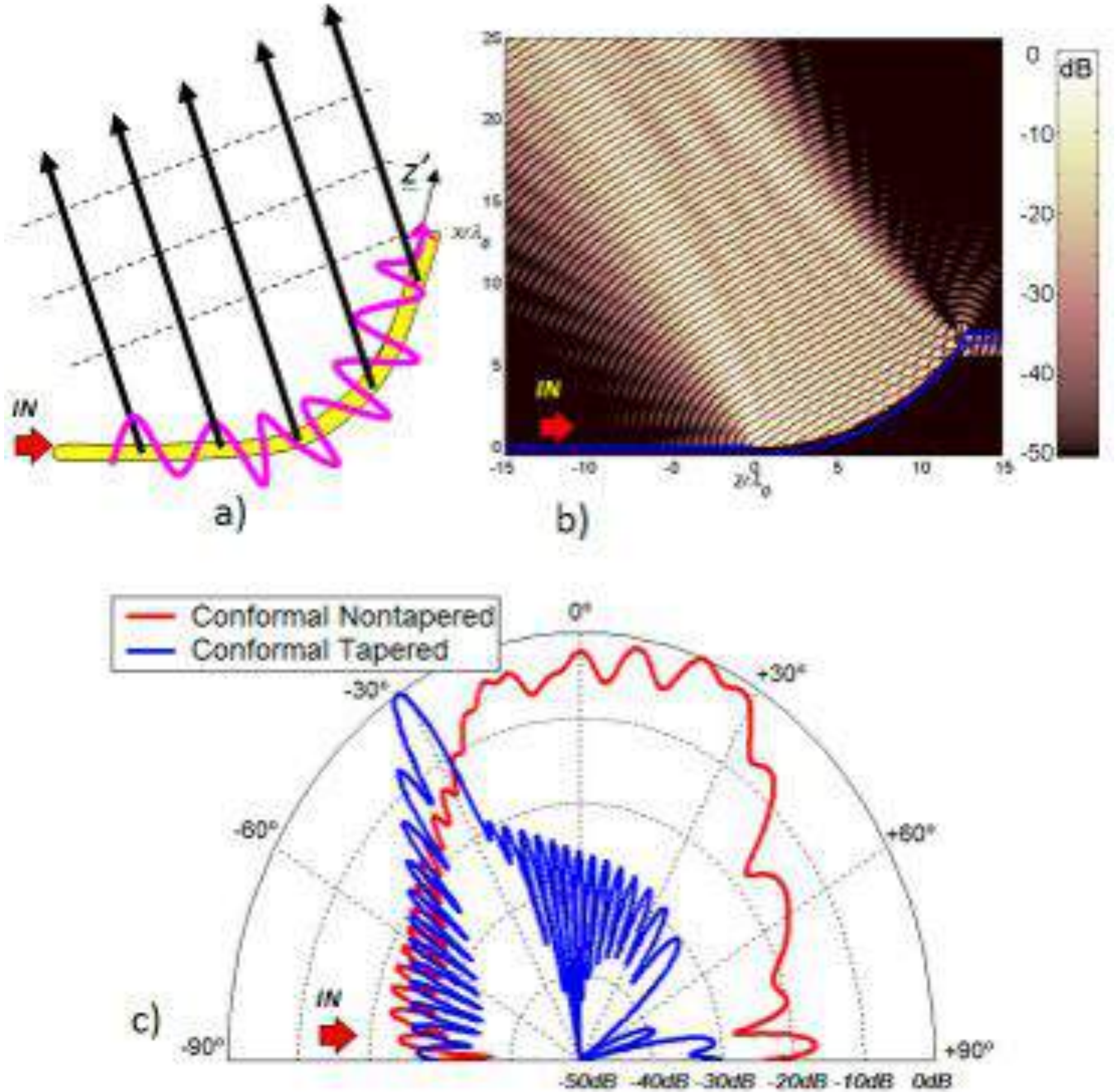






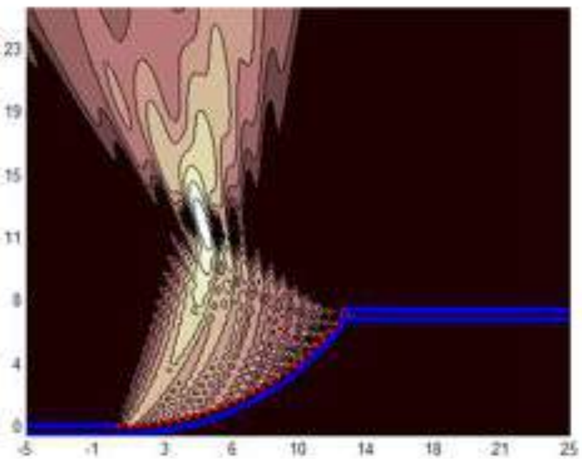
2.5- Conformal scanning antenna design.

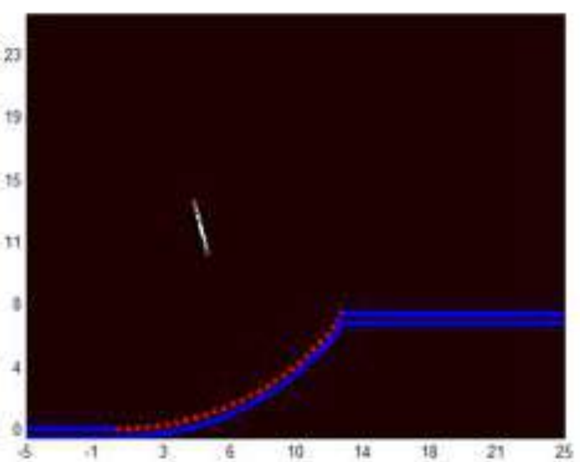
Take into account both concave and convex geometries…

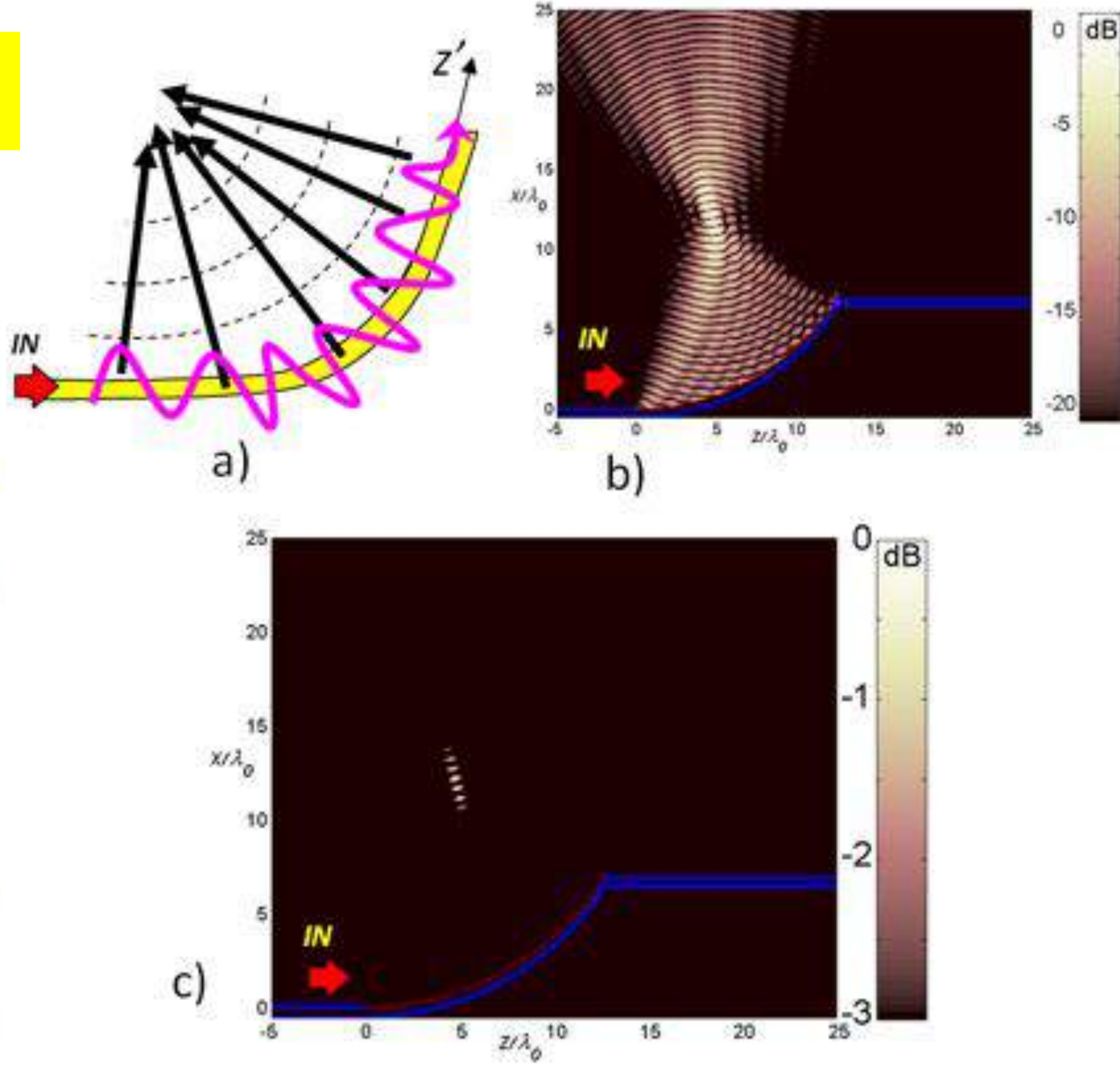


2.5- Conformal scanning antenna design.

Conformal antenna with near-field focus



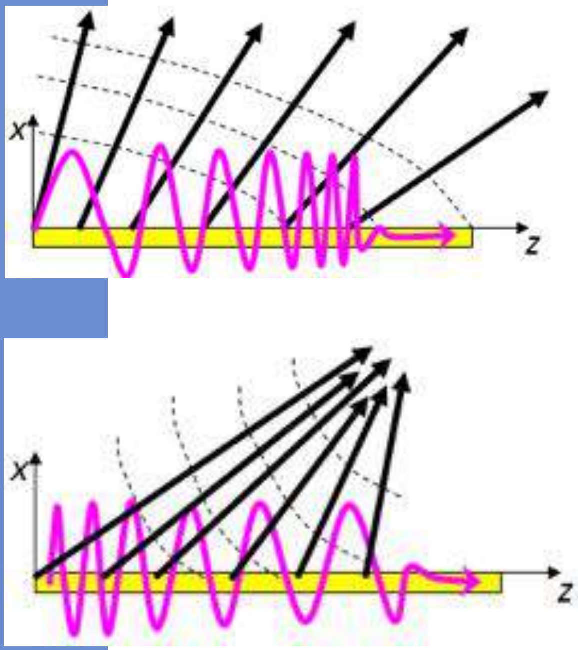


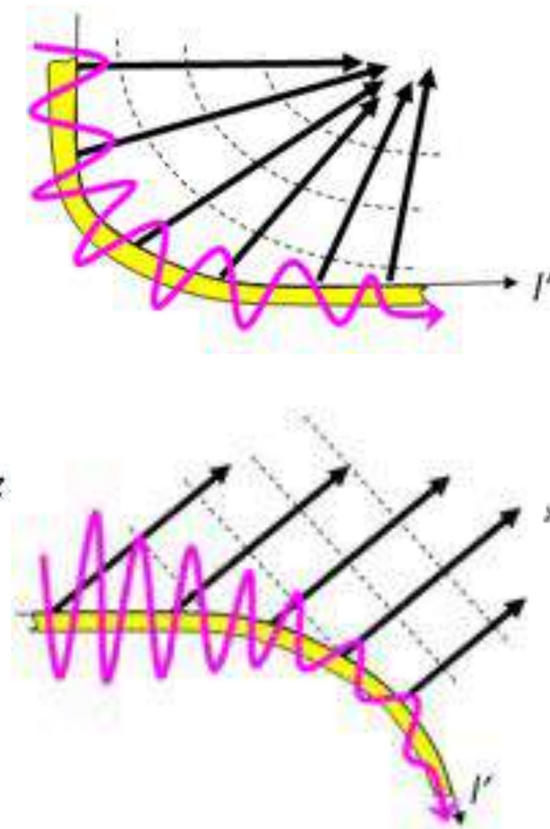


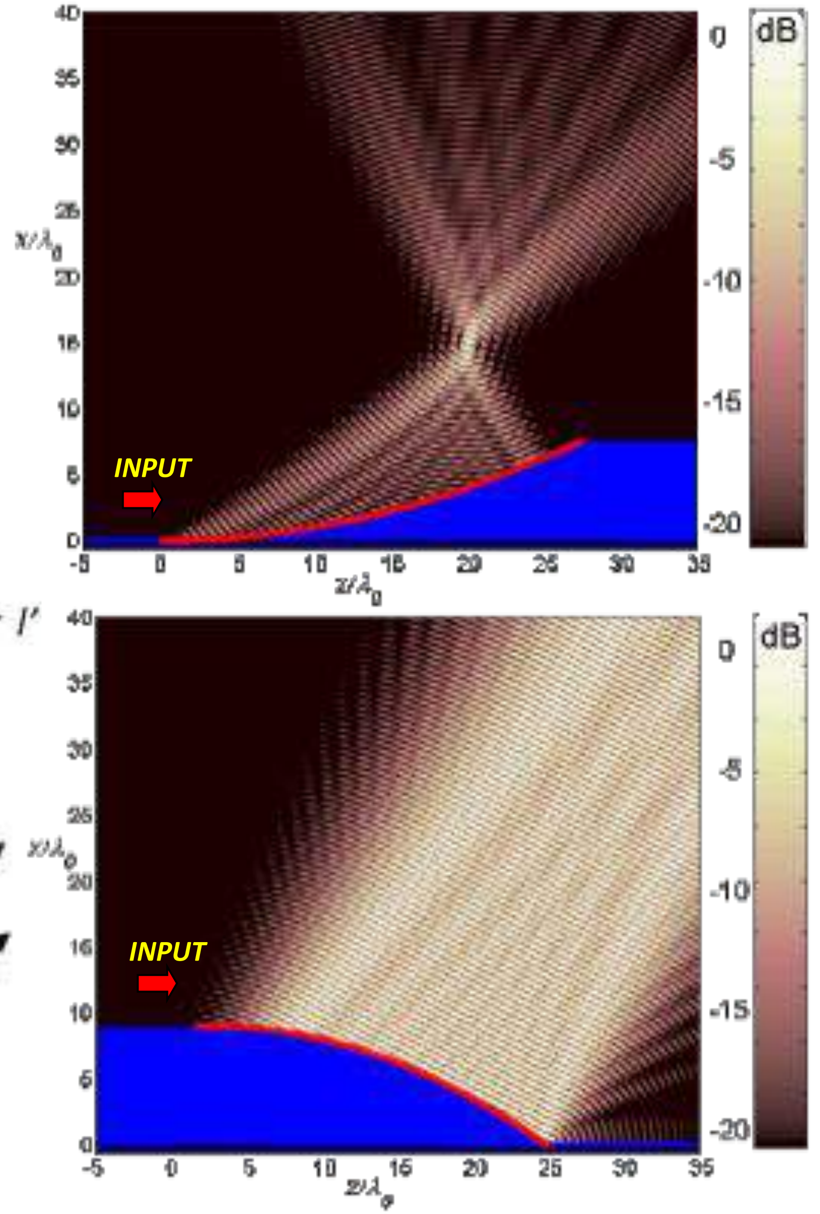
2.5- Conformal scanning antenna design.

Rectilinear tapered PLWAs

Conformal tapered PLWAs



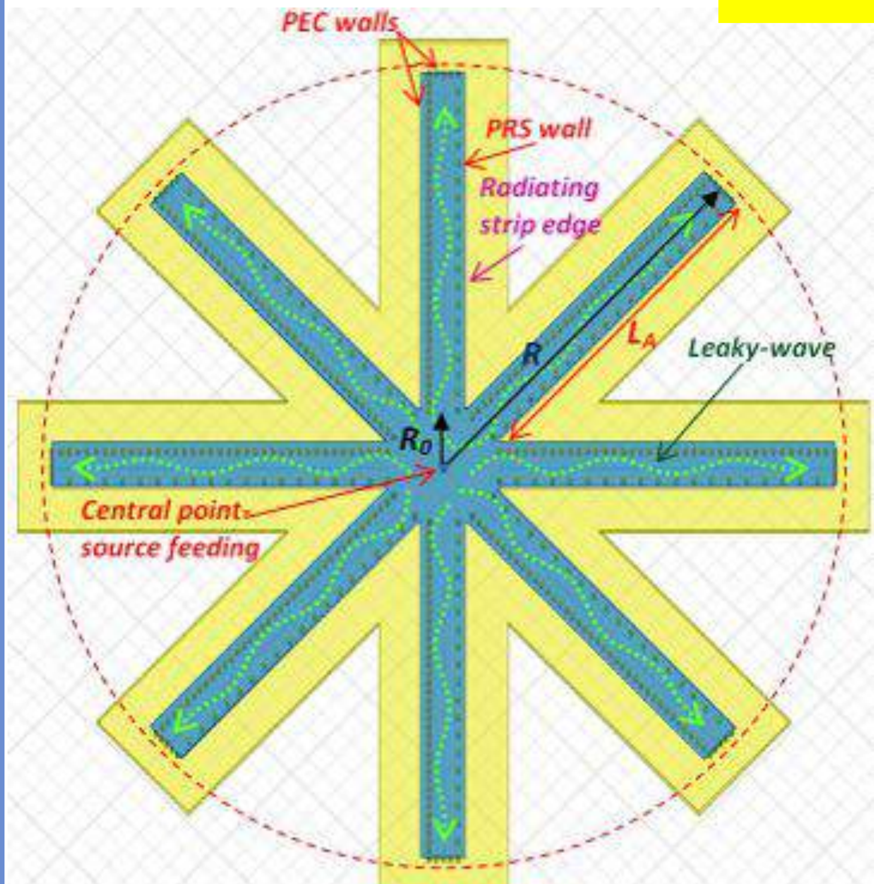


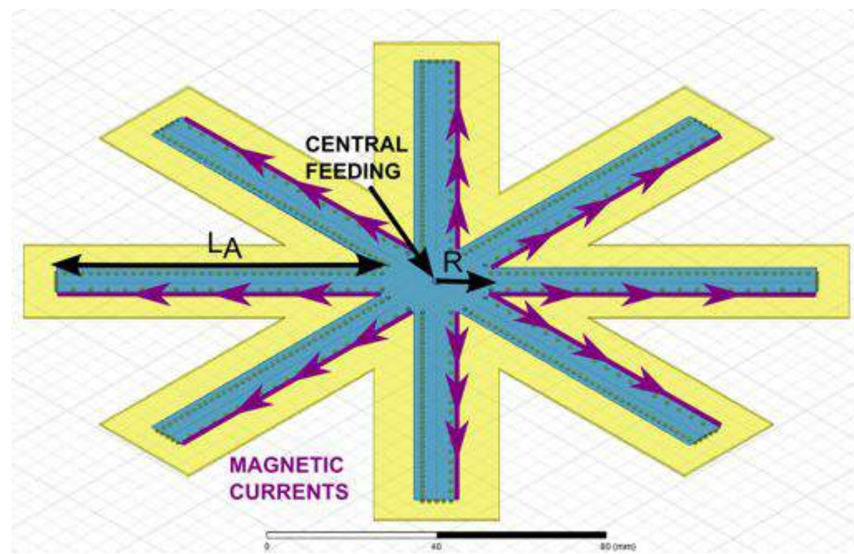


3- Future lines.

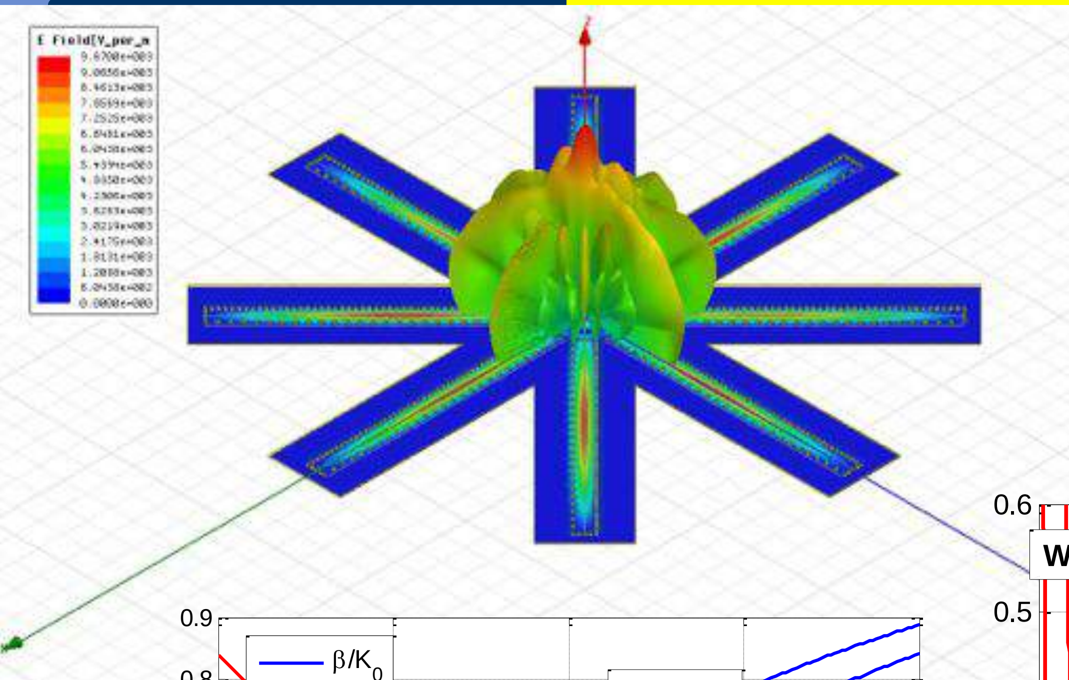
Extend to 2D holographic-surface SIW antennas to synthesize 3D holographic microwave patterns

Example: Radial Array of SIW antennas

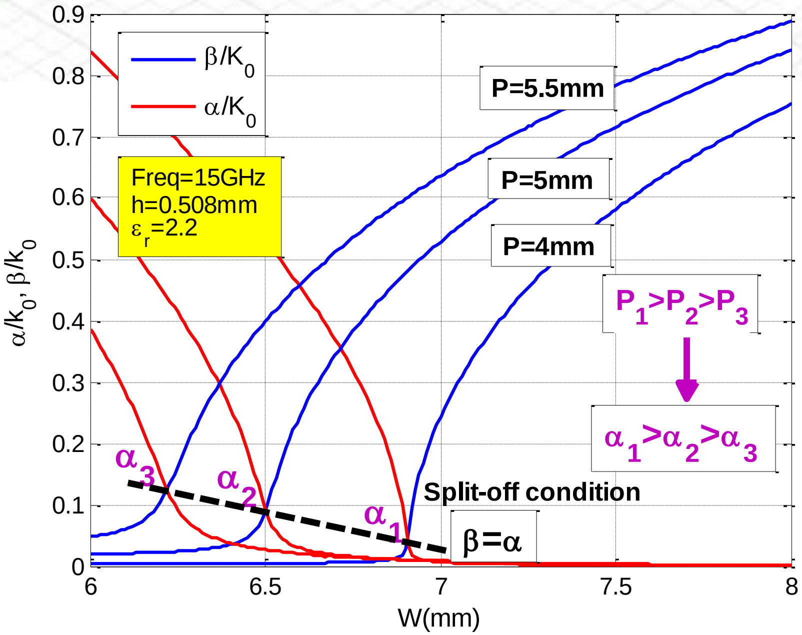


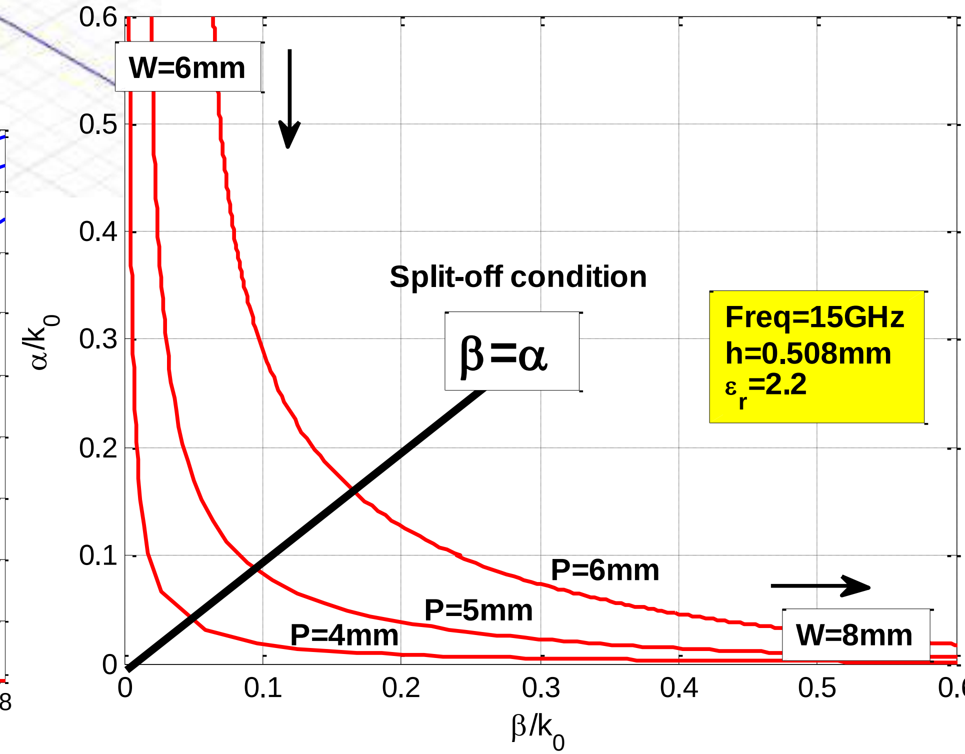


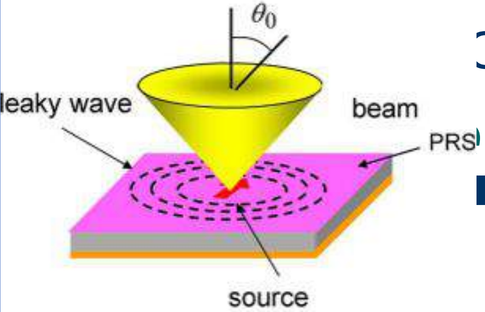
3- Future: Radial Array of SIW antennas focused in Far Field



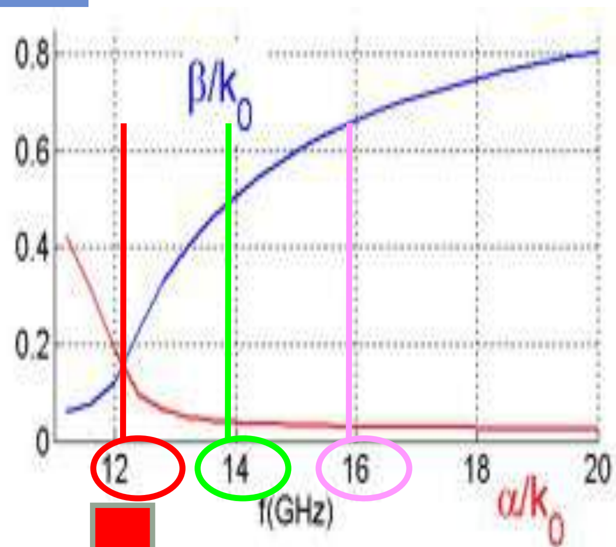
Splitting condition for Far-field focusing at broadside $\beta=\alpha$





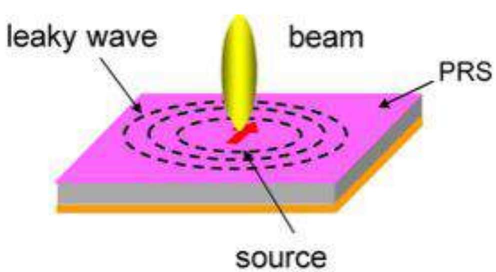


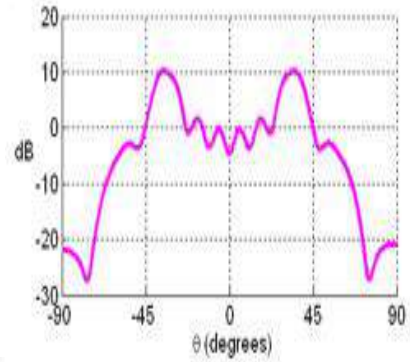
Radial Array of SIW antennas focused in Far Field

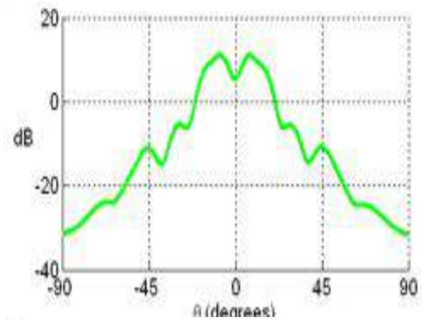


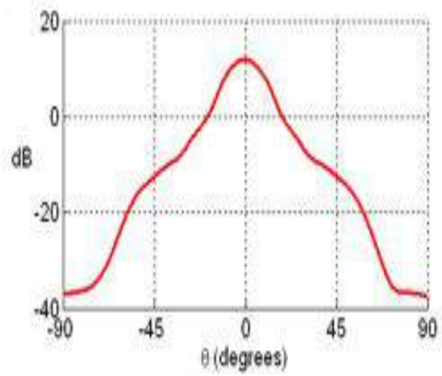
β=α
Splitting condition

Coalescensce of the two beams

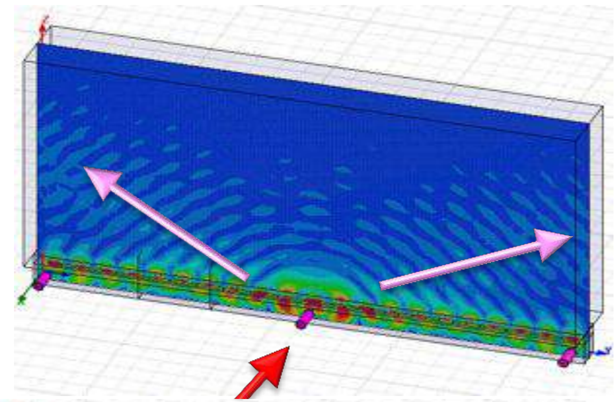


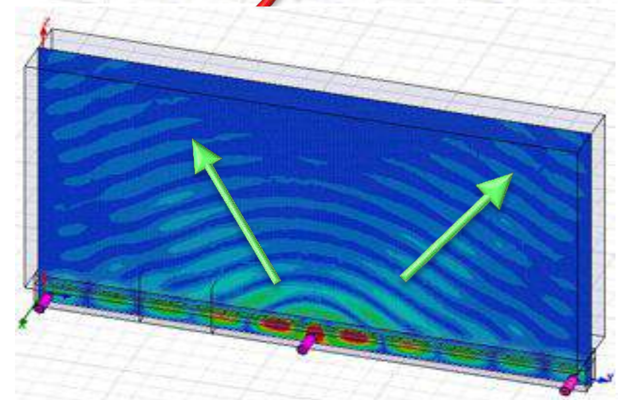


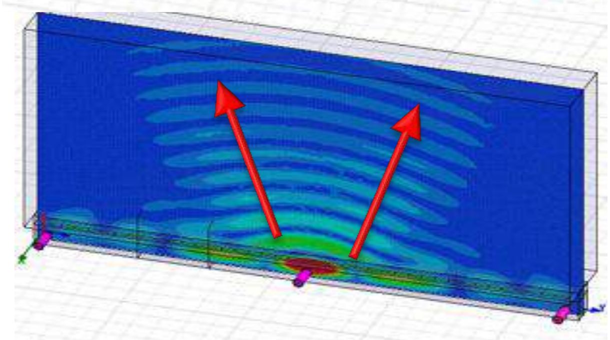




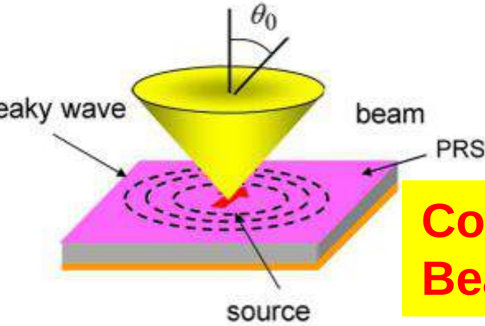
Single beam
BROADSIDE



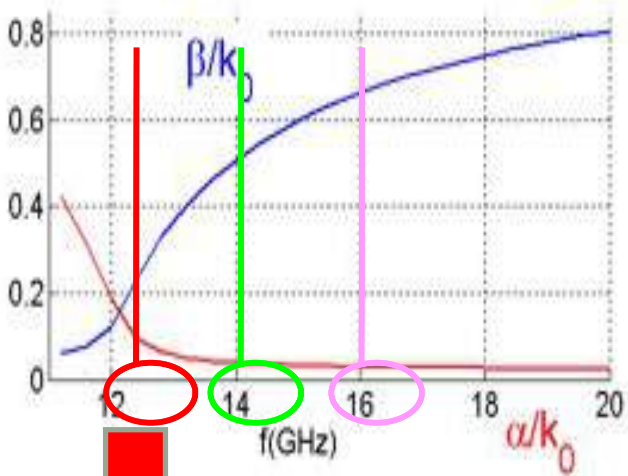




Radial Array of SIW antennas focused in Far Field

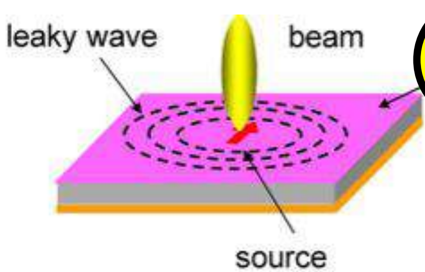


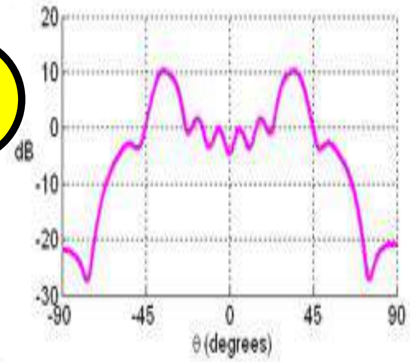
Conical Beam

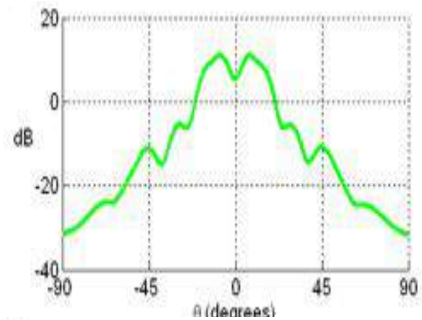


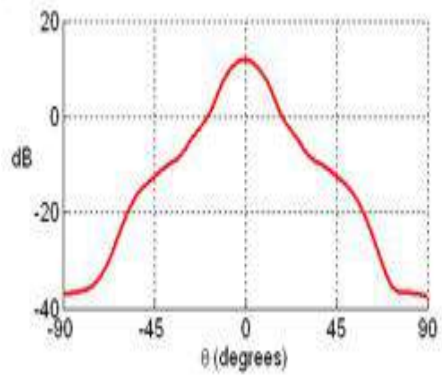
β=α
Splitting condition

Coalescensce of
the two beams

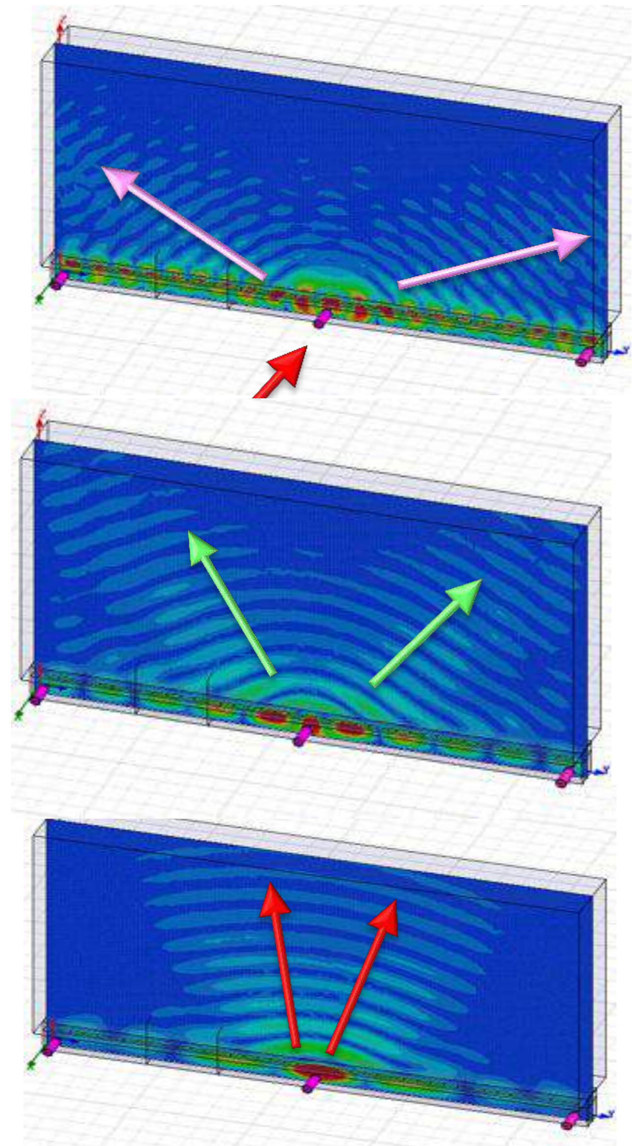






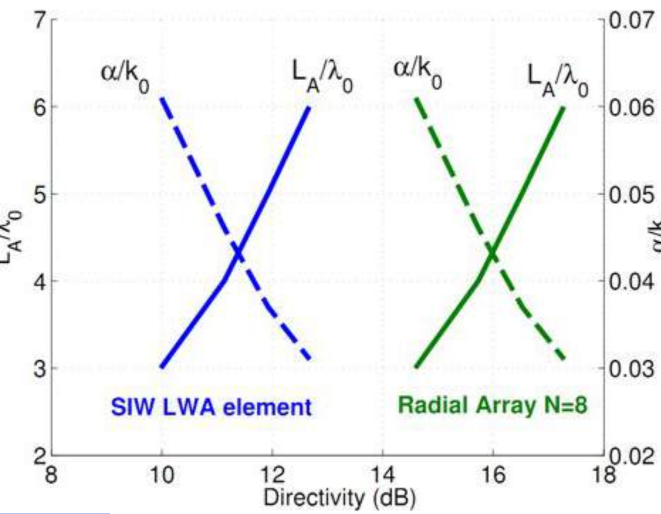


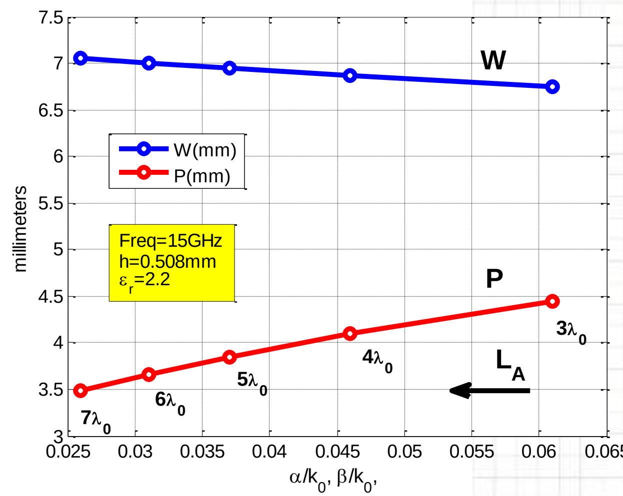
Single beam
BROADSIDE

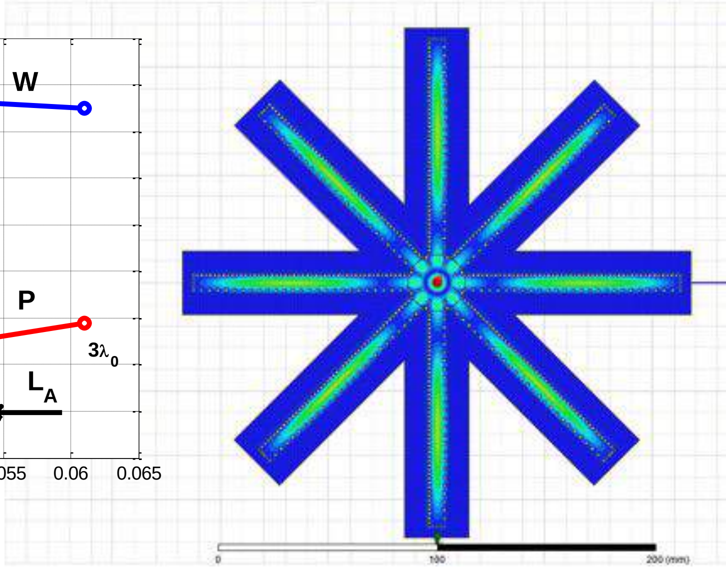


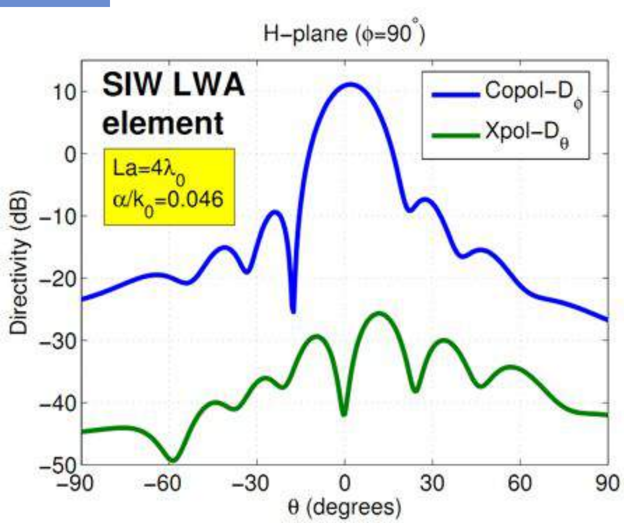
Radial Array of SIW antennas focused in Far Field

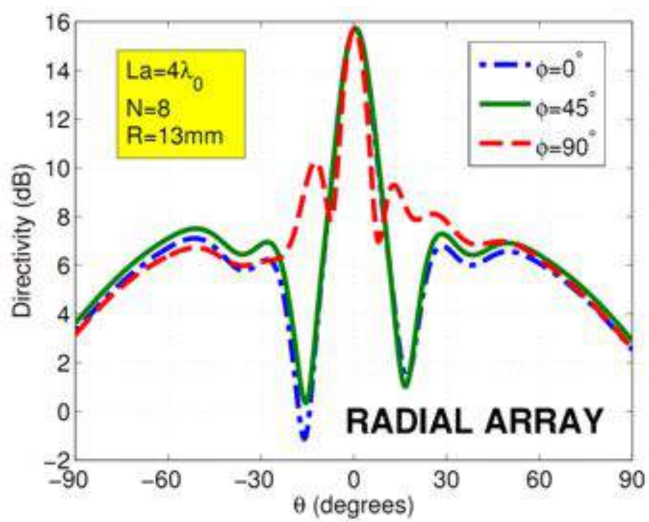
L_A/λ_0	$\alpha/k_0 = \beta/k_0$	$W(mm)$	$P(mm)$	$D_E(dB)$	$D_A(dB)$
3	0.061	6.75	4.45	9.98	14.59
4	0.046	6.87	4.10	11.13	15.73
5	0.037	6.95	3.85	11.92	16.85
6	0.031	7.00	3.66	12.67	17.05

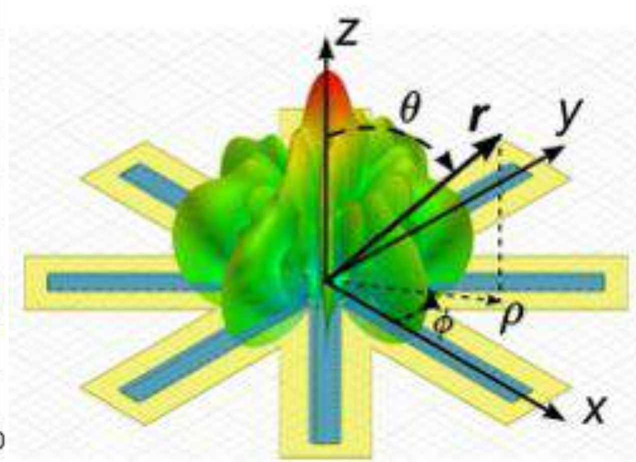




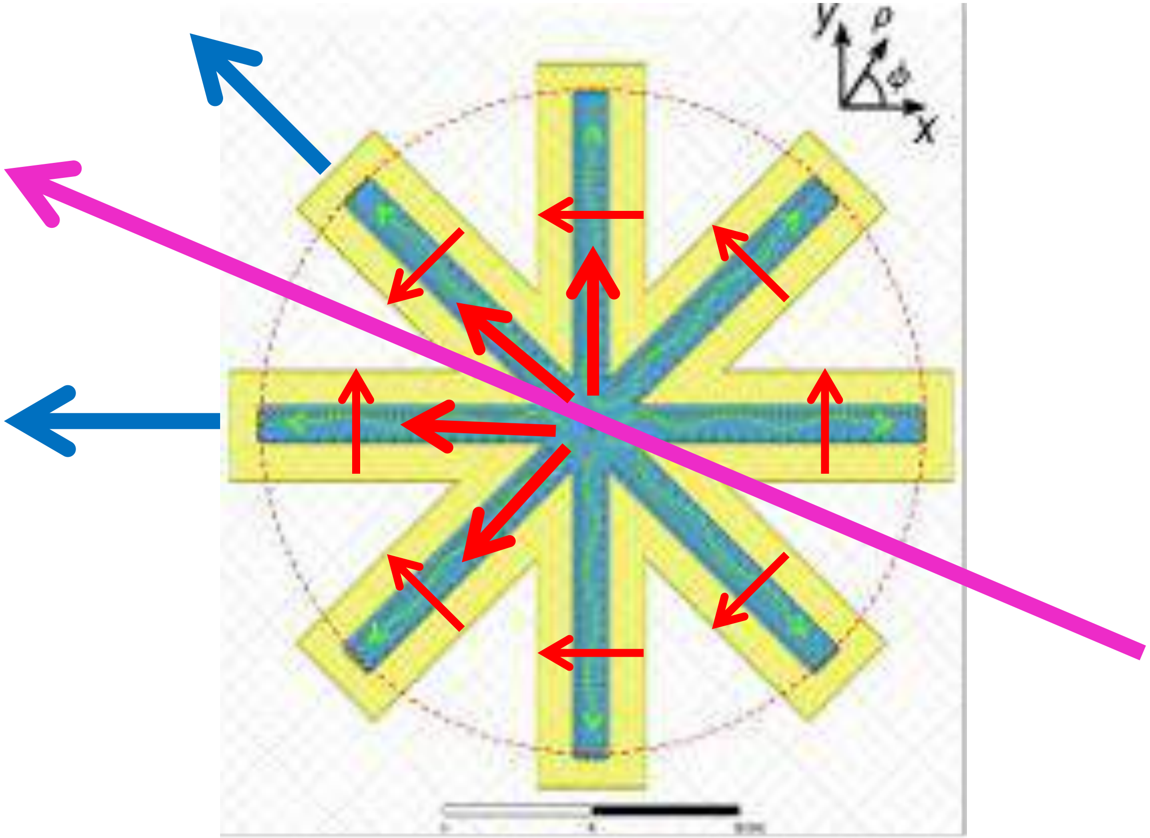




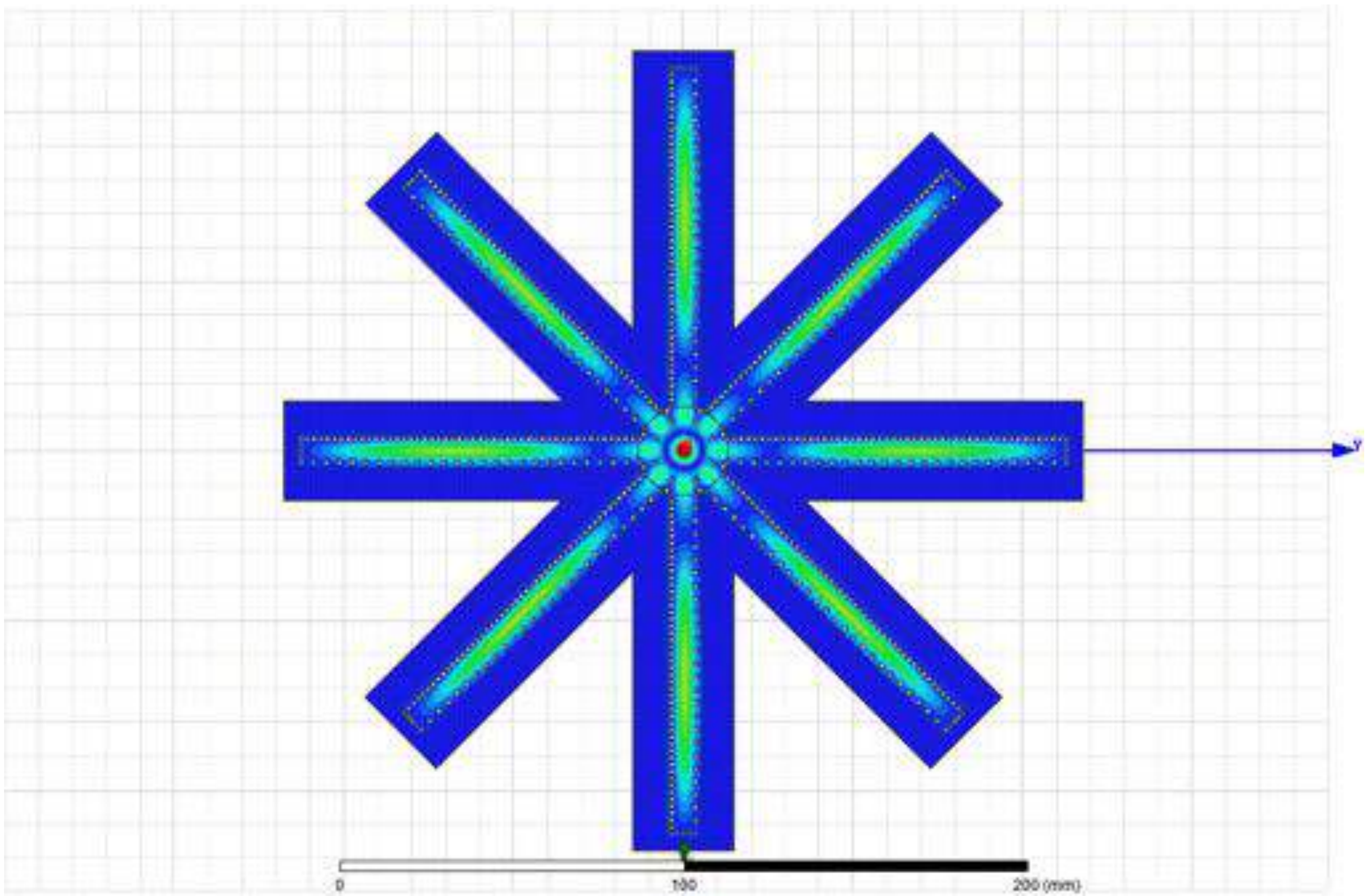




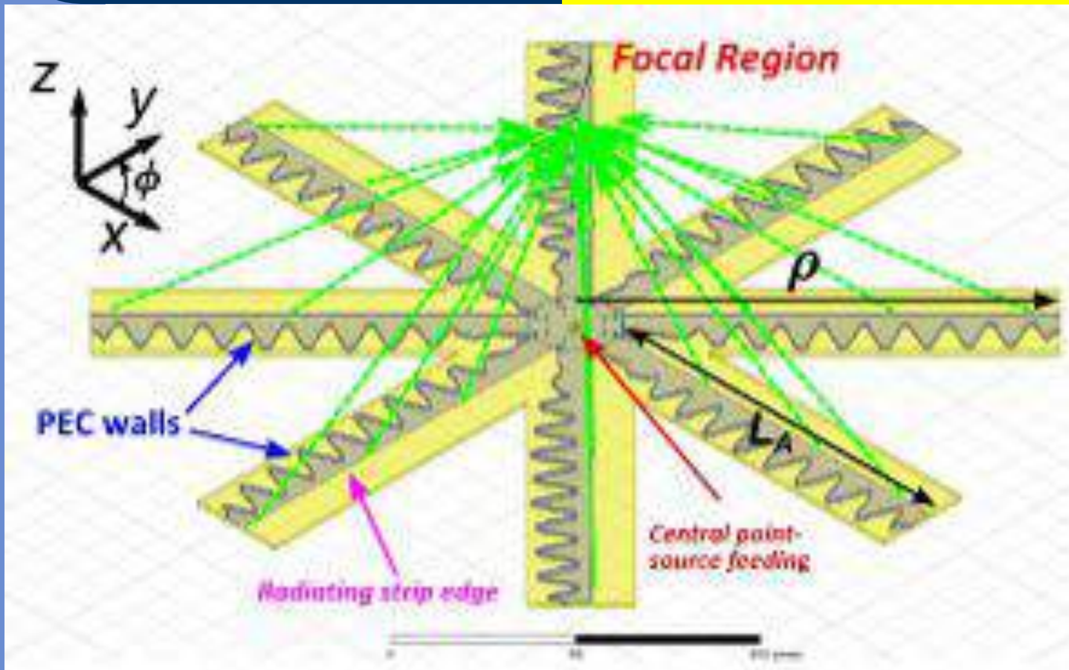
Linear Polarization



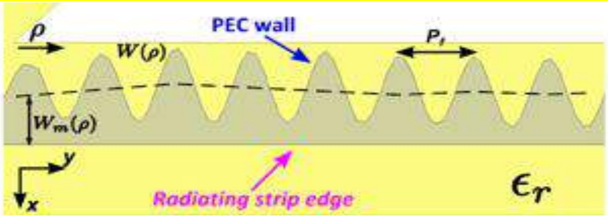
3- Future: Radial Array of SIW antennas focused in Far Field

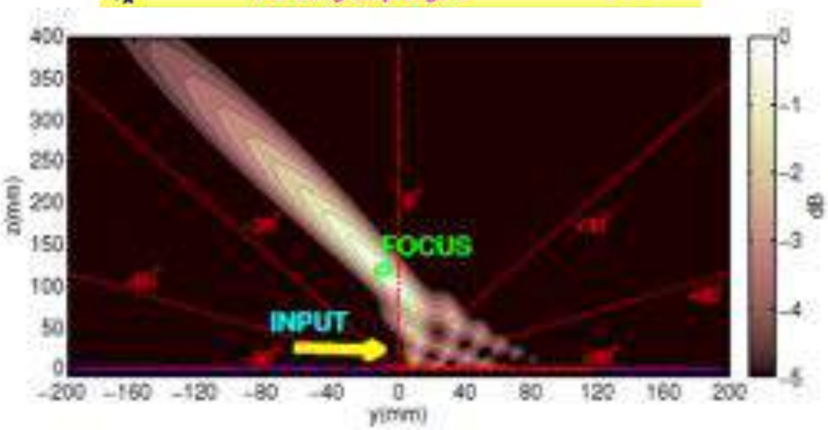


3- Future: Radial Array of SIW antennas focused in Near Field

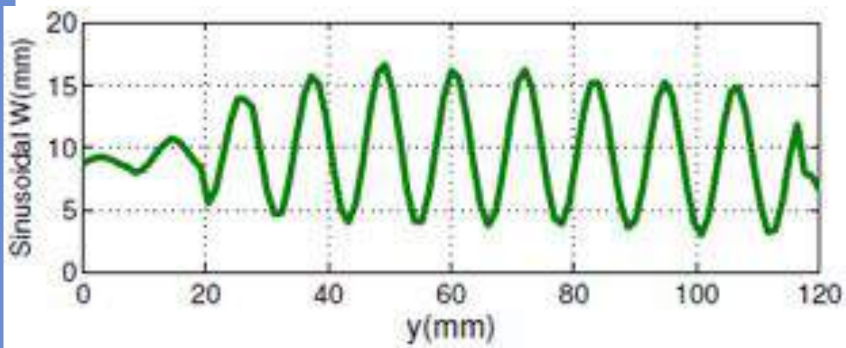


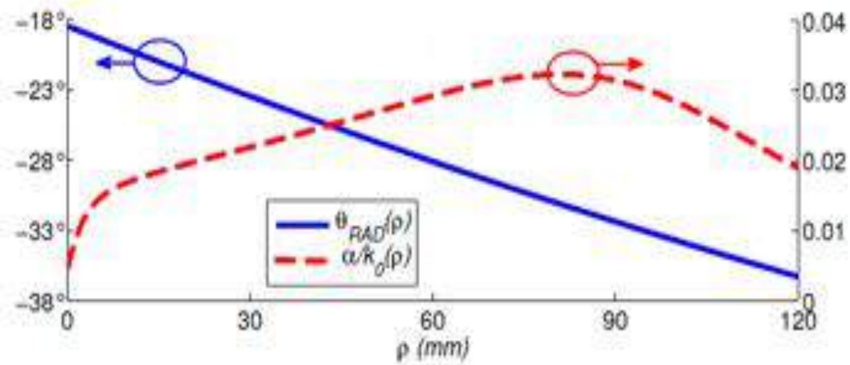
Sinusoidal modulation to excite higher-order space harmonic in backward leaky regime



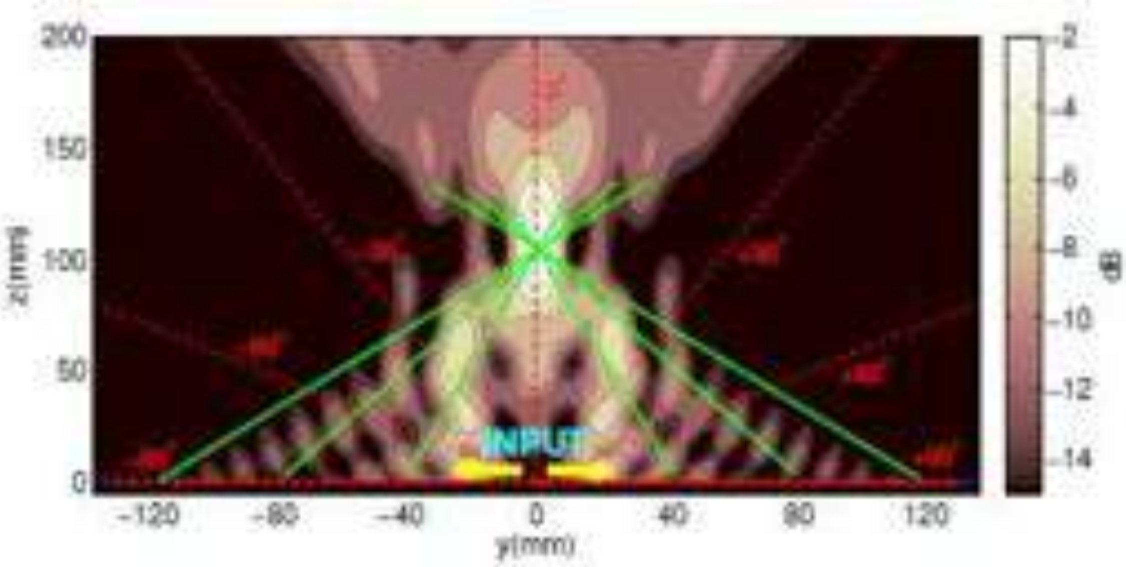


$$W(y) = W_m(y)\left[1 + M(y)\sin\left(\frac{2\pi}{P}y\right)\right]$$



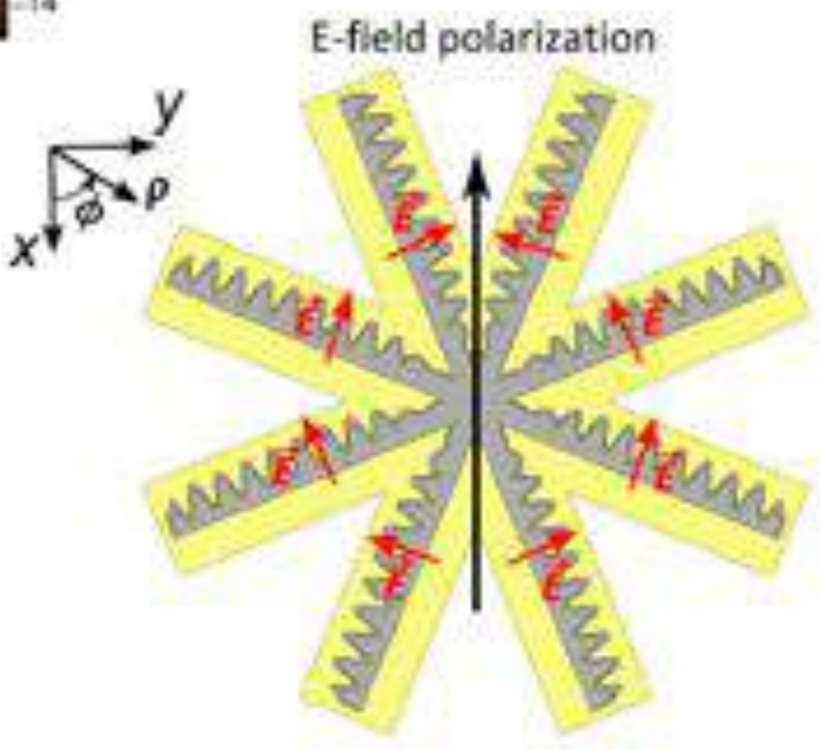


3- Future: Radial Array of SIW antennas focused in Near Field

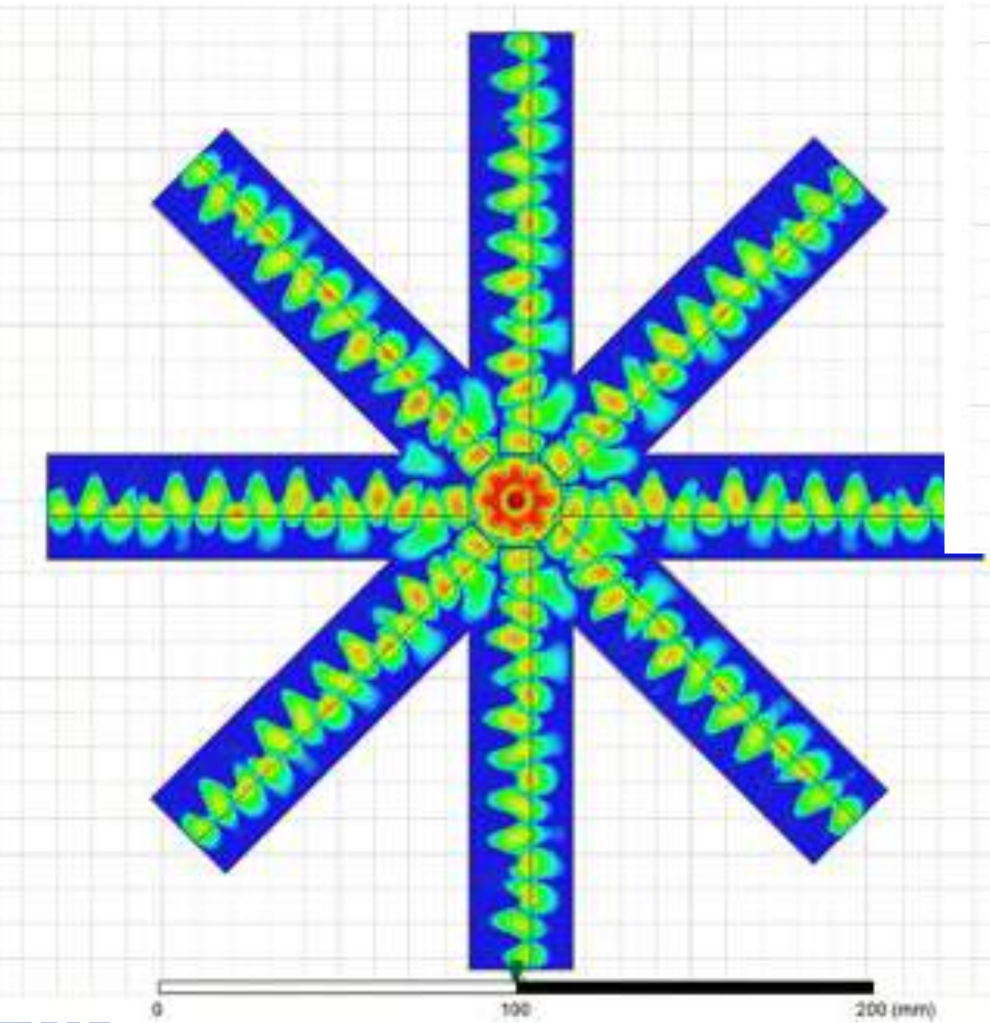


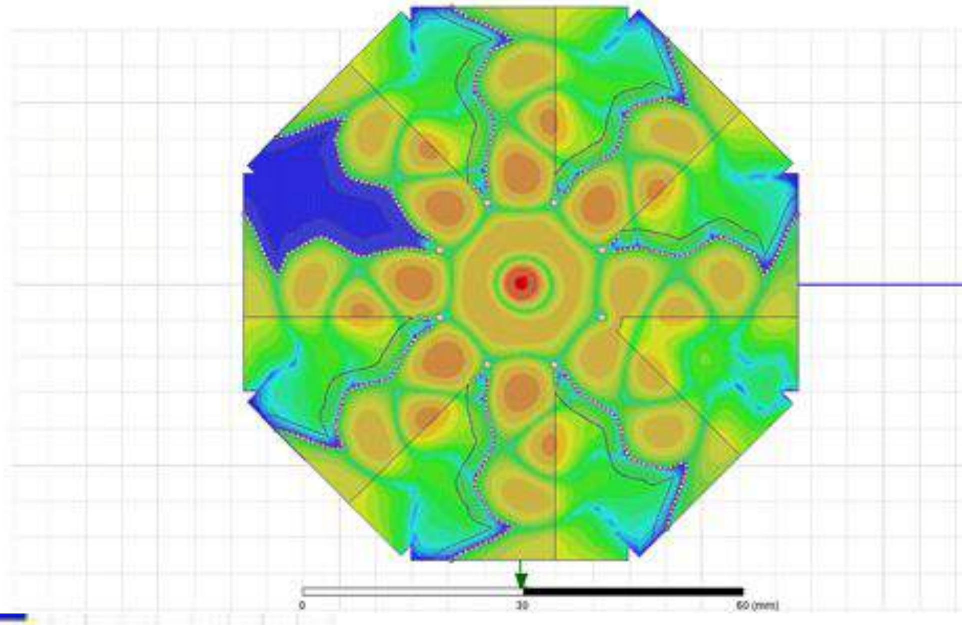
LINEAR POLARIZATION

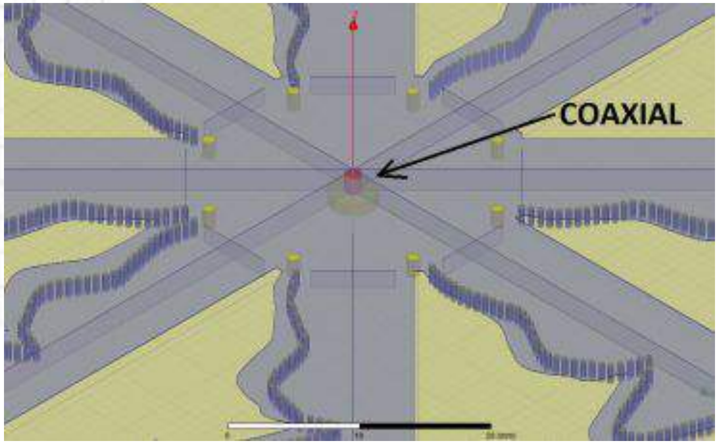
CONSTRUCTIVE INTERFERENCE IN THE NEAR-FIELD FOCUSED SPOT z=110mm @15GHz



3- Future: **Radial Array of SIW antennas focused in Near Field**

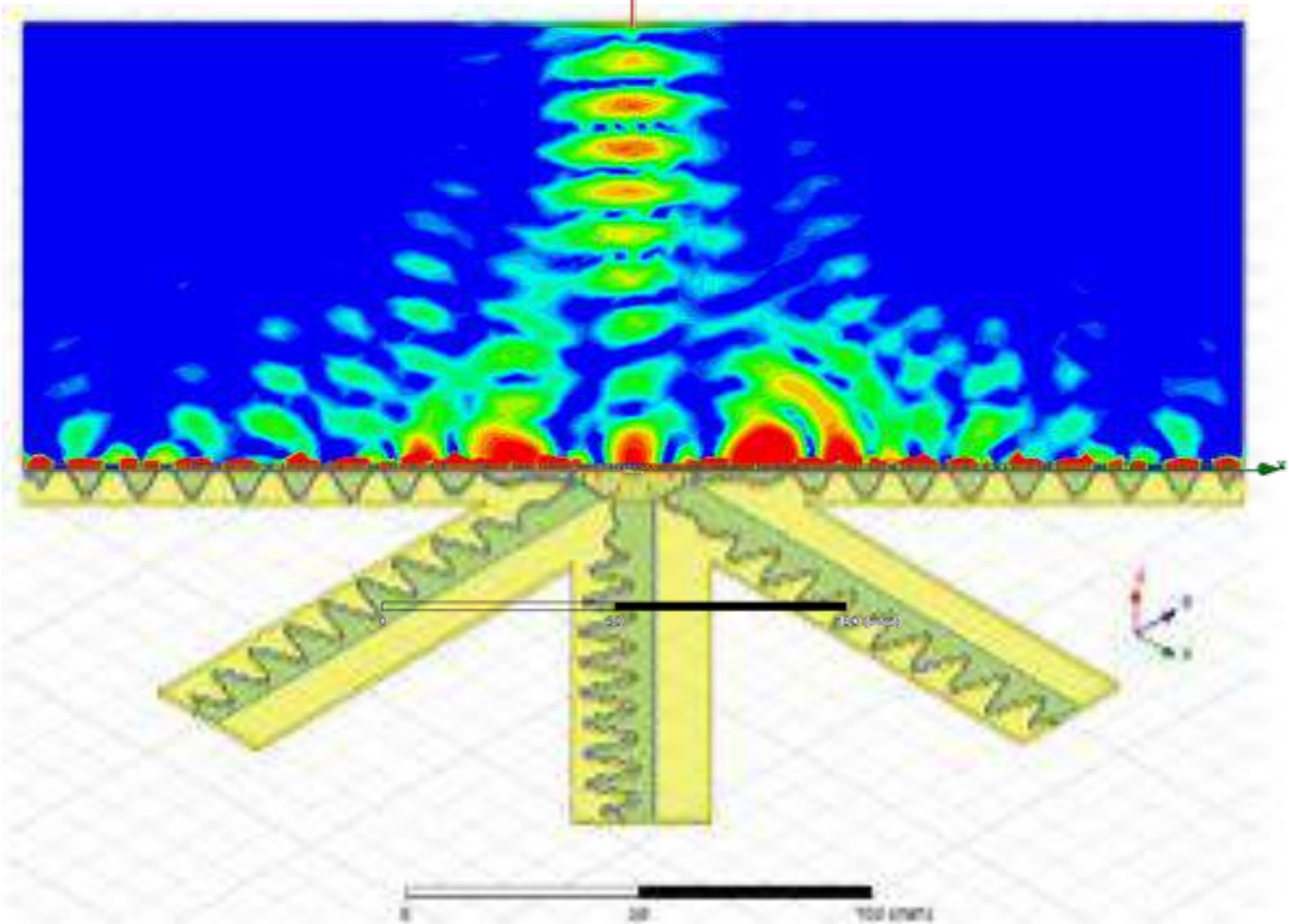


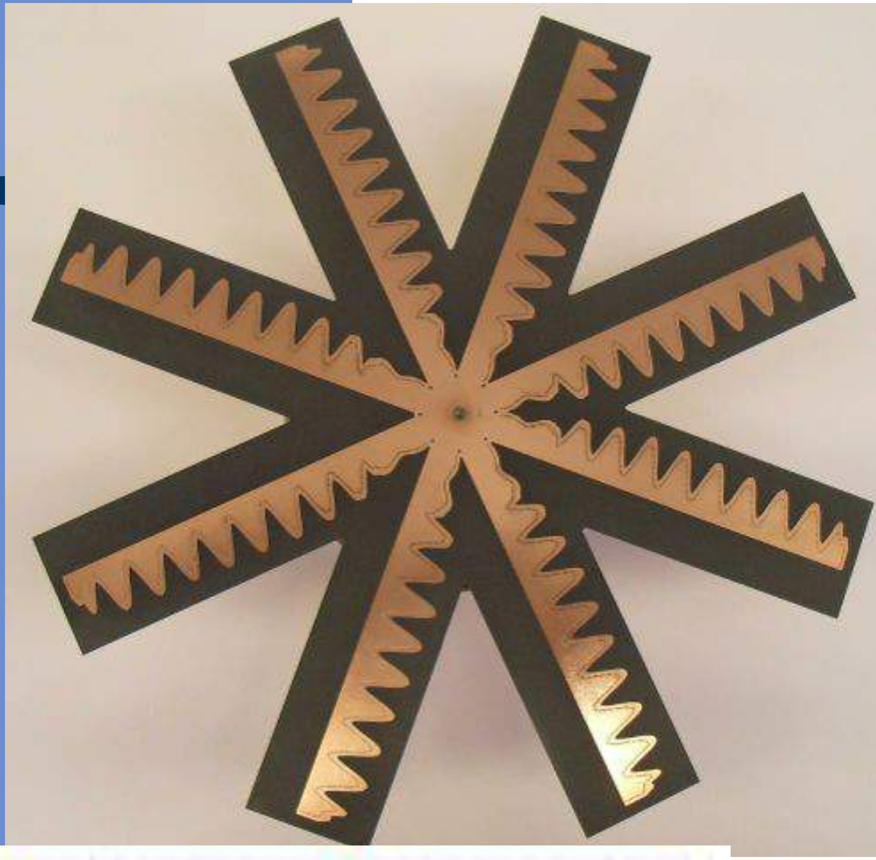


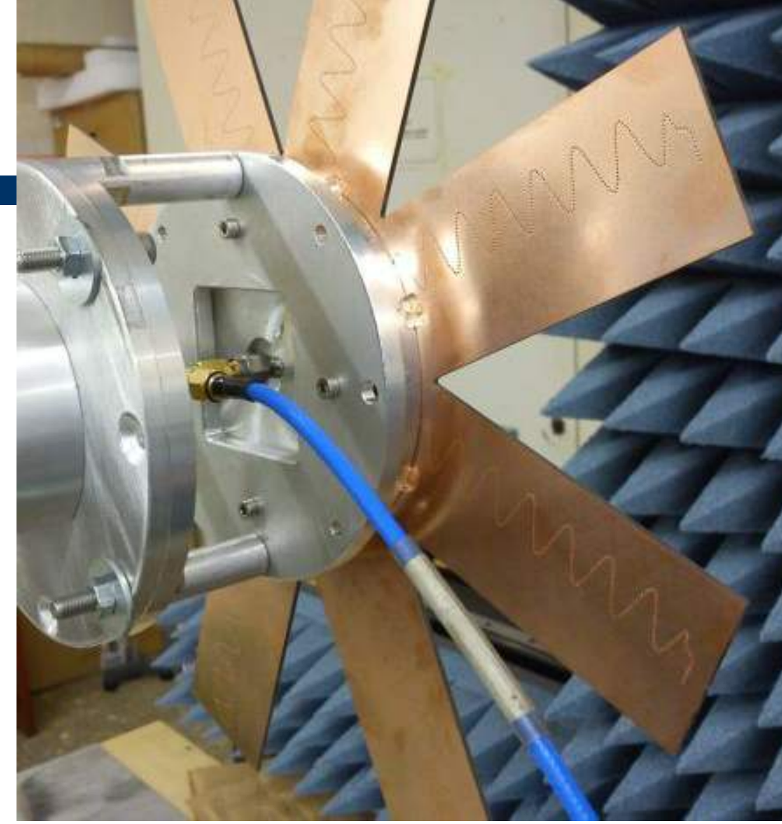


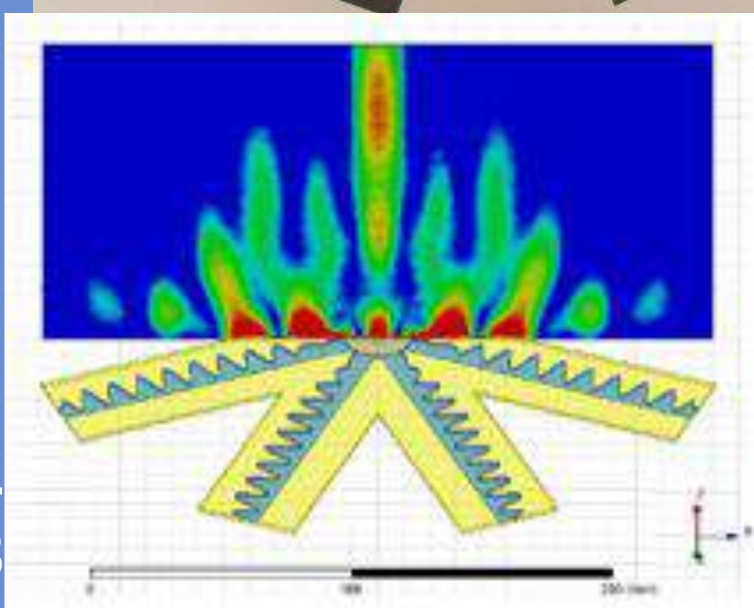
3- Future:

Radial Array of SIW antennas focused in Near Field

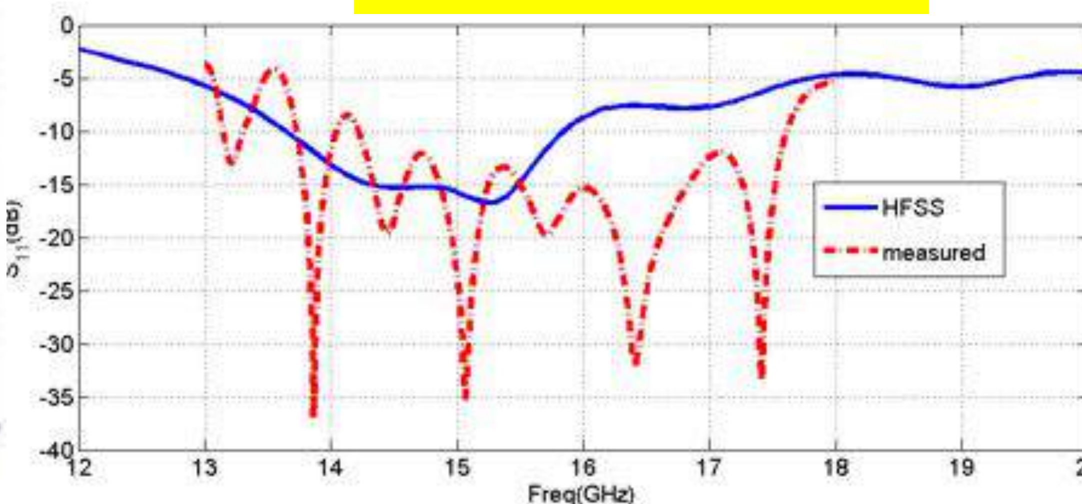






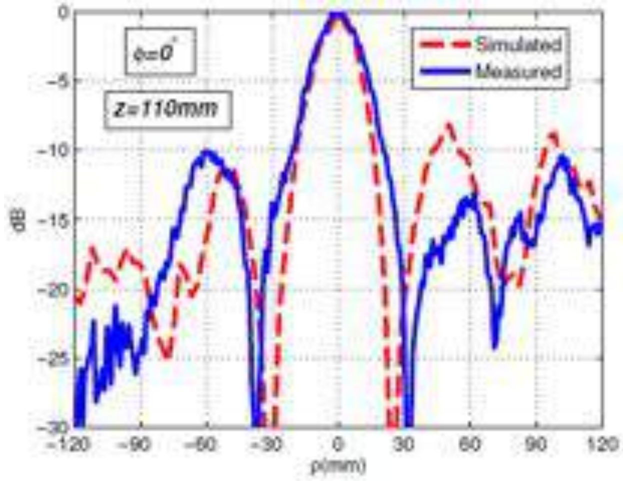


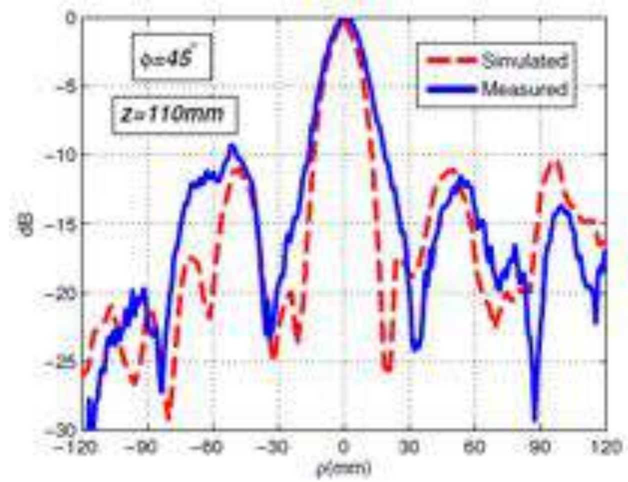
S11<-20dB @15GHz

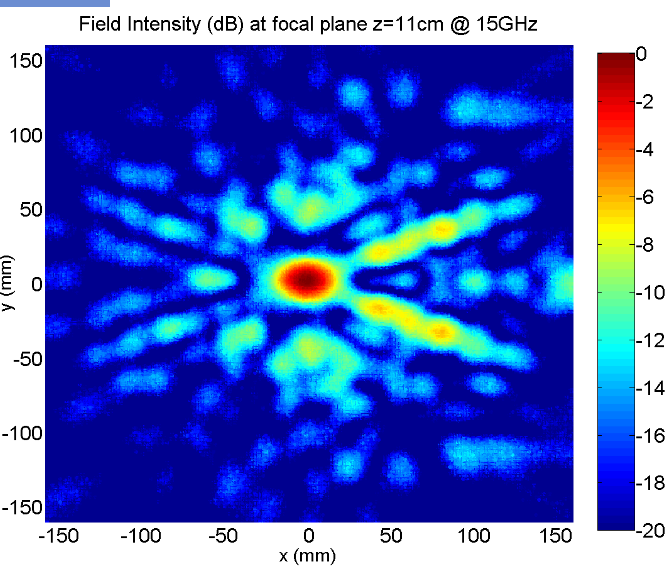


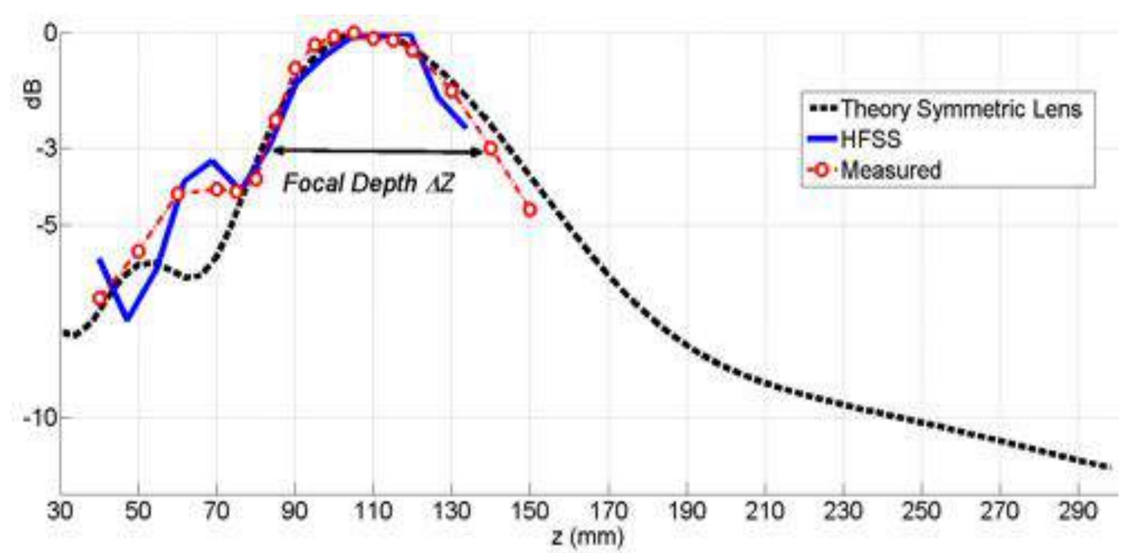
Radial Array of SIW antennas focused in Near Field

3- Future:









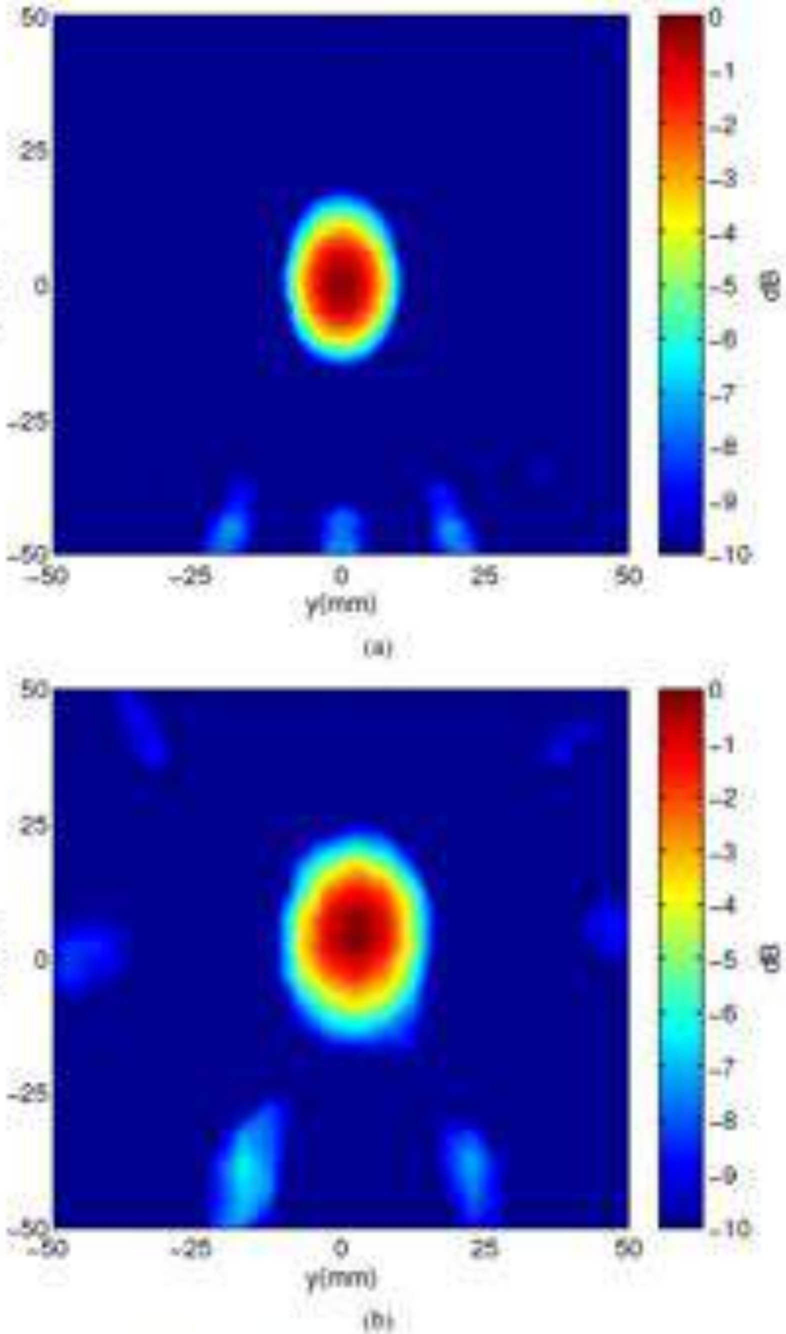


Fig. 17. Near-field plane at the focal height $z_F = 110$ mm for the design frequency of 15 GHz: a) simulated and b) measured.

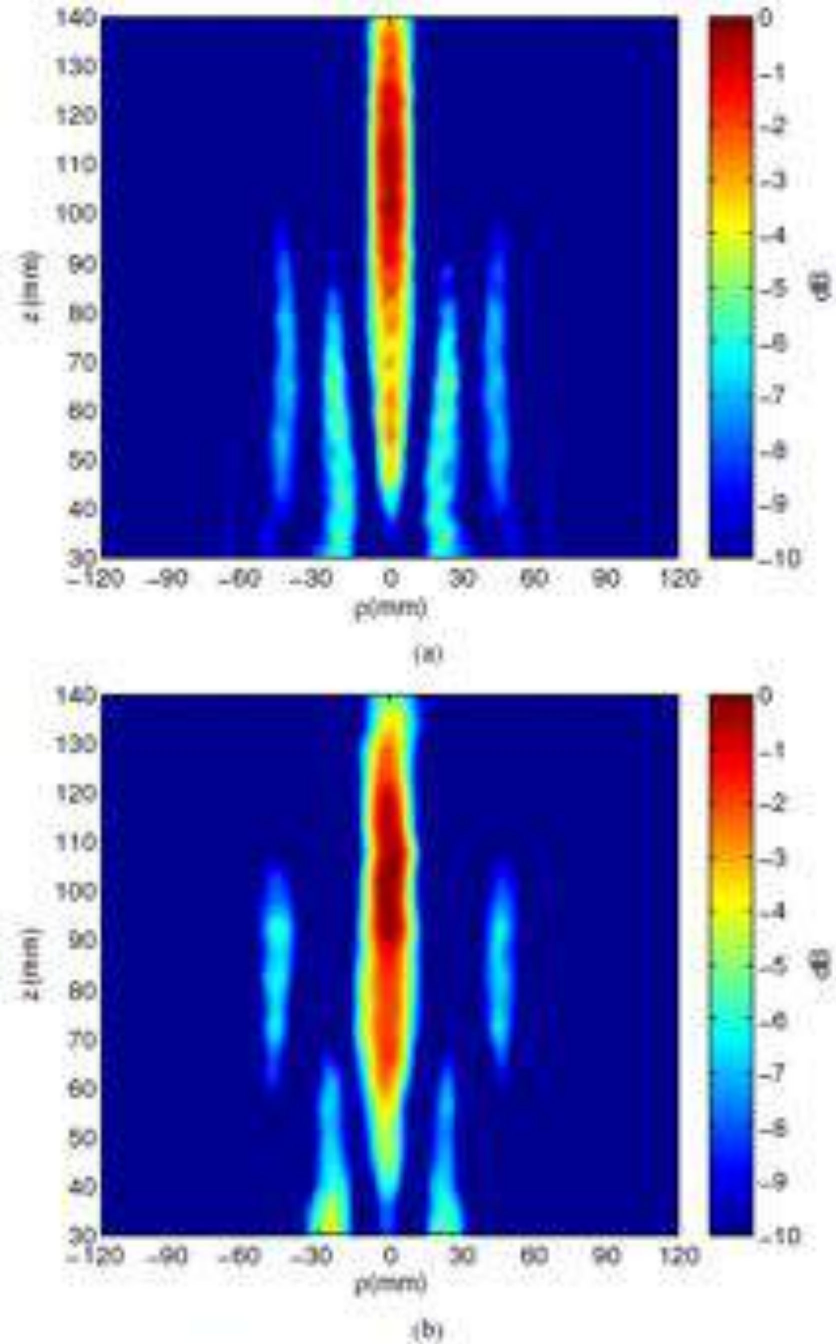
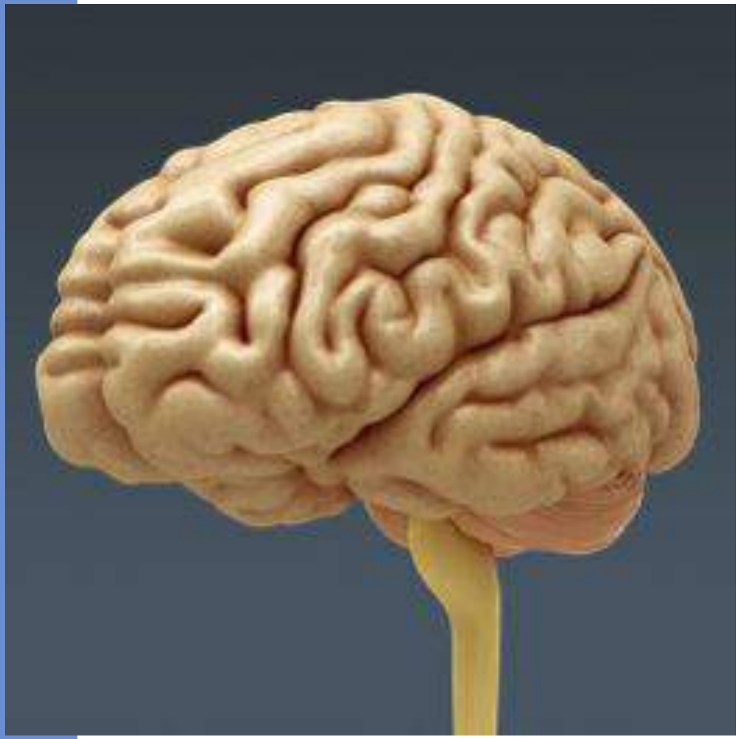


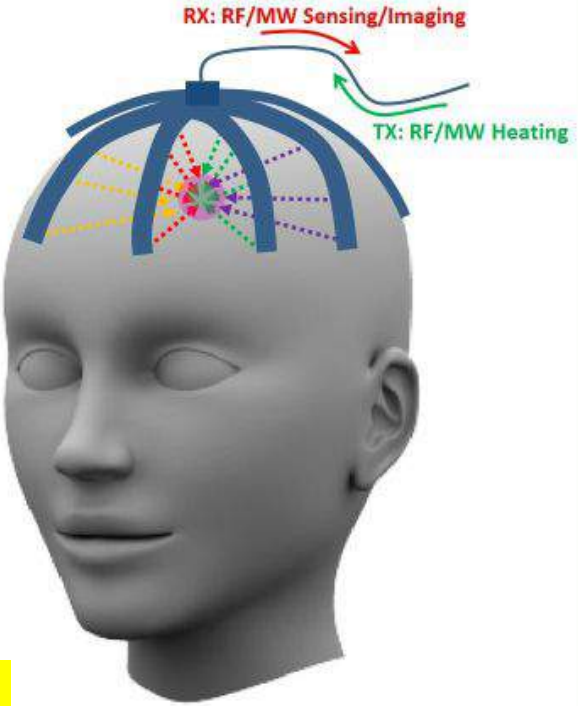
Fig. 18. Near-field plane at $\phi = 0°$ along the z-axis for the design frequency of 15 GHz: a) simulated and b) measured.

3- Future:

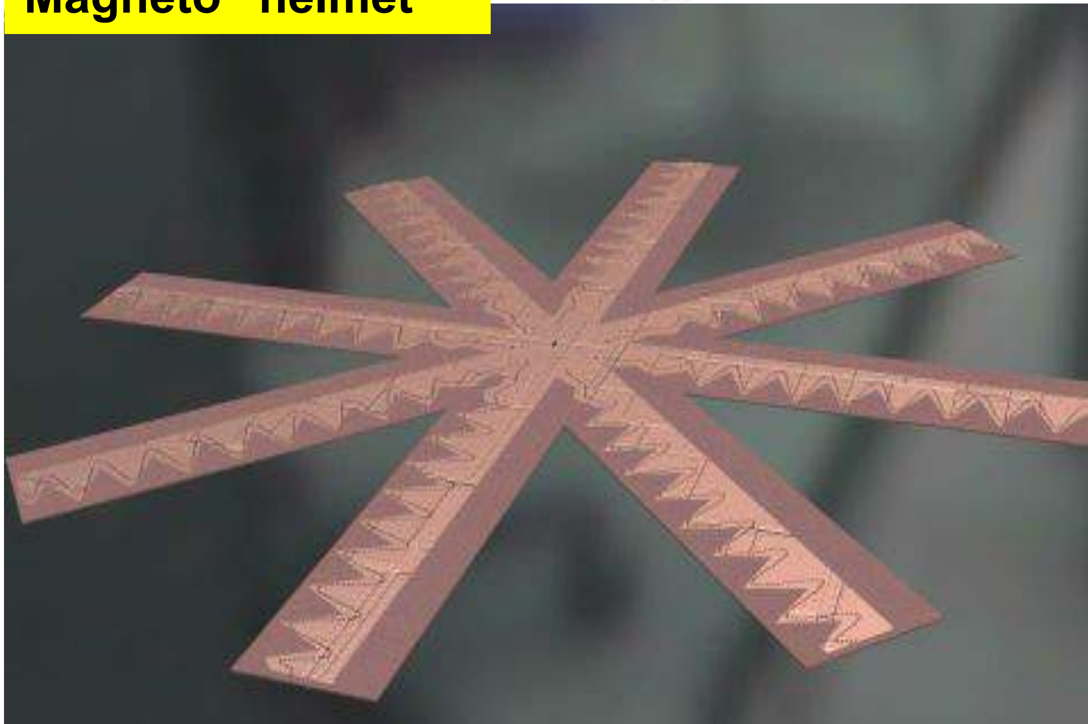
Conformal radial SIW array focused in Near Field

- **Sensing / Imaging (RX)**
- **Heating / Hyperthermia (TX)**

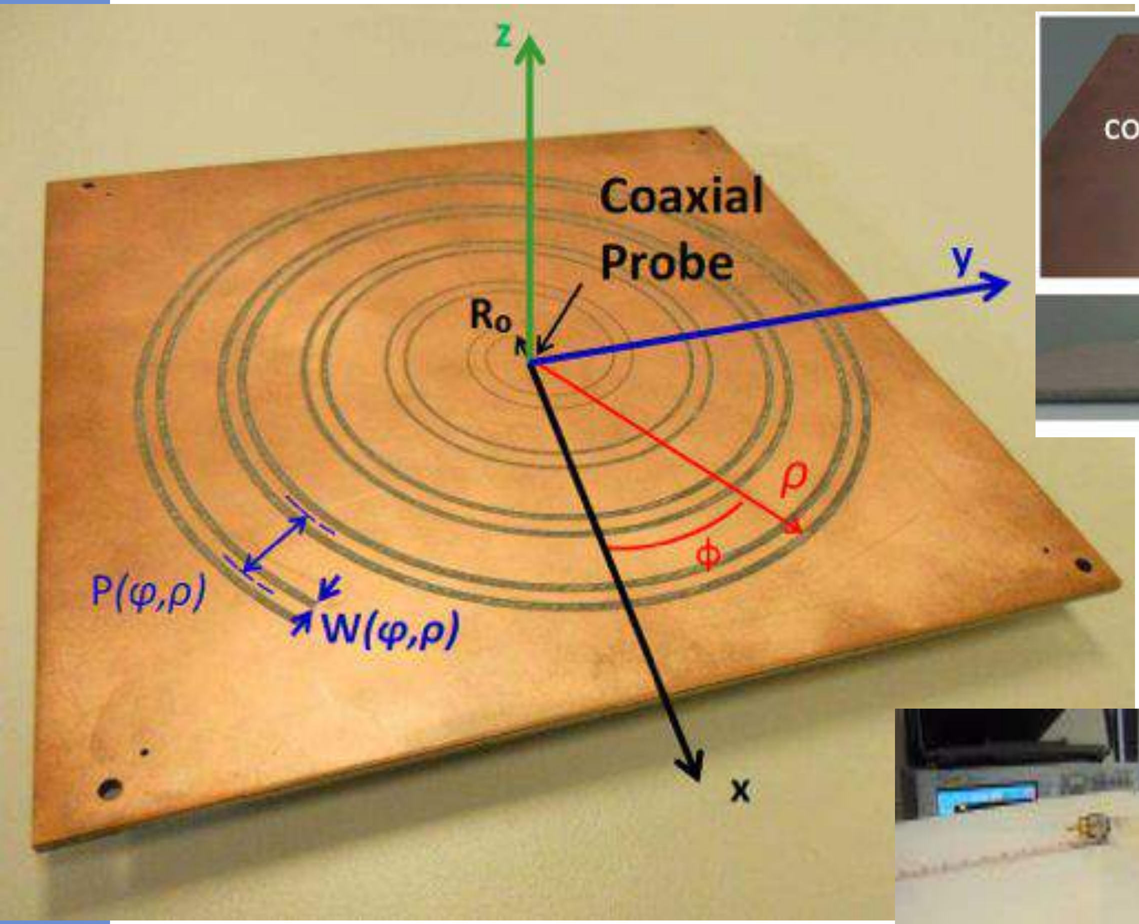


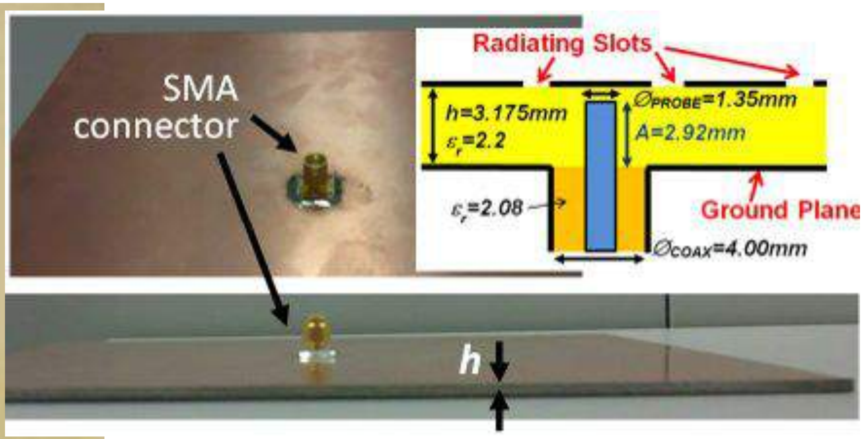


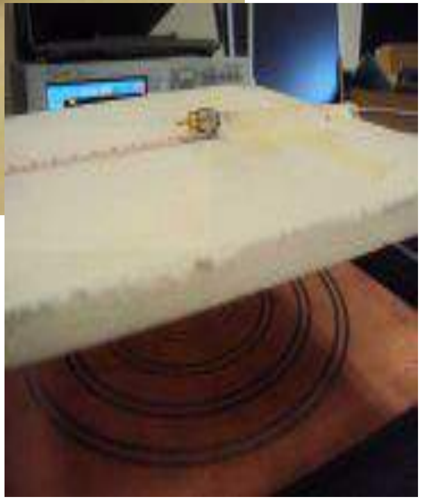
Magneto "helmet"



Fully-2D holographic lens focused in Near Field



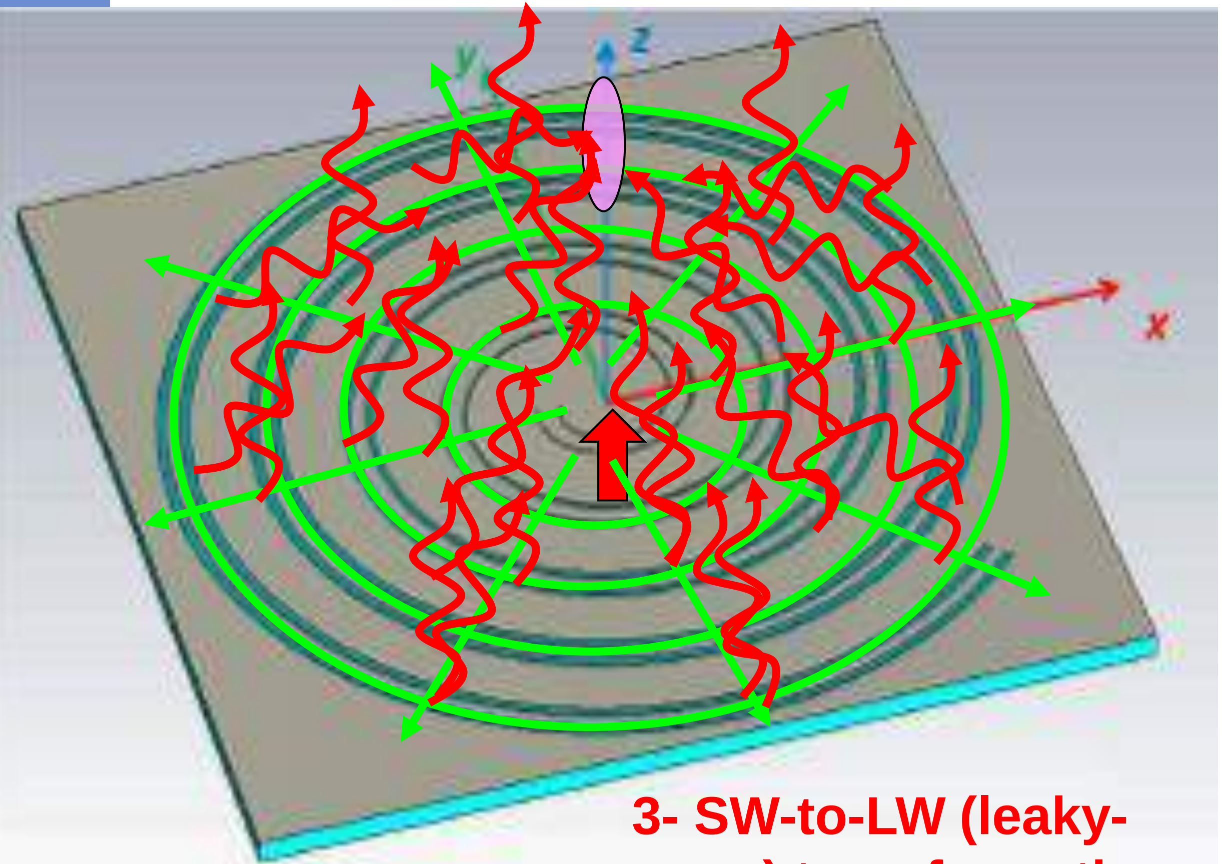




1-Motivation. Planar microwave lenses.

4- 2D Modulation of Cylindrical LW

5- Synthesis of Near-Field focusing region



3- SW-to-LW (leaky-wave) transformation

1- Point-source center feeding

2- Cylindrical Surface Wave (2D SW)

Desirable features:

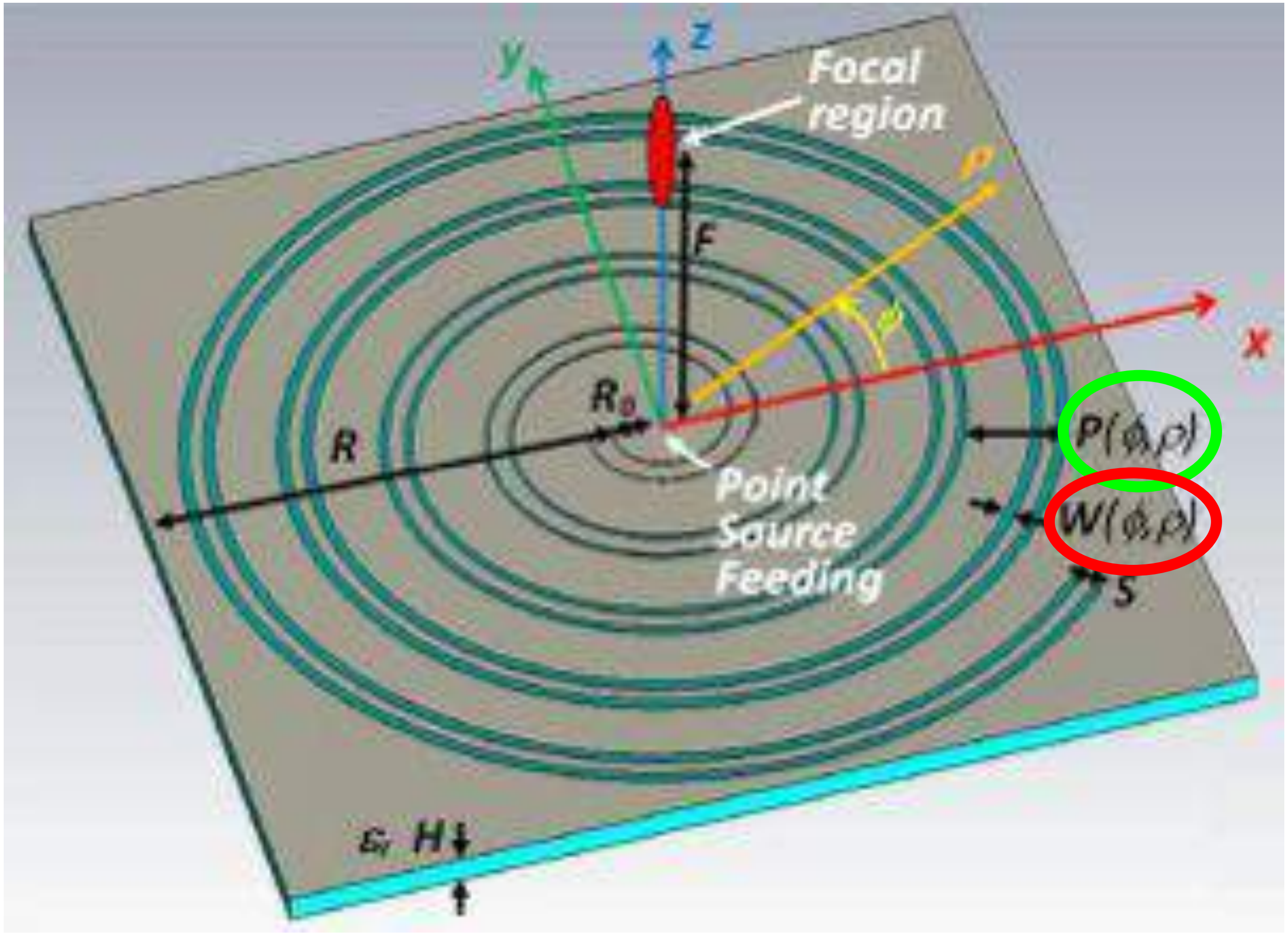
- Near-field focusing.
- Simple feeding.
- Planar low-profile structure.
- Simple printed-slot circuit.
- Direct analysis and design.

Applications:

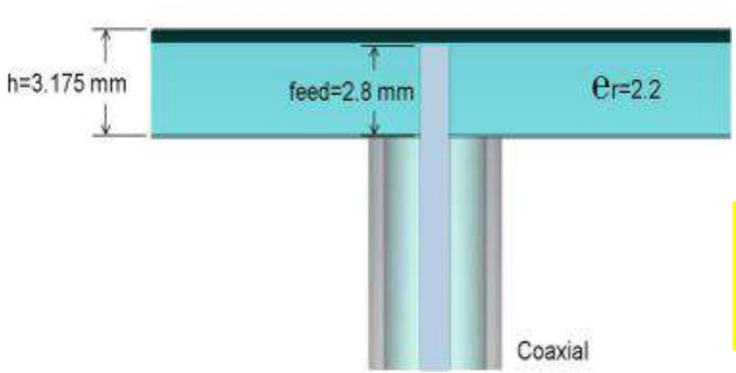
- Imaging/sensing.
- Heating.
- Power transmission.

1-Motivation. Planar microwave lenses.

2D Modulation of Cylindrical LW → Modulation of printed-slot dimensions *W(ϕ,ρ) P(ϕ,ρ)*

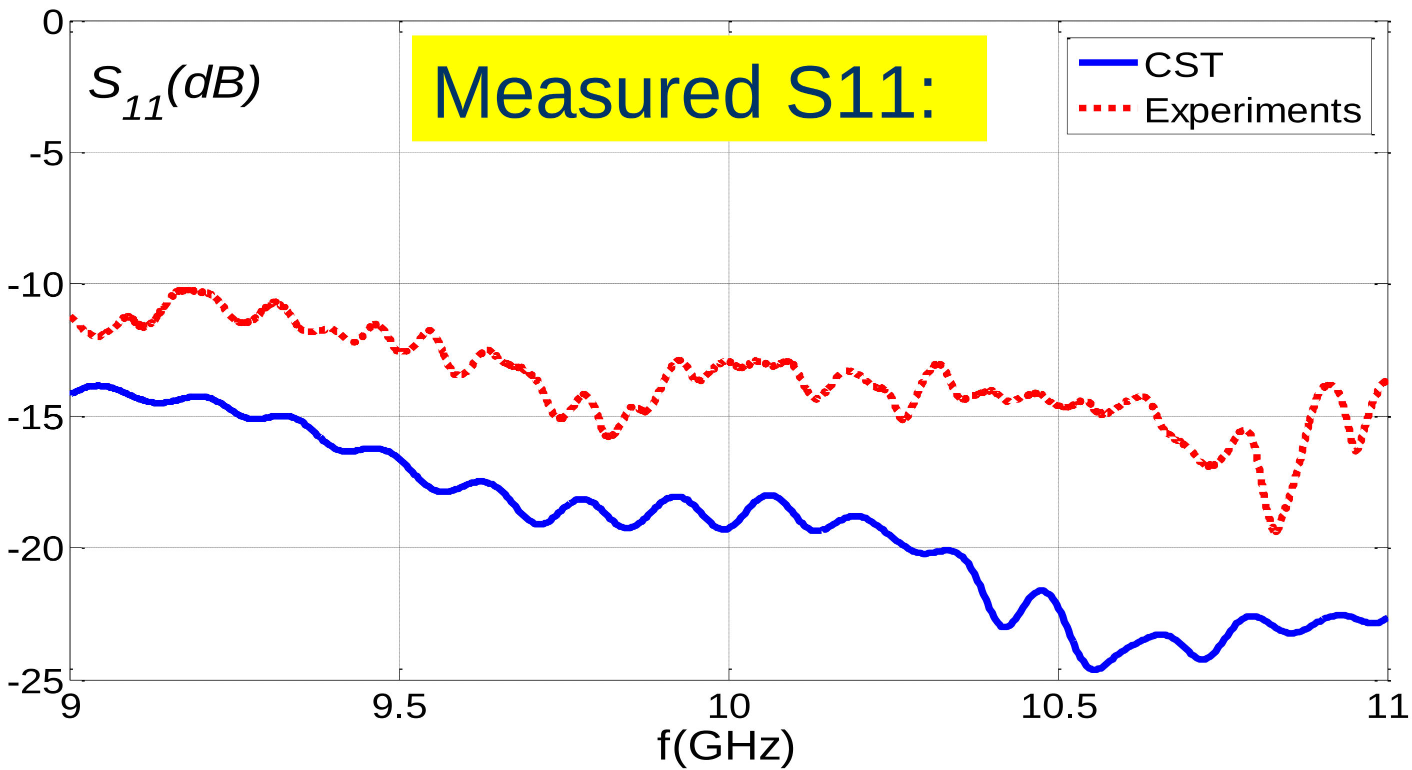


4- Theoretical and Experimental results.



FEEDING PROBE
∅=1.35mm h=2.92mm

COAX **$\varnothing_{IN}$=1.35mm** ***ε_r=2.08***
R_{IN}=0.675mm **R_{OUT}=2.00mm**



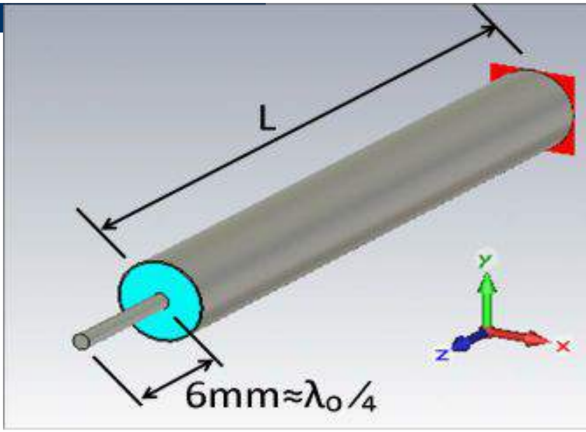
4- Theoretical and Experimental results.

Experimental
Near-Field Setup:

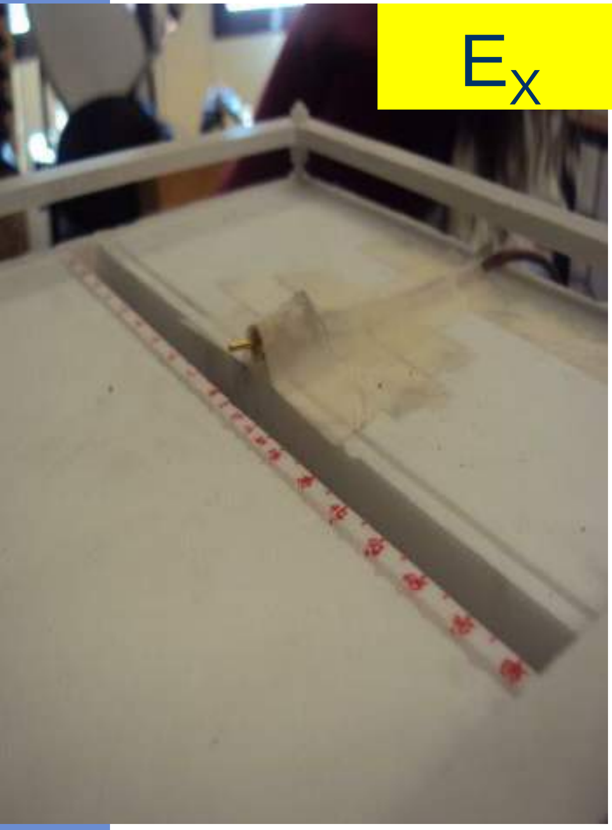
4- Theoretical and Experimental results.

Experimental Near-Field Setup:

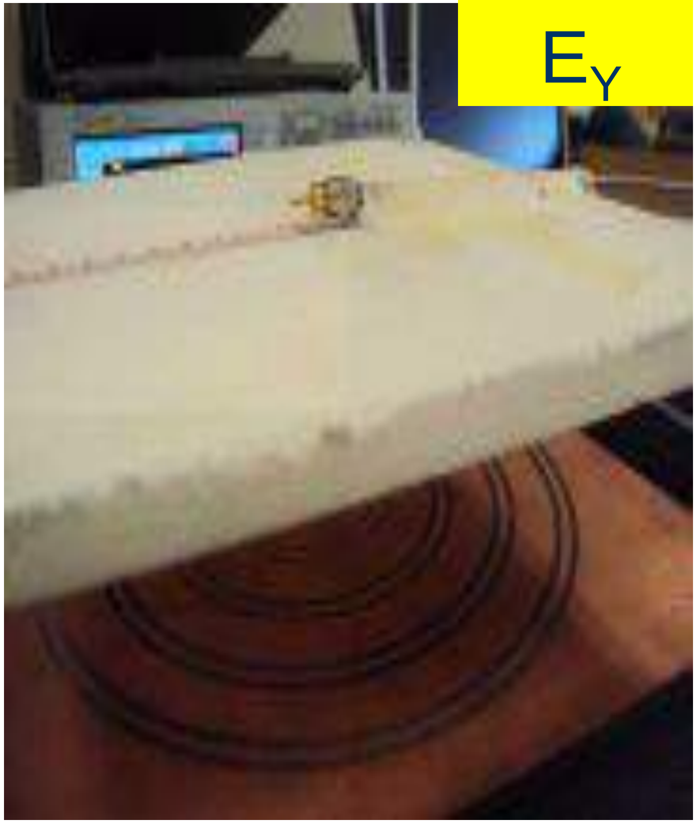
- Probe:



E_X



E_Y

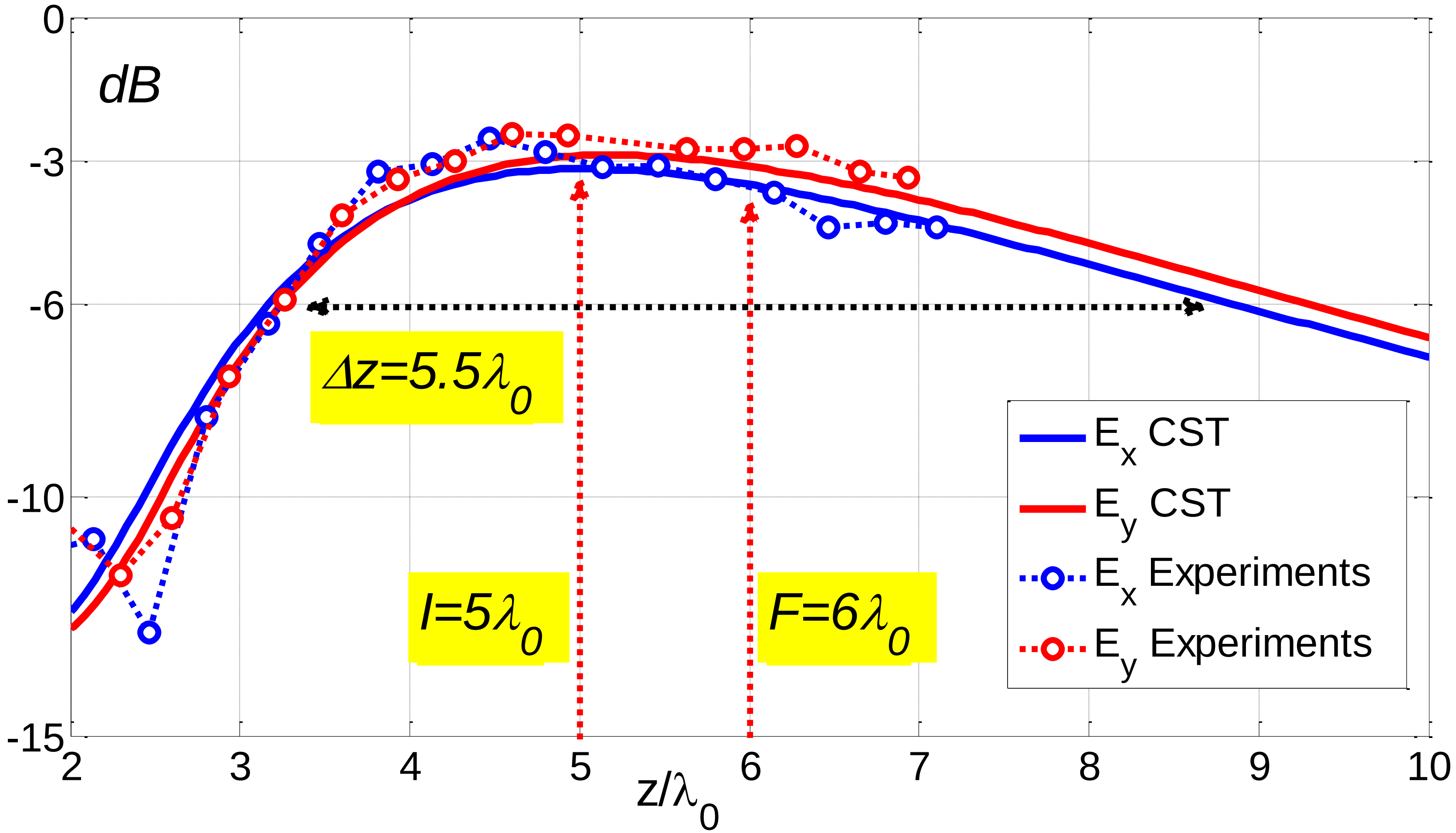


E_Z

4- Theoretical and Experimental results.

Measured Near Fields:

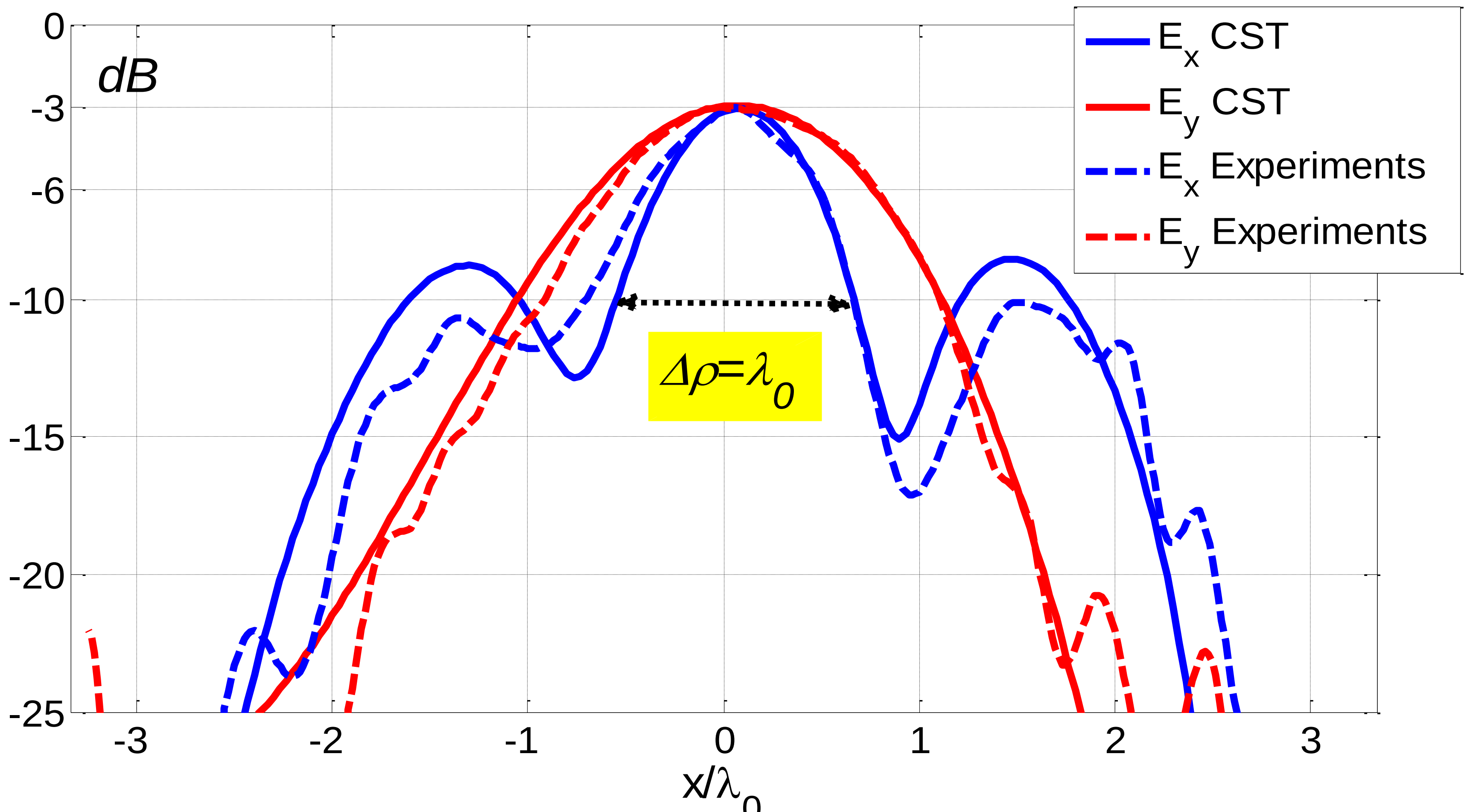
- Axial cut (z):



4- Theoretical and Experimental results.

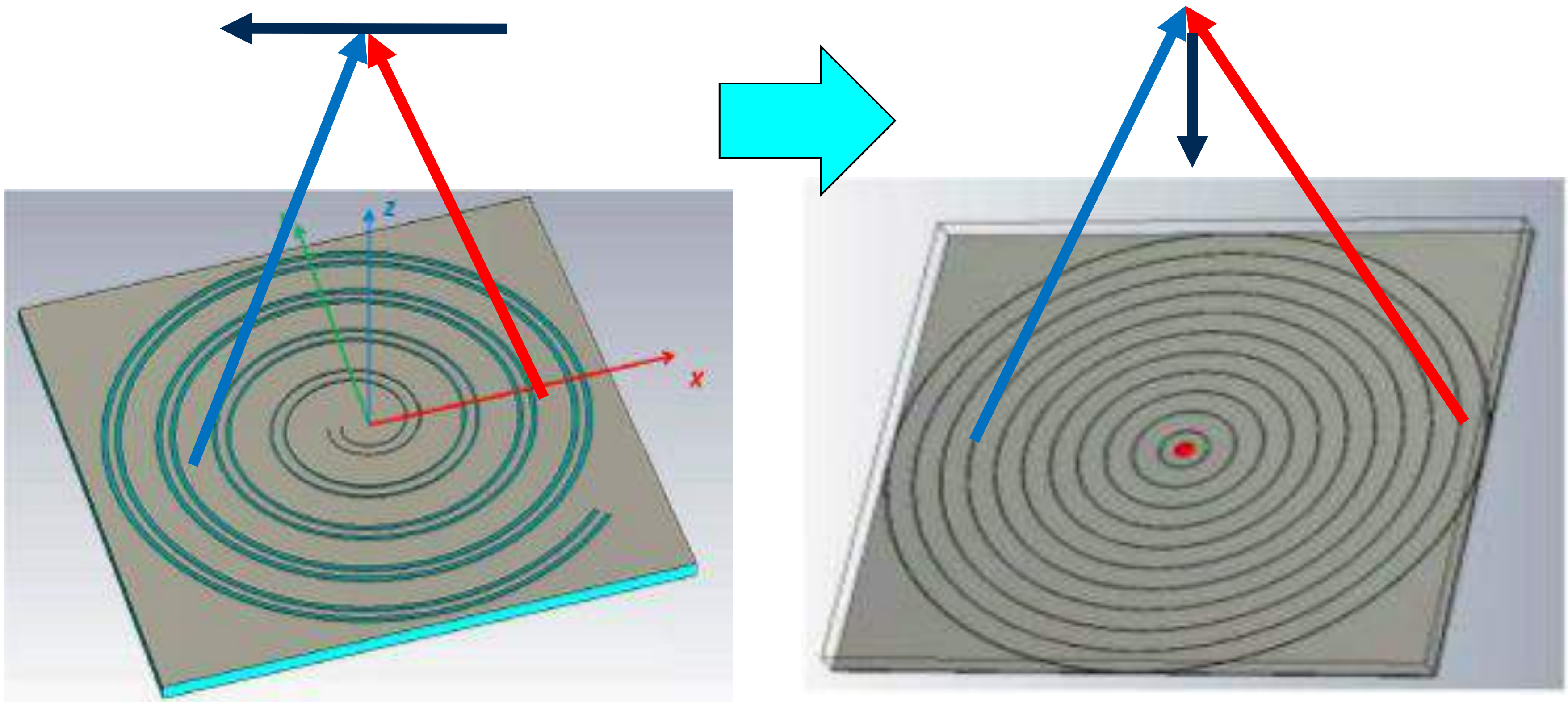
Measured Near Fields:

- Transverse cut (x):



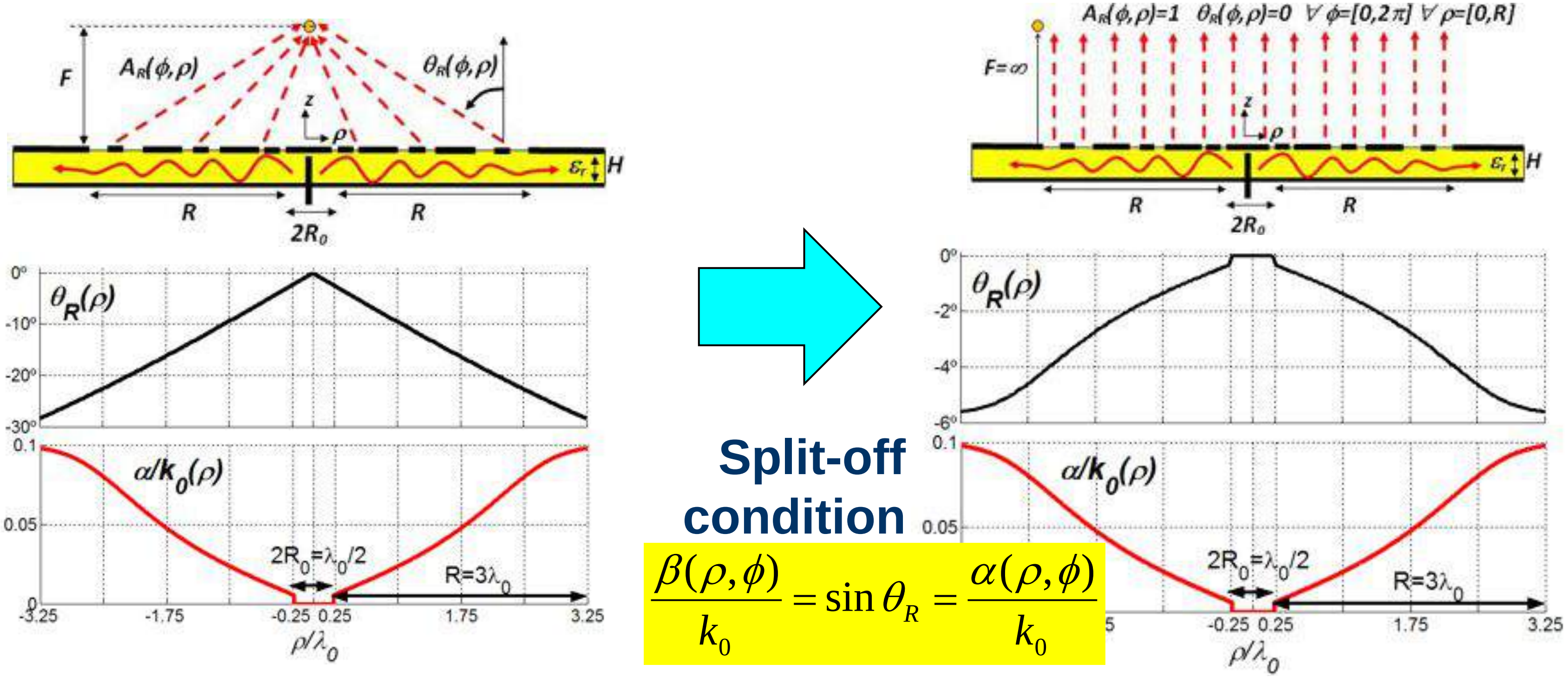
5- Future lines, conclusions.

1- Design of **HLWLs with** **linear circularly and vertical polarization** (*only in the* ***near field***)



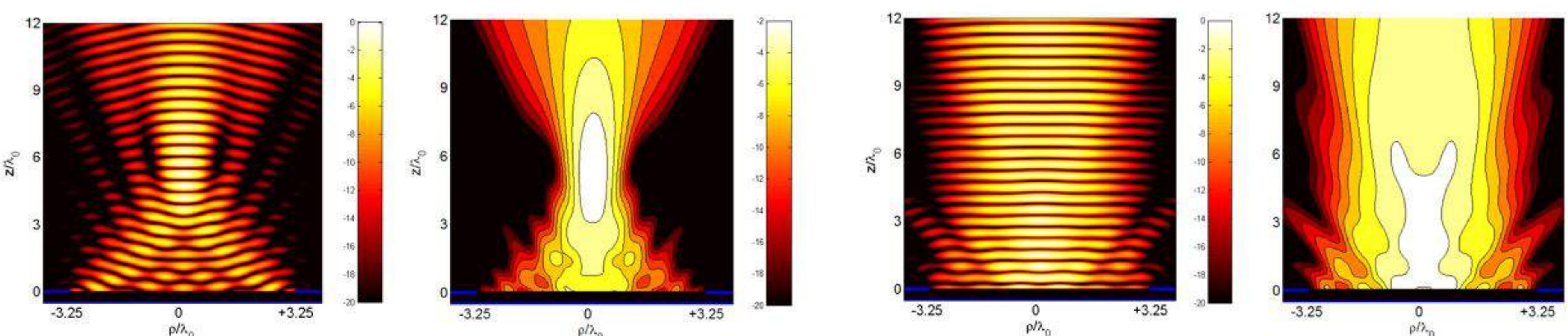
5- Future lines, conclusions.

2- Design of **HLWAs focused in the far field**.



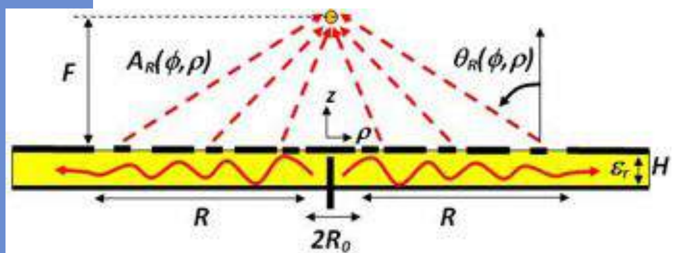
Split-off condition

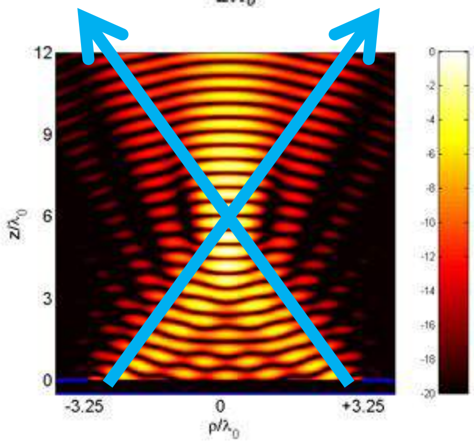
$$\frac{\beta(\rho,\phi)}{k_0}=\sin\theta_R=\frac{\alpha(\rho,\phi)}{k_0}$$

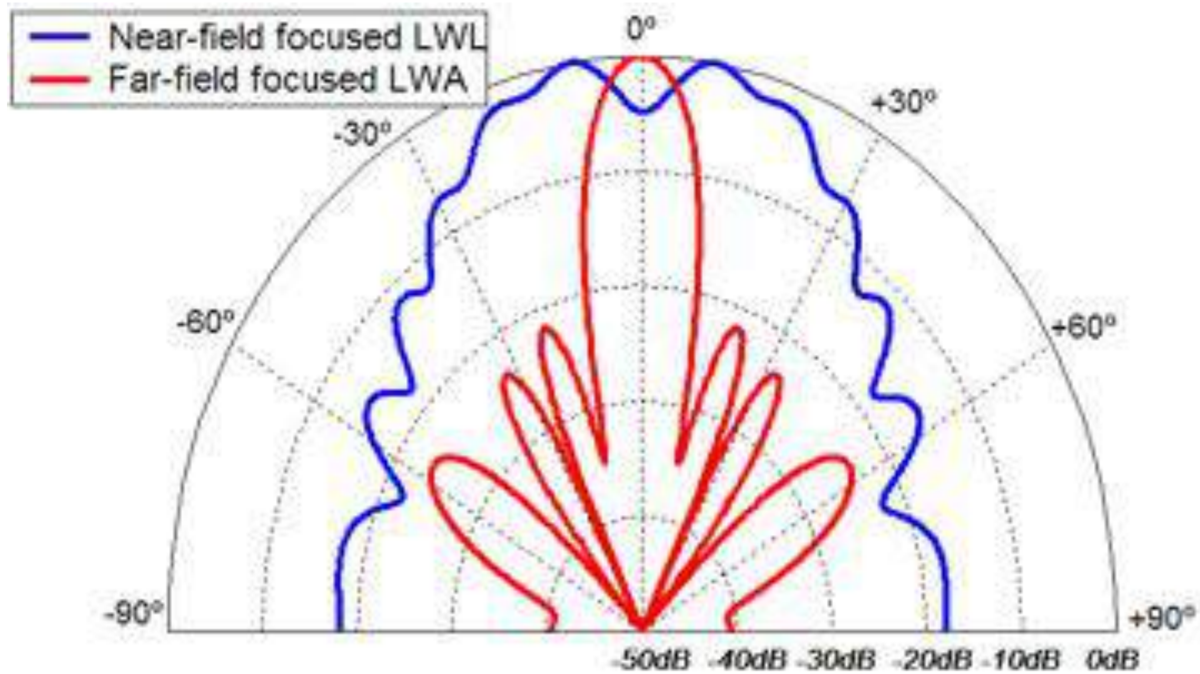


5- Future lines, conclusions.

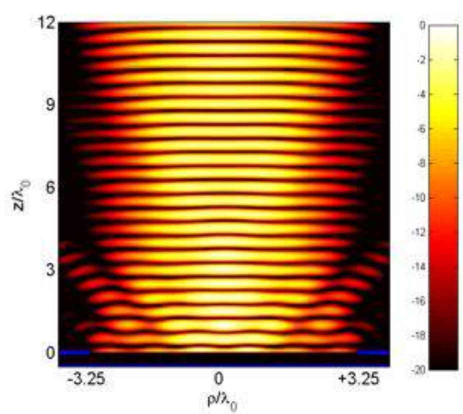
2- Design of **HLWAs focused in the** far field.

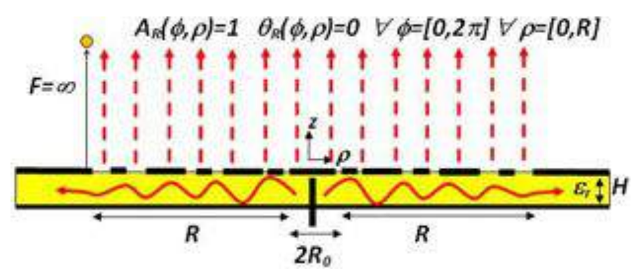






Near-field converging = Far-field diverging





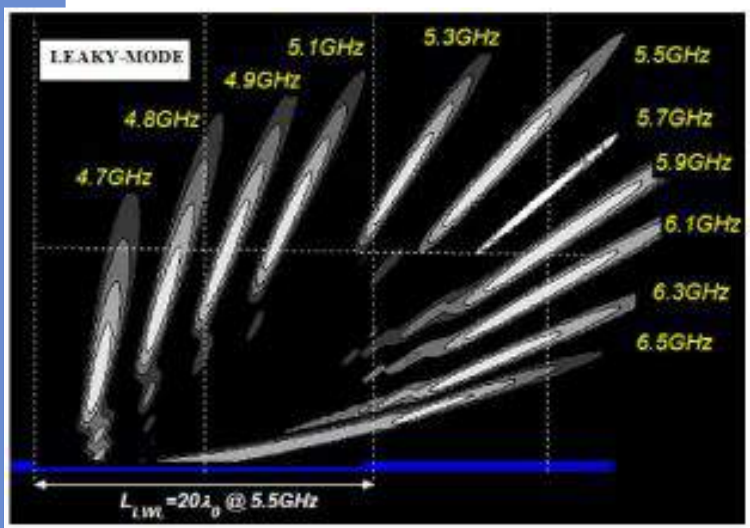
5- Future lines, conclusions.

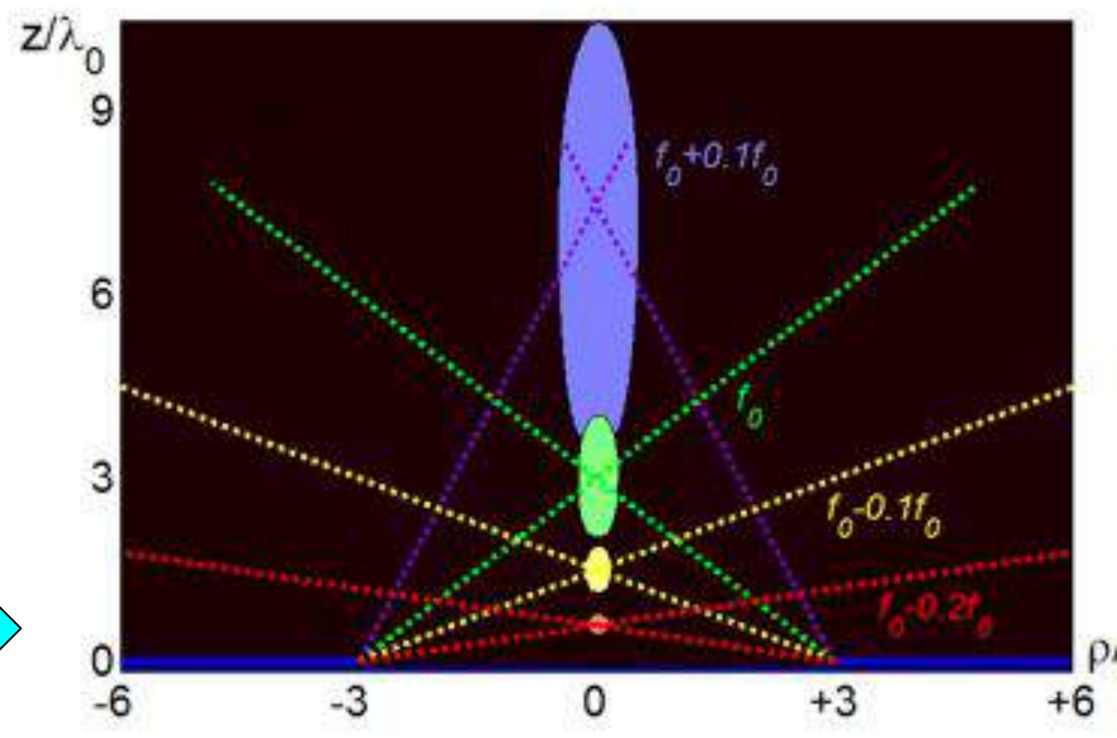
6- Study of **frequency shift of focused region**.

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 59, NO. 2, FEBRUARY 2011 407

Frequency Steerable Two Dimensional Focusing Using Rectilinear Leaky-Wave Lenses

José Luis Gómez-Tornero, *Member, IEEE*, Fernando Quesada-Pereira, *Member, IEEE*, Alejandro Alvarez-Melcón, *Senior Member, IEEE*, George Goussetis, *Member, IEEE*, Andrew R. Weily, *Member, IEEE*, and Y. Jay Guo, *Senior Member, IEEE*

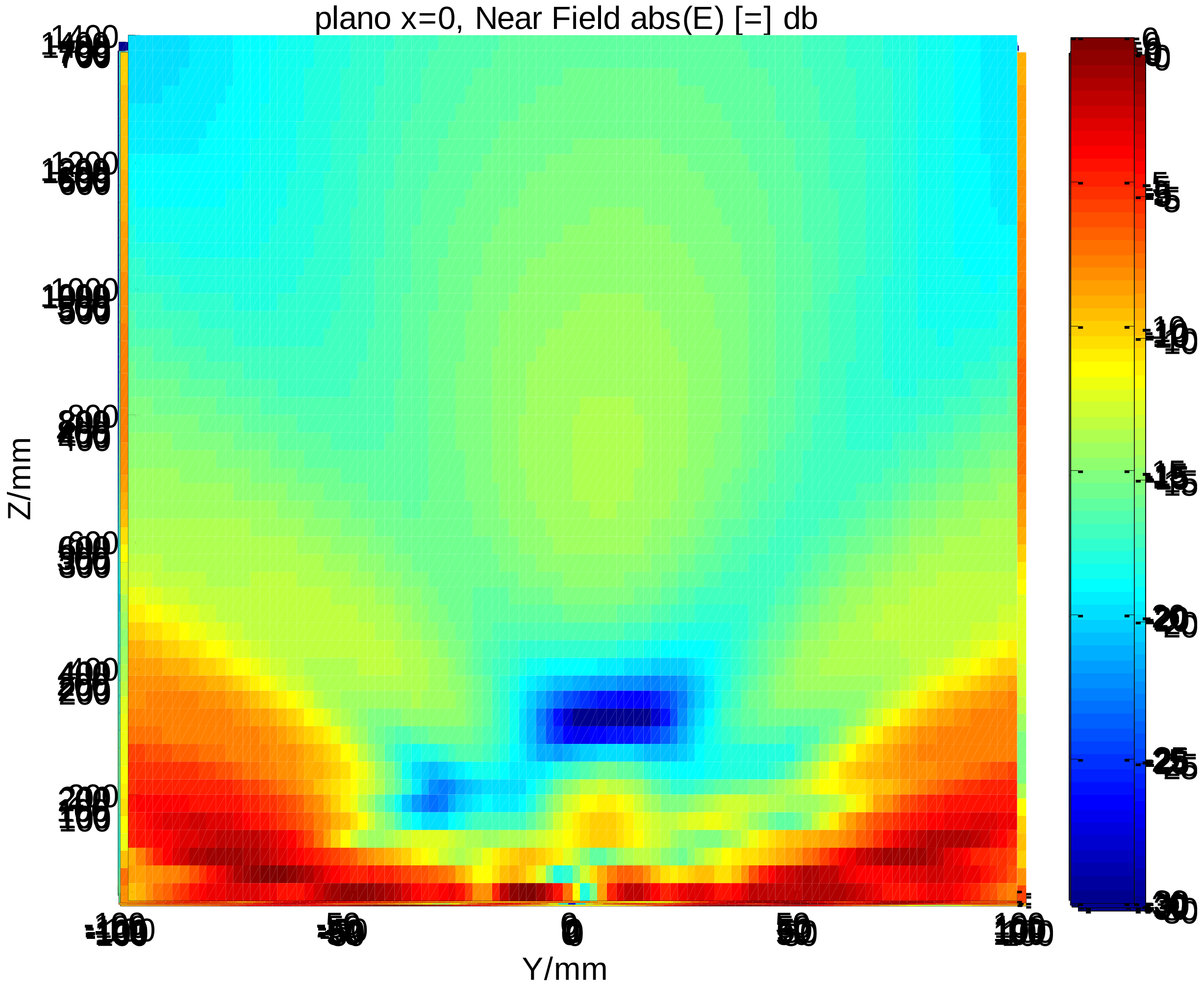




5- Future lines, conclusions.

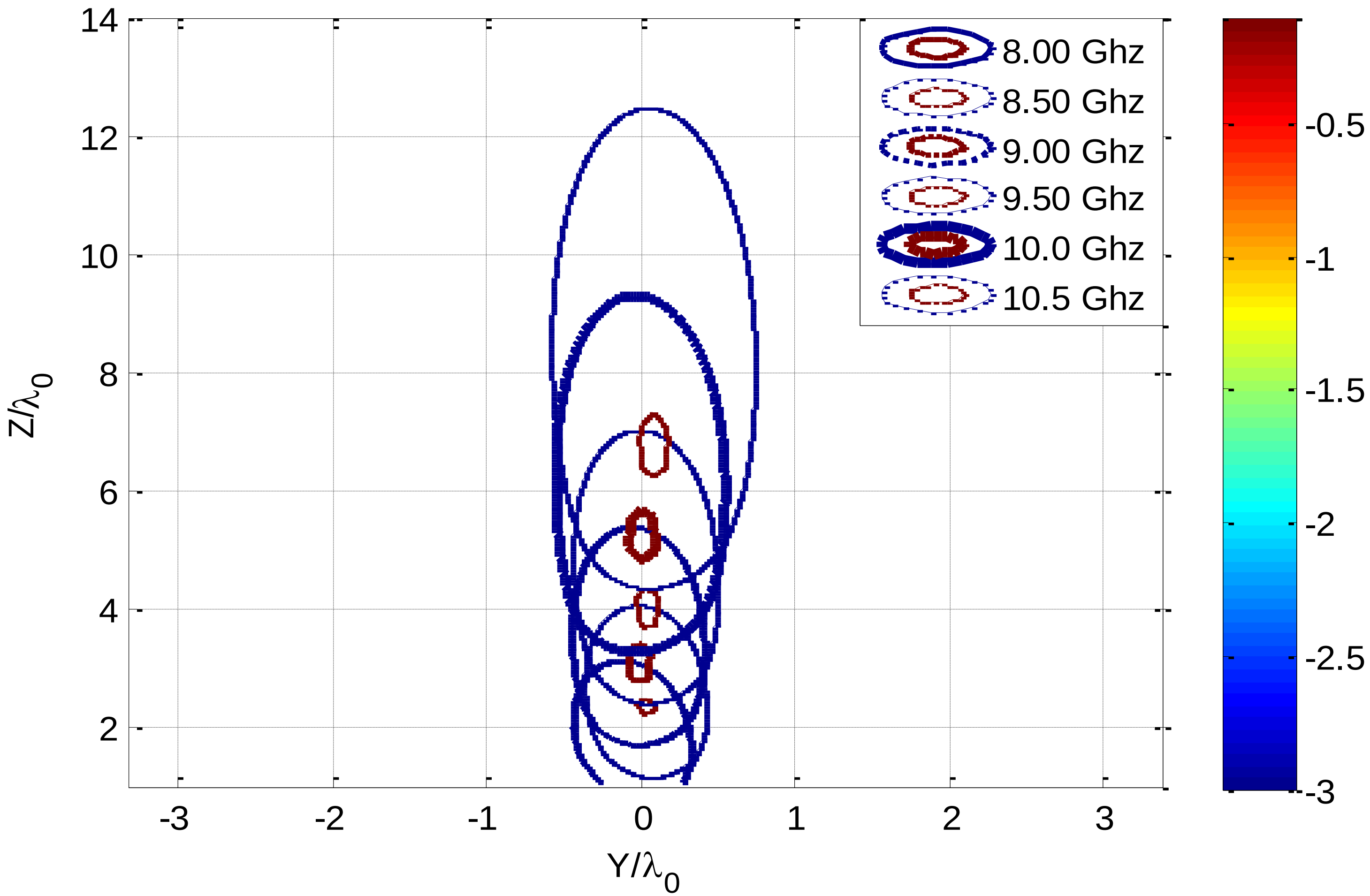
6- Study of **frequency shift** **of focused region**.

15GHz



5- Future lines, conclusions.

6- Study of **frequency shift of focused region**.



Applied systems related to some of WPT/RFID concepts:

Prof. Luca Roselli :

- Green electronics, low-power analog passive circuits

- Smart devices / Analog Signal Processing

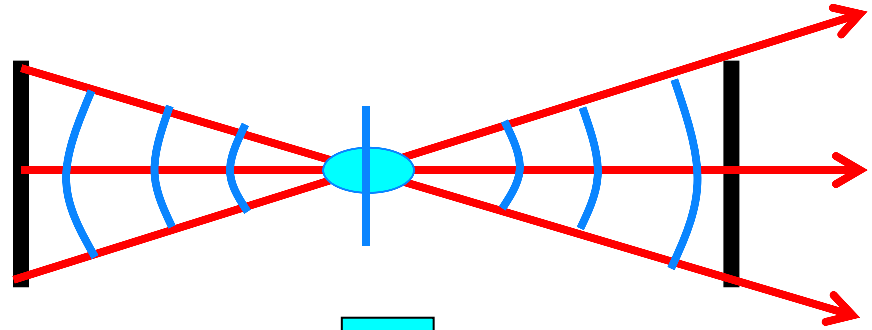
- Quasi-optic operation / Dispersion engineering (time, space, frequency).

- Wearable antennas, smart floor, smart skin.

- Dimensions are not a problem, electrically large antennas !

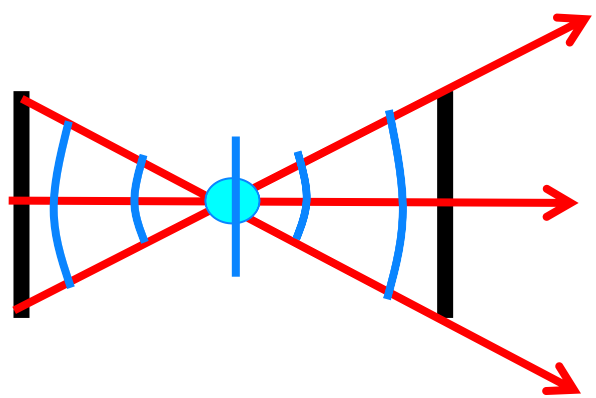
- Distributed antennas, space power combining

Near-field focused WPT
(common focus)



The focal point can be frequency-steered to adapt to different distance requirements/scenarios

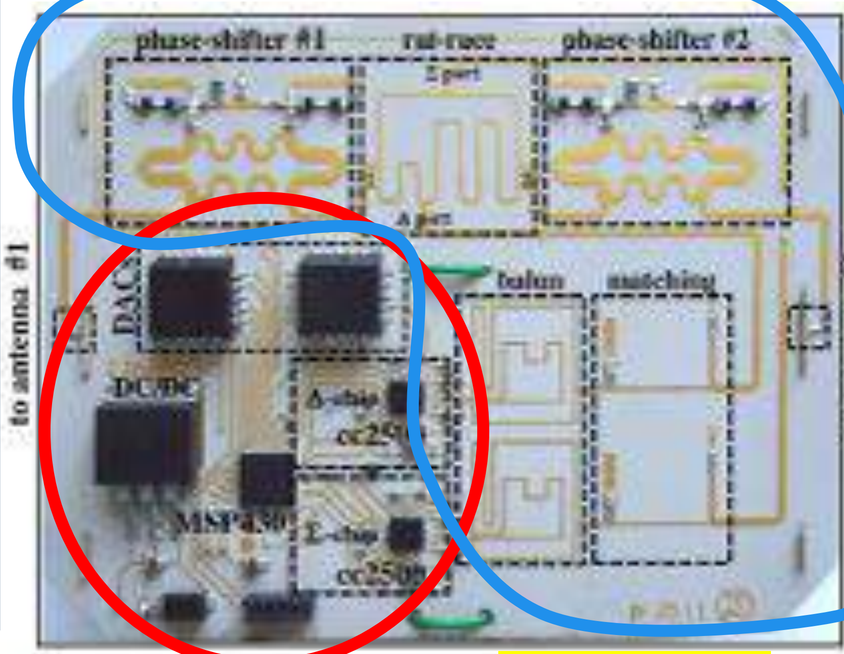
Electronic control on the focal distance = electronic control on the WPT range without losing beaming efficiency !!



Applied systems related to some of WPT/RFID concepts:

Prof. Alessandra Costanzo:

- **Impressive work on RFID localization electronic scanning**
- **“Smartification” of the physical space**
- **“Space sensing”**
- **Smart RFID readers avoiding complex expensive high-consumption DSP-UWB based**



DSP active circuits

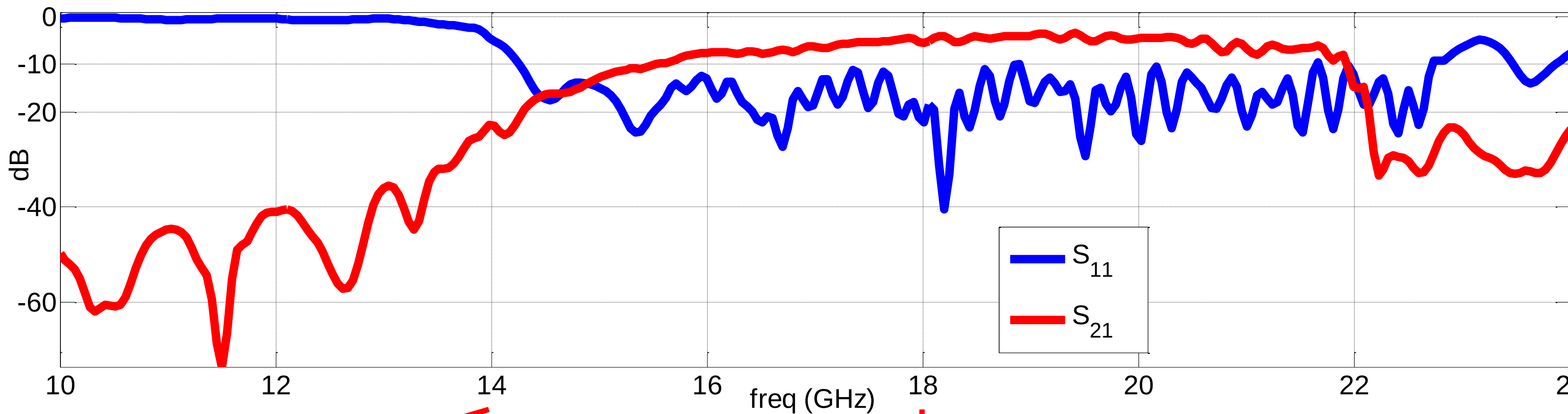
ASP passive circuits

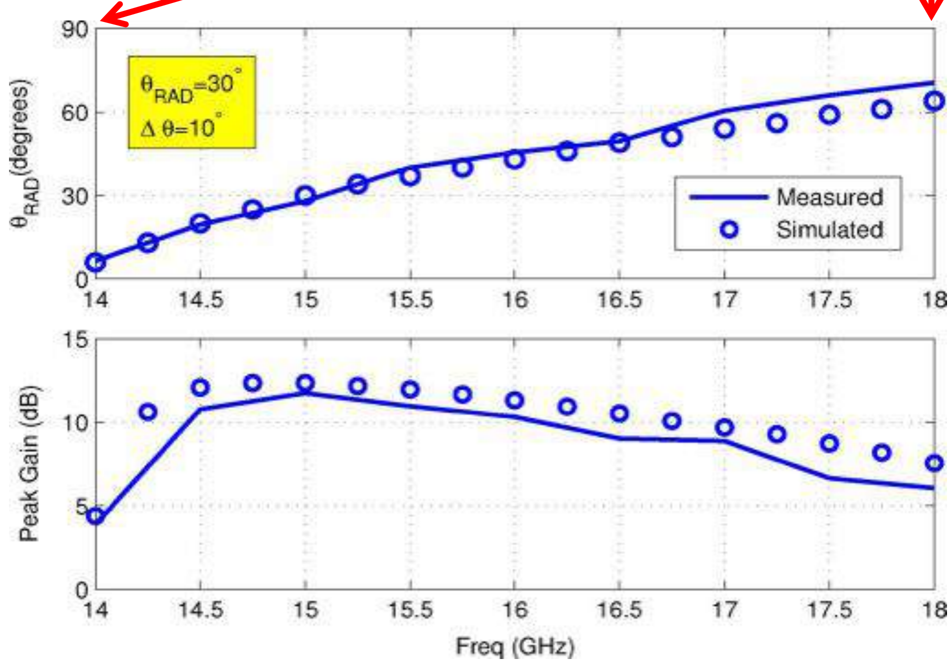
IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 61, NO. 1, JANUARY 2013

Remotely Identify and Detect by a Compact Reader With Mono-Pulse Scanning Capabilities

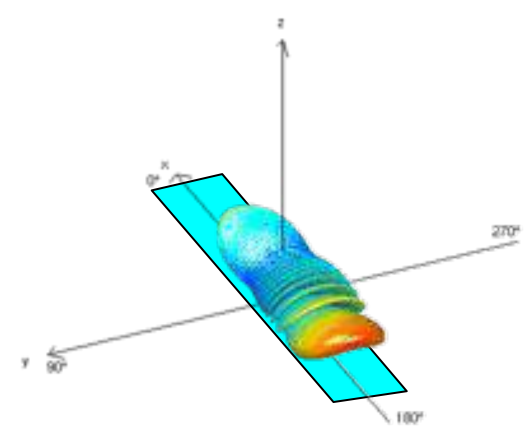
Massimo Del Prete, Diego Masotti, *Member, IEEE*, Nicola Arbizzani, and Alessandra Costanzo, *Member, IEEE*

What about the bandwidth ?





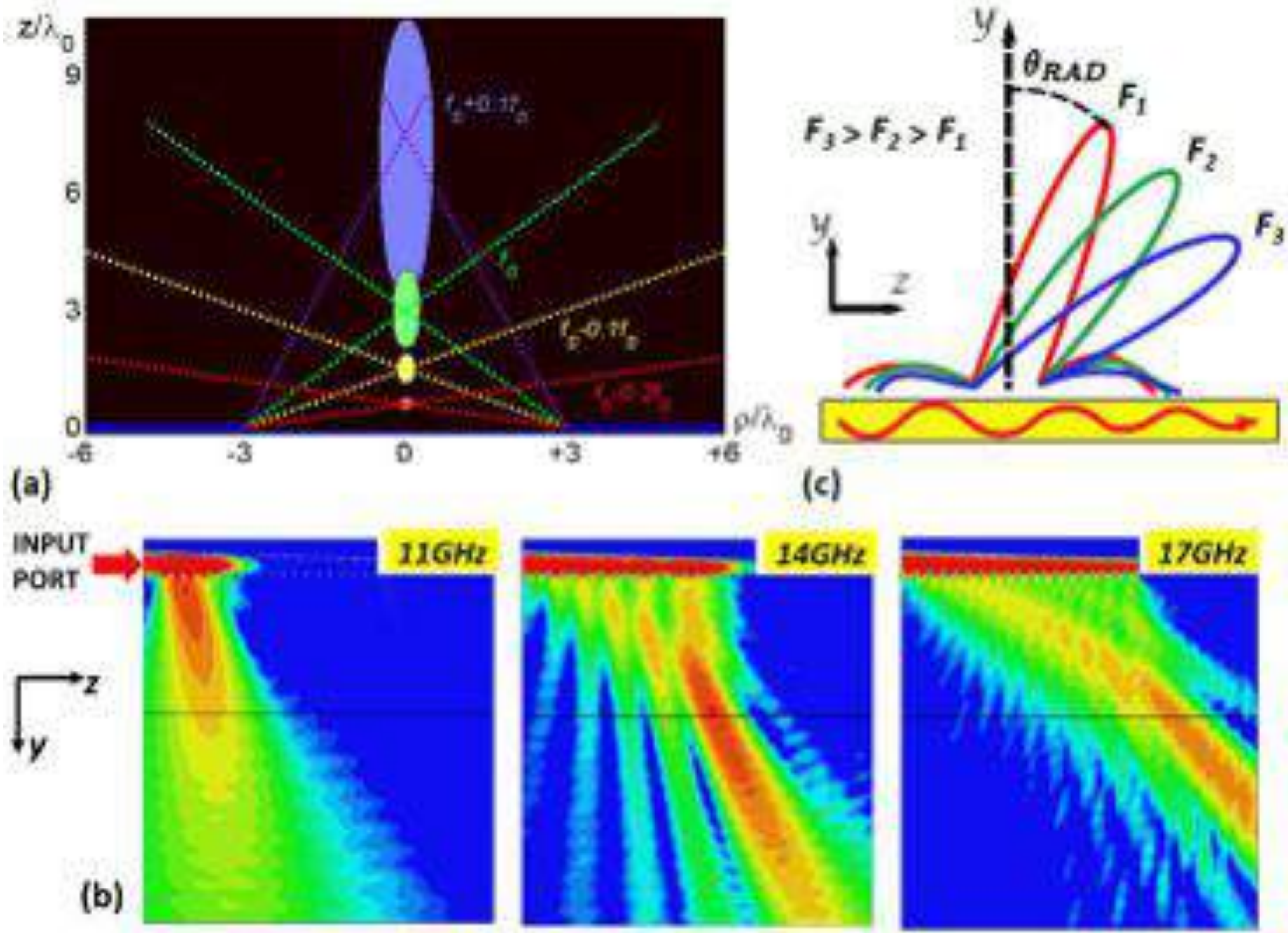
- **Matching / Efficiency**
- **Frequency beam scanning (dispersion)**



What about the bandwidth ?

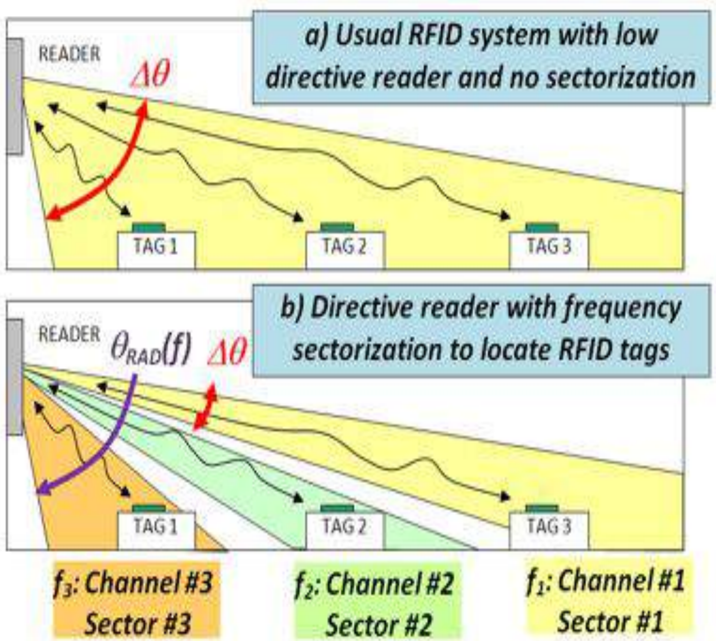
- **Wanted / useful dispersion**

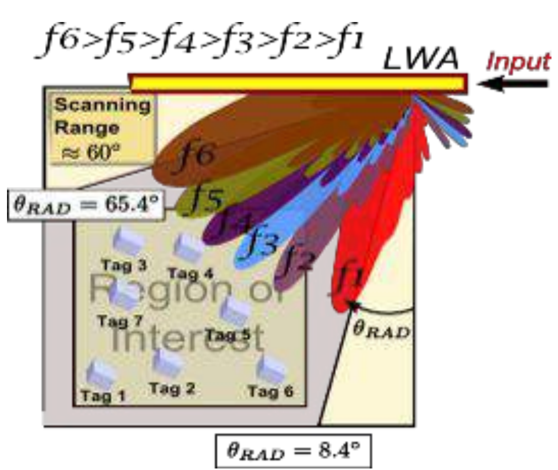
DISPERSION ENGINEERING

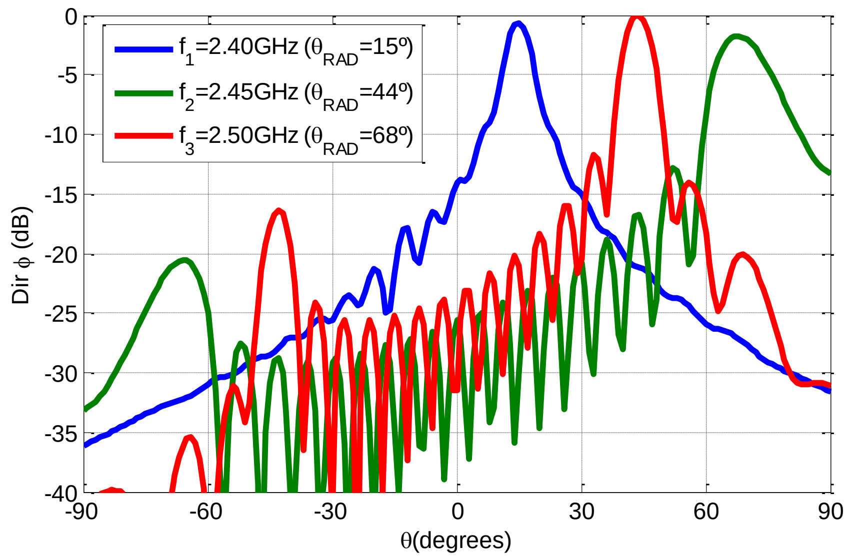


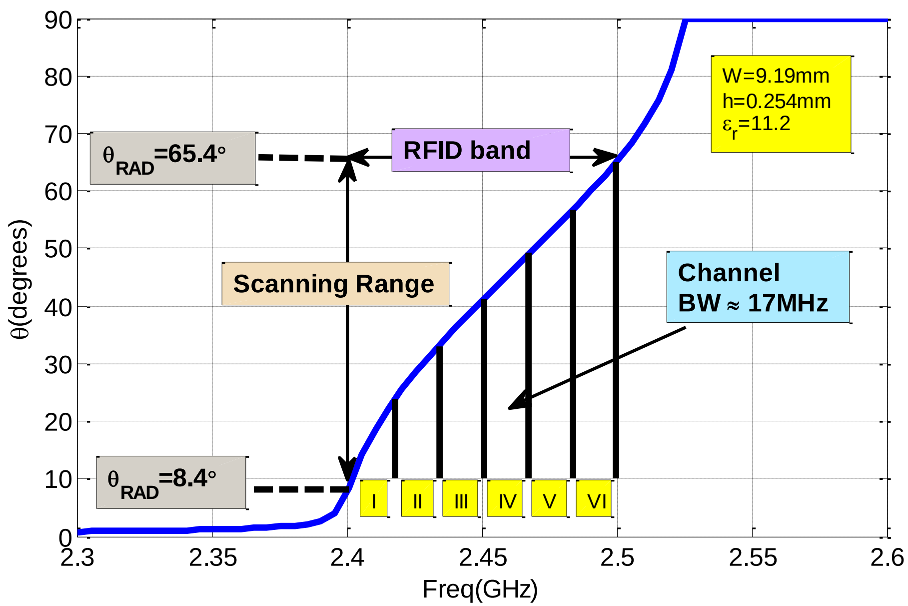
What about the bandwidth ?

- **Wanted / useful dispersion**

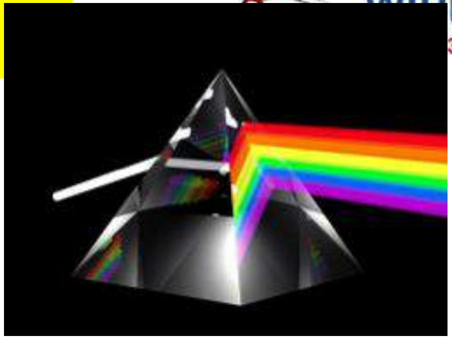








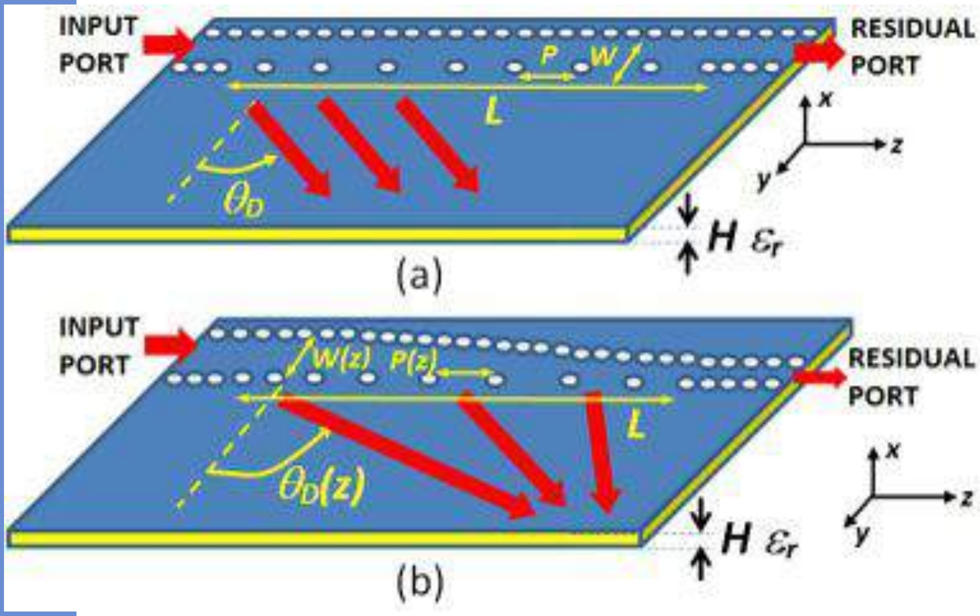
- **Wideband space multiplexer in SIW technology for real-time high-throughput Analog Signal Processing (ASP)**

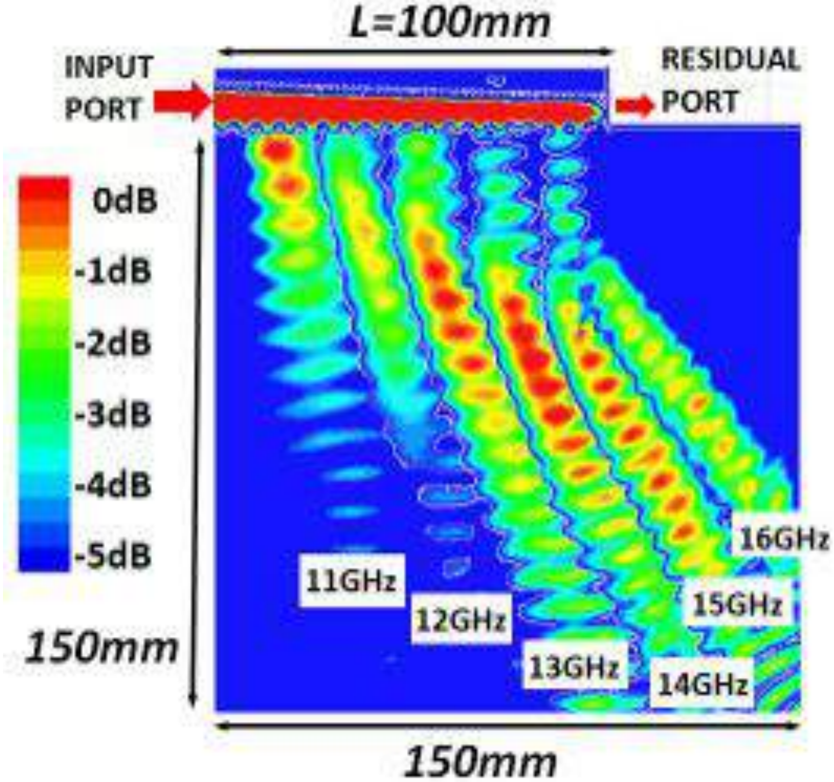


"Electrical prism"

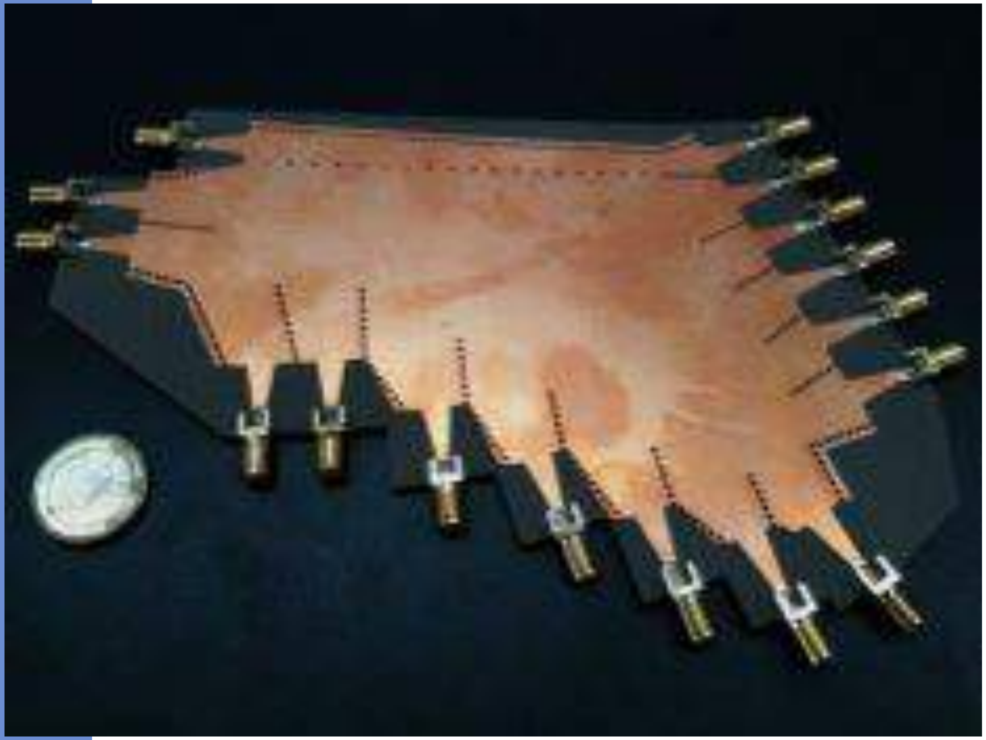
Quasi-optical operation

PINK FLOYD's "Dark side of the moon" Prof. Zoya Popovic



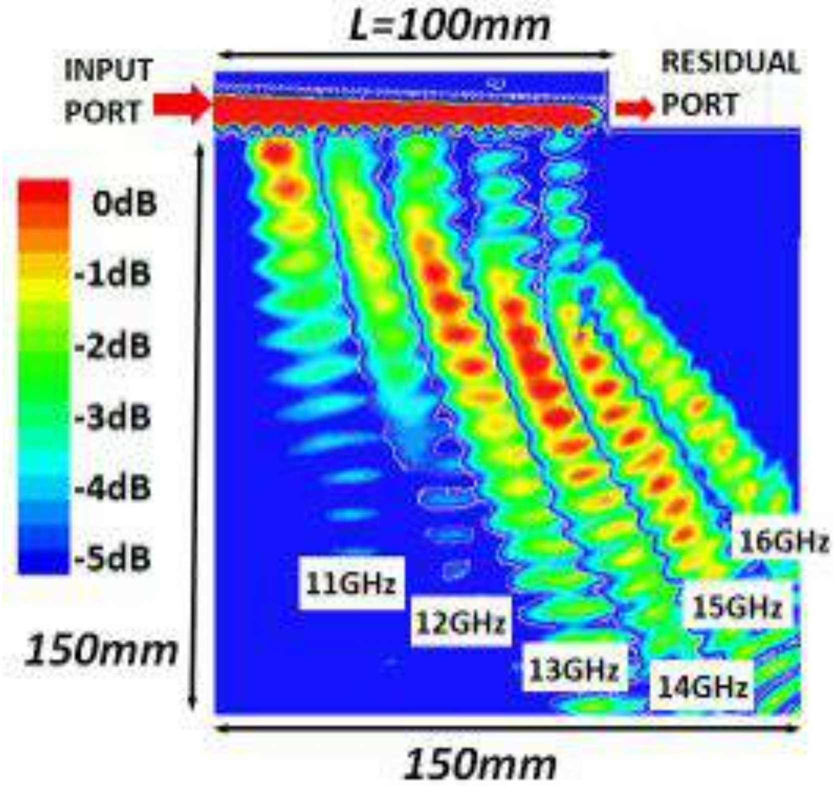


- **Wideband space multiplexer in SIW technology for real-time high-throughput Analog Signal Processing (ASP)**



Frequency-space dispersion engineering

Analog Signal Processing

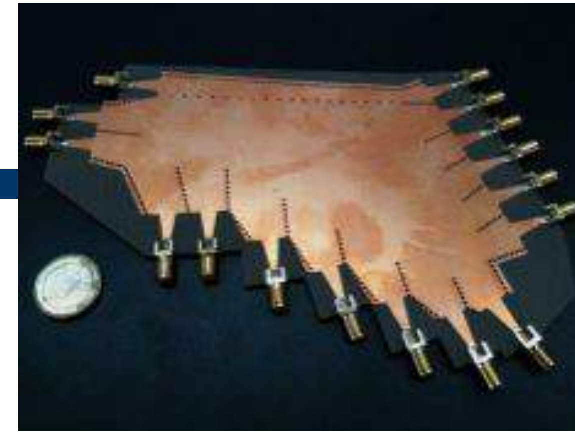


Wideband 11GHz-18GHz

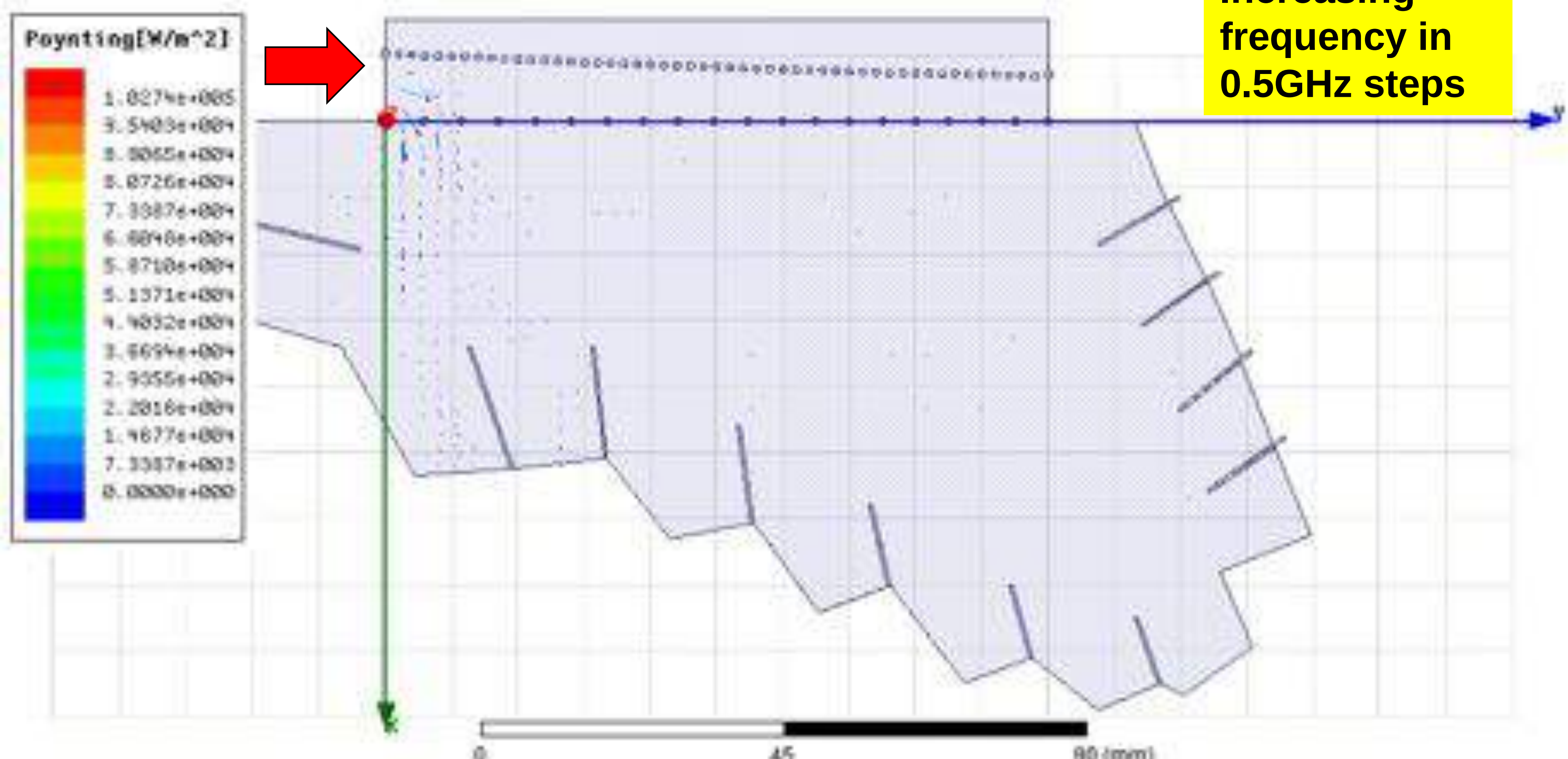
What about the bandwidth ?

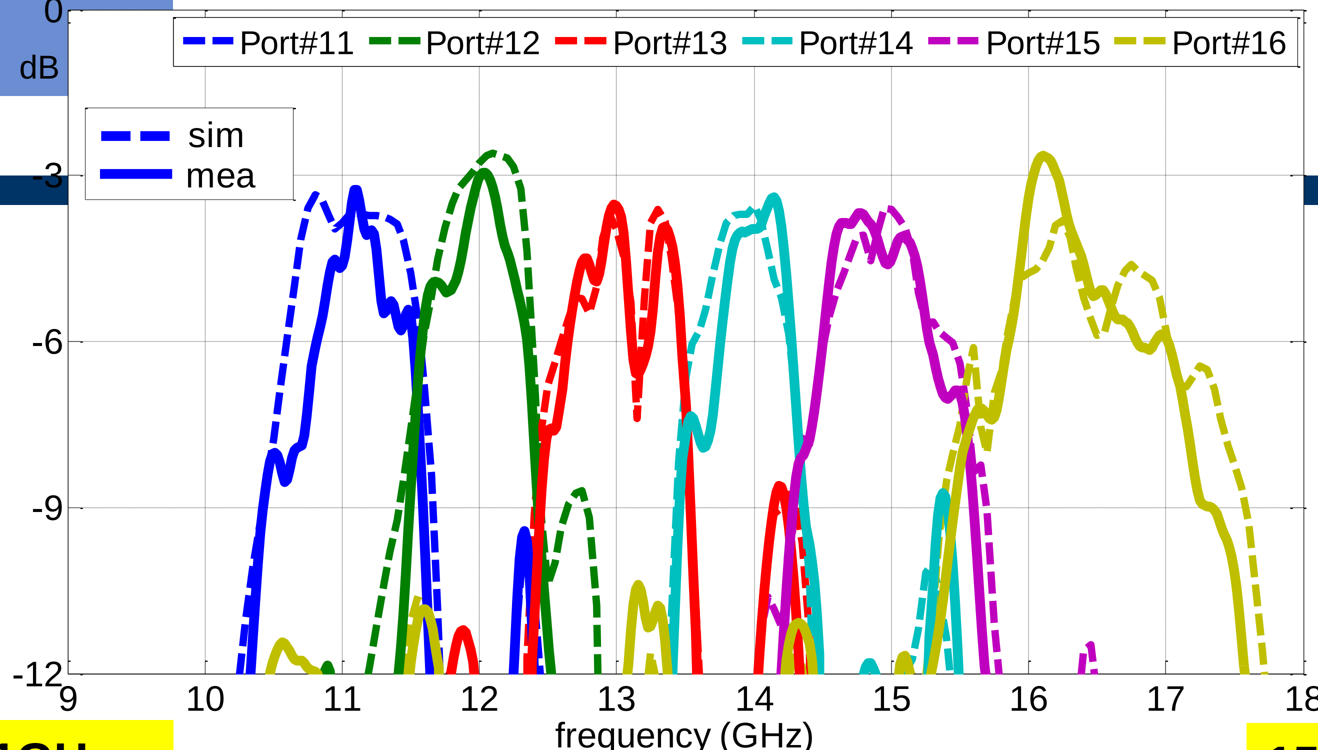
- **Wanted / useful dispersion:**

NOVEL QUASI-OPTICAL MULTIPLEXER



Increasing frequency in 0.5GHz steps

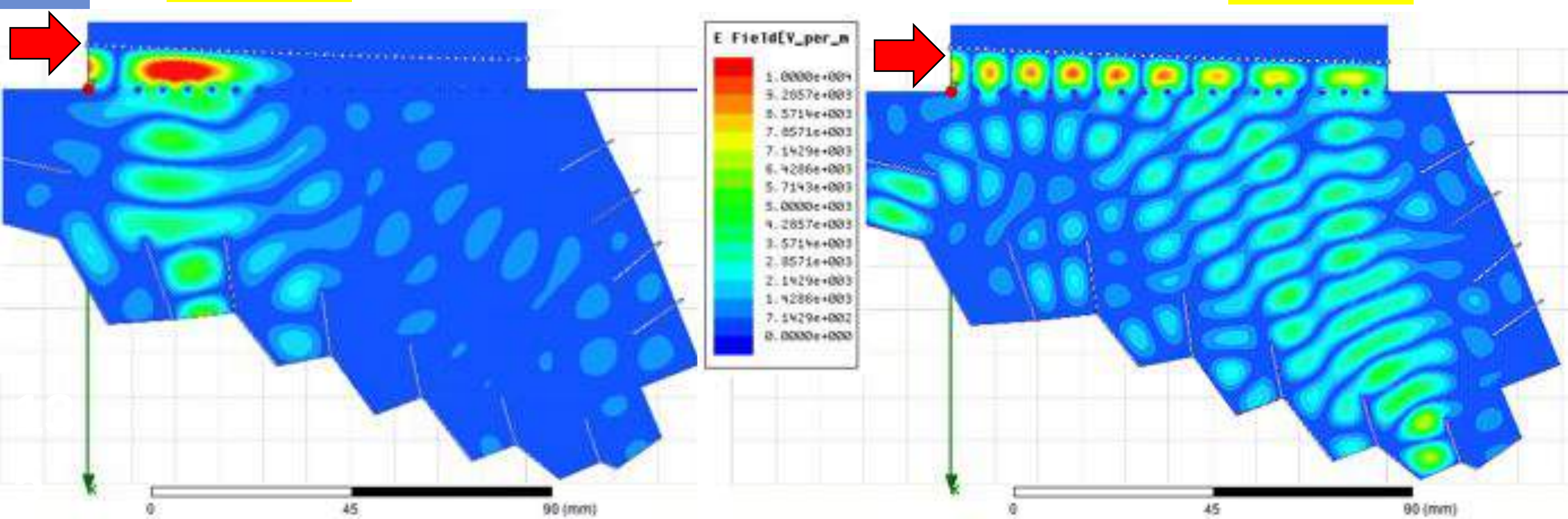




dB
0
-3
-6
-9
-12
9
10
11
12
13
14
15
16
17
18
frequency (GHz)
Port#11
Port#12
Port#13
Port#14
Port#15
Port#16
sim
mea

11GHz

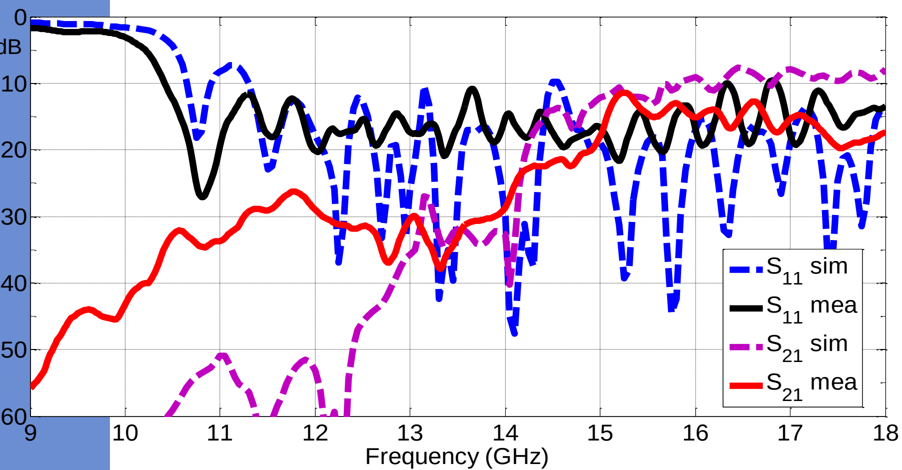
15GHz



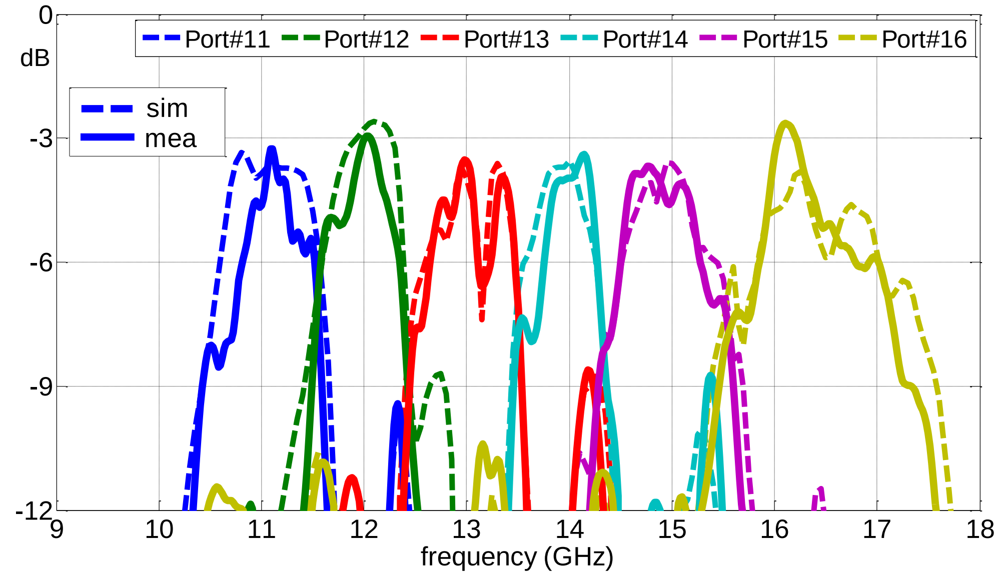
E Field[V_per_m]
1.0000e+004
9.2857e+003
8.5714e+003
7.8571e+003
7.1429e+003
6.4286e+003
5.7143e+003
5.0000e+003
4.2857e+003
3.5714e+003
2.8571e+003
2.1429e+003
1.4286e+003
7.1429e+002
0.0000e+000
0
45
90 (mm)

WIPE COST IC1301

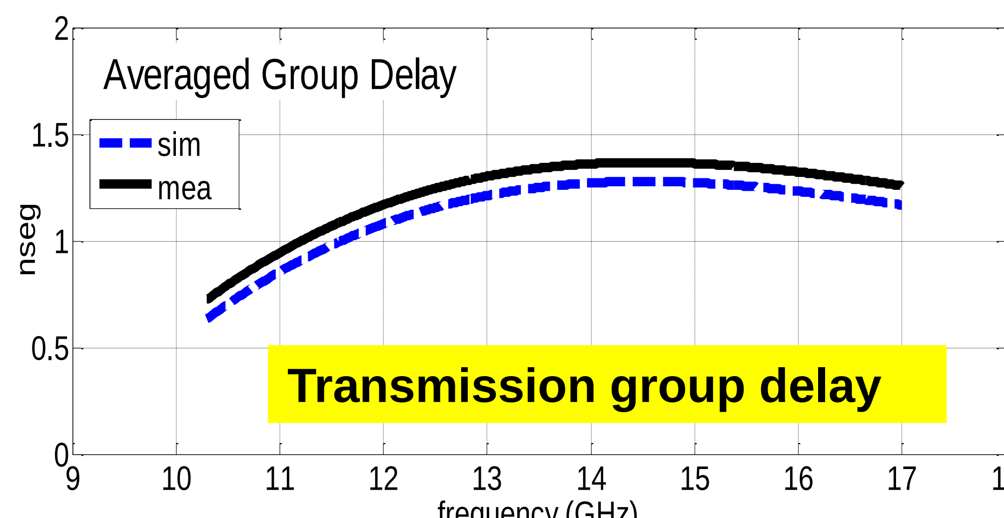
Input Matching



Transmission amplitude



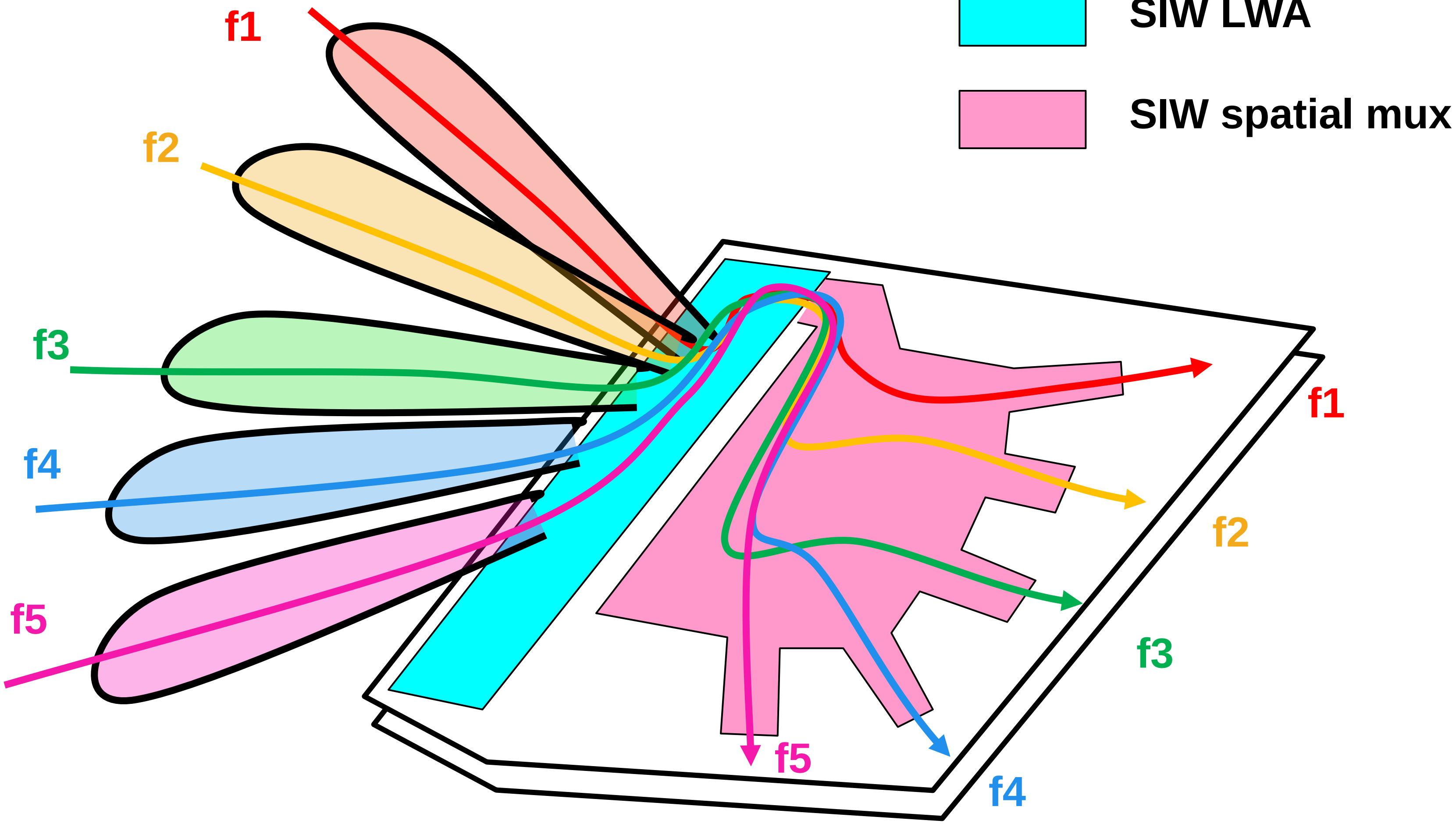
Travelling-wave nature, no resonant effects !



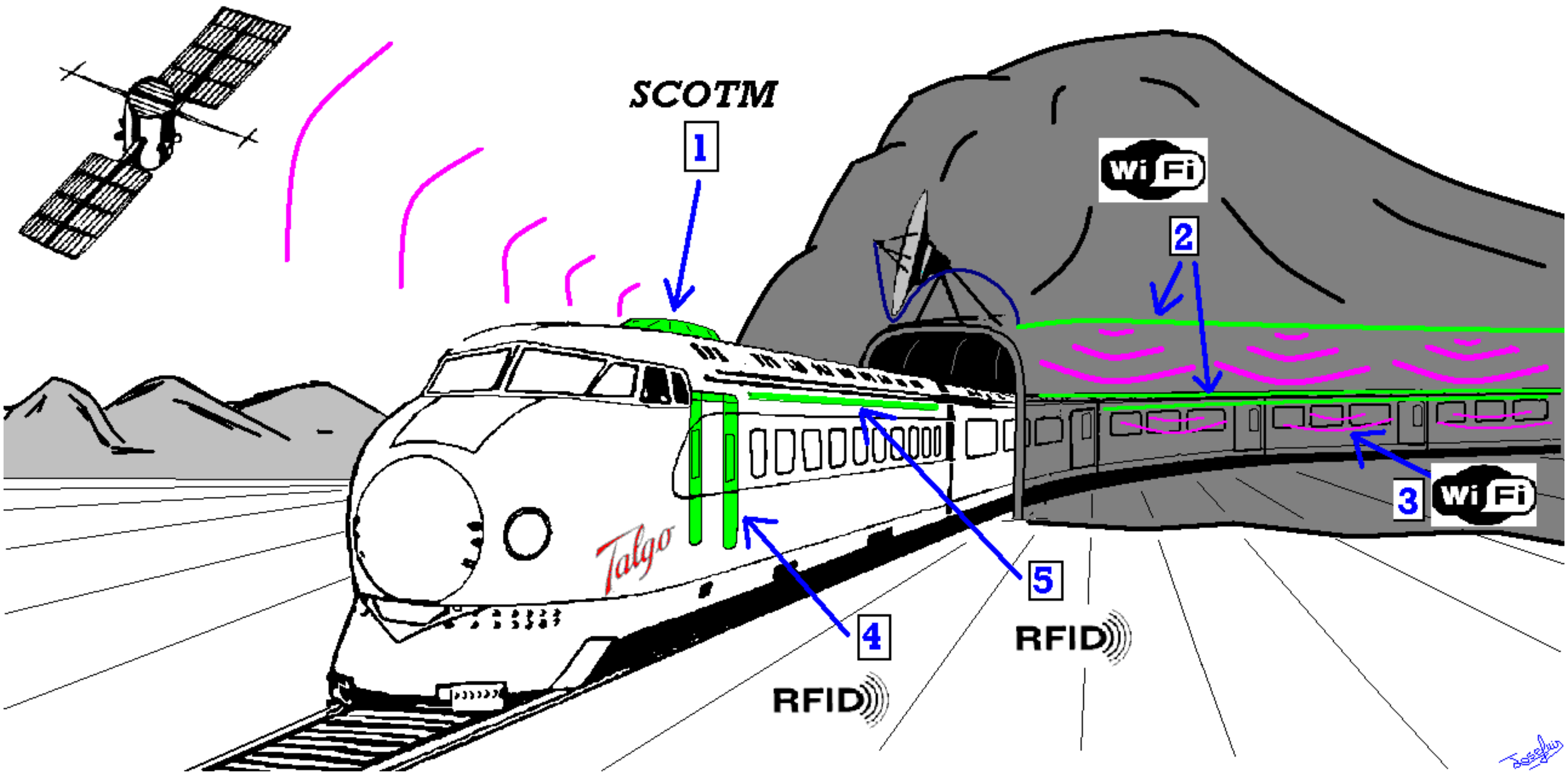
Transmission group delay

- **Passive**
- **Quasi-optical operation**
- **Smart device**
- **Spatial power combining**

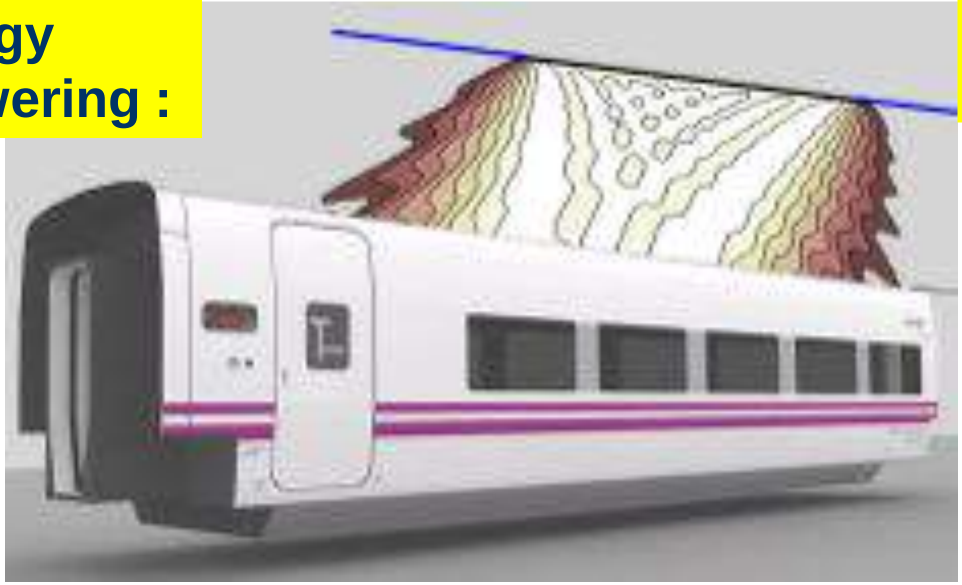
- **Passive, low-cost SIW (paper)**
- **Quasi-optical operation**
- **Smart device**
- **Spatial power combining**



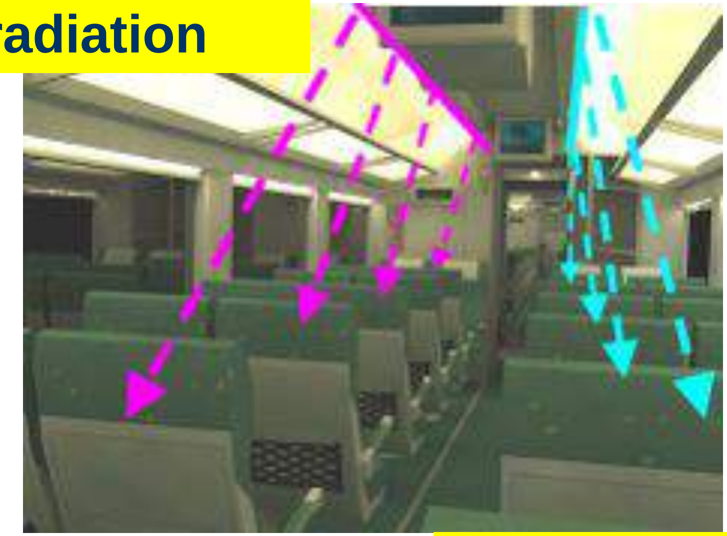
- **RFID localization using electrical prisms and focusing LWA in corridor-like scenarios (conveyors, corridors, queues…)**



Energy showering :

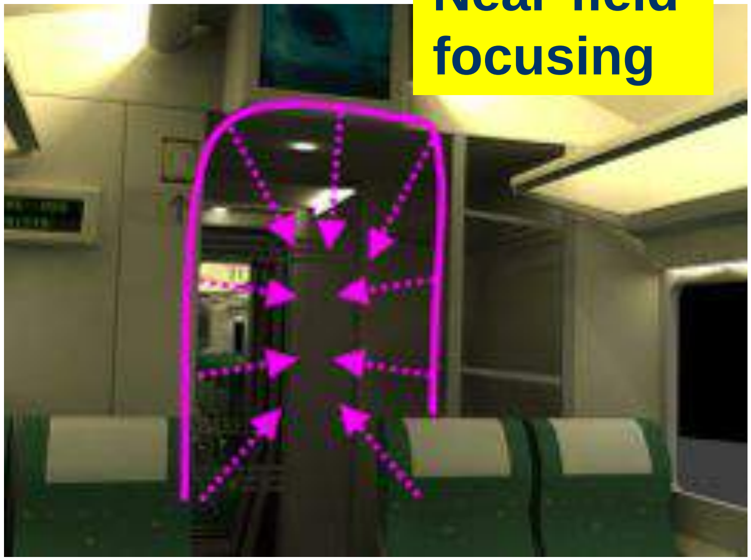


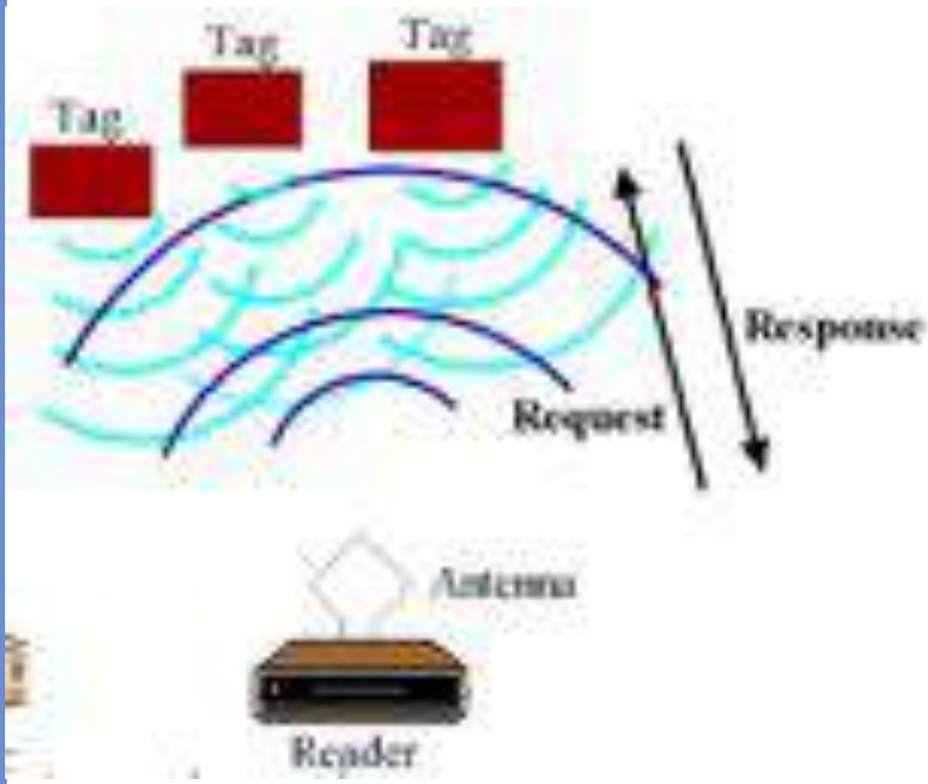
Distributed radiation



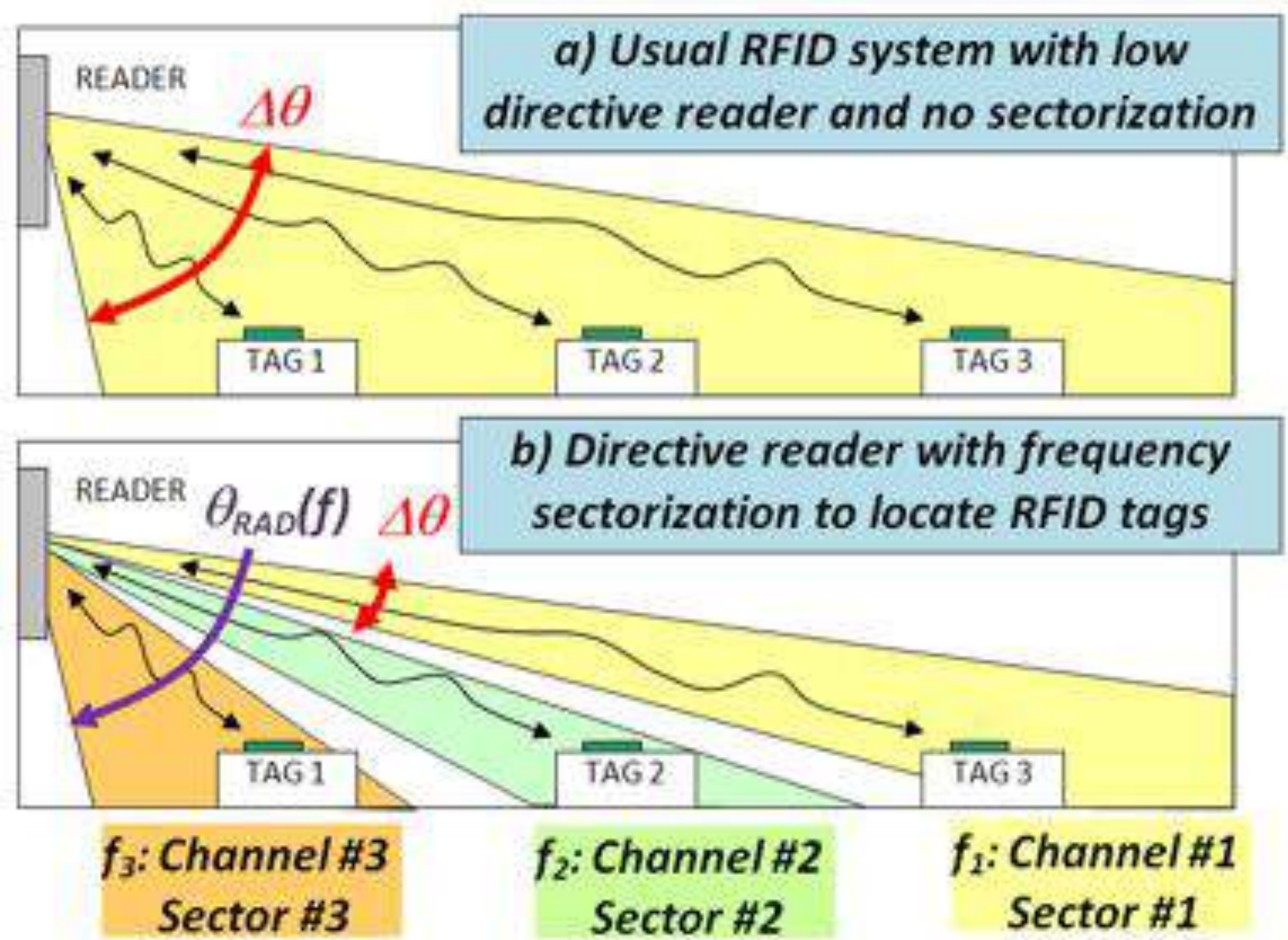
Energy evaporation:

Near-field focusing

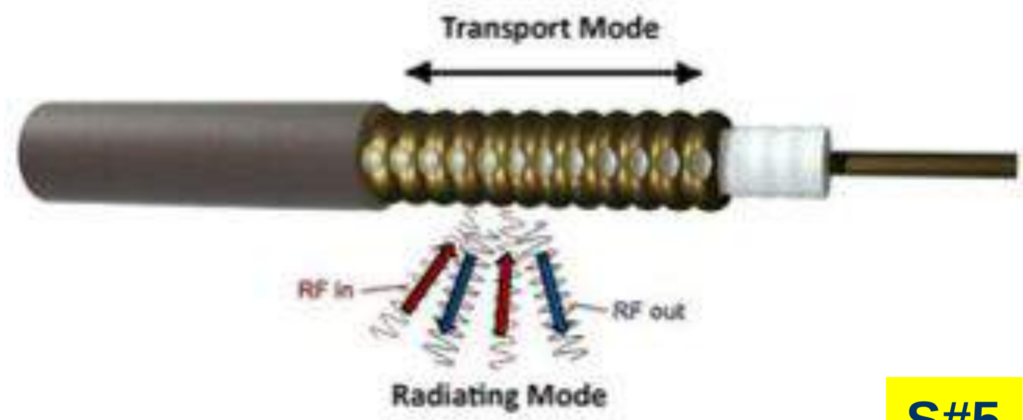



Tag
Tag
Tag
Response
Request
Antenna
Reader


07 15 2005


READER
$\Delta\theta$
a) Usual RFID system with low directive reader and no sectorization
TAG 1
TAG 2
TAG 3
READER
$\theta_{RAD}(f)$
$\Delta\theta$
b) Directive reader with frequency sectorization to locate RFID tags
TAG 1
TAG 2
TAG 3
f_3: Channel #3
Sector #3
f_2: Channel #2
Sector #2
f_1: Channel #1
Sector #1

Leaky-coax for tracking humans



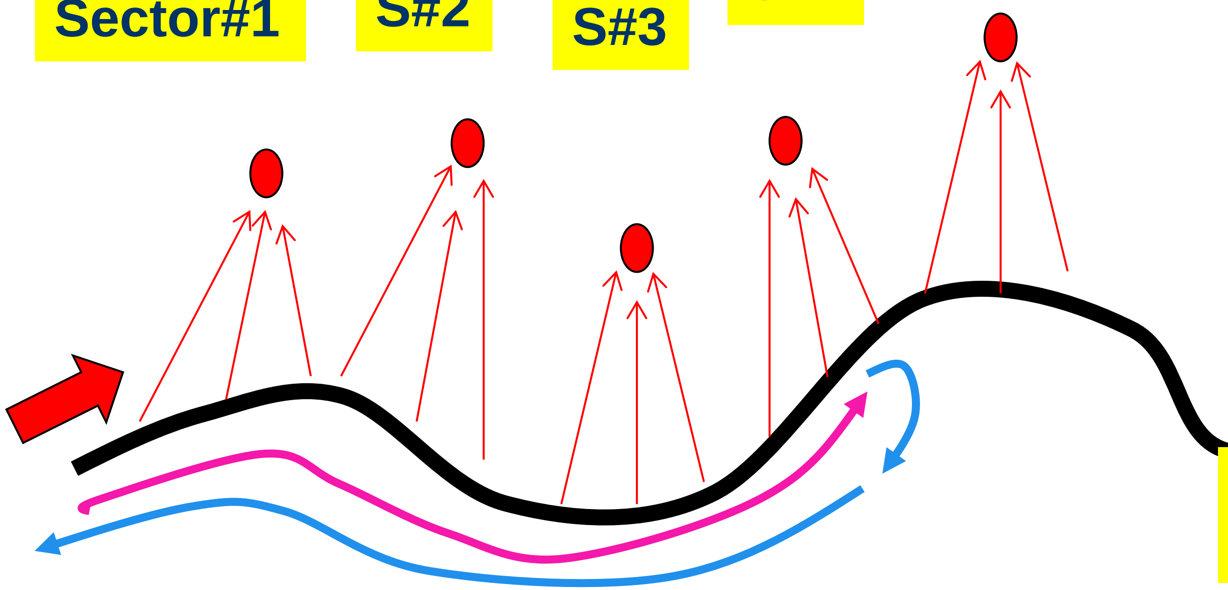
Sector#1

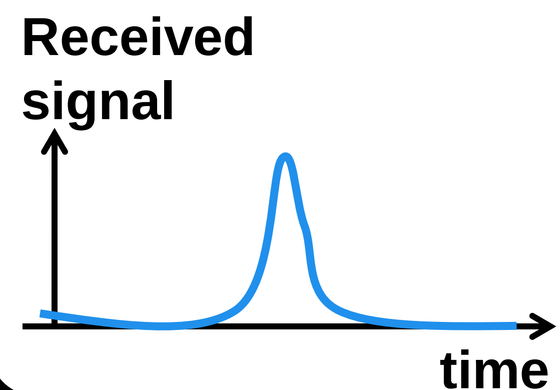
S#2

S#3

S#4

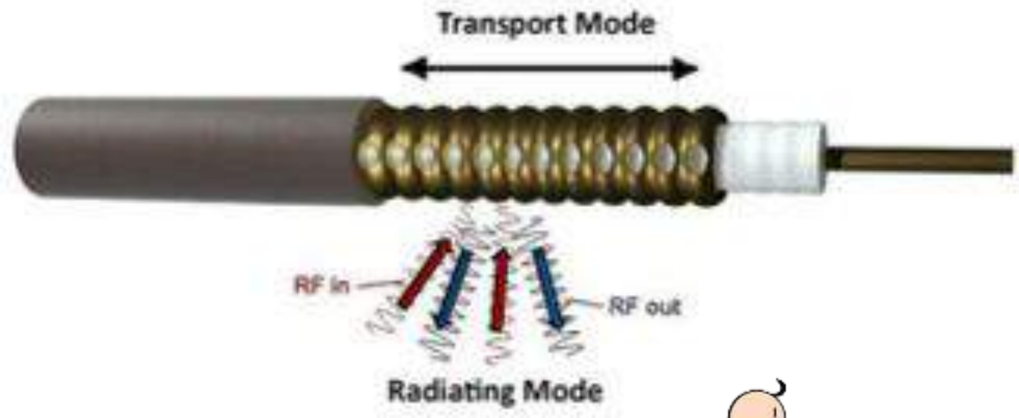
S#5



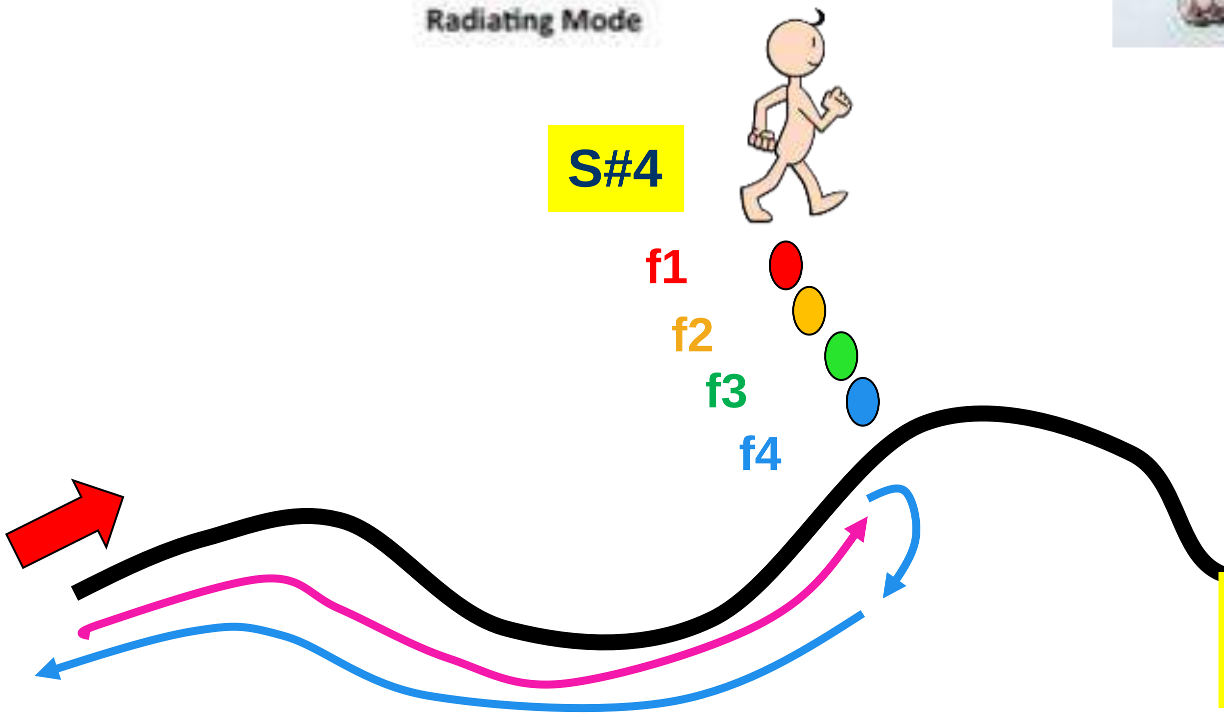


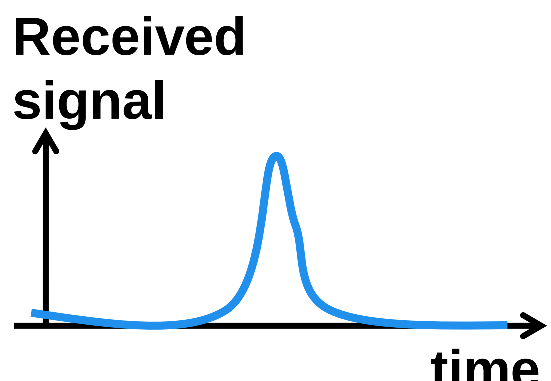
Time-space dispersion engineering

Leaky-coax for tracking humans



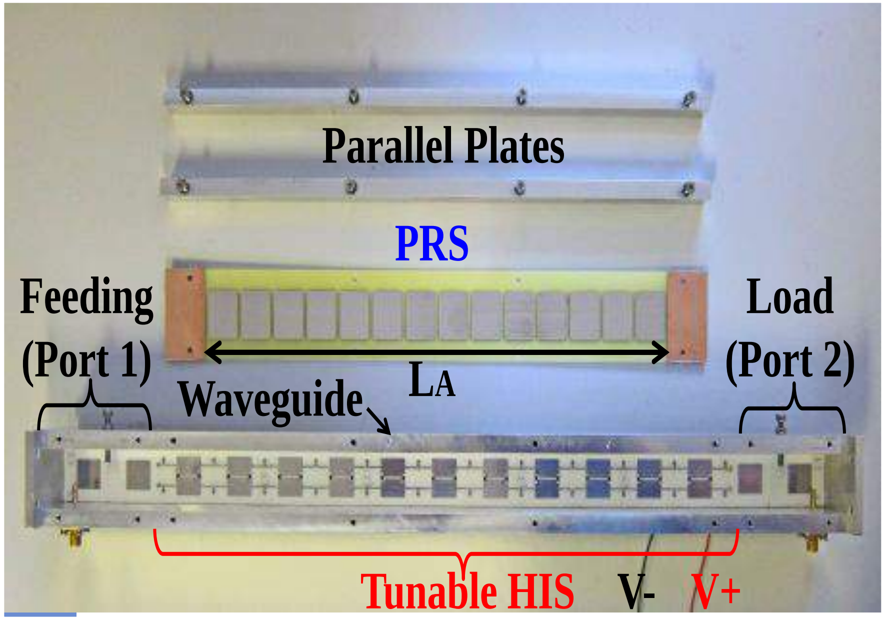
S#4

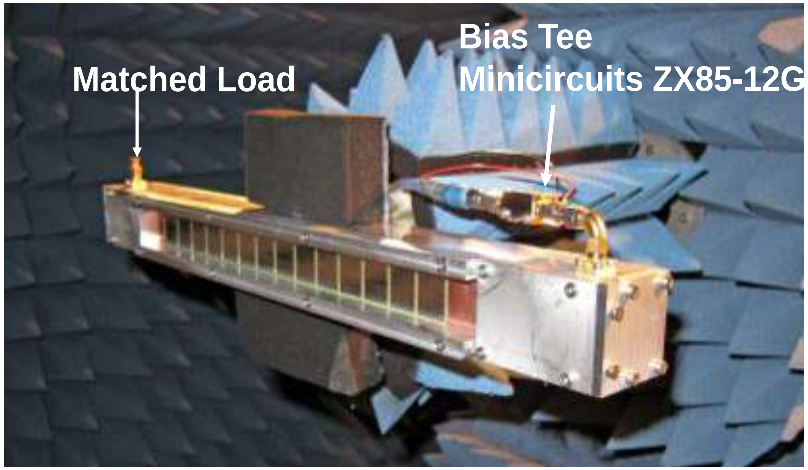


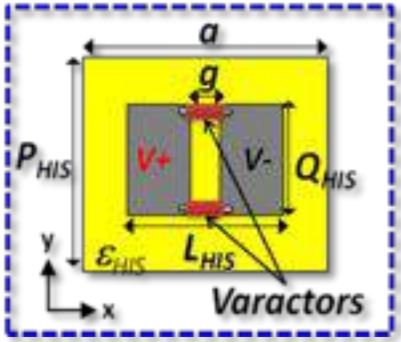


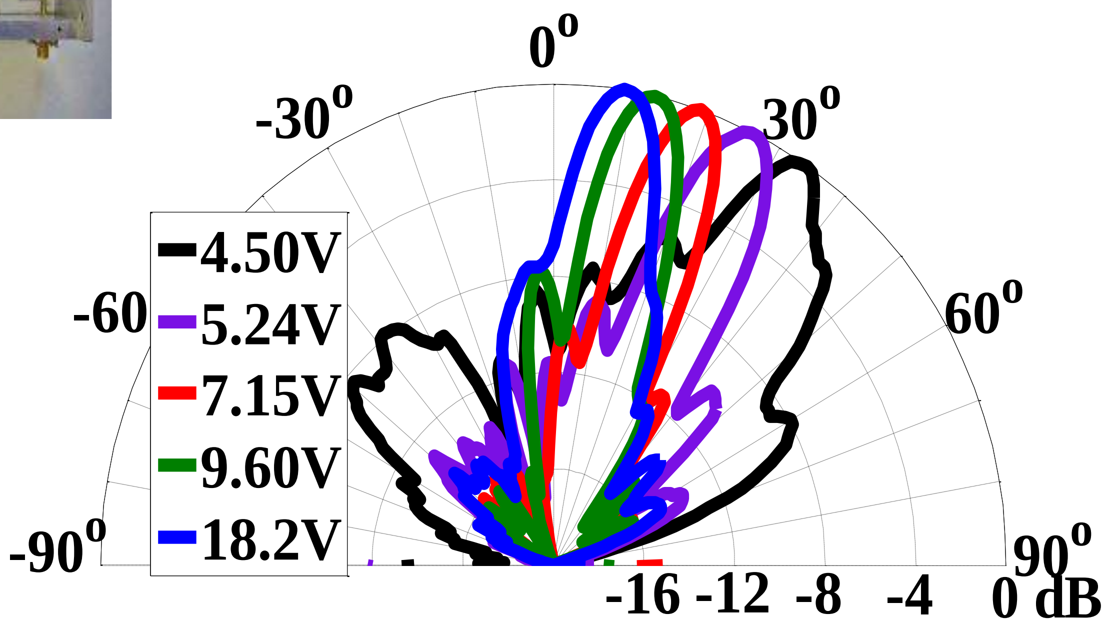
Time-frequency-space dispersion engineering

- **Not only frequency-scanned, but also electronically-scanned LWAs**

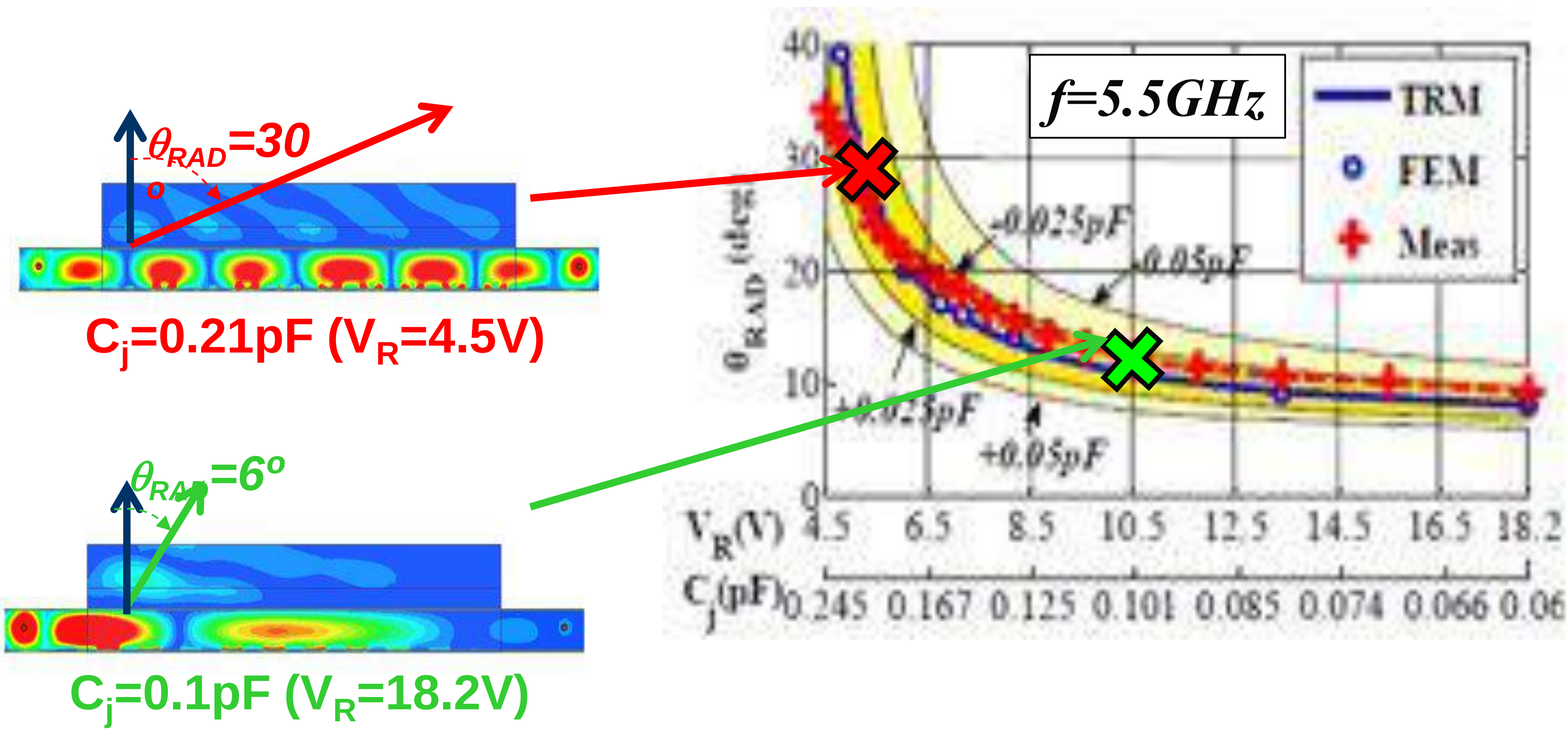








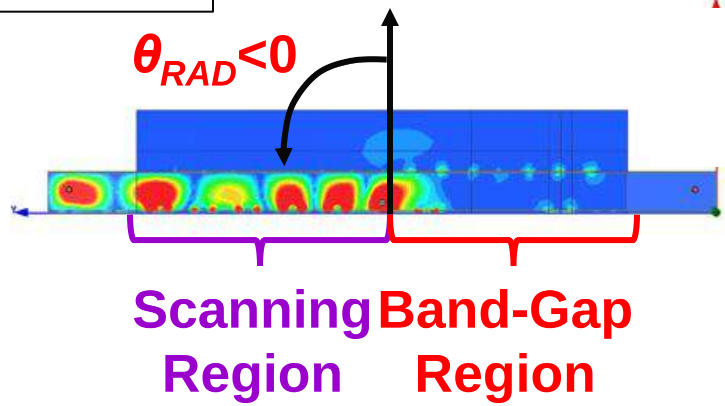
- **Not only frequency-scanned, but also electronically-scanned LWAs**

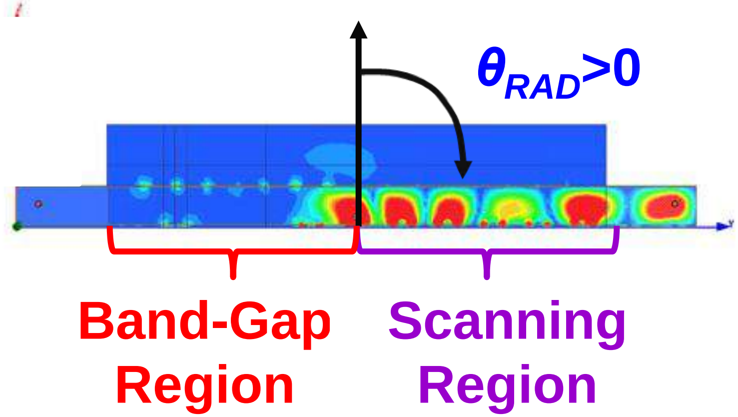


- **Not only frequency-scanned, but also electronically-scanned LWAs**

f=5.5GHz

Longitudinal Electric Field for Each Operation Regime

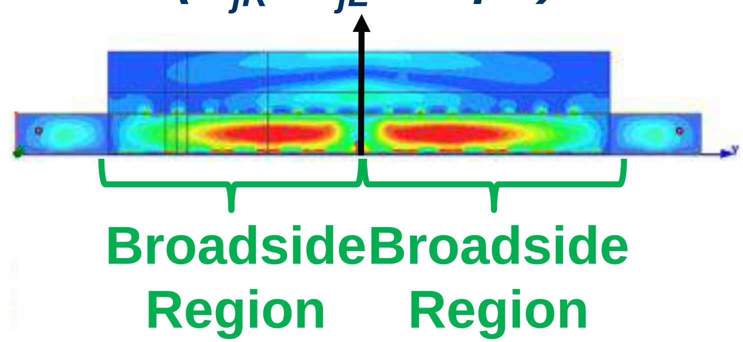




At EBG → no LM is propagating and energy is reflected back.

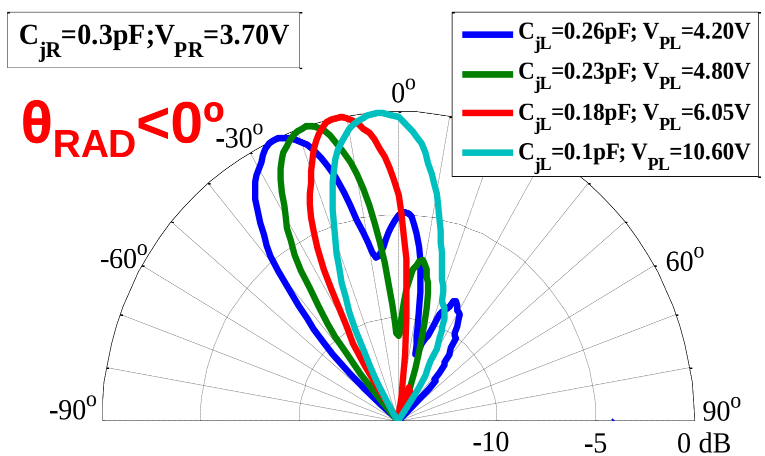
EBG-based routing mechanism

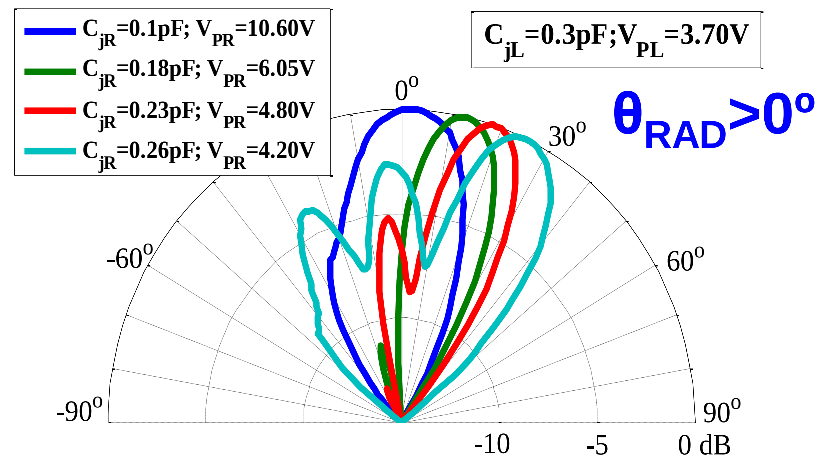
Splitting condition
($C_{jR}=C_{jL}=0.1pF$)

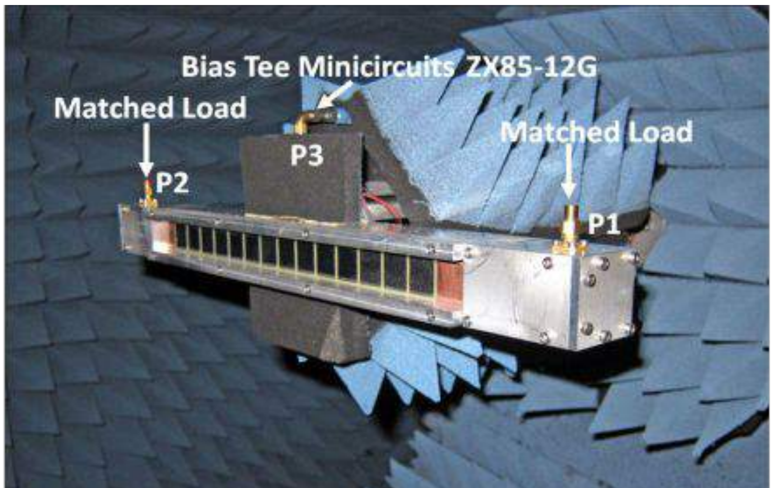


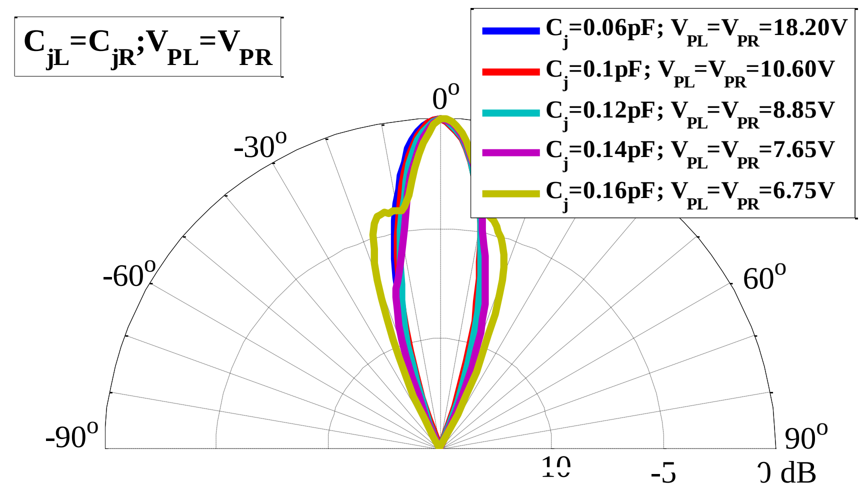
- **Not only frequency-scanned, but also electronically-scanned LWAs**

Measured Radiation Patterns @ 5.5GHz







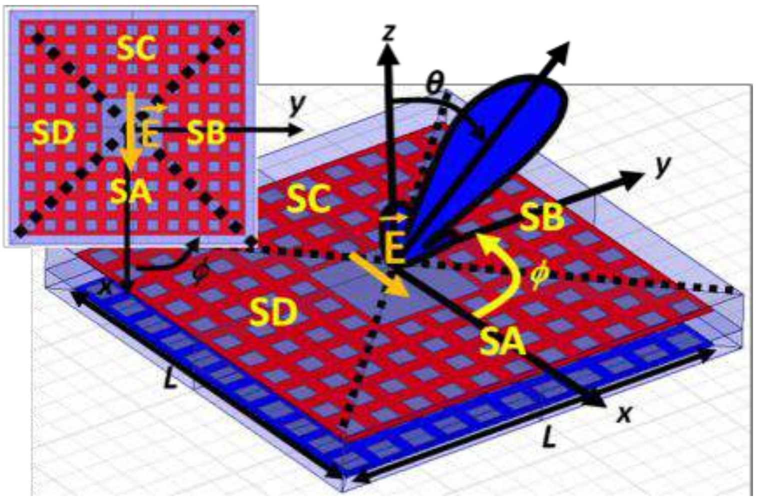


Broadside

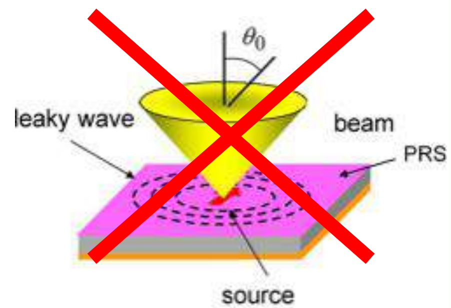
Measured scanning range: [-25º,+25º]

2D FP LWA with 2D Electronic Scanning

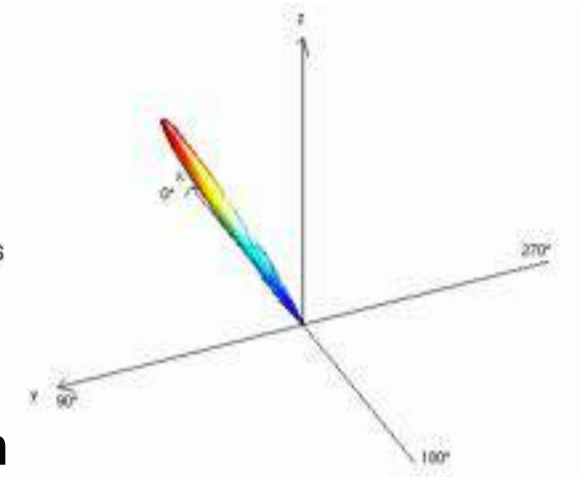
Full-2D (elevation θ and azimuth ϕ) electronic scanning



Electronically-steerable pencil beam at fixed operating frequency



NO conical beam



- **2D PRS + 2D Tunable HIS**
- **Horizontal E-field excitation**
- **Four independently biased angular sectors**

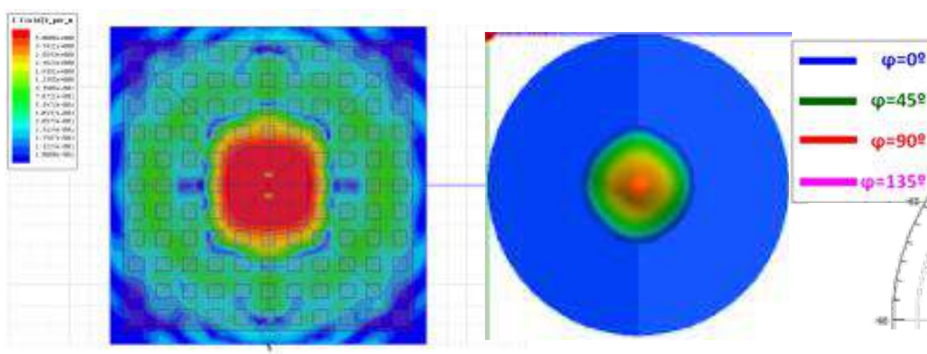
Electronic Synthesis of Aperture Illuminations

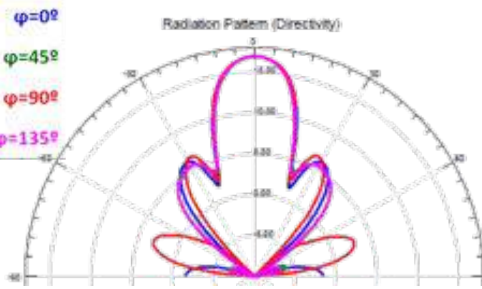
- **Energy routed by tuning sectors at EBG or Scanning Region**
- **Synthesize different aperture illuminations**

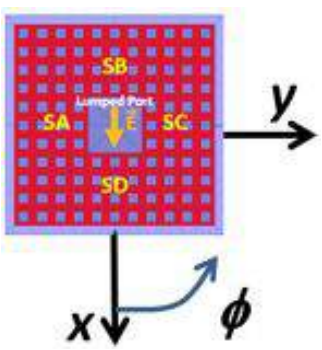
Simulated Fields and Radiation Patterns @ 5.5GHz

Operation Regime **Aperture Fields** **Radiation Pattern (u-v)/(θ-ϕ)**

Broadside







SA,SB,SC,SD at BS Region

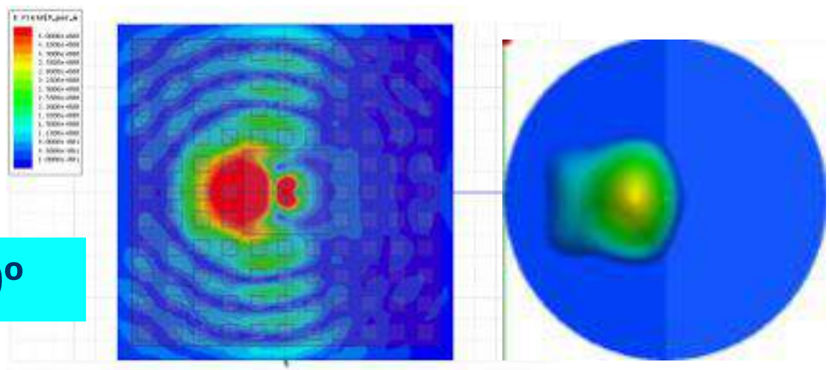
$5\lambda_0 x 5\lambda_0$ simulated prototype (5.5GHz)

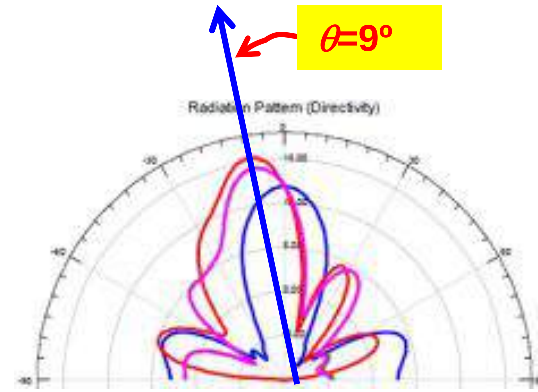
Electronic Synthesis of Aperture Illuminations

Operation Regime **Aperture Fields** **Radiation Pattern (u-v)/(θ-ϕ)**

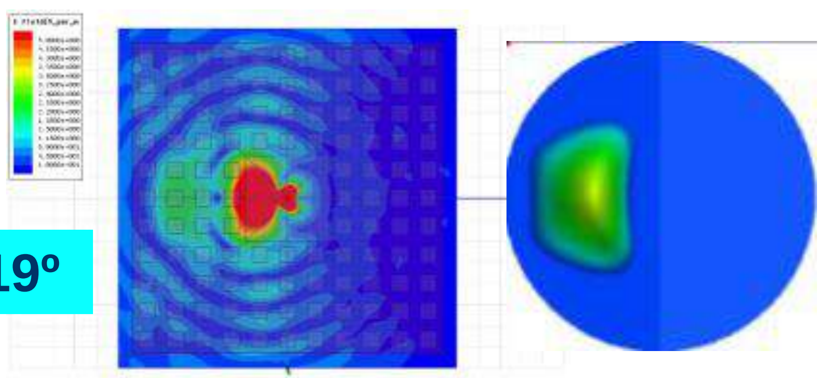
θ scanning At ϕ=270º

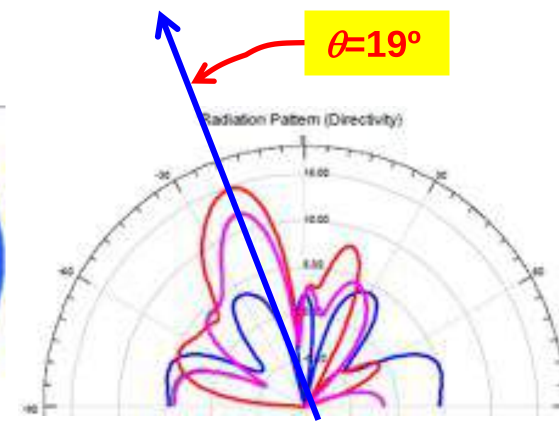
θ=9º

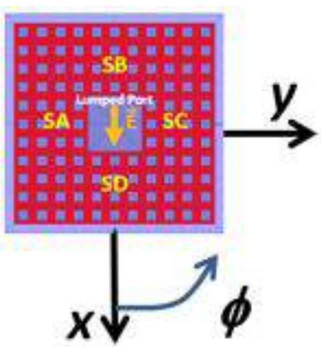




θ=19º







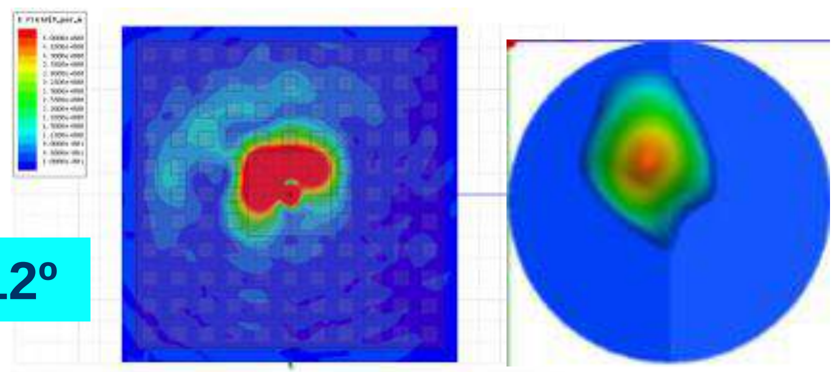
SA at Scanning Region & Rest to EBG

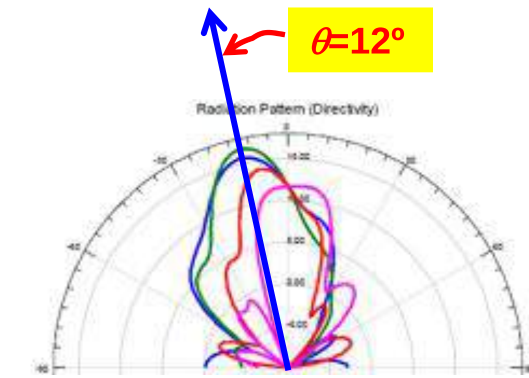
Electronic Synthesis of Aperture Illuminations

Operation Regime | **Aperture Fields** | **Radiation Pattern (u-v)/(θ-ϕ)**

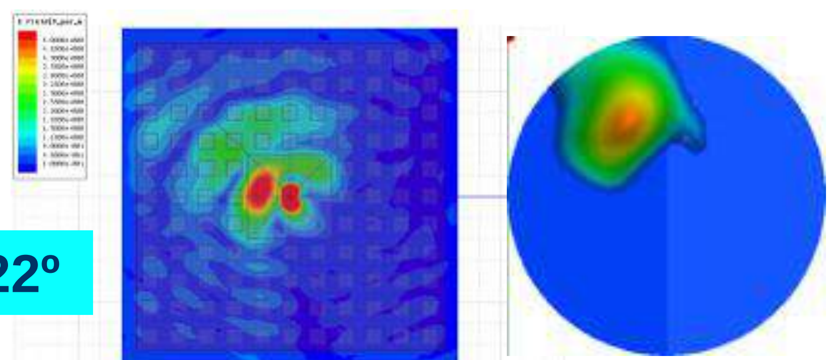
θ scanning At ϕ=225º

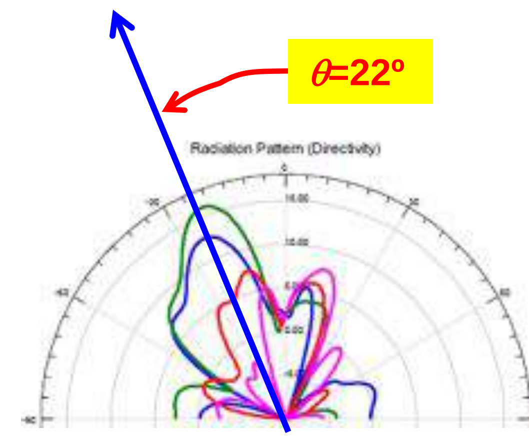
θ=12º

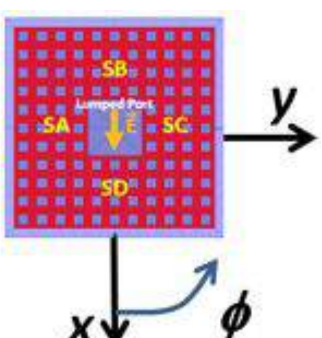




θ=22º







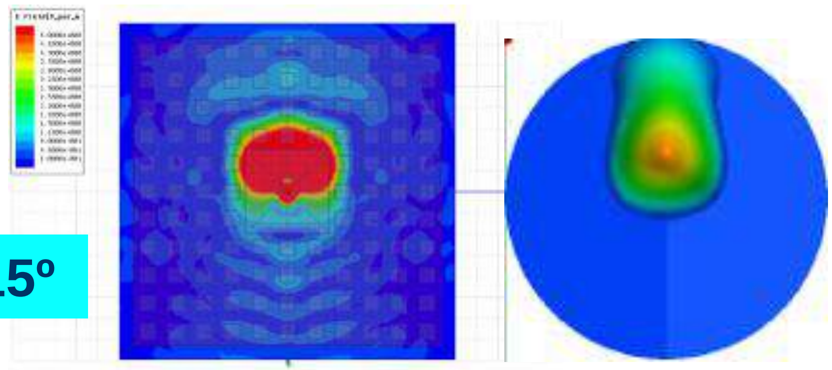
SA&SB at Scanning Region & SC&SD to EBG

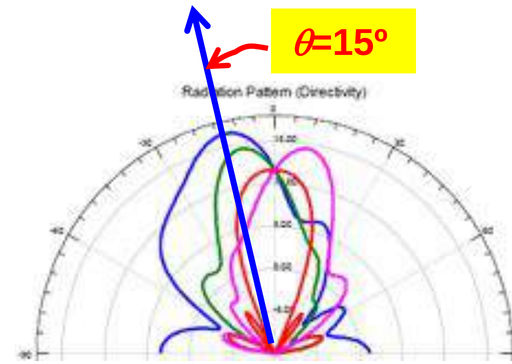
Electronic Synthesis of Aperture Illuminations

Operation Regime | **Aperture Fields** | **Radiation Pattern (u-v)/(θ-ϕ)**

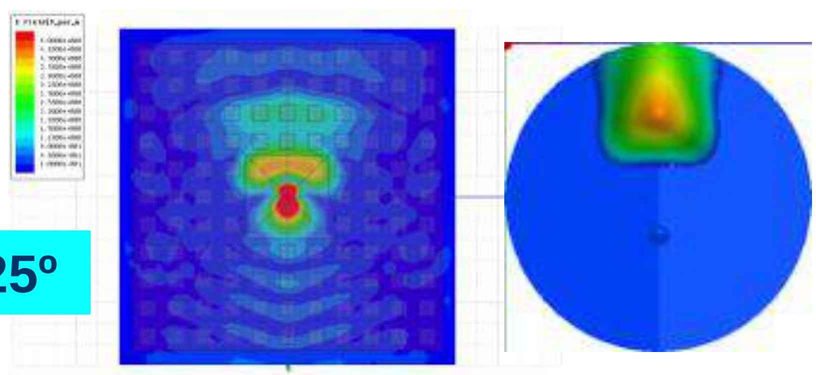
θ scanning At ϕ=180º

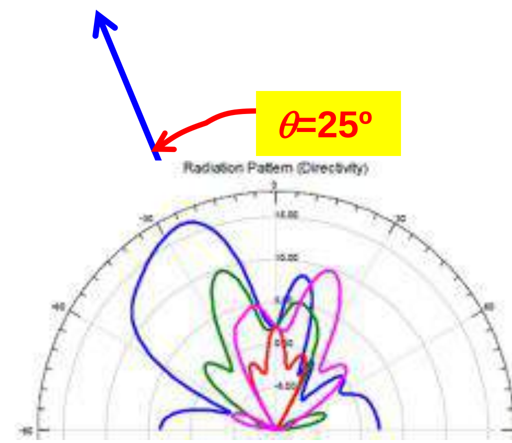
θ=15º

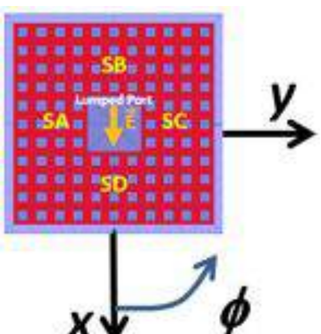




θ=25º

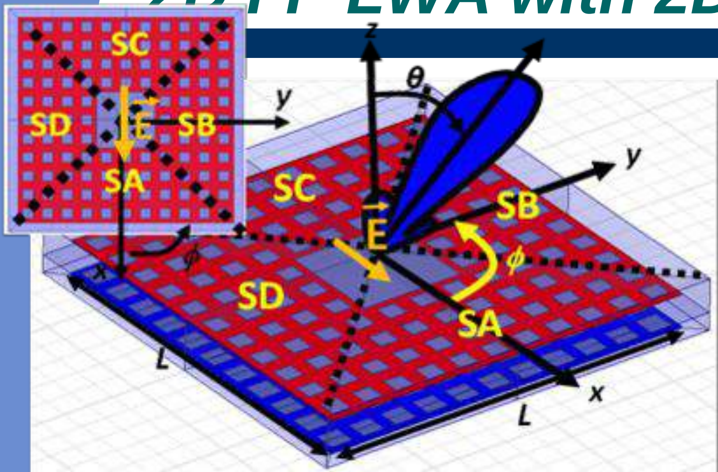






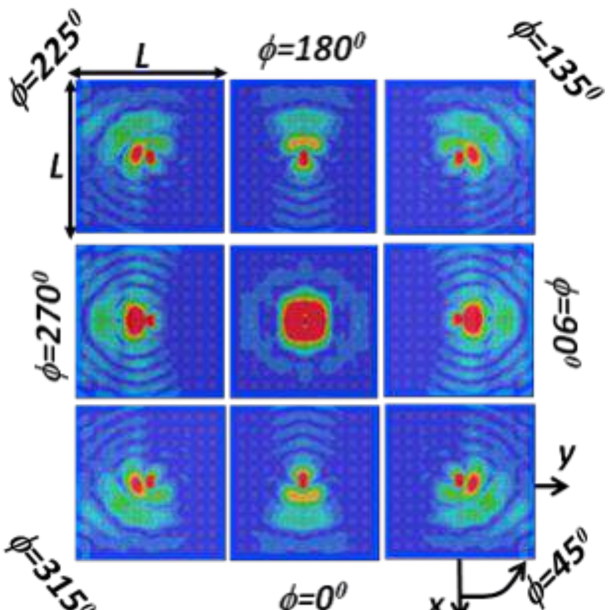
SB at Scanning Region & Rest to EBG

2D FP LWA with 2D Electronic Scanning

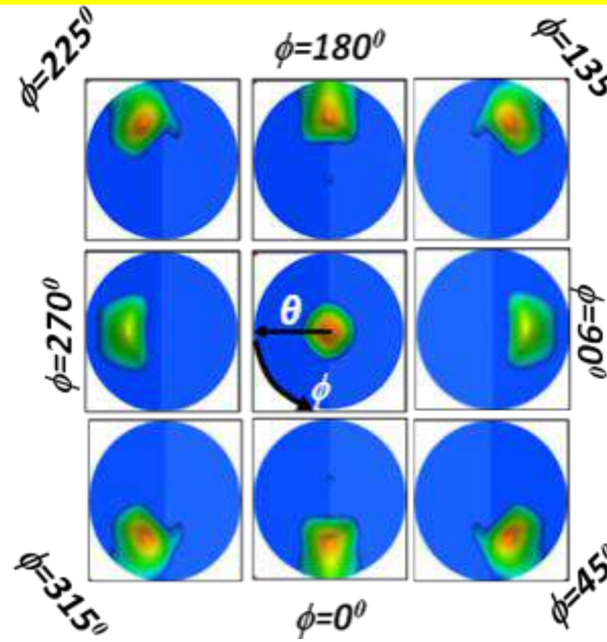


2D Full-Space Electronic Scanning in simple-fed FP LWA technology

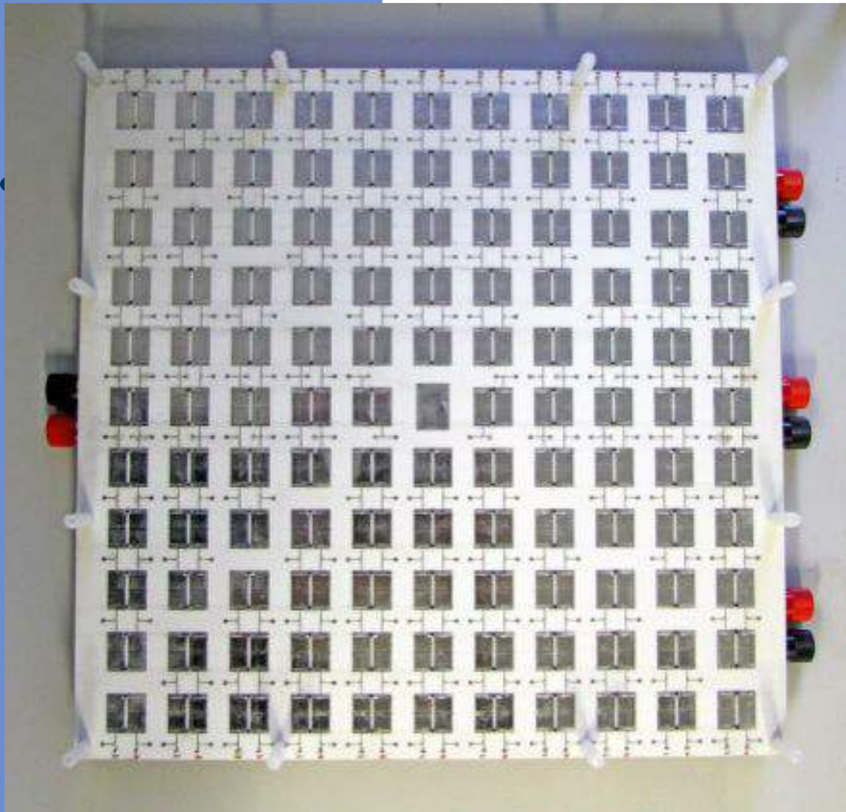
2D Scanning Radiation Pattern

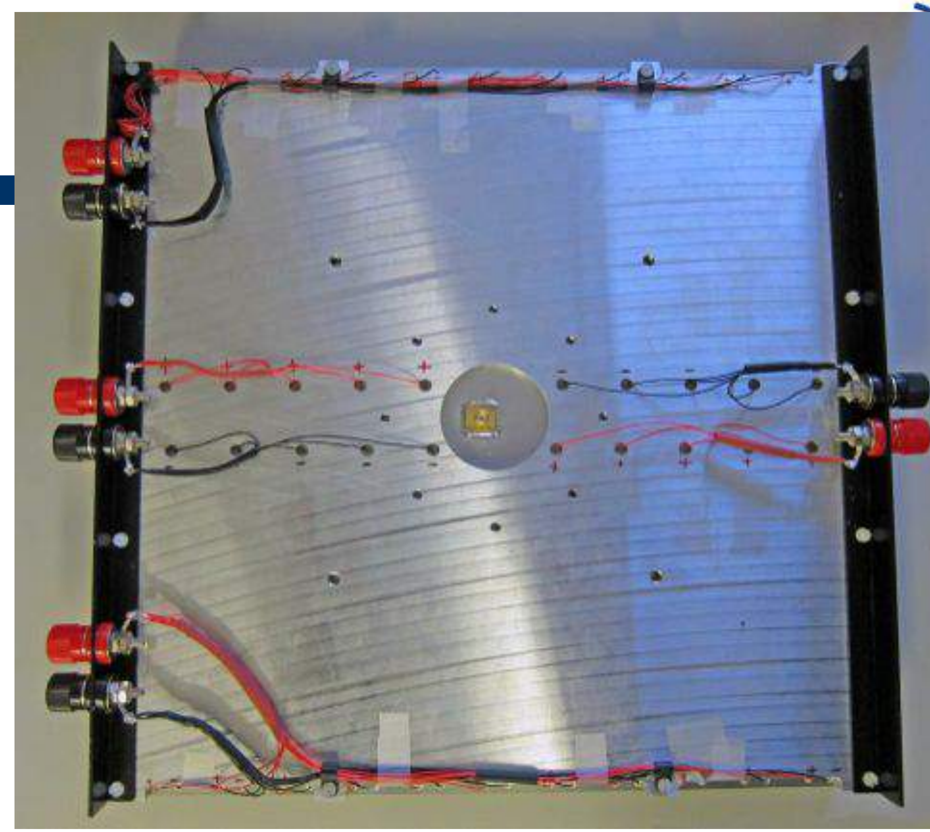


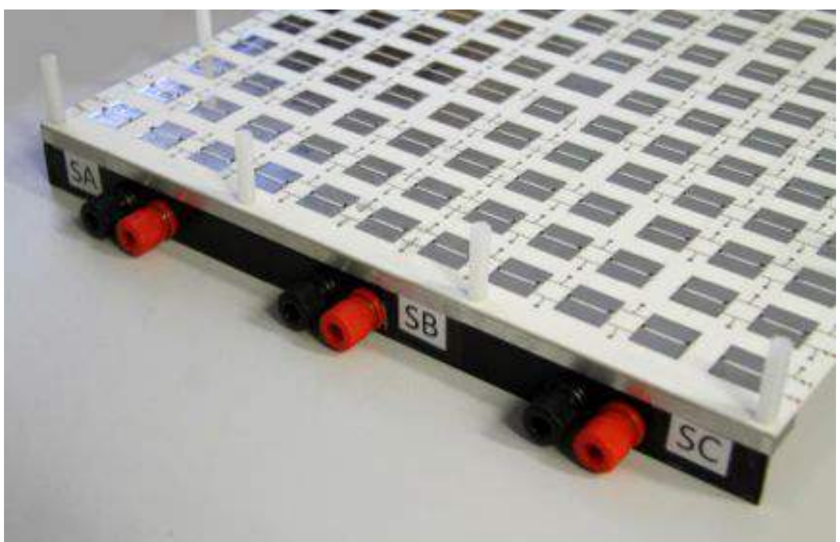
Aperture Fields



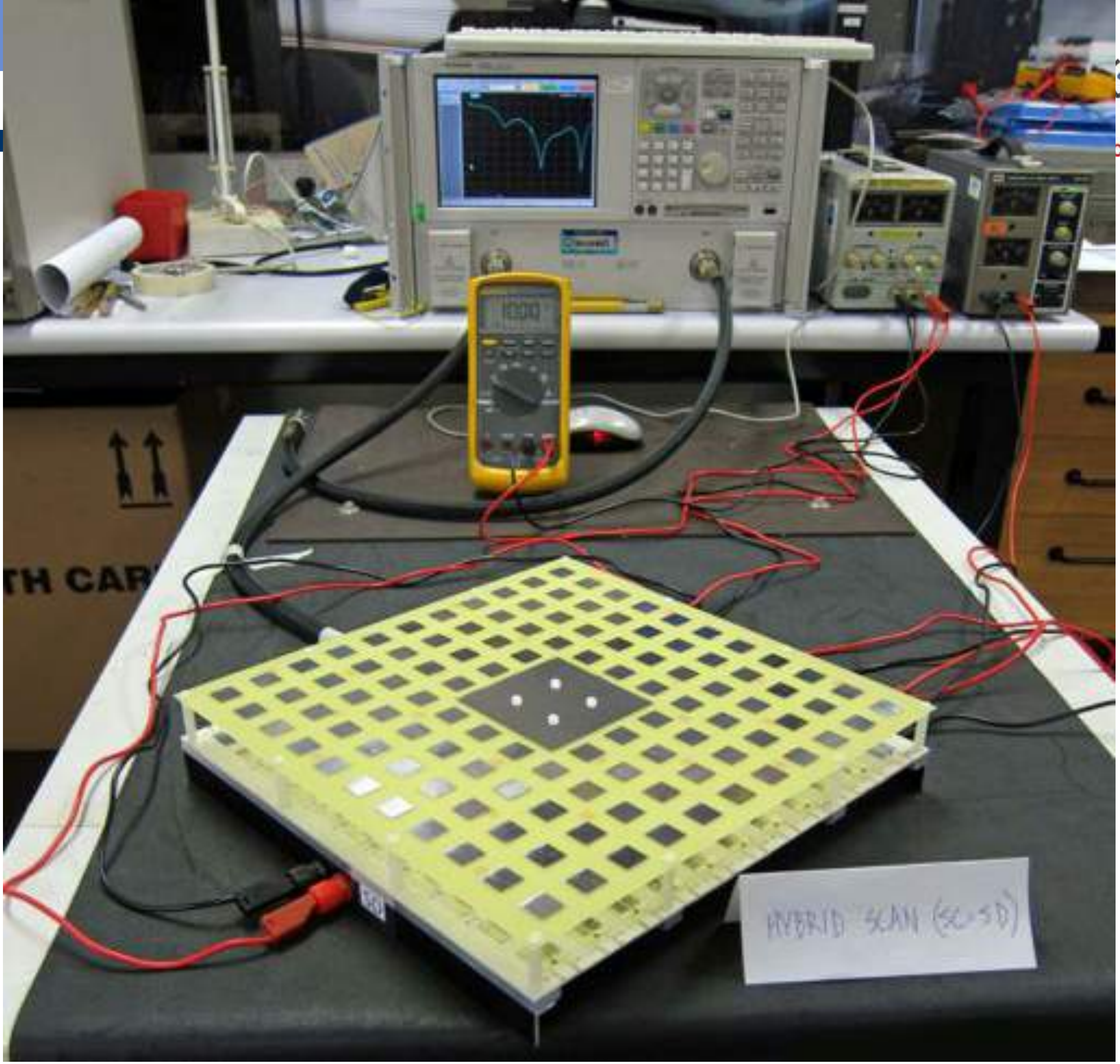
Elevation scanning at discrete azimuthal angles






SA
SB
SC


SD


HYBRID SCAN (SC-SD)

4- Conclusions.

1. Demonstration of **holographic antenna synthesis** using **modulated 1D SIW antennas**.
2. **Efficient analysis/synthesis technique based on LM theory**.
3. **Simple modulation of SIW** width & period.
4. **Low-loss SIW technology**, scalable to **high frequencies** (Ku-band and W-band), **low profile, easy conformation**.
5. Successful experimental designs shows **flexible control over amplitude and phase of radiated leaky-wave fields** with exotic and practical pattern synthesis.
6. **Simple and integrated feeding** (**compared with arrays, reflectarrays, transmitarrays…**).
7. The **difficulty / know-how** is in the modulation of the SIW geometry (hologram). **Efficient synthesis technique**.

4- Further Holistic Conclusions.

- With permission of **Prof. Luca Roselli** who gave the first day an impressive, inspiring and illuminating holistic view of WPT technologies and materials…

- **Life, love**, teamwork → **Wireless Power Transfer analogy**.

- Common language full of "**wavy concepts**":

shining/dark people, resonance (insight),
enlighten, radiate good/bad vibes
constructive/destructive interference,
coupling (this has more sexual facets…)
1+1 can be more (or less) than 2

- And important aspect is **self and mutual synchrony** and **breaking inner/outer barriers and fears**.

4- Further Holistic Conclusions.

- Synchronization of 32 metrometers (Ikeguchi Lab. Japan 2013):

  http://www.youtube.com/watch?v=kqFc4wriBvE (4:04)

- Flock of starlings' dance:

  https://www.youtube.com/watch?v=OxYn3e_imhA (3:27)

4- Further Holistic Conclusions.

- I end up as I started, with ocean waves, but closing with **beliefs/energy**

- **What energy do you worship?**

https://www.youtube.com/watch?v=73WCKk3dX3s (3:52)

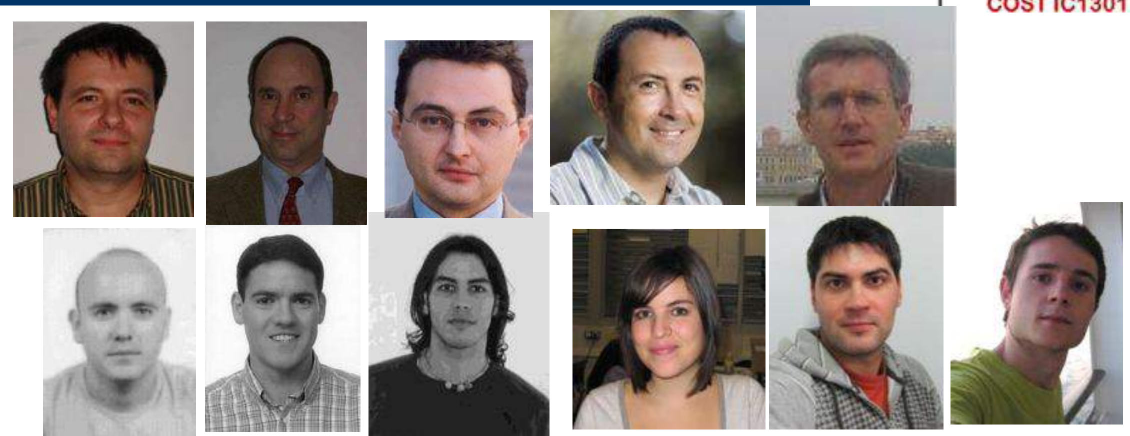
4- Further Holistic Conclusions.

Advices/flagships for the students

(from **Prof. Jay Guo**):

- **Stay ambitious**
- **Stay adventurous**
- **Stay social**

THE CONNECTED .
GOOD PEOPLE :



- The GrEAT group at UPCT.
- My mentors at UPV / UV.
- My Ph.D students
- Heriot-Watt University Edinburgh (UK)
- Queens University Belfast (UK)
- University of Seville
- CSIRO ICT Centre, Sydney (Australia)
- UC3M (Madrid), TUDelft (Netherlands)
- An all MSc. Students (>100 already)…

THANK YOU
SO MUCH
FOR YOUR ATTENTION!

José Luis Gómez Tornero
Josel.Gomez@upct.es

George Goussetis
G.Goussetis@hw.ac.uk

Technical University of Cartagena (Spain)