International Spring School on Electromagnetics and emerging technologies for pervasive applications: Internet of Things, Health and Safety

18-20 April 2016, Bologna, Italy

WIreless Power Transmission for Sustainable Electronics

WIPE
COST IC1301

Leaky-wave antenna design for analog-signal-processing oriented devices for WPT, Energy Harvesting, Smart Cities and IoT devices

José Luis Gómez-Tornero

Technical University of Cartagena (Spain)

Wednesday, April 20th, 15:30-16:30

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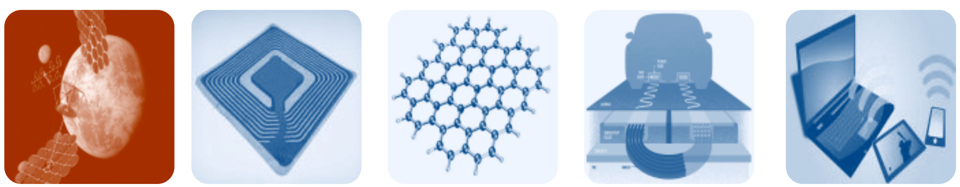
IC1301 – WIPE
Wireless Power Transmission for Sustainable Electronics

@ www.cost-ic1301.org

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY



WG1: Far-field WPT systems

WG2: Near-field WPT Systems

WG3: Novel Materials and Technologies

WG4: Applications

WG5: Regulation and Society impact

Prof. Nuno Borges

Prof. Alessandra Costanzo

Prof. Diego Masotti

Fondazione Guglielmo Marconi

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UPCT- Cartagena (Carthago-nova)

Technical University of Cartagena (Spain)

Annibal and his elephants...

24 centuries ago…

Annibal and his elephants...

https://www.theguardian.com/science/2016/apr/03/where-muck-hannibals-elephants-alps-italy-bill-mahaney-york-university-toronto

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Leaky-wave antenna design for analog-signal-processing oriented devices for WPT, Energy Harvesting, Smart Cities and IoT devices

1- Internet of Things (IoT).

2- Travelling-Wave and Leaky-Wave Antenna (LWA).

3- Analog Signal Processing (ASP) by LWA for IoT.

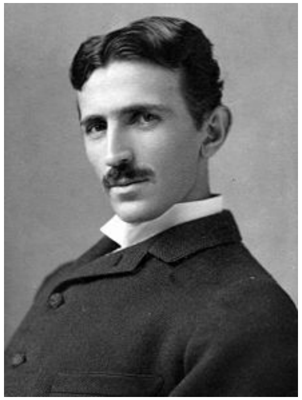
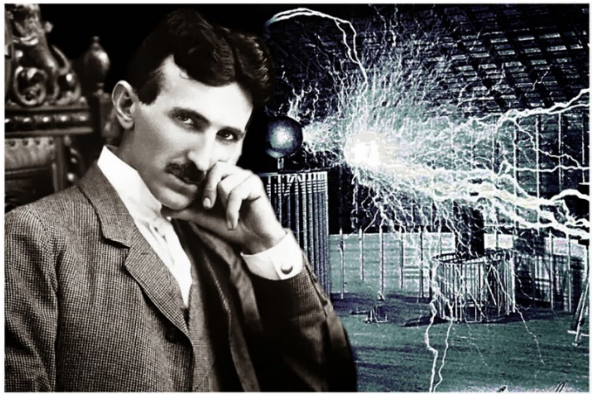
OUTLINE

1- Internet of Things (IoT).

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

3- Analog Signal Processing (ASP) by LWA for IoT.

1- Internet of Things (IoT).

Nikola Tesla, 1856 –1943


Guglielmo Marconi, 1874 –1937

Picture of me and Marconi's statue (last Monday)

1- Internet of Things.

Three different mechanisms for WPT:

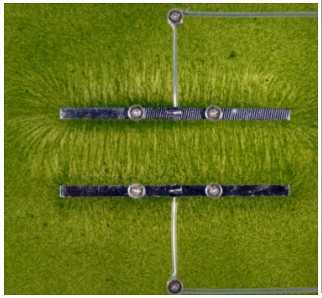
1- Conduction :
(plasma arcs – conducting current "breaking" the air)

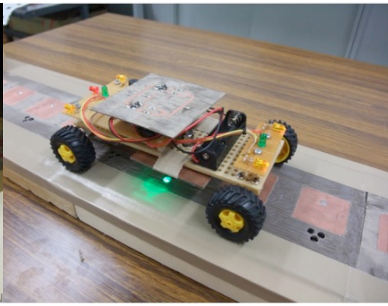
***Tesla coils* :**



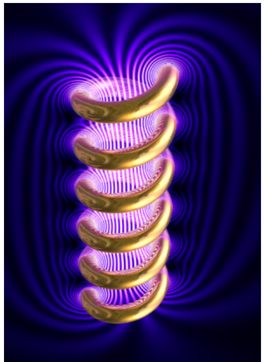
2- Induction :
(reactive near field coupling)

2.1- Capacitive





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

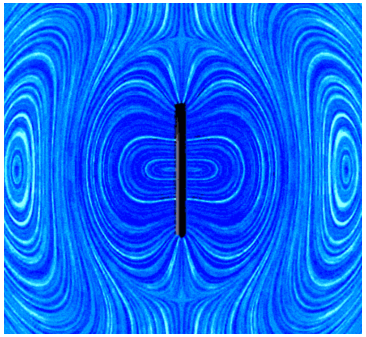


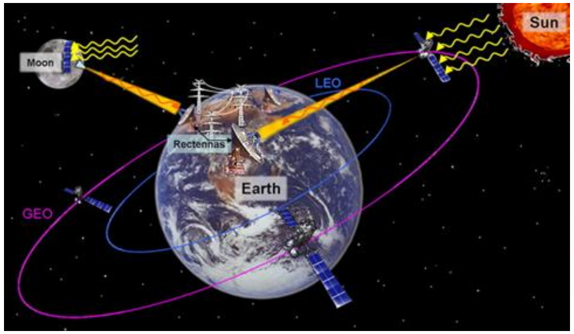


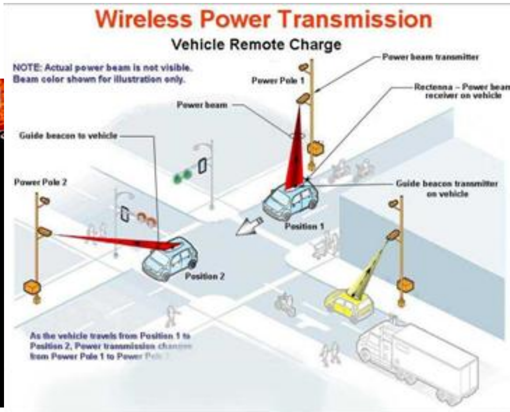
1- Internet of Things.

Three different mechanisms for WPT:

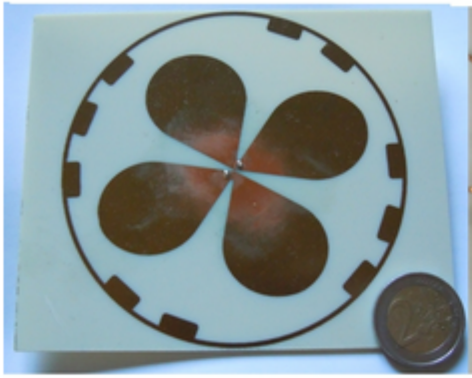
3- Radiation :
(radiative coupling)



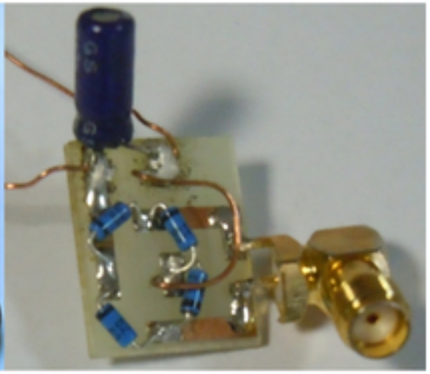




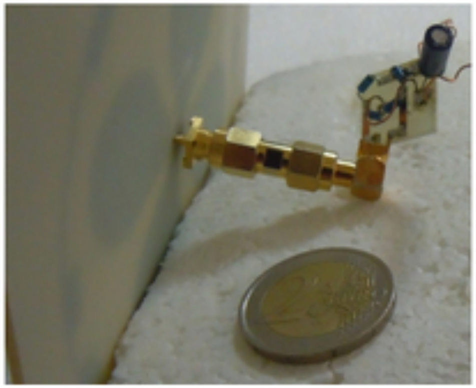
Antenna



Rectifier



Rectenna



3.1- Far-field focusing

3.2- Near-field focusing

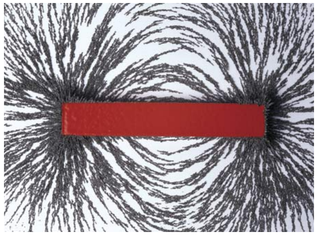
DO NOT CONFUSE !
- **REACTIVE NEAR-FIELD COUPLING / RESONANCE**
- **RADIATIVE MICROWAVE TRANSMISSION USING NEAR-FIELD FOCUSING TECHNIQUES**

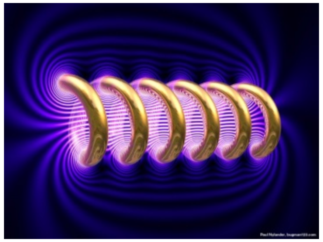
1- Internet of Things.

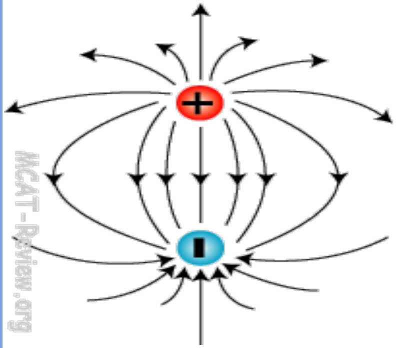
DO NOT CONFUSE !

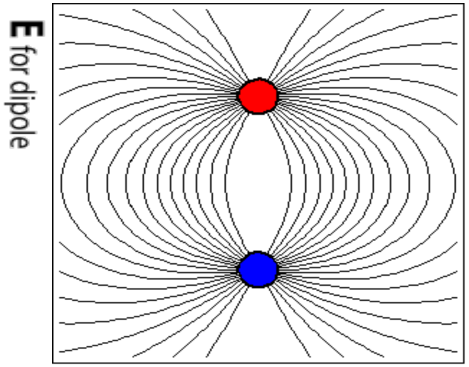
REACTIVE NEAR-FIELDS (STORED ENERGY)

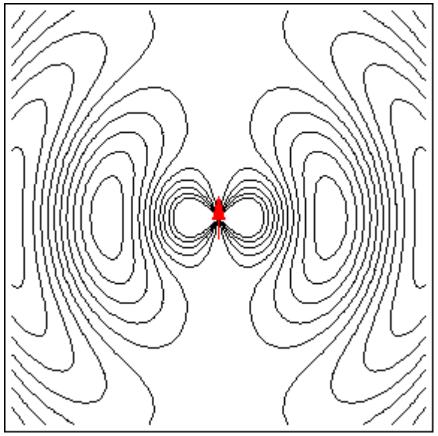
RADIATIVE FIELDS (RADIATED ENERGY)

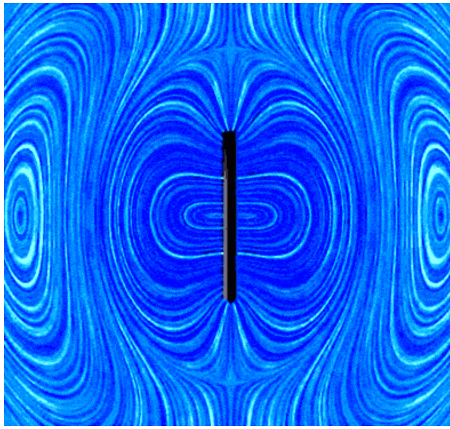


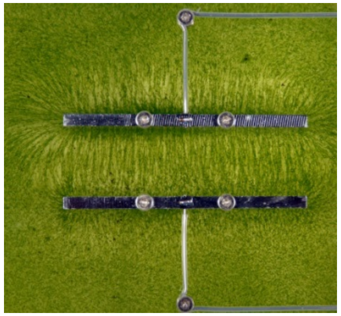












radiated fields exists even if the source disappears…

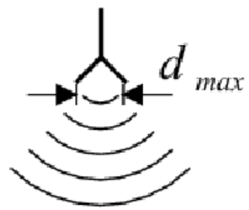
(we can see stars which do no exist since they disappeared M years ago)

1- Internet of Things.

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: $d_{\max}$

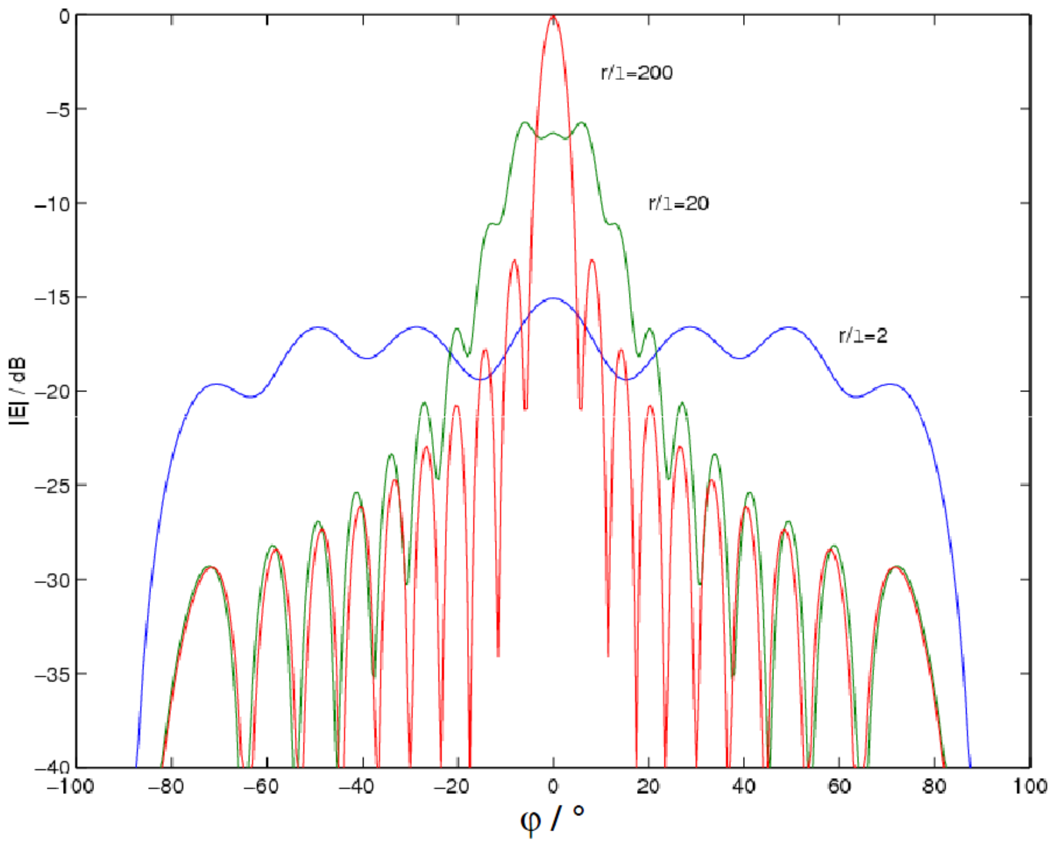
1- Internet of Things.

DO NOT CONFUSE !

REACTIVE NEAR-FIELDS (STORED ENERGY)

RADIATIVE FIELDS (RADIATED ENERGY)

Radiation Regions Example – Large Antenna

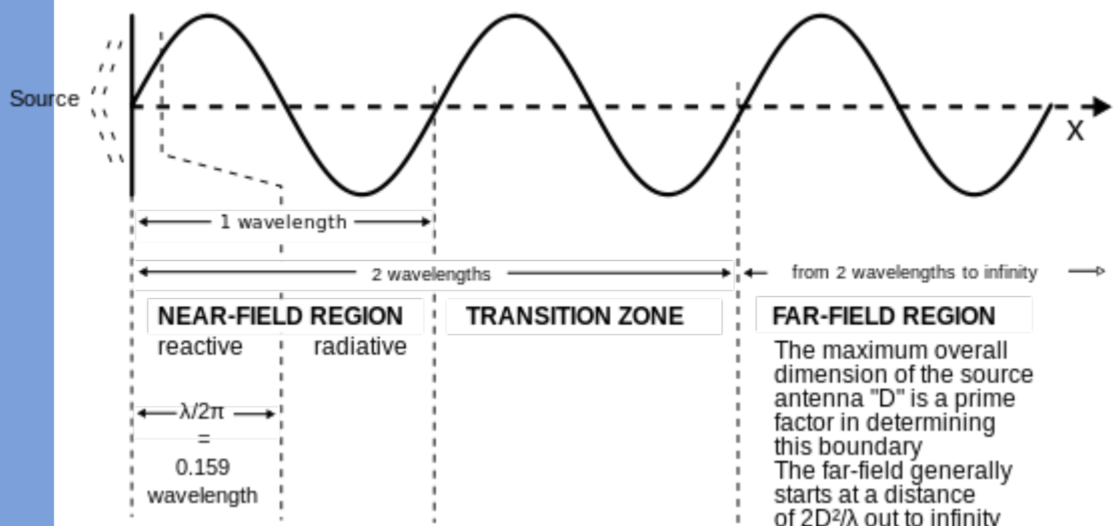


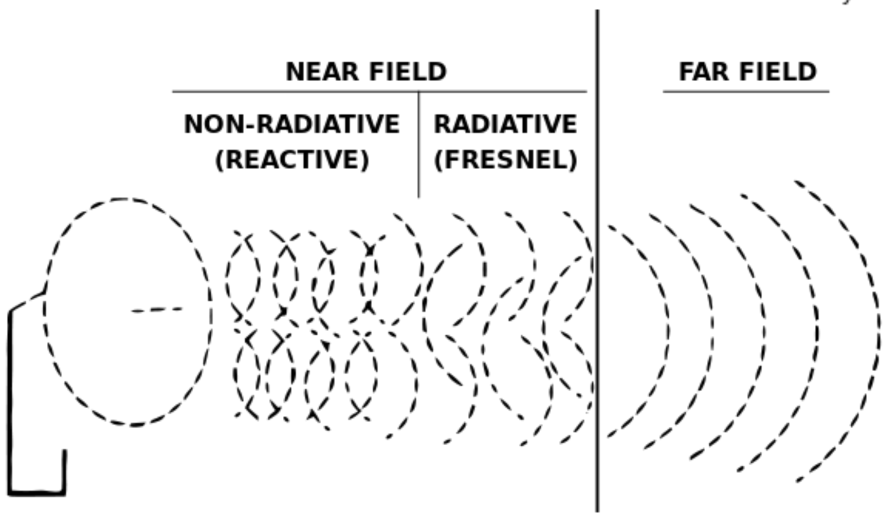
Antenna with $d_{\max} = 10\lambda$

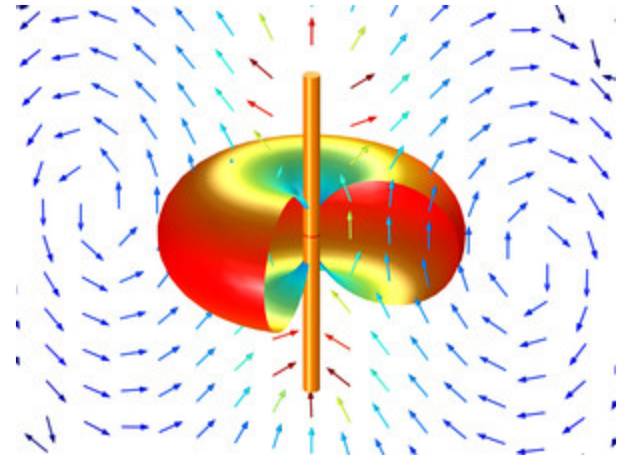
1- Internet of Things.

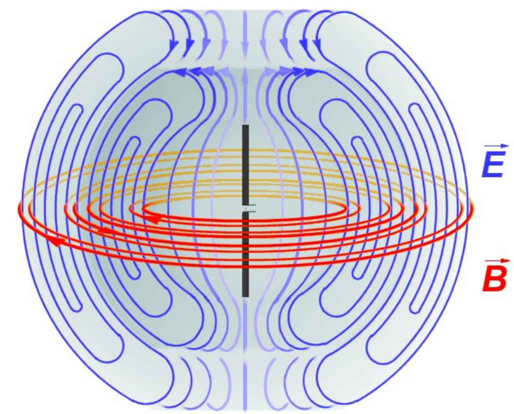
DO NOT CONFUSE !

REACTIVE NEAR-FIELDS | **RADIATIVE FIELDS**









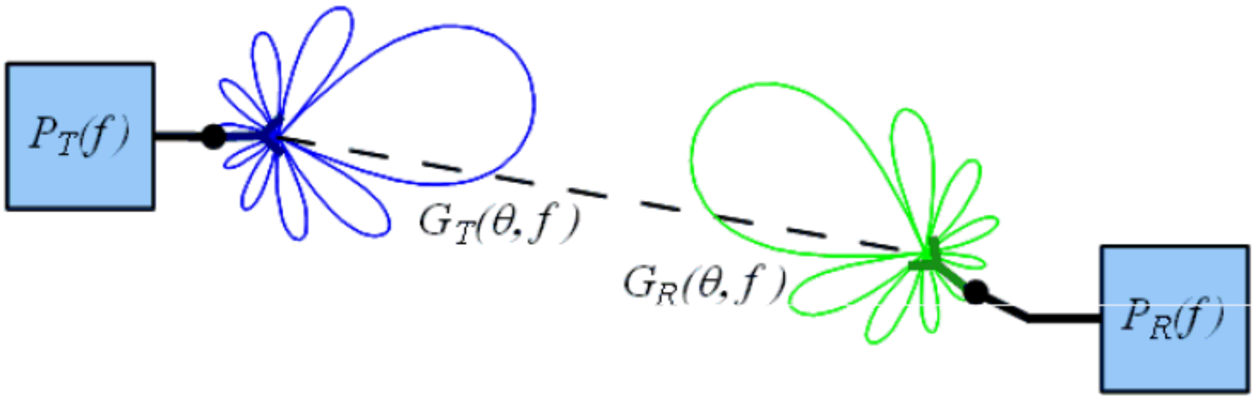
John David Jackson,
Classical Electrodynamics,
3rd edition (Wiley: New York, 1998)

1- Internet of Things.

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.

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

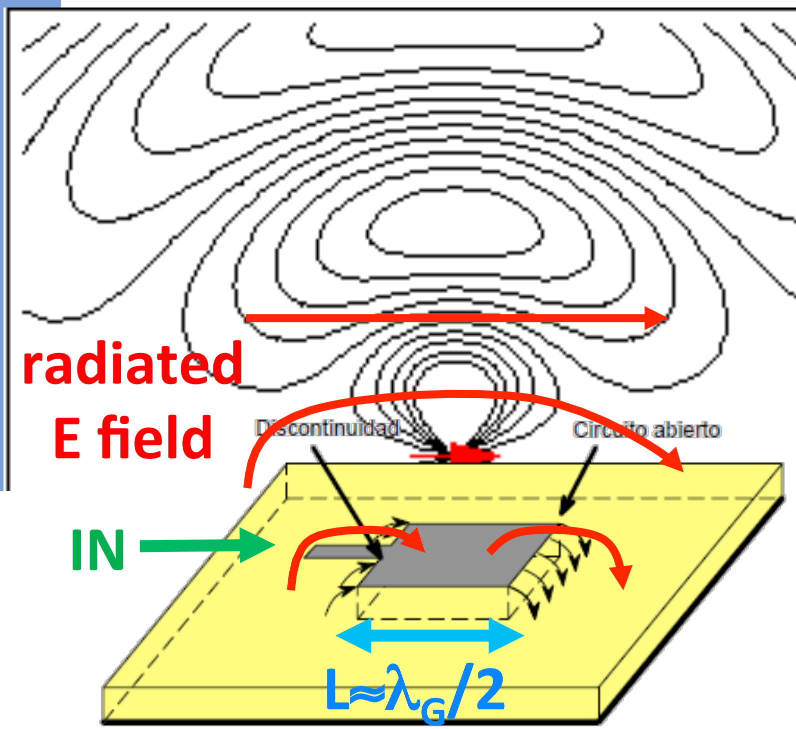
1- Internet of Things (IoT).

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

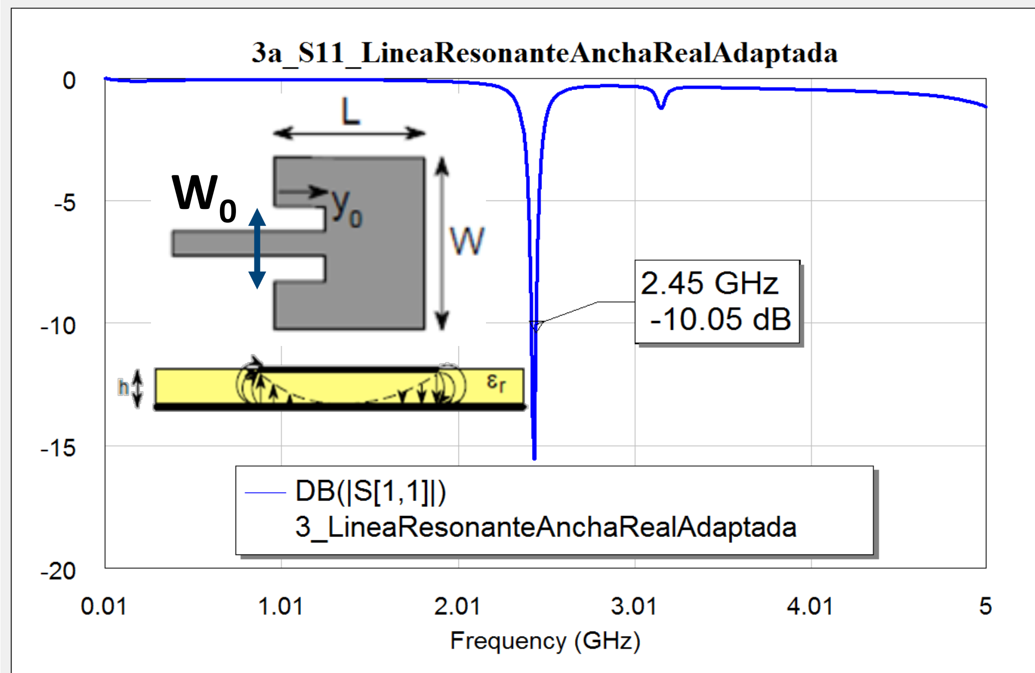
3- Analog Signal Processing (ASP) by LWA for IoT.

2- Travelling-Wave and Leaky-Wave

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



Resonant Impedance Matching S11



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

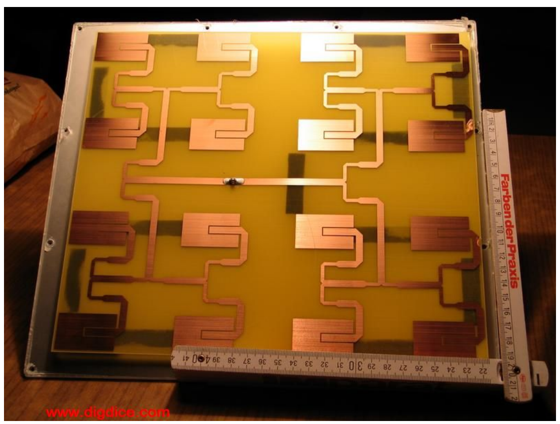
f_0=2.45GHz
BW=50MHz=2% (S_{11}<-10dB)
η_{RAD}=30% (losses↑↑ resonance)

2- Travelling-Wave and Leaky-Wave

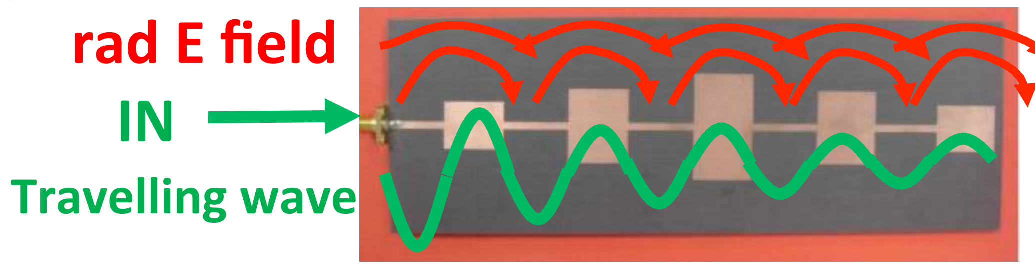
2.2- Radiation mechanisms of series-patch / slotted travelling-wave antenna

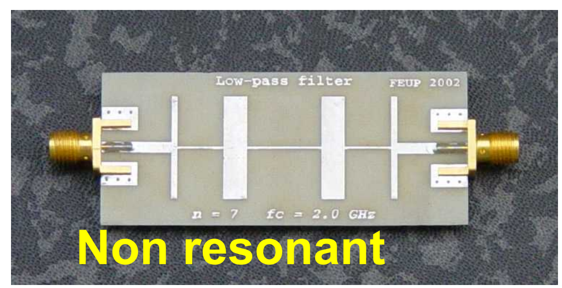
- The periodic strips / slots are resonant !
- But they are distributely fed by a travelling / propagating wave instead of a discrete distributed network:

- Phased array (shunt feeding):



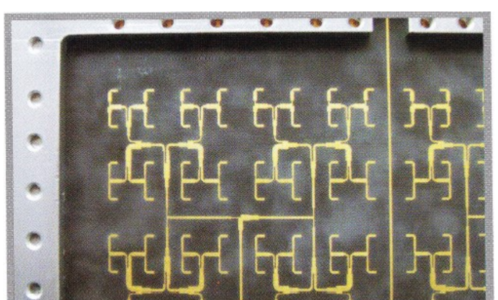
- Phased array (series feeding):



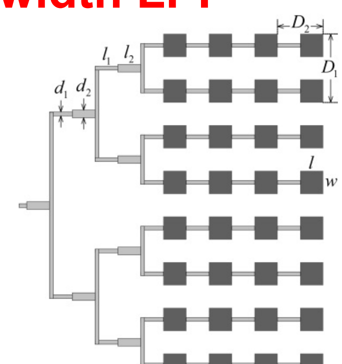


Do not confuse with stepped width LPF

Complex distribution / feeding network

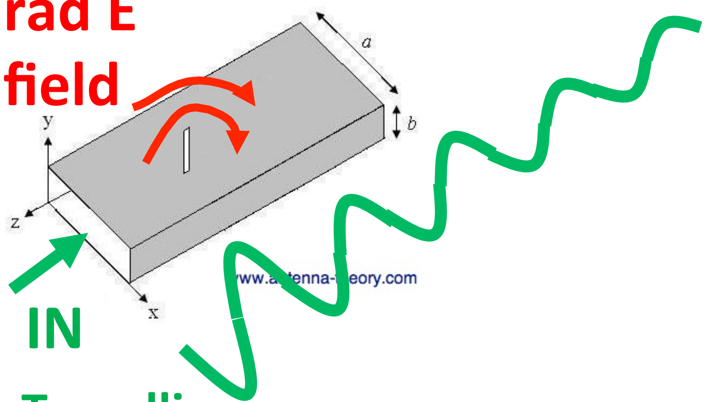


- Shunt & series feeding:

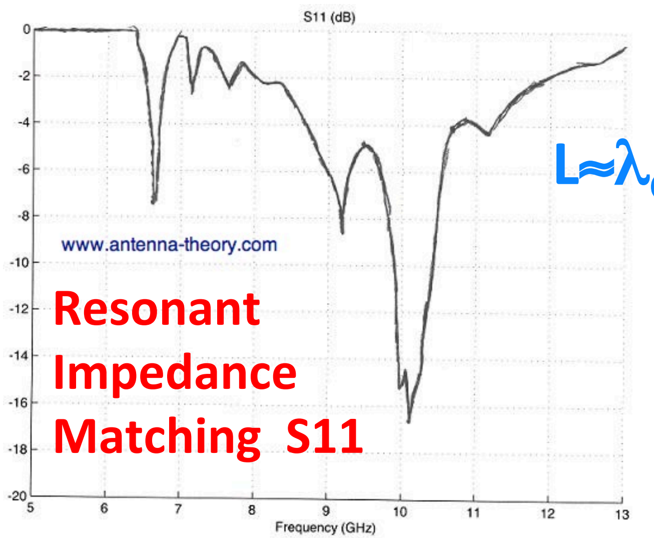


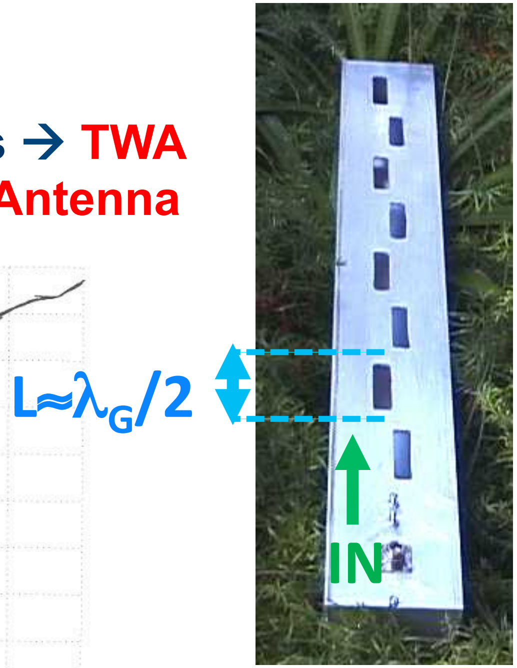
2- Travelling-Wave and Leaky-Wave

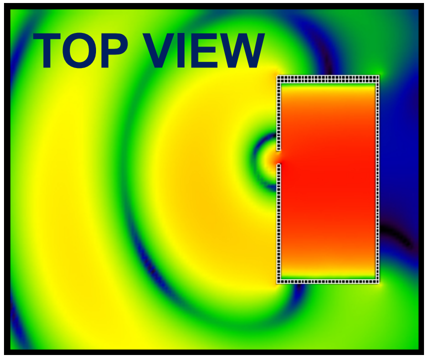
- **Slotted waveguide TWA (Series feeding):**

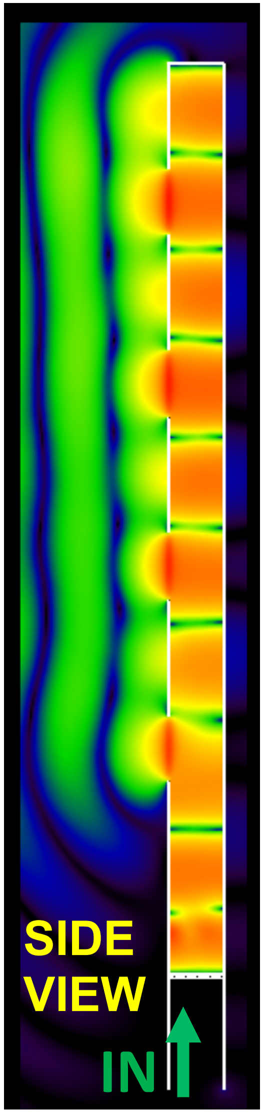


- **If resonant slots → TWA**
  Travelling-Wave Antenna









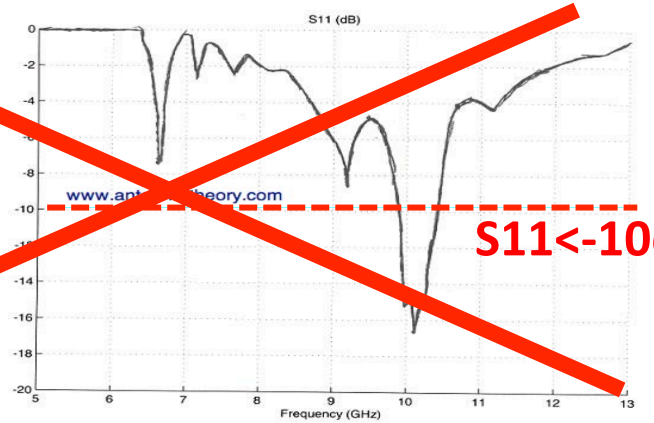
2- Travelling-Wave and Leaky-Wave

- If NON resonant slots → LWA Leaky-Wave Antenna

~~Resonant Impedance Matching S11~~

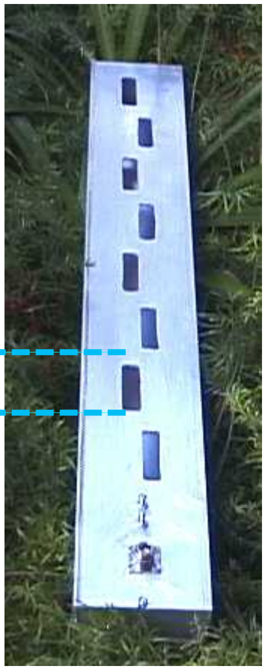
~~f_0=10GHz~~

~~BW=0.2GHz=2%~~



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

$L<\lambda_G/2$



IN

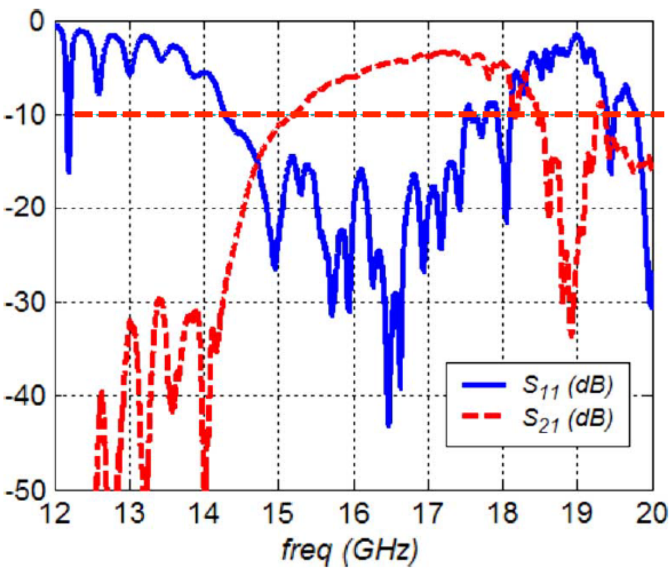
IN

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)

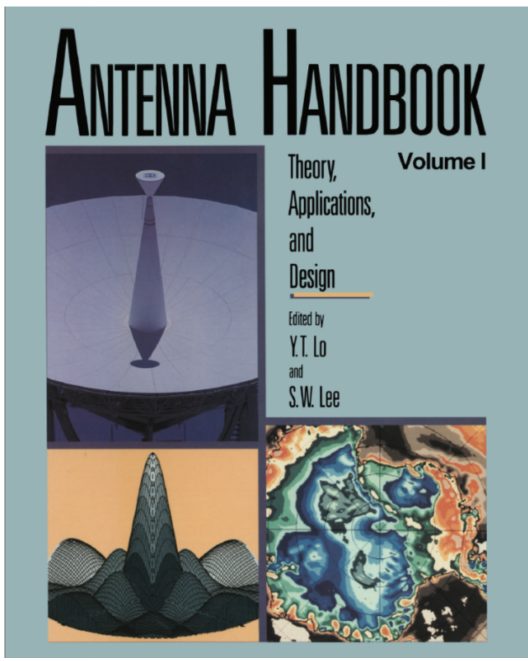
"Antenna Handbook , Theory, Applications, and Design"
Y. T. Lo, S. W. Lee (Springer, 1988)
Ch.12, pp 805-842:
"The Design of Waveguide-Fed Slot Arrays",
By Robert S. Elliot.

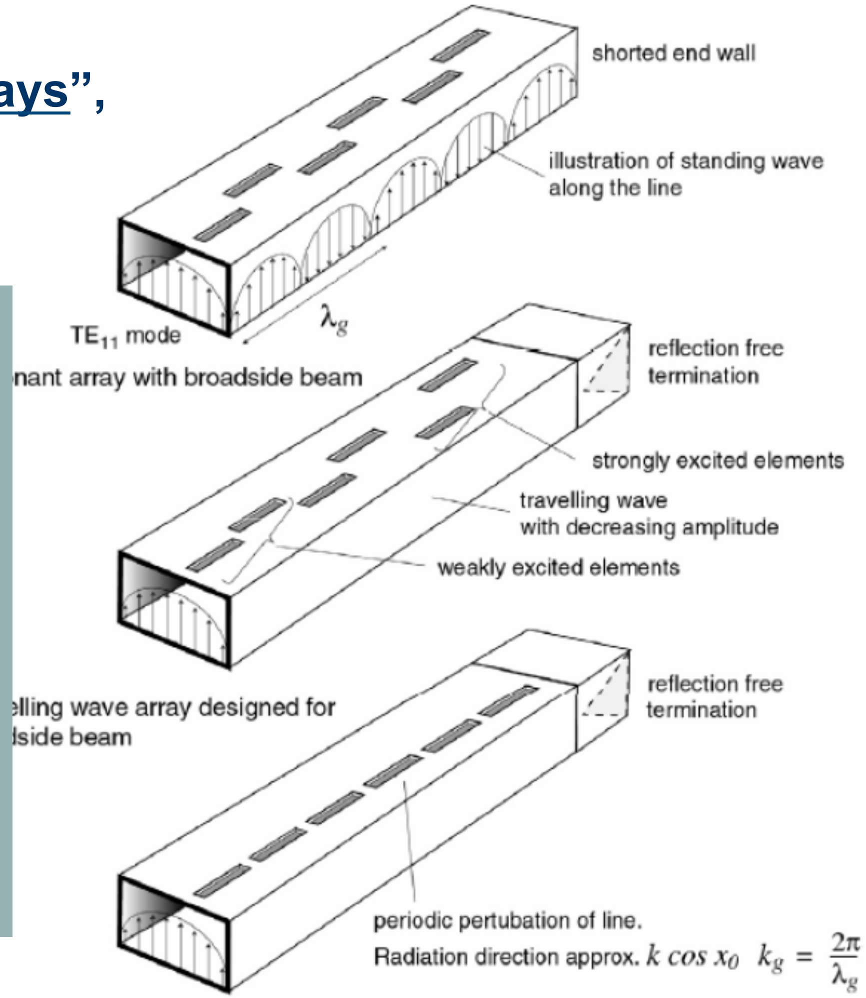
Chapter 12

The Design of Waveguide-Fed Slot Arrays

Robert S. Elliott
University of California at Los Angeles

CONTENTS





2- Travelling-Wave and Leaky-Wave

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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

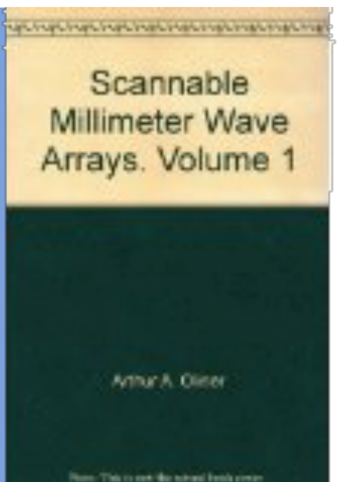
2- Travelling-Wave and Leaky-Wave

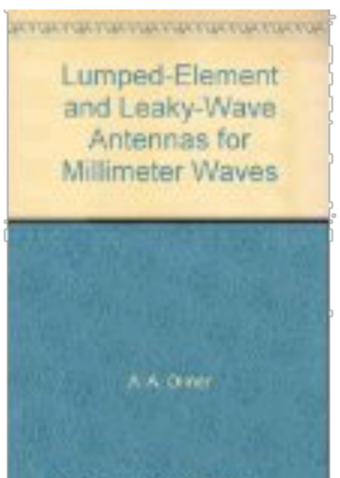
2.4- Leaky-wave antennas (LWA) and leaky modes (LM)

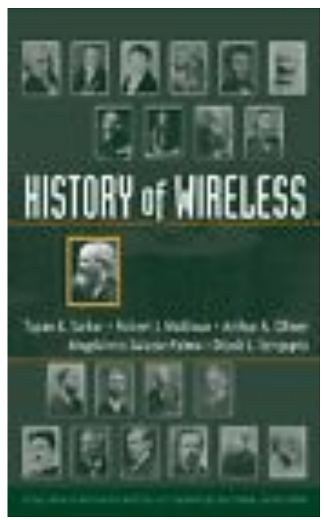
IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. MTT-32, NO. 9, SEPTEMBER 1984

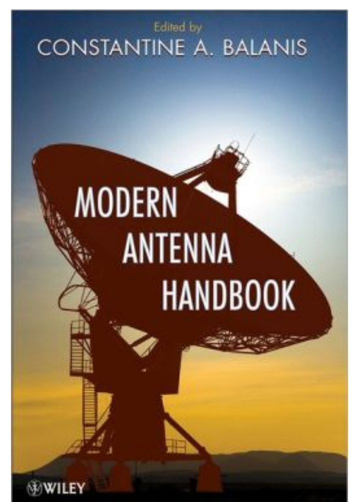
Historical Perspectives on Microwave Field Theory

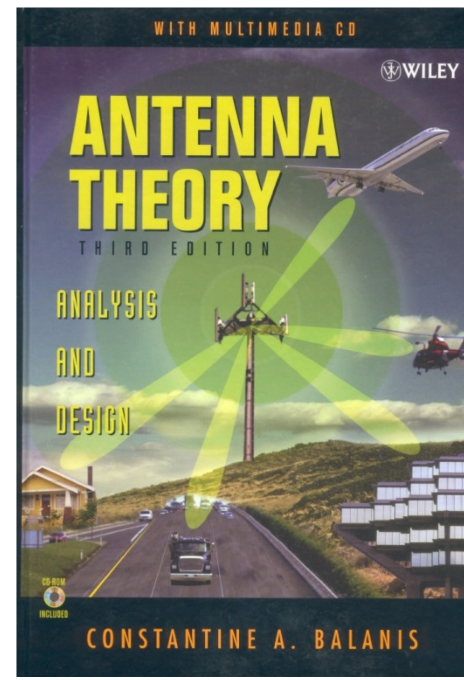
A. A. OLINER, FELLOW, IEEE



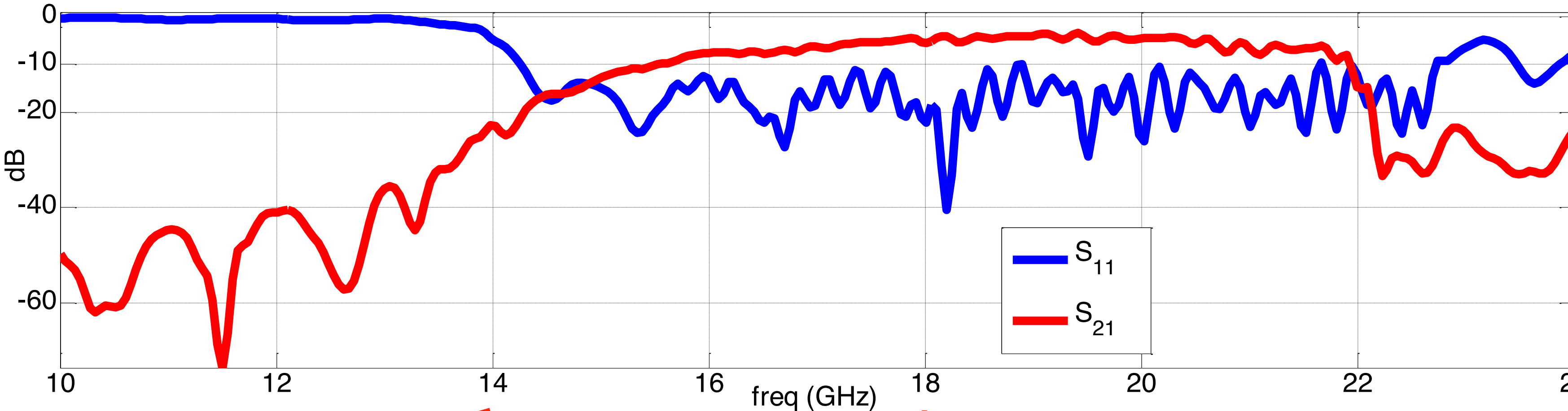


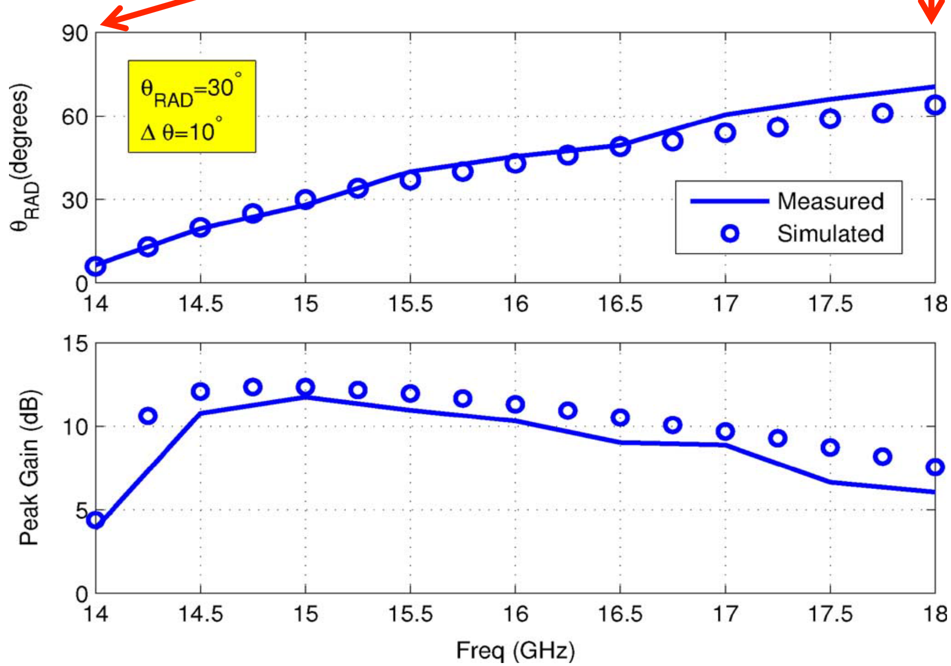




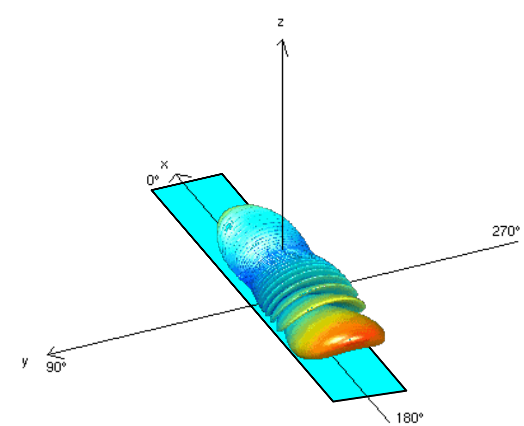


What about the bandwidth ?



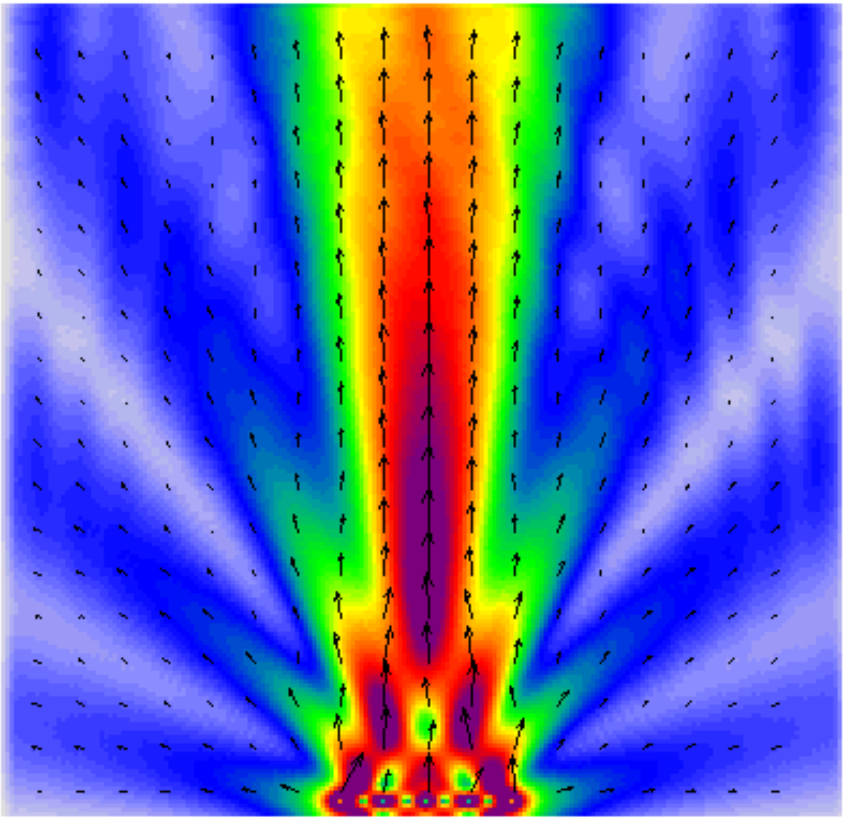


- **Matching / Efficiency**
- **Frequency beam scanning (dispersion)**
- **Fan beam**



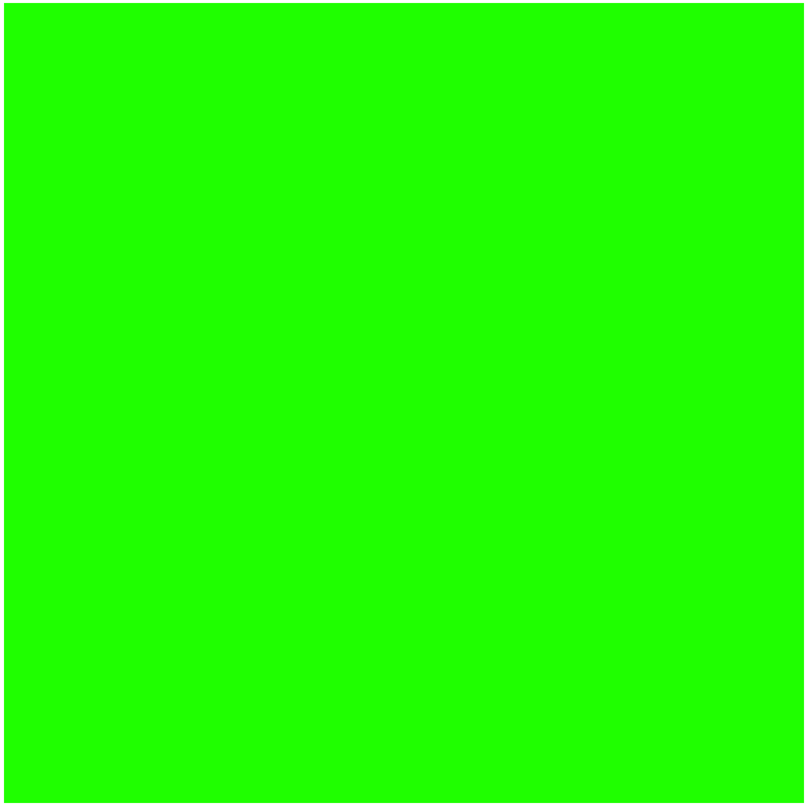
2- Travelling-Wave and Leaky-Wave

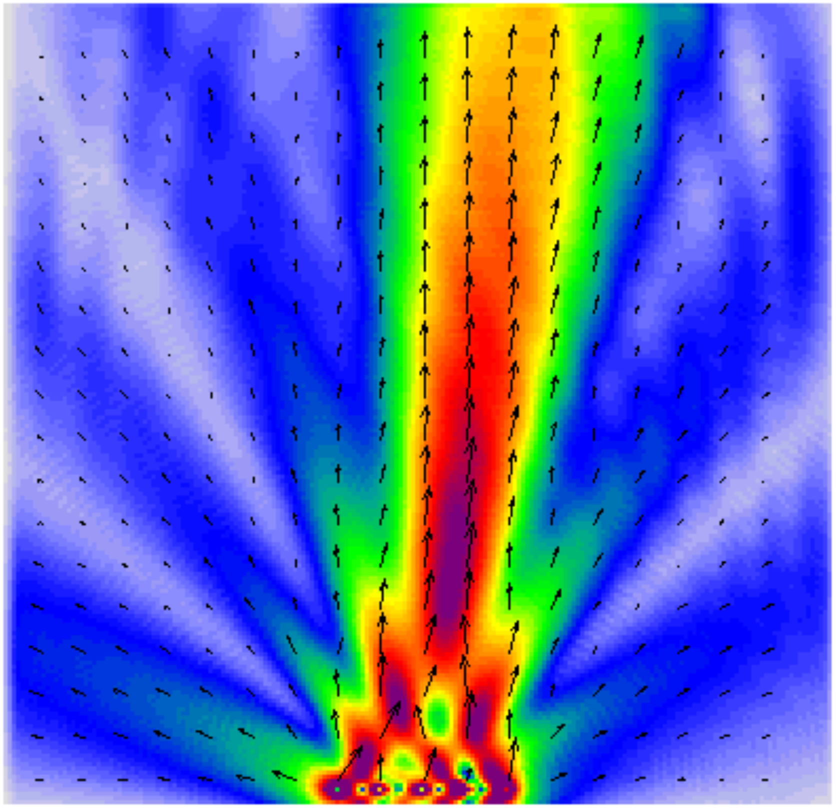
Phased array antenna – phase feed



2- Travelling-Wave and Leaky-Wave

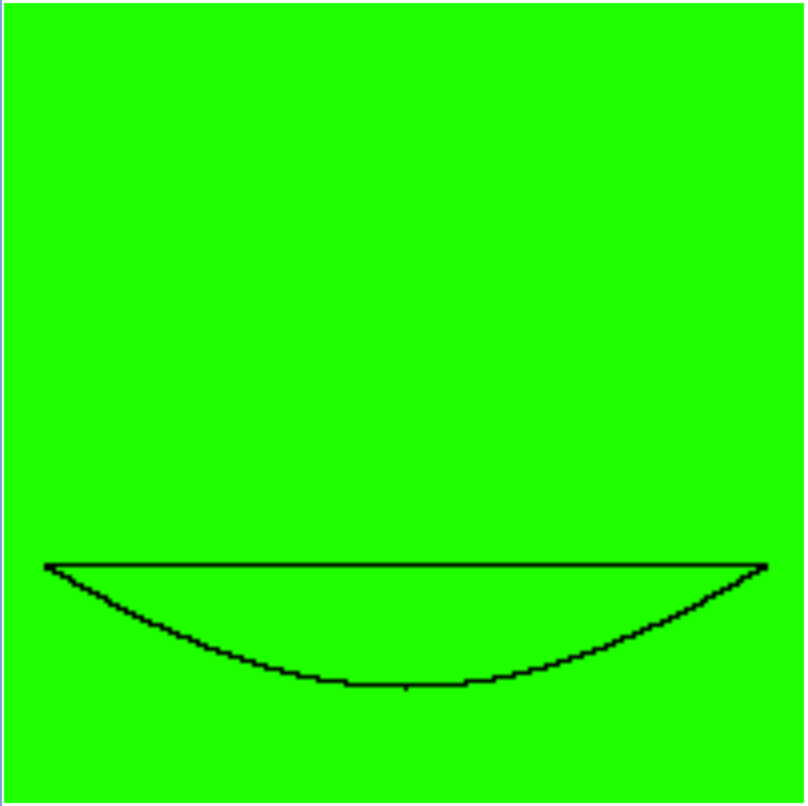
Phased array antenna – beam steering

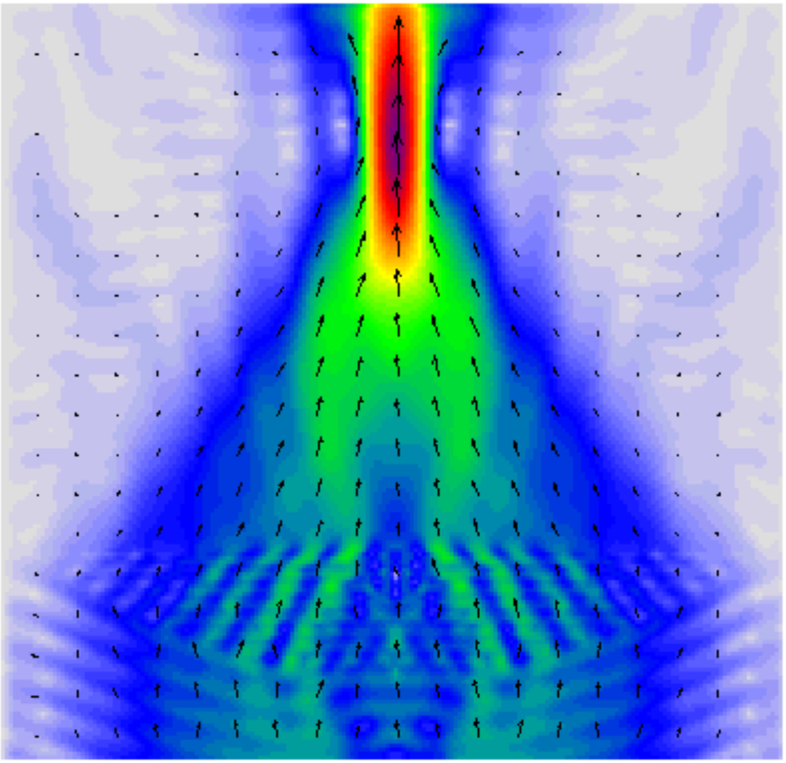




2- Travelling-Wave and Leaky-Wave

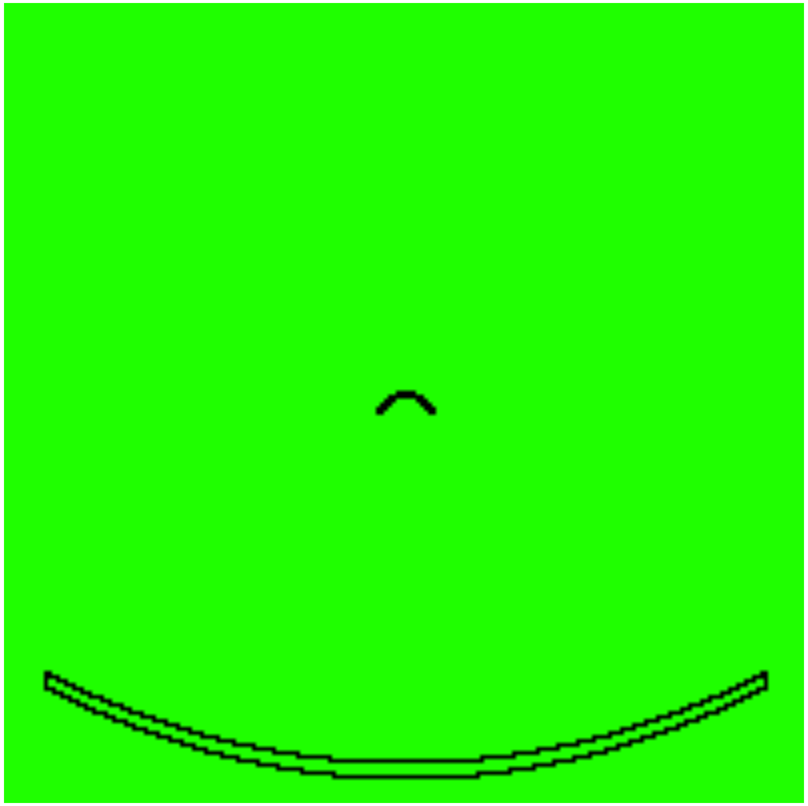
Convex lens antenna

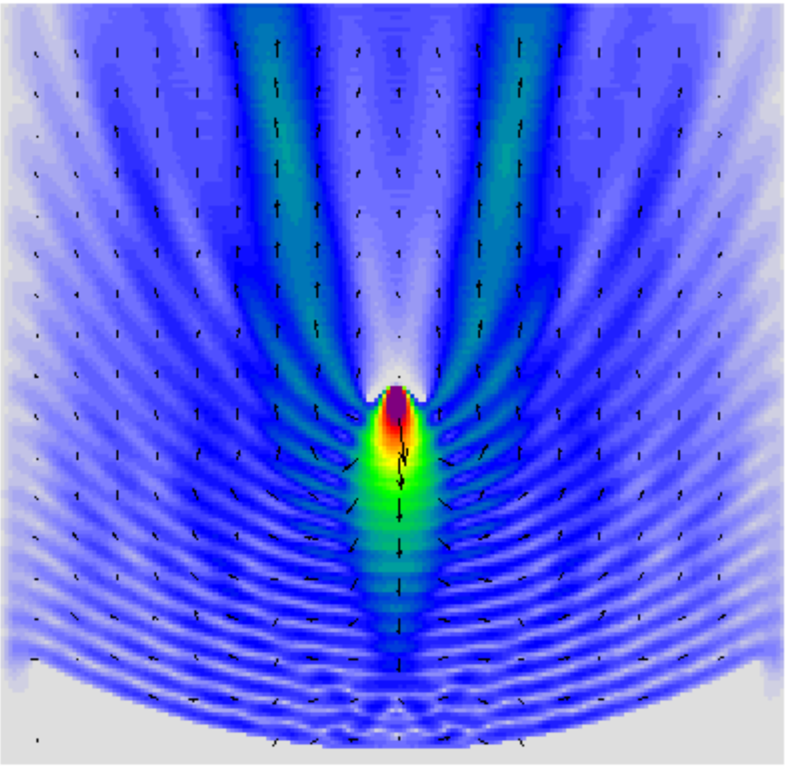




2- Travelling-Wave and Leaky-Wave

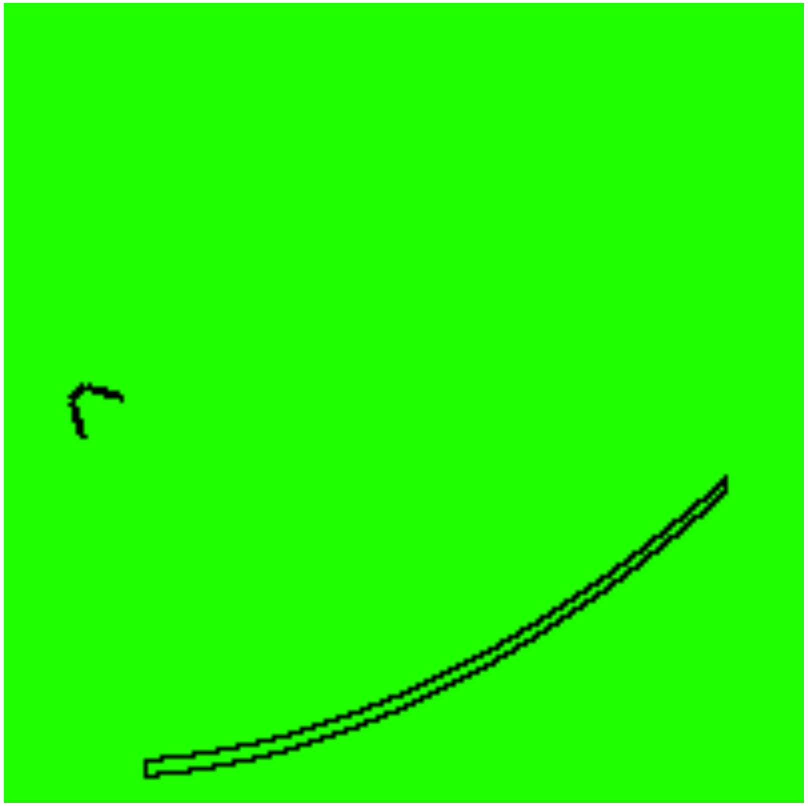
Parabolic dish antenna

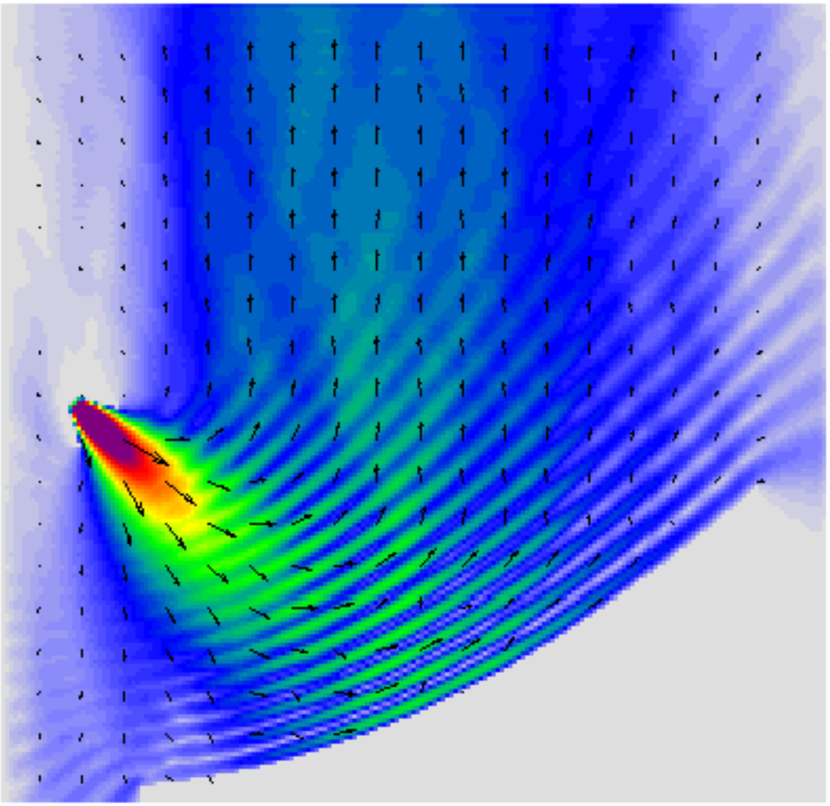




2- Travelling-Wave and Leaky-Wave

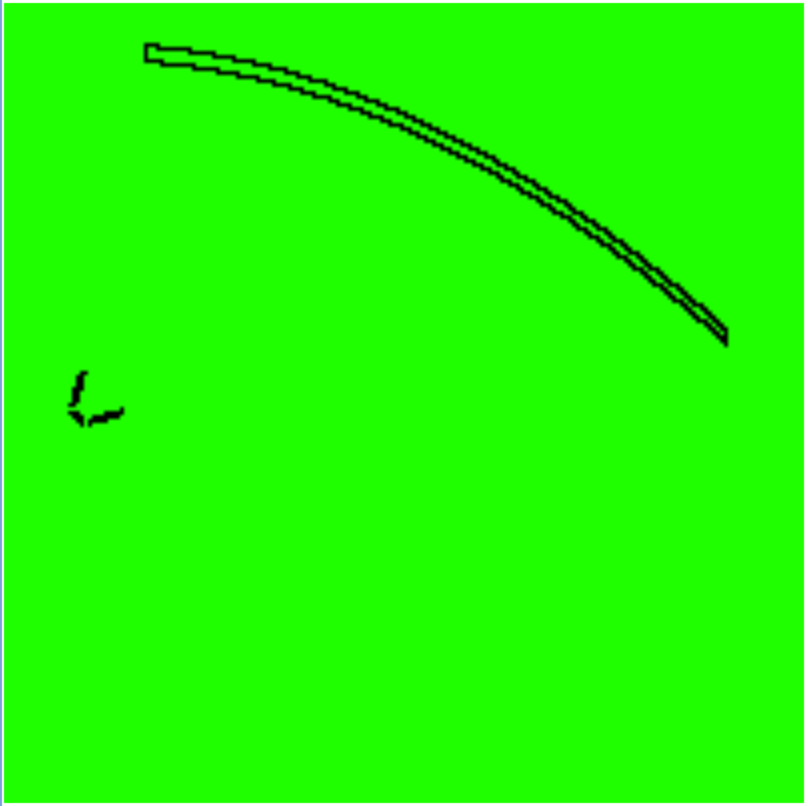
Offset Parabolic dish antenna - transmitting

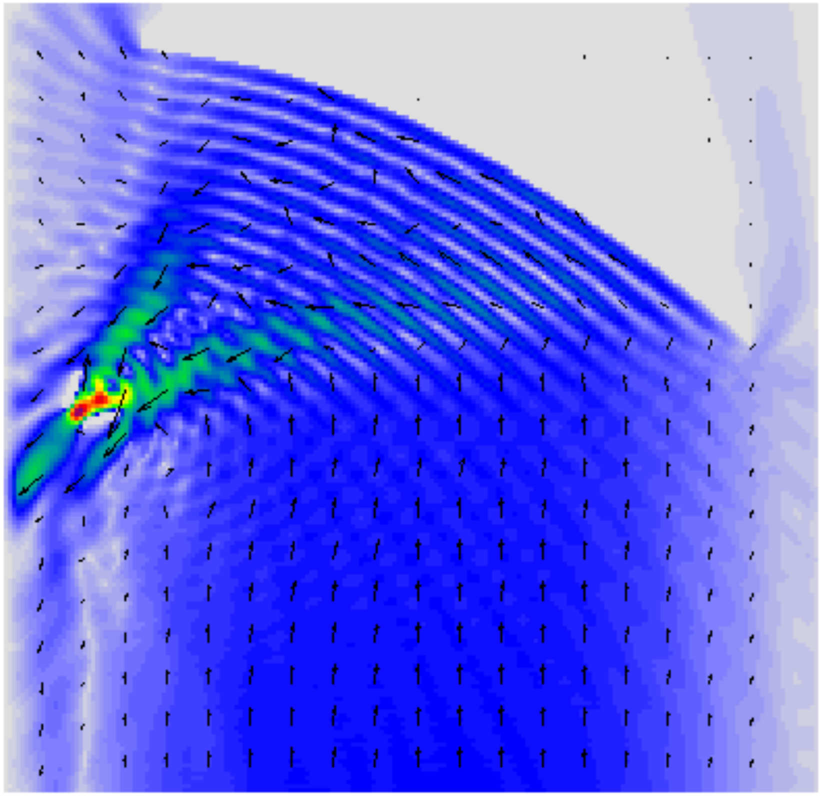




2- Travelling-Wave and Leaky-Wave

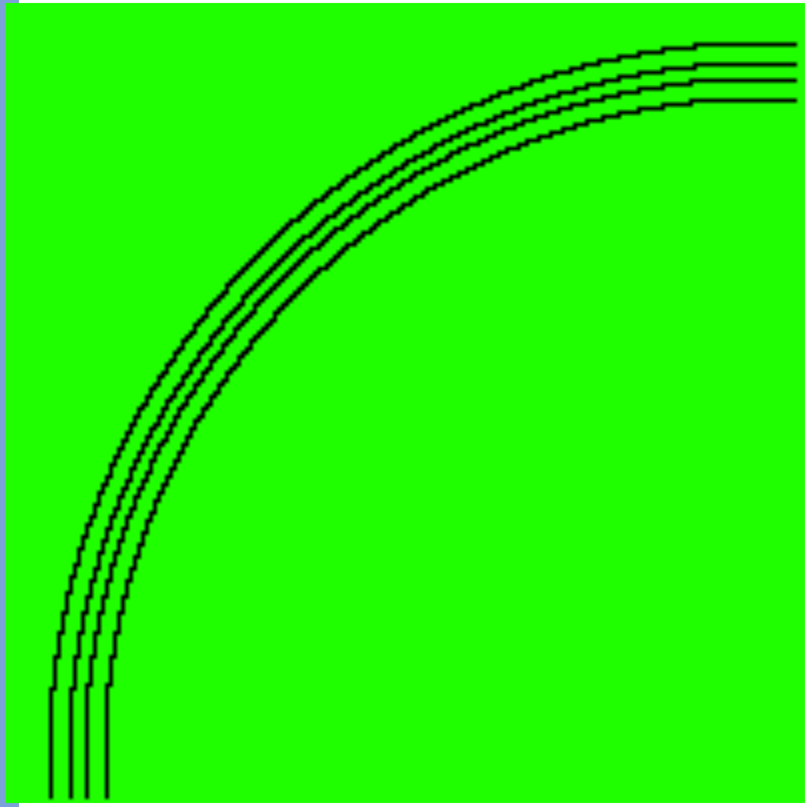
Offset Parabolic dish antenna - receiving

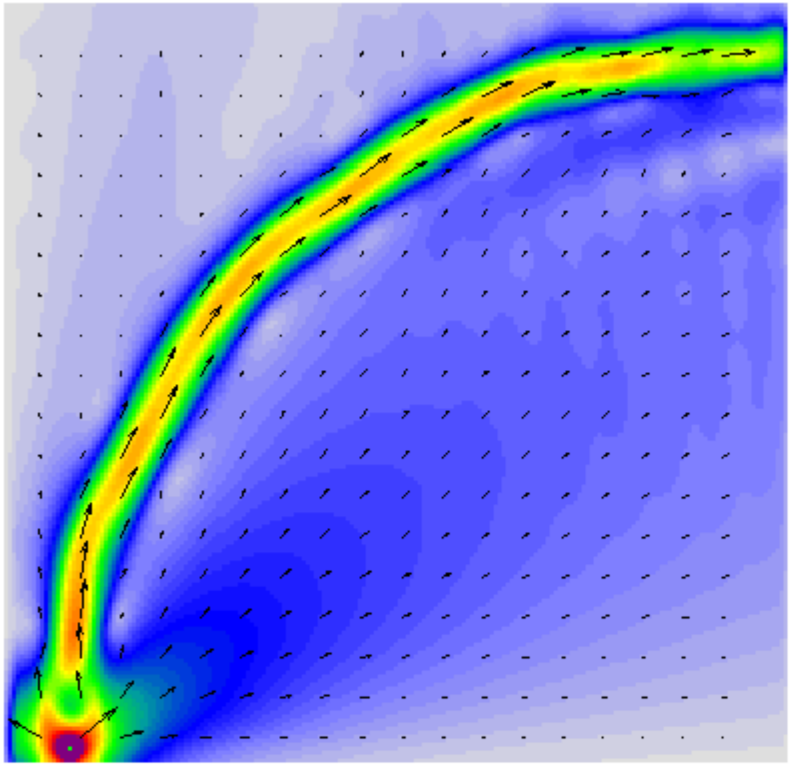




2- Travelling-Wave and Leaky-Wave

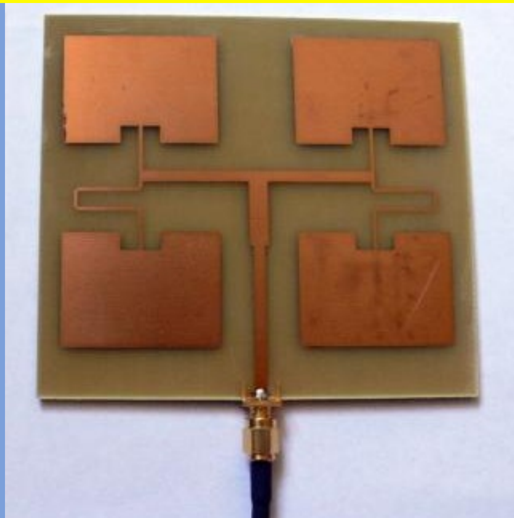
Waveguide – wave guiding and leakage



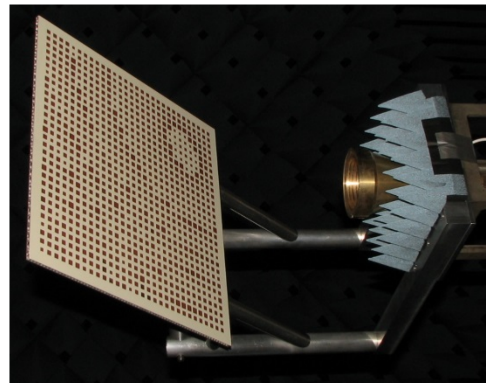


2- Travelling-Wave and Leaky-Wave

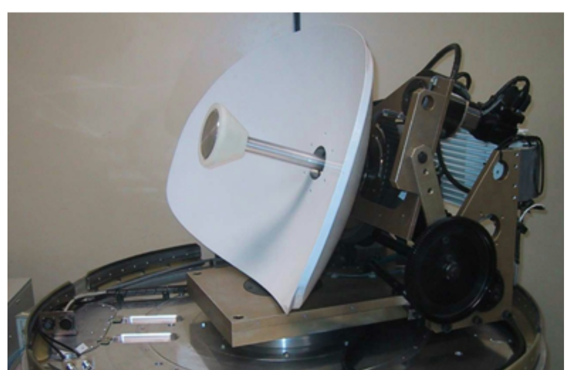
Phased array antenna



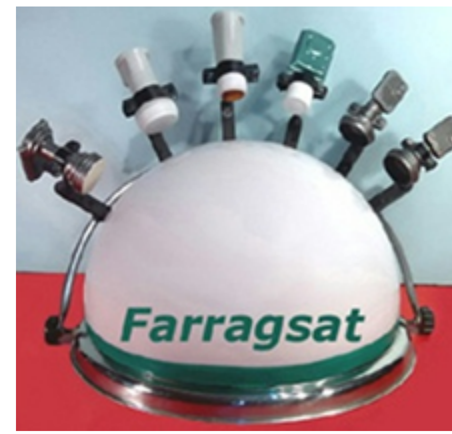
Reflect / transmit arrays



Reflector antennas



Lens antennas



2- Travelling-Wave and Leaky-Wave

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

- Simple structure, integrated single feeding.
- Low profile, low cost, PCB compatible with novel materials.
- Robust designs, insensible to environment → Non resonant, distributed (travelling-wave) radiation
- 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

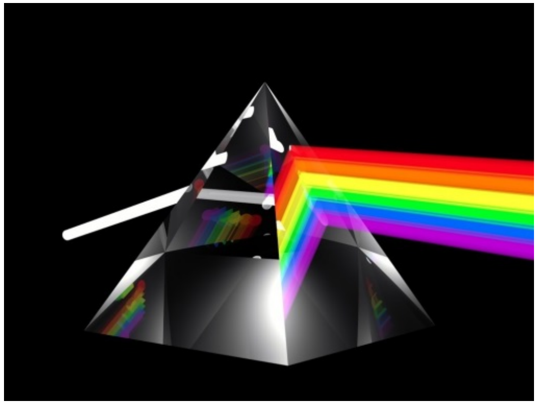
OUTLINE

1- Internet of Things (IoT).

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

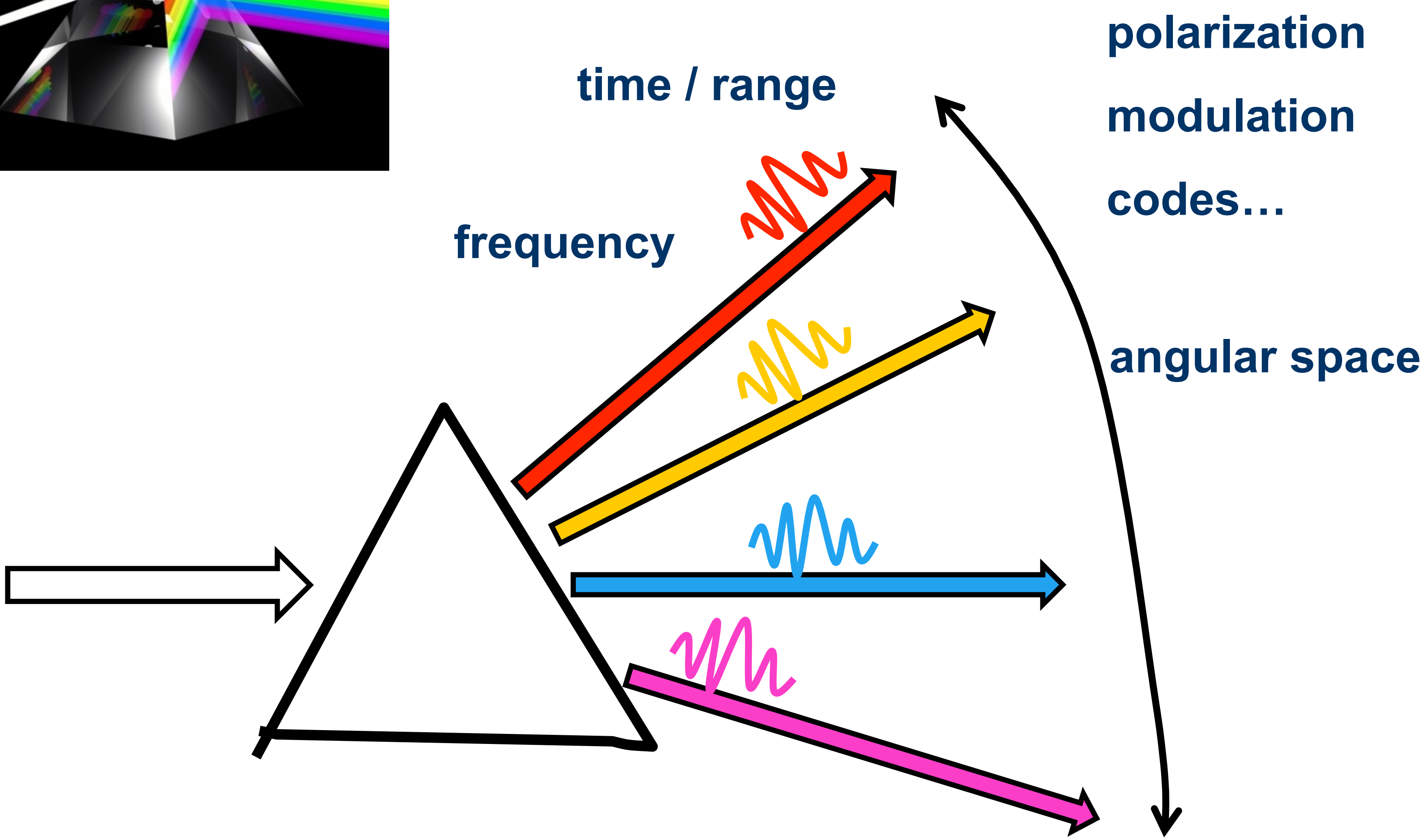
3- Analog Signal Processing (ASP) by LWA for IoT.

ANALOG SIGNAL PROCESSING



Concepts from optics, acoustics, RADAR…

And also from telecommunications…



OUTLINE

1- Modulated SIW antenna.

2- Synthesis Design Examples.

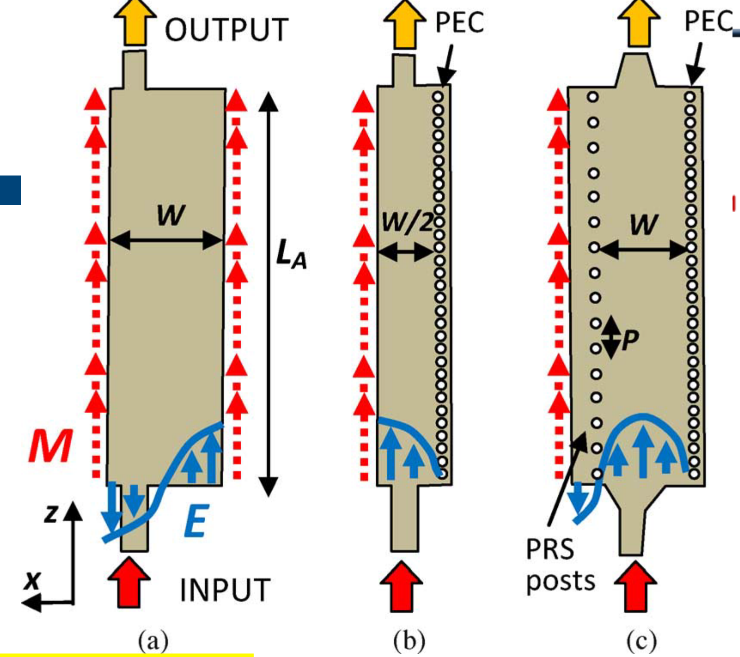
3- Conclusions.

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



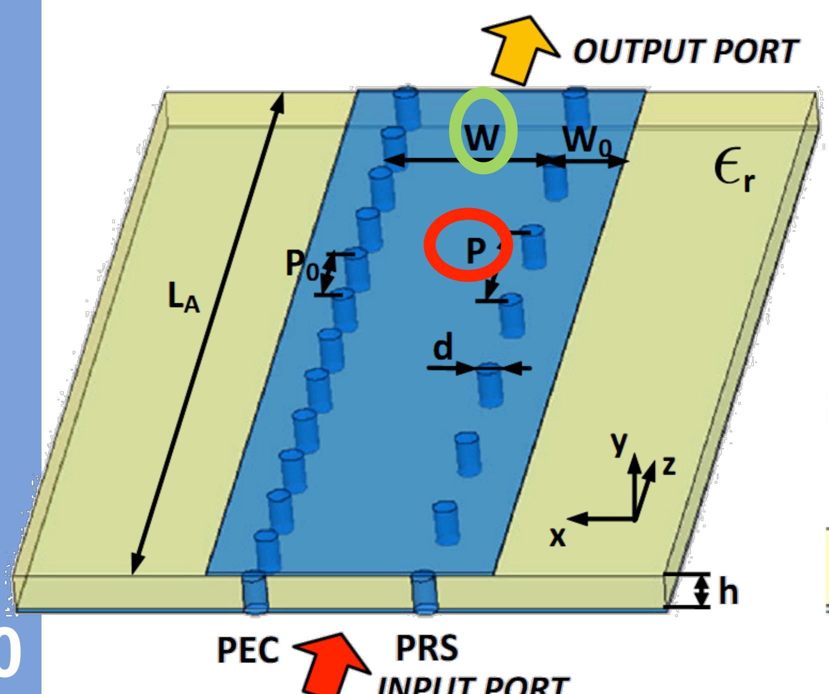
W → Controls the scanning angle (aperture phase)

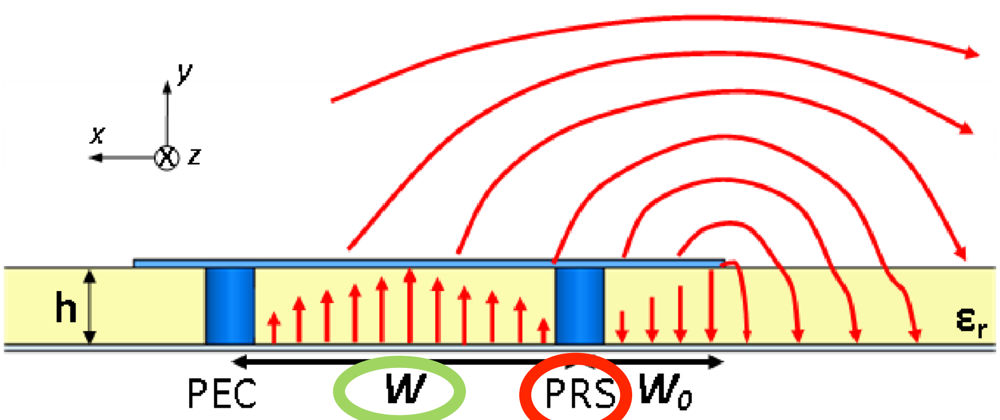
P → Controls the leakage rate (aperture amplitude)

Menzel LWA [1979]

Half-width LWA Zelinski [2004]

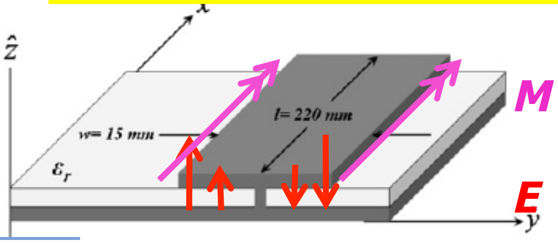
SIW LWA lateral Deslandes [2005]



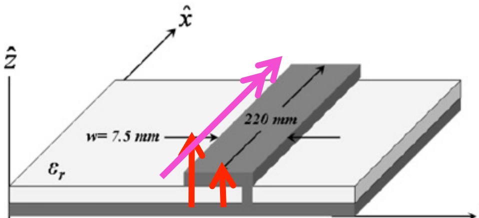


1- Modulated SIW antenna.

Control of the leakage rate on Menzel LWA



Menzel LWA [1979]



Half-width LWA Zelinski [2004]

- **Half width**
- **Easier feeding**
- **No qTEM mode**

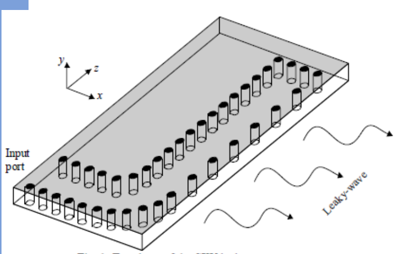
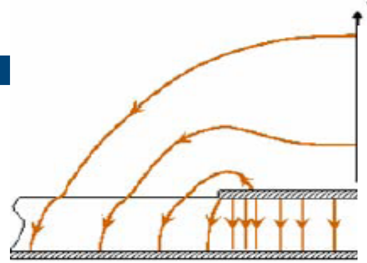


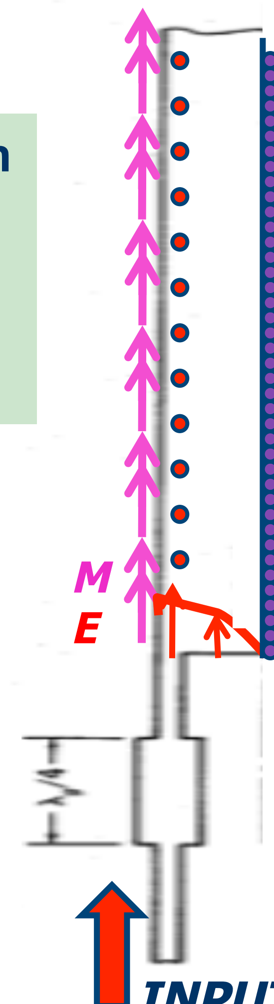
Fig. 1: Topology of the SIW leaky-wave antenna.

SIW LWA lateral Deslandes [2005]

EH₁

First higher order mode





PEC posts

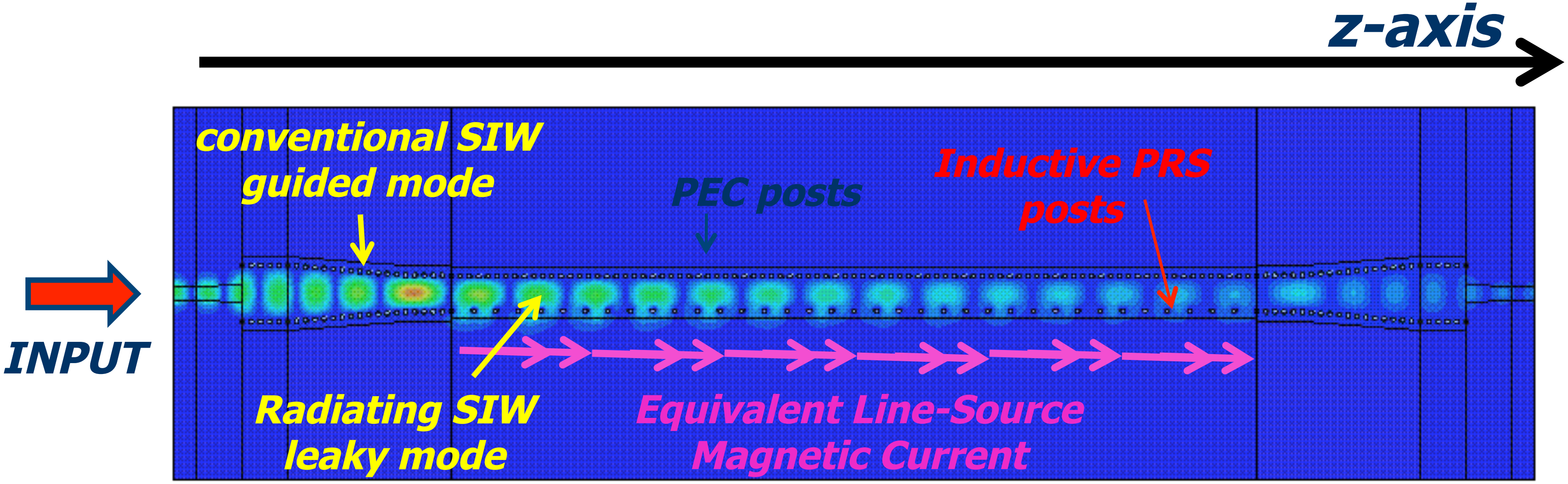
Inductive PRS posts

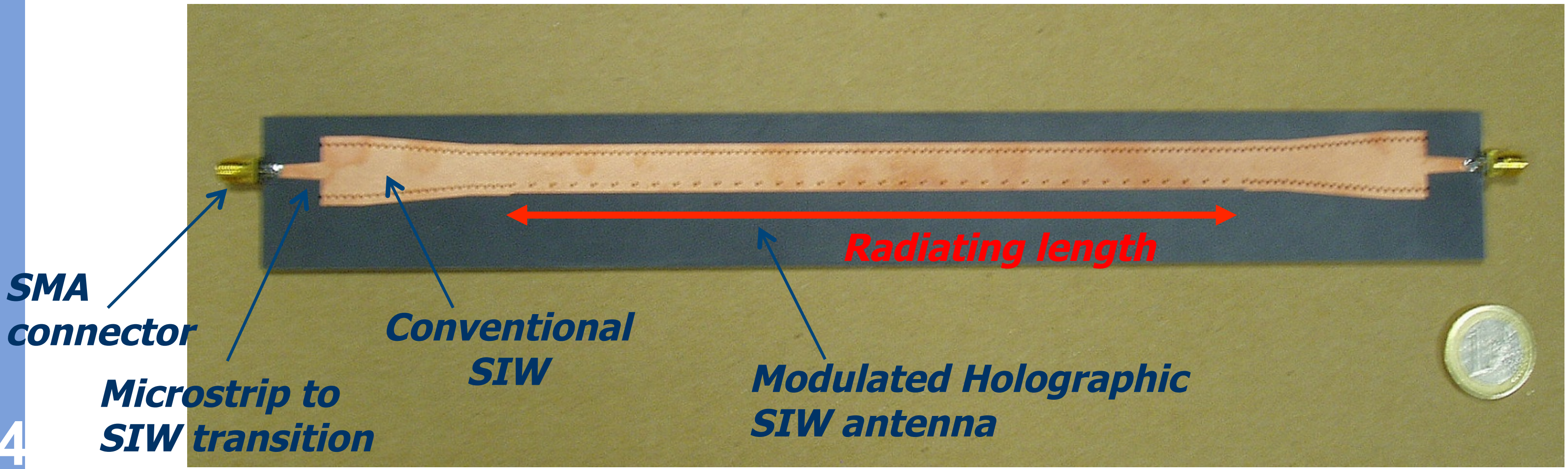
Inductive POST to control the intensity of the induced equivalent magnetic current

J.S. Radcliffe, G.A. Thiele, and G.M. Zelinski, "A Microstrip Leaky Wave Antenna and Its Properties", *Symposium of the Antenna Measurement Techniques Association*, Oct. 2004

D.Deslandes and K. Wu, “Substrate Integrated Waveguide Leaky-Wave Antenna: Concept and Design Considerations”, APMC 2005.

1- Modulated SIW antenna.





SIW technology

Prof. Maurizio Bozzi

Prof. Hendrik Rogier

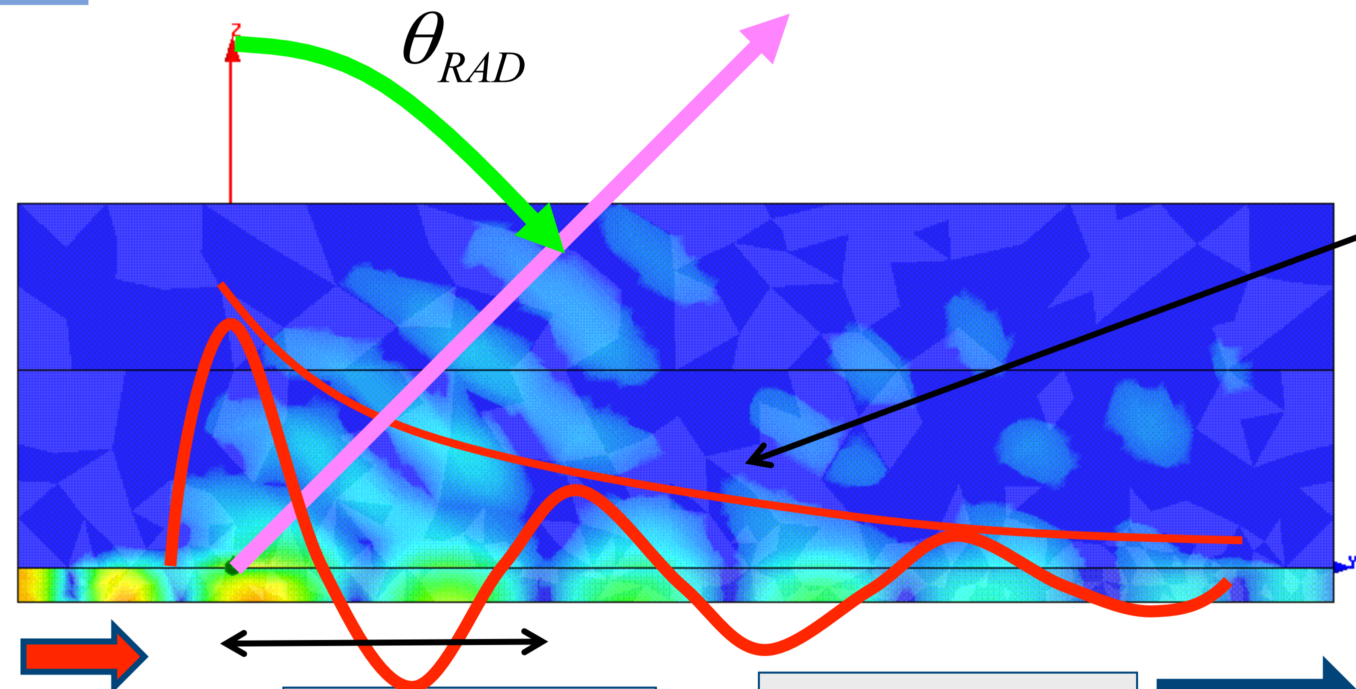
1- Modulated SIW antenna. Leaky Waves.

LEAKY-MODE COMPLEX PROPAGATION CONSTANT

$$\boldsymbol{k} = \beta - j\alpha$$

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.

SYNTHESIS PROCEDURE: relation with Microwave HOLOGRAPHY

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: $\Psi_{OUT} = \Psi_{LW}$

(surface-to-leaky transformation)

4- Holographic antenna modulated dimensions $P(z)$ $W(z)$

3- Modulated leaky wave $k(z) = \beta(z) - j\alpha(z)$

2- Radiating aperture fields $E_{RAD}^{APERT}(z) = M(z) \cdot e^{j\phi(z)}$

1- Objective radiation pattern $E_{RAD}(\theta)$

1- Modulated SIW antenna.

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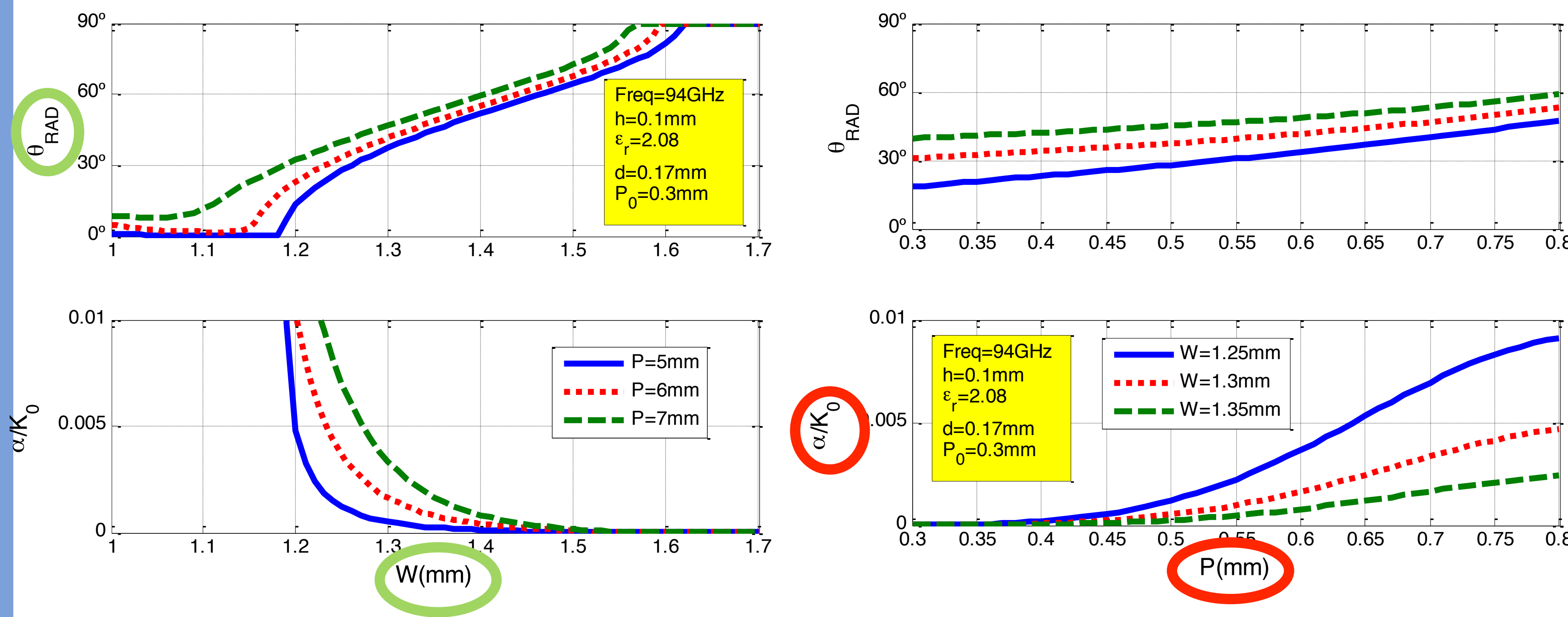
LEAKY-MODE COMPLEX PROPAGATION CONSTANT DISPERSION CURVES

APPROXIMATION OF LOCAL PERIODICITY AND SMOOTH VARIATIONS

Two design parameters to freely control θ_{RAD} and α/k_0 ($\Delta\theta$)



1- Modulated SIW antenna.

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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

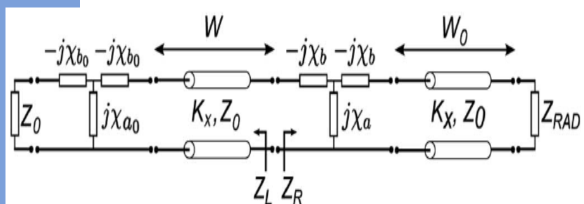
496 IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 12, 2013

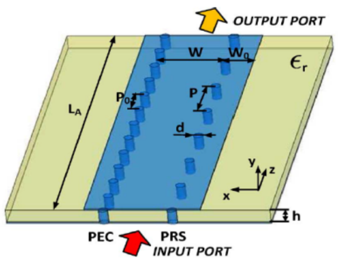
Efficient Analysis and Design of Novel SIW Leaky-Wave Antenna

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

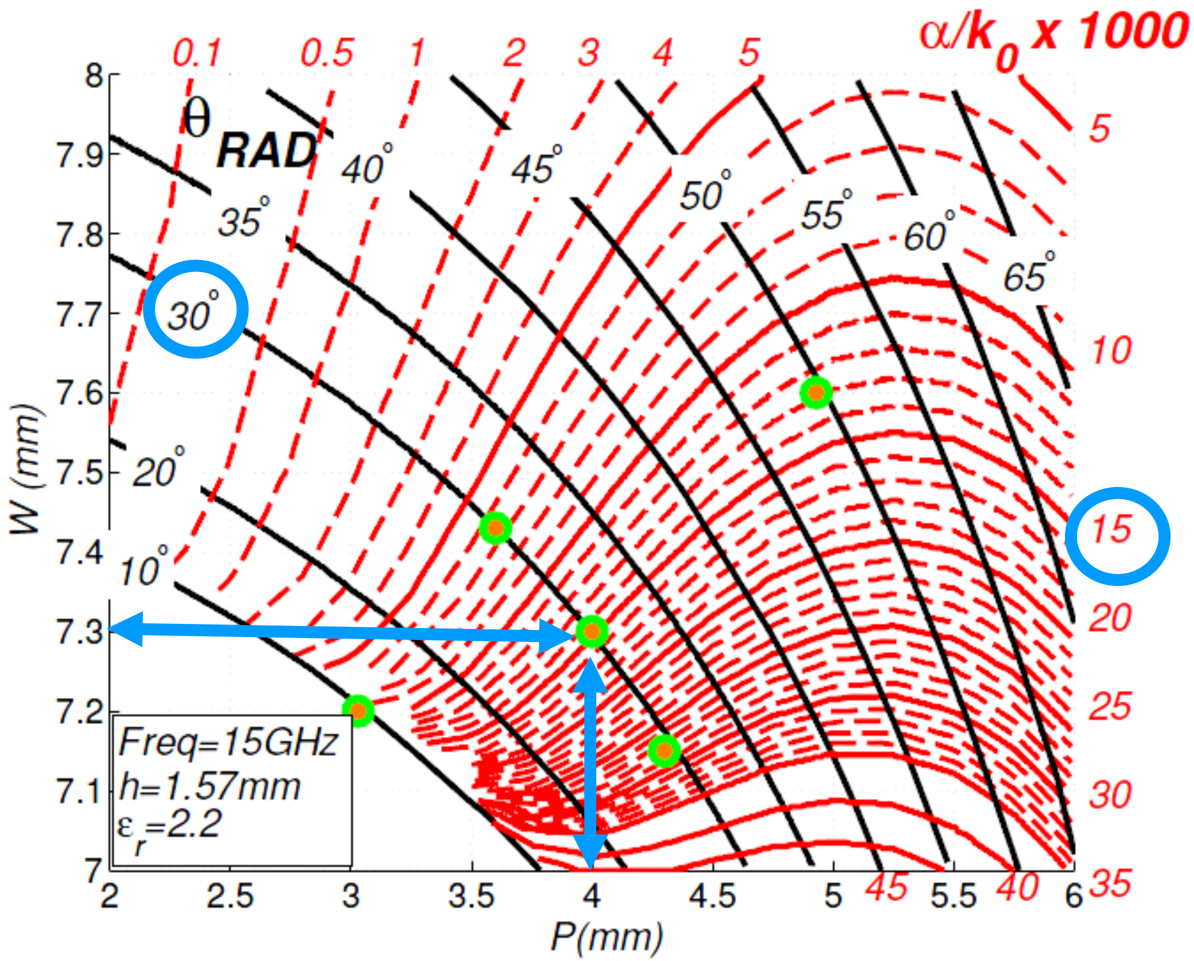
WIPE COST IC1301

Efficient Analysis with Transverse Equivalent Network





Geometry design chart "look-up table"



Modulated leaky wave

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

Holographic antenna modulated dimensions

P(z) *W(z)*

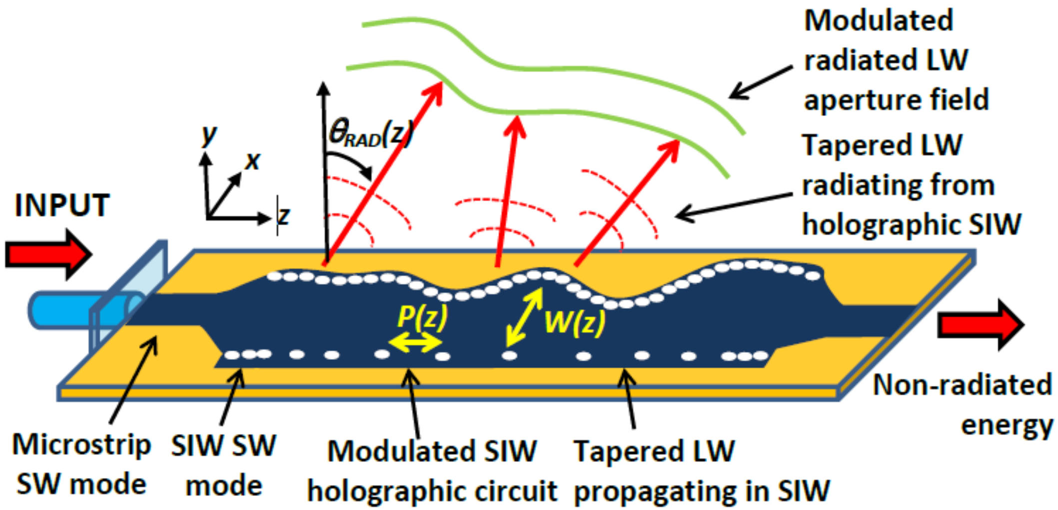
1- Modulated SIW antenna.

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

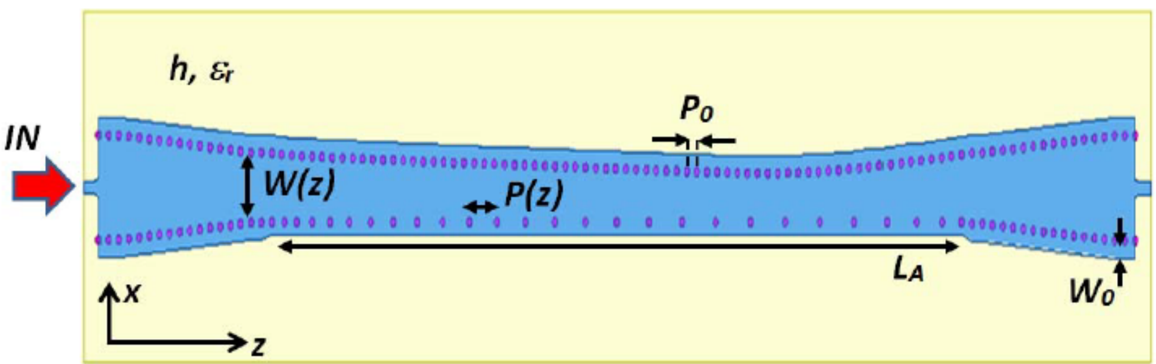
Scheme of holographic antenna in SIW technology:

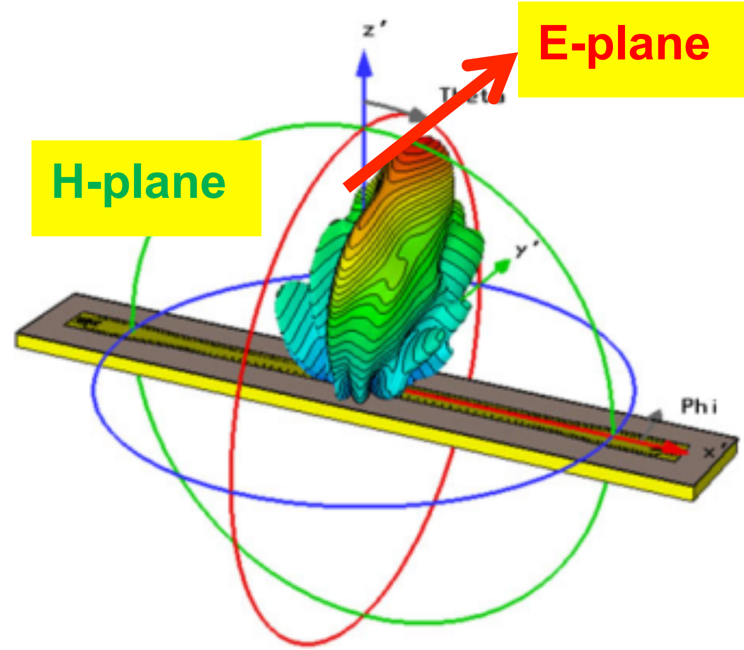
Holographic Pattern Synthesis With Modulated Substrate Integrated Waveguide Line-Source Leaky-Wave Antennas

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



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*

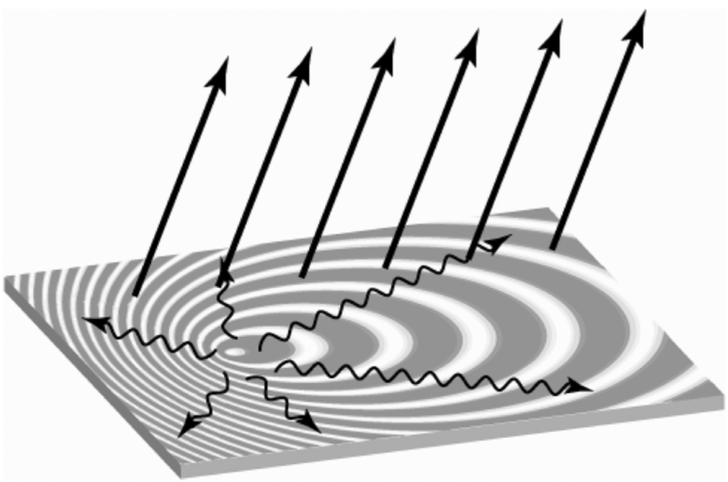
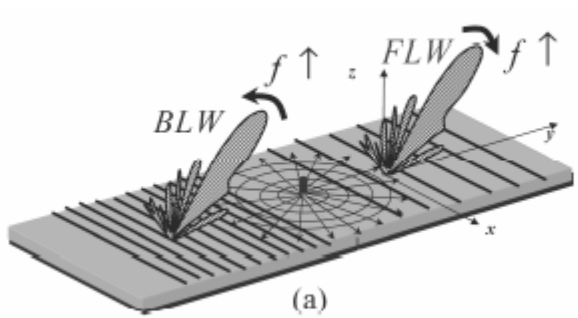


Fig. 1. Holographic leaky wave antenna concept. Surface waves (undulating arrows) are excited on an artificial impedance surface, and are scattered by variations in the surface impedance to produce the desired radiation (straight arrows).

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[(*)]

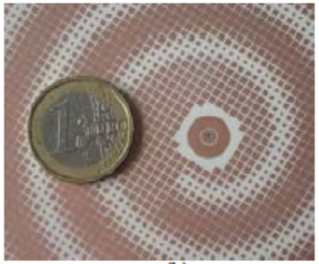
1- Modulated SIW antenna.

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

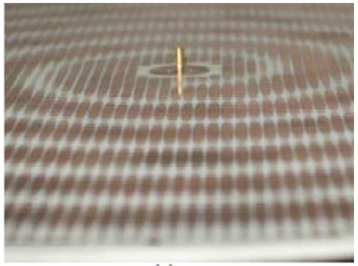
IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 10, 2011 1499

Metasurfing: Addressing Waves on Impenetrable Metasurfaces

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



(b)

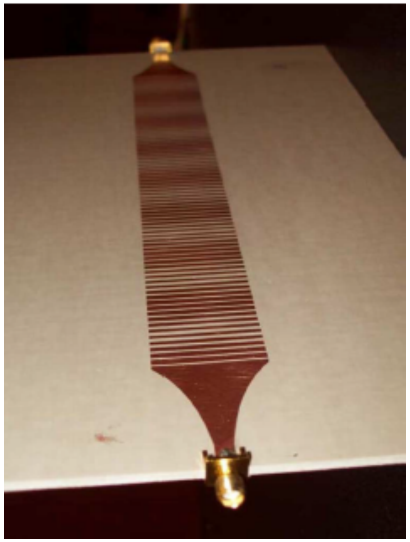


(c)

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.

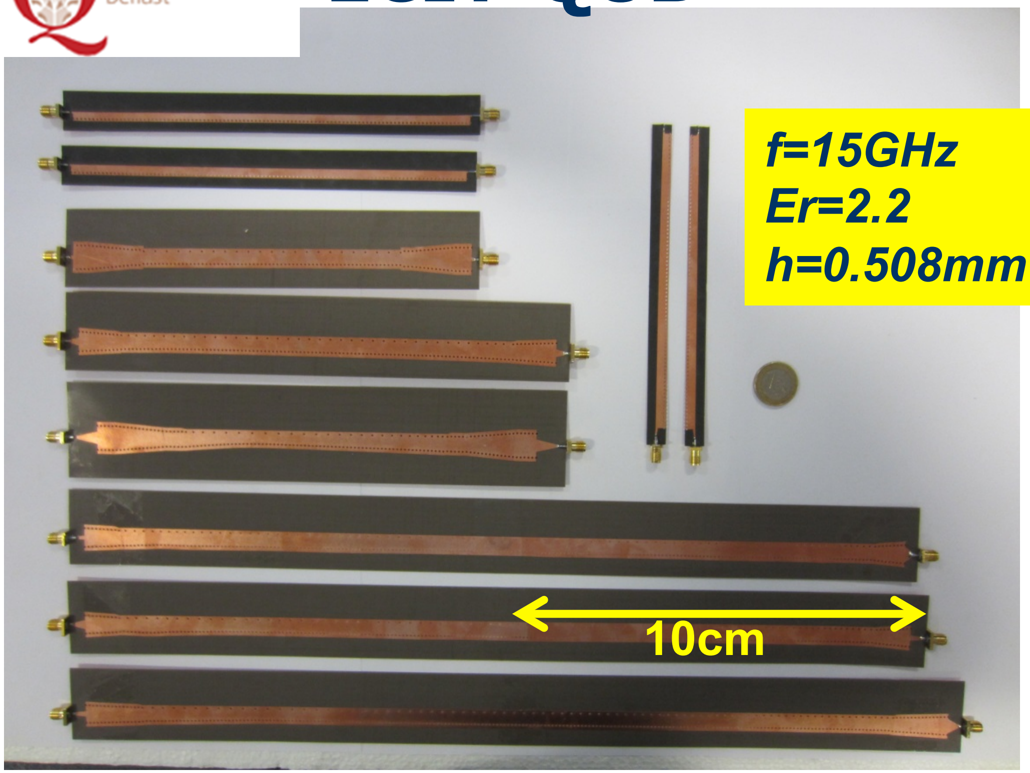
3- Conclusions.

2- Manufactured prototypes.

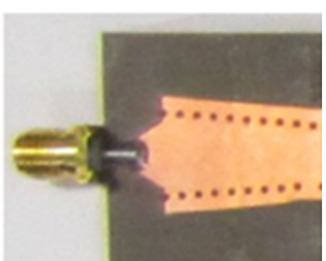
Manufactured prototypes @15GHz:

Queen's University Belfast

ECIT-QUB

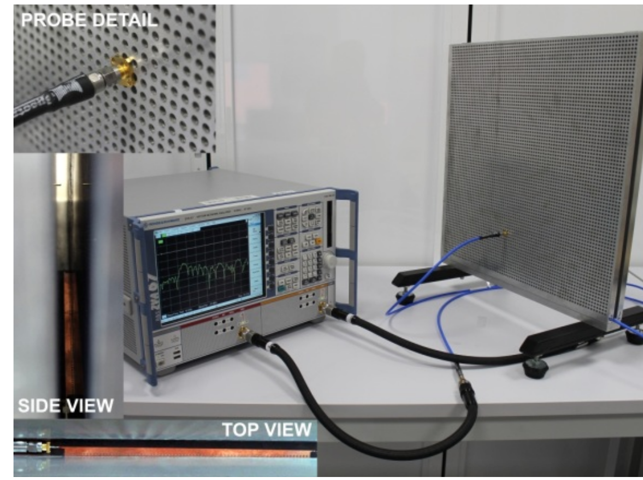


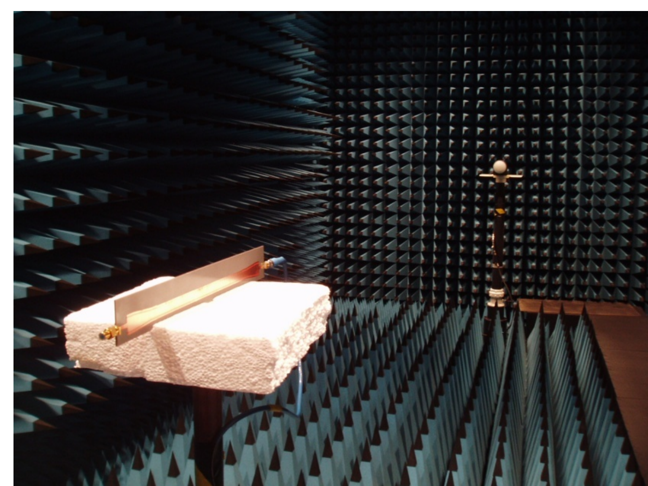
f=15GHz
Er=2.2
h=0.508mm



SMA-microstrip-SIW transition

Near and far field measurement set-up:



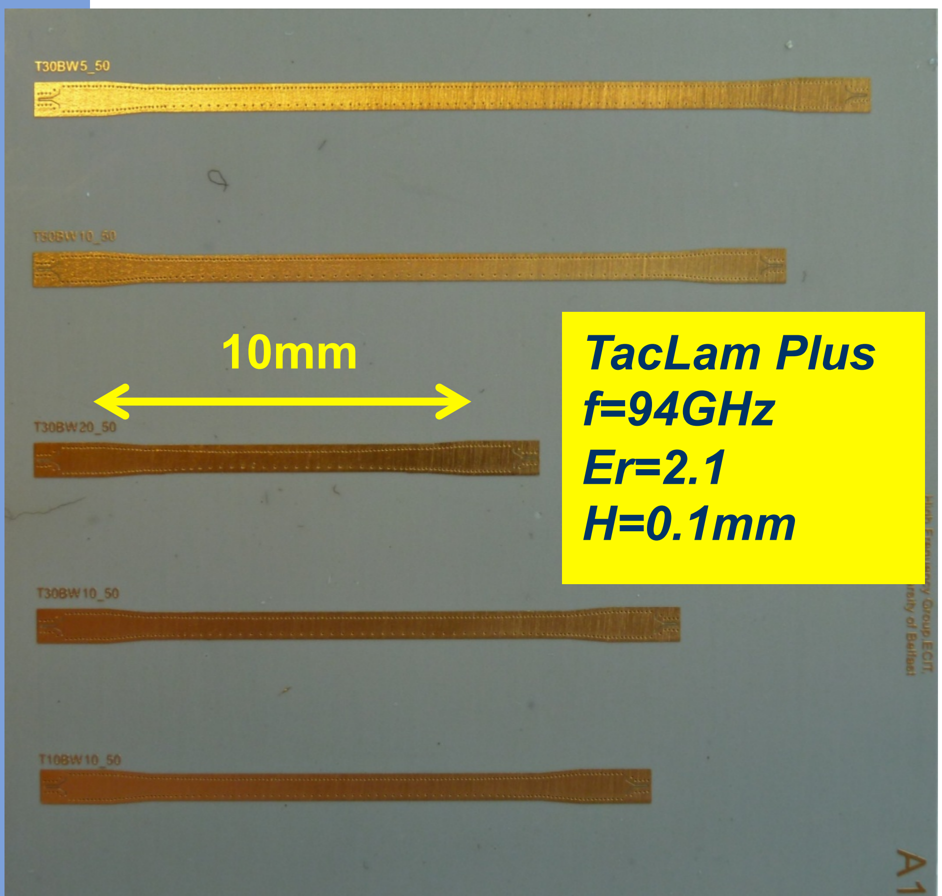


2- Manufactured prototypes.

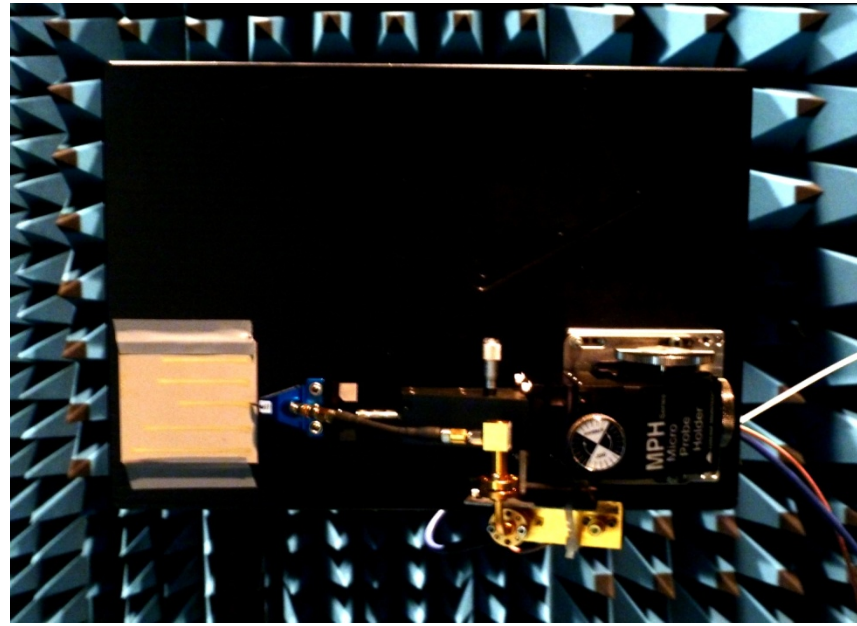
Queen's University Belfast

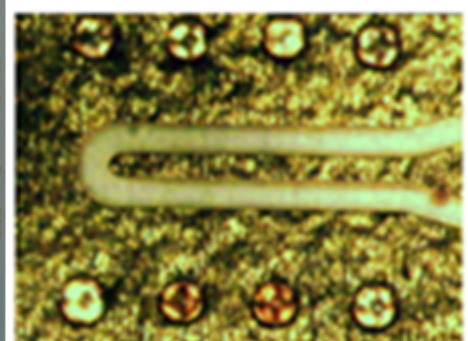
ECIT-QUB

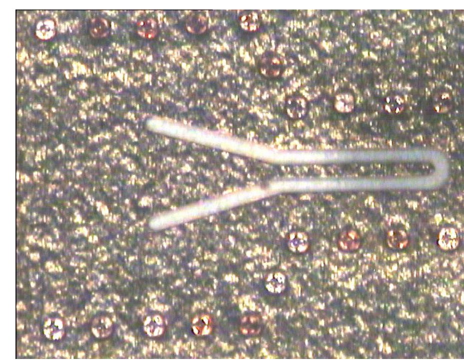
Manufactured prototypes @ 95GHz:



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.

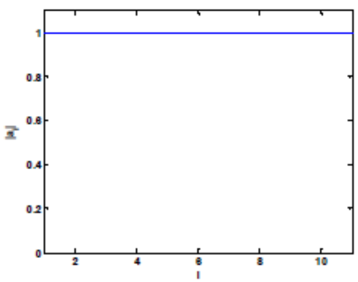
2.5- Conformal antennas.

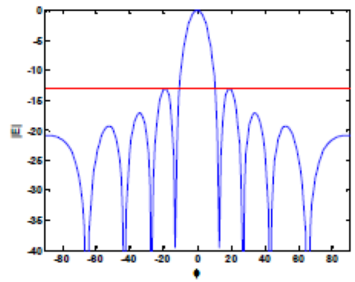
3- Conclusions.

2.1- Scanning Antenna with Reduced SLL.

Aperture Distribution (Taper) Function and Far Field

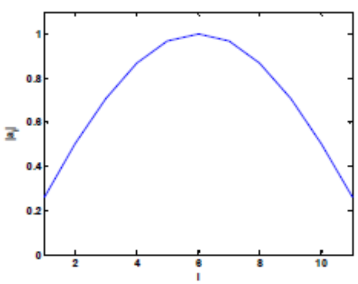
- Uniform

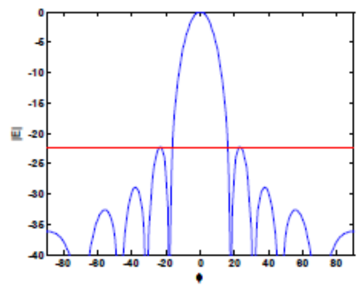




$$\mathrm{SLL} \approx -13\,\mathrm{dB}$$
$$\Delta\phi_{3\mathrm{dB}} \approx 11.6^\circ$$
$$\eta_{\mathrm{Taper}} = 100\%$$

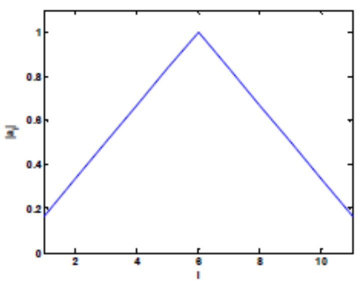
- Cosine

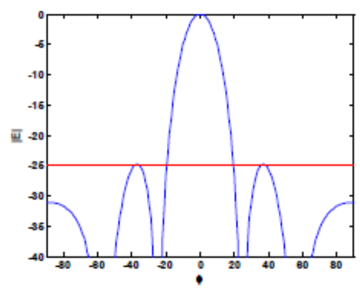




$$\mathrm{SLL} \approx -23\,\mathrm{dB}$$
$$\Delta\phi_{3\mathrm{dB}} \approx 14.3^\circ$$
$$\eta_{\mathrm{Taper}} = 81\%$$

- Triangular





$$\mathrm{SLL} \approx -25\,\mathrm{dB}$$
$$\Delta\phi_{3\mathrm{dB}} \approx 15.3^\circ$$
$$\eta_{\mathrm{Taper}} = 50\%$$

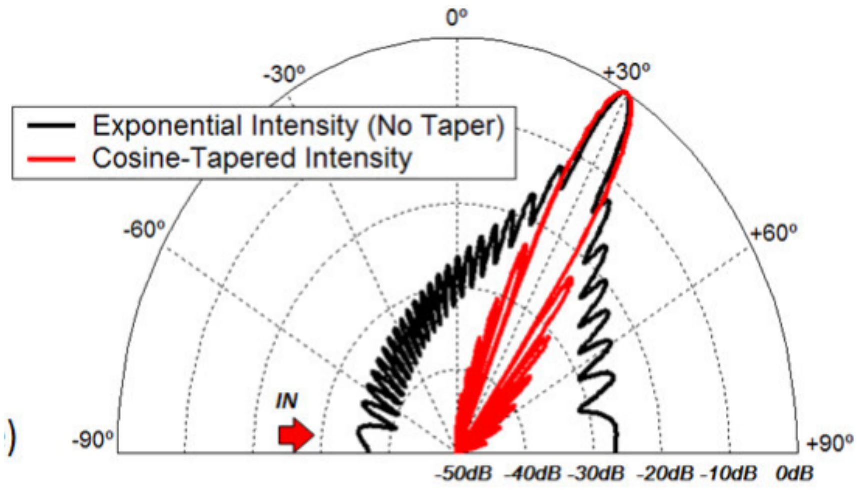
Array Geometry

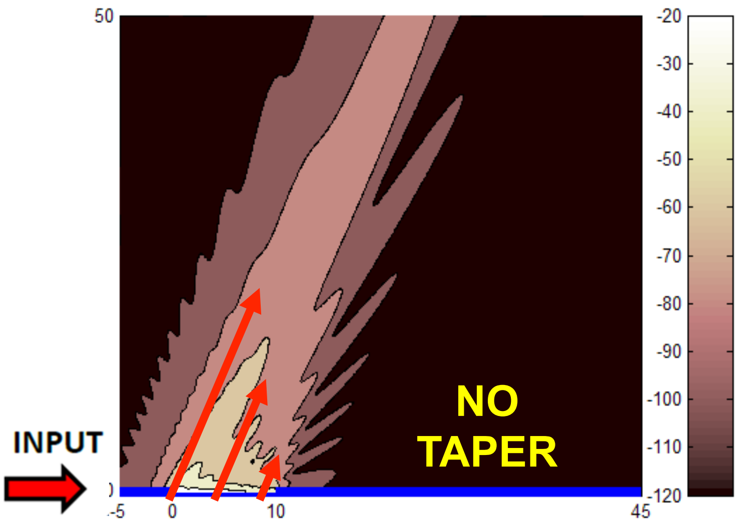
N = 11

d = 0.4 λ

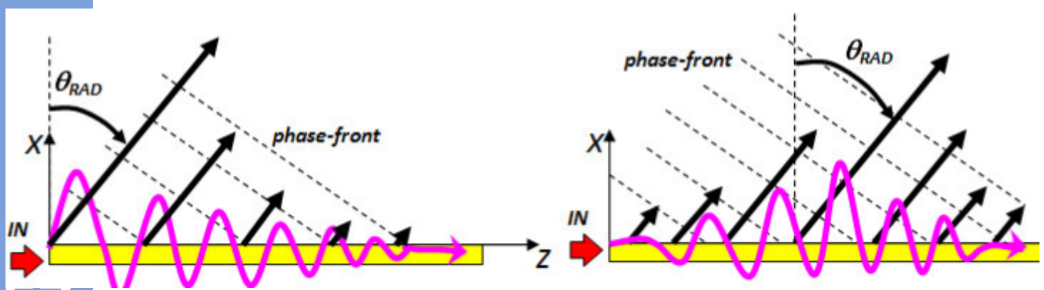
2.1- Scanning Antenna with Reduced SLL.

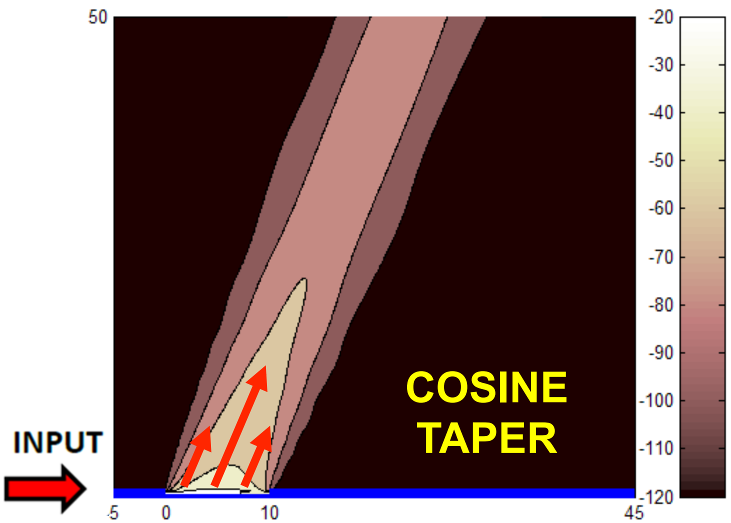
Objective:





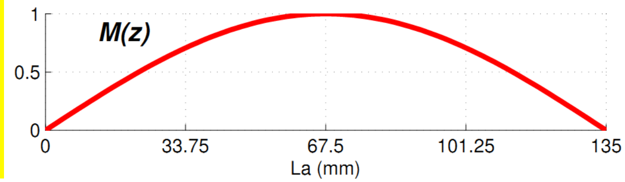
Scanned antenna with reduction of SLL



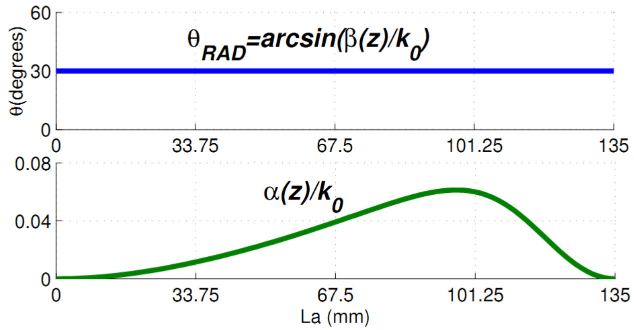


2.1- Scanning Antenna with Reduced SLL.

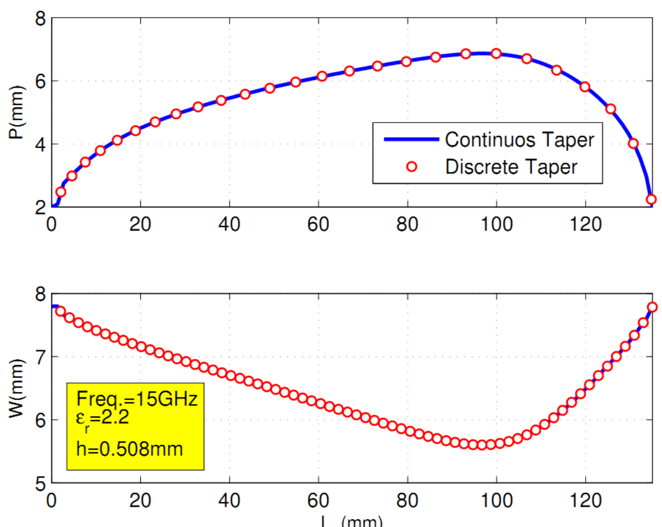
- Modulation of aperture fields and leaky wave:

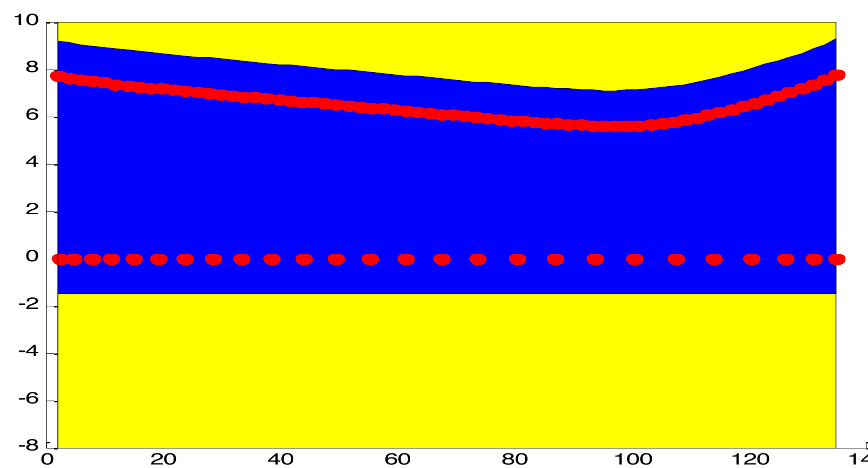


(a)



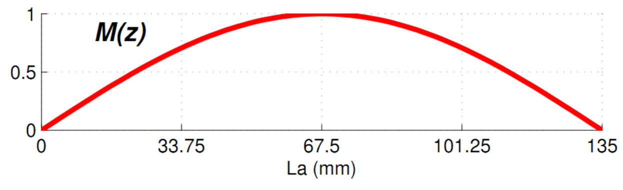
- Modulation of holographic antenna dimensions



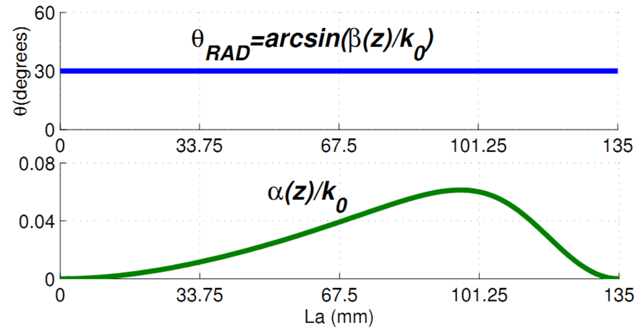


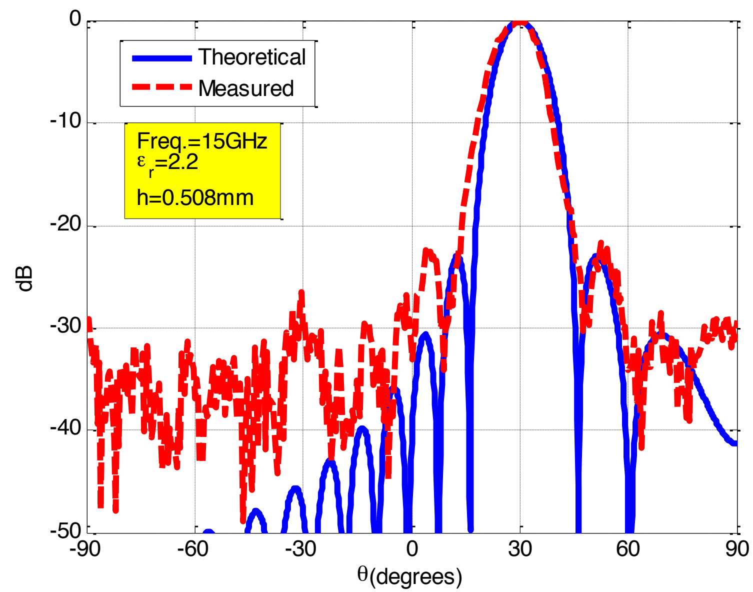
2.1- Scanning Antenna with Reduced SLL.

- Modulation of aperture fields and leaky wave:

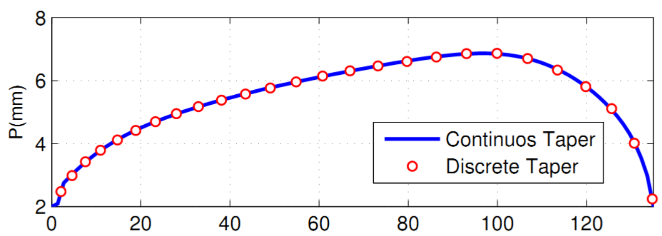


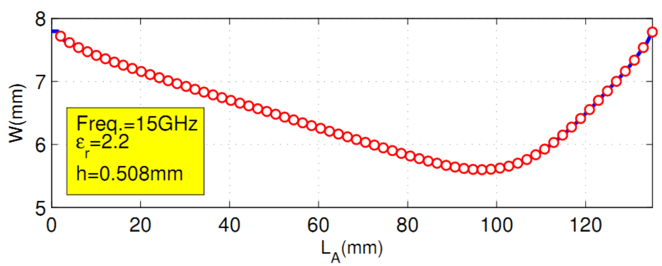
(a)

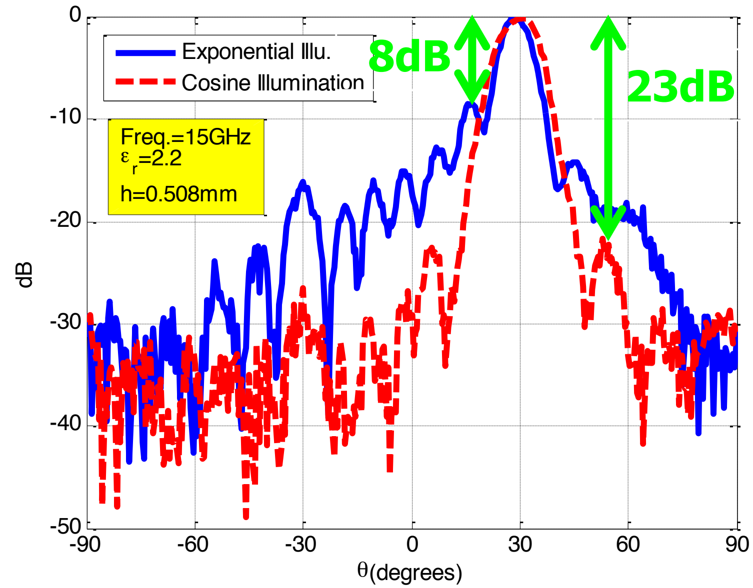




- Modulation of holographic antenna dimensions

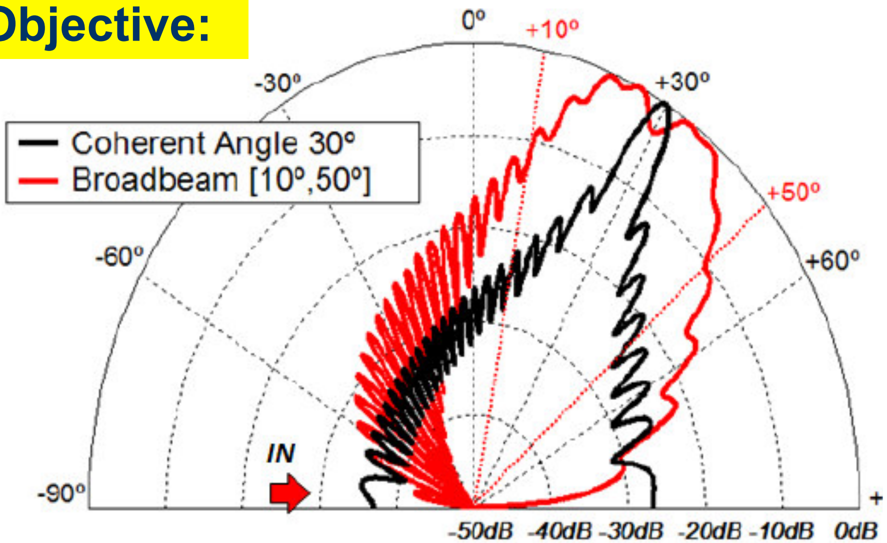


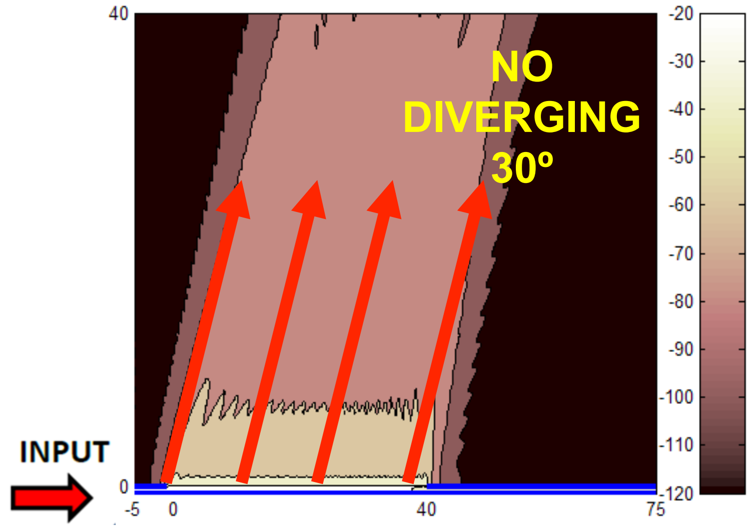




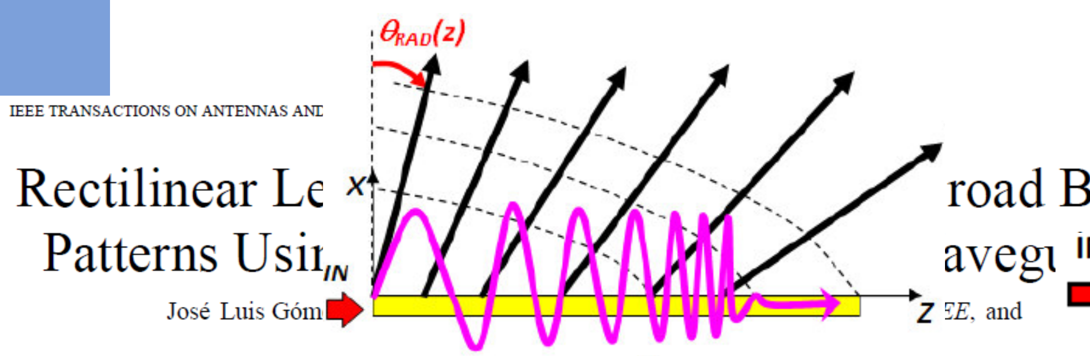
2.2- Shaped beam.

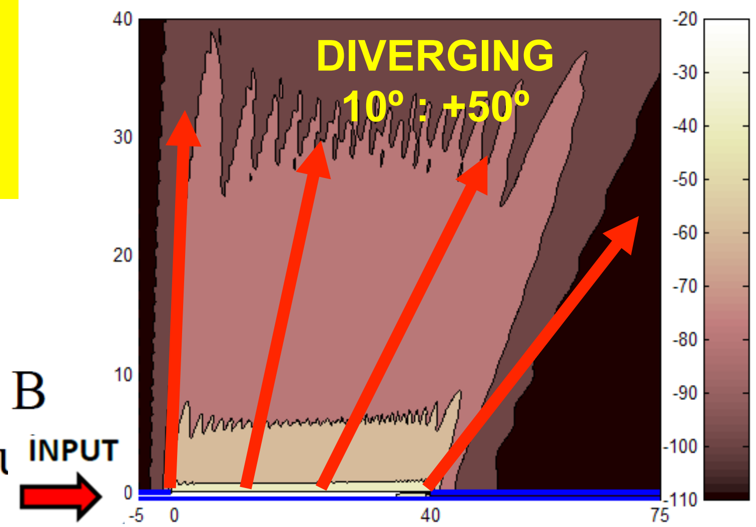
Objective:





Scanned broadbeam with high rejection out from the prescribed angular region





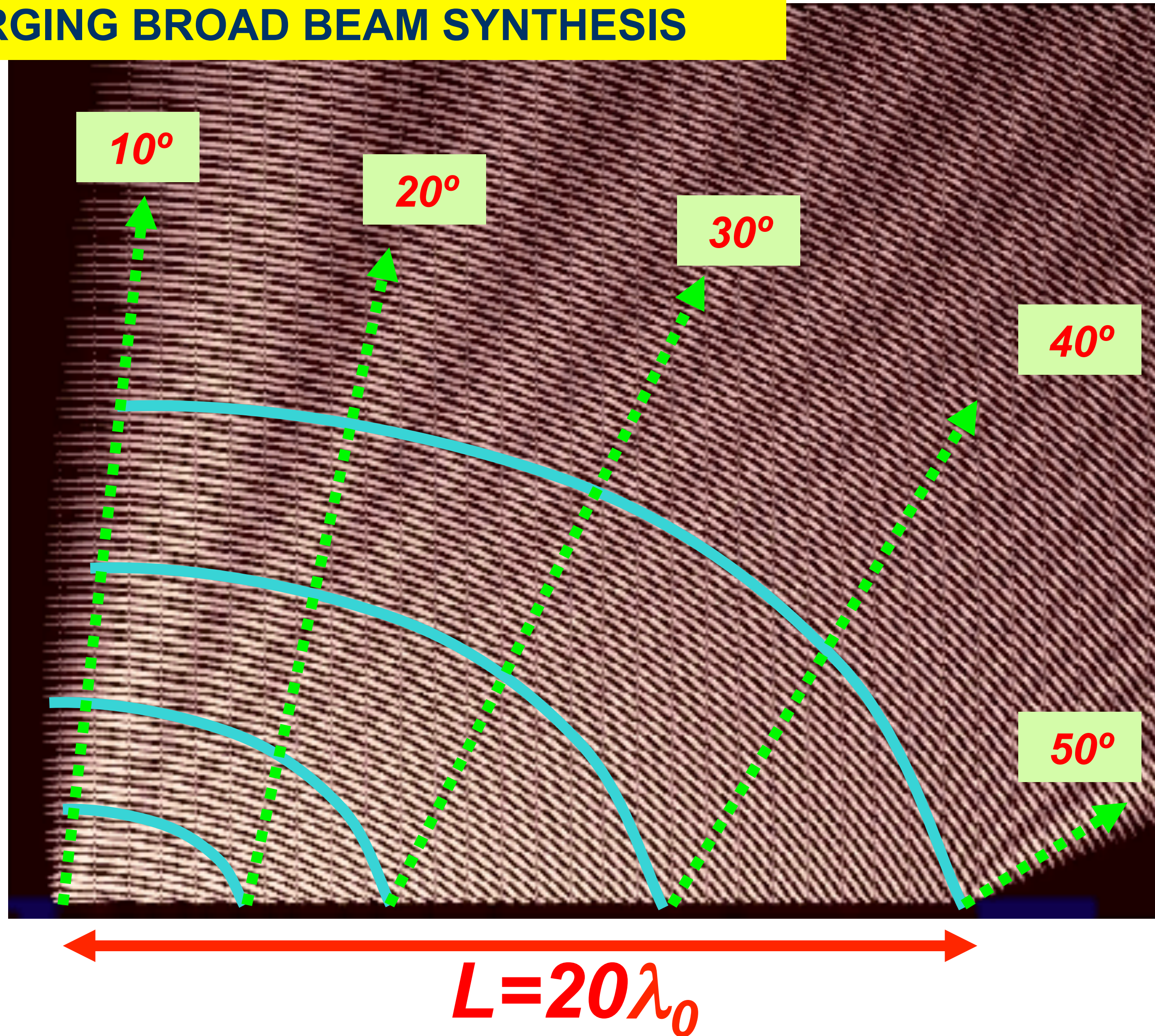
2.2- Shaped beam.

Holographic modulation OF POINTING FOR DIVERGING BROAD BEAM SYNTHESIS

Diverging phase front

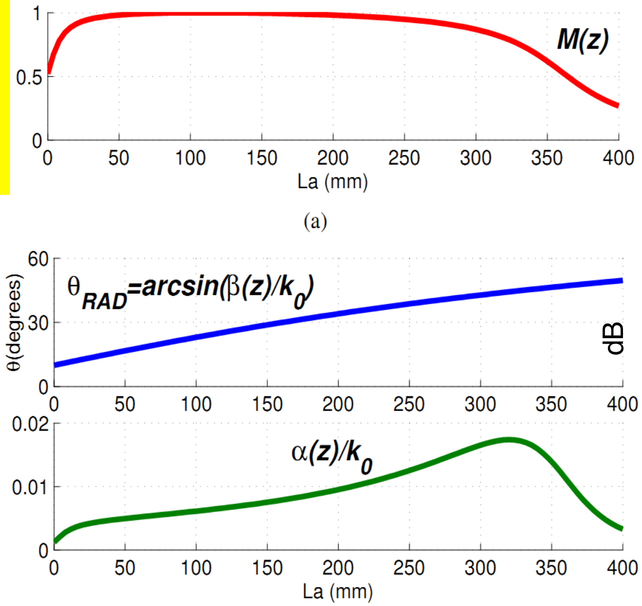
Local Modulation of equivalent radiation angle

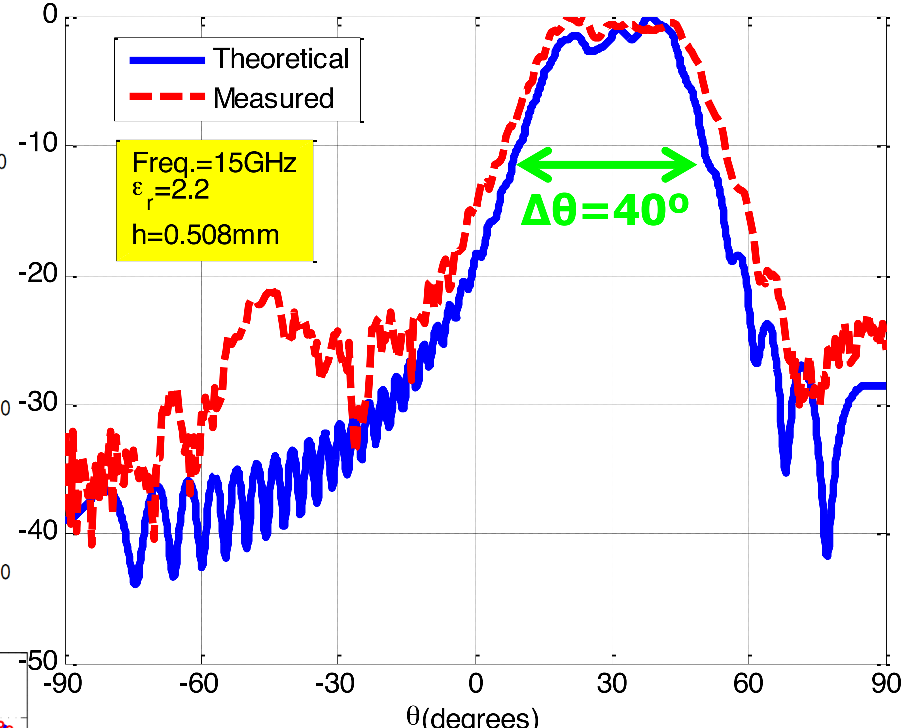
INPUT



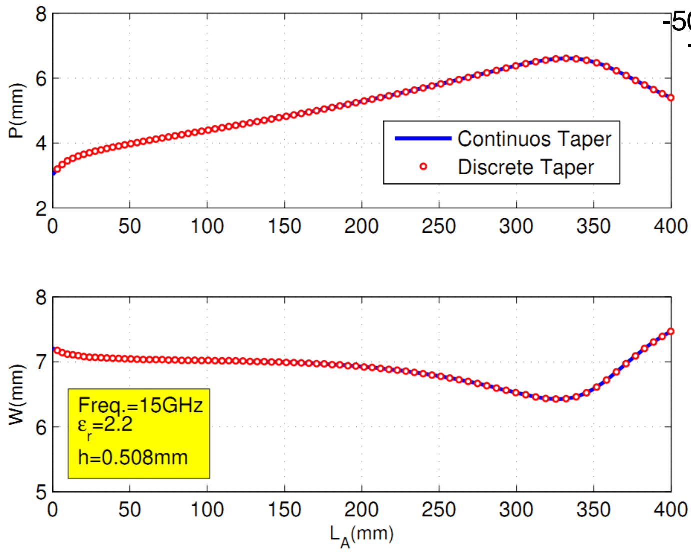
2.2- Shaped beam.

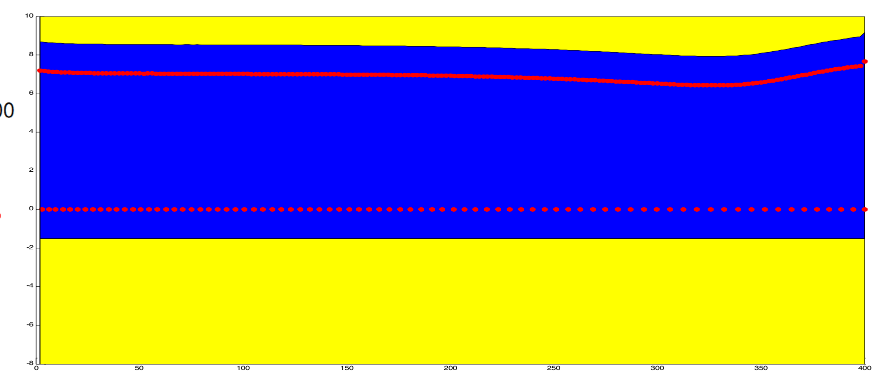
- Modulation of aperture fields and leaky wave:





- Modulation of holographic antenna dimensions

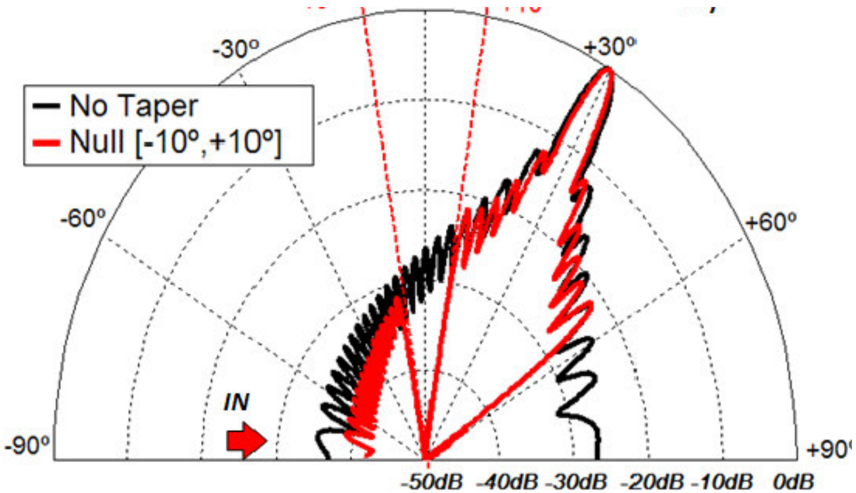


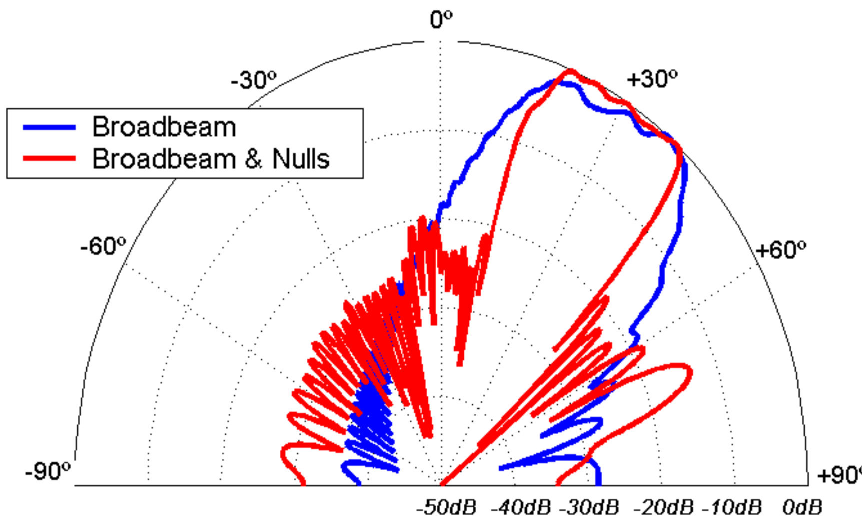


2.3- Synthesis of radiation nulls.

WIPE COST IC1301

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

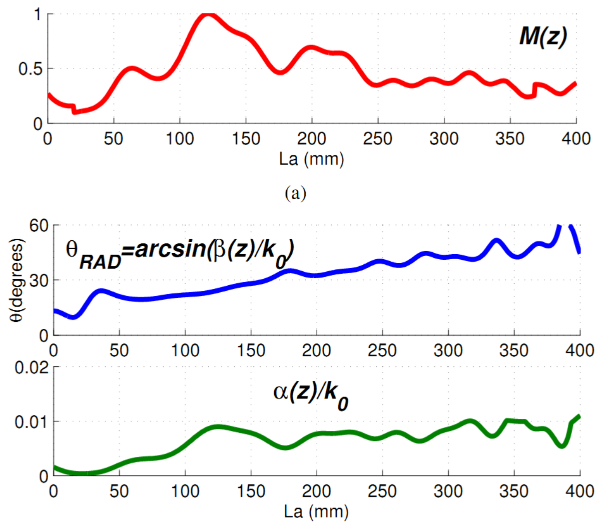
518 IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 9, 2010

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

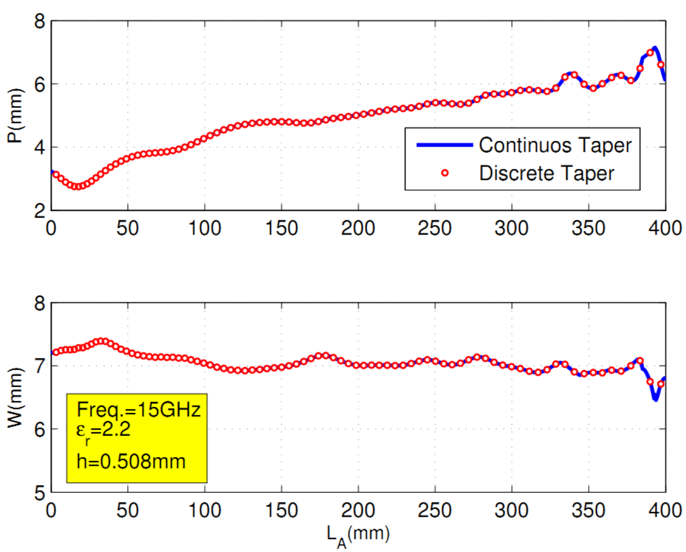
José Luis Gómez-Tornero, *Member, IEEE*, Alejandro Javier Martínez-Ros, and Rafael Verdú-Monedero

2.3- Synthesis of radiation nulls.

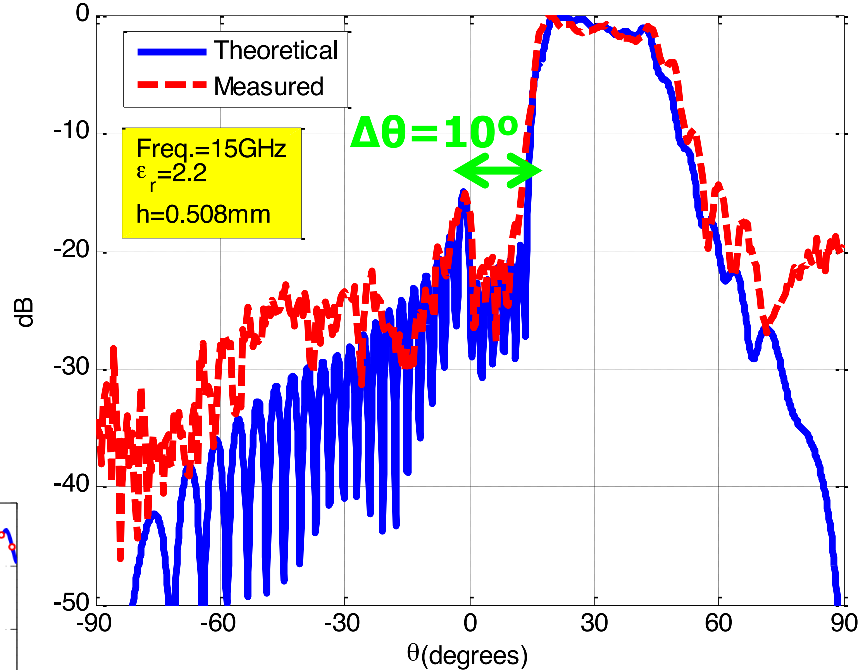
- Modulation of aperture fields and leaky wave:

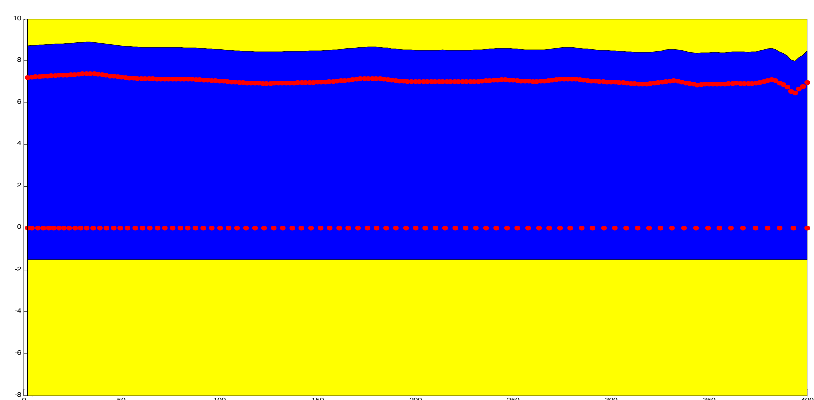


- Modulation of holographic antenna dimensions



Broadbeam & One Null

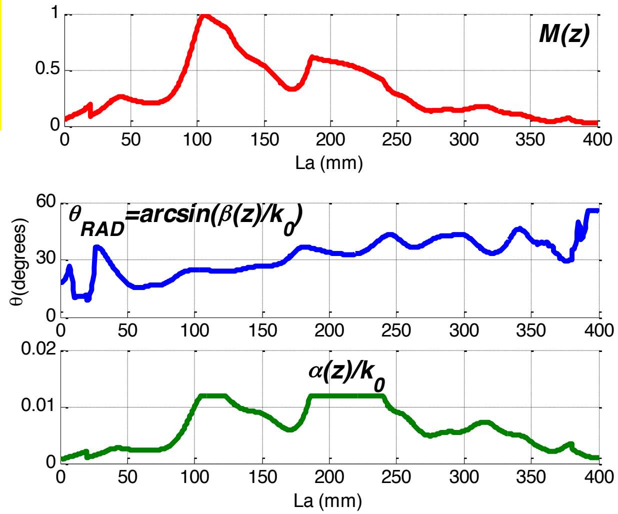




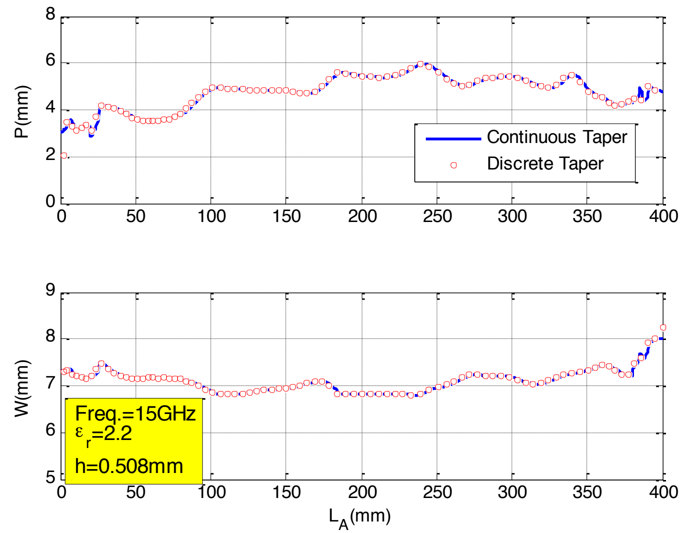
2.3- Synthesis of radiation nulls.

WIPE COST IC1301

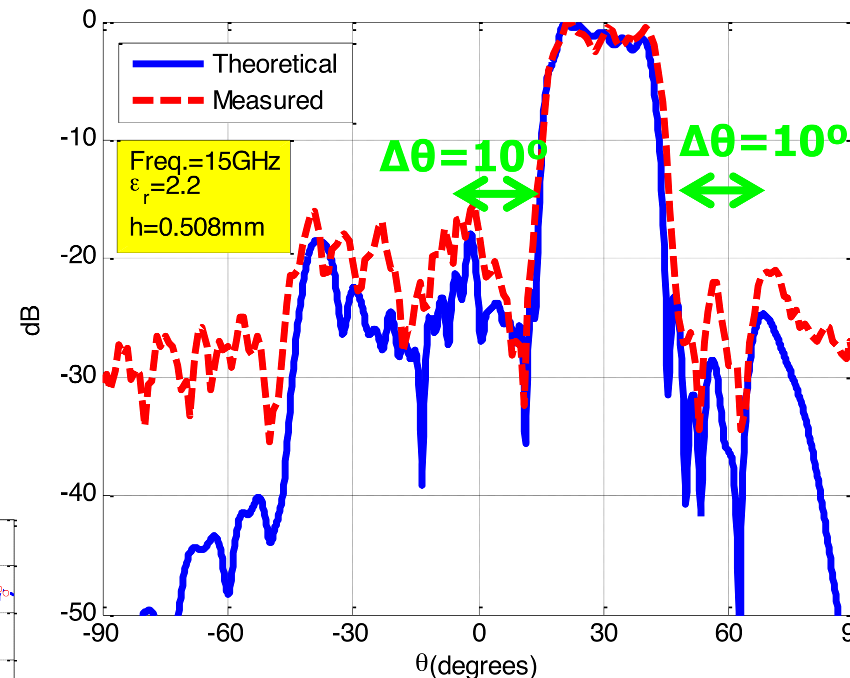
- Modulation of aperture fields and leaky wave:

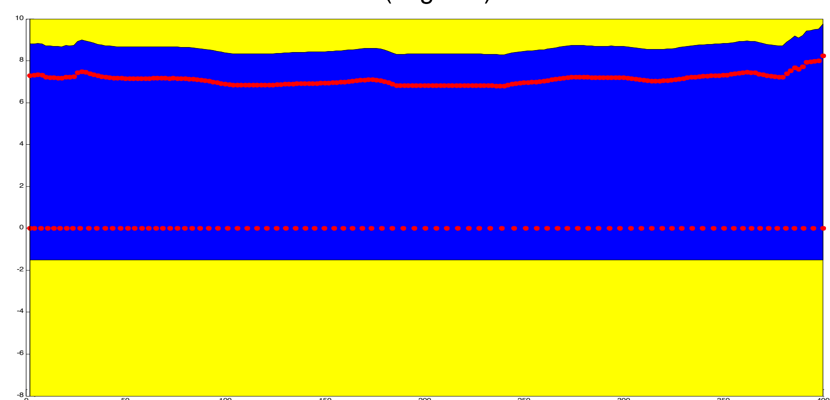


- Modulation of holographic antenna dimensions



Broadbeam & Two Nulls

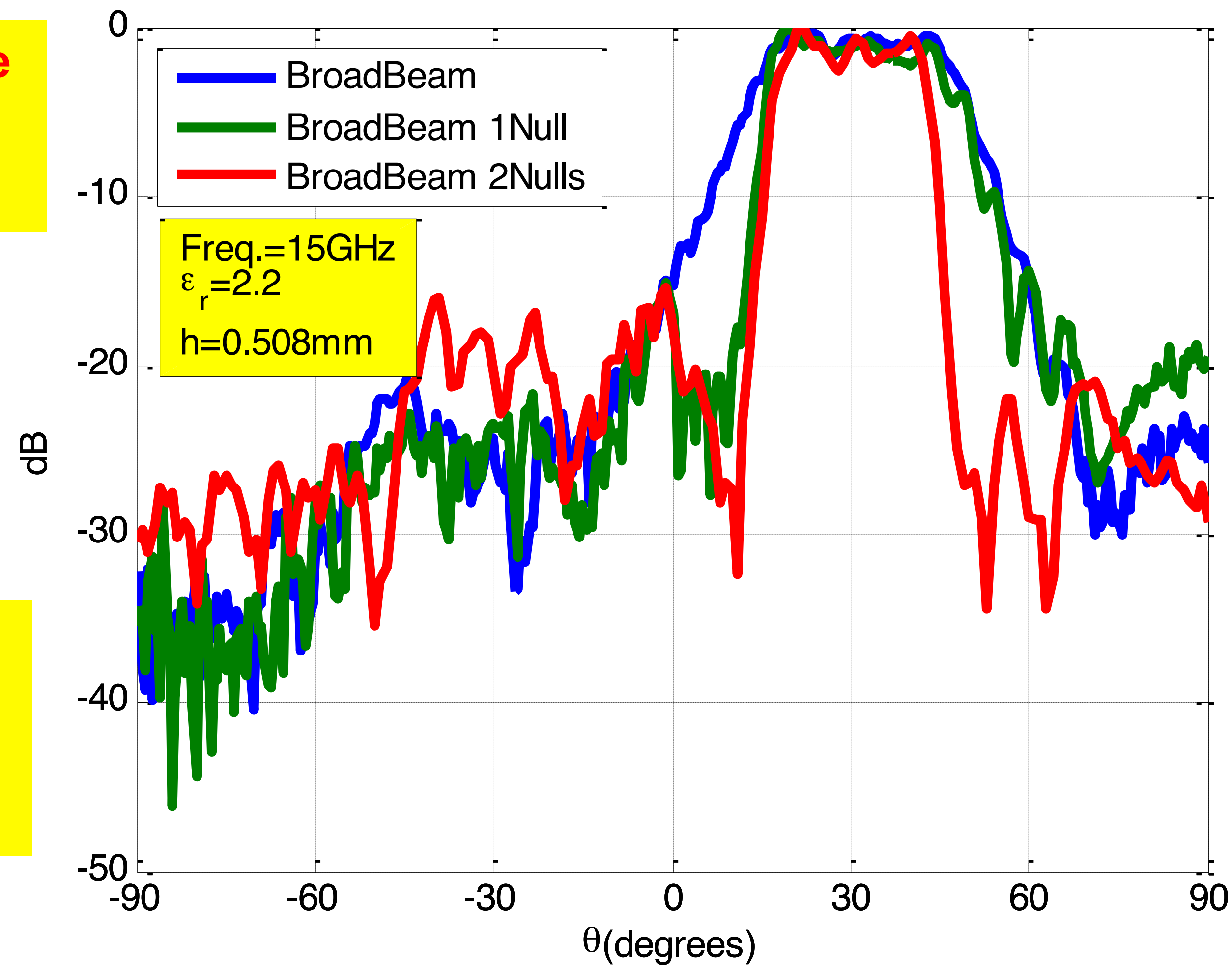




2.3- Synthesis of radiation nulls.

Holographic design of selective elliptic angular filters

From Chebyshev-type to Elliptic-type angular responses

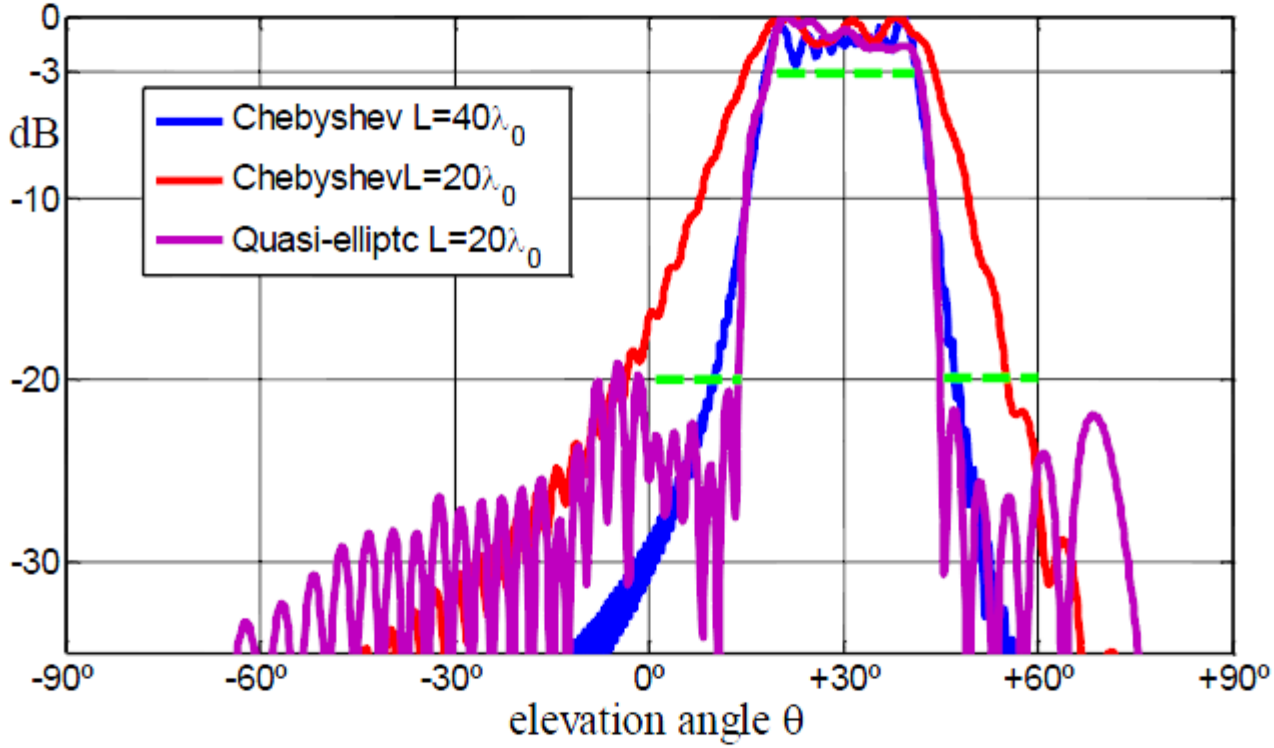


Measured Increase in the spatial filtering rejection (roll-off)

2.3- Synthesis of radiation nulls.

Holographic design of selective elliptic angular filters

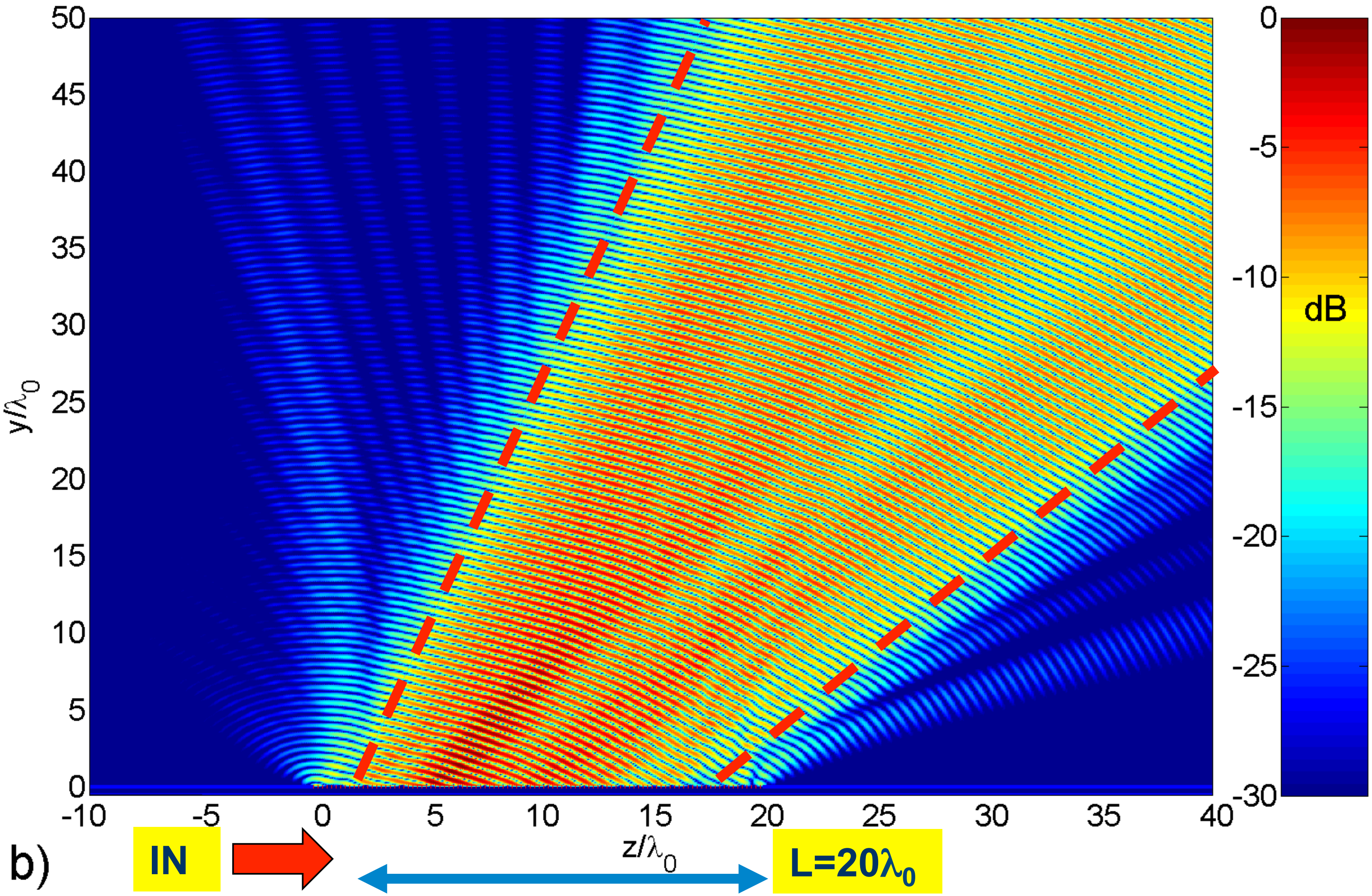
From Chebyshev-type to Elliptic-type angular responses



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

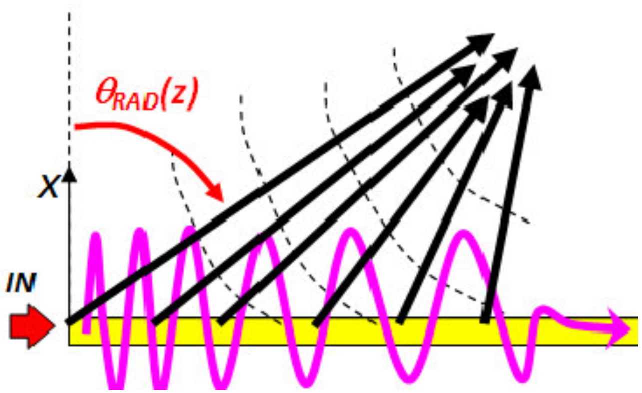
2.3- Synthesis of radiation nulls.

Holographic design of ultra selective ANGULAR BANDPASS filters



2.4- Near-field focusing synthesis.

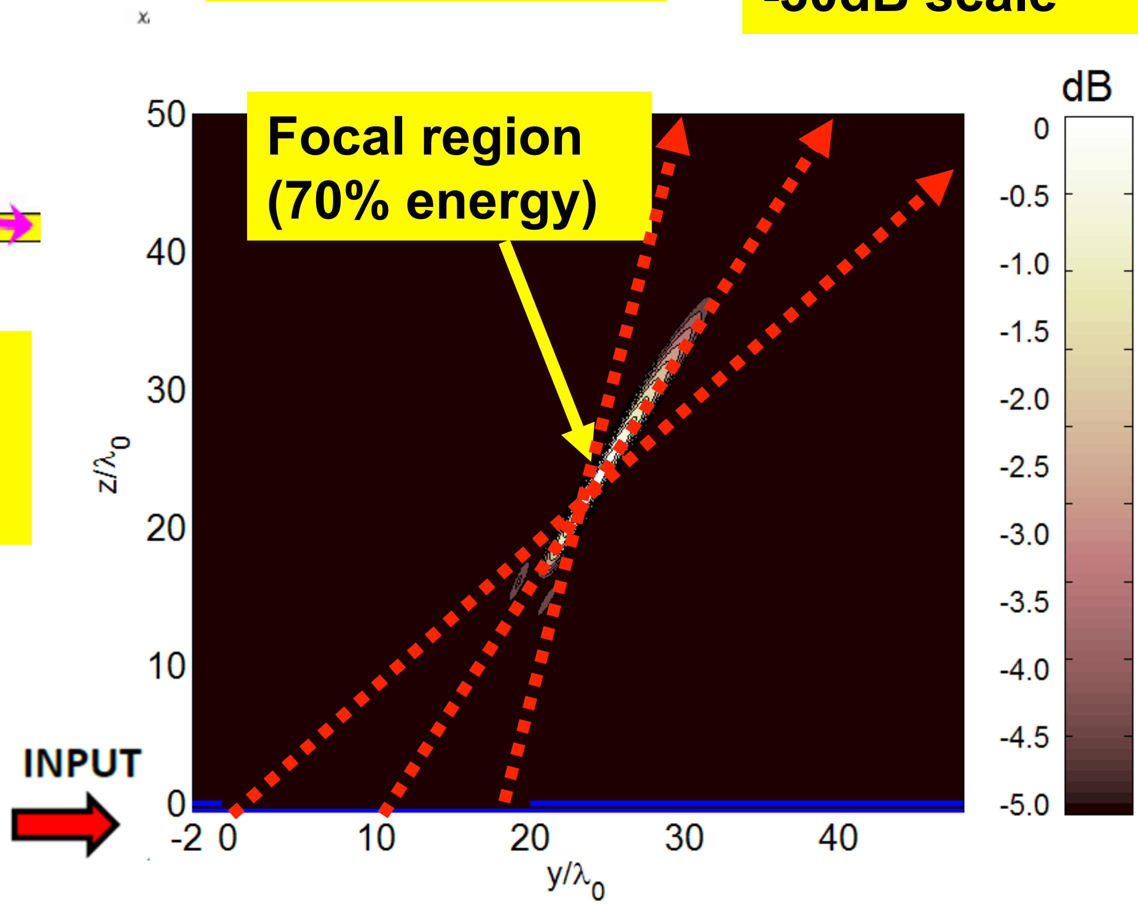
Objective:



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

Power focusing pattern with -5dB scale.

Converging / Diverging pattern with -30dB scale



Prof. Paolo Nepa

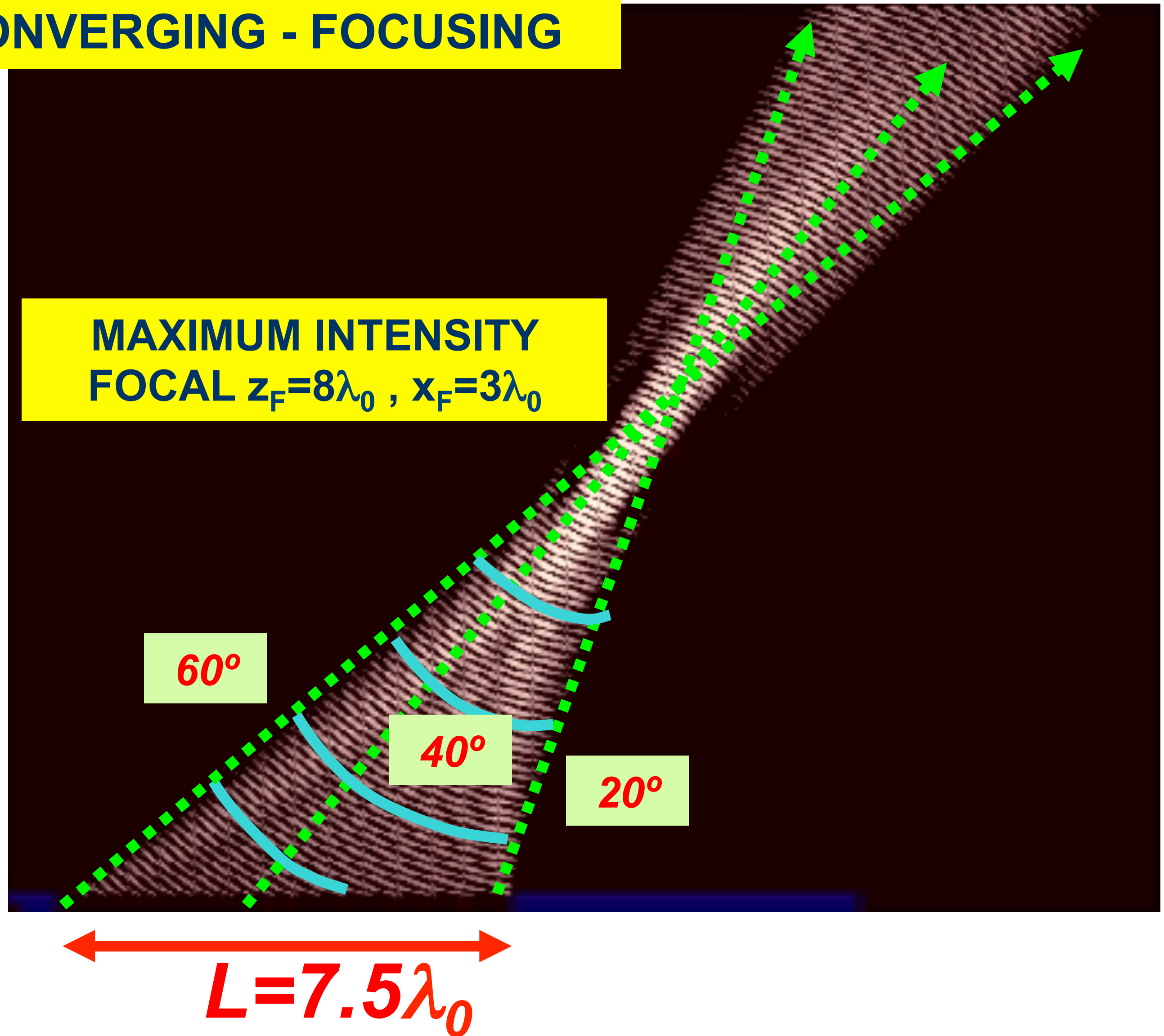
2.4- Near-field focusing synthesis.

Holographic Modulation OF POINTING FOR CONVERGING - FOCUSING

Converging phase front

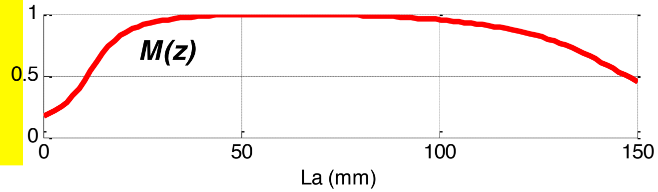
Local modulation of equivalent radiation angle

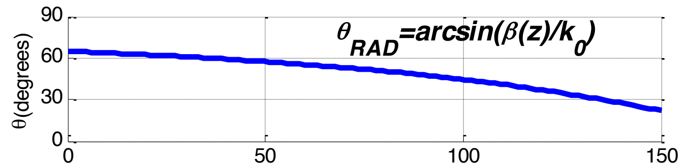
INPUT

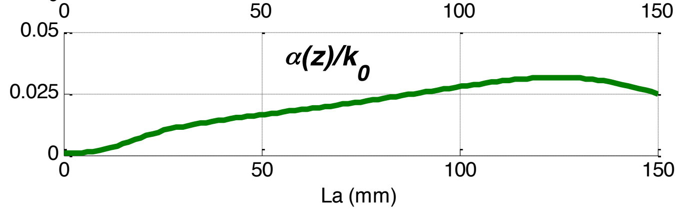


2.4- Near-field focusing synthesis.

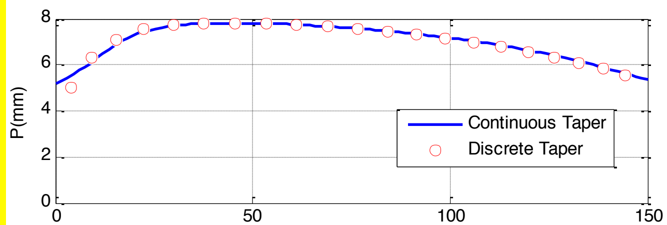
- Modulation of aperture fields and leaky wave:

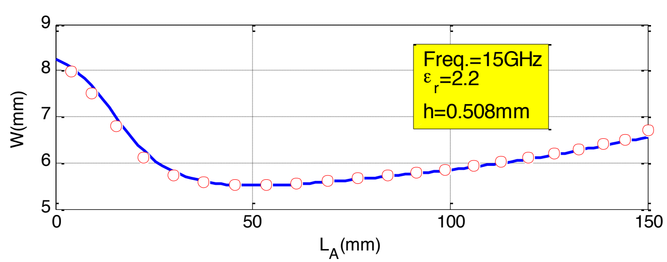




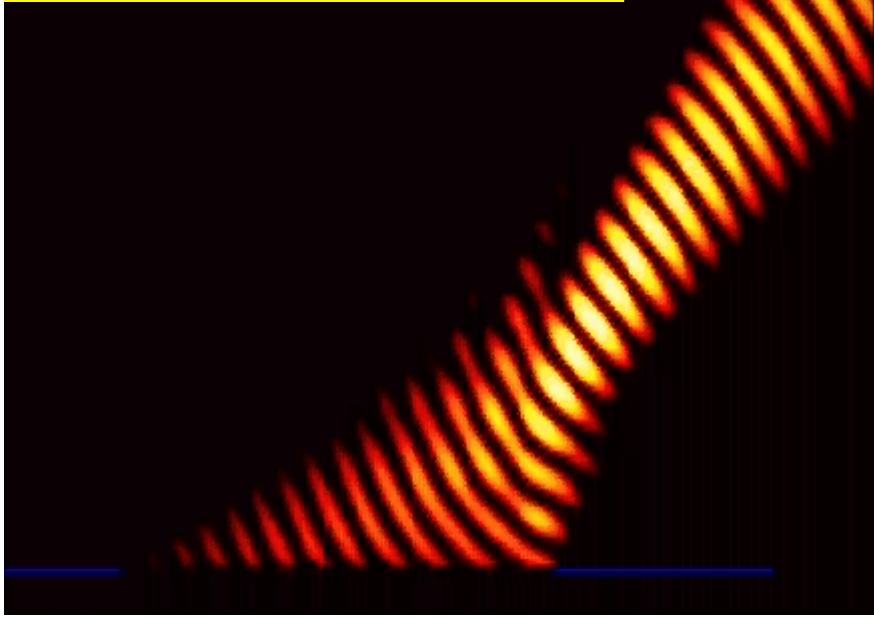


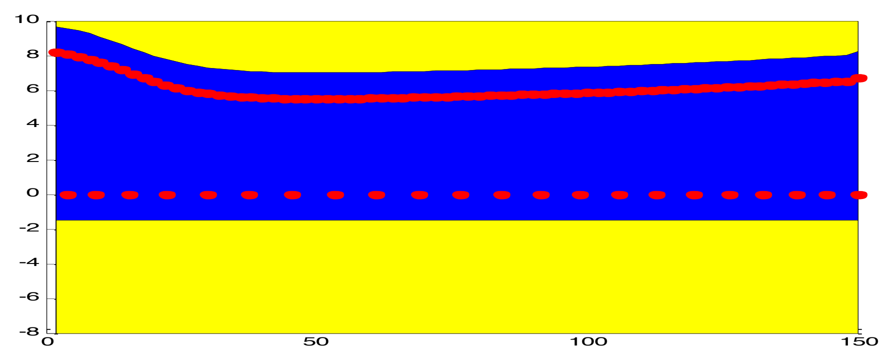
- Modulation of holographic antenna dimensions





Objective near fields



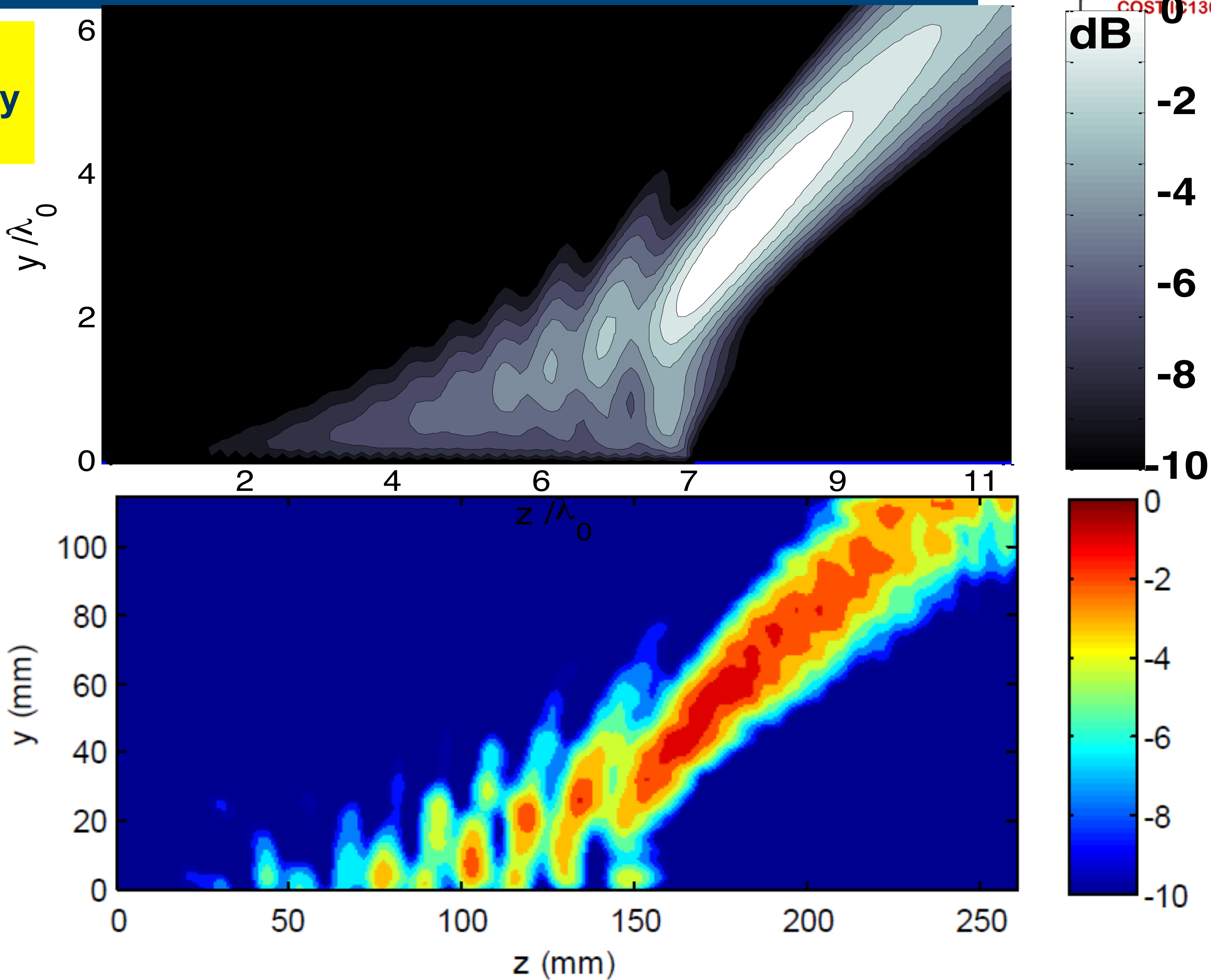


2.4- Near-field focusing synthesis.

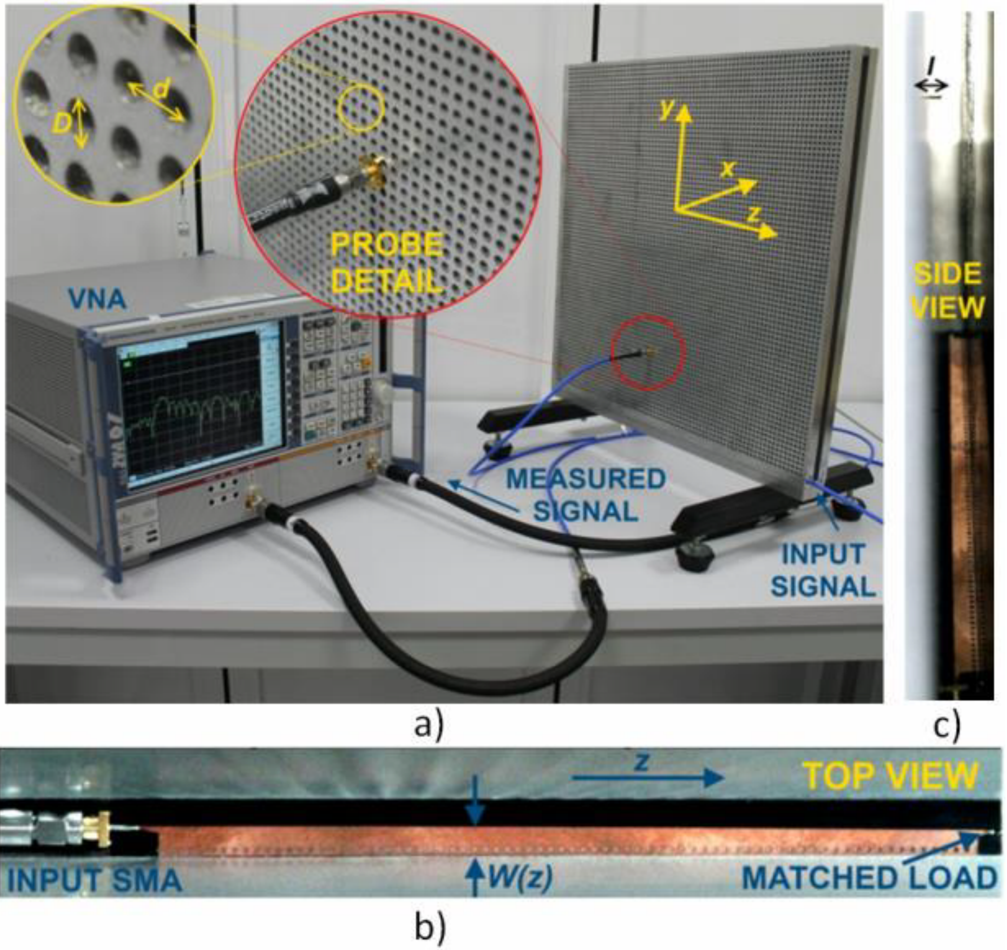
Holographic design of leaky lenses

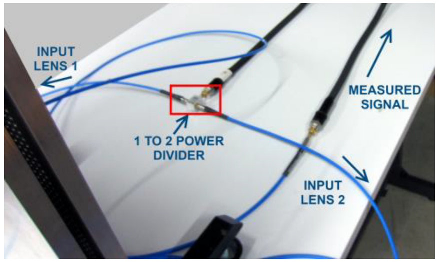
Objective near fields

Measured near fields

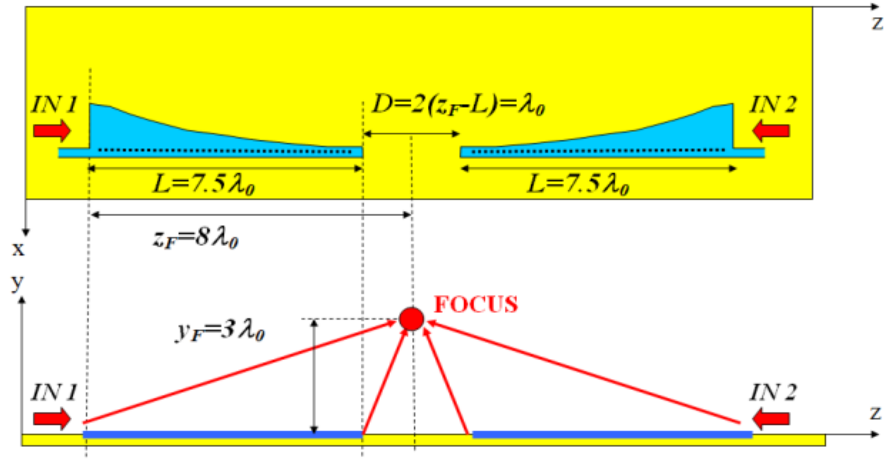


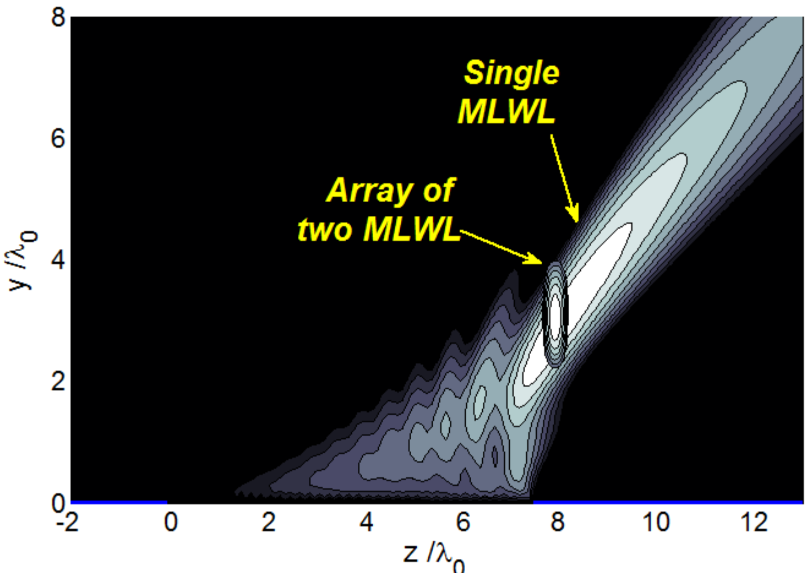
2.4- Near-field focusing synthesis.





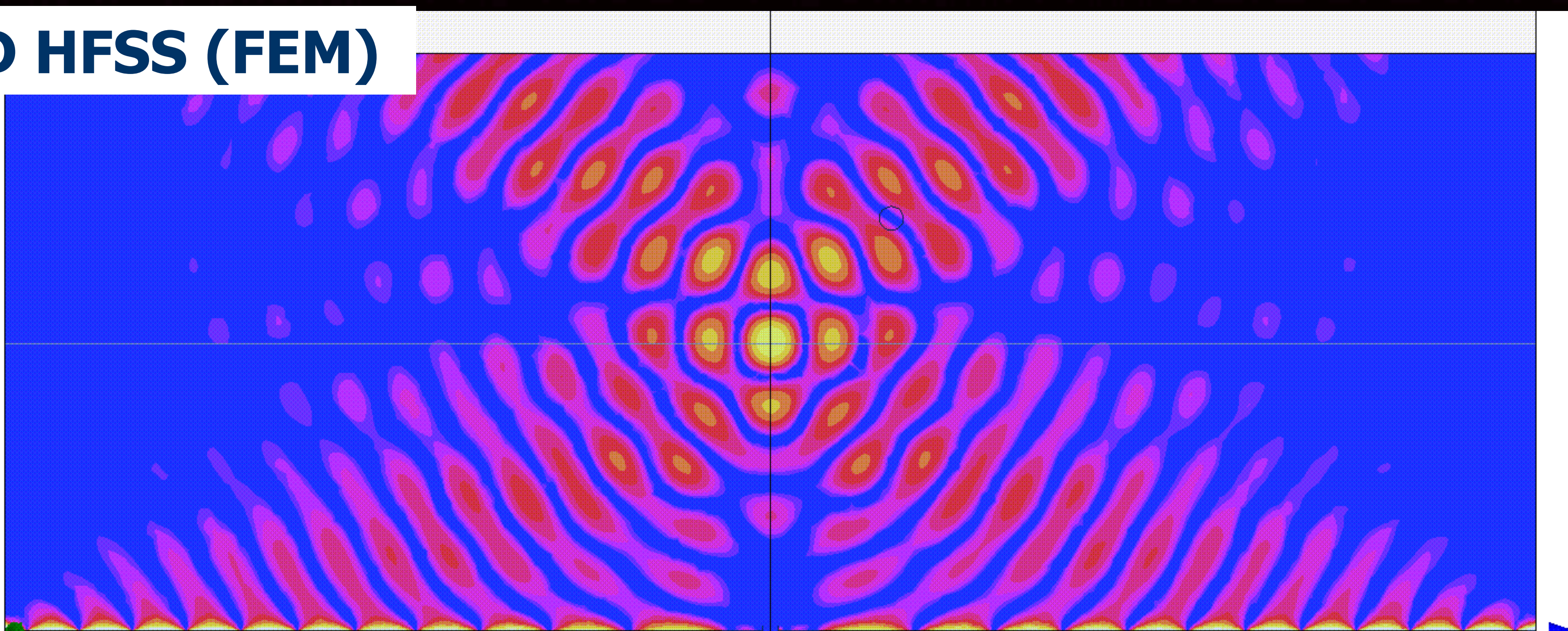
Array of two front-to-front leaky-wave lenses





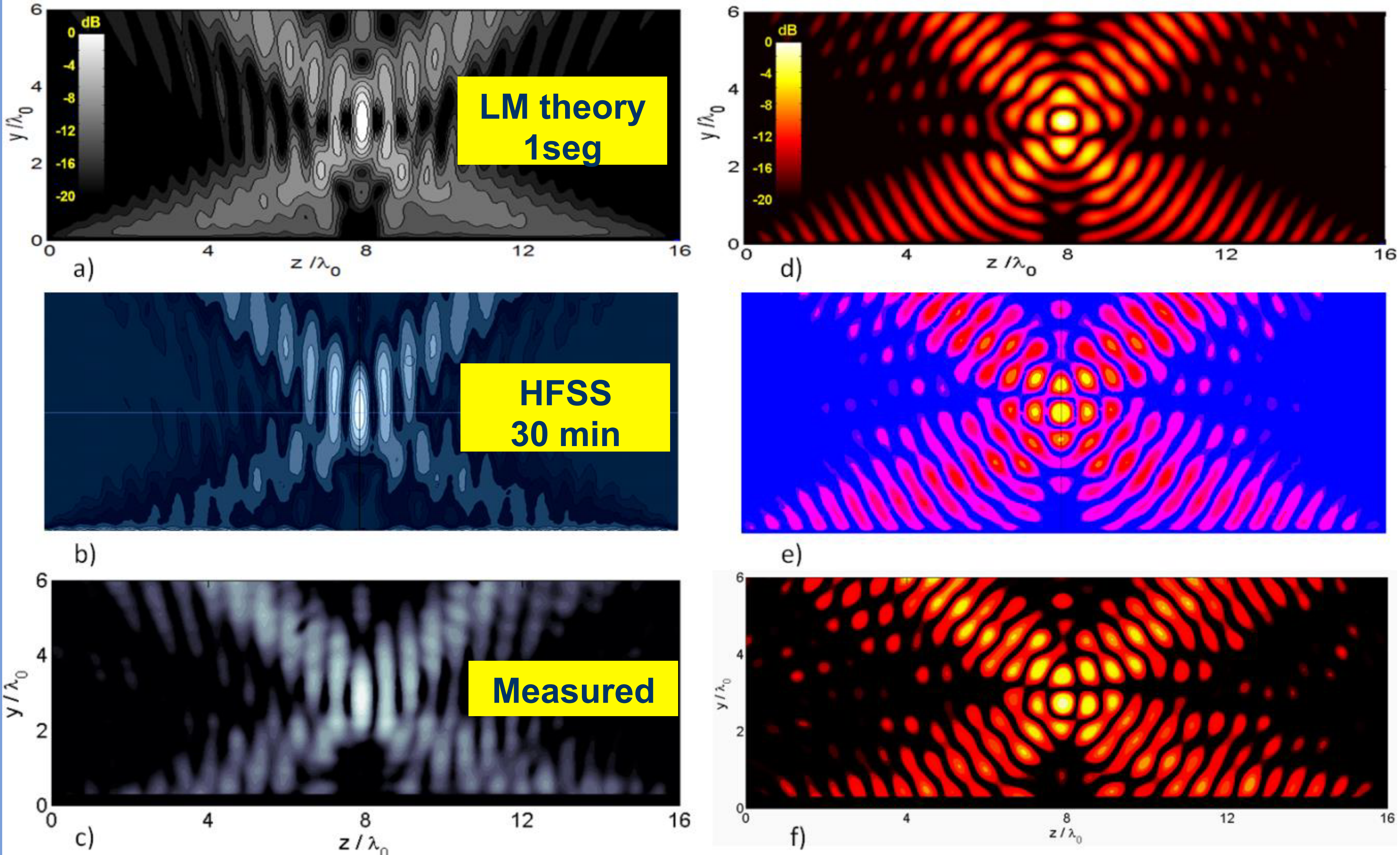
2D Leaky-Mode

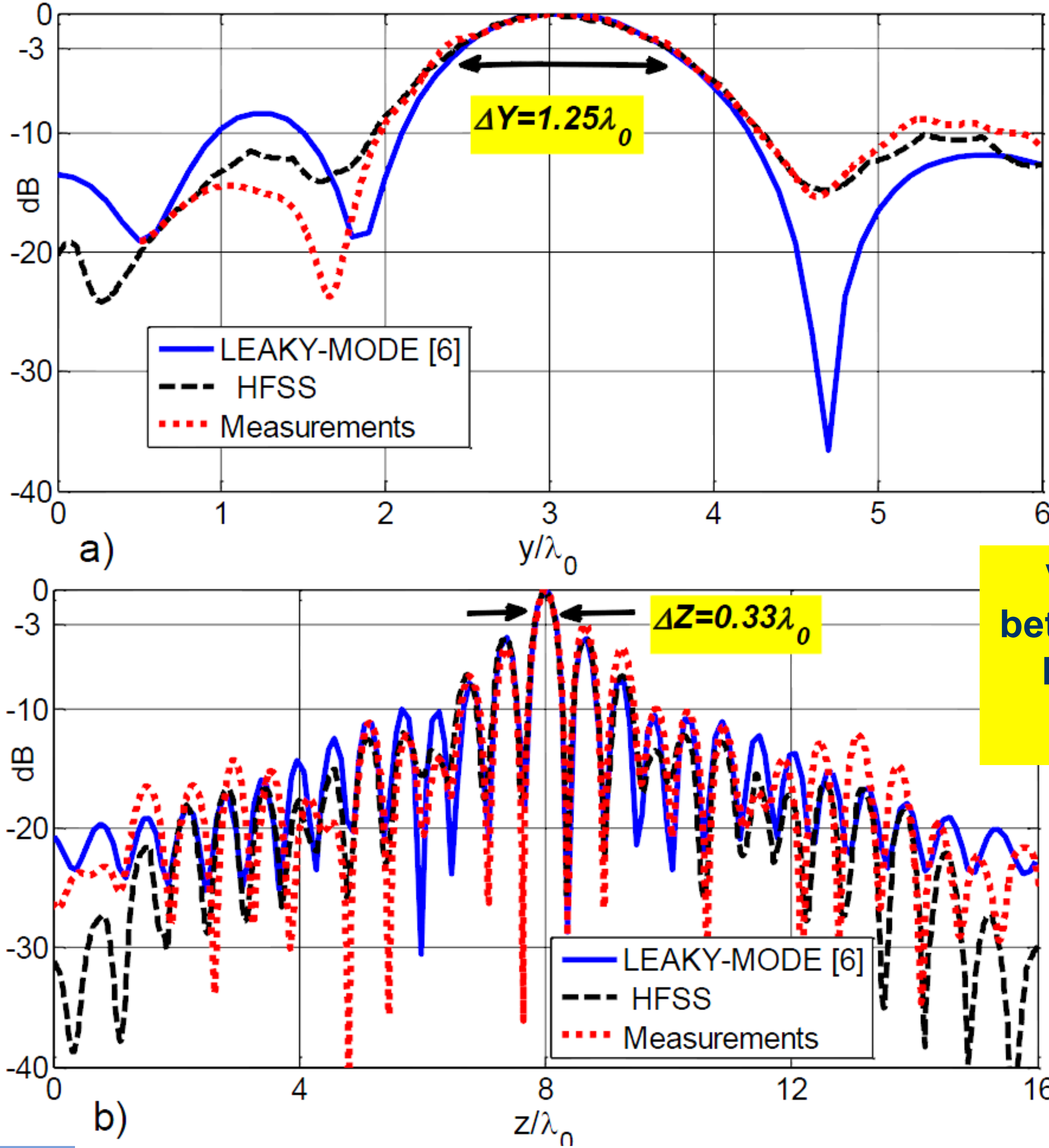
3D HFSS (FEM)



2.4- Near-field focusing.

Array of two front-to-front leaky-wave lenses L=16λ_0

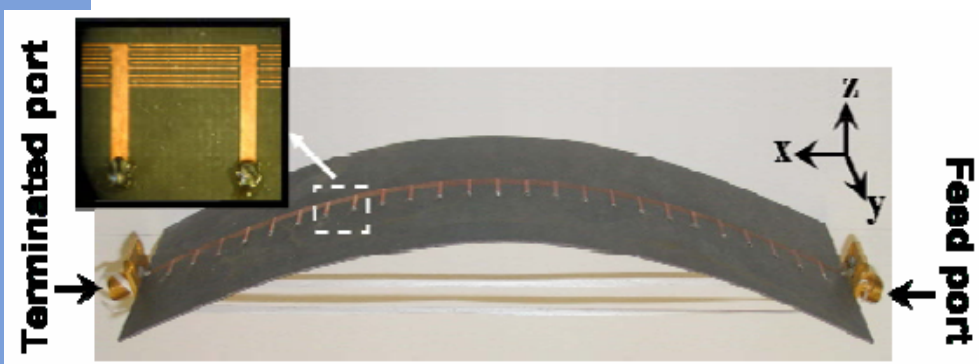


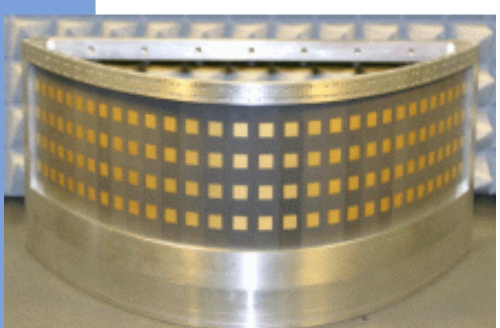


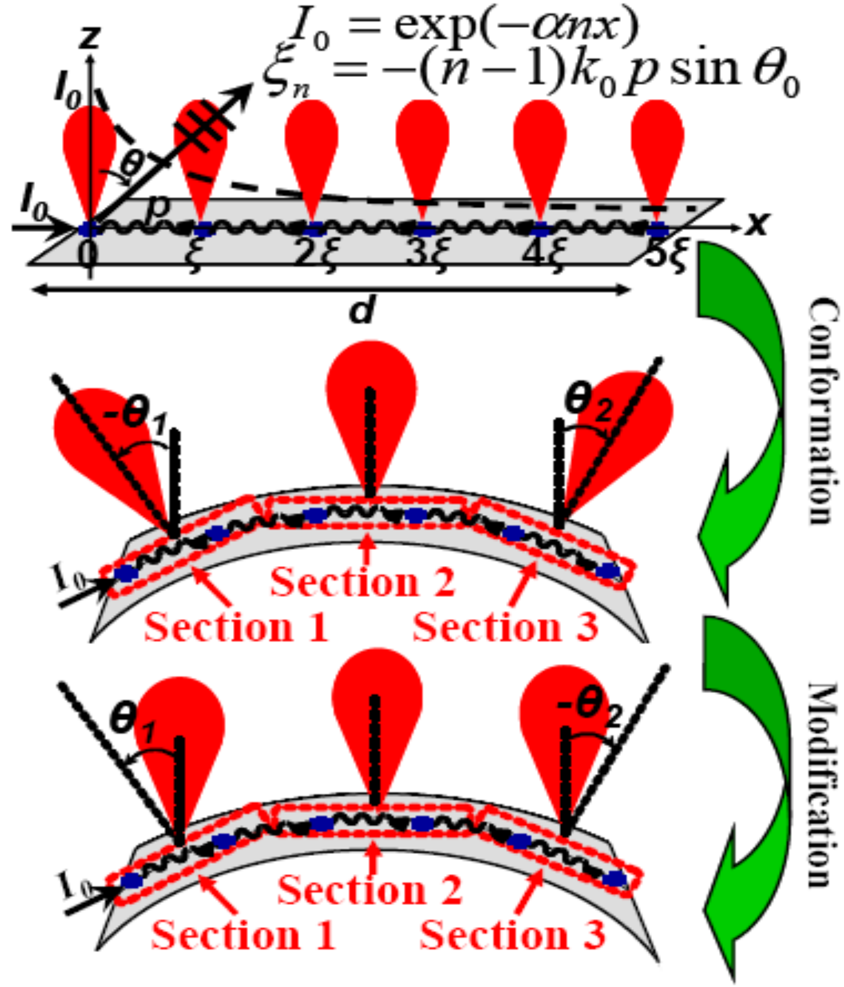
Very good agreement between: experiments and LM theory / HFSS full-wave simulations

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

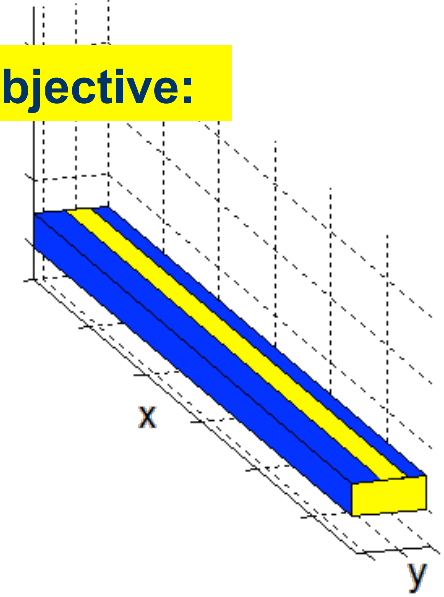
1068 IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 10, 2011

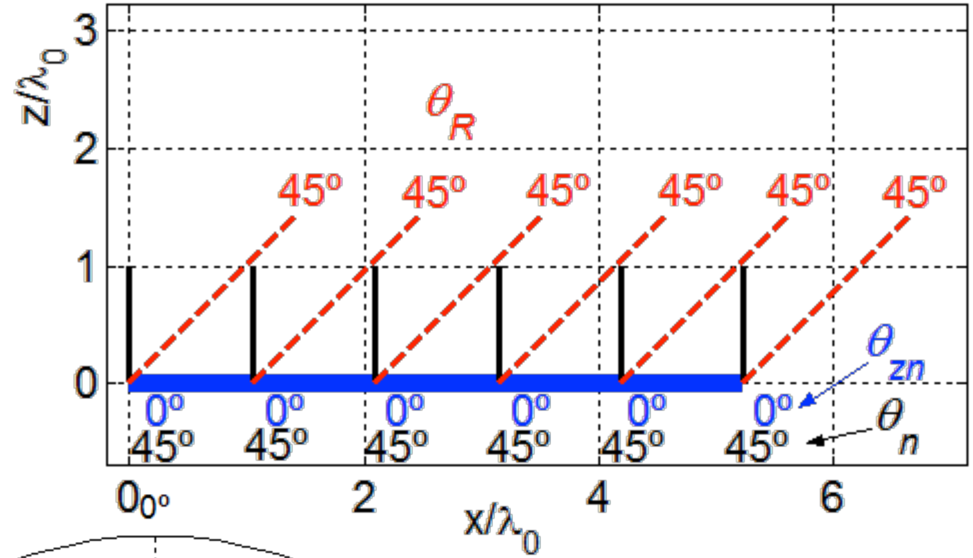
Analysis and Design of Conformal Tapered Leaky-Wave Antennas

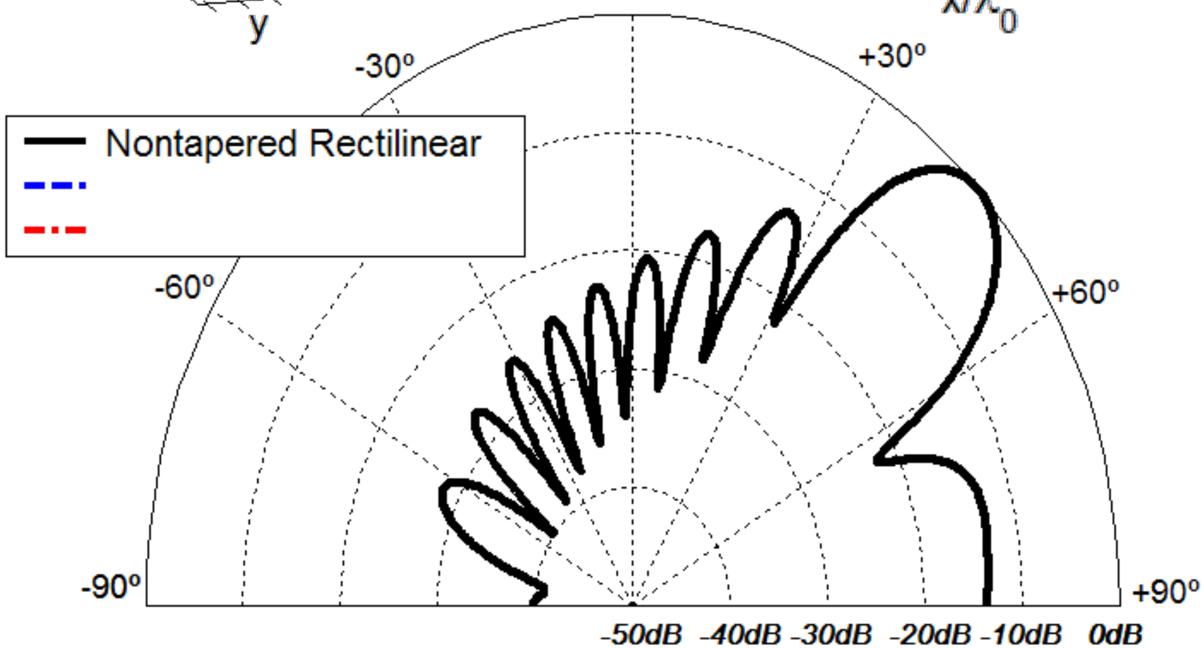
José Luis Gómez-Tornero, *Member, IEEE*

2.5- Conformal scanning antenna design.

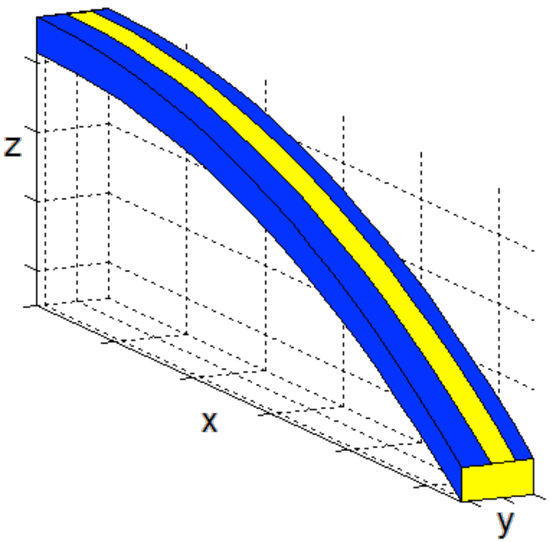
Objective:

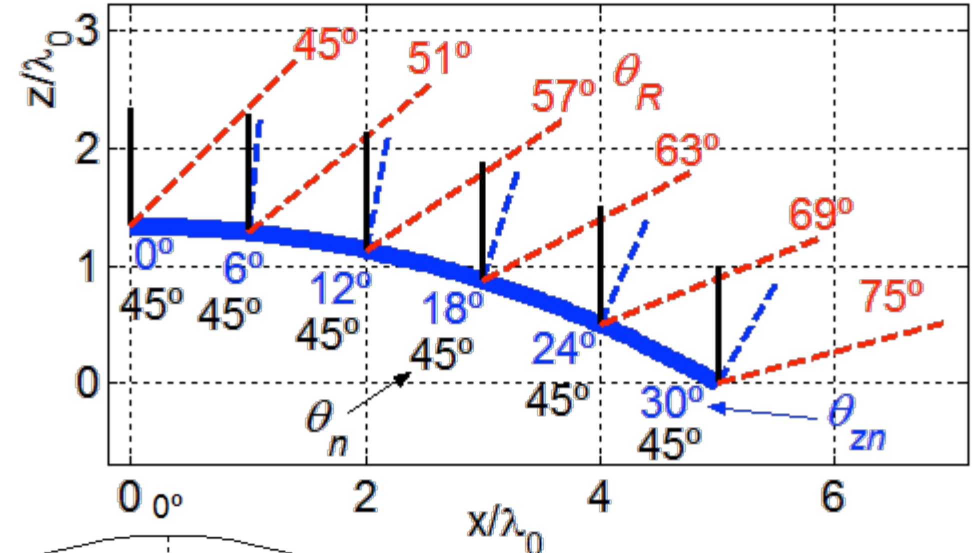


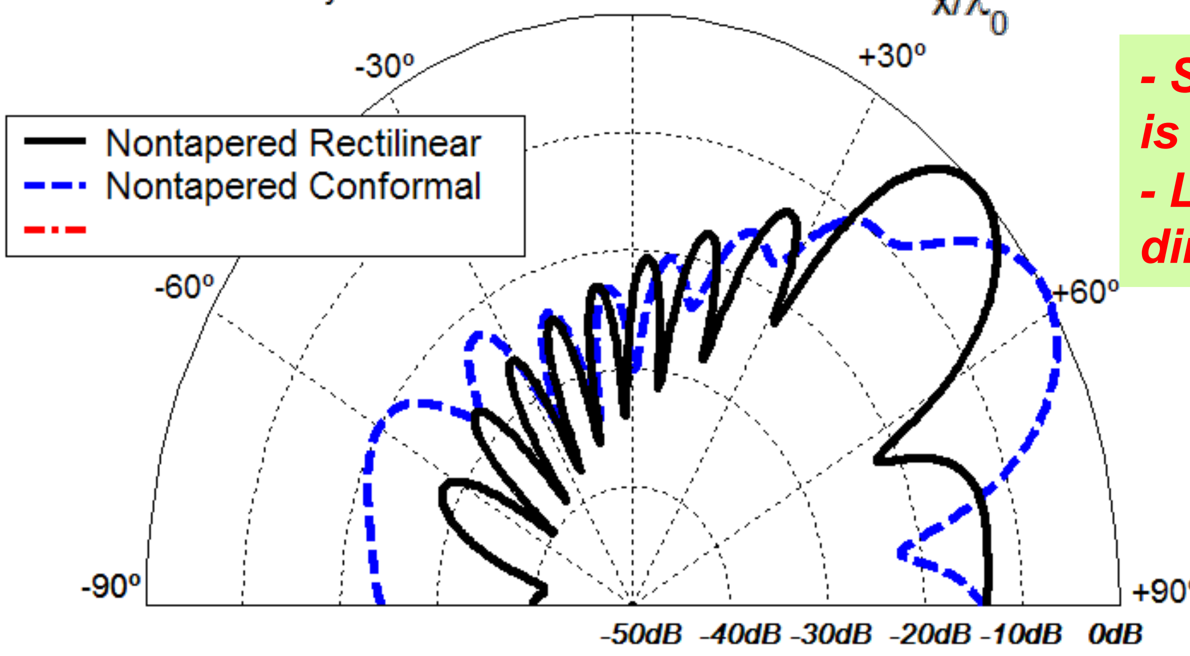




2.5- Conformal scanning antenna design.

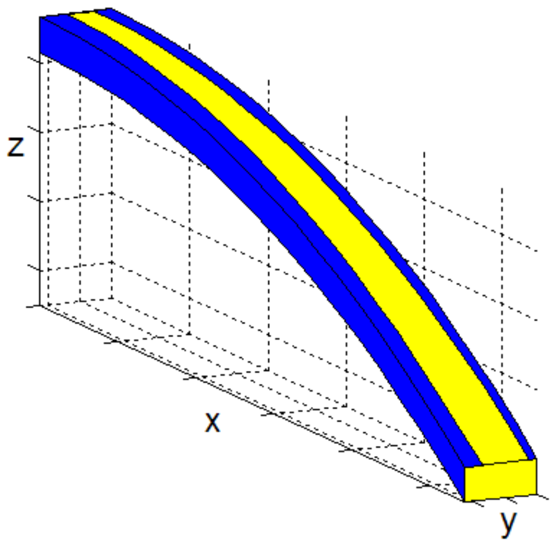


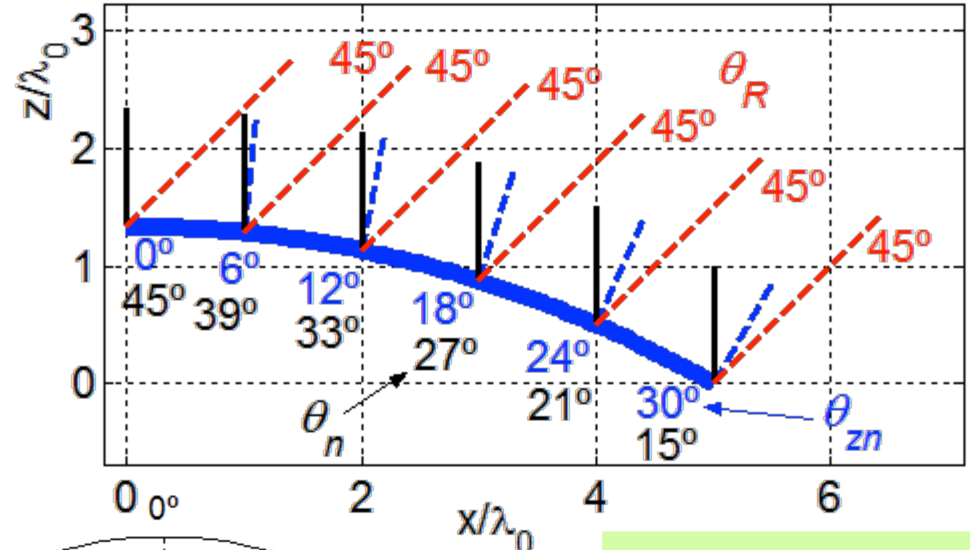


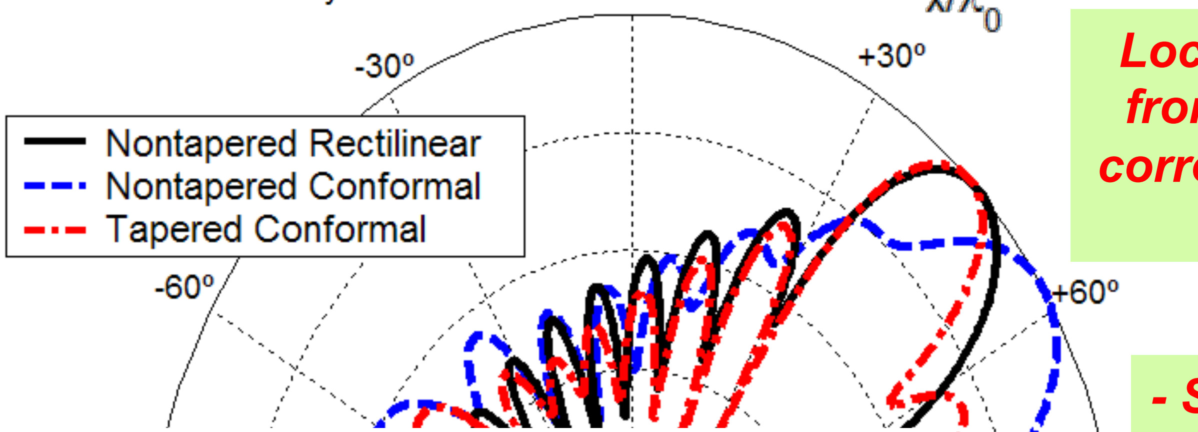


- Scanning angle is modified
- Loss of directivity

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

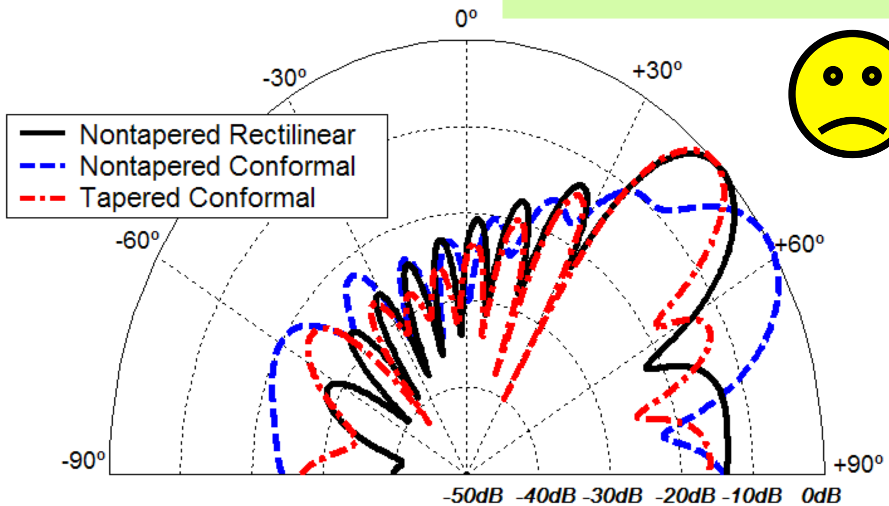
Analysis and Design of Conformal Tapered Leaky-Wave Antennas

José Luis Gómez-Tornero, *Member, IEEE*

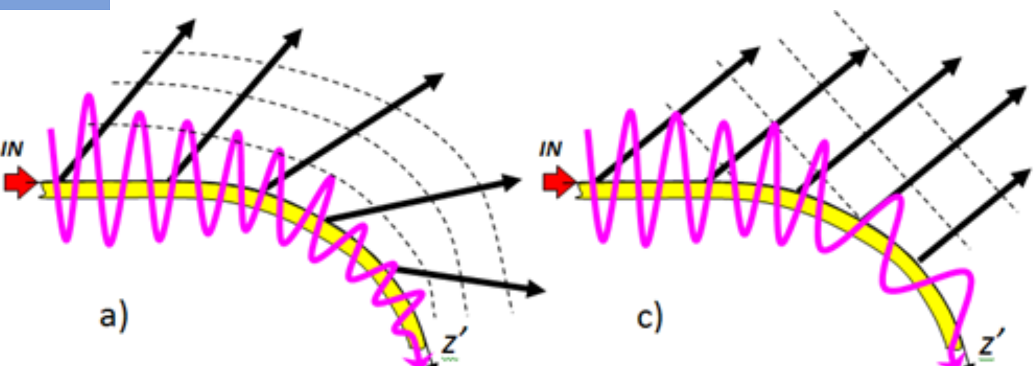
2.5- Conformal antenna

Objective:

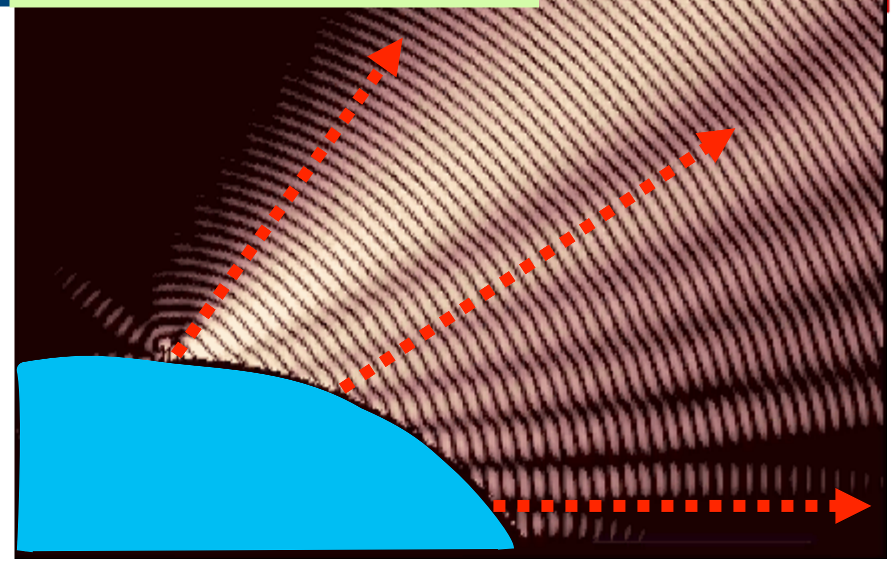
- Scanning angle is modified
- Loss of directivity



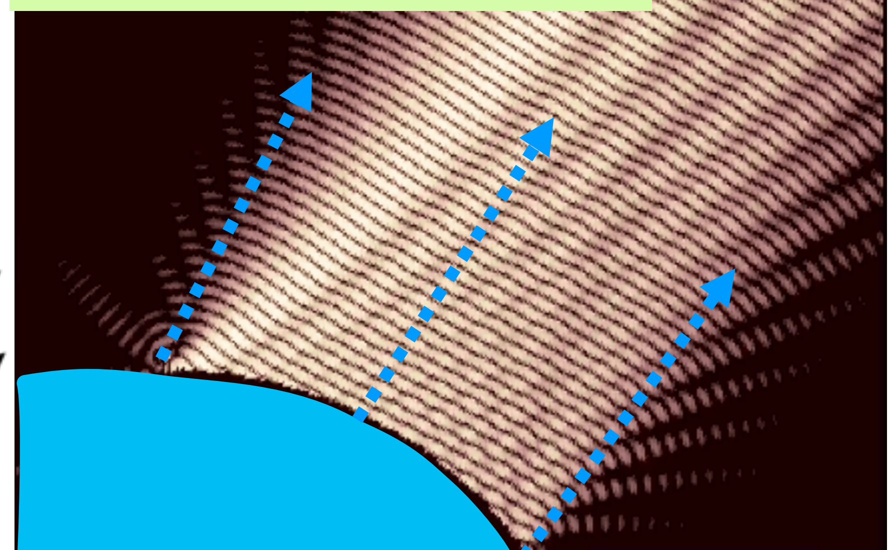
Correct for curvature to keep highly-directive scanning radiation



Non Modulated Conformal Antenna

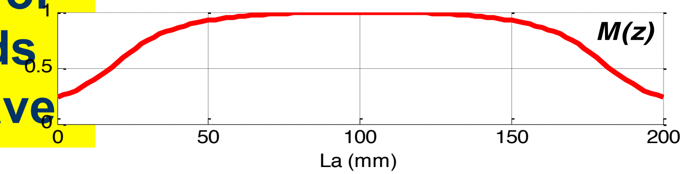


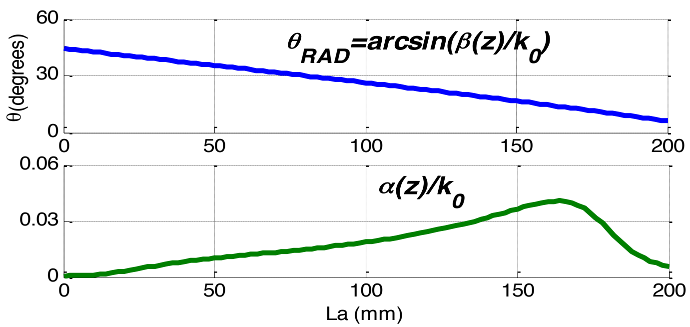
Modulated (holographic) Conformal Antenna



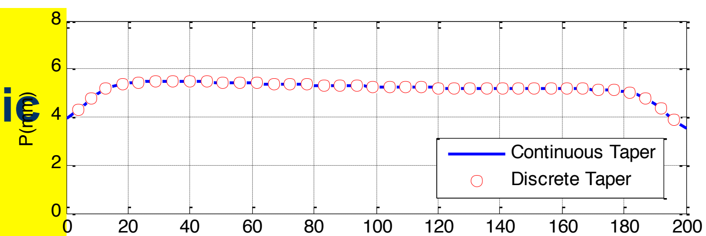
2.5- Conformal scanning antenna design.

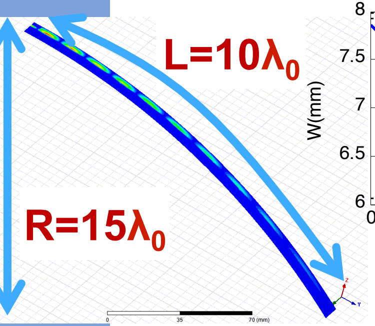
- Modulation of aperture fields and leaky wave

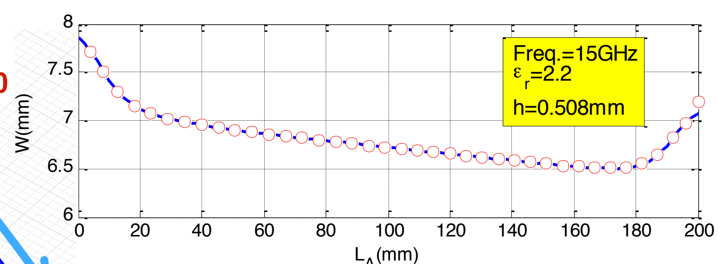


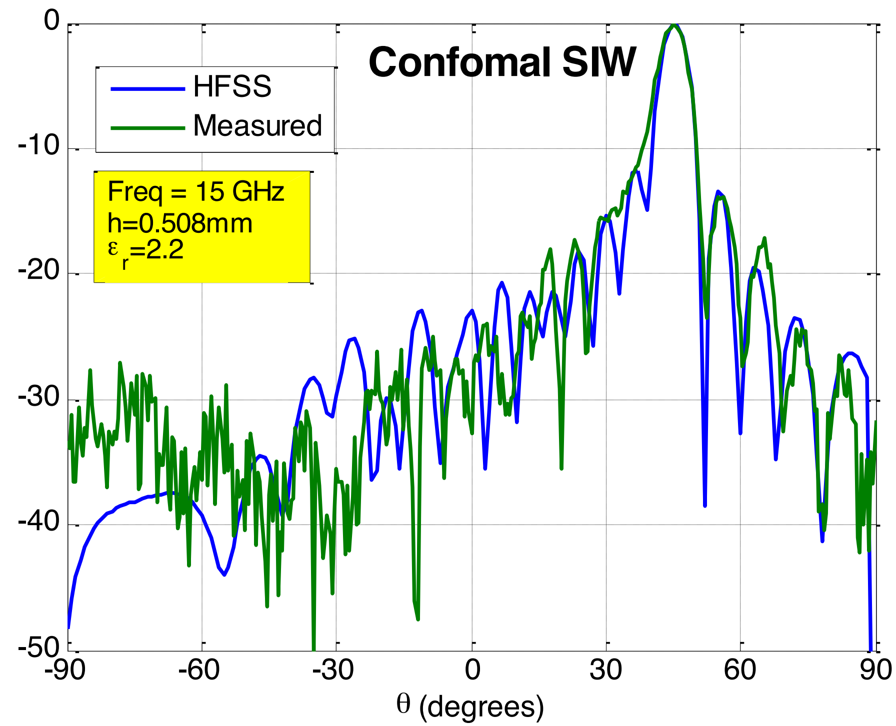


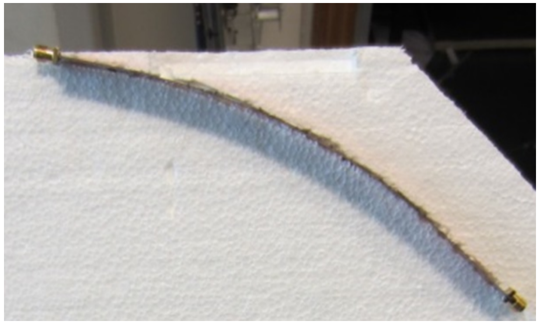
- Modulation of holographic antenna dimensions

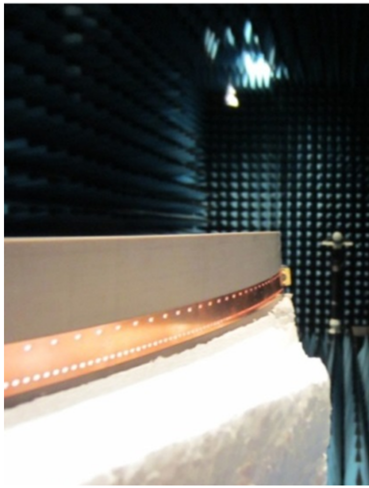












2.5- Conformal scanning antenna design.

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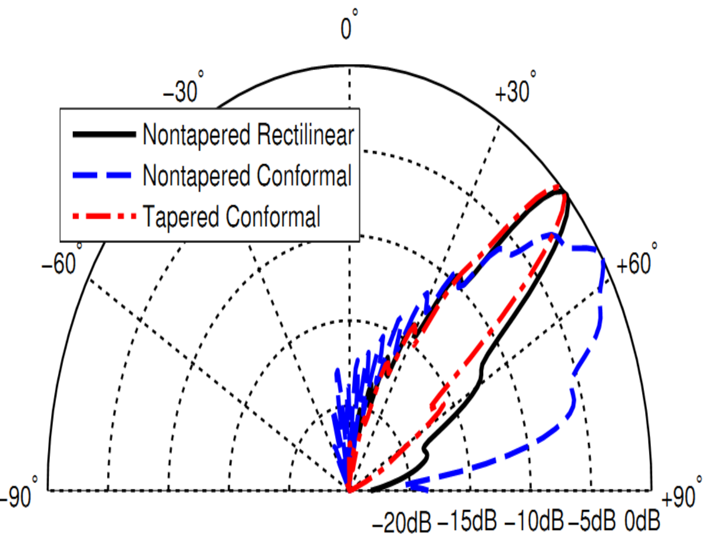
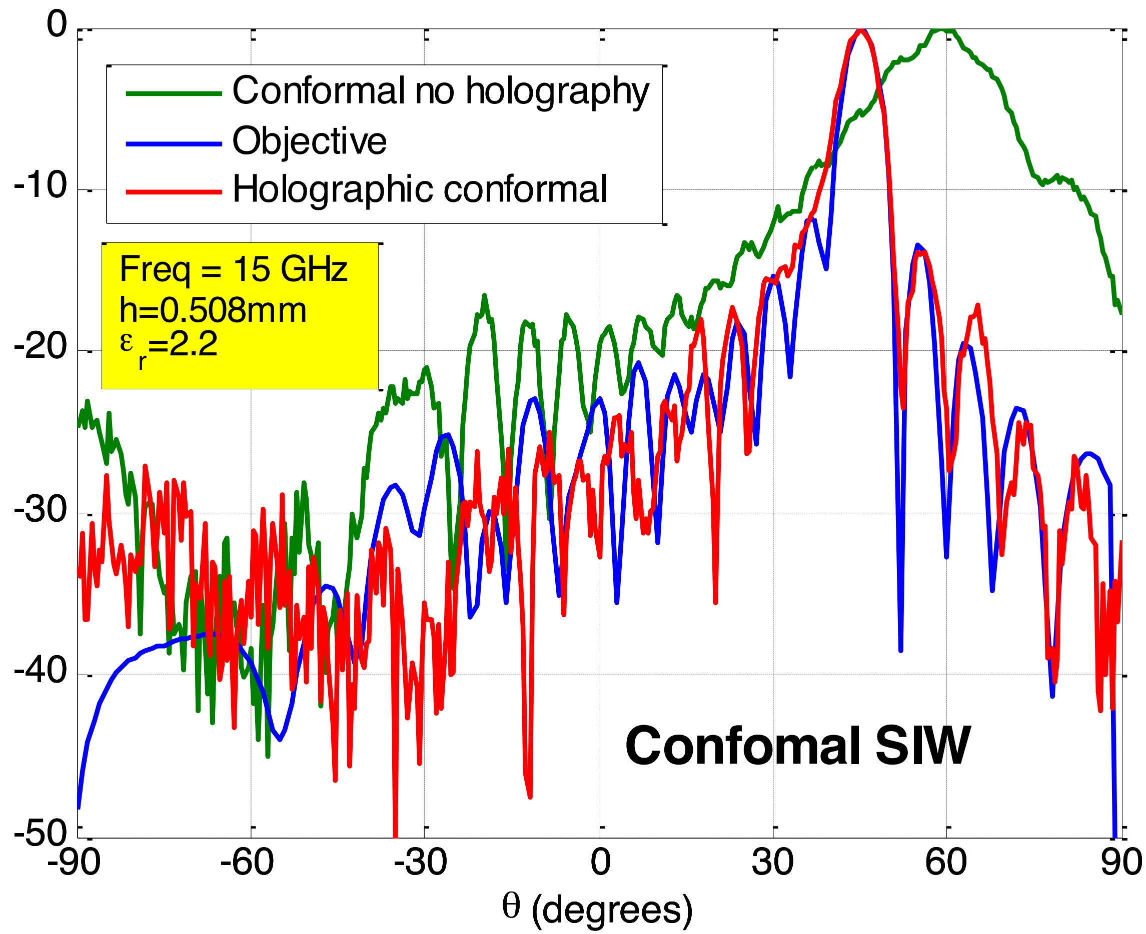
COST IC1301

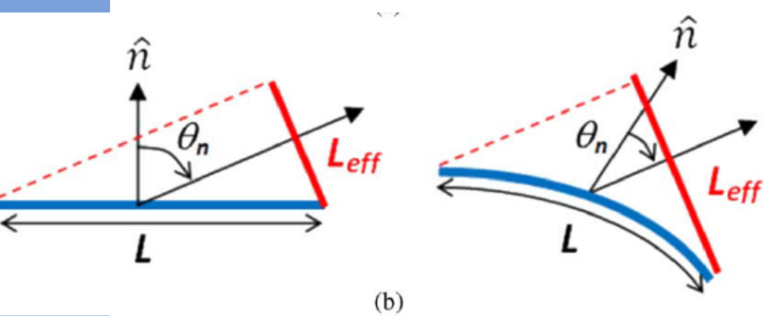
Measured radiation patterns

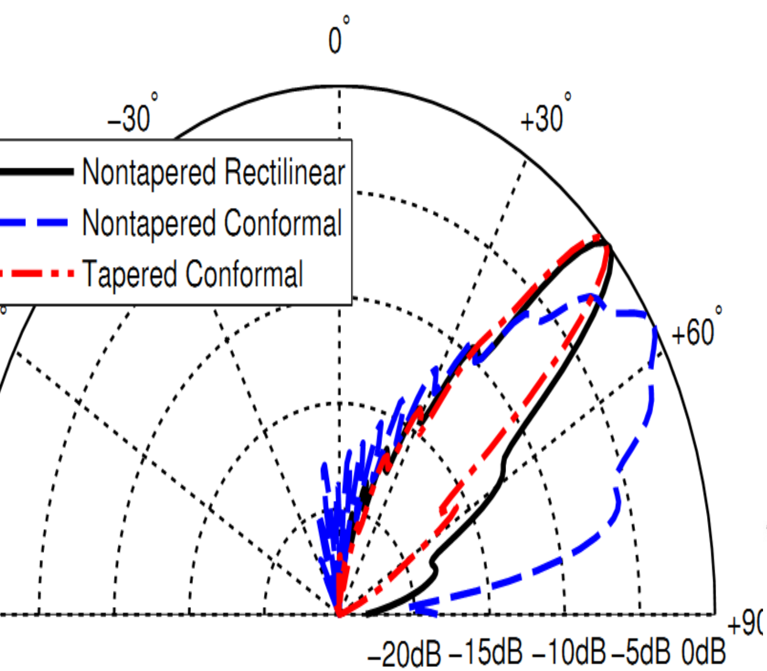


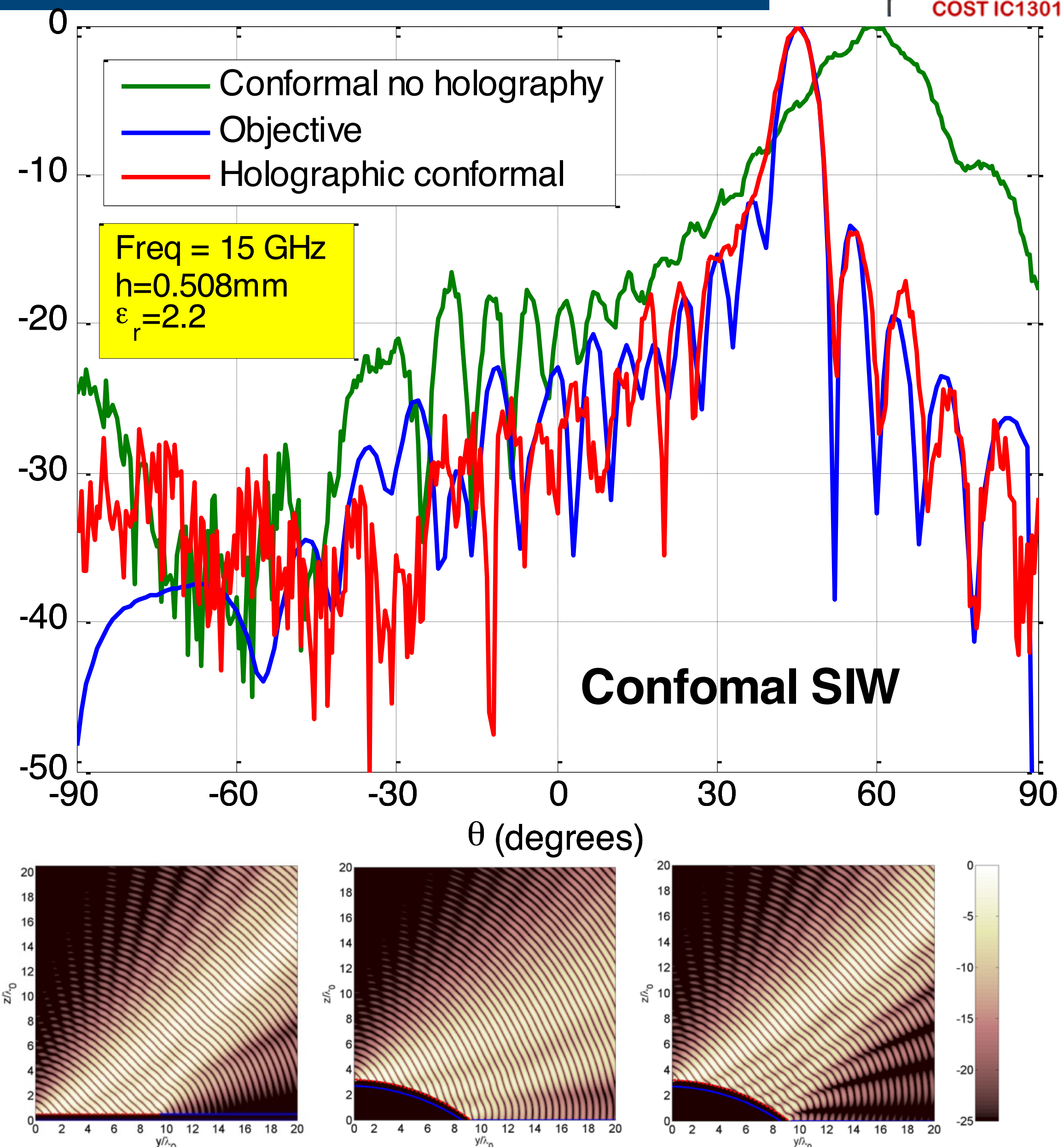


2.5- Conformal scanning antenna design.

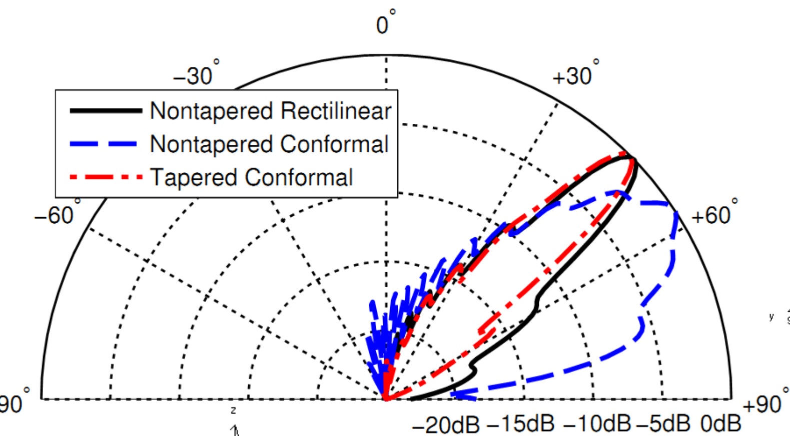
Measured radiation patterns

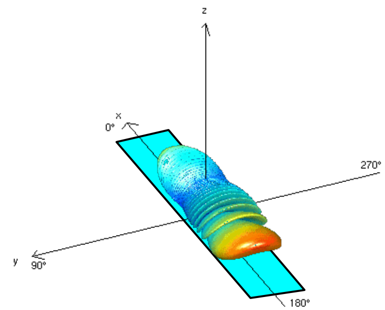


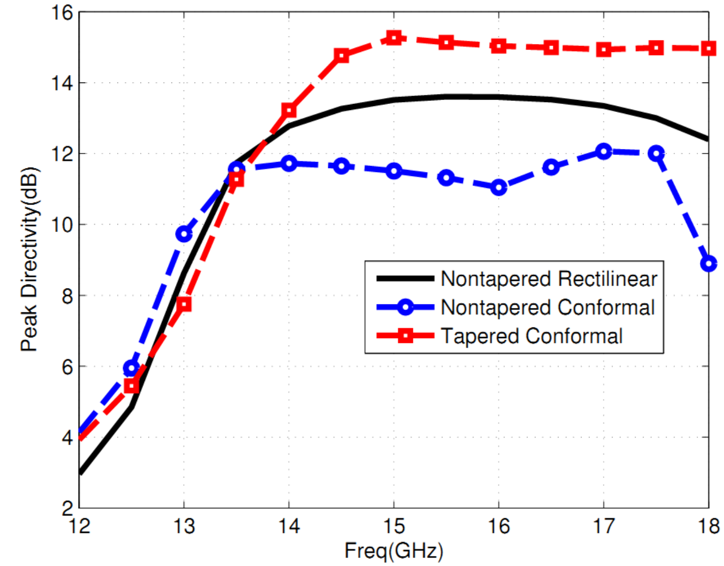


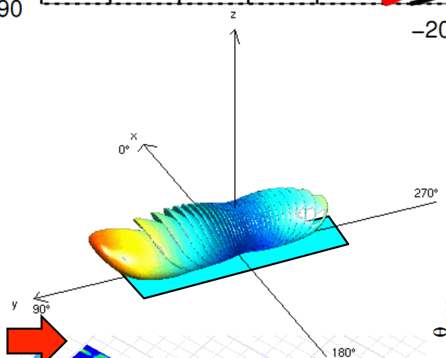


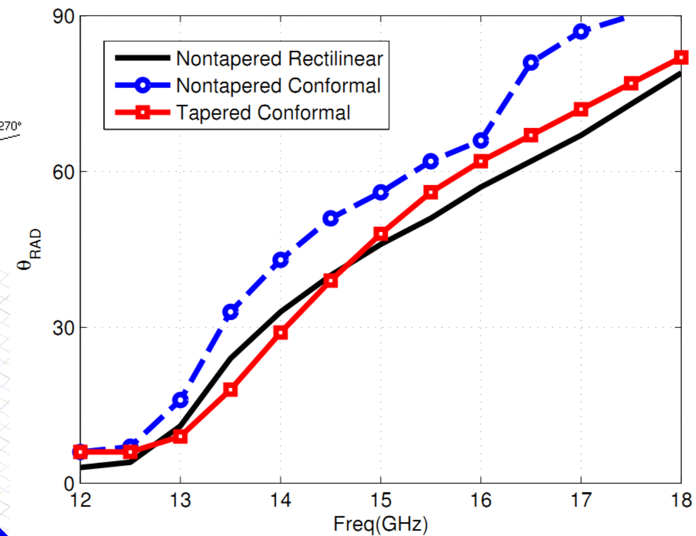
2.5- Conformal scanning antenna design.

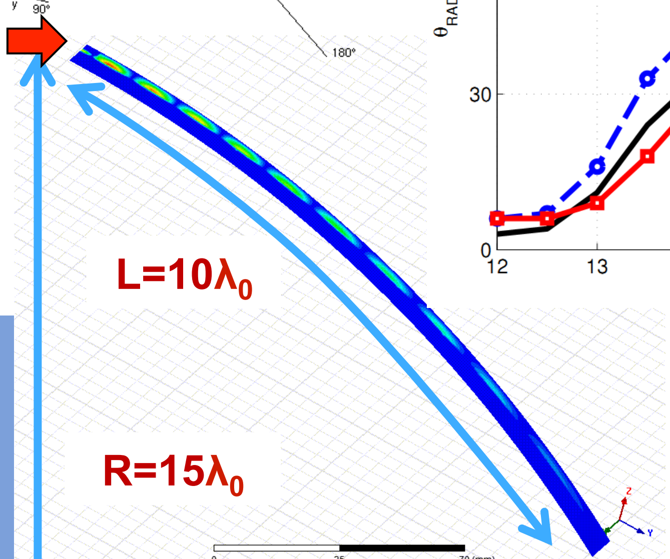


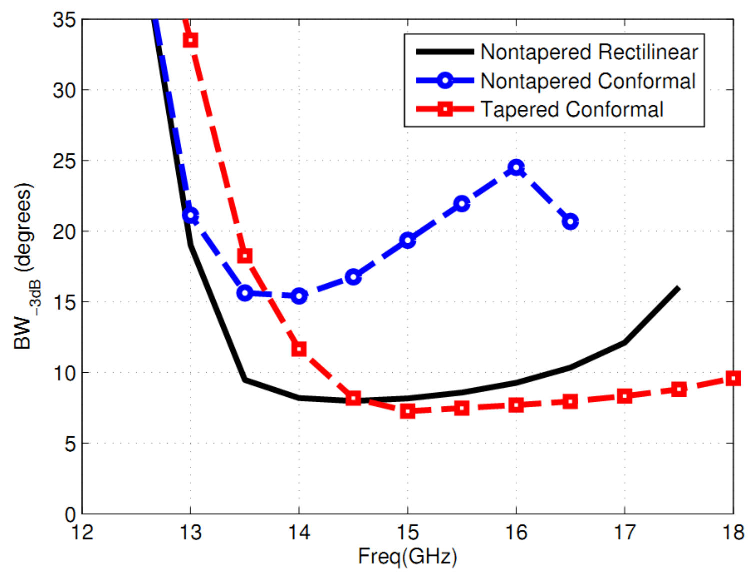






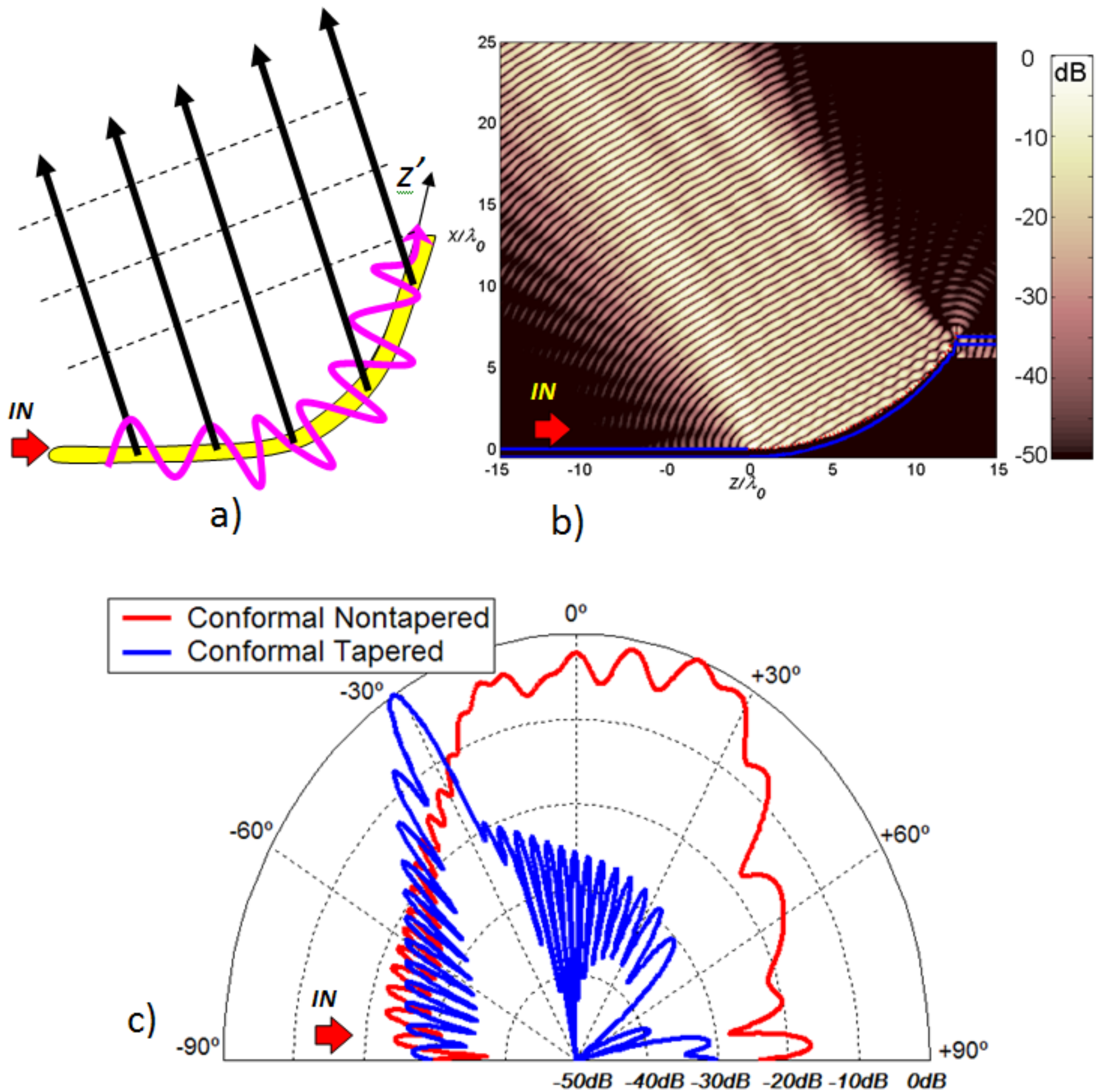






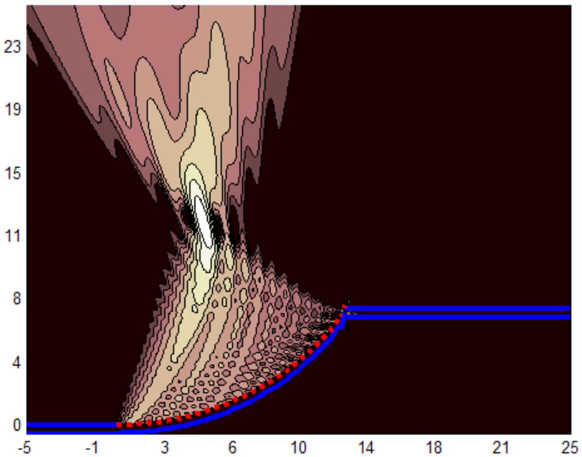
2.5- Conformal scanning antenna design.

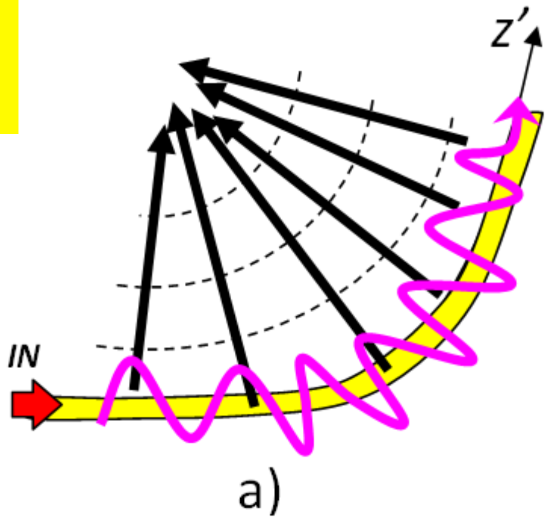
Take into account both concave and convex geometries…

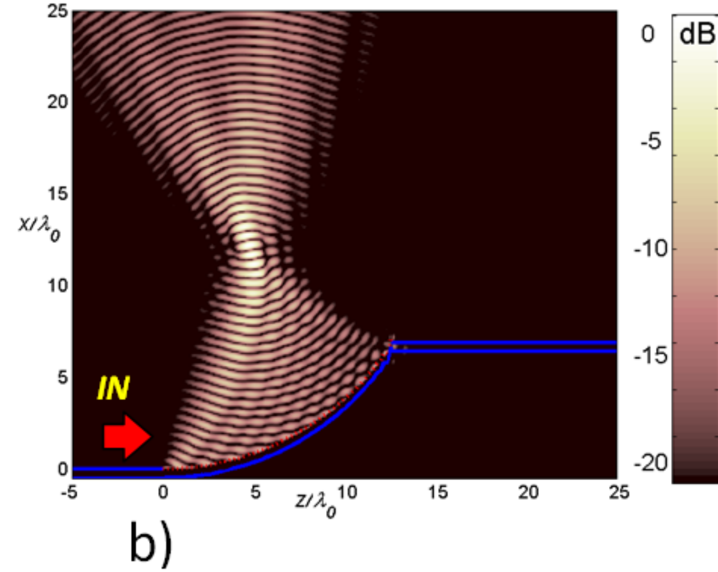


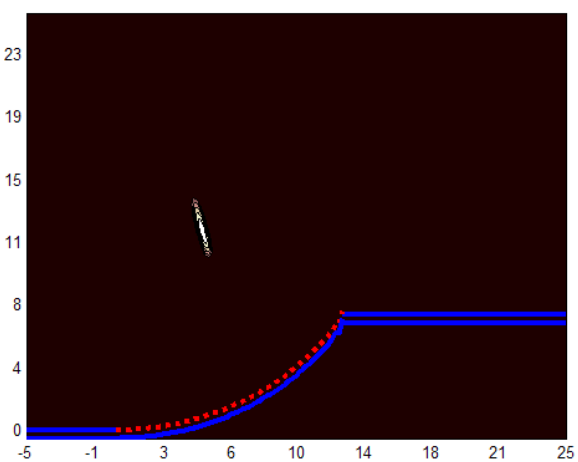
2.5- Conformal scanning antenna design.

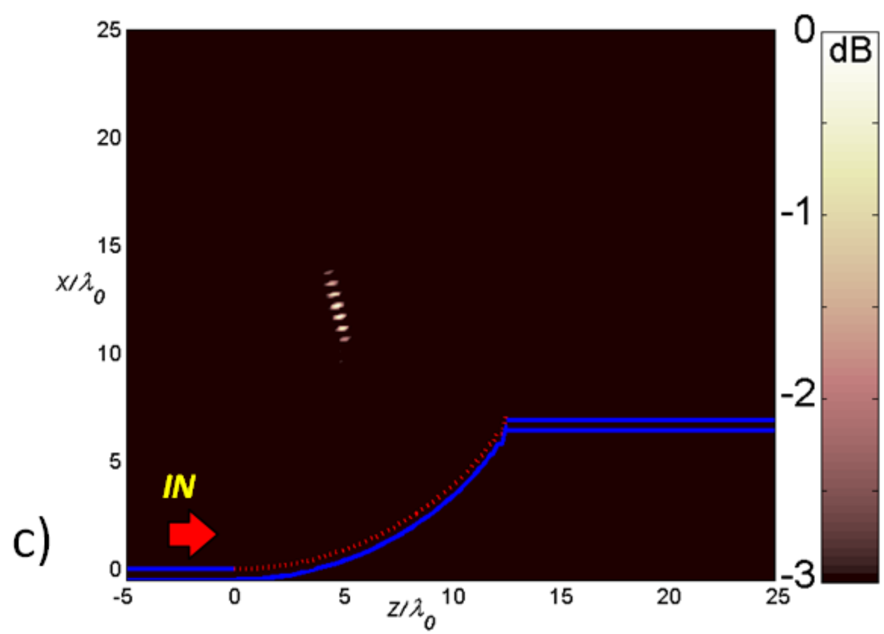
Conformal antenna with near-field focus







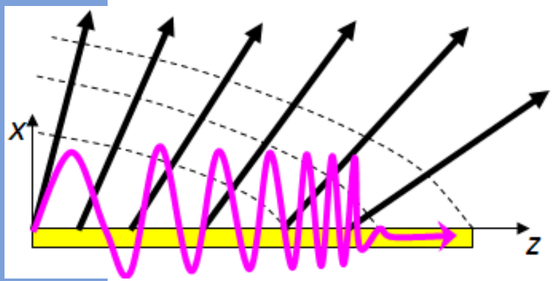


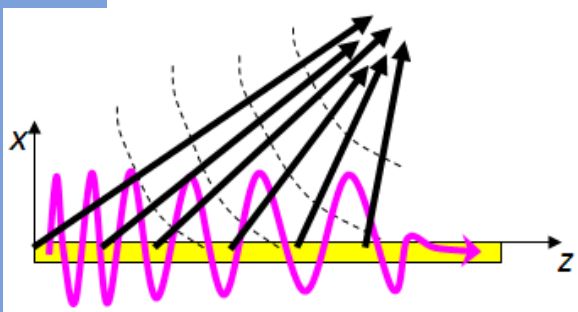


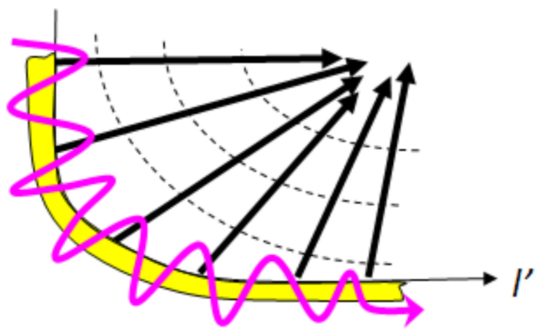
2.5- Conformal scanning antenna design.

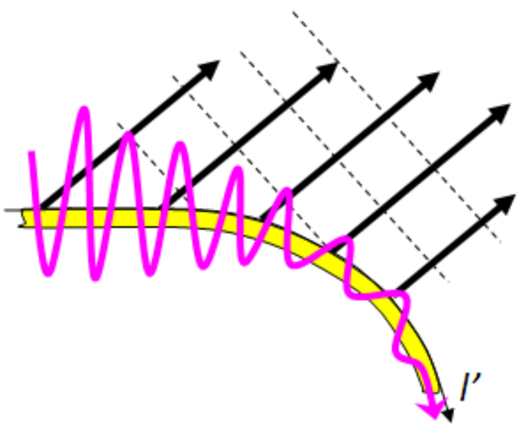
Rectilinear tapered PLWAs

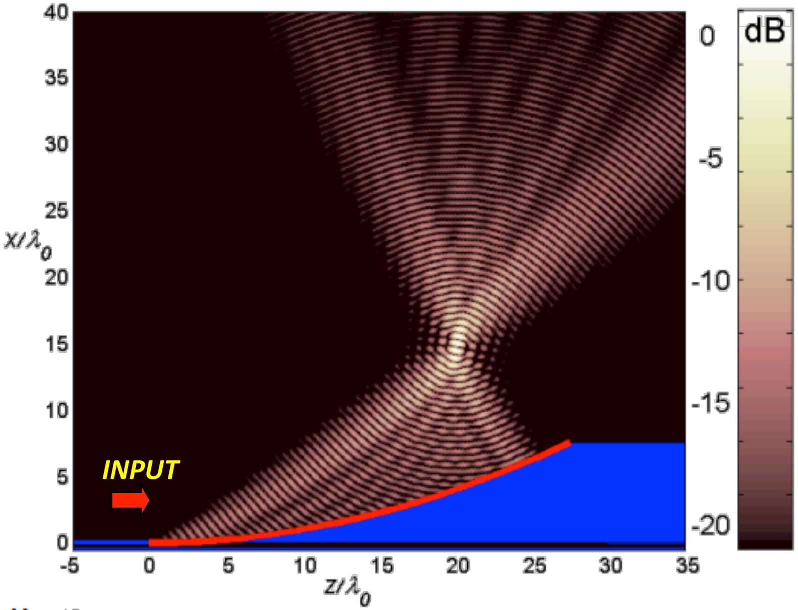
Conformal tapered PLWAs

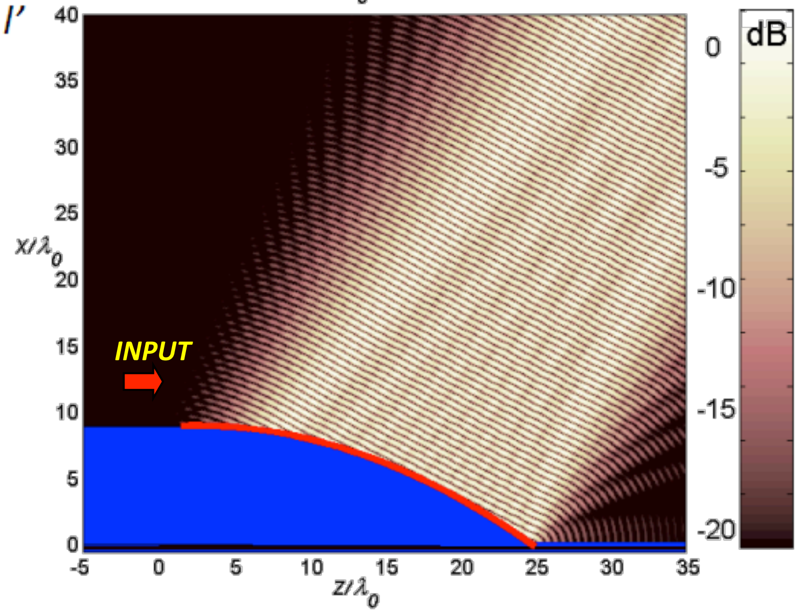








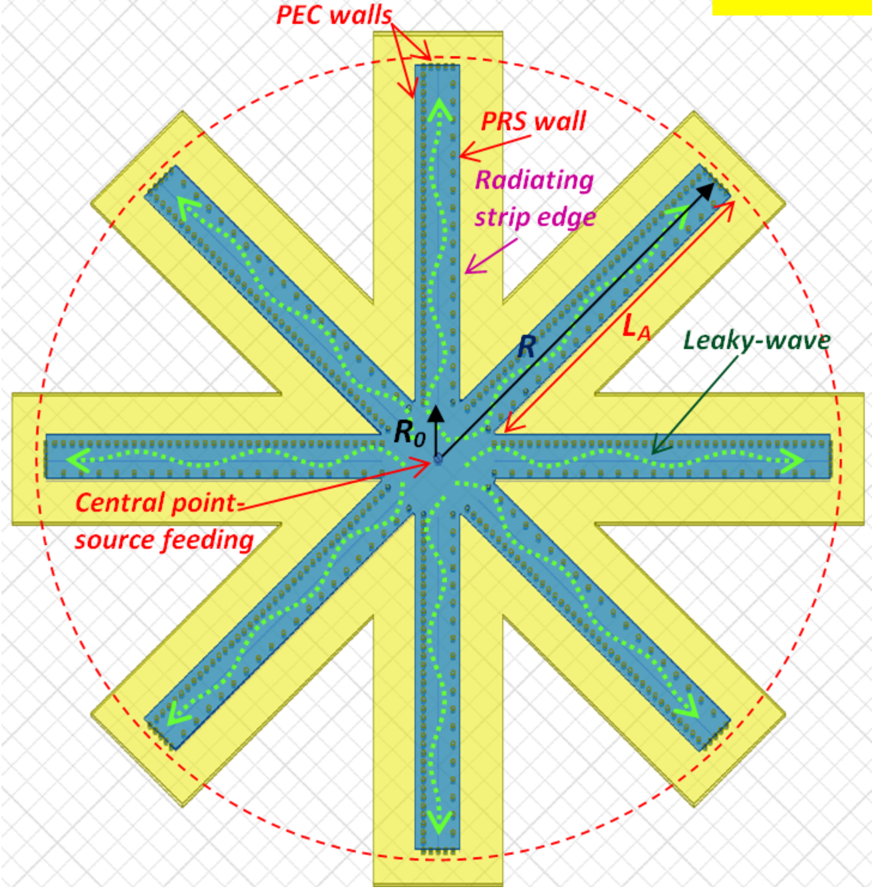


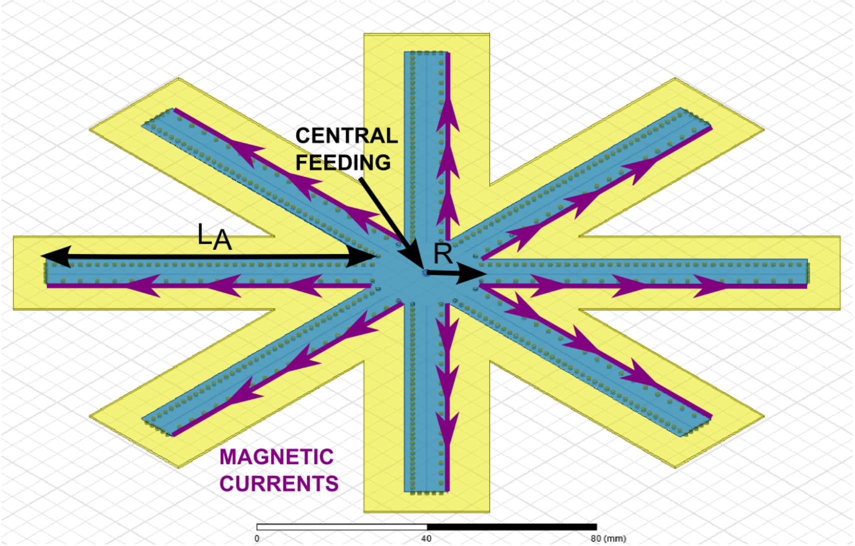


3- Future lines.

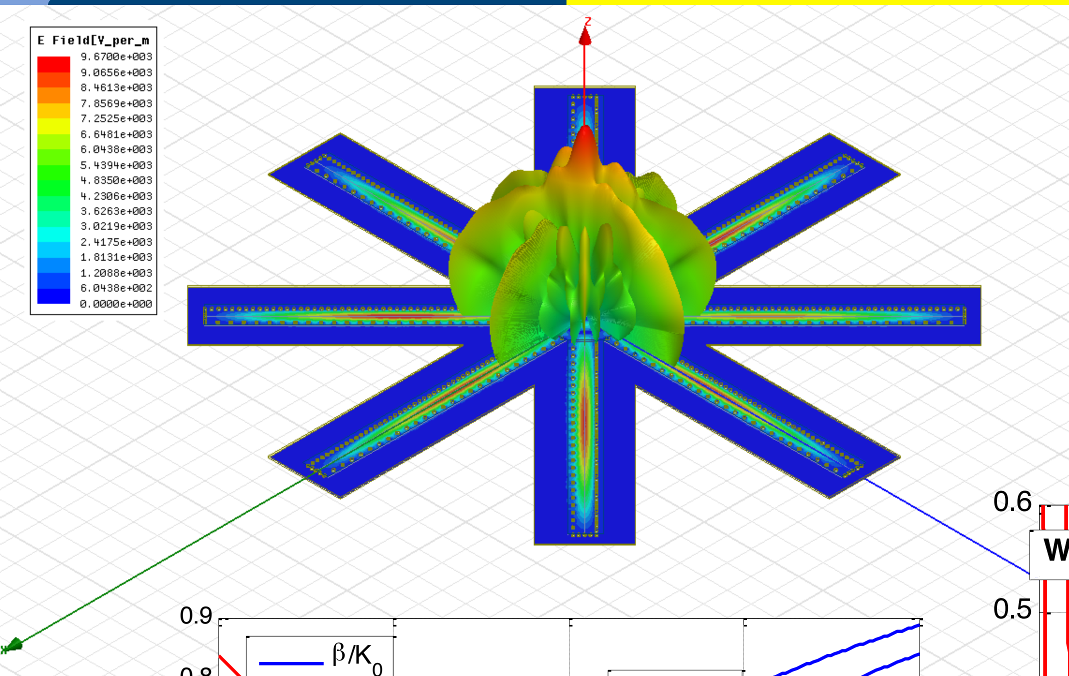
Extend to 2D holographic-surface SIW antennas to synthesize 3D holographic microwave patterns

Example: Radial Array of SIW antennas

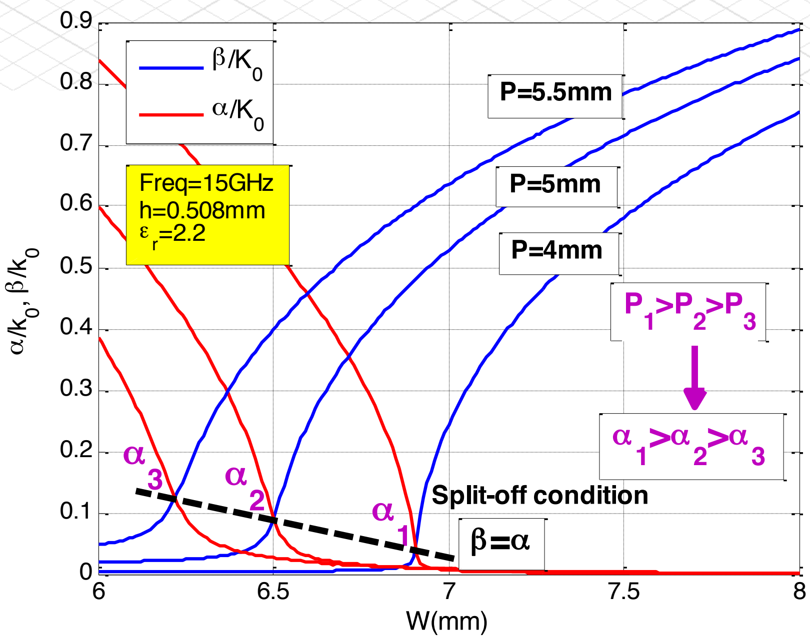


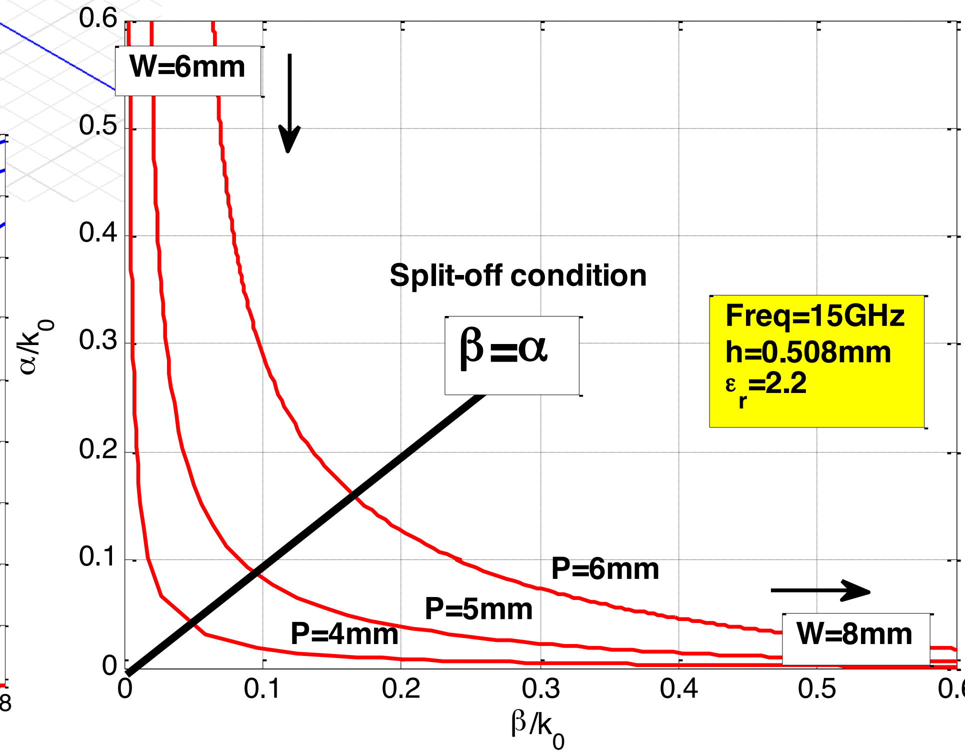


3- Future: Radial Array of SIW antennas focused in Far Field

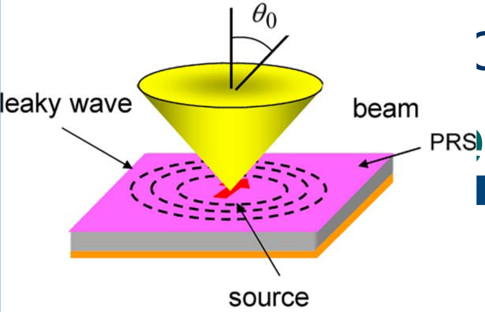


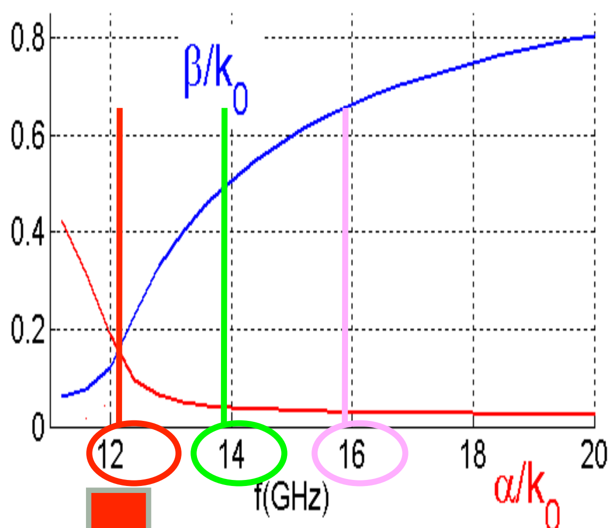
Splitting condition for Far-field focusing at broadside β=α





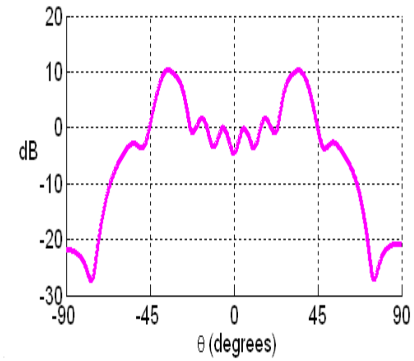
Radial Array of SIW antennas focused in Far Field

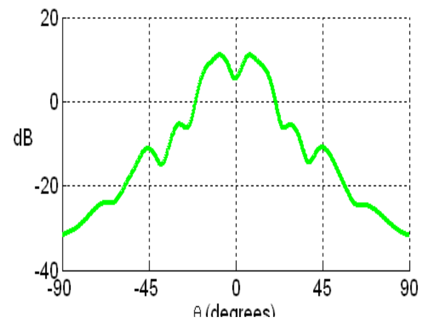


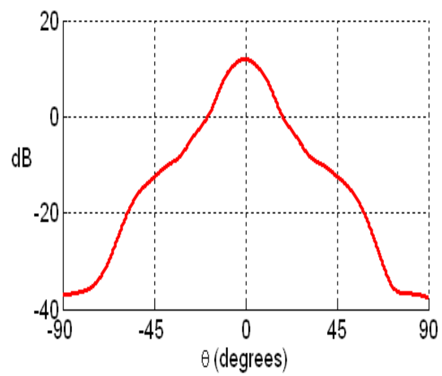


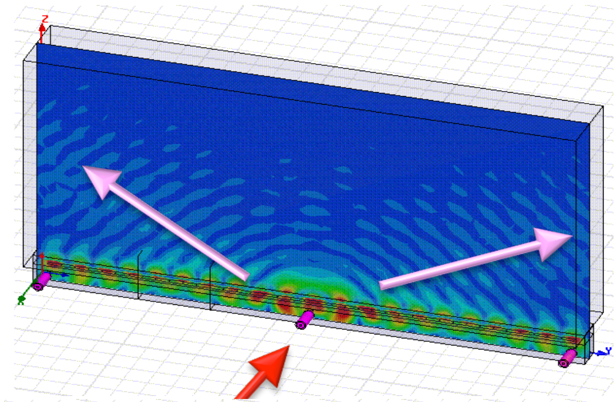
β=α
Splitting condition

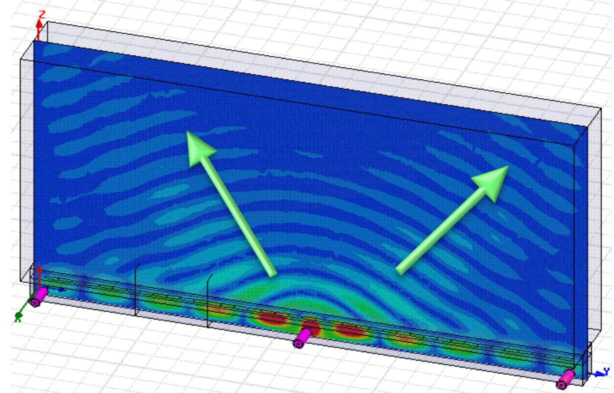
Coalescensce of the two beams

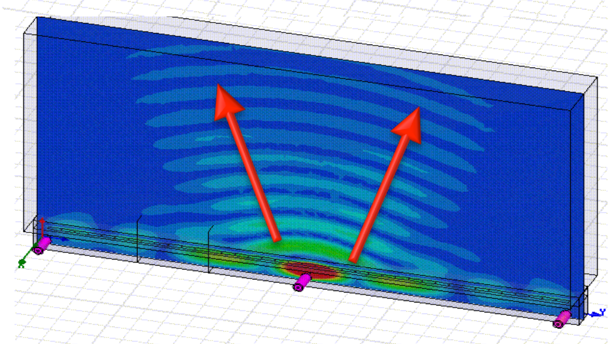


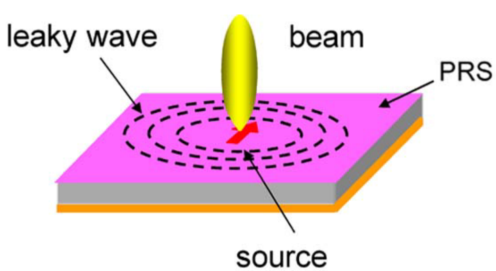






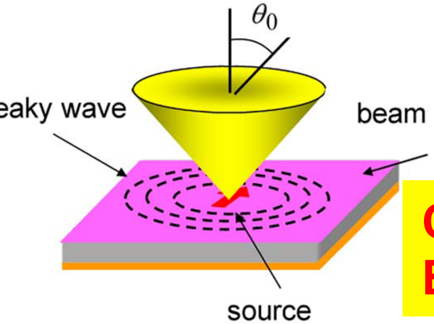




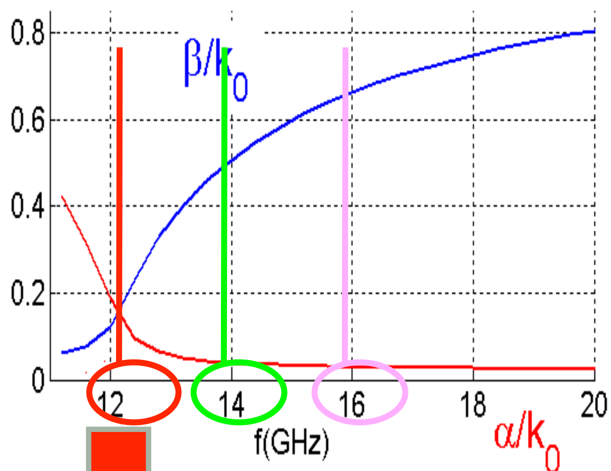


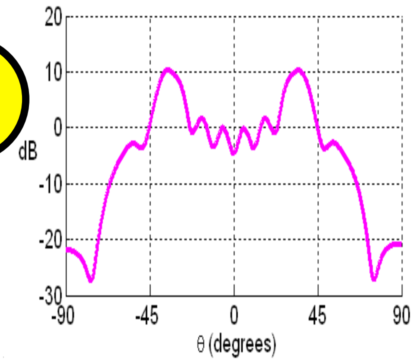
Single beam BROADSIDE

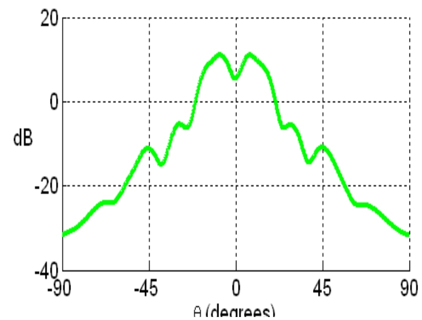
Radial Array of SIW antennas focused in Far Field

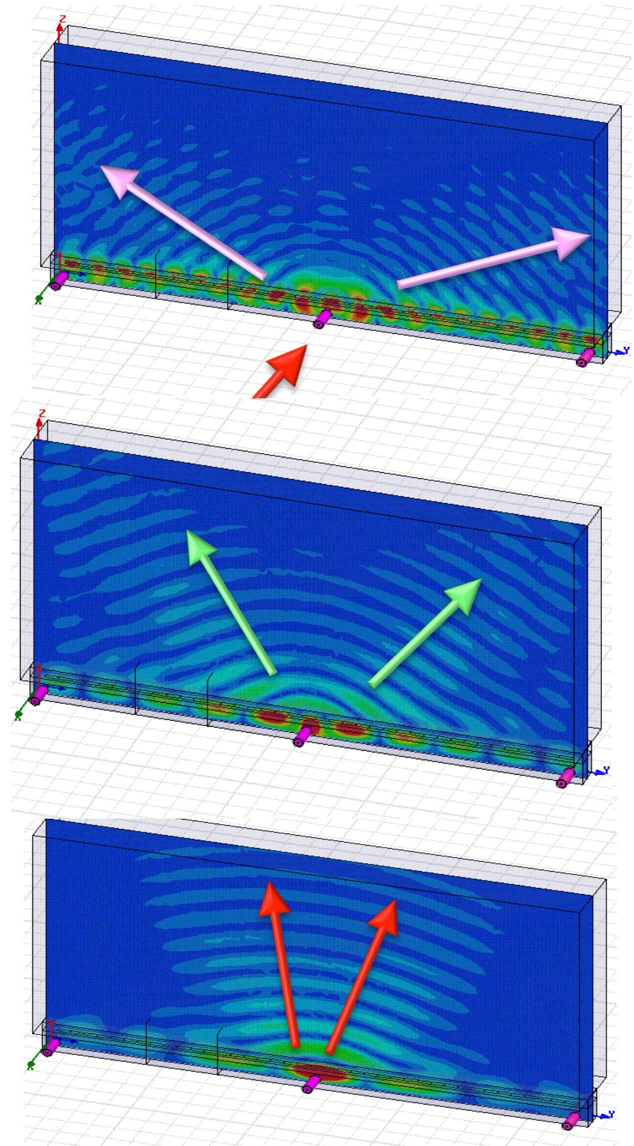


Conical Beam



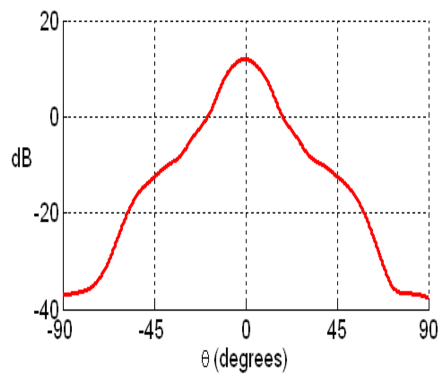


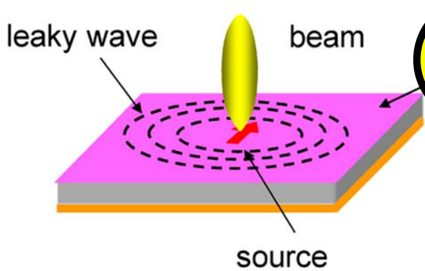




β=α
Splitting condition

Coalescensce of
the two beams

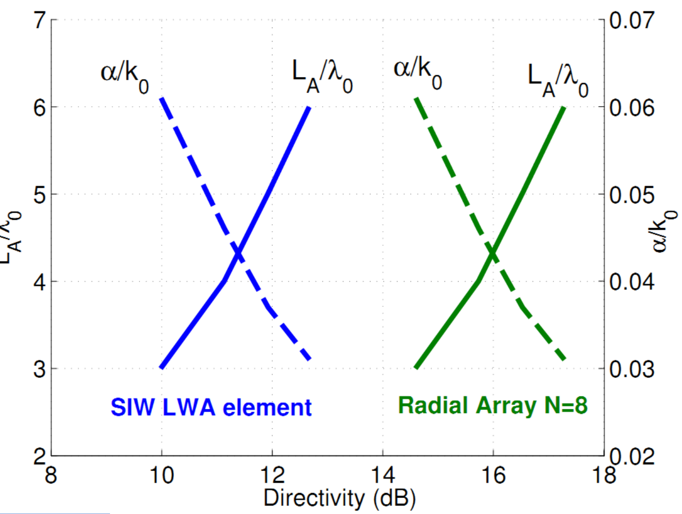


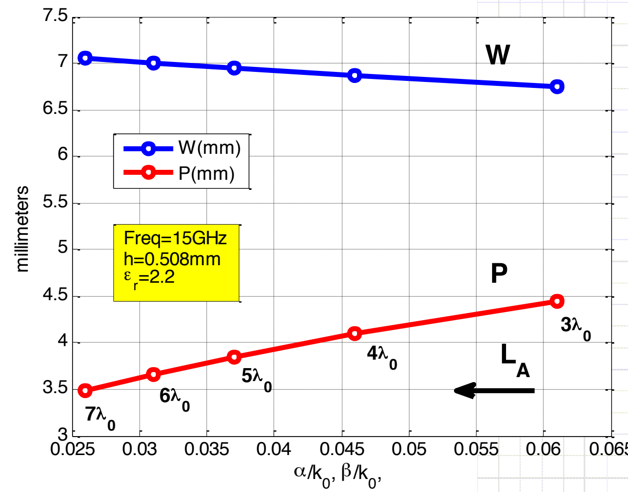


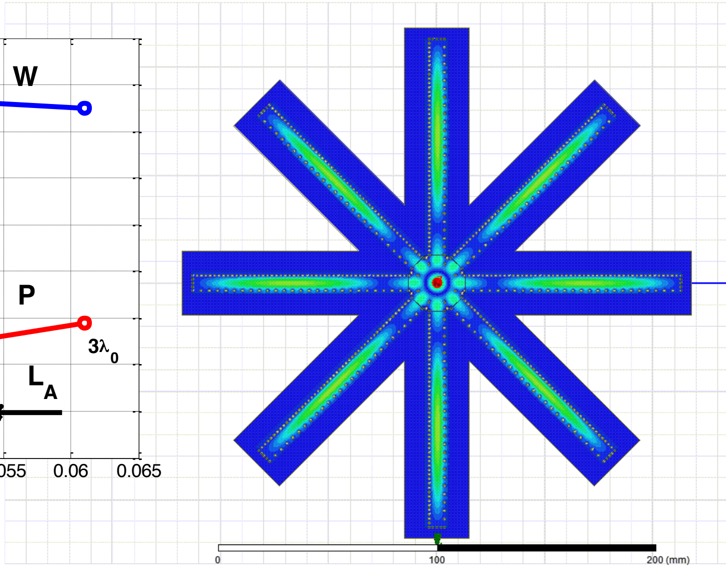
Single beam BROADSIDE

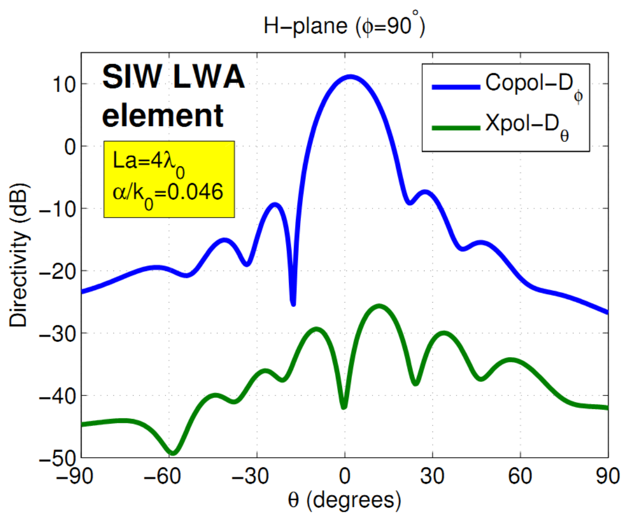
Radial Array of SIW antennas focused in Far Field

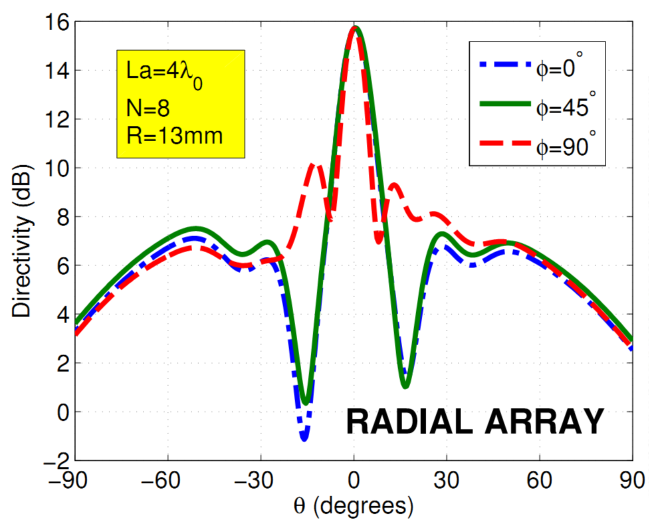
L_A/λ_0	$\alpha/k_0 = \beta/k_0$	$W(mm)$	$P(mm)$	$D_E(dB)$	$D_A(dB)$
3	0.061	6.75	4.45	9.98	14.59
4	0.046	6.87	4.10	11.13	15.73
5	0.037	6.95	3.85	11.92	16.85
6	0.031	7.00	3.66	12.67	17.05

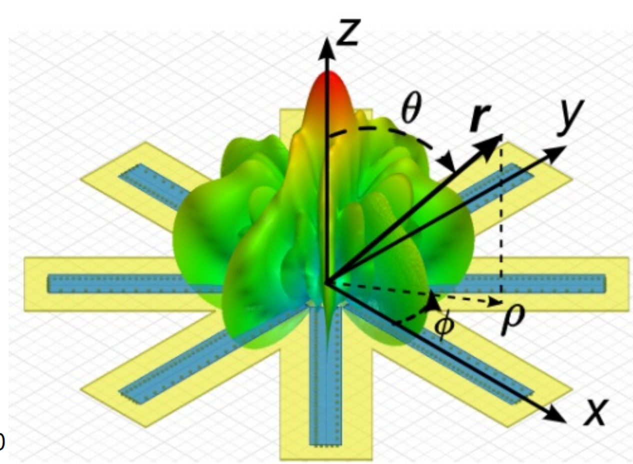




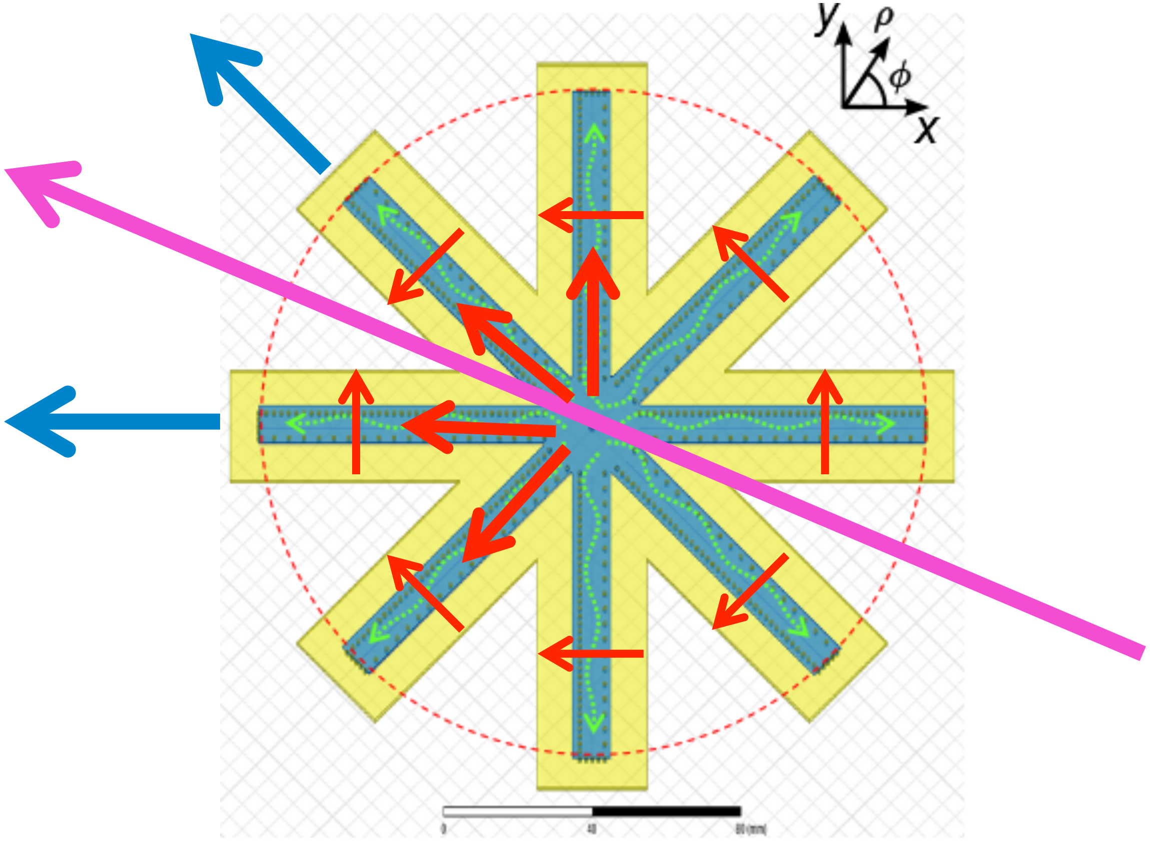




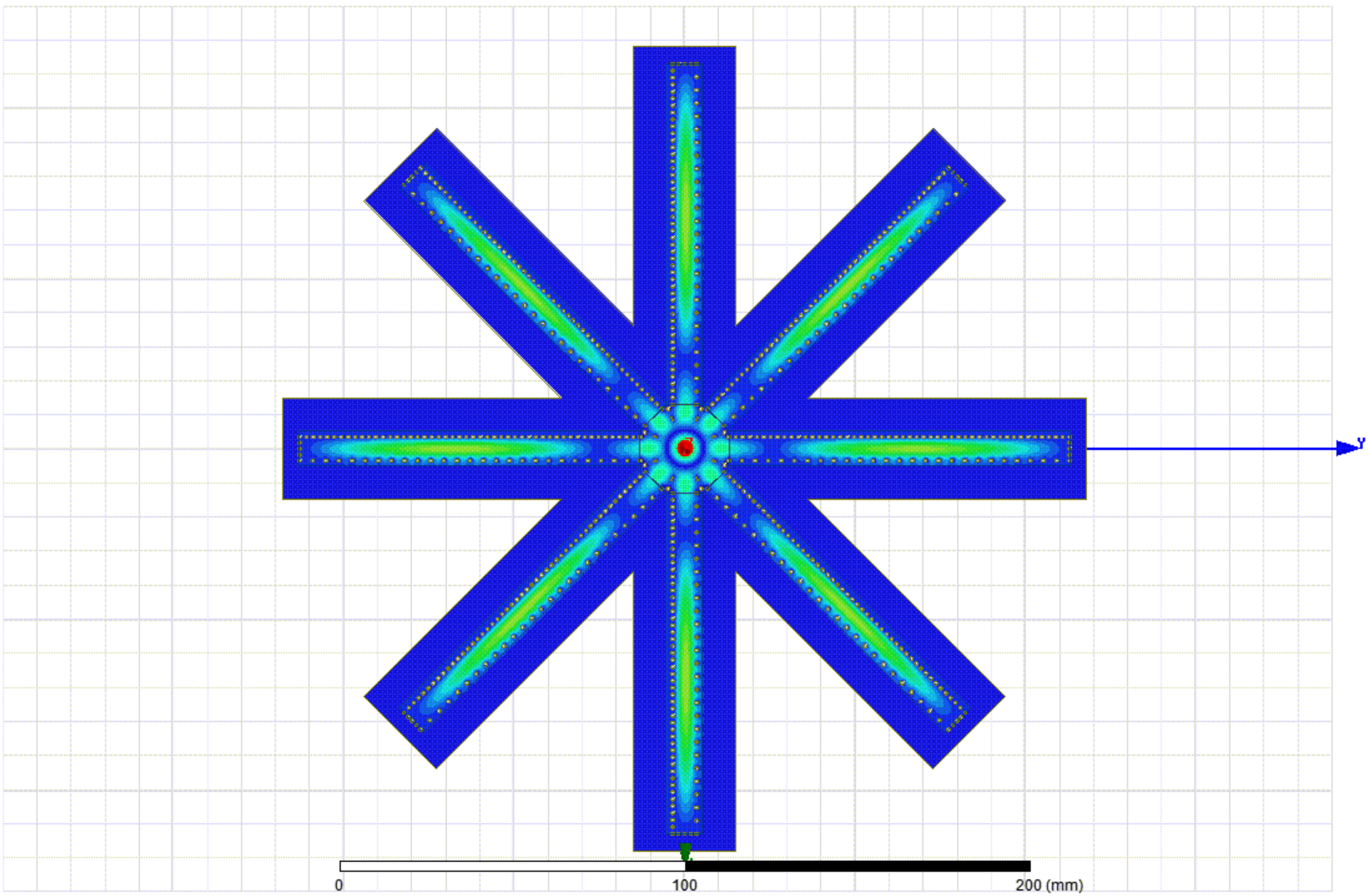




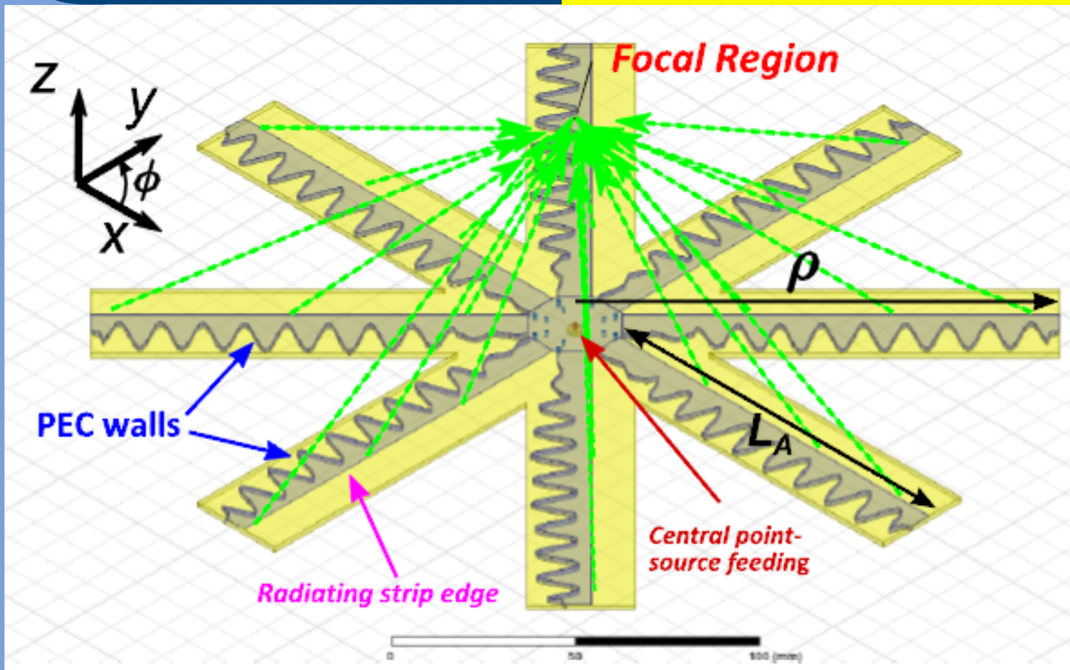
Linear Polarization



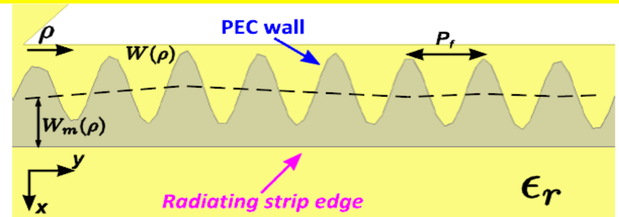
3- Future: **Radial Array of SIW antennas focused in Far Field**

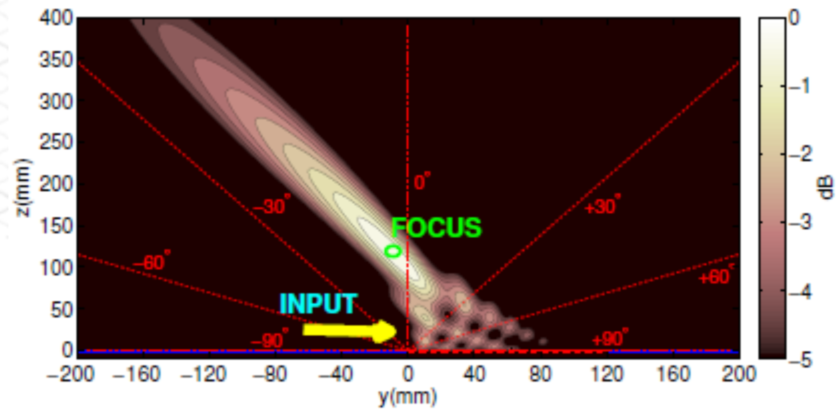


3- Future: Radial Array of SIW antennas focused in Near Field

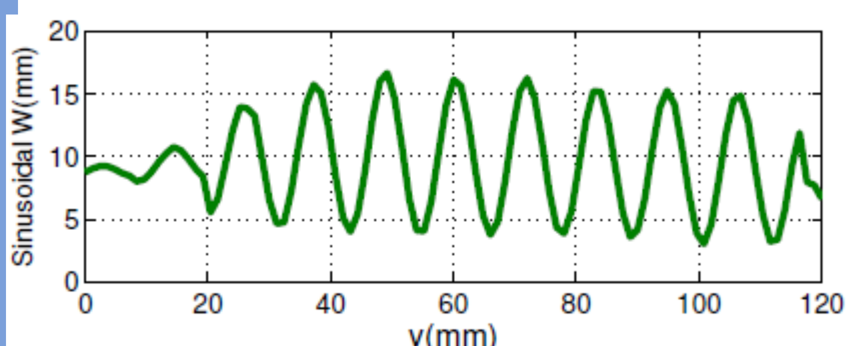


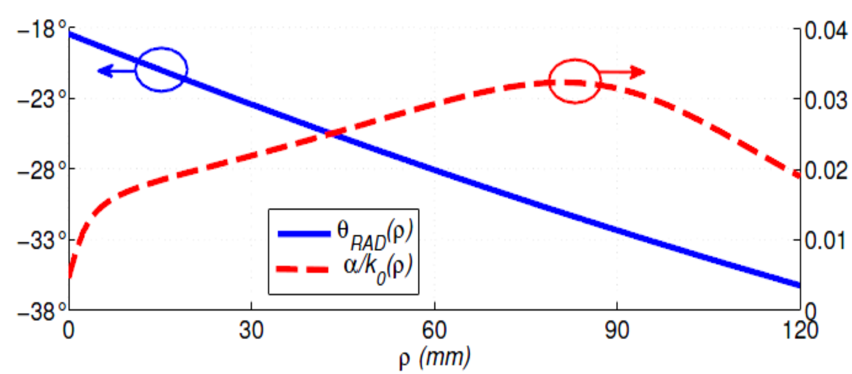
Sinusoidal modulation to excite higher-order space harmonic in backward leaky regime



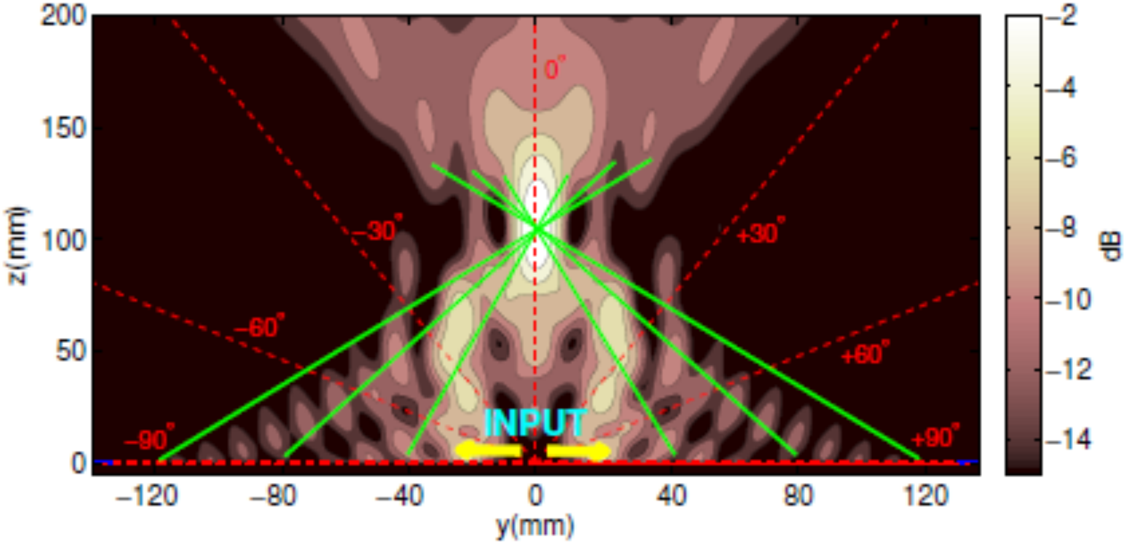


$$W(y) = W_m(y)\left[1 + M(y)\sin\left(\frac{2\pi}{P}y\right)\right]$$



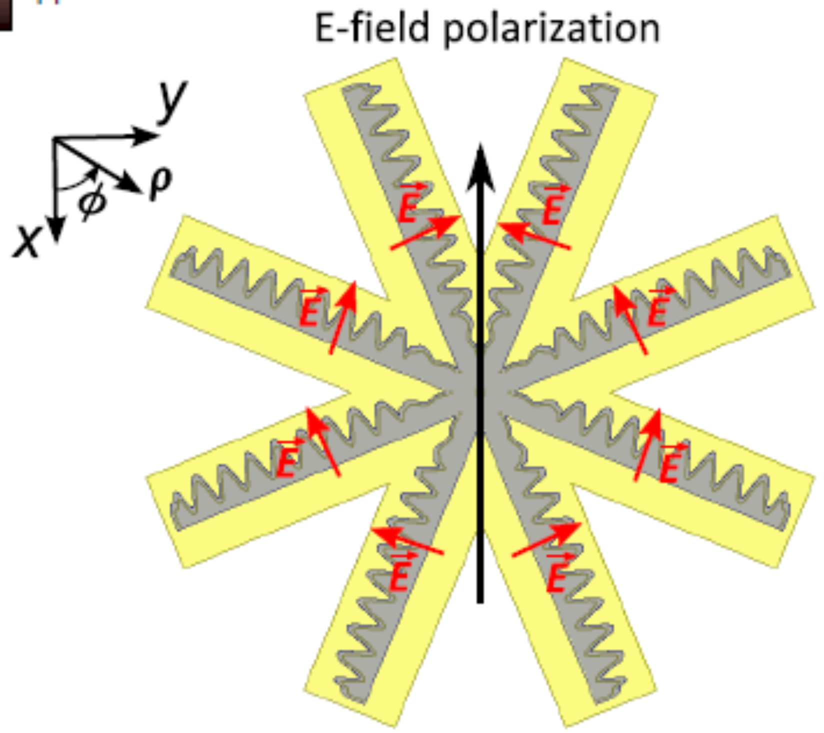


3- Future: Radial Array of SIW antennas focused in Near Field

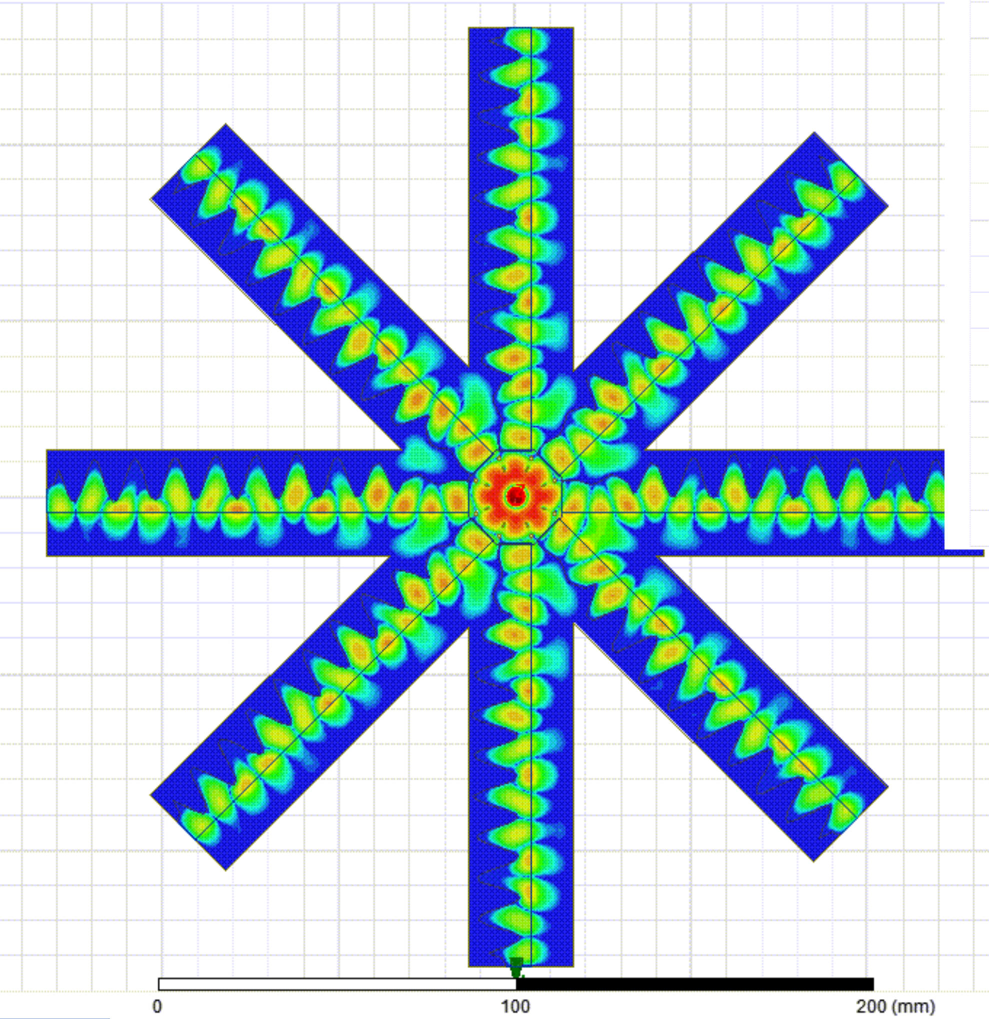


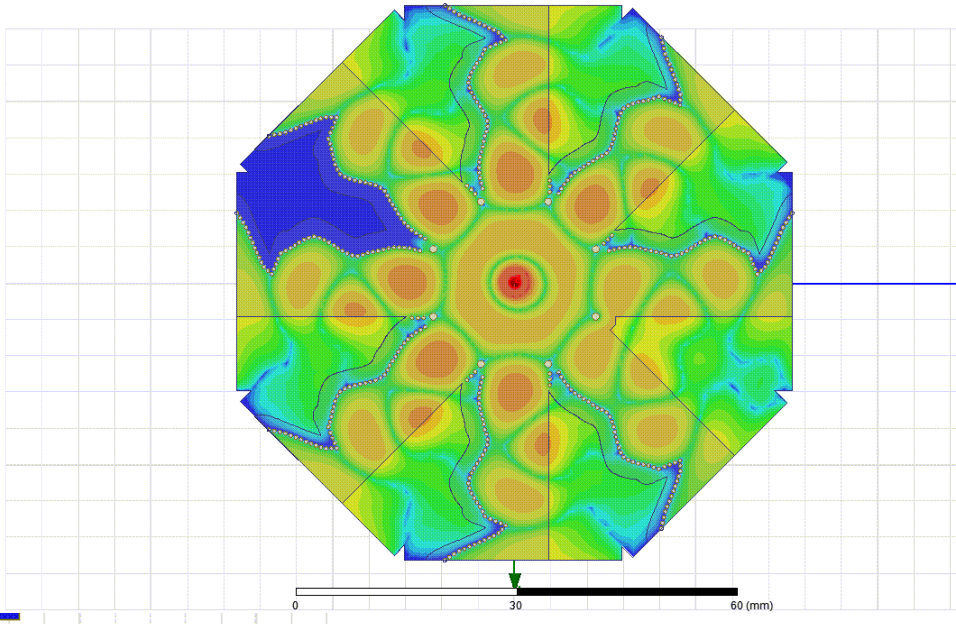
CONSTRUCTIVE INTERFERENCE IN THE NEAR-FIELD FOCUSED SPOT z=110mm @15GHz

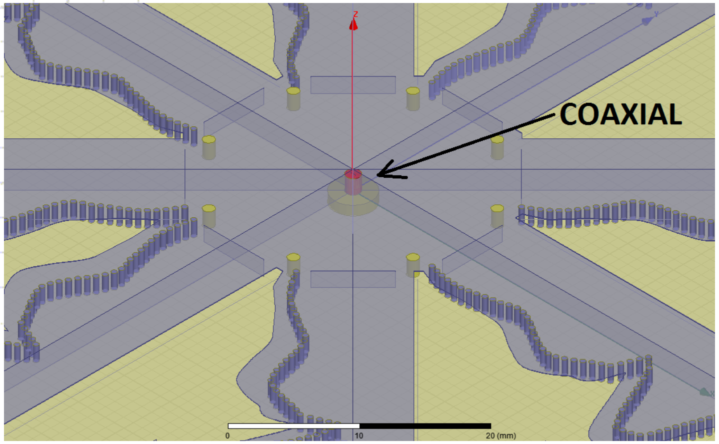
LINEAR POLARIZATION



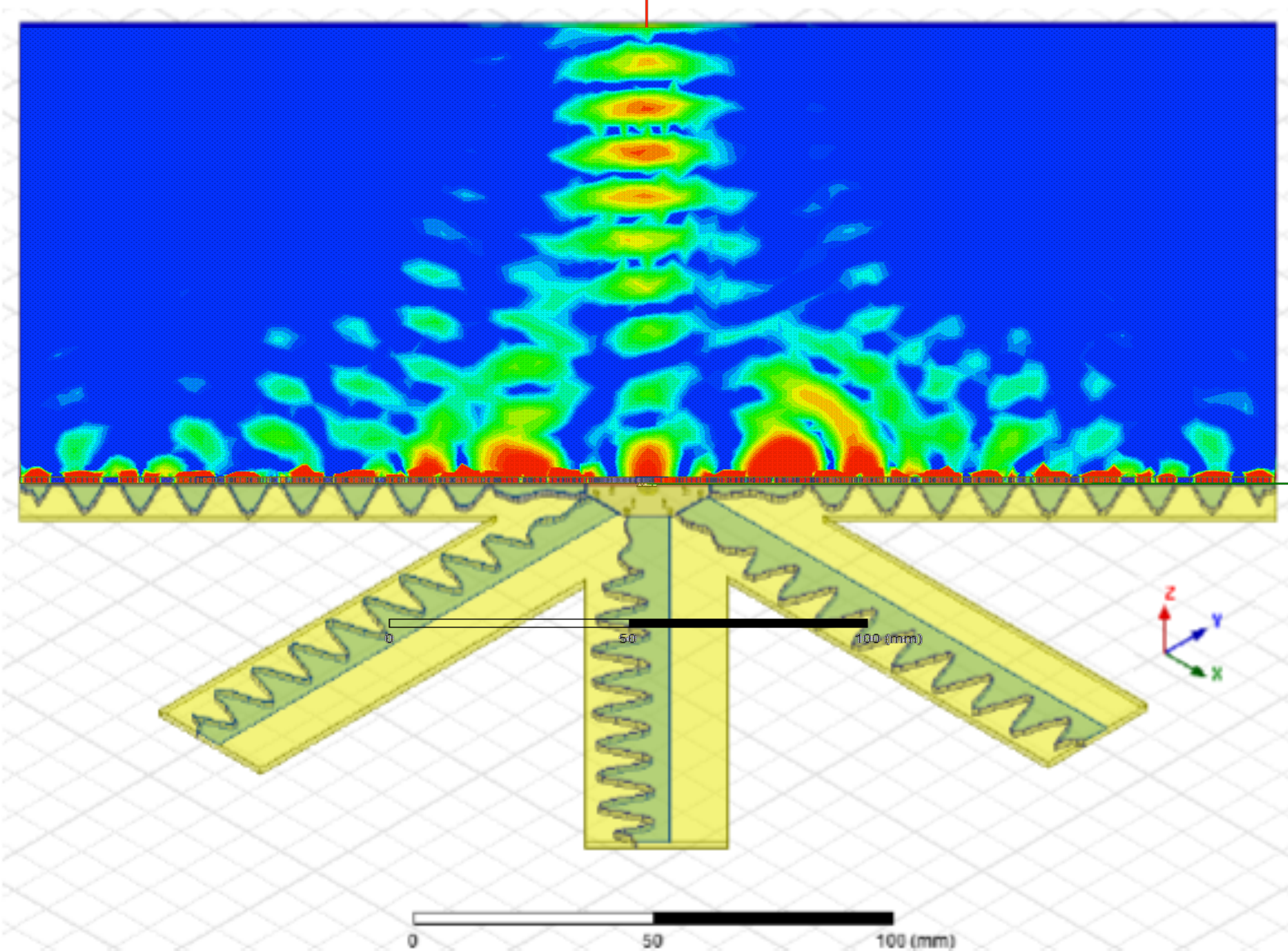
3- Future: Radial Array of SIW antennas focused in Near Field

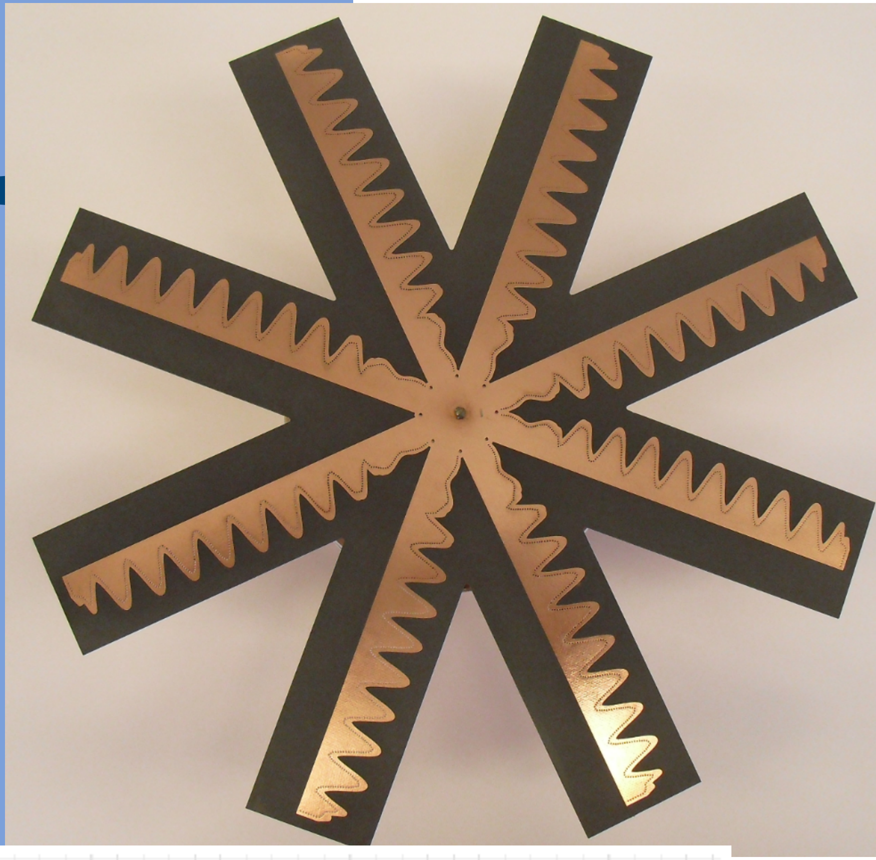


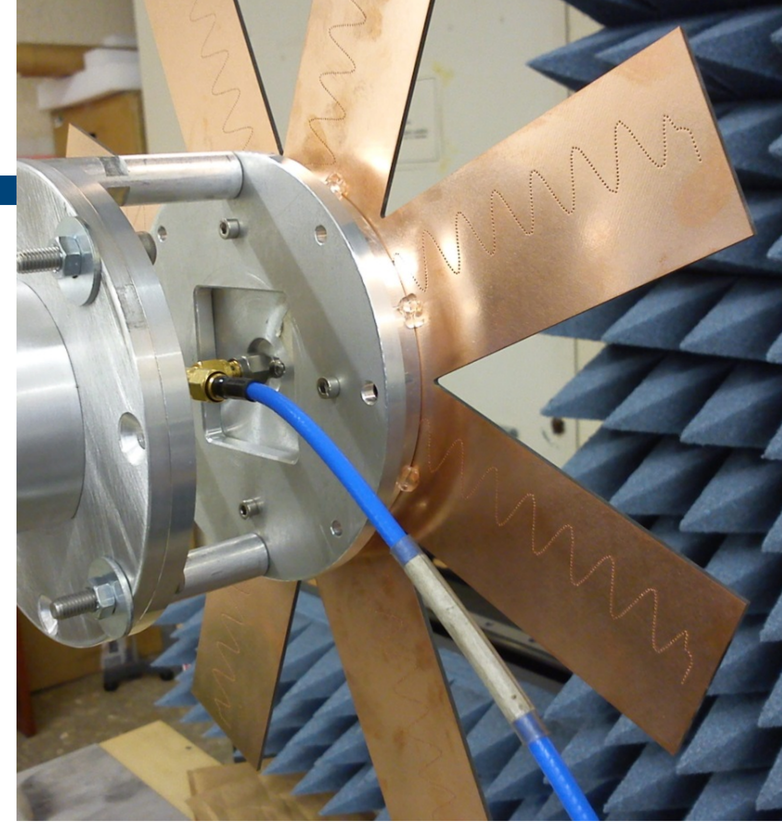


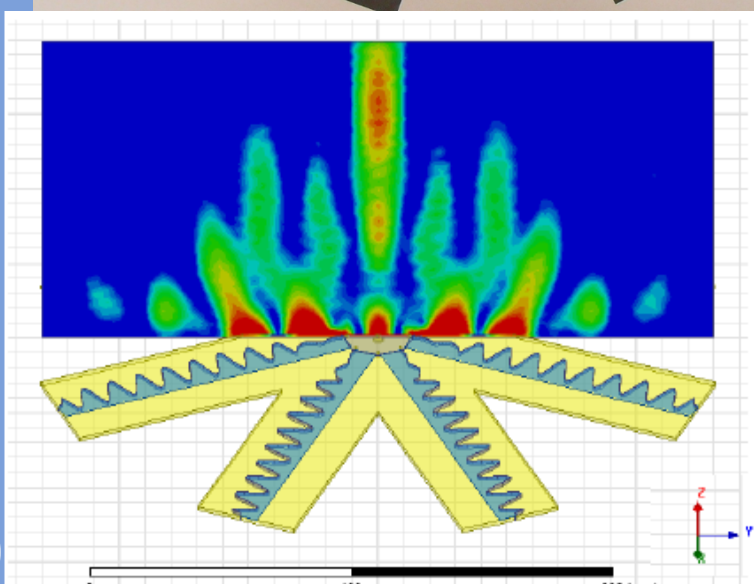


3- Future: Radial Array of SIW antennas focused in Near Field

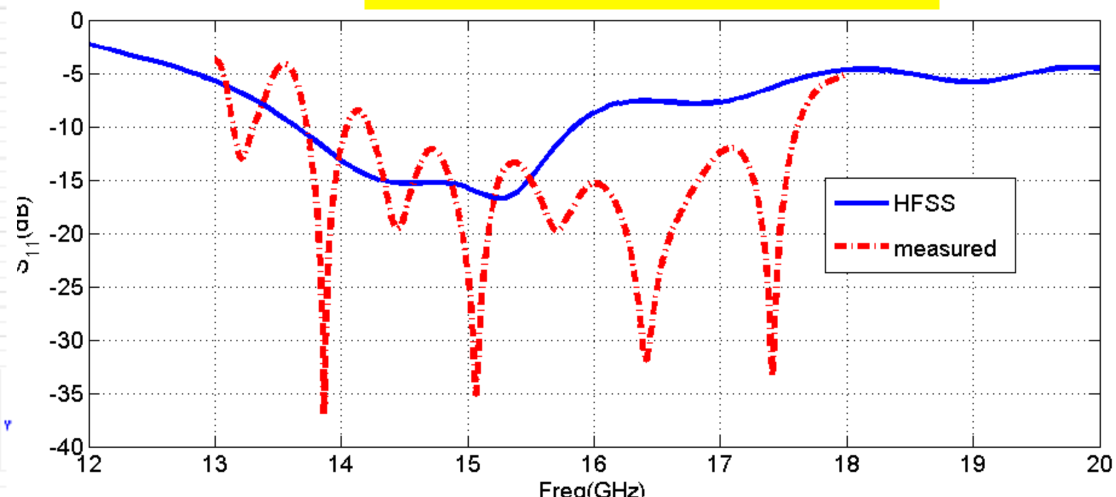








S11<-20dB @15GHz

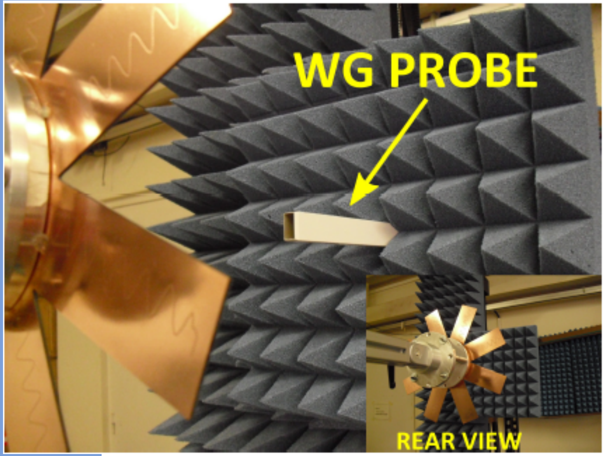


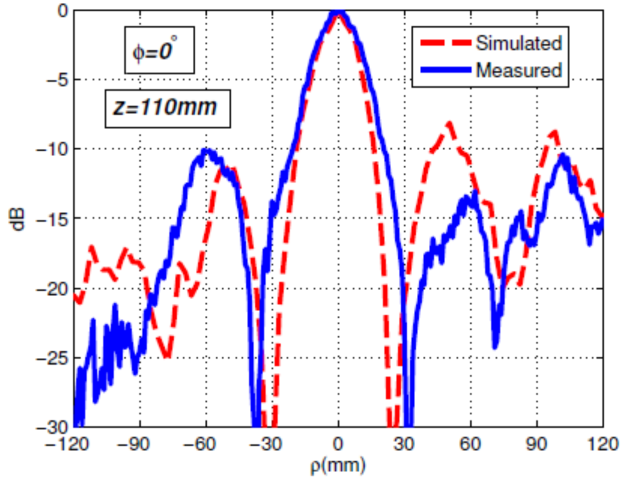
IC130

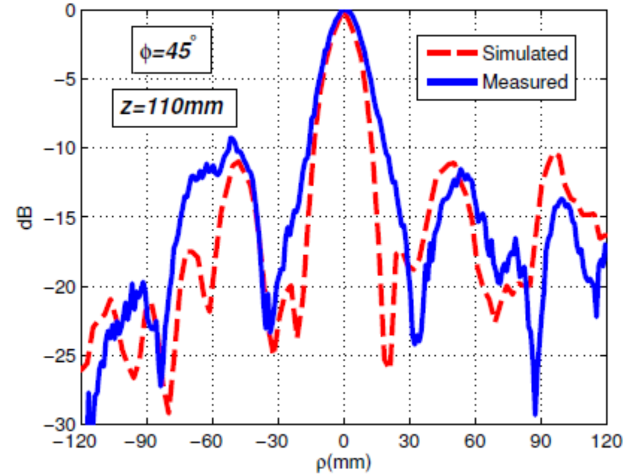
Radial Array of SIW antennas focused in Near Field

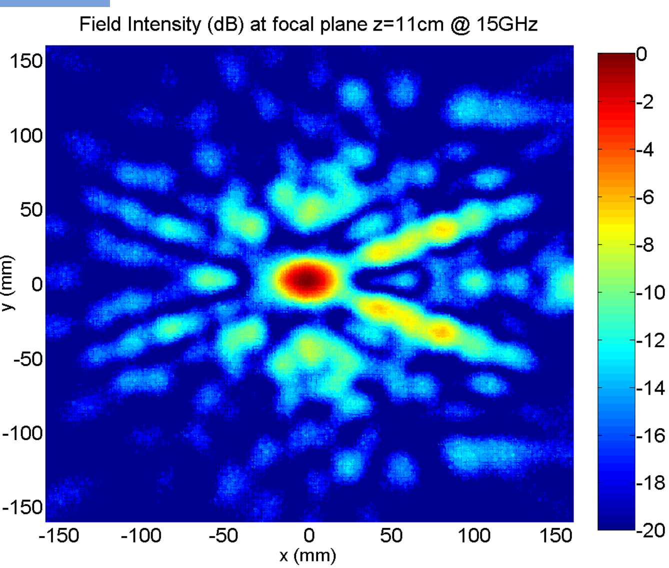
WIPE
COST IC1301

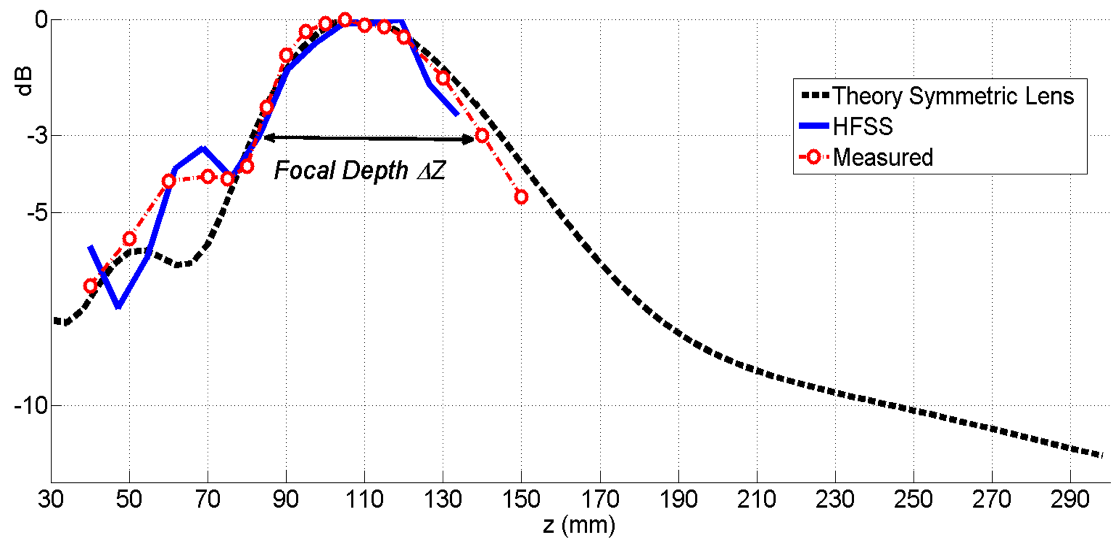
3- Future:











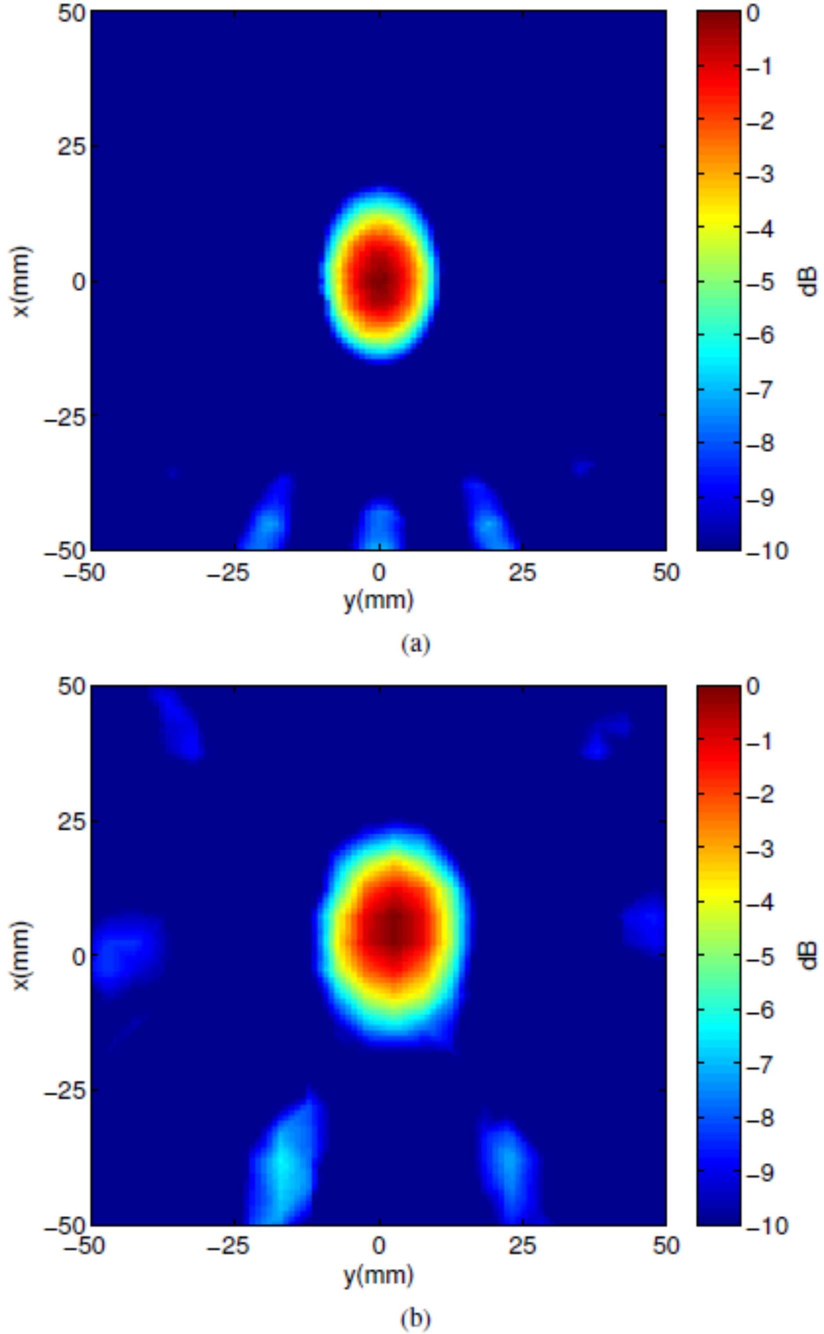


Fig. 17. Near-field plane at the focal height $z_F = 110\,\mathrm{mm}$ for the design frequency of 15 GHz: a) simulated and b) measured.

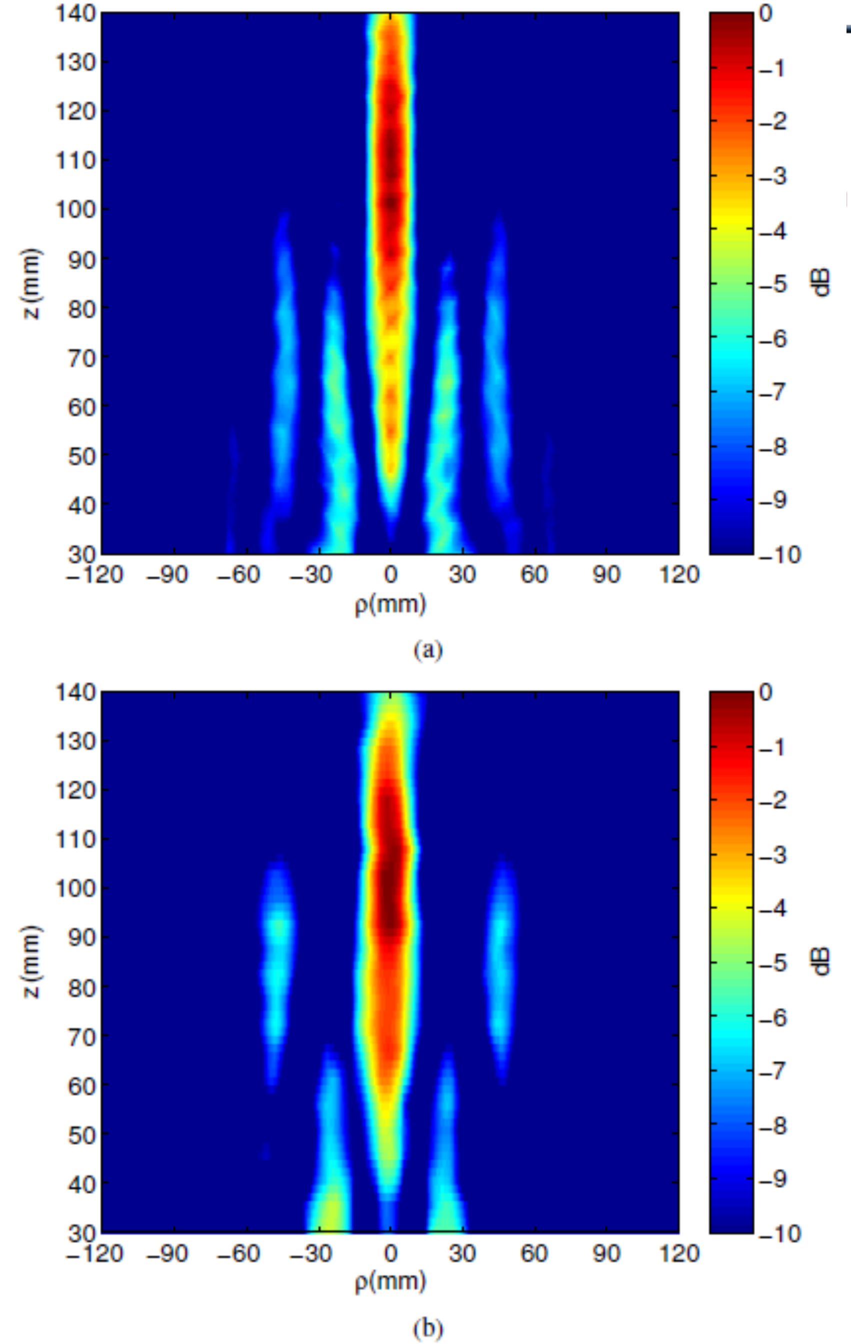
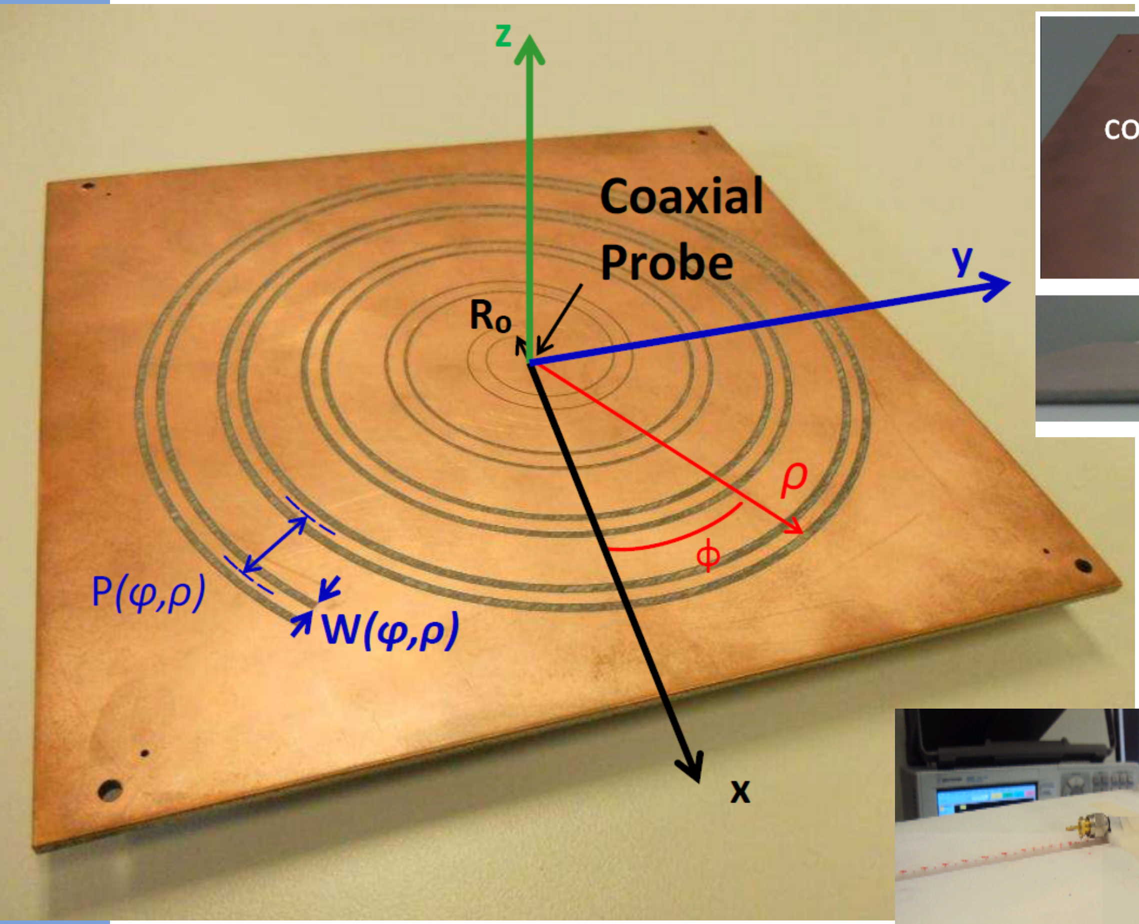
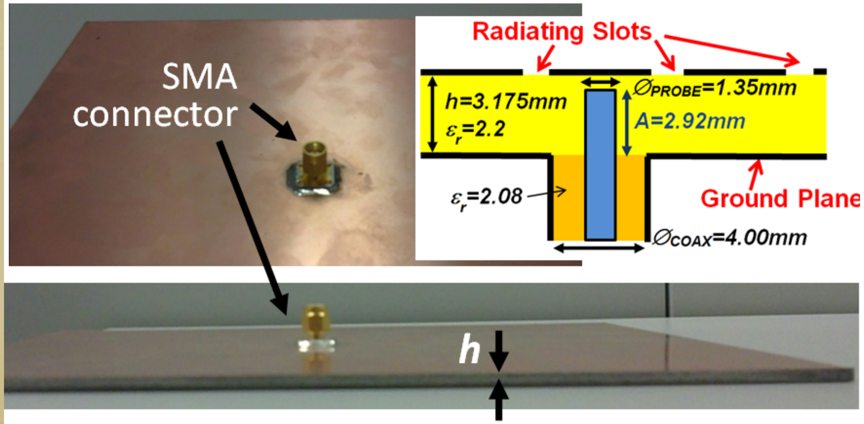
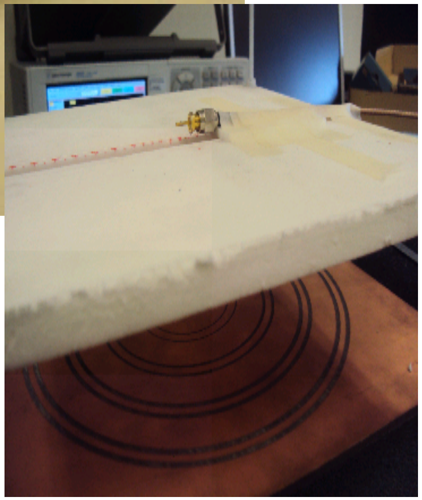


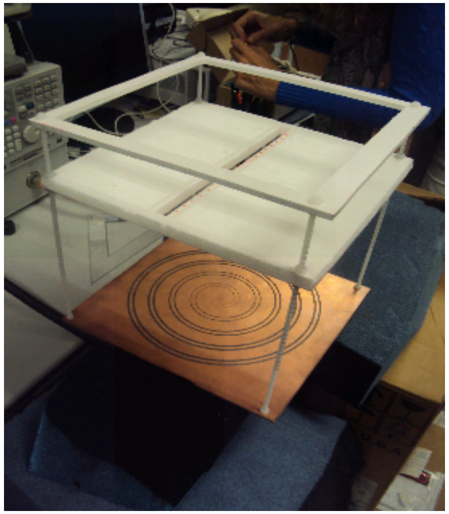
Fig. 18. Near-field plane at $\phi = 0°$ along the z-axis for the design frequency of 15 GHz: a) simulated and b) measured.

Fully-2D holographic lens focused in Near Field





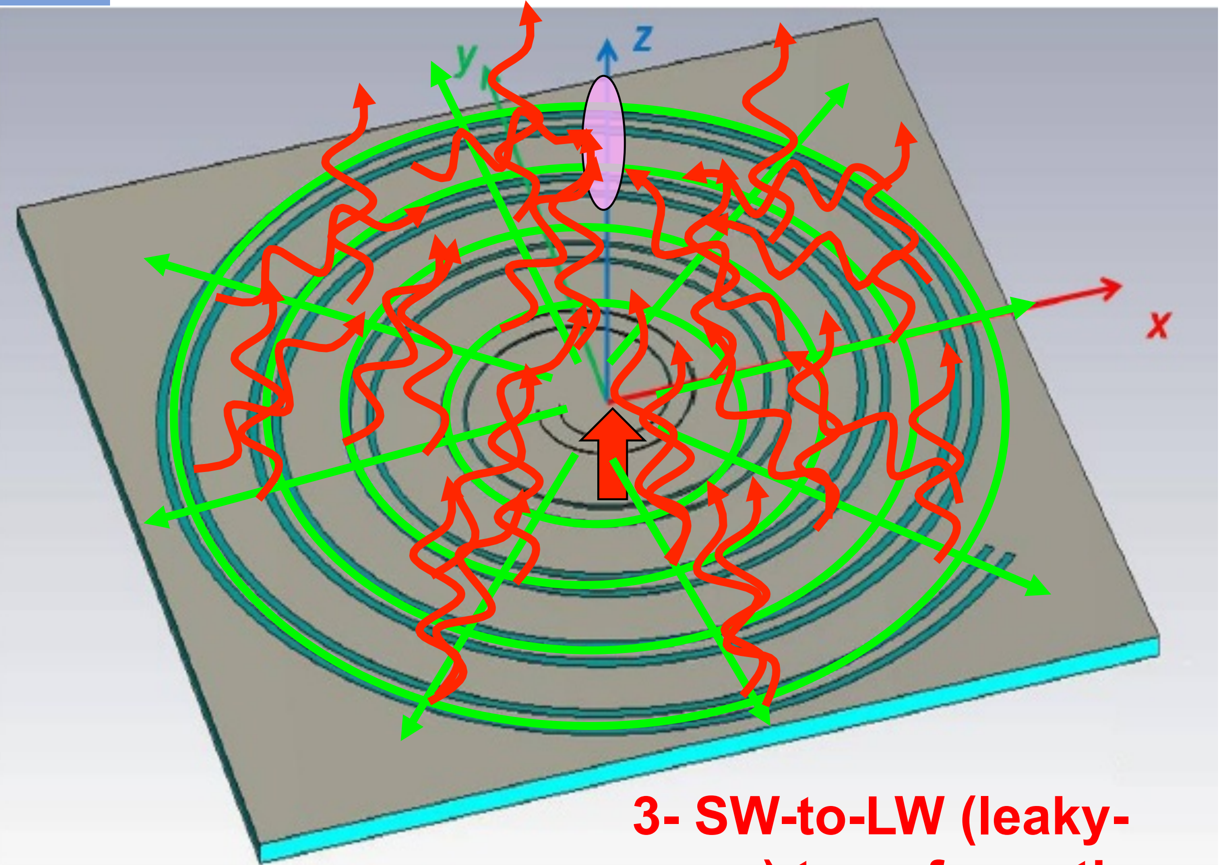




1-Motivation. Planar microwave lenses.

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:

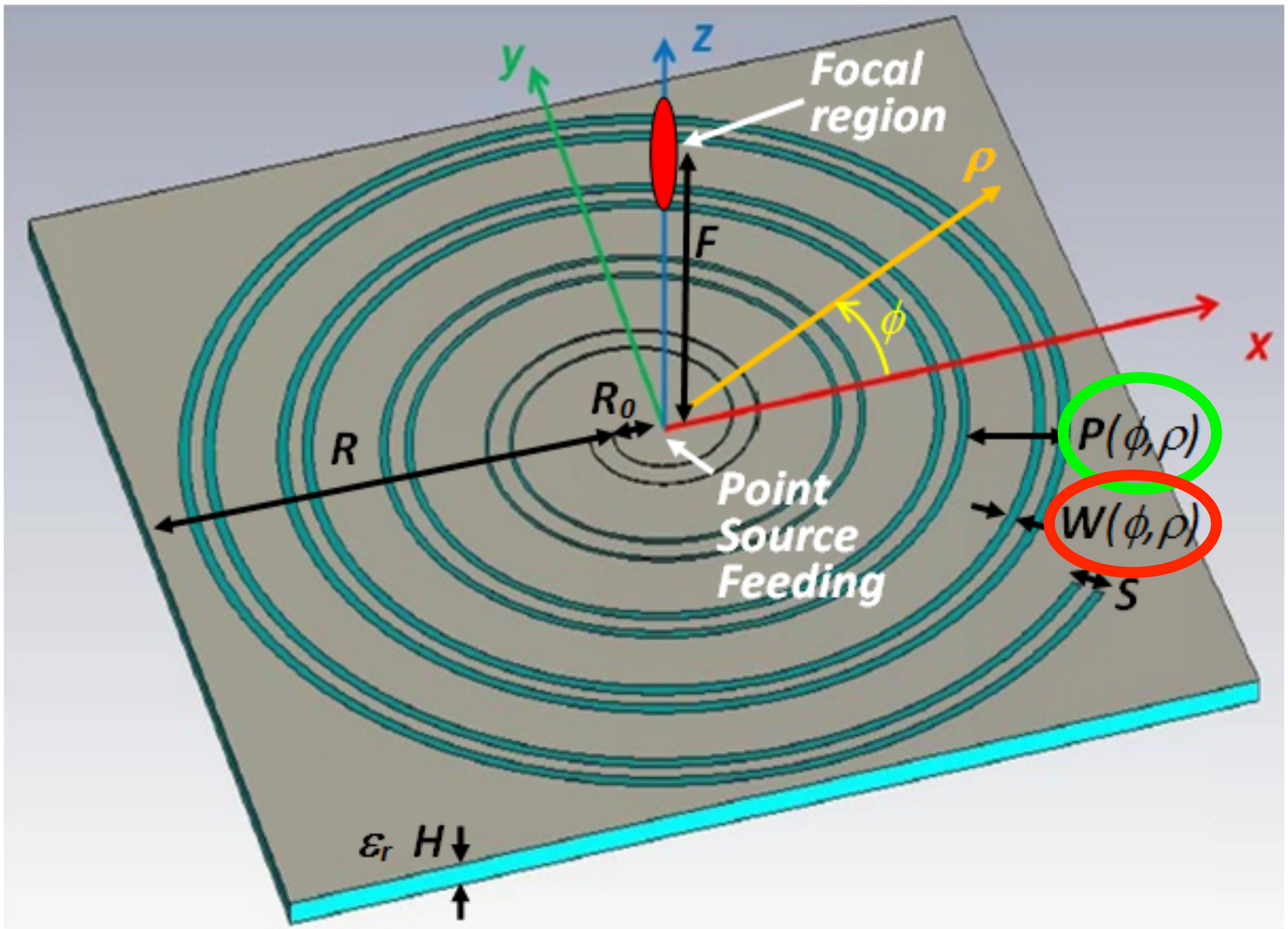
- Near-field focusing.
- Simple feeding.
- Planar low-profile structure.
- Simple printed-slot circuit.
- Direct analysis and design.

Applications:

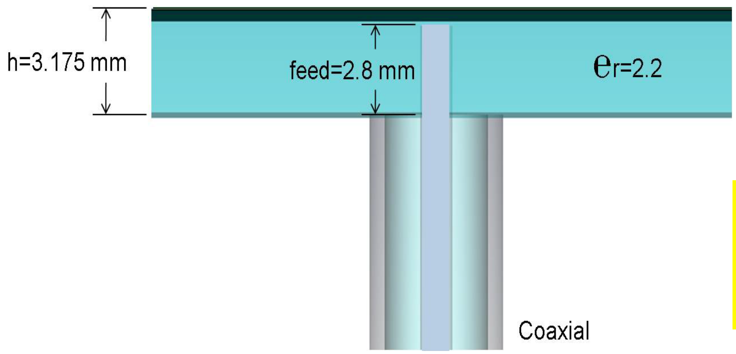
- Imaging/sensing.
- Heating.
- Power transmission.

1-Motivation. Planar microwave lenses.

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



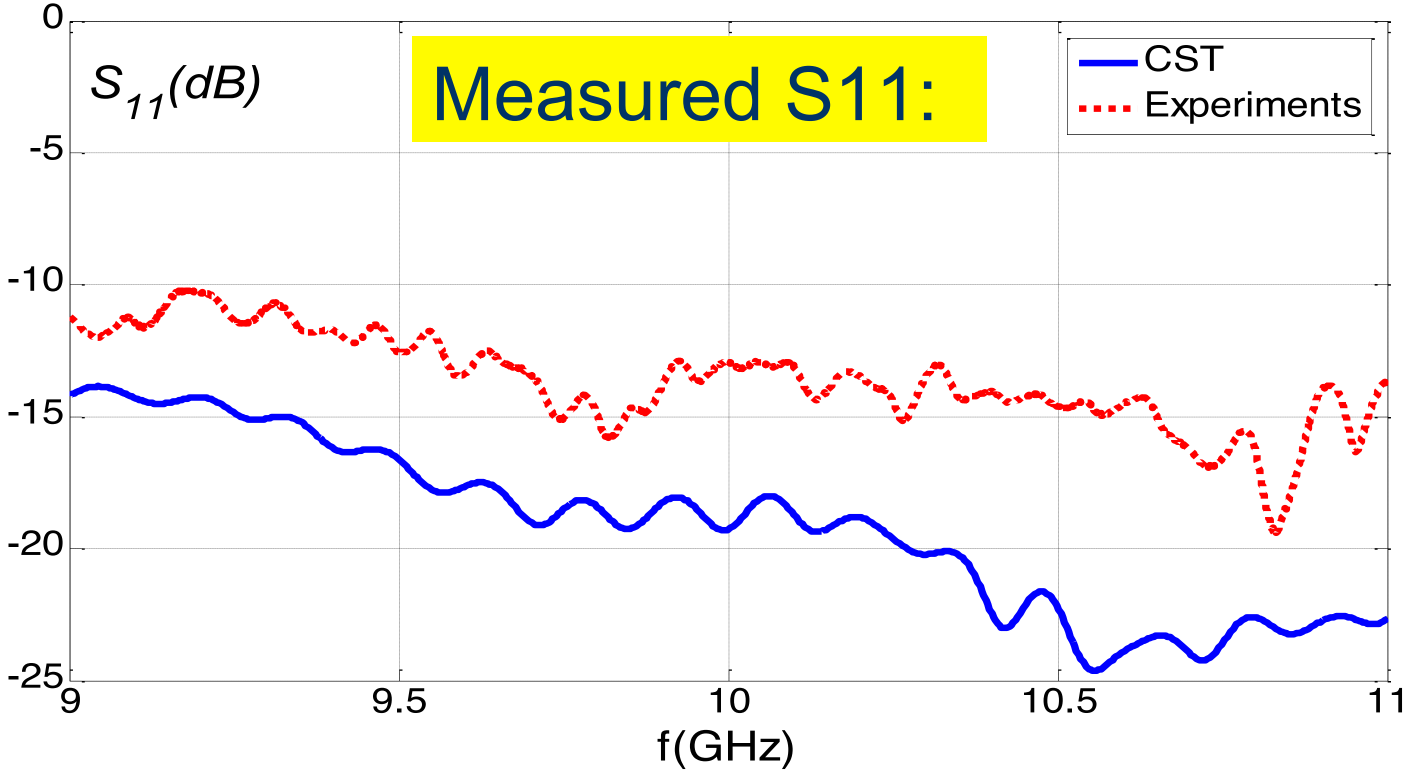
4- Theoretical and Experimental results.



FEEDING PROBE
∅=1.35mm h=2.92mm

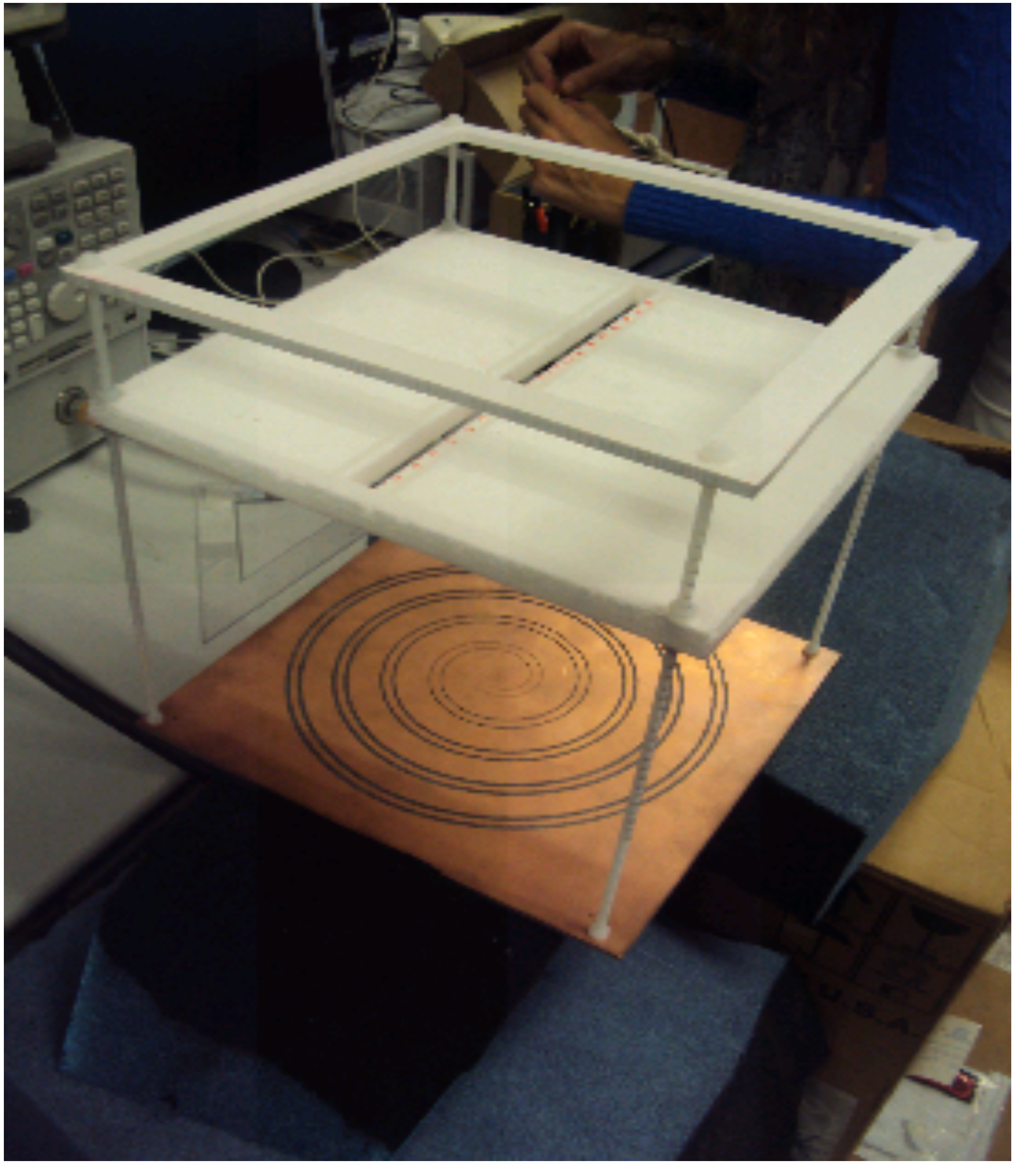
COAX **$\varnothing_{IN}$=1.35mm** ***ε_r=2.08***
R_{IN}=0.675mm **R_{OUT}=2.00mm**

Measured S11:



4- Theoretical and Experimental results.

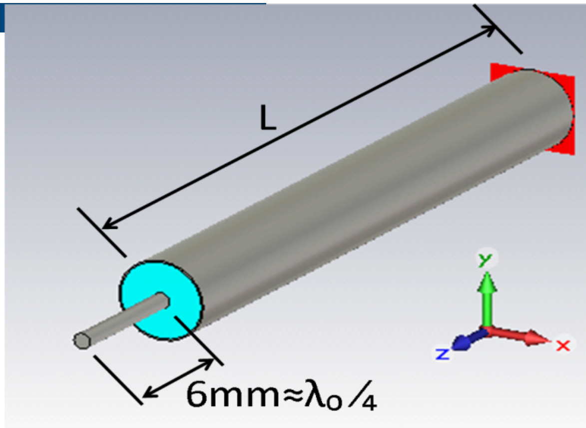
Experimental
Near-Field Setup:

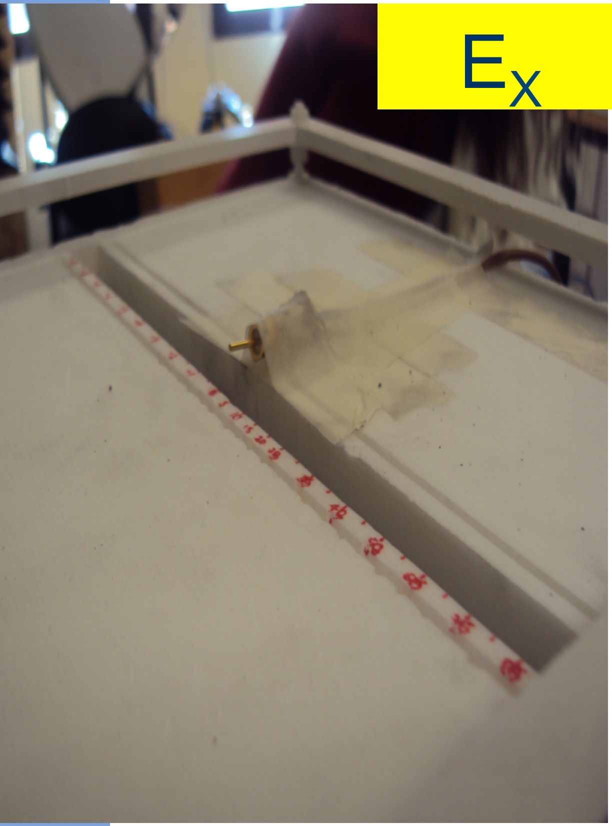


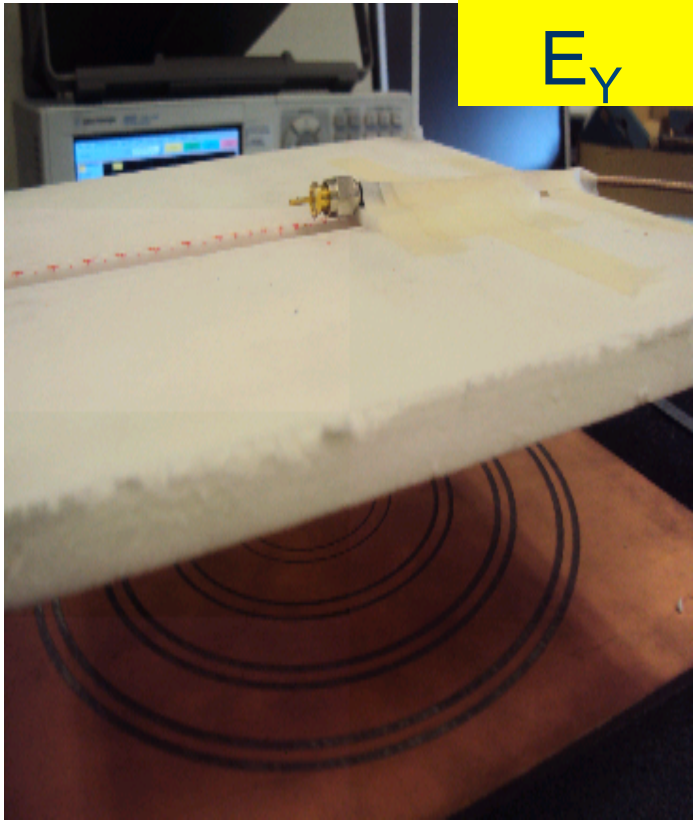
4- Theoretical and Experimental results.

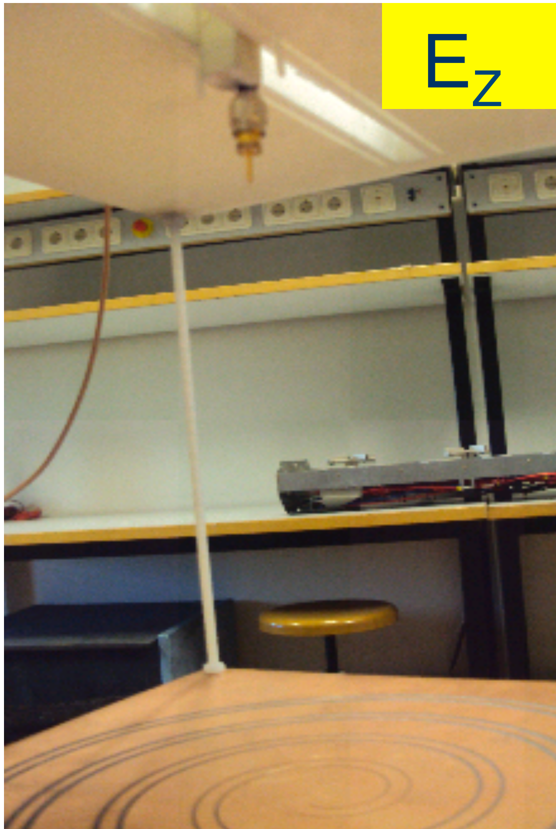
Experimental Near-Field Setup:

- Probe:





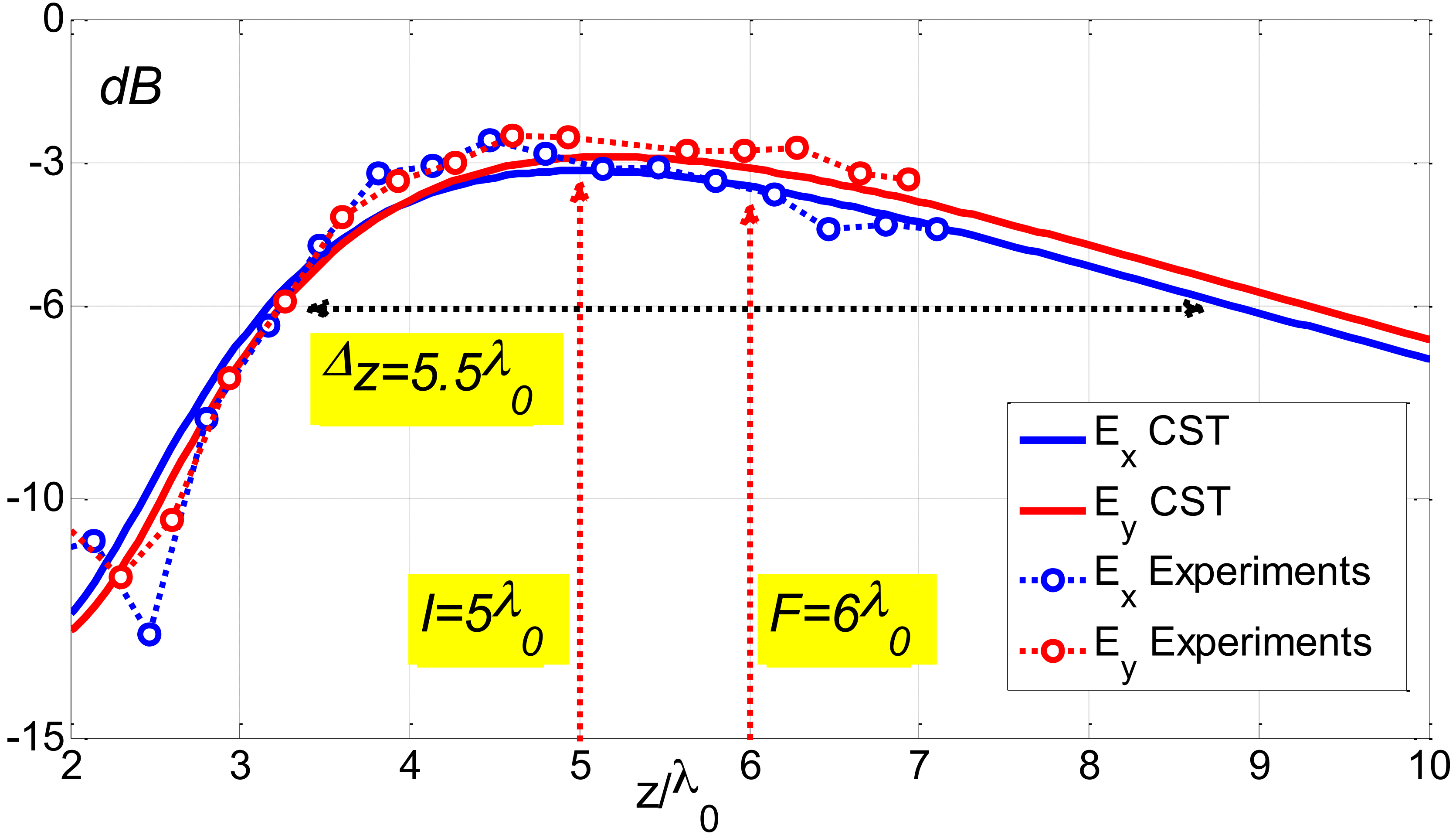




4- Theoretical and Experimental results.

Measured Near Fields:

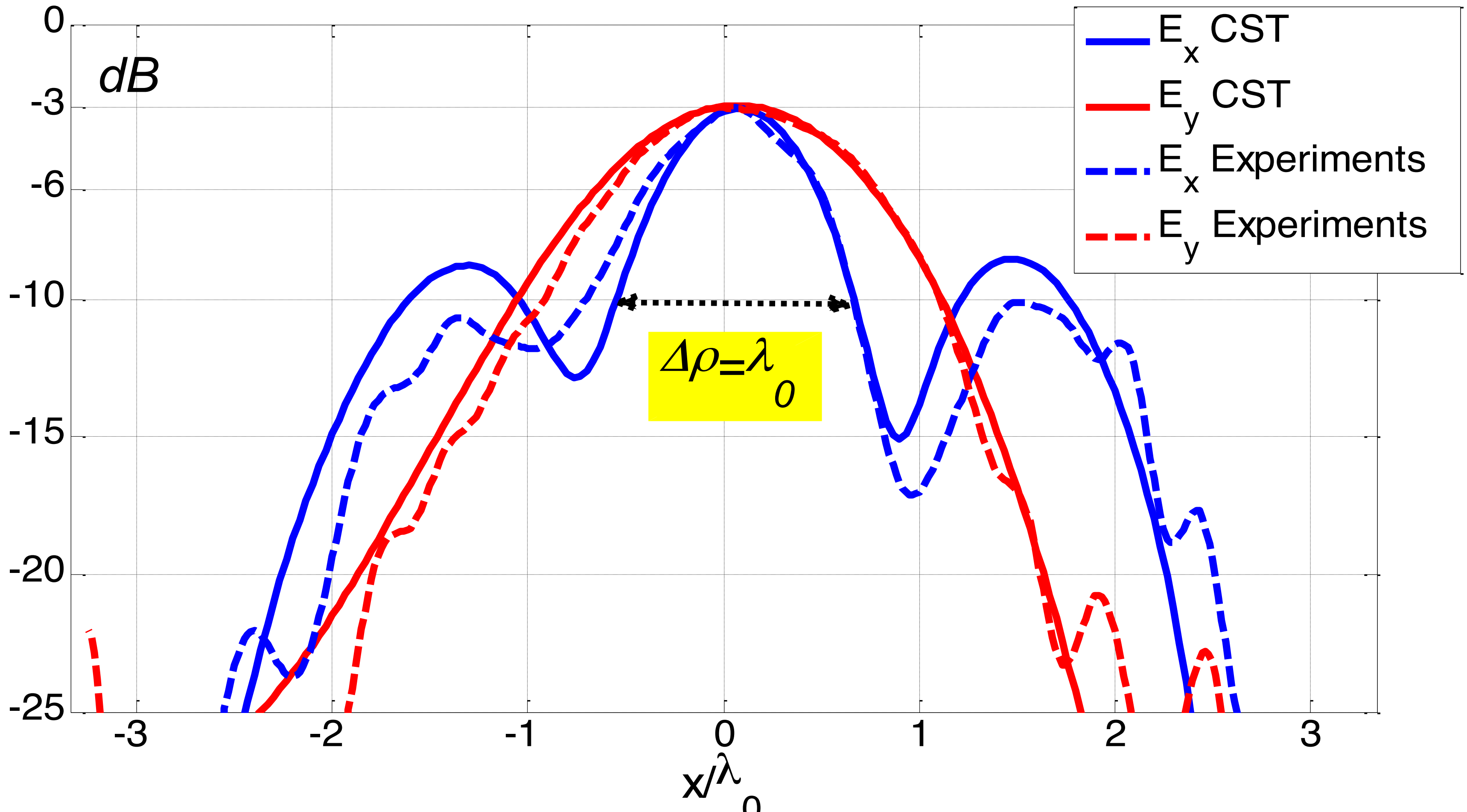
- Axial cut (z):



4- Theoretical and Experimental results.

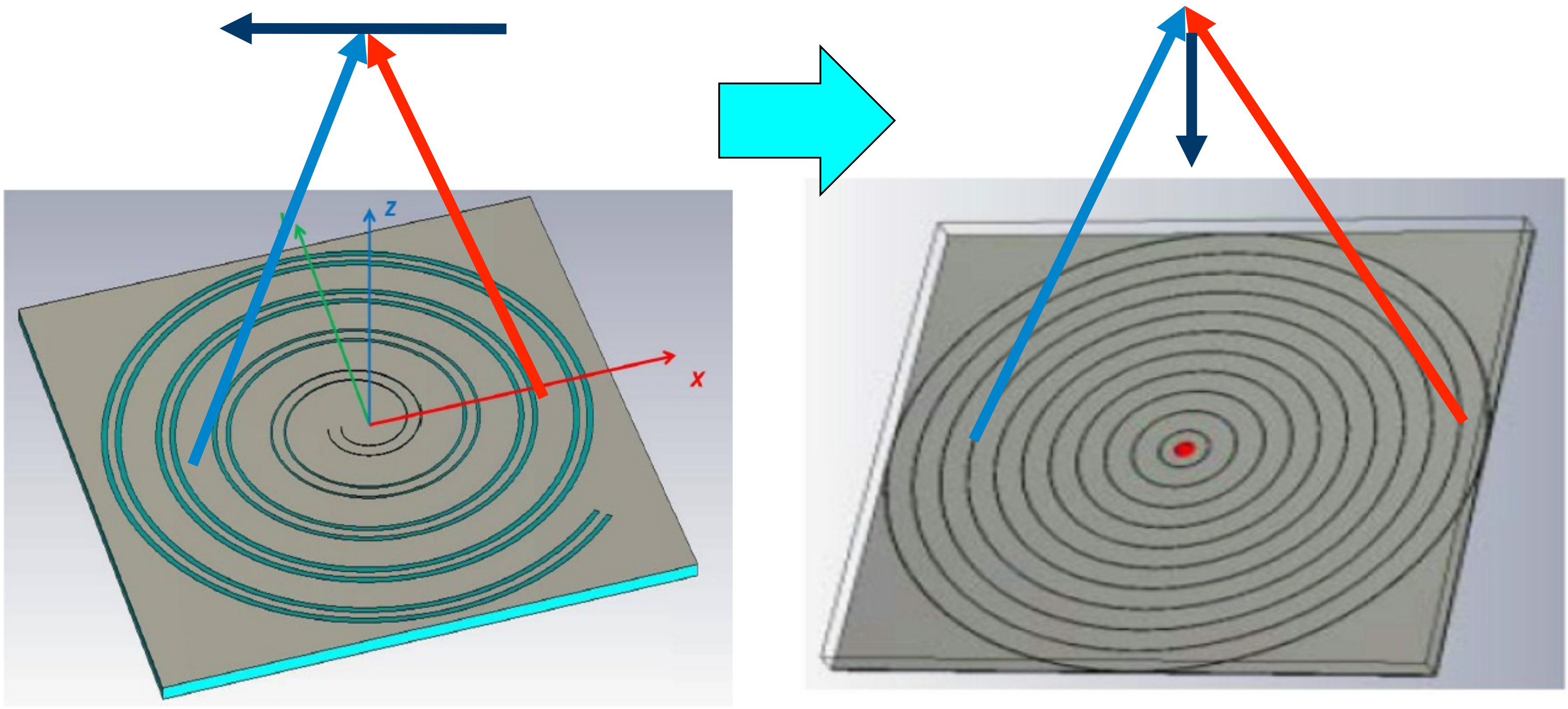
Measured Near Fields:

- Transverse cut (x):



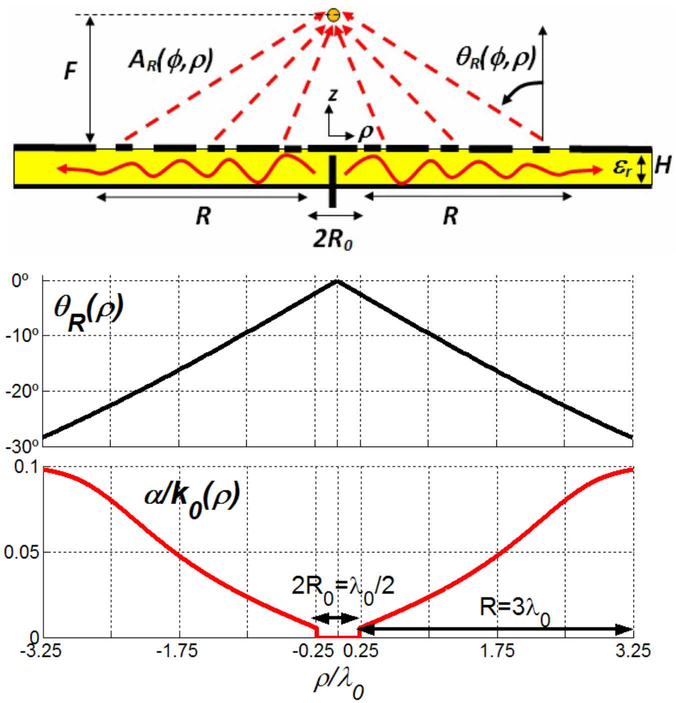
5- Future lines, conclusions.

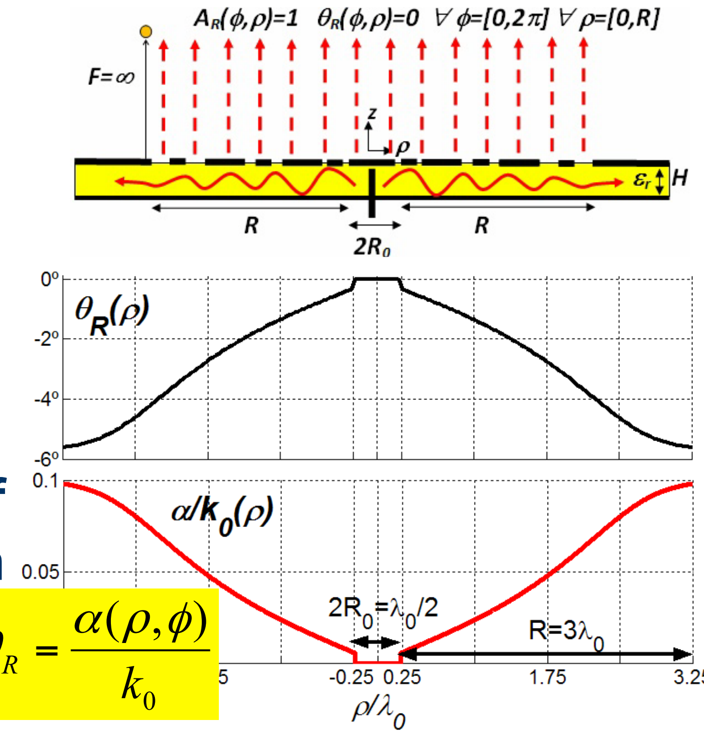
1- Design of **HLWLs with** **linear circularly and vertical polarization** (*only in the* ***near field***)



5- Future lines, conclusions.

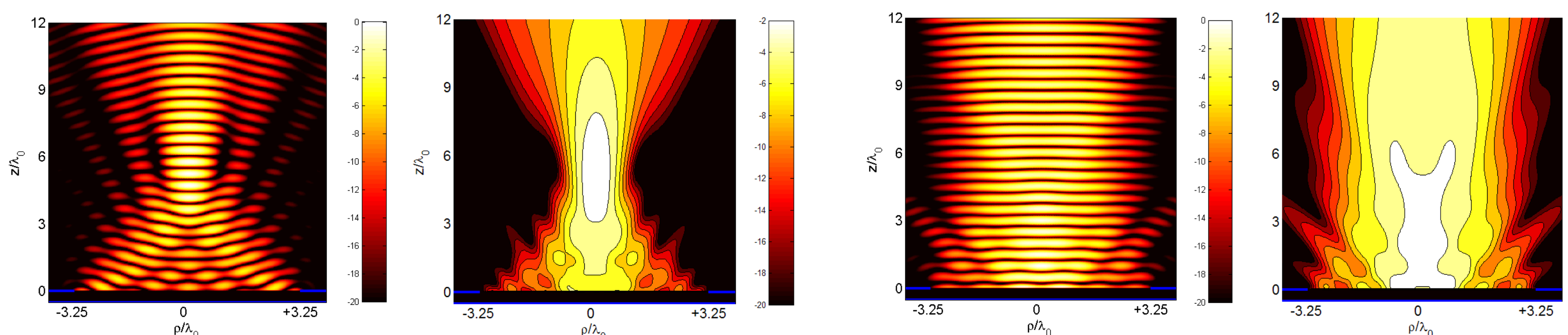
2- Design of **HLWAs focused in the far field**.





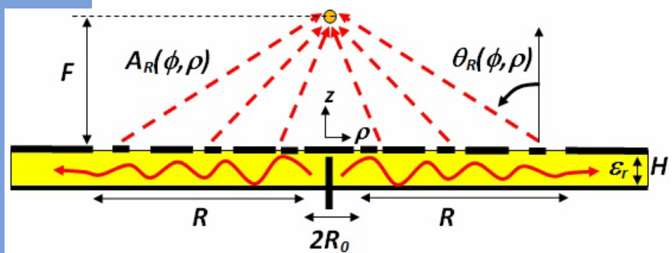
Split-off condition

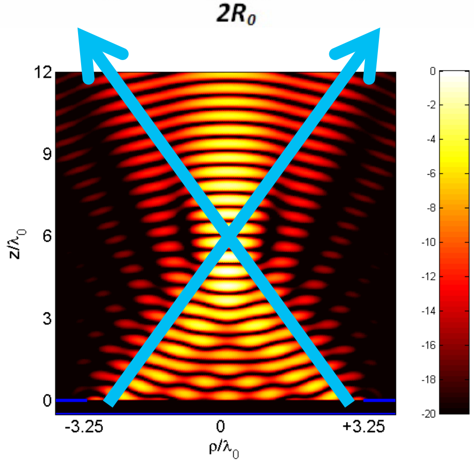
$$\frac{\beta(\rho,\phi)}{k_0} = \sin\theta_R = \frac{\alpha(\rho,\phi)}{k_0}$$

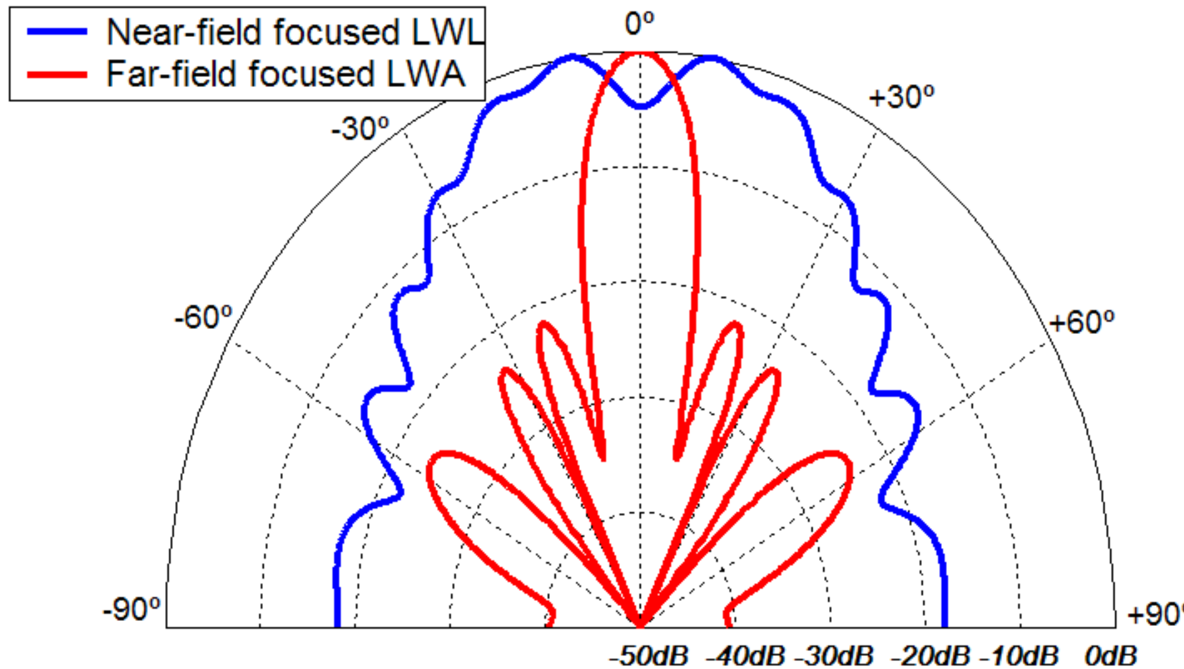


5- Future lines, conclusions.

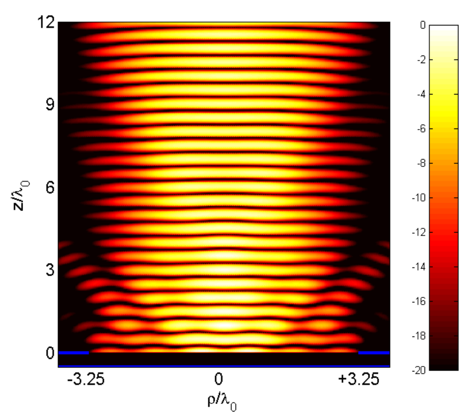
2- Design of **HLWAs focused in the** **far field**.

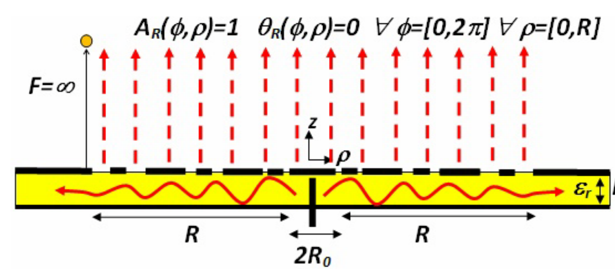






Near-field converging = Far-field diverging





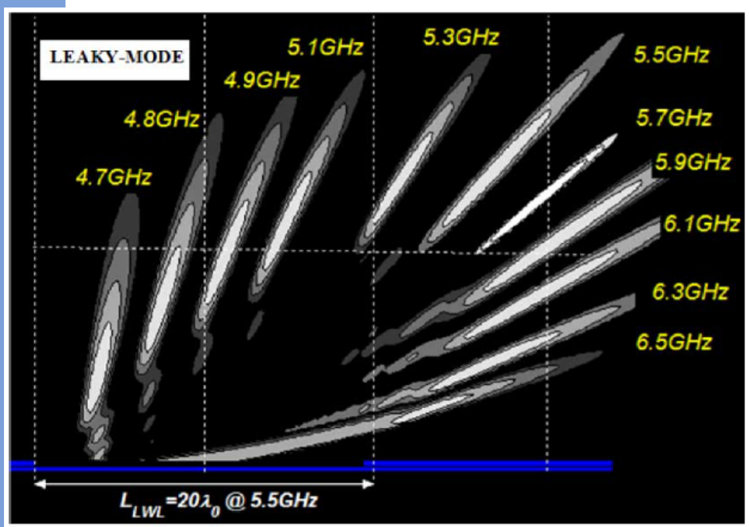
5- Future lines, conclusions.

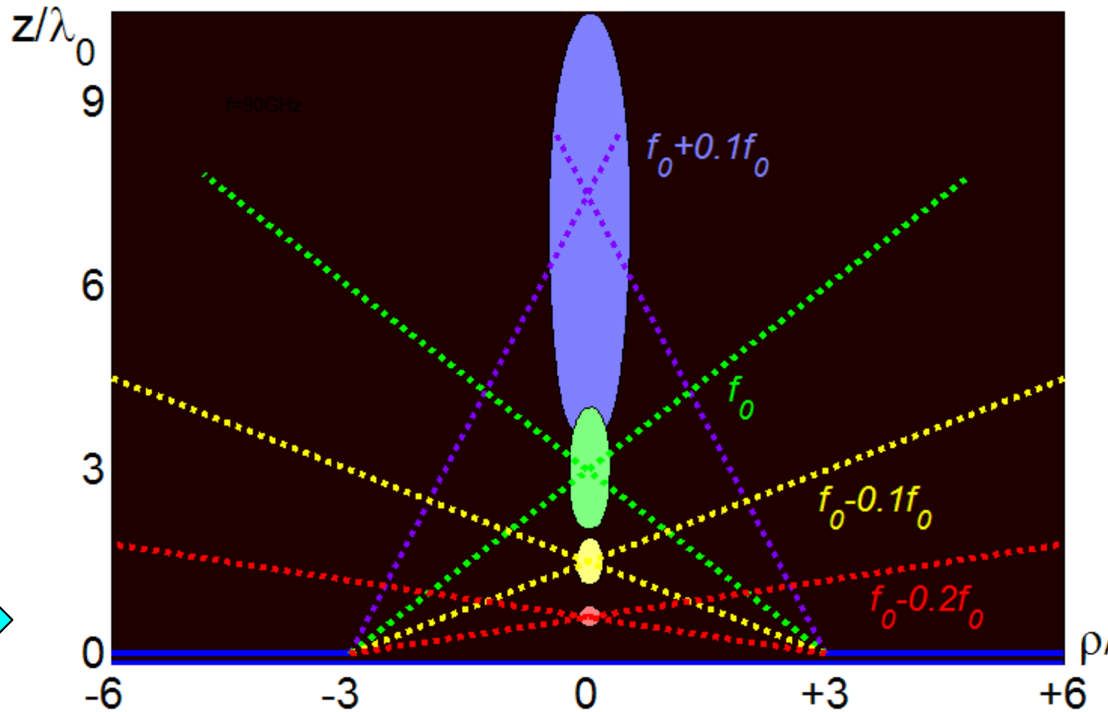
6- Study of **frequency shift** of focused region.

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*

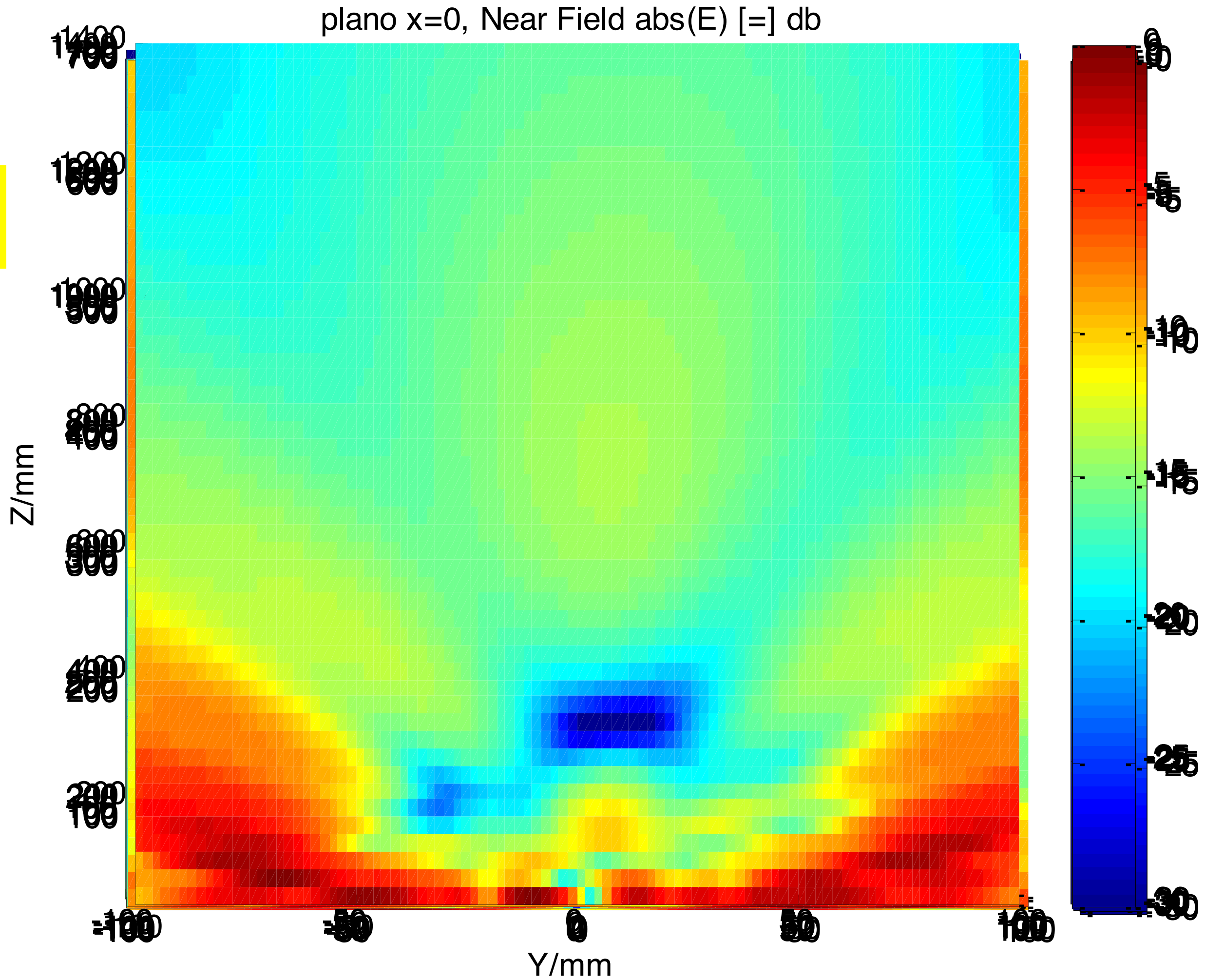




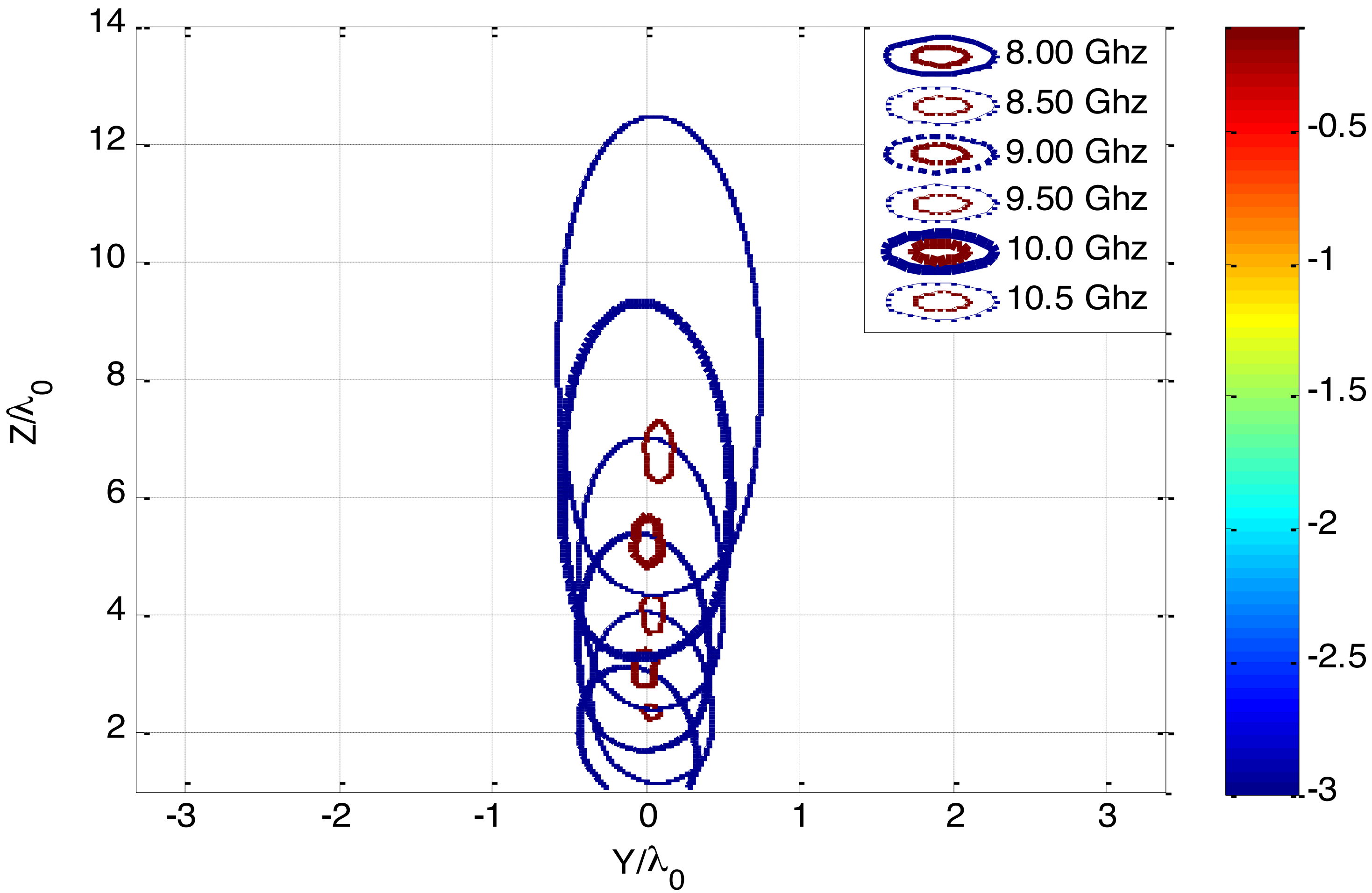
5- Future lines, conclusions.

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

15GHz



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



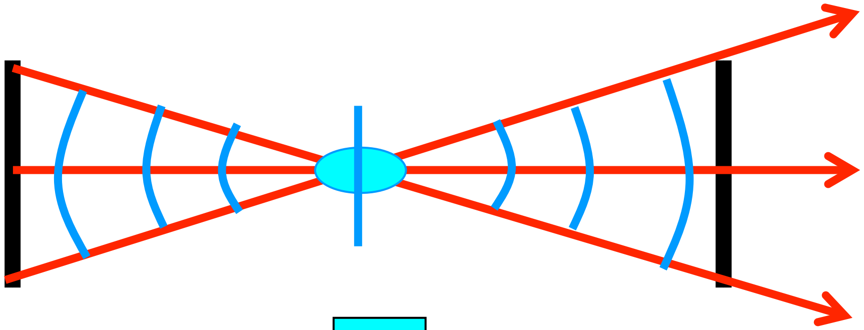
LWAs FOR IoT APPLICATIONS

Applied systems related to some of IoT/WPT/RFID concepts:

Prof. Luca Roselli :

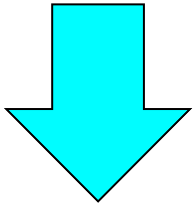
- Green electronics,
  low-power analog passive circuits
- Smart devices / Analog Signal Processing
- Quasi-optic operation / Dispersion engineering (time, space, frequency).
- Wearable antennas, smart floor, smart skin.
- Dimensions are not such a big problem, electrically large antennas !
- Distributed antennas, space power combining

Near-field focused WPT
(common focus)



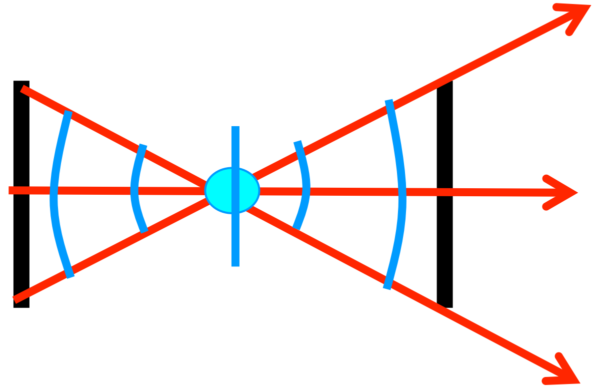
Prof. Paolo
Nepa

Prof. Huib Visser



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

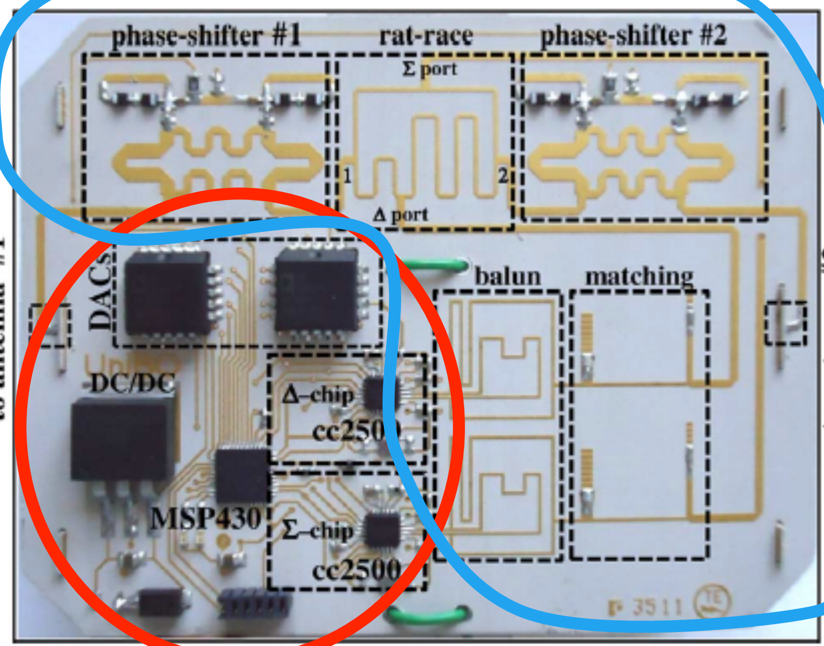
Electronic control on the focal distance = electronic control on the WPT range without losing beaming efficiency !!



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



ph of the prototype of the 2

DSP active circuits

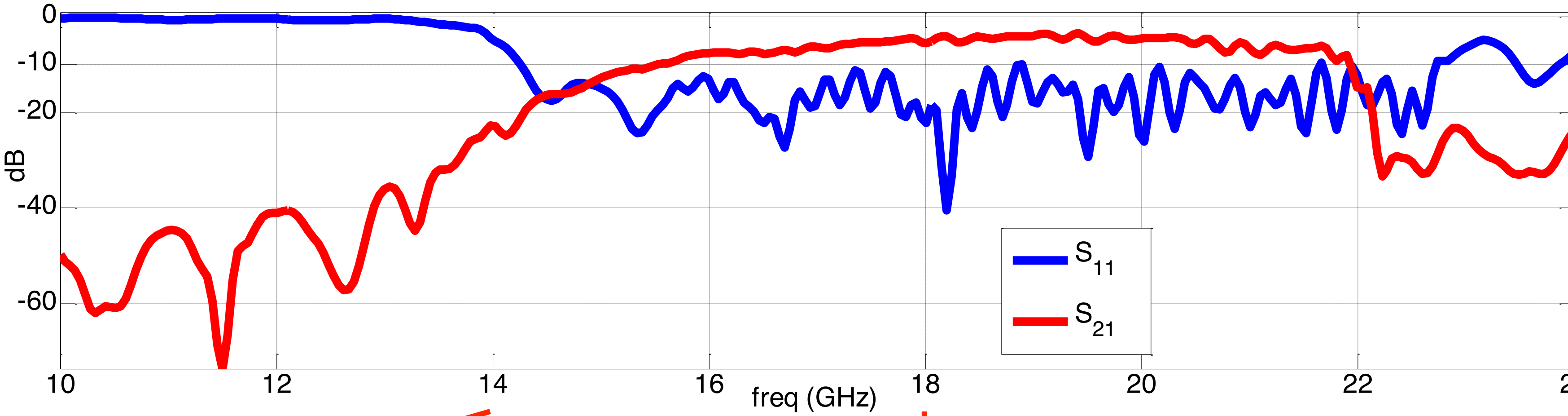
ASP passive circuits

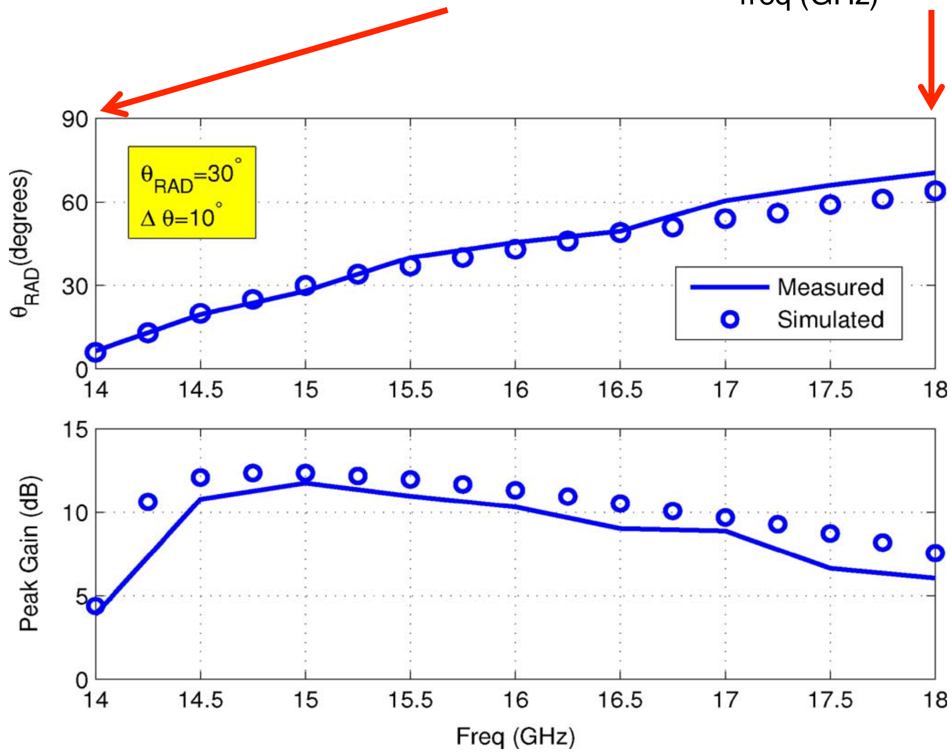
IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 61, NO. 1, JANUARY 2013 41

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

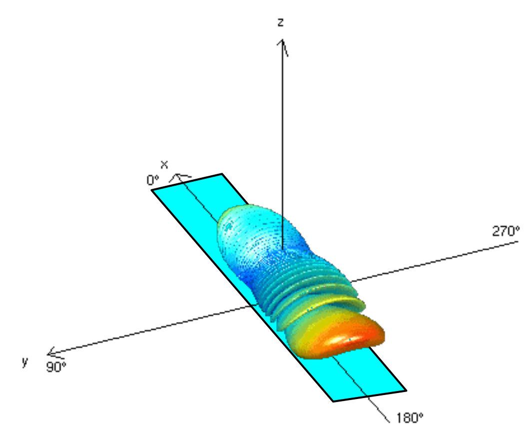
Massimo Del Prete, Diego Masotti, *Member, IEEE*, Nicola Arbizzani, and Alessandra Costanzo, *Member, IEEE*

What about the bandwidth ?





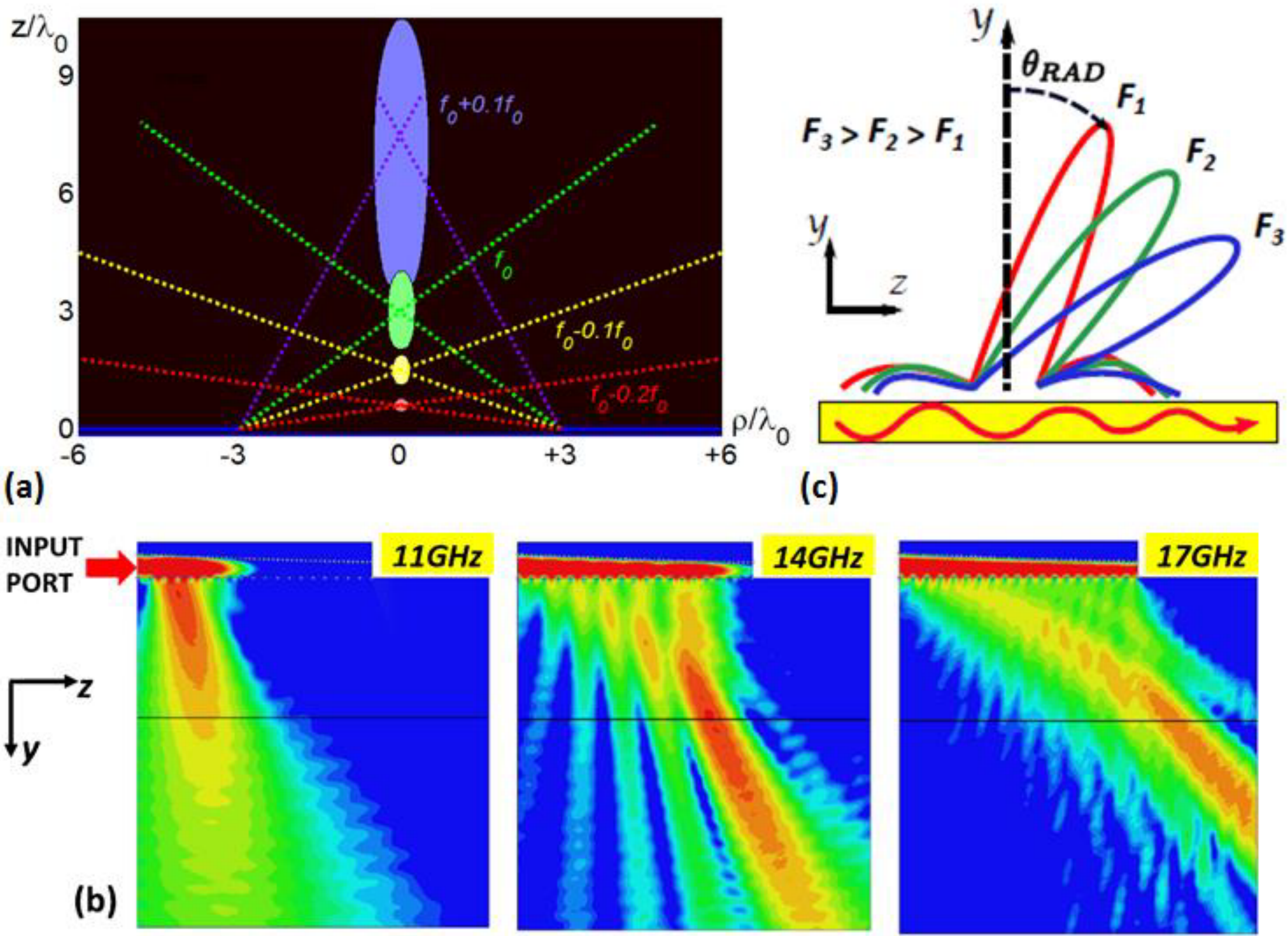
- **Matching / Efficiency**
- **Frequency beam scanning (dispersion)**



What about the bandwidth ?

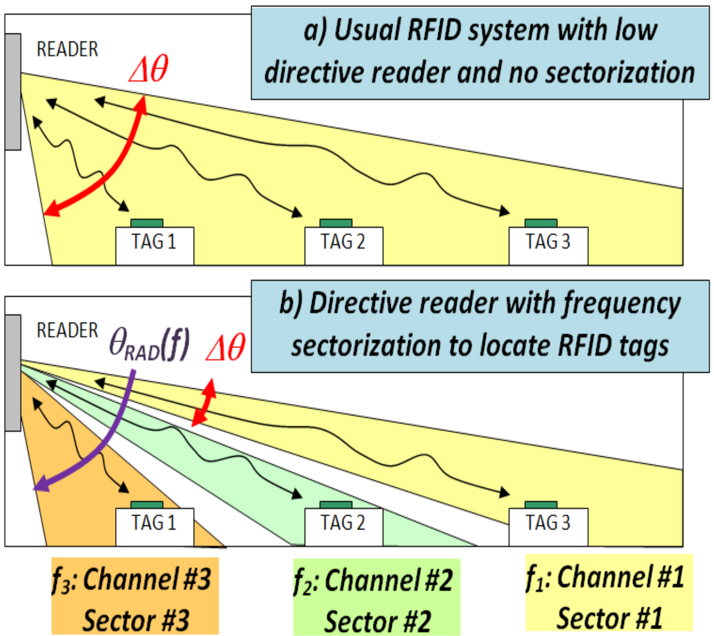
- **Wanted / useful dispersion**

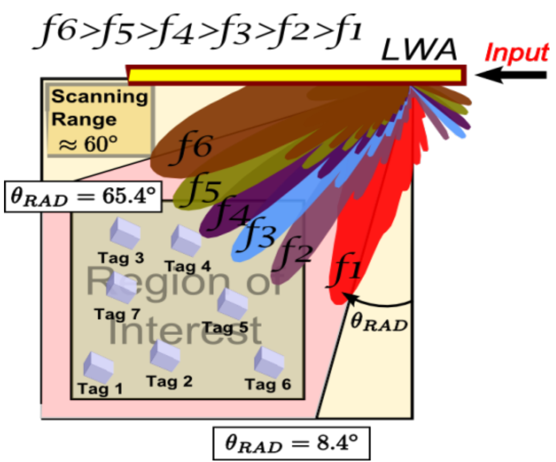
DISPERSION ENGINEERING

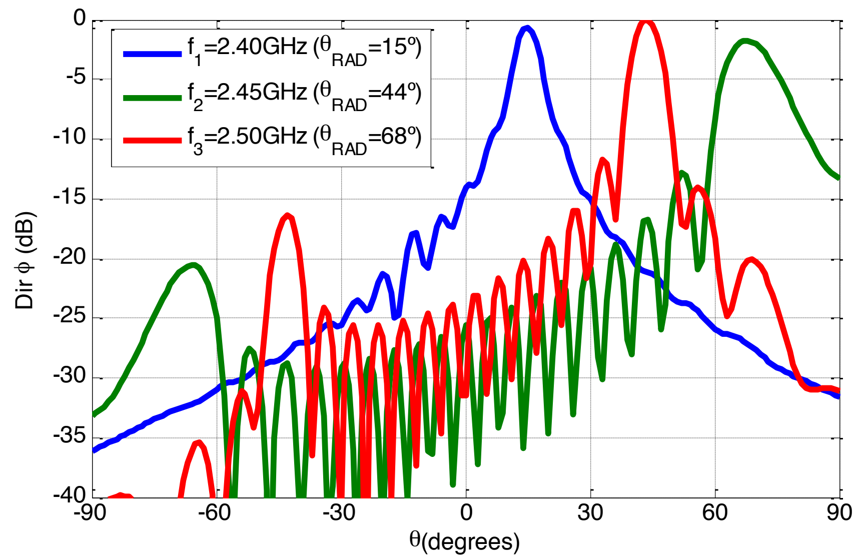


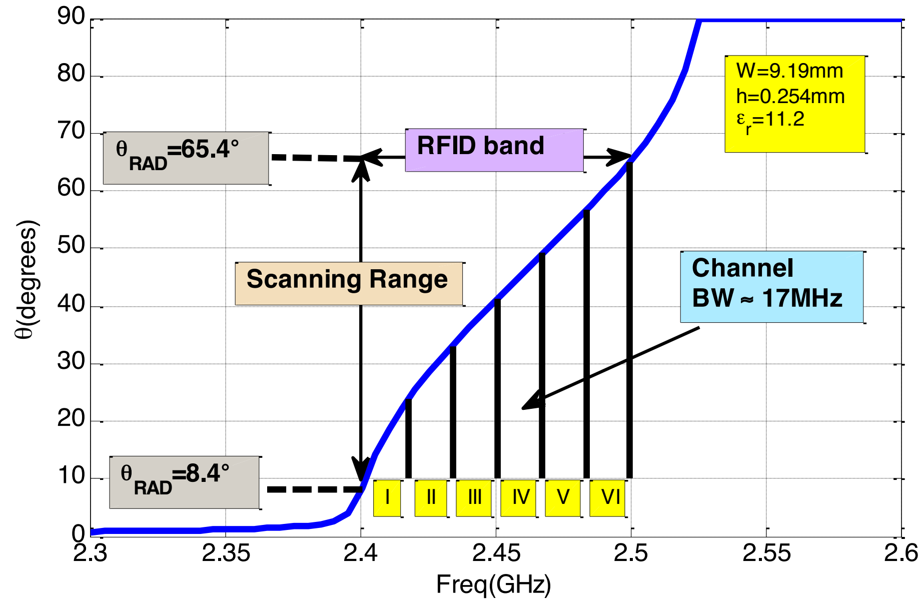
What about the bandwidth ?

- **Wanted / useful dispersion**





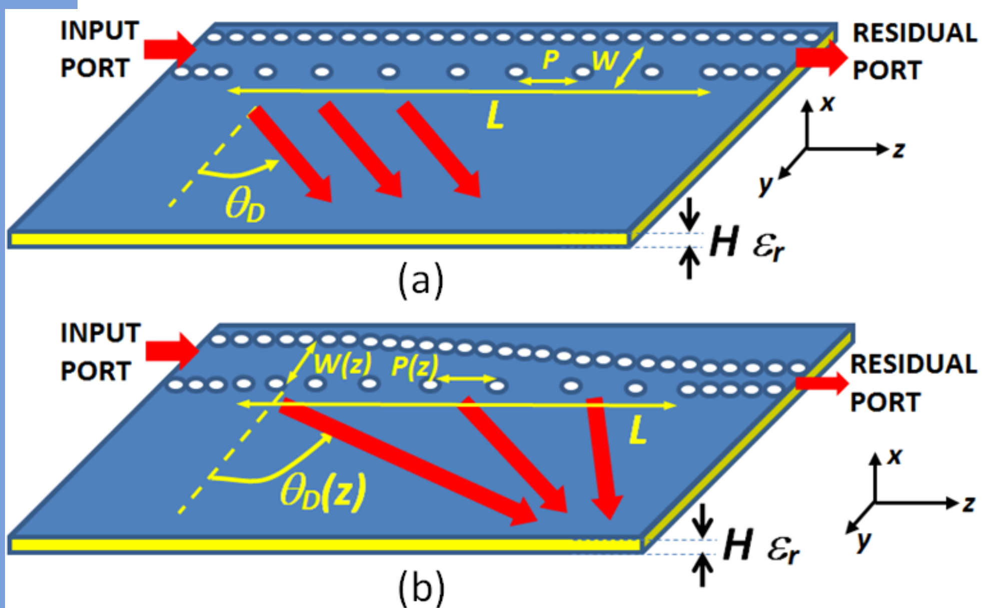


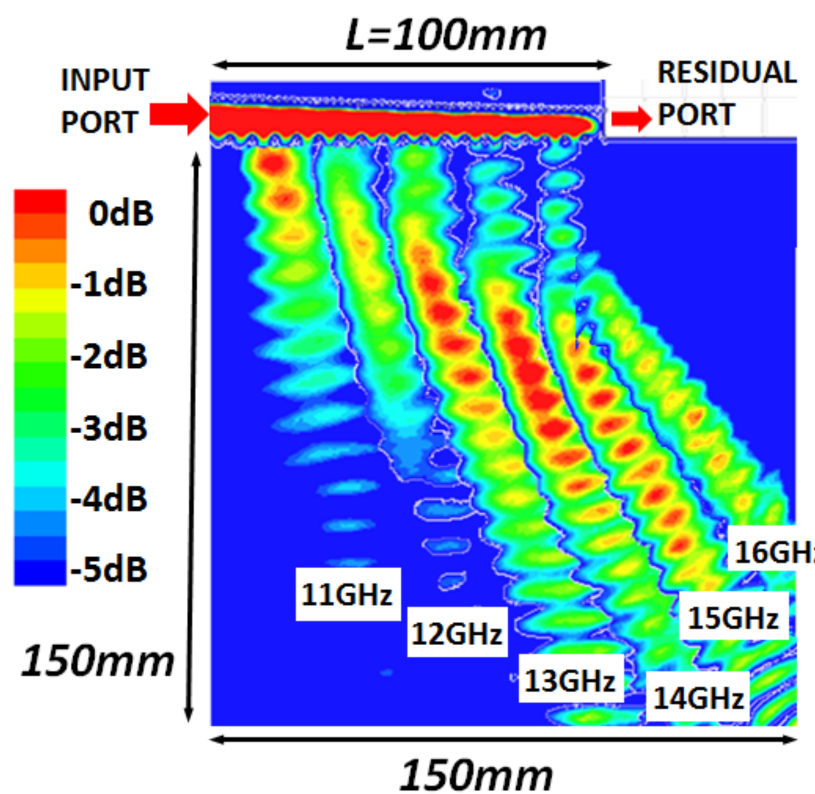


- **Wideband space multiplexer in SIW technology for real-time high-throughput Analog Signal Processing (ASP)**

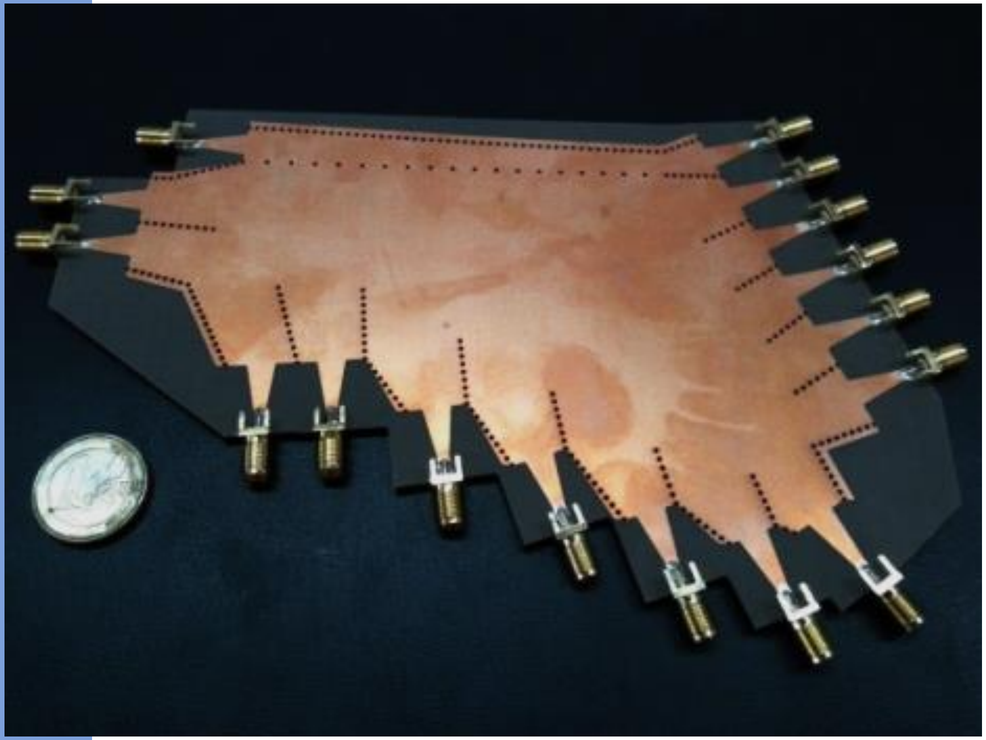
“Electrical prism”

Quasi-optical operation



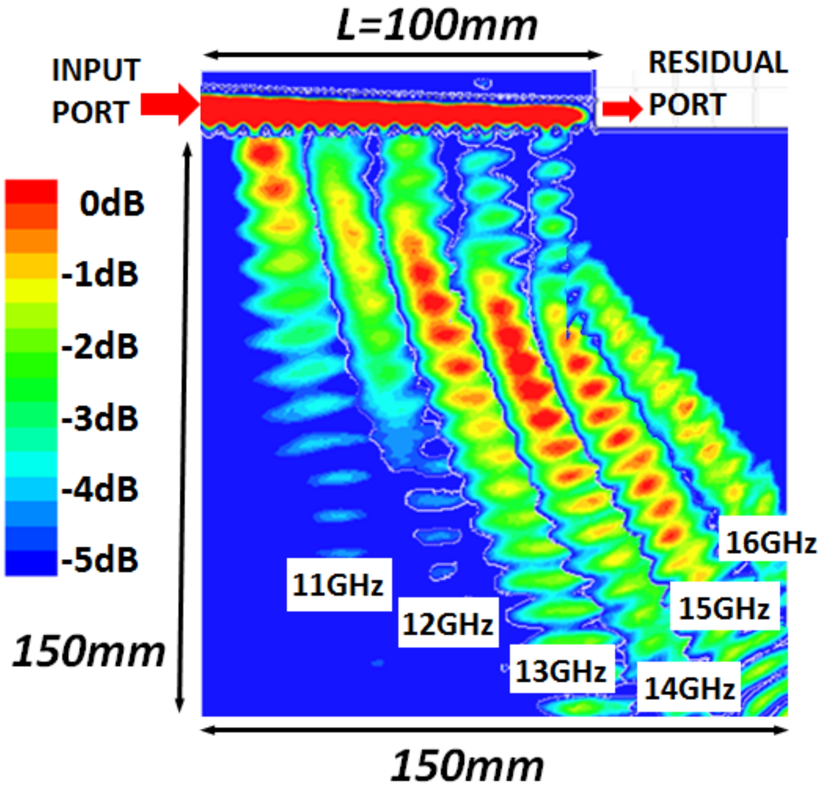


- **Wideband space multiplexer in SIW technology for real-time high-throughput Analog Signal Processing (ASP)**



Frequency-space dispersion engineering

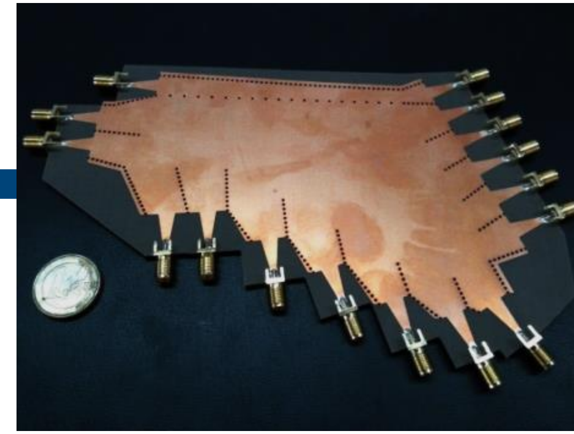
Analog Signal Processing



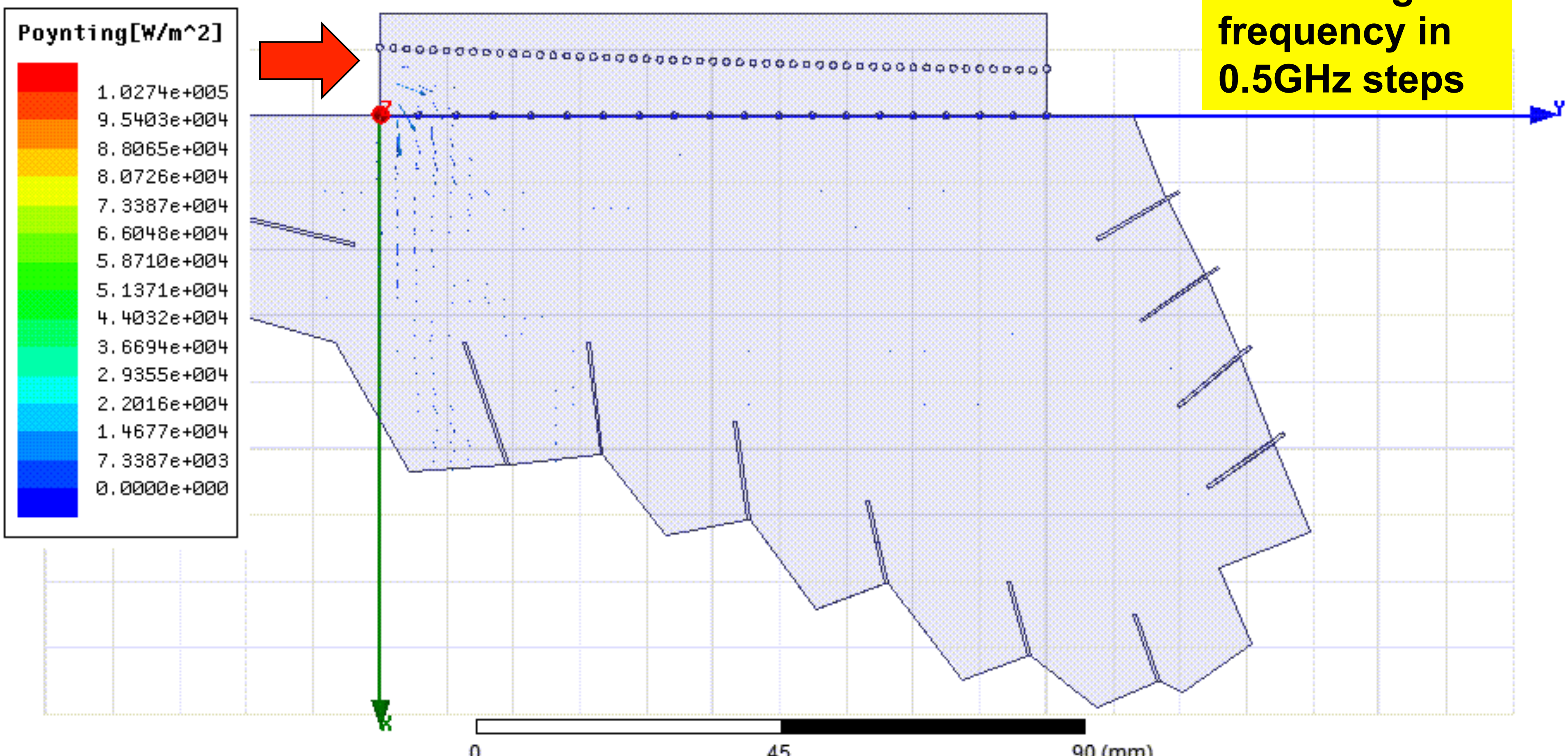
Wideband 11GHz-18GHz

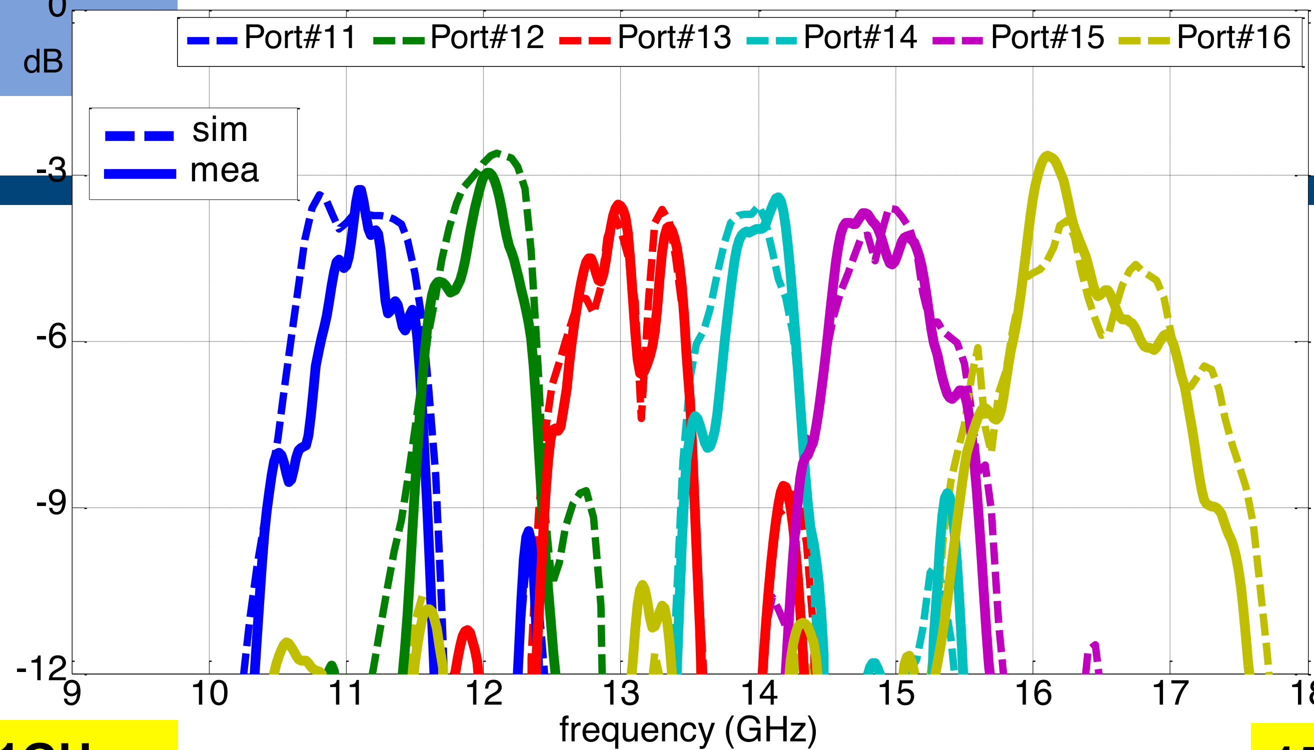
What about the bandwidth ?

- **Wanted / useful dispersion:**
NOVEL QUASI-OPTICAL MULTIPLEXER



Increasing frequency in 0.5GHz steps

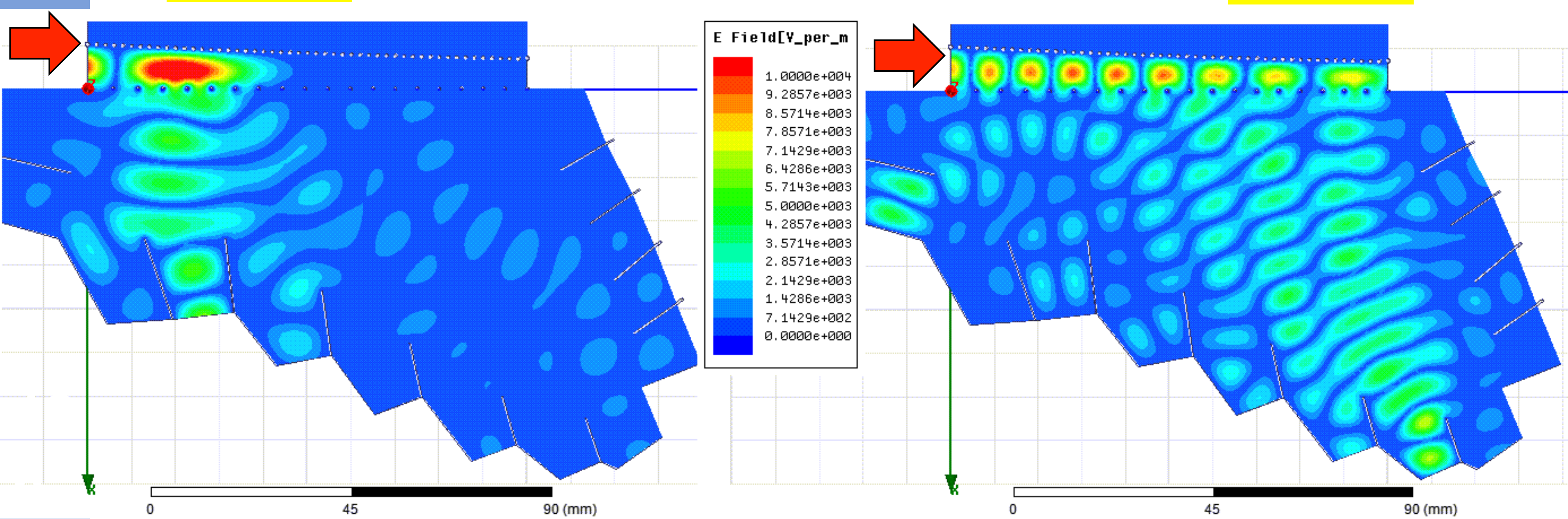




dB
0
-3
-6
-9
-12
Port#11
Port#12
Port#13
Port#14
Port#15
Port#16
sim
mea
9
10
11
12
13
14
15
16
17
18
frequency (GHz)

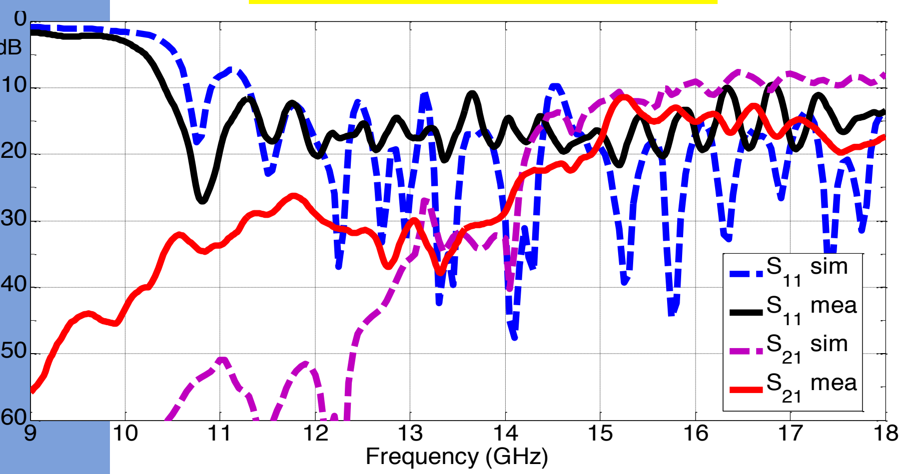
11GHz

15GHz

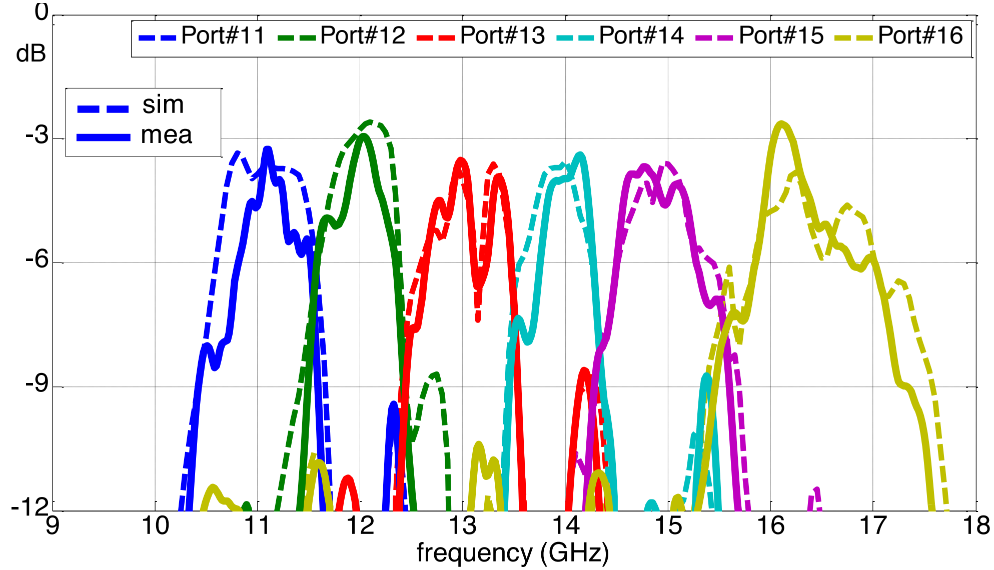


E Field[V_per_m
1.0000e+004
9.2857e+003
8.5714e+003
7.8571e+003
7.1429e+003
6.4286e+003
5.7143e+003
5.0000e+003
4.2857e+003
3.5714e+003
2.8571e+003
2.1429e+003
1.4286e+003
7.1429e+002
0.0000e+000
0
45
90 (mm)
0
45
90 (mm)

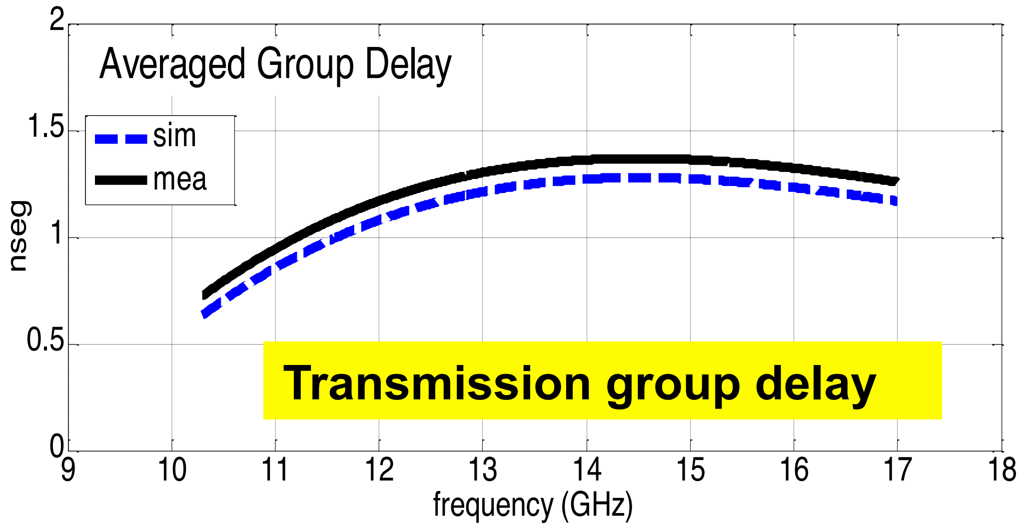
Input Matching



Transmission amplitude



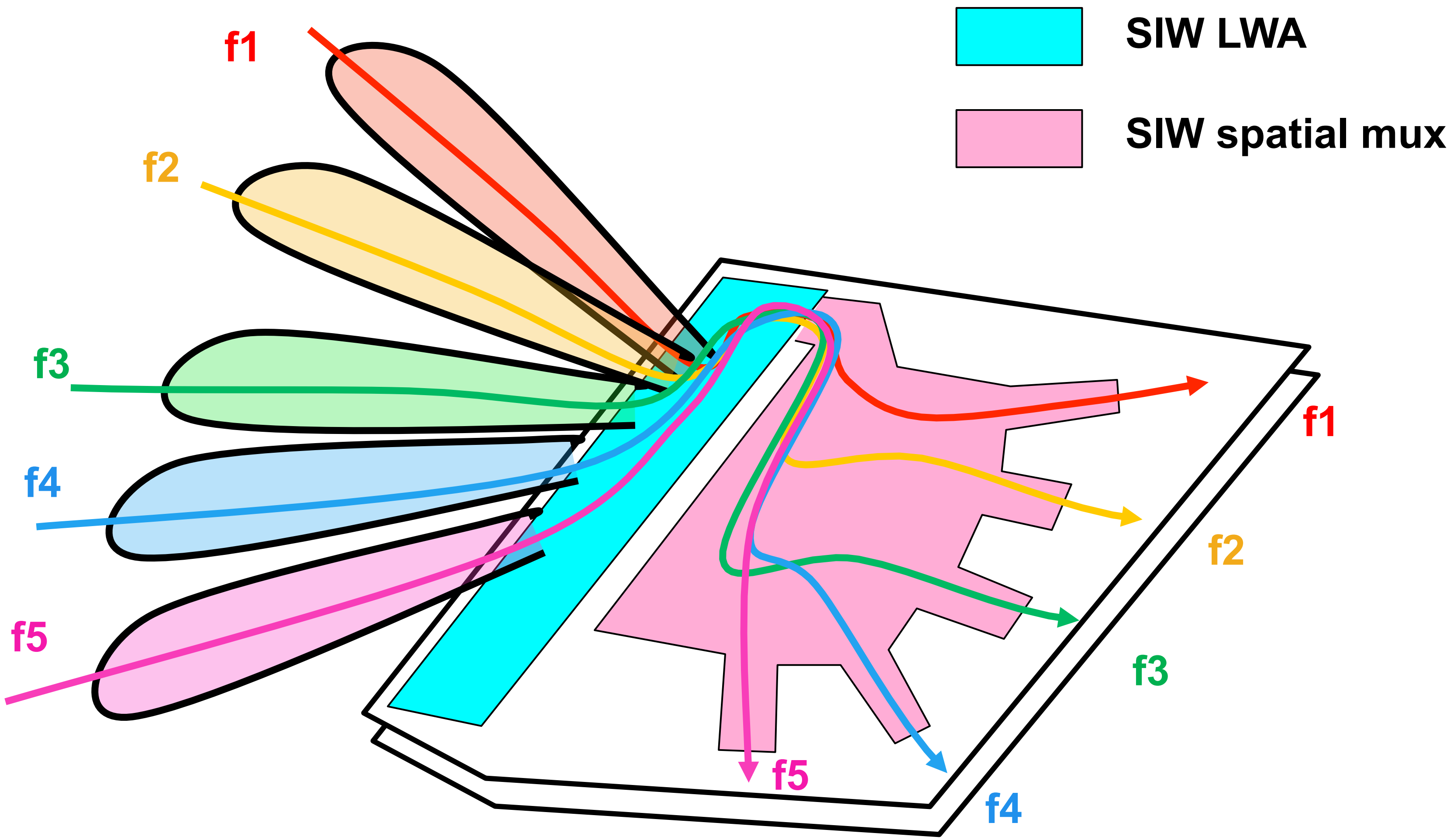
Travelling-wave nature, no resonant effects !



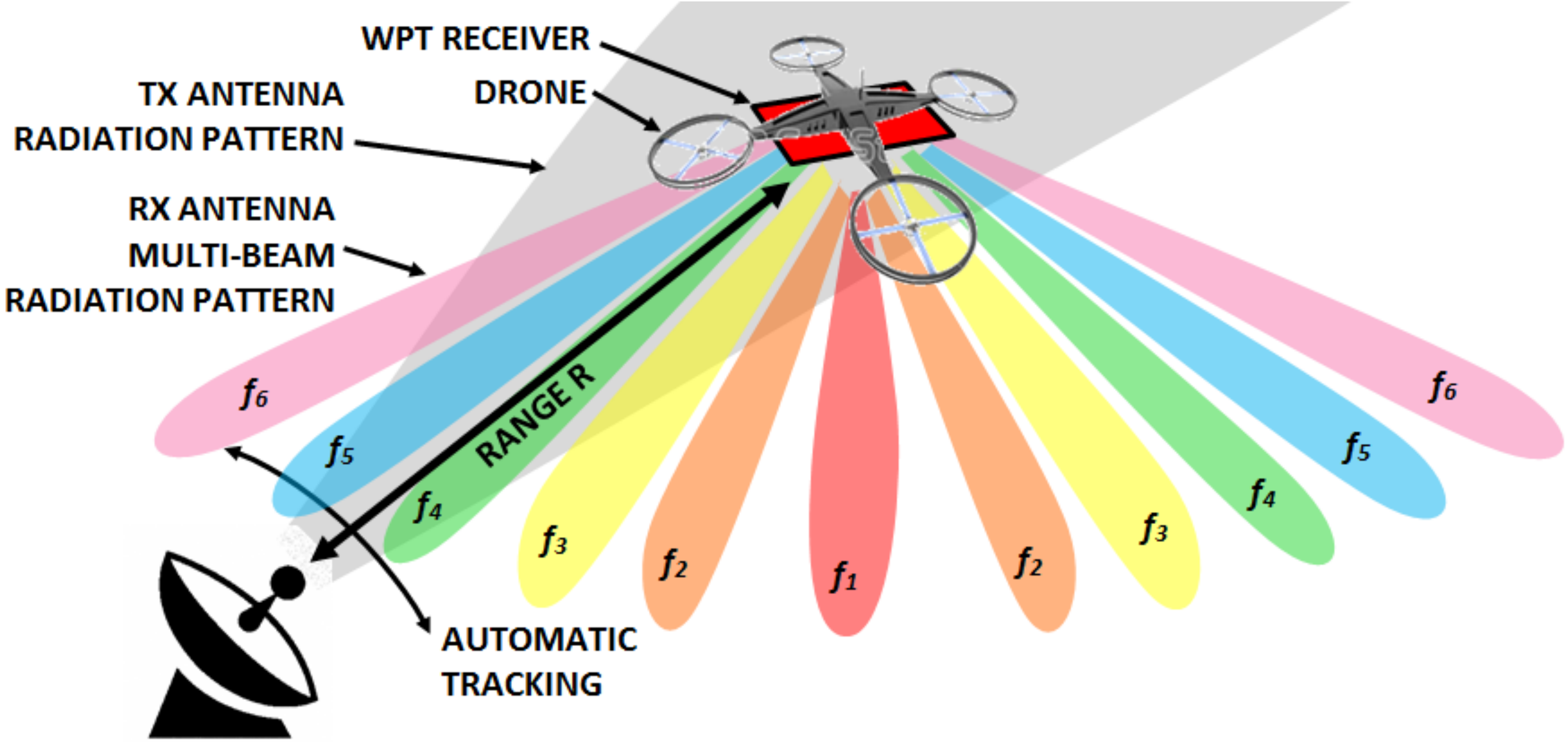
Transmission group delay

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

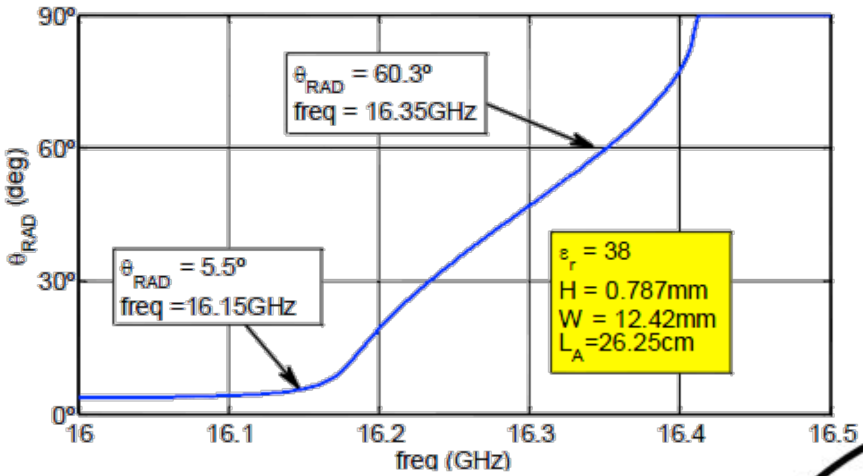
- **Passive, low-cost SIW (paper)**
- **Quasi-optical operation**
- **Smart device**
- **Spatial power combining**

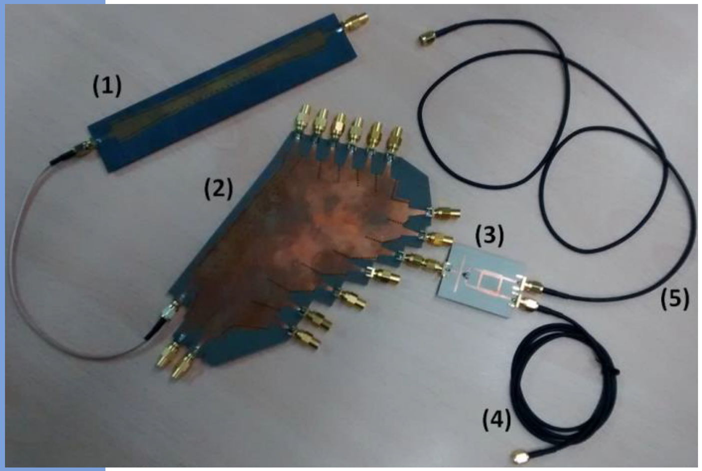


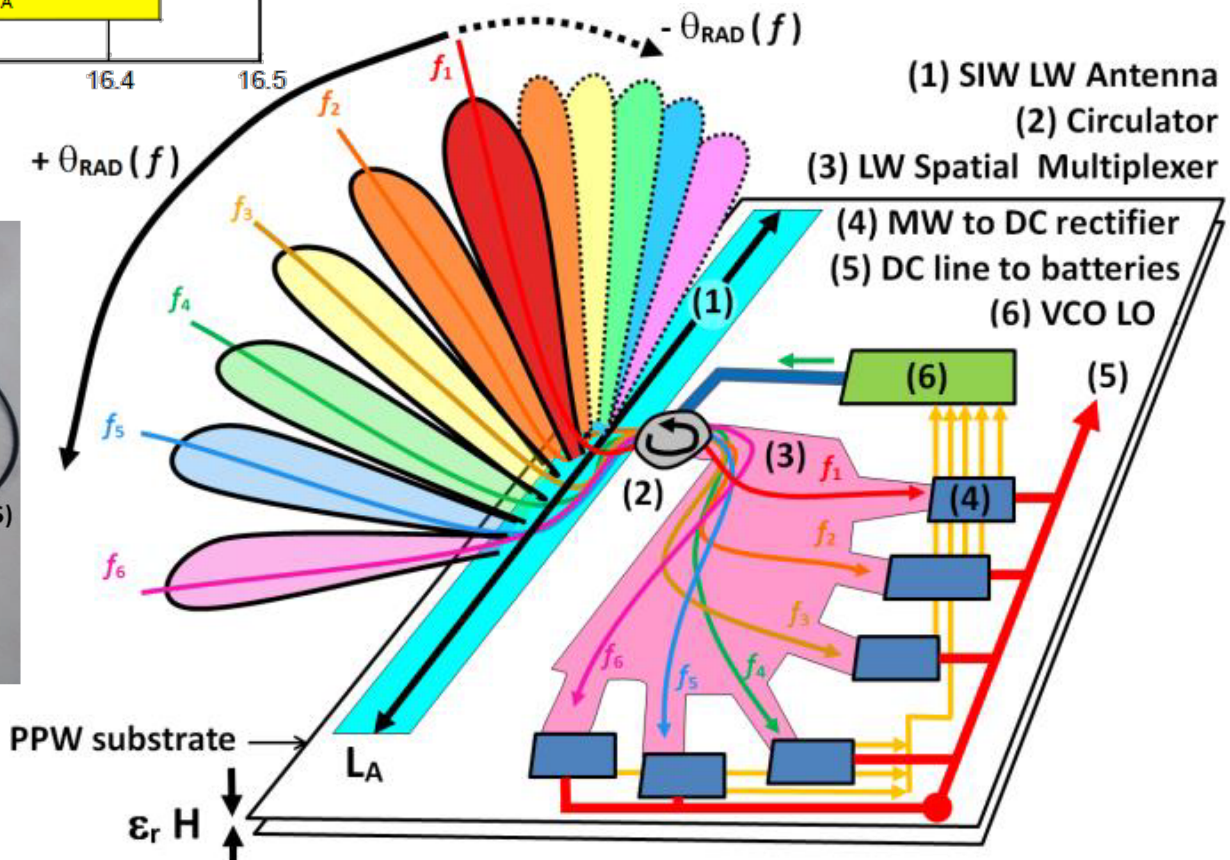
Empowering Drones



Empowering Drones





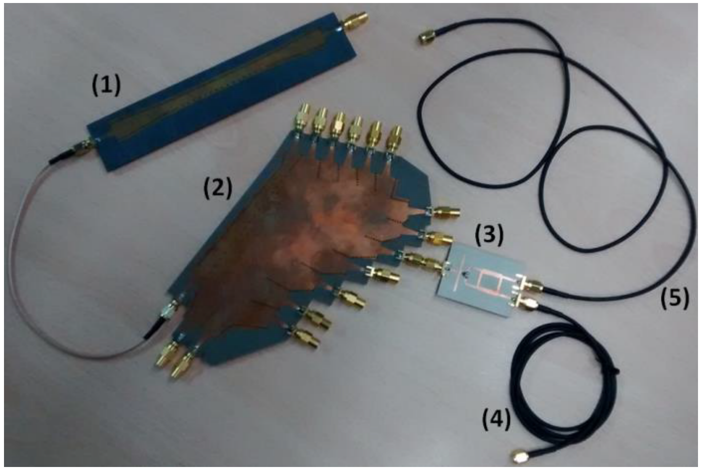


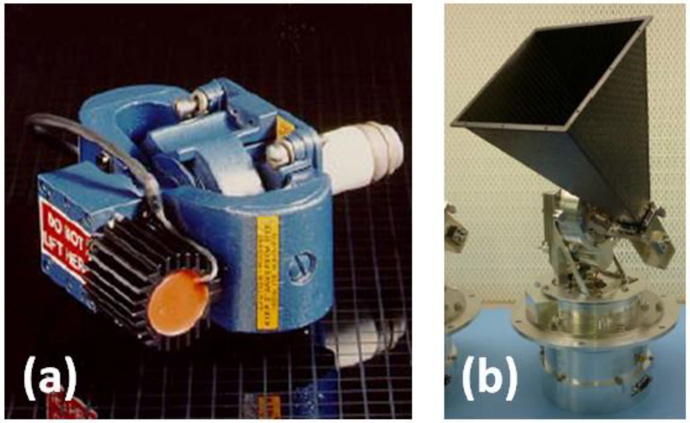
Empowering Drones

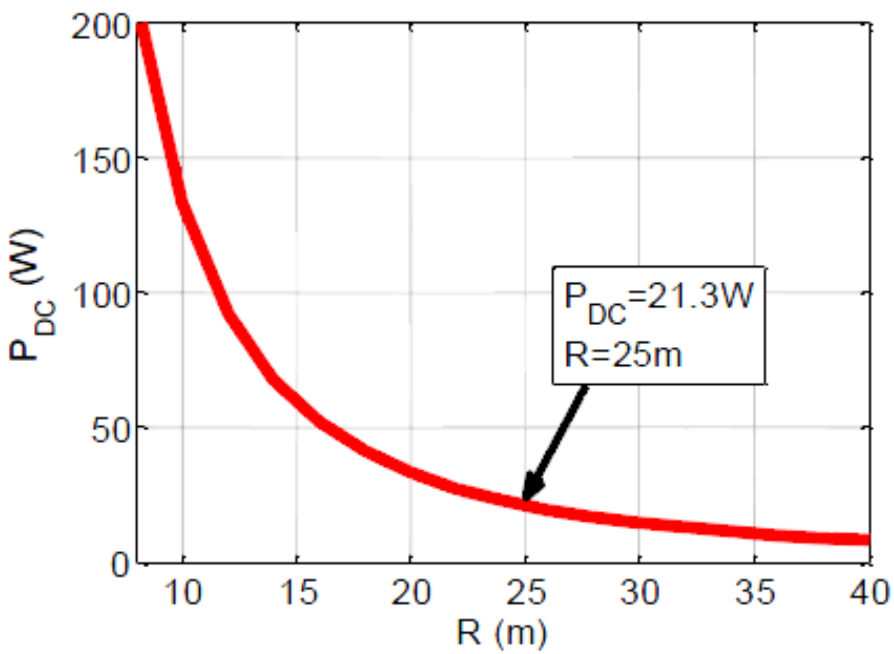
$$P_{RX}^{DC} = P_{TX}^{RF} \frac{G_{TX}}{4\pi\left(R/_{\lambda}\right)^2} D_{RX} \cdot \eta_{RX} \cdot \eta_{MUX} \cdot \eta_{DC}$$

TABLE I
ELECTRICAL PARAMETERS FOR KU-BAND WPT SYSTEM

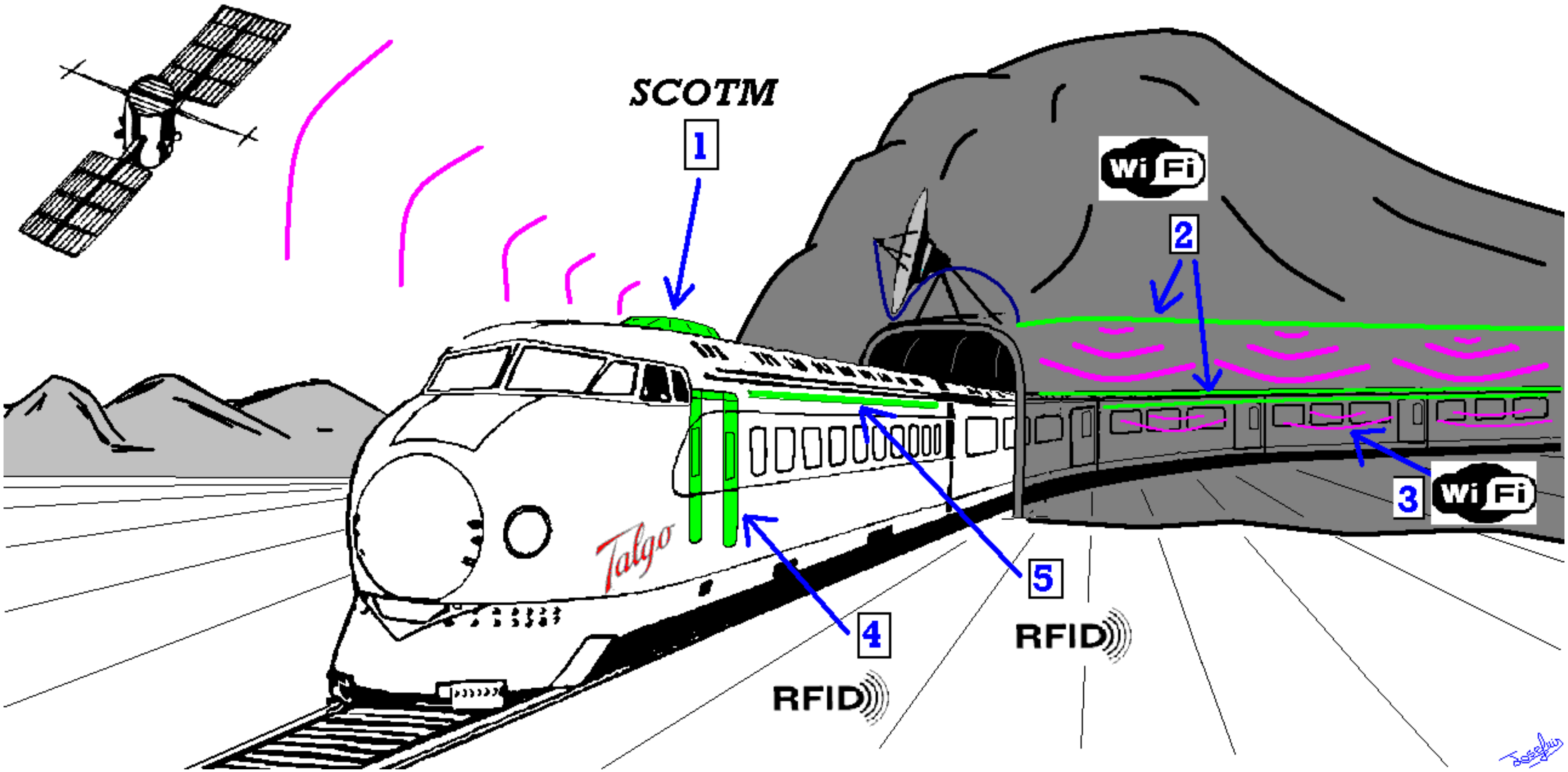
RF FREQ. RANGE	P_{TX} RF	GTX	D_{RX}
[16.15-16.35] GHz	70 KW	25 dB	22 dB
θ_{RAD} RANGE	η_{RX}	η_{MUX}	η_{DC}
[5º, 60º]	0.8	0.25	0.5



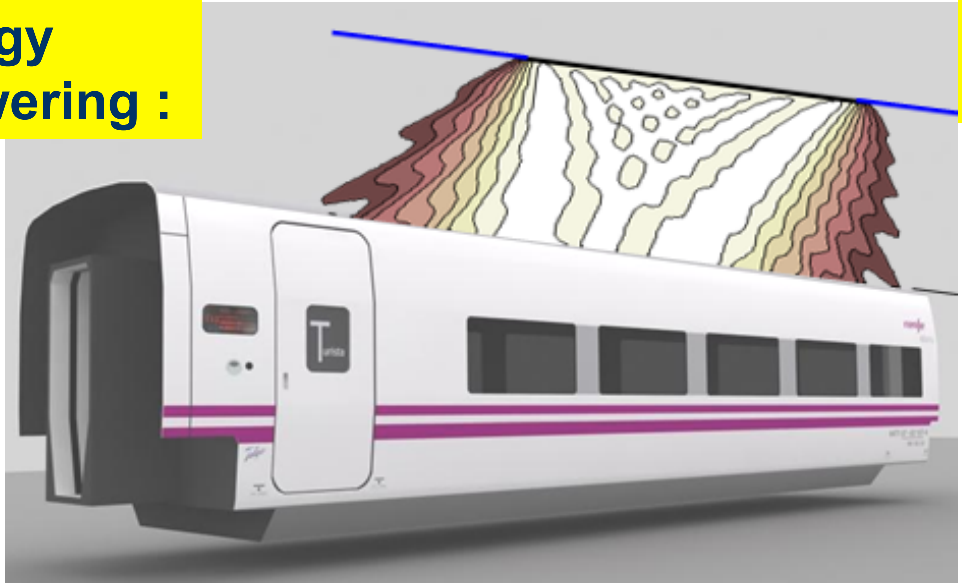




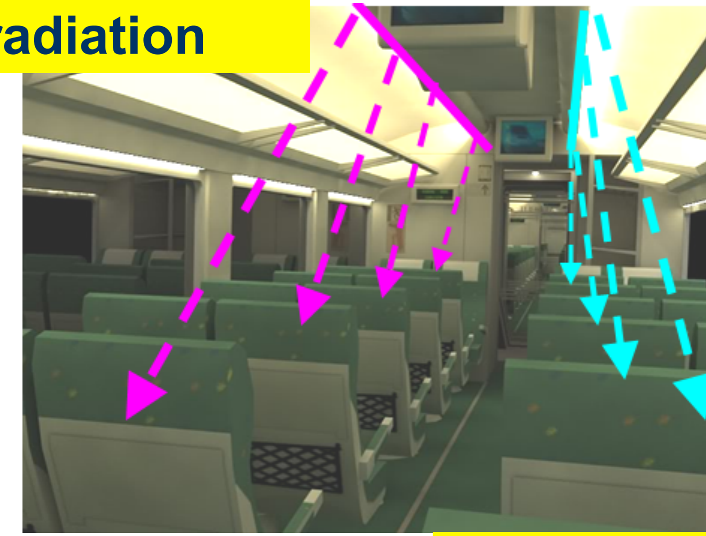
- **RFID localization using electrical prisms and focusing LWA in corridor-like scenarios (conveyors, corridors, queues…)**



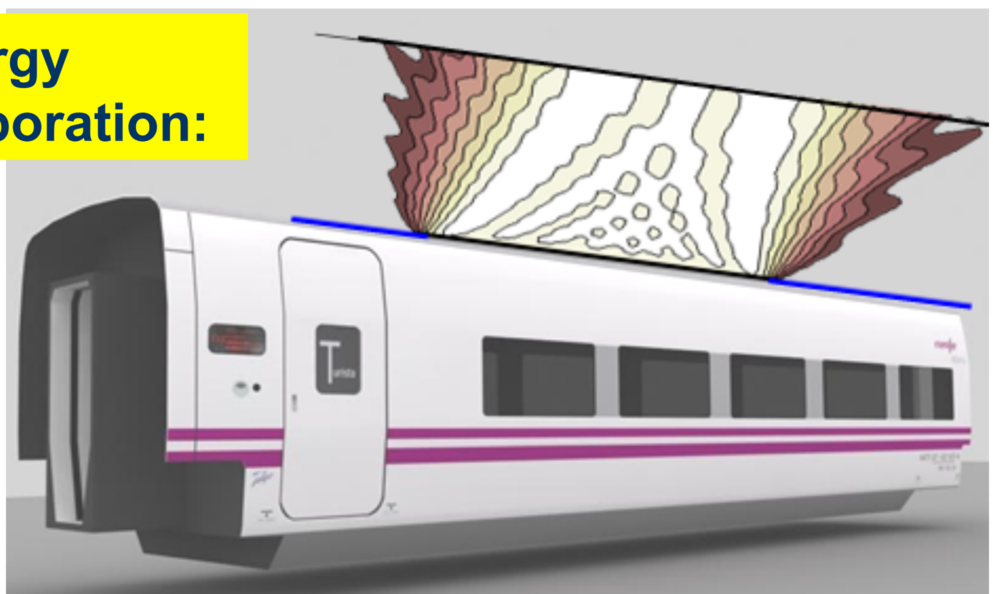
Energy showering :



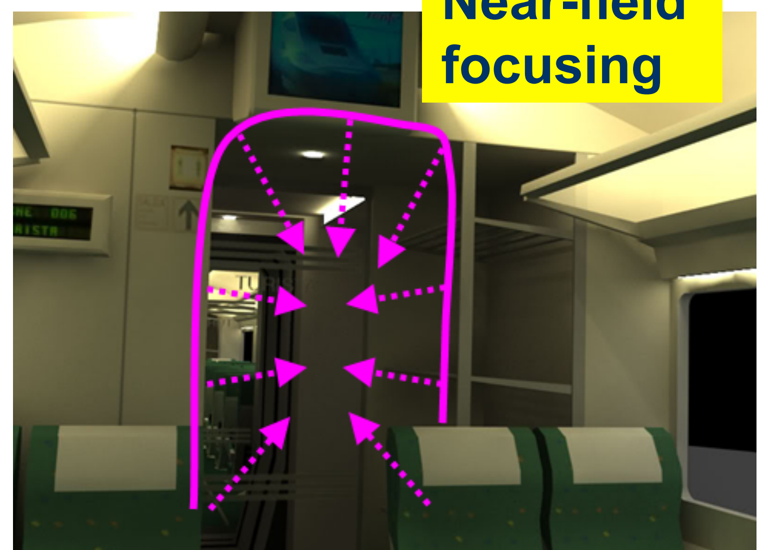
Distributed radiation



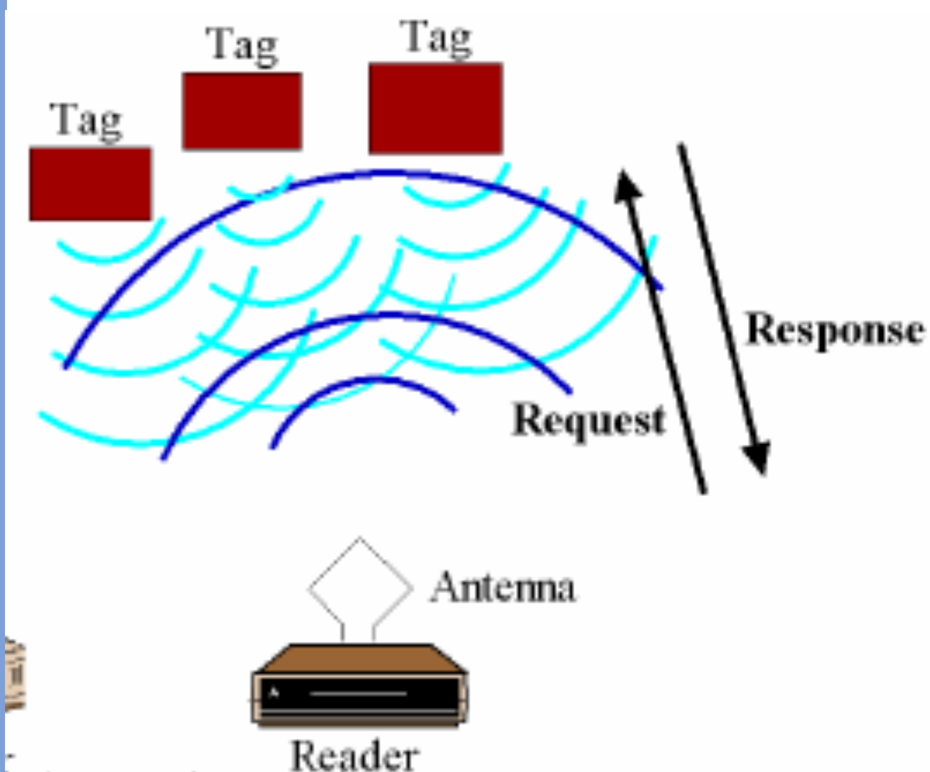
Energy evaporation:



Near-field focusing



Prof. Alessandra Costanzo



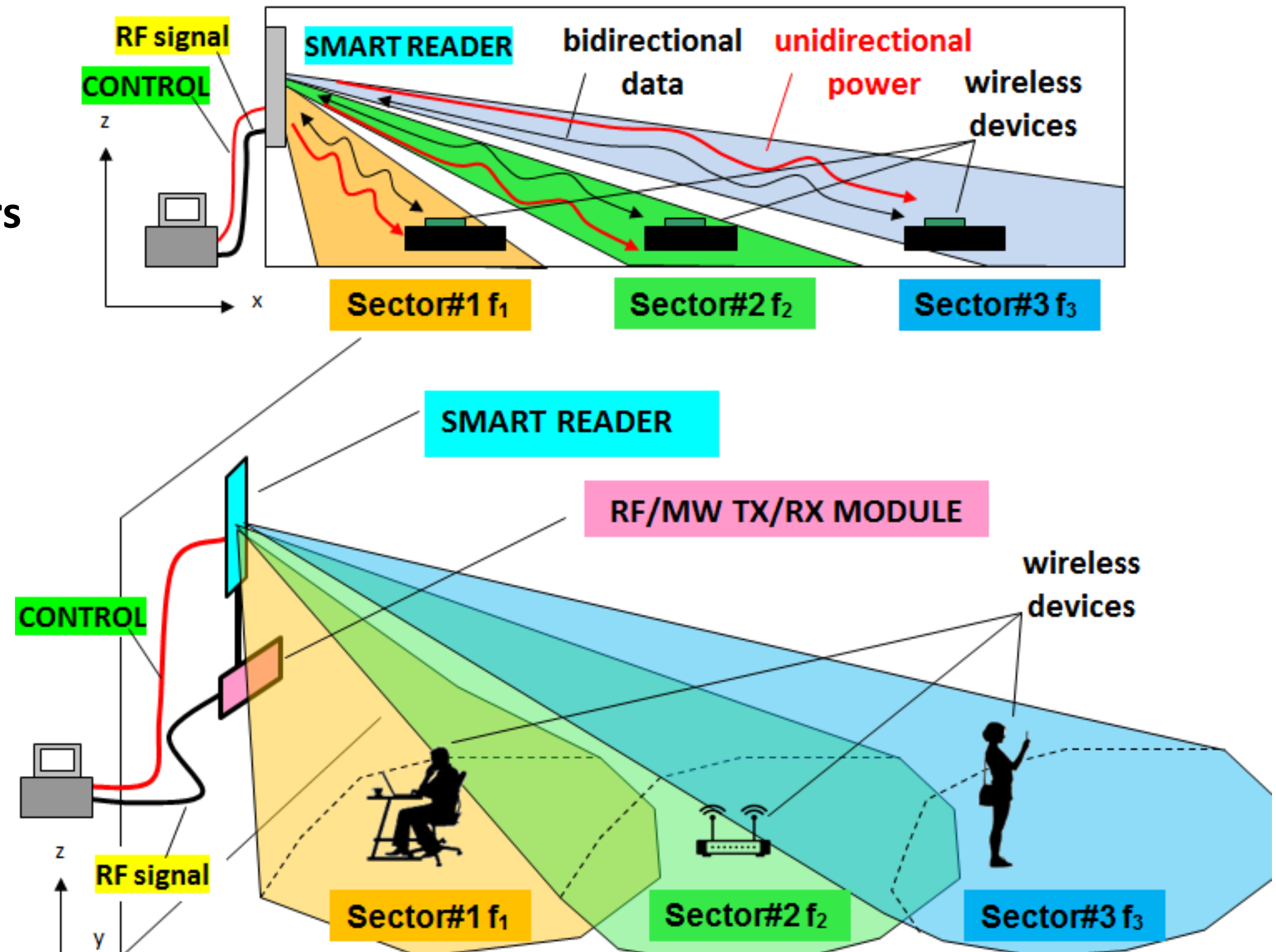
Stepped Frequency CW

Prof. Dominique Schreurs

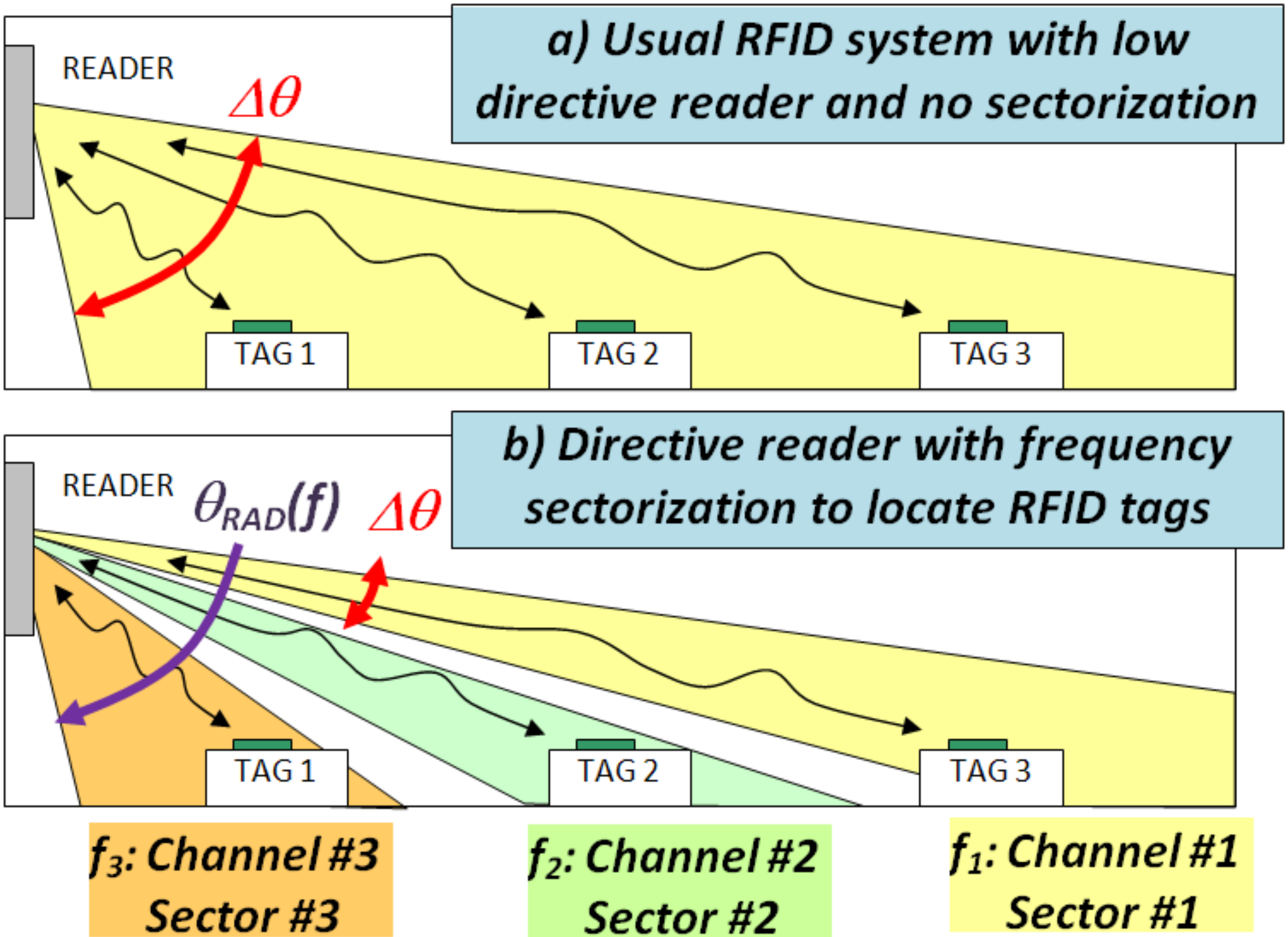
Prof. Smail Tedjini

Prof. Federico Viani

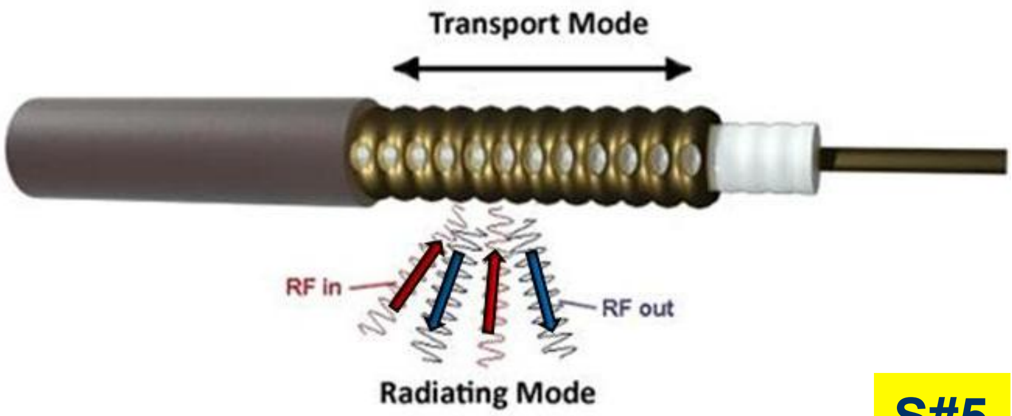
"**Smartification**" of the physical space by **space/frequency/time dispersion engineering** provided by **high-gain smart antenna focused in the far-field**

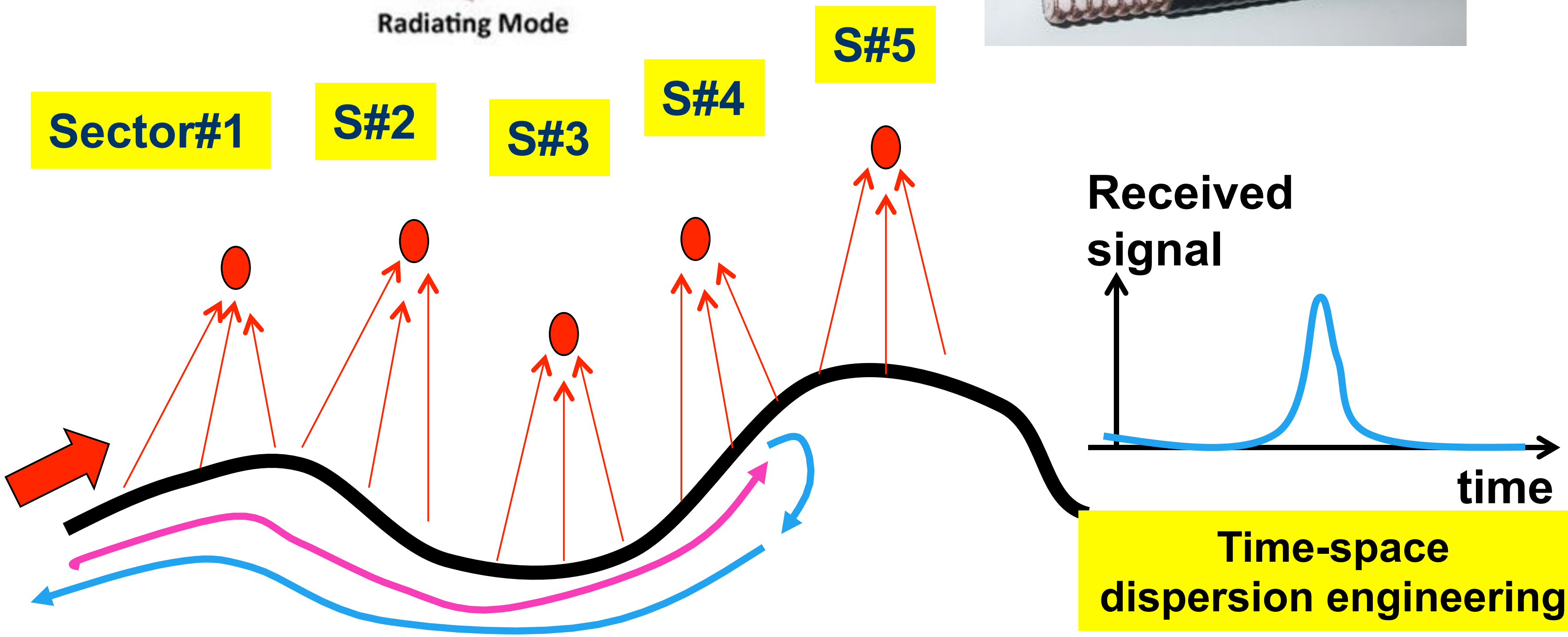


Correspondence (mapping) between frequency and space can be **dynamically configured** with **control signal** for **adaptive sensing/monitoring**


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

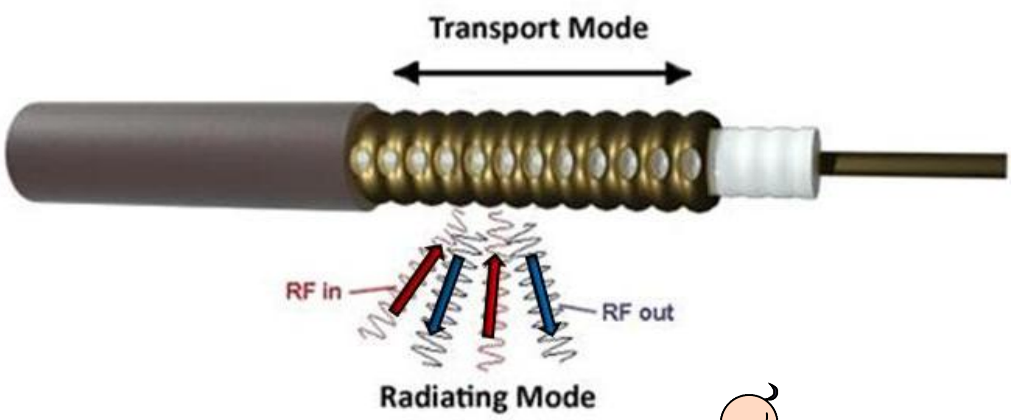
Leaky-coax for tracking humans



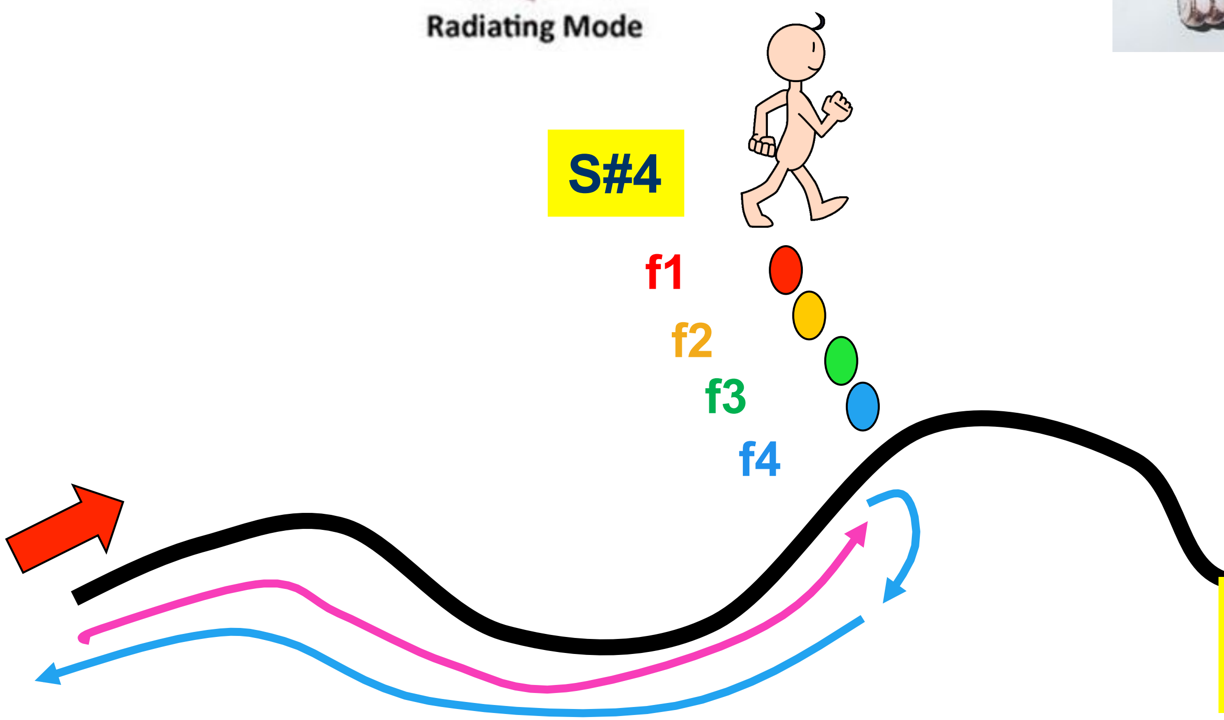


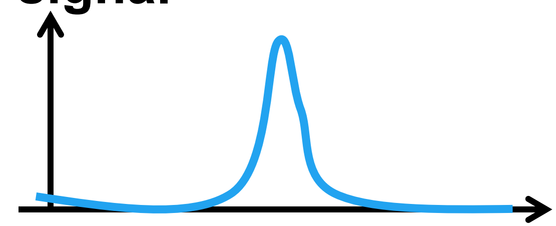
Time-space dispersion engineering

Leaky-coax for tracking humans



S#4

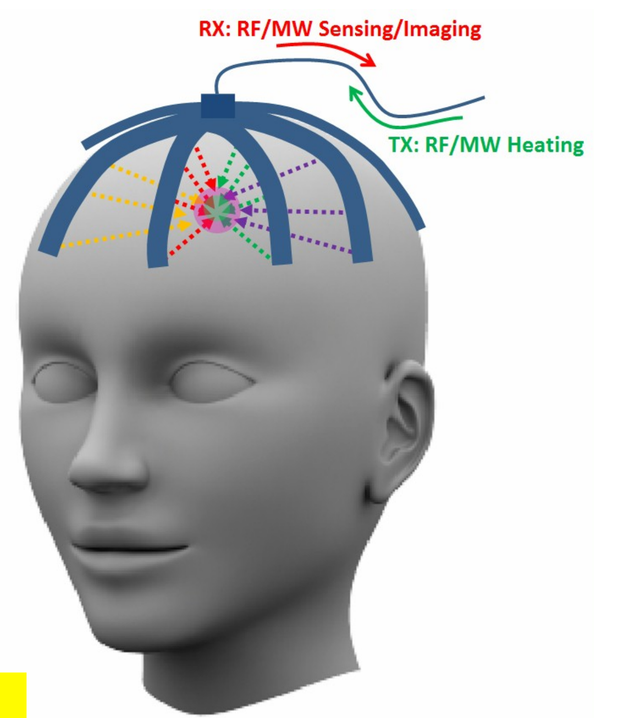


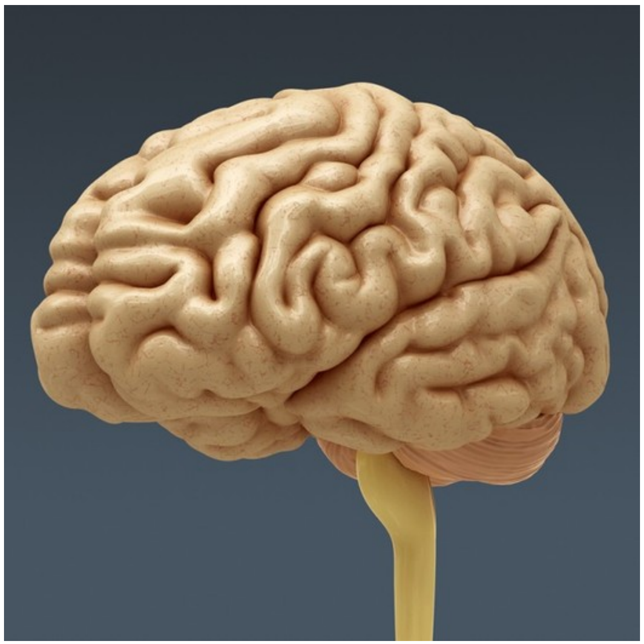


Time-frequency-space dispersion engineering

3- Future: Conformal radial SIW array focused in Near Field

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

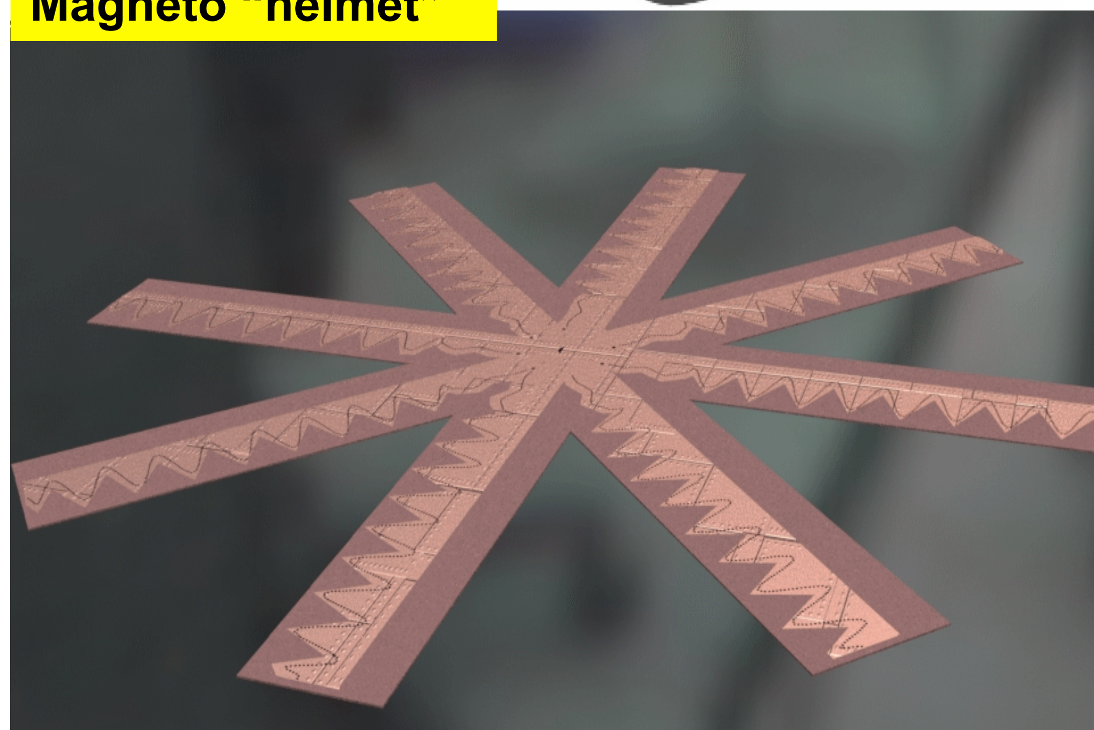




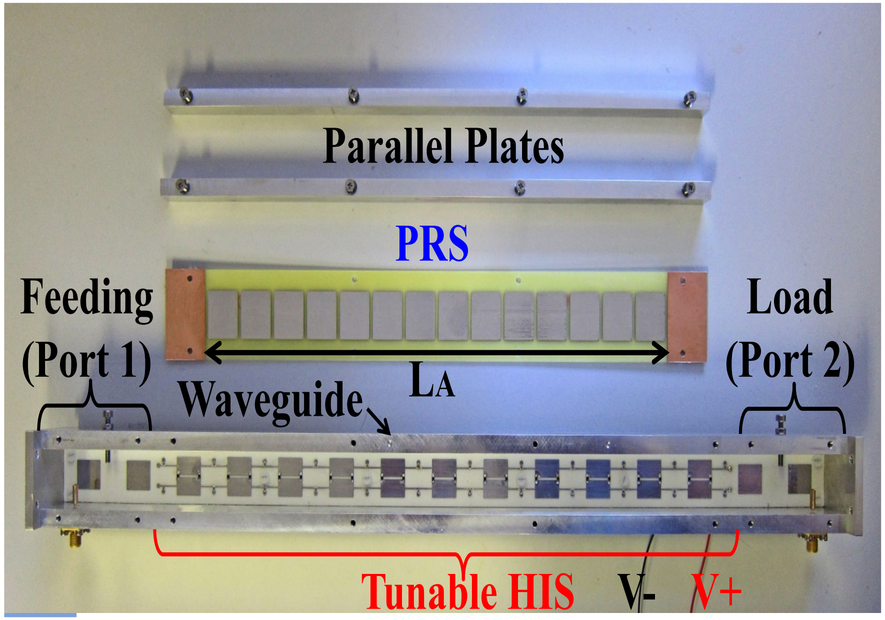
Prof. Chiao

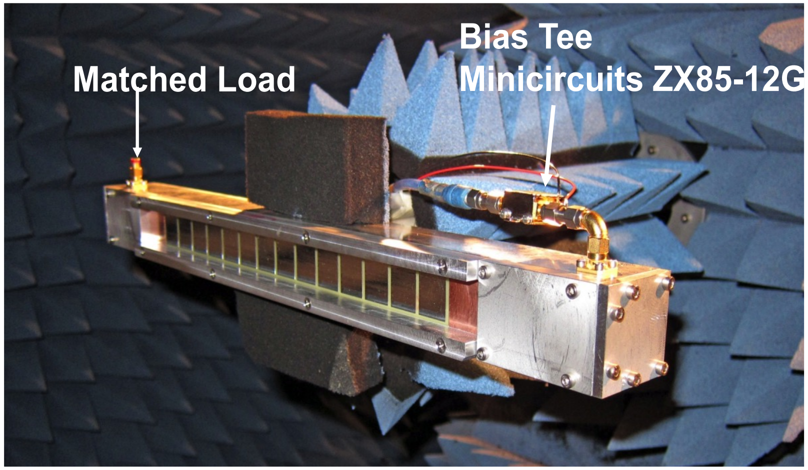
Prof. Marroco

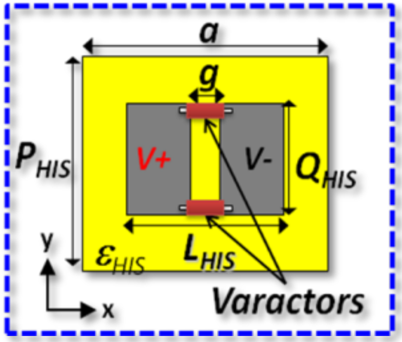
Magneto "helmet"

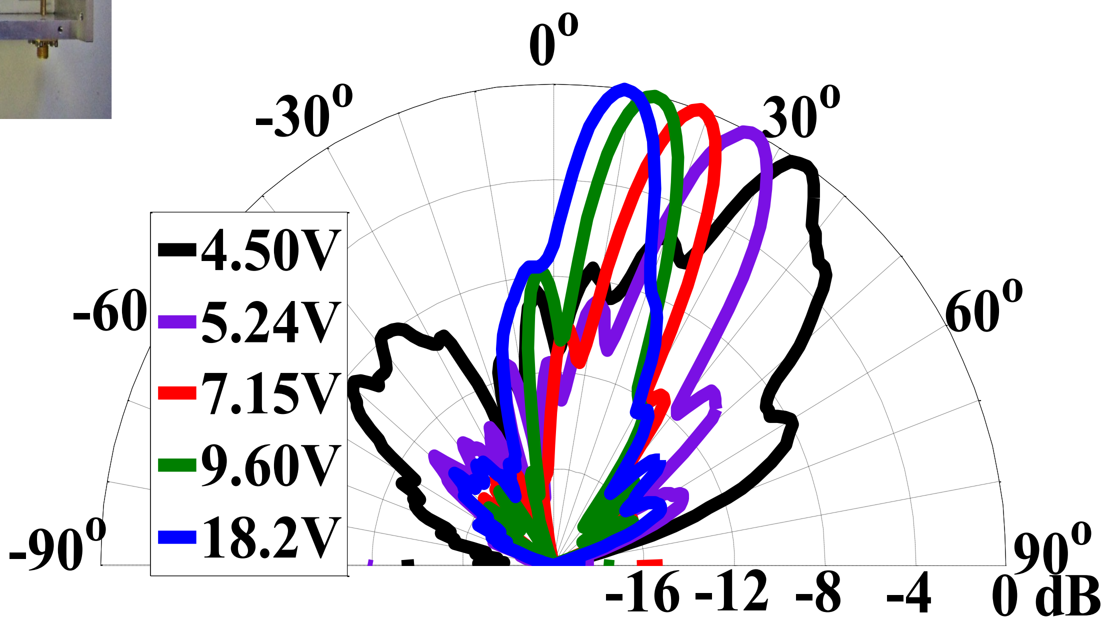


- **Not only frequency-scanned, but also electronically-scanned LWAs**



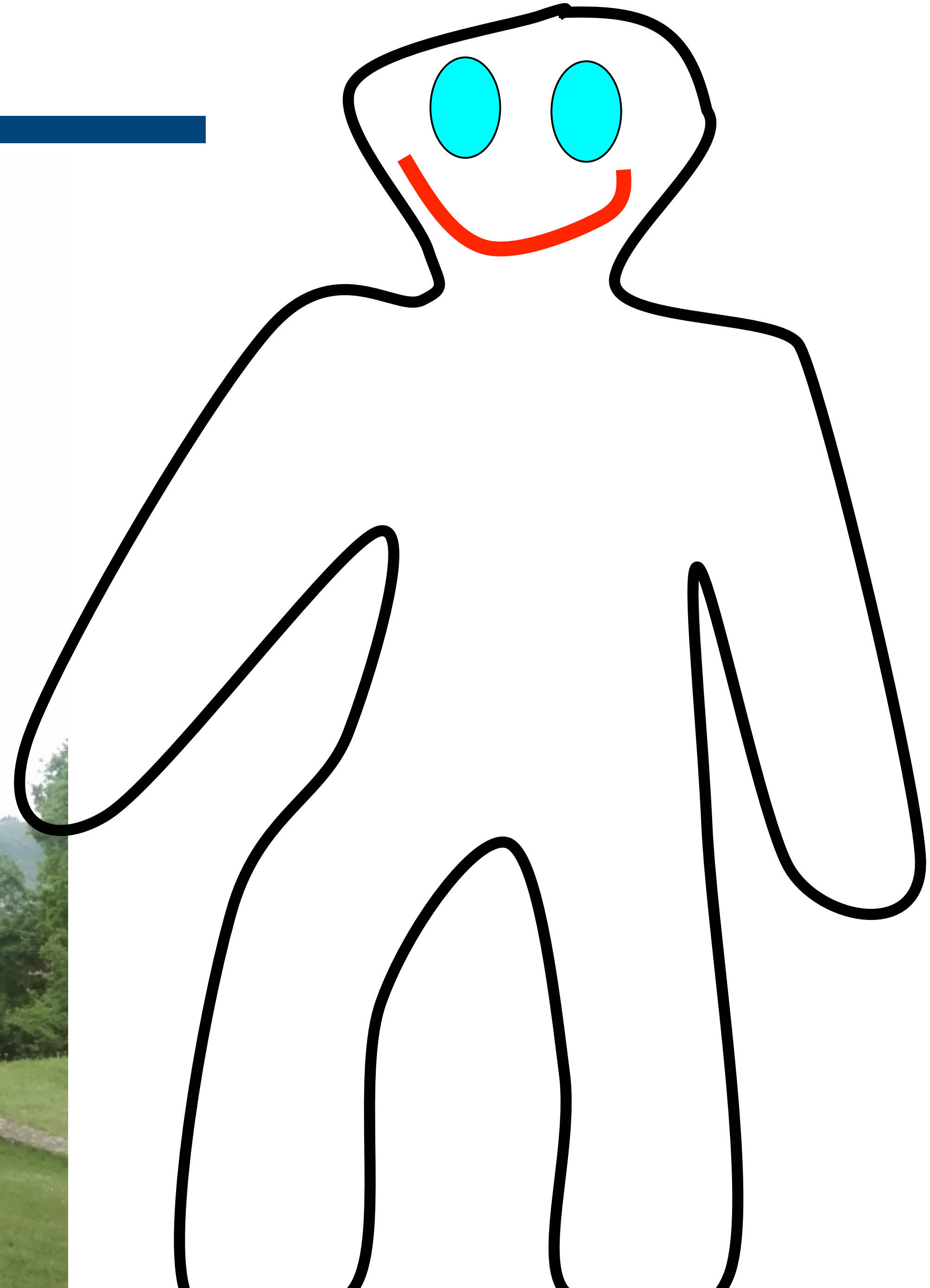






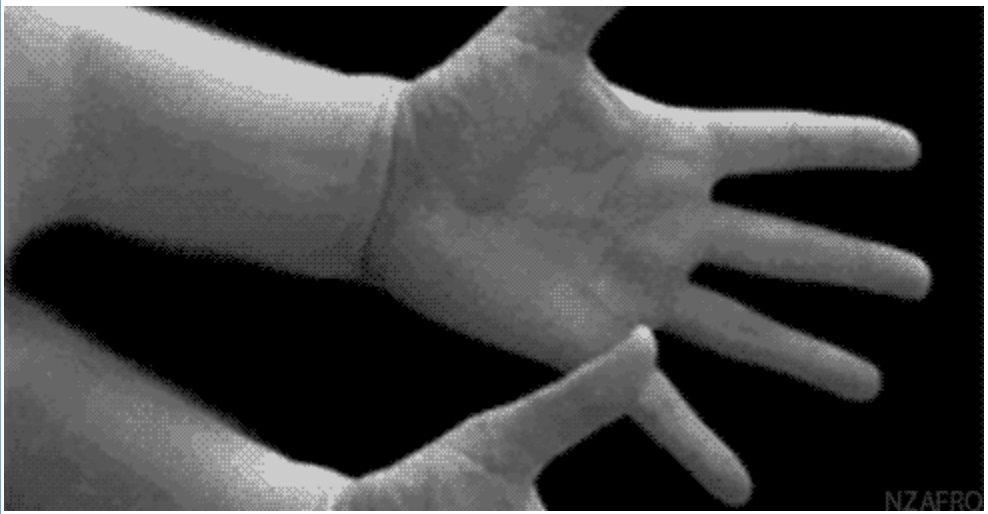
Annibal and his elephants...

From an arrogant, centralized attitude… → To a distributed, ecological, sustainable, more natural way of creating and maintaining…



1- Internet of Things (IoT).

Distributed network of powerful minds and hearts



Internet made by the people for the people making a more sustainable world:

Internet of the People (IoP)

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)…

4- Further Holistic Conclusions.

- Flock of starlings' dance:

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

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

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

WIPE
COST IC1301

QUESTIONS ?

**THANK YOU
SO MUCH
FOR YOUR ATTENTION!**

José Luis Gómez Tornero
Josel.Gomez@upct.es

Technical University of Cartagena (Spain)

European Science Foundation

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY