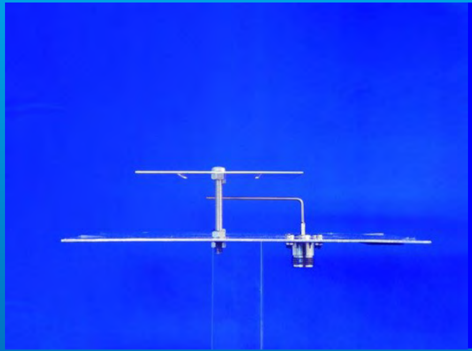
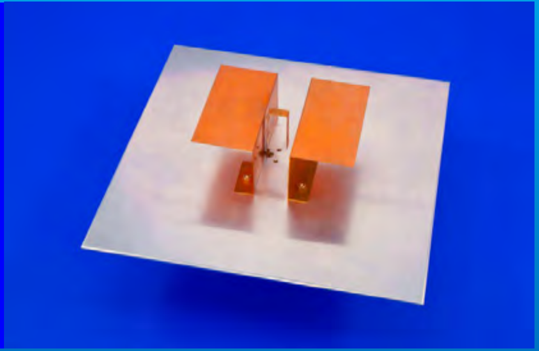
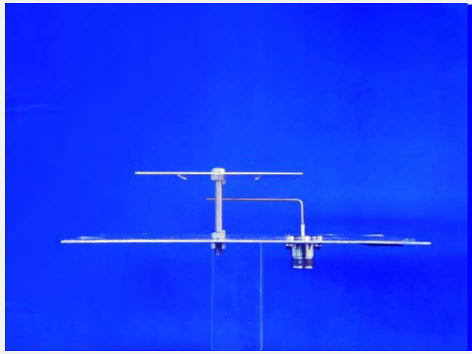


ANTENNA SCIENTISTS – MAGICIANS IN THE ERA OF WIRELESS CONNECTIVITY

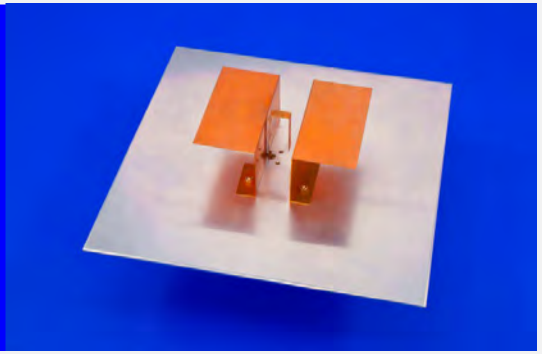


Kwai Man Luk, FREng, FHKEng
Department of Electrical Engineering and State Key Laboratory of Terahertz and Millimeter Waves

17 March 2022



ANTENNA SCIENTISTS – MAGICIANS IN THE ERA OF WIRELESS CONNECTIVITY



OUTLINE

- Introduction
- Basic design techniques
- Most popular works
- Recent research outputs
- Work done by others
- Acknowledgements
- Concluding remarks

MOST POPULAR TOPICS

IEEE PRODUCTS

IEEE Xplore's 10 Hottest Topics

Below are the 10 most popular topics being searched in the IEEE Xplore Digital Library as of press time.

1	Image processing	6	Cloud computing
2	Antenna	7	VLSI
3	Artificial intelligence	8	Deep learning
4	Machine learning	9	Big data
5	Data mining	10	Internet of things

SOURCE: IEEE XPLORE

WHERE DO WE NEED ANTENNAS?

- Mobile Communications: 5G, 6G
- Wireless local area networks: WiFi, WiGig
- Intelligent transportation: Collision avoidance systems, autonomous driving, V2V
- Navigation satellite systems: GPS, BeiDou, GALILEO, GLONASS, GNSS
- Satellite internet: Starlink (SpaceX), Kuiper (Amazon)
- IoT: mm-wave sensors
- Unmanned aerial vehicles and drones: radio altimetry
- Satellite microwave remote sensing: altimeter, polarimeter
- Medical imaging: stroke detection and other diseases
- Energy harvesting
- Optical technologies: nanoantennas
- Deep space exploration: FAST, Kilometer Arrays
- Wireless power transfer

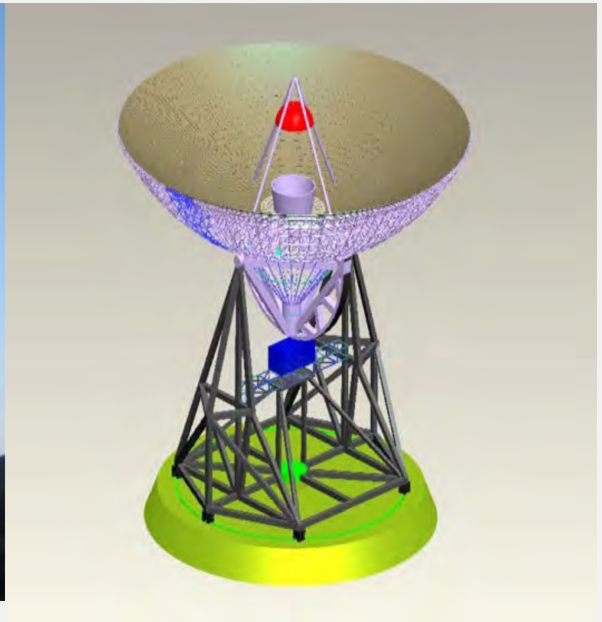
RADIO TELESCOPE: VERY LARGE ANTENNAS
(BY COURTESY OF PROF BAOYAN DUAN, XIDIAN UNIVERSITY)

(a) Bird view of the FAST telescope

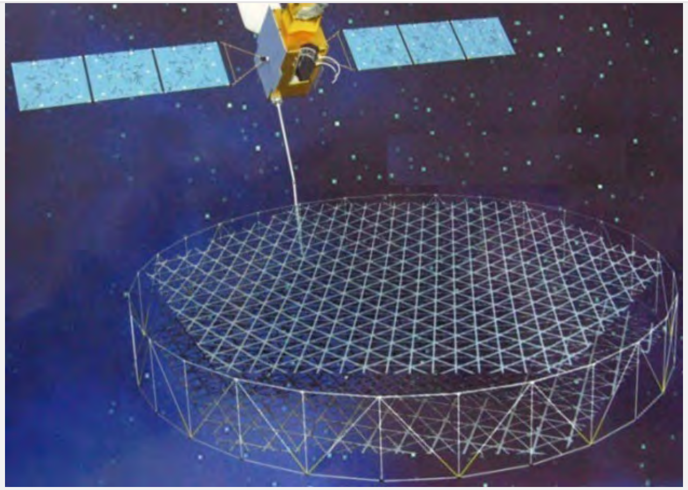
(b) Feed cabin and cable system

FAST 500m largest radio telescope

A 66m S/X-beam guide antenna for Mars detection

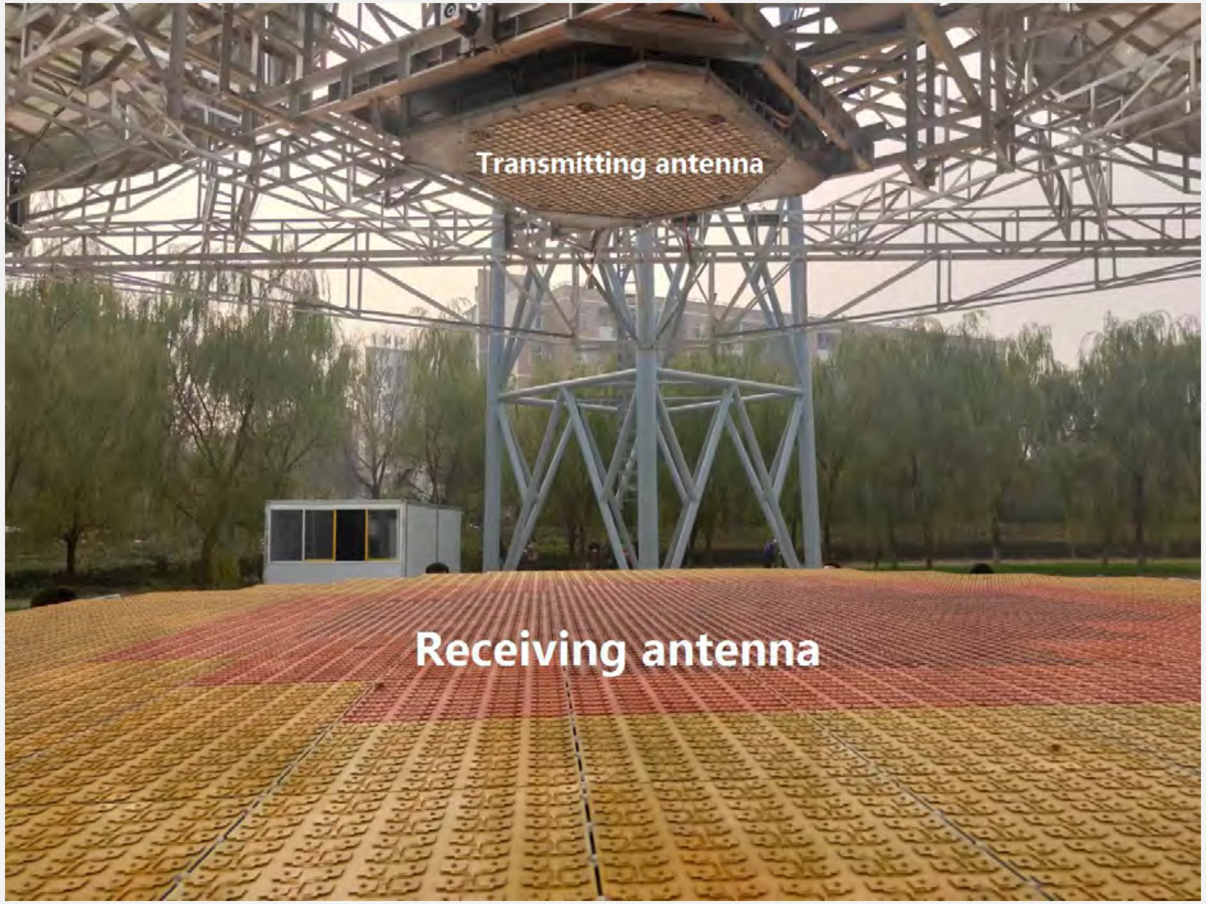


The world's largest fully steerable QTT110 m radio telescope



A China "Tian Tong No.1" spaceborne deployable antenna

WIRELESS POWER TRANSFER
(BY COURTESY OF PROF BAOYAN DUAN, XIDIAN UNIVERSITY)



Arrays of Microstrip antennas

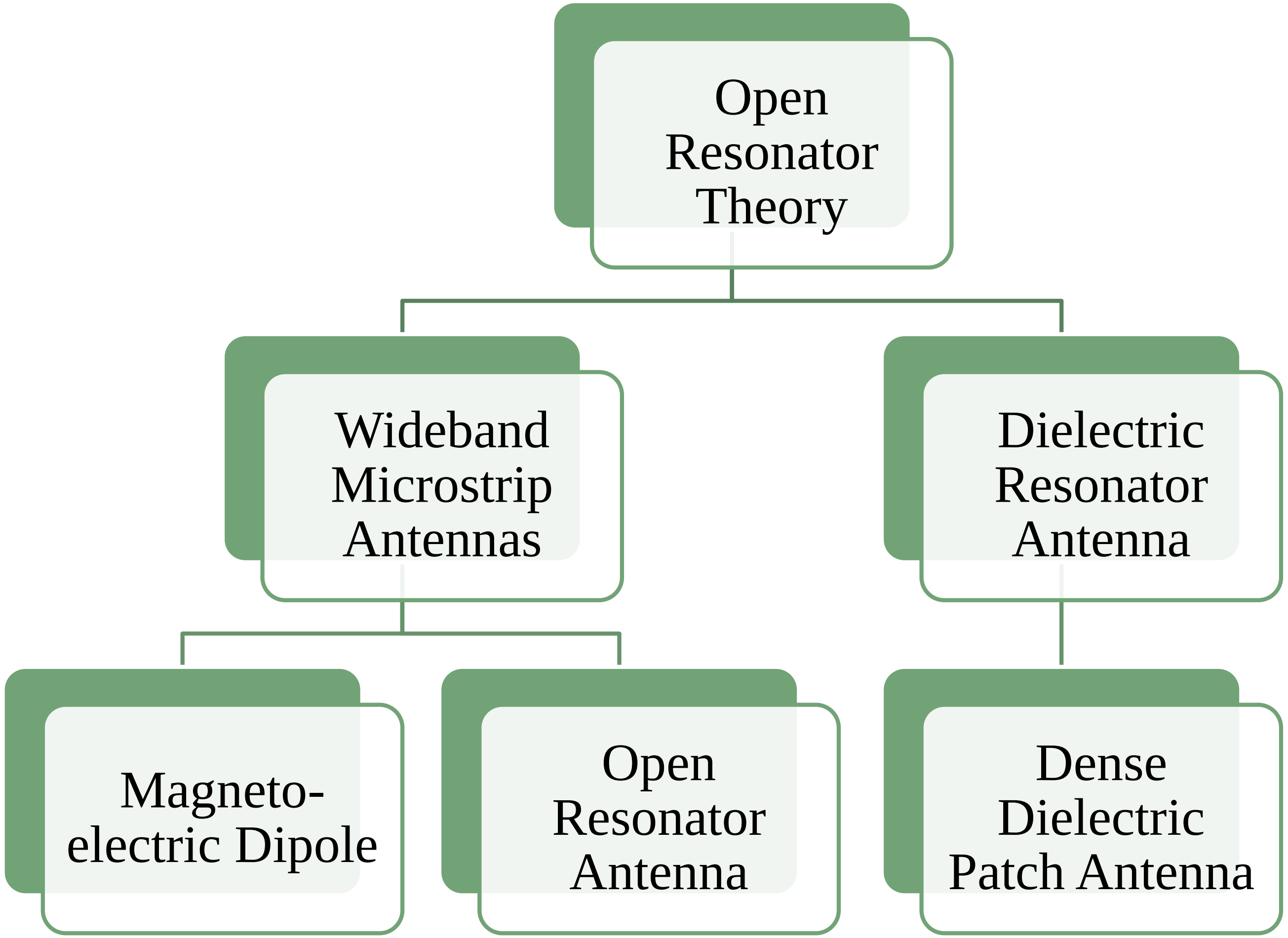
Major Milestones in Antenna Designs over the Past 3 Decades

IEEE APS JOHN KRAUS ANTENNA AWARDS

Year	Name(s)	Major Contributions	
2004	V. H. Rumsey	Reaction Theorem	
2005	Walter Rotman	Rotman Lens	
2006	Carl E. Baum, D.V. Giri, and Everett G. Farr	Ultra-wideband antennas	
2007	Benedikt A. Munk	Microstrip antennas and arrays	
2008	Daniel H. Schaubert	Microstrip antennas	
2009	Kai Fong Lee	U-slot microstrip antennas	
2010	D. E. Anagnostou, Guizhen Zheng, C. Christodoulou, and J. Papapolymerou	Reonfigurable antennas	
2011	D. Filipovic and G. M. Rebeiz	Millimeter-wave antennas	
2012	Peter Hall	Microstrip antennas	

Year	Name(s)	Major Contributions	
2013	Lot Shafai	Wideband microstrip antennas	
2014	Stuart A. Long	Dielectric resonator antenna	
2015	G. Eleftheriades	Metamaterial antennas	
2016	Yahya Rahmat-Samii	Reflector antennas	
2017	Kwai Man Luk	L-probe microstrip antenna, Magneto-electric dipole	
2018	W. D. Burnside	Compact range with blended-rolled edges	
2019	Dan Sievenpiper	High impedance surface	
2020	Yue Ping Zhang, Duixian Liu	Antenna in Package	
2021	Zhi Ning Chen	Metantennas	

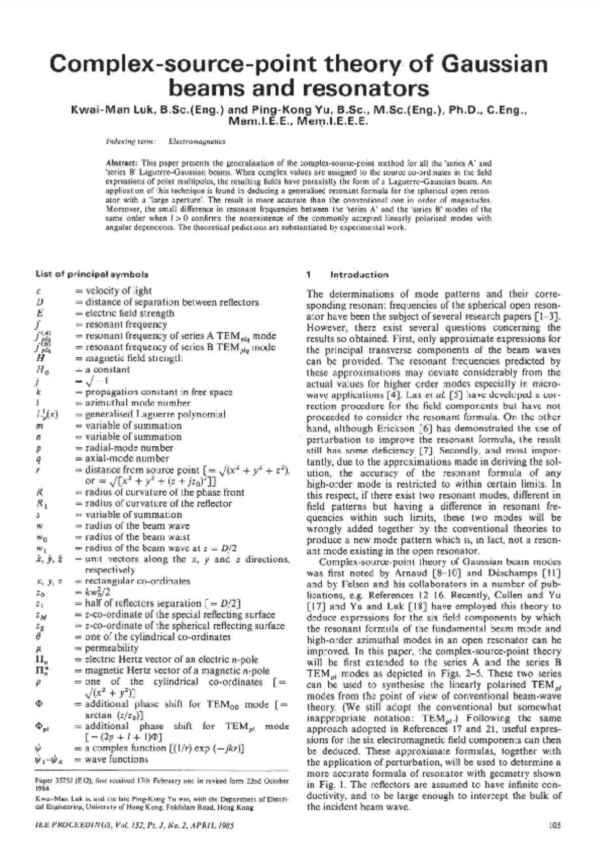
Research Activities



OPEN RESONATOR THEORY

- Improved the theory of the spherical Fabry-Perot cavity
- Derived a more accurate resonant formula based on complex-source-point theory
- Discovered the frequency splitting of polarization eigenmodes of the higher-order Laguerre-Gaussian beam modes

1985 summer



Complex-source-point theory of Gaussian beams and resonators

Kwai-Man Luk, B.Sc.(Eng.) and Ping-Kong Yu, B.Sc., M.Sc.(Eng.), Ph.D., C.Eng., Mem.I.E.E., Mem.I.E.E.E.

Indexing term: *Electromagnetics*

Abstract: This paper presents the generalisation of the complex-source-point method for all the 'series A' and 'series B' Laguerre–Gaussian beams. When complex values are assigned to the source co-ordinates in the field expressions of point multipoles, the resulting fields have paraxially the form of a Laguerre–Gaussian beam. An application of this technique is found in deducing a generalised resonant formula for the spherical open resonator with a 'large aperture'. The result is more accurate than the conventional one in order of magnitudes. Moreover, the small difference in resonant frequencies between the 'series A' and the 'series B' modes of the same order when $l > 0$ confirms the nonexistence of the commonly accepted linearly polarised modes with angular dependence. The theoretical pedictions are substantiated by experimental work.

List of principal symbols

c = velocity of light
D = distance of separation between reflectors
E = electric field strength
f = resonant frequency
$f^{(A)}_{plq}$ = resonant frequency of series A TEM_{plq} mode
$f^{(B)}_{plq}$ = resonant frequency of series B TEM_{plq} mode
H = magnetic field strength
H_0 = a constant
j = $\sqrt{-1}$
k = propagation constant in free space
l = azimuthal mode number
$L^l_p(x)$ = generalised Laguerre polynomial
m = variable of summation
n = variable of summation
p = radial-mode number
q = axial-mode number
r = distance from source point [$= \sqrt{(x^2 + y^2 + z^2)}$, or $= \sqrt{[x^2 + y^2 + (z + jz_0)^2]}$]
R = radius of curvature of the phase front
R_1 = radius of curvature of the reflector
s = variable of summation
w = radius of the beam wave
w_0 = radius of the beam waist
w_1 = radius of the beam wave at $z = D/2$
$\hat{x}, \hat{y}, \hat{z}$ = unit vectors along the x, y and z directions, respectively
x, y, z = rectangular co-ordinates
z_0 = $kw_0^2/2$
z_1 = half of reflectors separation [$= D/2$]
z_M = z-co-ordinate of the special reflecting surface
z_S = z-co-ordinate of the spherical reflecting surface
θ = one of the cylindrical co-ordinates
μ = permeability
Π_n = electric Hertz vector of an electric n-pole
Π^*_n = magnetic Hertz vector of a magnetic n-pole
ρ = one of the cylindrical co-ordinates [$= \sqrt{(x^2 + y^2)}$]
Φ = additional phase shift for TEM_{00} mode [$= \arctan(z/z_0)$]
Φ_{pl} = additional phase shift for TEM_{pl} mode [$-(2p + l + 1)\Phi$]
ψ = a complex function [$(1/r)\exp(-jkr)$]
ψ_1–ψ_4 = wave functions

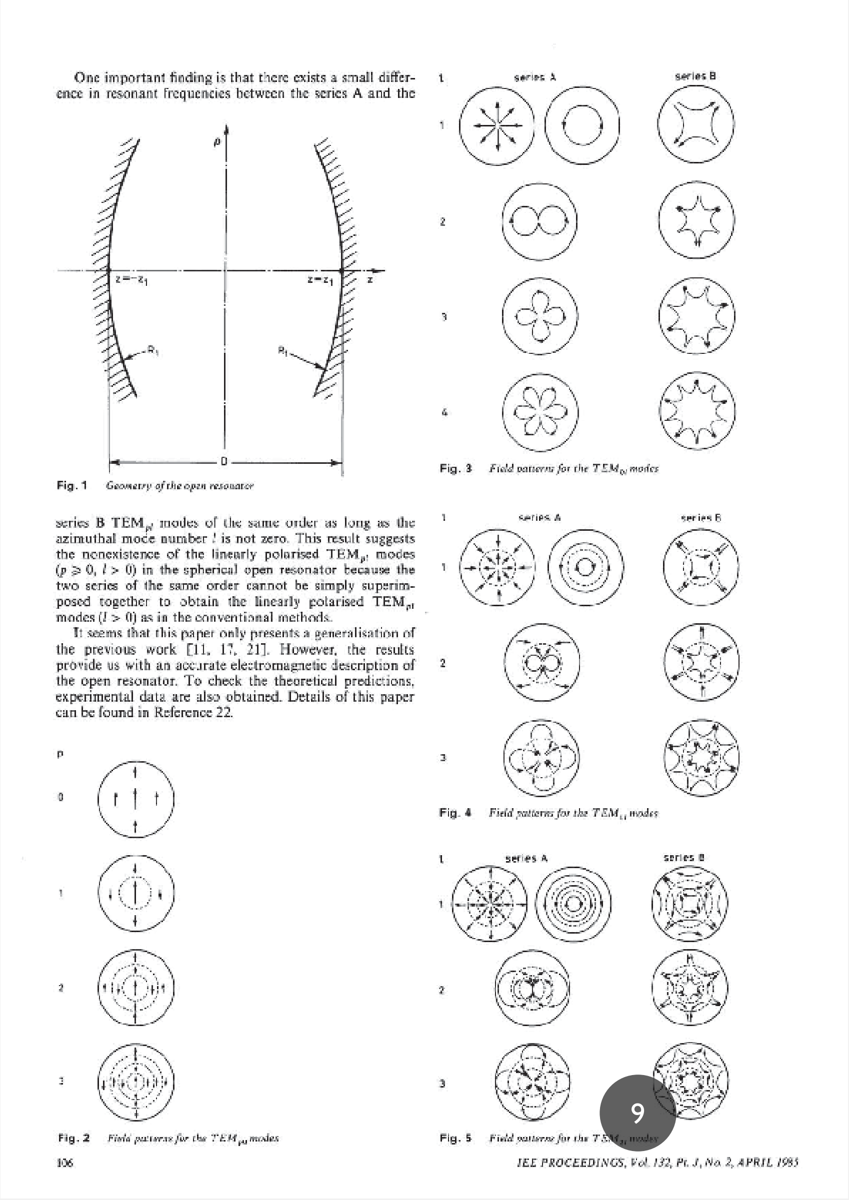
Paper 3575J (E12), first received 17th February and in revised form 22nd October 1984

Kwai-Man Luk is, and the late Ping-Kong Yu was, with the Department of Electrical Engineering, University of Hong Kong, Pokfulam Road, Hong Kong

1 Introduction

The determinations of mode patterns and their corresponding resonant frequencies of the spherical open resonator have been the subject of several research papers [1–3]. However, there exist several questions concerning the results so obtained. First, only approximate expressions for the principal transverse components of the beam waves can be provided. The resonant frequencies predicted by these approximations may deviate considerably from the actual values for higher order modes especially in microwave applications [4]. Lax *et al.* [5] have developed a correction procedure for the field components but have not proceeded to consider the resonant formula. On the other hand, although Erickson [6] has demonstrated the use of perturbation to improve the resonant formula, the result still has some deficiency [7]. Secondly, and most importantly, due to the approximations made in deriving the solution, the accuracy of the resonant formula of any high-order mode is restricted to within certain limits. In this respect, if there exist two resonant modes, different in field patterns but having a difference in resonant frequencies within such limits, these two modes will be wrongly added together by the conventional theories to produce a new mode pattern which is, in fact, not a resonant mode existing in the open resonator.

Complex-source-point theory of Gaussian beam modes was first noted by Arnaud [8–10] and Déschamps [11] and by Felsen and his collaborators in a number of publications, e.g. References 12–16. Recently, Cullen and Yu [17] and Yu and Luk [18] have employed this theory to deduce expressions for the six field components by which the resonant formula of the fundamental beam mode and high-order azimuthal modes in an open resonator can be improved. In this paper, the complex-source-point theory will be first extended to the series A and the series B TEM_{pl} modes as depicted in Figs. 2–5. These two series can be used to synthesise the linearly polarised TEM_{pl} modes from the point of view of conventional beam-wave theory. (We still adopt the conventional but somewhat inappropriate notation: TEM_{pl}.) Following the same approach adopted in References 17 and 21, useful expressions for the six electromagnetic field components can then be deduced. These approximate formulas, together with the application of perturbation, will be used to determine a more accurate formula of resonator with geometry shown in Fig. 1. The reflectors are assumed to have infinite conductivity, and to be large enough to intercept the bulk of the incident beam wave.



One important finding is that there exists a small difference in resonant frequencies between the series A and the series B TEM_{pl} modes of the same order as long as the azimuthal mode number l is not zero. This result suggests the nonexistence of the linearly polarised TEM_{pl} modes ($p \geq 0$, $l > 0$) in the spherical open resonator because the two series of the same order cannot be simply superimposed together to obtain the linearly polarised TEM_{pl} modes ($l > 0$) as in the conventional methods.

It seems that this paper only presents a generalisation of the previous work [11, 17, 21]. However, the results provide us with an accurate electromagnetic description of the open resonator. To check the theoretical predictions, experimental data are also obtained. Details of this paper can be found in Reference 22.

Fig. 1 *Geometry of the open resonator*

Fig. 2 *Field patterns for the TEM_{p0} modes*

Fig. 3 *Field patterns for the TEM_{0l} modes*

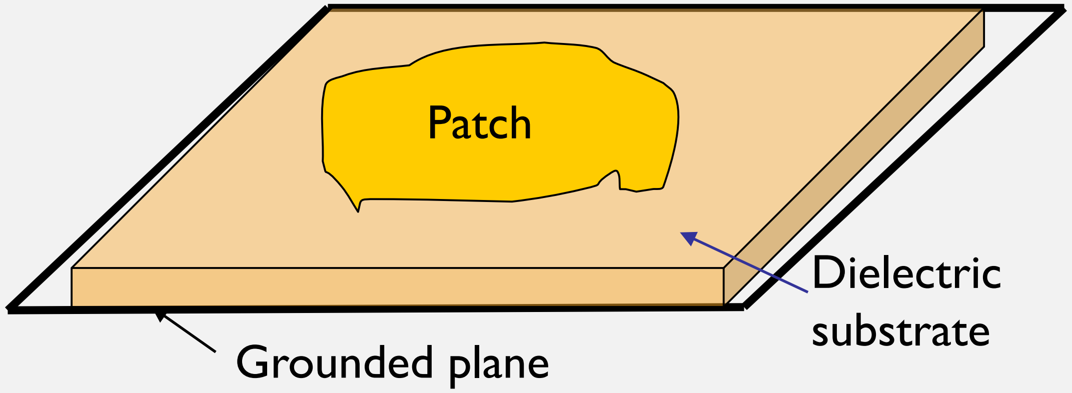
Fig. 4 *Field patterns for the TEM_{1l} modes*

Fig. 5 *Field patterns for the TEM_{2l} modes*

BASIC MICROSTRIP PATCH ANTENNA

- Most popular antenna structure over the past 4 decades

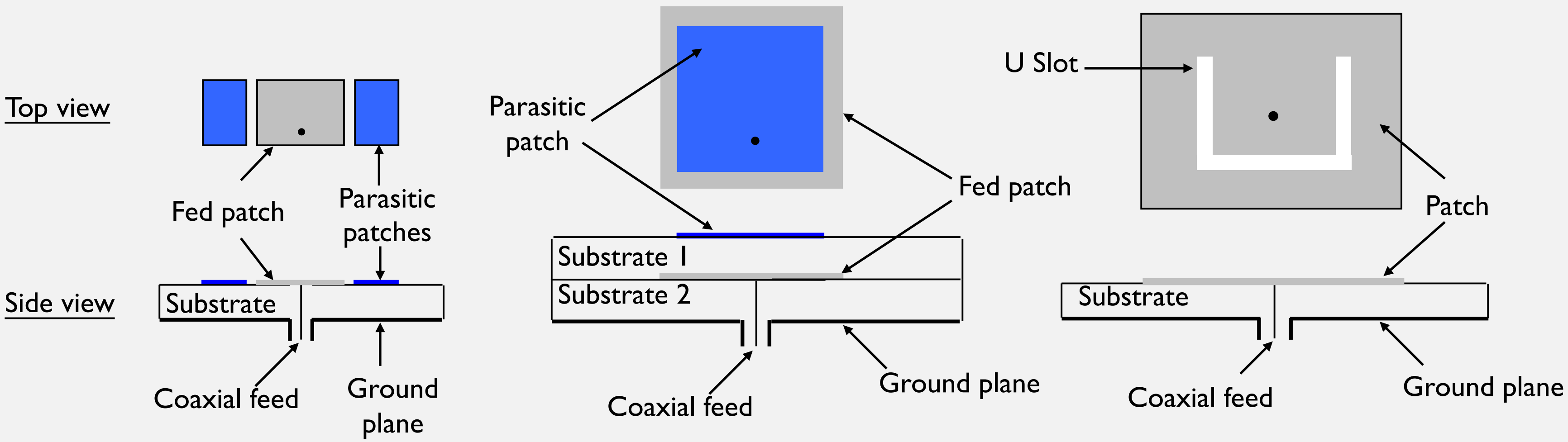
- Low profile
- Narrow bandwidth <2%; low gain~6.5dBi
- Broadside or conical radiation pattern



G. A. Deschamps, "Microstrip microwave antennas," presented at the 3rd USAF Symposium on Antennas, 1953.

WIDEBAND MICROSTRIP ANTENNAS

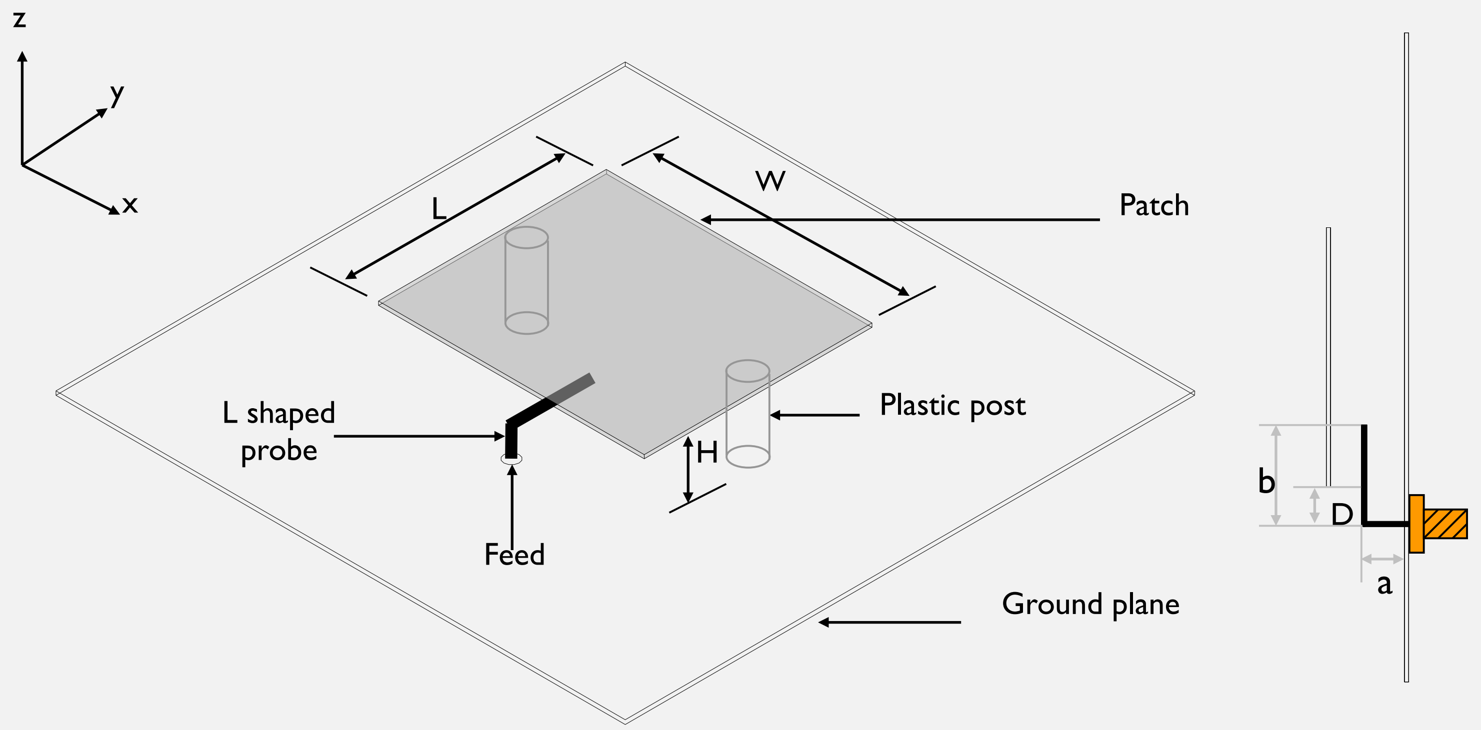
Coplanar parasitic patches | **Stacked parasitic patch** | **U-shaped slot**



(a) (b) (c)

K F Tong, K M Luk, K F Lee and R Q Lee, "A broadband U-slot rectangular patch antenna on a microwave substrate," IEEE TAP 2000
K F Lee, K M Luk, K F Tong, S M Shum, T Huynh and R Q Lee, "Experimental studies of the coaxially fed U-slot rectangular patch antenna," IEE Proc. H 1997

L-PROBE PATCH ANTENNA



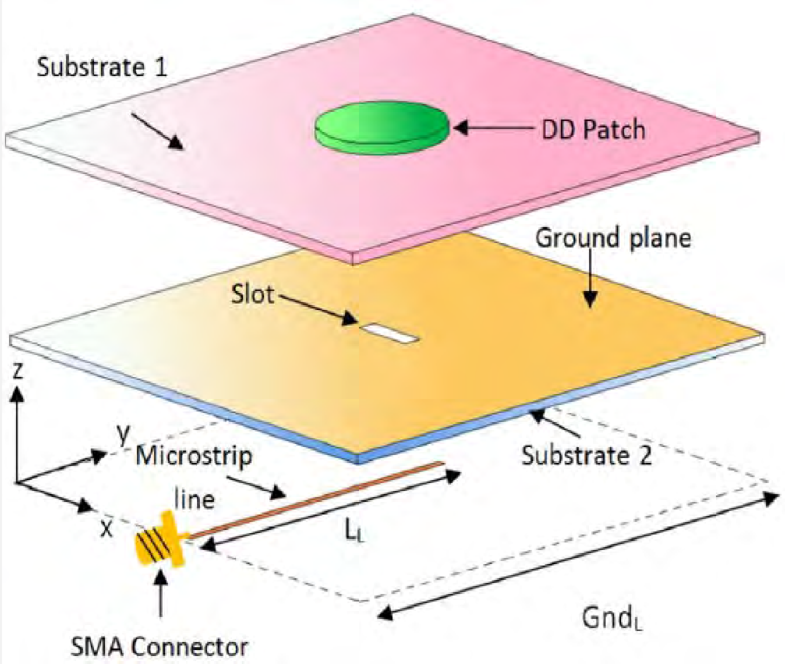
(a) Perspective view

(b) Side view

- Can be designed with linear, circular and dual polarizations
- Flexible in selecting feed locations
- Non-contacted feed

K M Luk, C L Mak, Y L Chow and K F Lee, "Broadband microstrip patch antenna," Electronics Letters, 1998

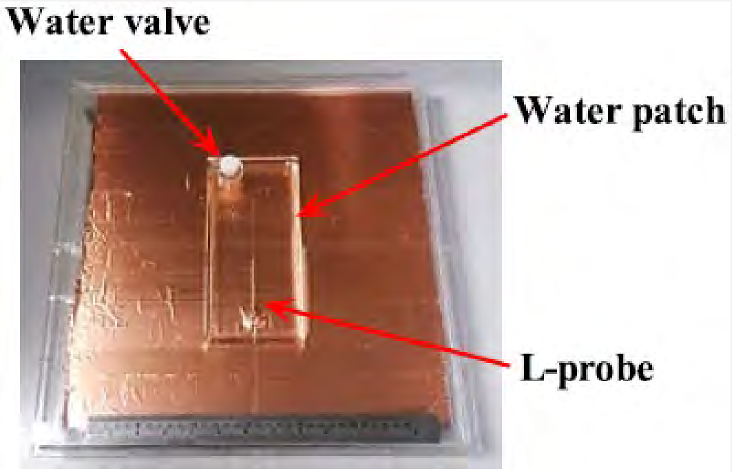
DENSE DIELECTRIC PATCH ANTENNA



- **Operating at 3.98 GHz with an impedance bandwidth of 1% and a gain of 5.6 dBi**
- **The metallic patch is replaced by a thin dielectric patch with high dielectric constant**
- **Attractive for millimeter-wave and terahertz applications as surface roughness problem of metallic patch is mitigated.**

H. W. Lai, K. M. Luk, and K. W. Leung, "Dense dielectric patch antenna – A new kind of low-profile antenna element for wireless communications," IEEE Trans. Antennas Propagation, vol. 61, no. 8, pp. 4239–4245, Aug. 2013.

Water Patch Antenna



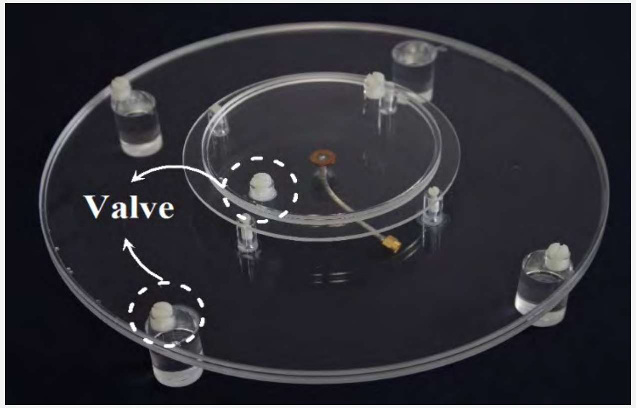
- Water has high dielectric constant
- Working at 0.9 GHz
- Bandwidth: up to 22.6 % for $|S_{11}|$< -10 dB
- Gain: up to 8 dBi
- Unidirectional radiation pattern

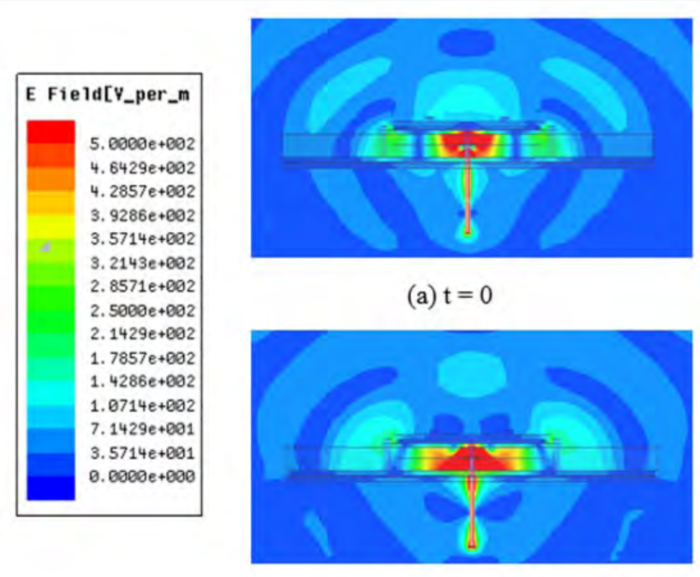
- Three layers: Water patch + air substrate + metallic ground plane
- Circular water patch and metallic ground for obtaining omnidirectional radiation patterns
- A disk-loaded probe in the center to excite the water patch & achieve wide impedance bandwidth

Y Li and K M Luk, "A Water Dense Dielectric Patch Antenna", IEEE Access, pp. 274-280, 2015.

J Sun and K M Luk, "Design of water dielectric patch antenna for conical beam radiation," *IEEE International Workshop on Electromagnetics: Application Student Innovation Competition (iWEM)*, 2016.

A Wideband Transparent Water Patch Antenna





(a) t = 0

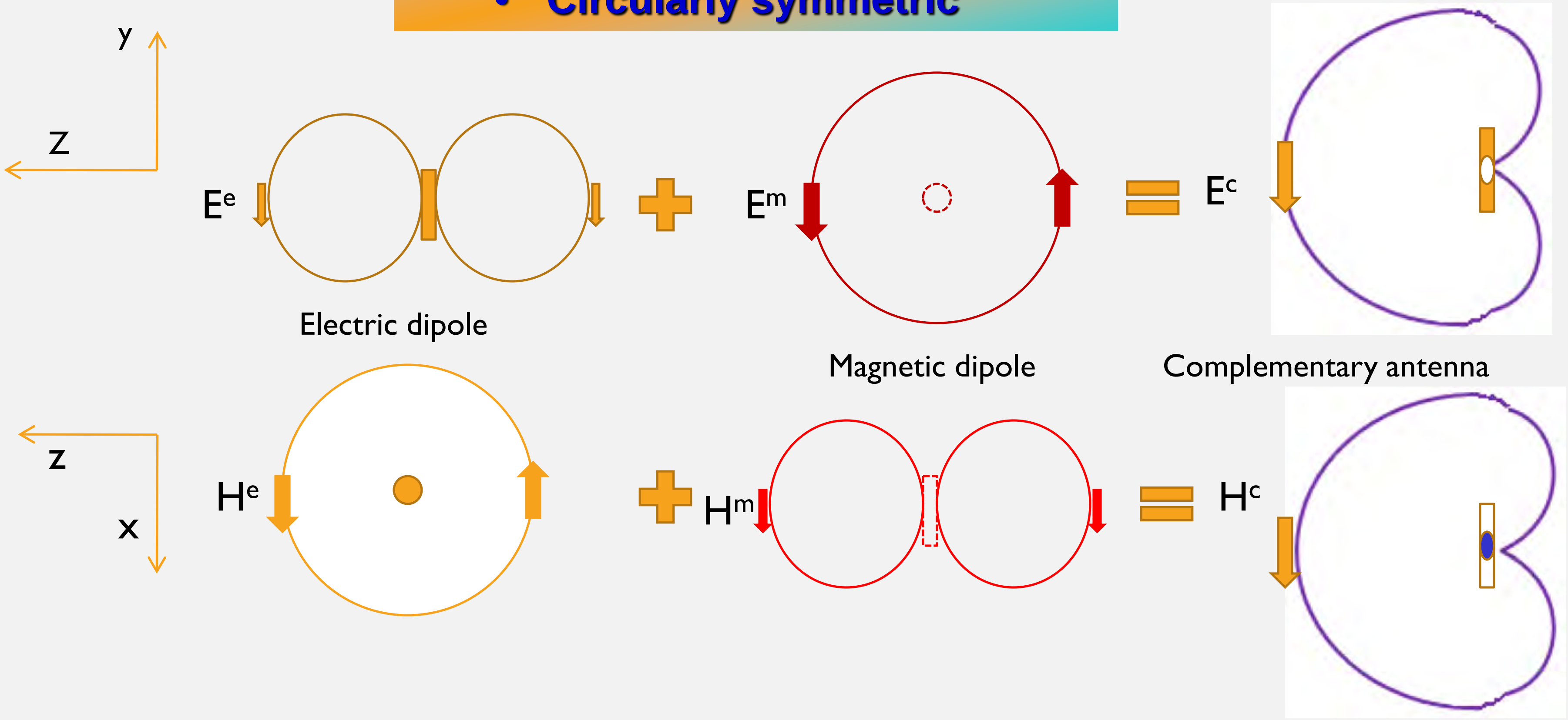
(b) t = T/4

- **Three layers: two water layers and an air layer sandwiched in the middle.**
- **Circular shape for both water layers**
- **A disk-loaded probe feed at the center**

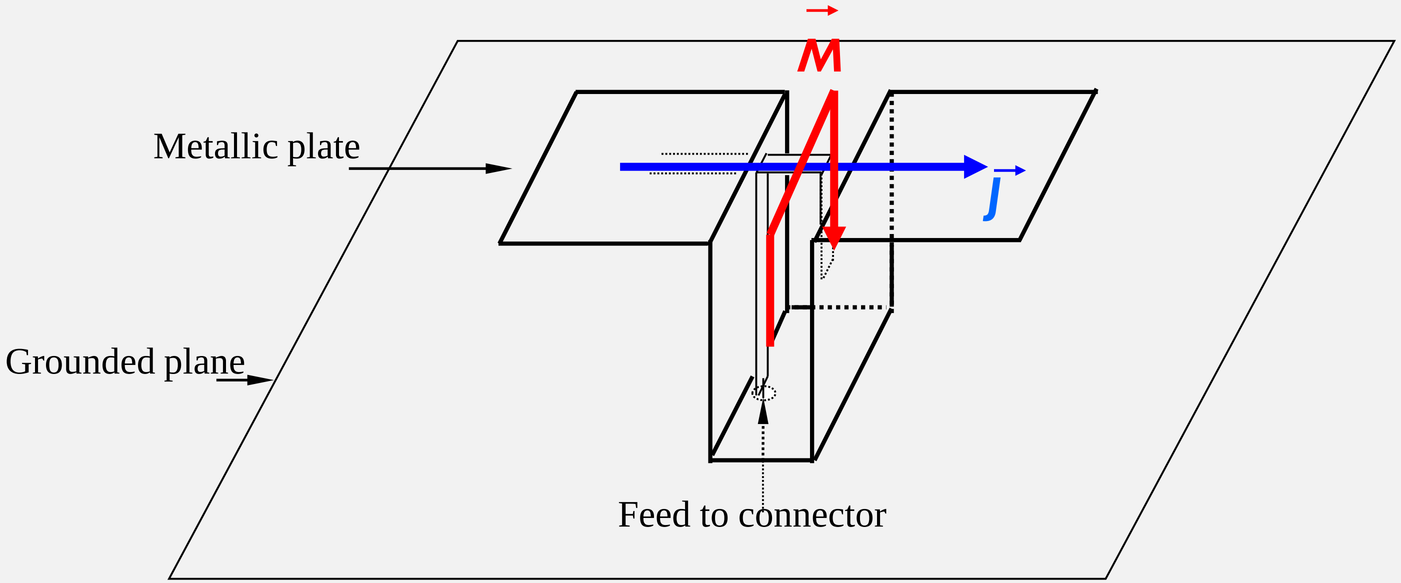
Jie Sun and Kwai-Man Luk, "Design of transparent multilayer film antenna for wireless communication," *IEEE Transactions on Antenna & Propagations*, accepted for publication, 2016.

COMPLEMENTARY ANTENNA CONCEPT

- **Cardiac shape radiation pattern**
  - **Back-lobe suppression**
  - **Circularly symmetric**



MAGNETO-ELECTRIC DIPOLE
– BY GENERALIZING THE COMPLEMENTARY ANTENNA CONCEPT

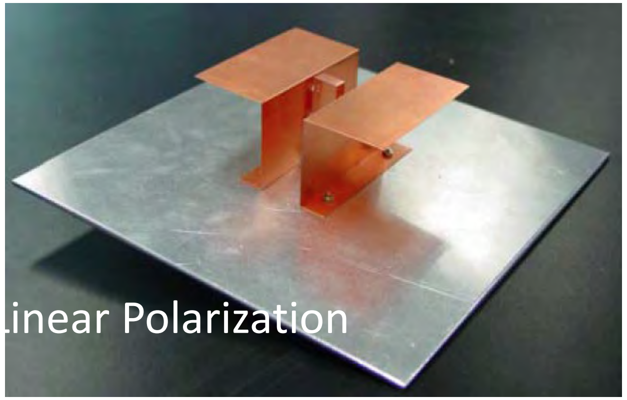


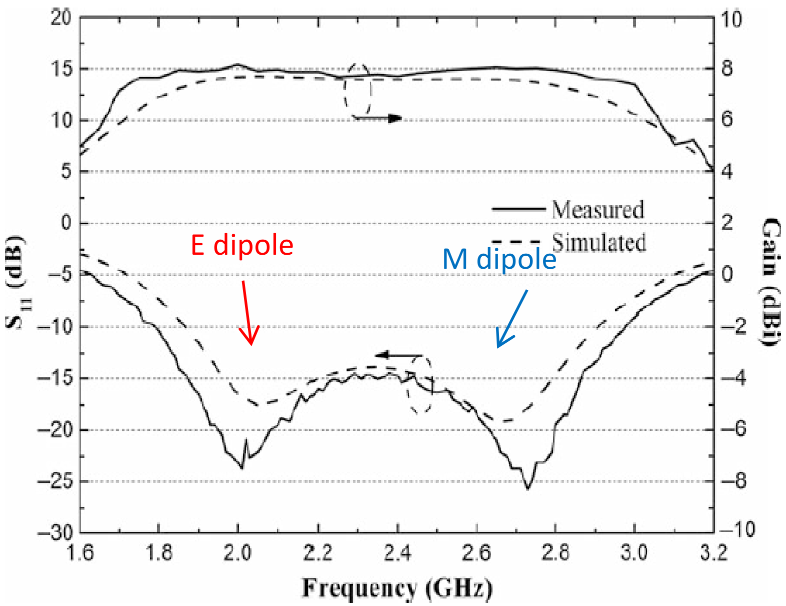
Both electric and magnetic dipole modes are excited simultaneously

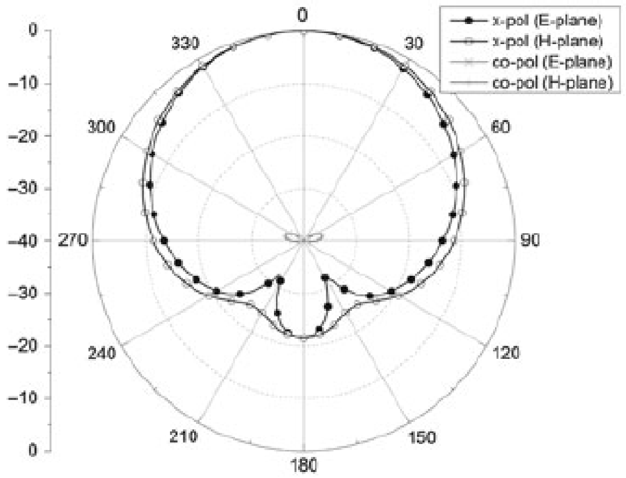
K M Luk and H Wong, "A new wideband unidirectional antenna," International Journal of Microwaves and Optical Technologies, 2006

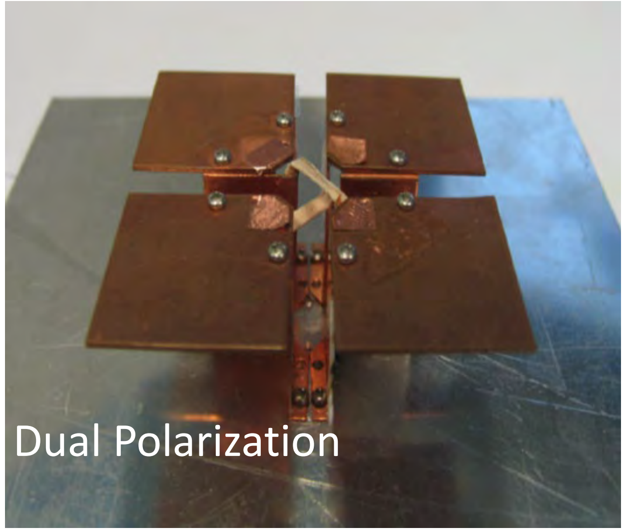
BASIC ME DIPOLE STRUCTURE

- Wide impedance bandwidth: ~50%
- Stable gain performance (~ 8 dBi)
- Cardiac shape radiation pattern
- Low cross-polarization (< 20 dB) and low back radiation (< 20 dB)









K.-M. Luk and H. Wong, "A new wideband unidirectional antenna element," *Int. J. Microw. Opt. Technol.*, vol. 1, no. 1, pp. 35–44, Jun. 2006

B. Q. Wu and K. M.Luk, "A broadband dual-polarized magneto-electric dipole antenna with simple feeds," IEEE Antennas and Wireless Propagation Letters, vol.8, pp.60-63,2009

Open Resonator Antenna (with a spherical Fabry-Perot cavity)

6G communications
Frequency increase: from microwave to terahertz

↓

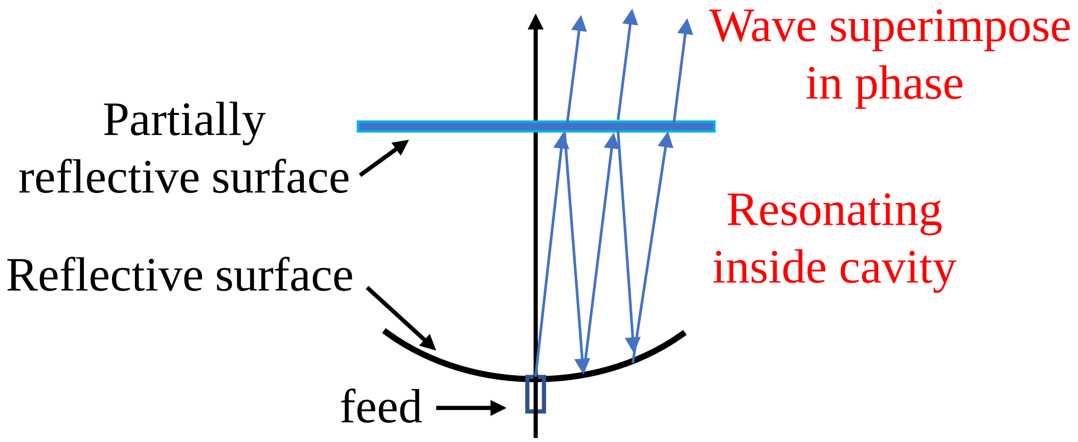
Higher air attenuation
Weaker penetration power

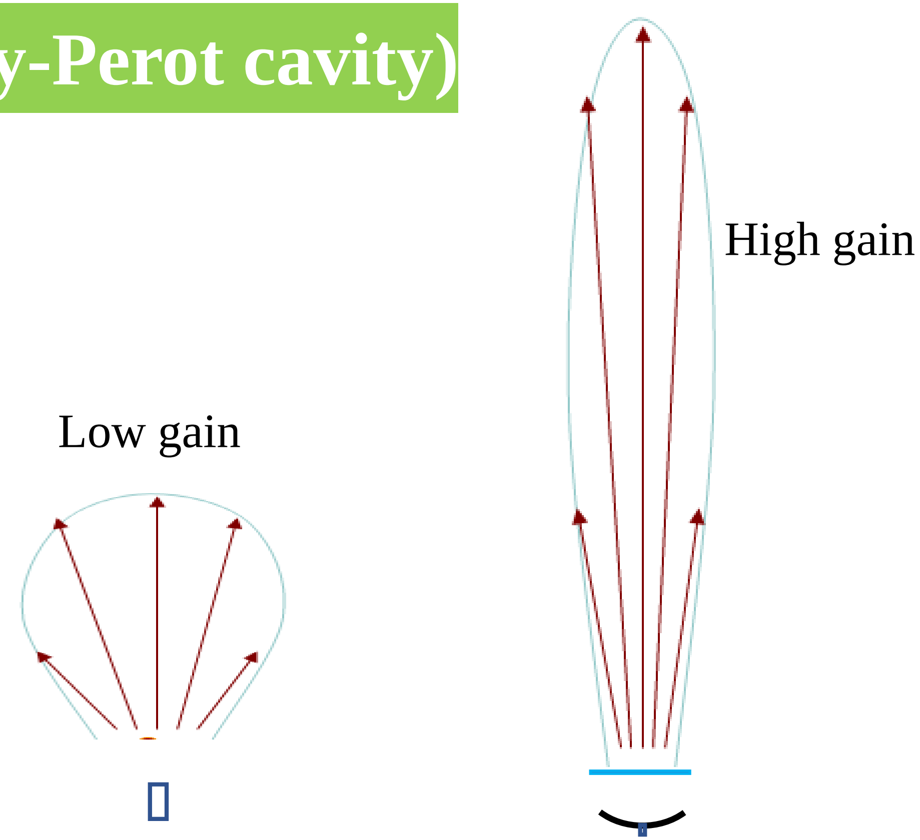
↓

High gain antenna
to cover longer distance

↓

Open resonator antenna





Feed only

Feed with resonator
(Open resonator antenna)

Advantages:

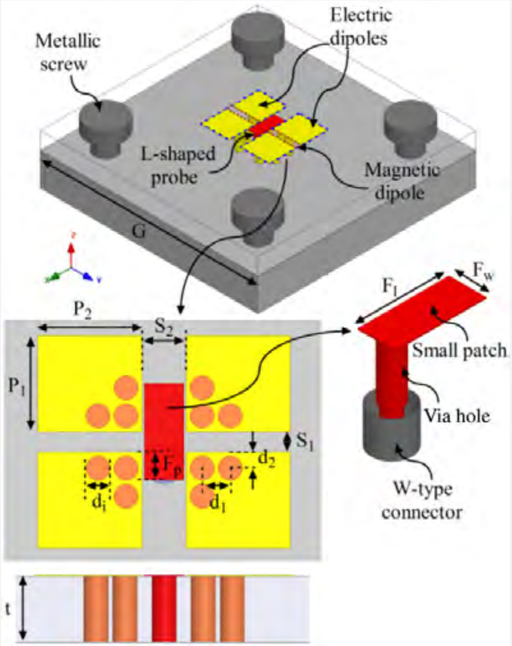
- High gain (Comparing to patch/dipole/monopole…)
- Low profile (Comparing to horn/lens…)
- Easily integrated with integrated circuits
- No complex feeding network, low loss (comparing with antenna arrays)

MOST POPULAR PAPERS

- From IEEE Xplore, Kwai Man Luk has 301 papers with a total of 460,000 full text views.
- And has 19 papers each with over 5000 full text views

RANK 19 – NO. OF VIEWS 5004

M. Li and K. M. Luk, "Wideband Magneto-Electric Dipole Antenna for 60-GHz Millimeter-Wave Communications," IEEE Transactions on Antennas and Propagation, 2015

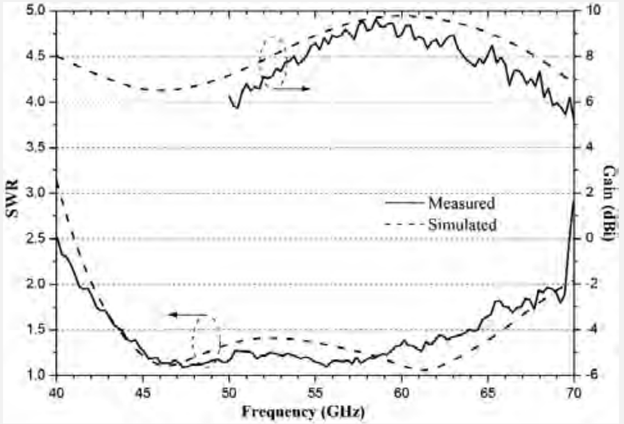


Design Principle:

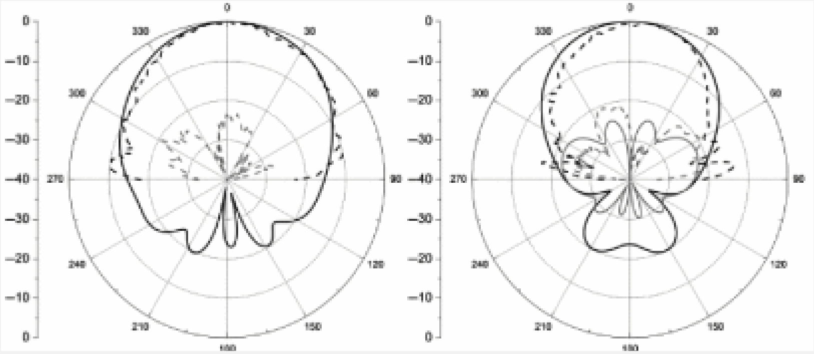
- L-shaped probe feed principle
- Vertical vias to realize vertical walls

Attractive Features:

- Single layer design
- Stable gain and radiation pattern
- Low cross-polar & back radiation
- Suit for array
- Low fabrication cost
- Low surface wave loss



SWR and Gain



E-plane

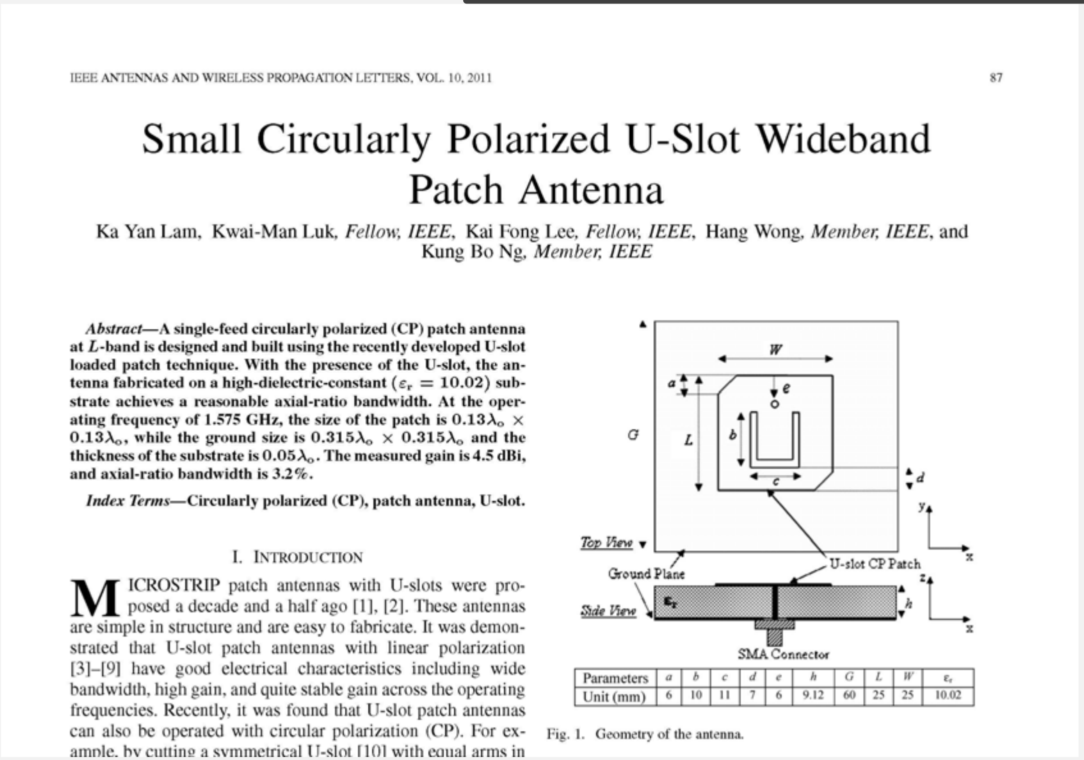
H-plane

Radiation Patterns at 55 GHz

Performance:

- f = 60 GHz
- SWR BW = 51%
- Gain = 8 dBic
- Size: $0.73\lambda \times 0.87\lambda$

RANK 12 – NO. OF VIEWS 5532


IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 10, 2011 87

Small Circularly Polarized U-Slot Wideband Patch Antenna

Ka Yan Lam, Kwai-Man Luk, *Fellow, IEEE*, Kai Fong Lee, *Fellow, IEEE*, Hang Wong, *Member, IEEE*, and Kung Bo Ng, *Member, IEEE*

***Abstract*—A single-feed circularly polarized (CP) patch antenna at *L*-band is designed and built using the recently developed U-slot loaded patch technique. With the presence of the U-slot, the antenna fabricated on a high-dielectric-constant ($\varepsilon_r = 10.02$) substrate achieves a reasonable axial-ratio bandwidth. At the operating frequency of 1.575 GHz, the size of the patch is $0.13\lambda_o \times 0.13\lambda_o$, while the ground size is $0.315\lambda_o \times 0.315\lambda_o$ and the thickness of the substrate is $0.05\lambda_o$. The measured gain is 4.5 dBi, and axial-ratio bandwidth is 3.2%.**

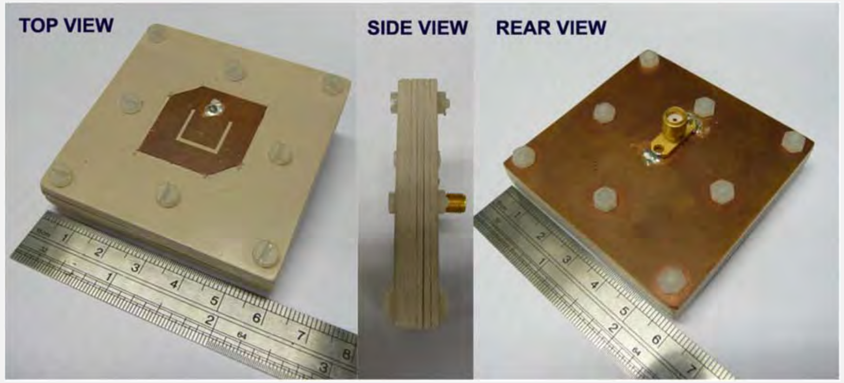
***Index Terms*—Circularly polarized (CP), patch antenna, U-slot.**

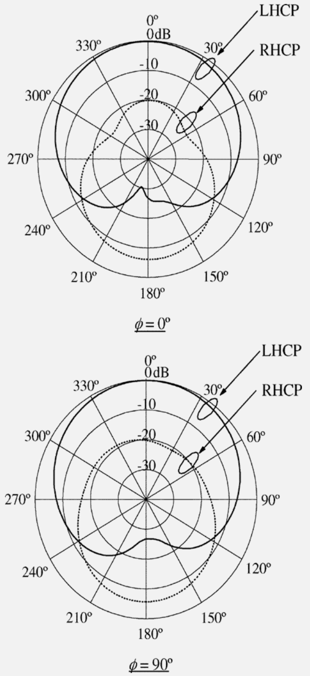
I. INTRODUCTION

MICROSTRIP patch antennas with U-slots were proposed a decade and a half ago [1], [2]. These antennas are simple in structure and are easy to fabricate. It was demonstrated that U-slot patch antennas with linear polarization [3]–[9] have good electrical characteristics including wide bandwidth, high gain, and quite stable gain across the operating frequencies. Recently, it was found that U-slot patch antennas can also be operated with circular polarization (CP). For example, by cutting a symmetrical U-slot [10] with equal arms in

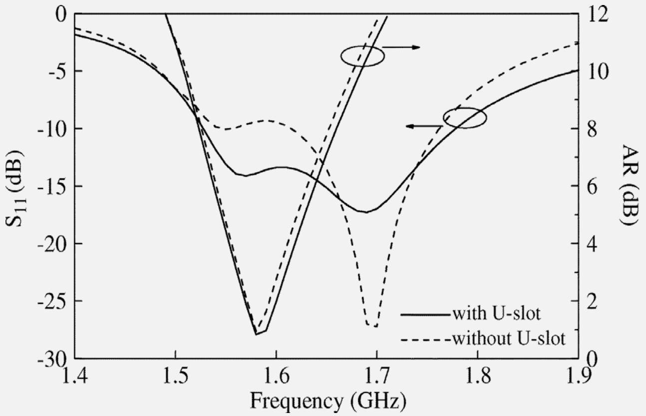
Parameters	a	b	c	d	e	h	G	L	W	ε_r
Unit (mm)	6	10	11	7	6	9.12	60	25	25	10.02

Fig. 1. Geometry of the antenna.





Radiation Patterns at 1.575 GHz



Comparison of simulated return loss and axial ratio with/without U-slot

Design Principle:

- U-slot for wideband matching
- Chamfer corner for CP excitation
- High dielectric constant material for size reduction (εr = 10.02)

Attractive Features:

- Small size
- Large overlapping impedance and SWR bandwidth

Performance:

- f = 1.575 GHz
- SWR BW = 4.2%
- Gain = 4.5 dBic
- Size: 0.13λ×0.13λ

RANK 10 – NO. OF VIEWS 6235

A Low-Profile Magneto-Electric Dipole Antenna

Lei Ge and Kwai Man Luk, *Fellow, IEEE*

***Abstract*—A new low-profile magneto-electric dipole antenna composed of a horizontal planar dipole and a vertically oriented folded shorted patch antenna is presented. The antenna is simply excited by a coaxial feed without the need of an additional balun. A rectangular cavity-shaped reflector is introduced for enhancing the stability in radiation pattern over the operating frequencies. A parametric study is performed for providing practical design guidelines. A prototype with a thickness of 0.173λ was designed, fabricated and measured. Results show that an impedance bandwidth of 54.8% for SWR ≤ 1.5 from 1.88 to 3.3 GHz was achieved. Stable radiation pattern with low cross polarization, low back radiation and an antenna gain of 8.6 ± 0.8 dBi was found over the operating frequencies. In addition, the antenna is d.c. grounded, which satisfies the requirement of many outdoor antennas.**

***Index Terms*—Low profile, magneto-electric dipole, unidirectional patterns, wideband antenna.**

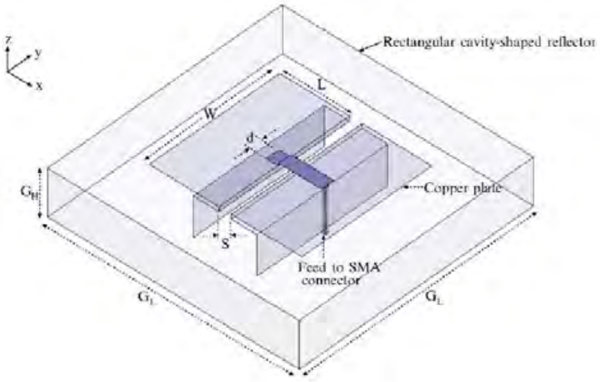
I. Introduction

With the rapid development of modern wireless communications, wideband and low-profile unidirectional antennas with high performance, such as low cross polarization, low back radiation, and stable gain, are in great demand. Many different methods were proposed to achieve good electrical characteristics in the literature. Several types of antennas, such as log-periodic, horn, and reflector antennas [1], are disadvantageous by their bulky structures. The patch antennas [2]–[4] can provide unidirectional patterns and have major advantages proposed by Luk *et al.* [11]. By combining a magnetic dipole and an electric dipole, good electrical characteristics such as low back radiation, stable antenna gain over the operating frequency band, and symmetric radiation patterns are achieved. Based on these previous works, a novel wideband unidirectional antenna is presented in this paper. The antenna comprises a pair of horizontal planar patches and a pair of vertically oriented folded shorted patches, which works as an electric dipole and a magnetic dipole, respectively. A coaxial feed is designed to feed the antenna, which makes the antenna d.c. grounded, satisfying the requirement of many outdoor antennas. To obtain low back radiation and stable pattern beamwidth, a rectangular cavity-shaped reflector is introduced.

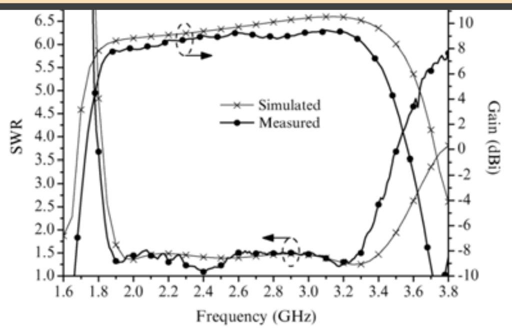
A prototype was built and tested. Experimental results agree well with simulations. Based on simulation results by HFSS [12], the effects of various parameters on the performance of the proposed antenna are discussed.

II. Antenna Geometry

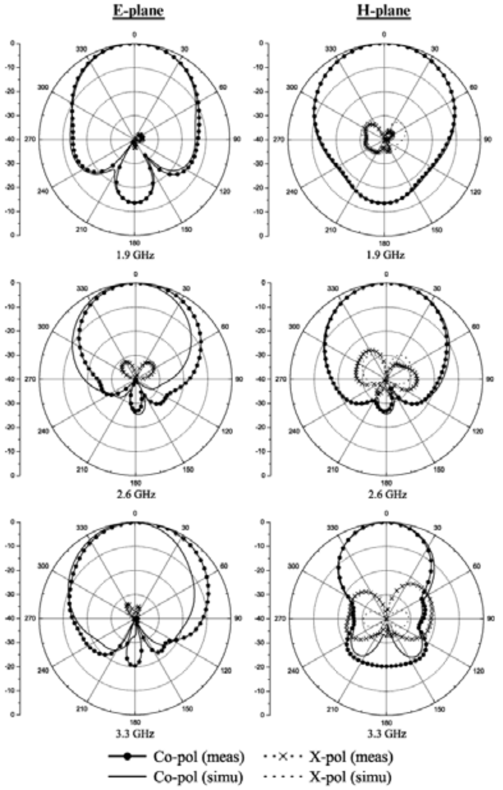
Fig. 1 shows the geometry of the proposed antenna with detailed dimensions. Basically, the antenna consists of a rectangular cavity-shaped reflector, a pair of horizontal planar patches, a pair of vertically oriented folded shorted patches, and a coaxial feed. The rectangular cavity-shaped reflector with dimensions of 112 mm × 112 mm × 20 mm (0.967λ by 0.967λ by 0.173λ) is used to adjust the back radiation. The



Geometry



SWR and Gain



Radiation patterns

Design Principle:

- Magneto-electric dipole as radiator
- Folded patch for low profile
- Metallic cavity for reducing back radiation

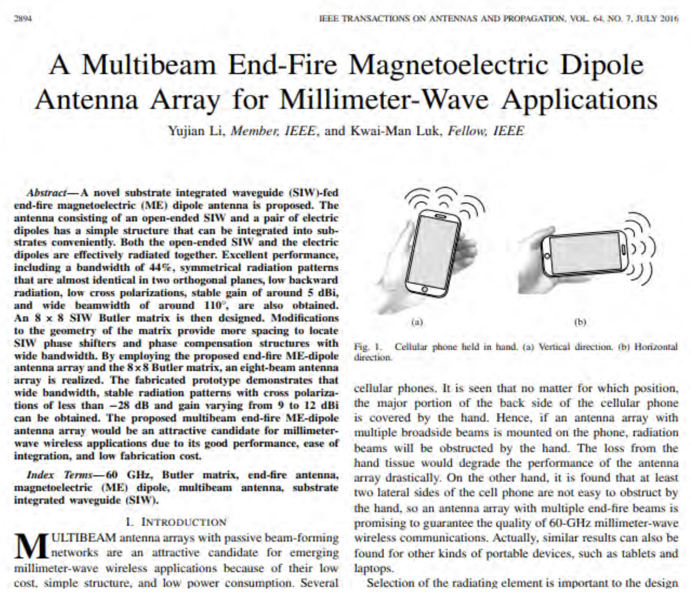
Attractive Features:

- Low profile
- Simple feeding structure
- Wide bandwidth
- Low back radiation
- Low cross polarization
- D.C. grounded

Performance:

- Bandwidth: 1.88-3.3 GHz (54.8%)
- Gain: 8.6 dBi
- Size: $0.967\lambda_0 \times 0.967\lambda_0 \times 0.173\lambda_0$

RANK 9 – NO. OF VIEWS 6617



2894 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 64, NO. 7, JULY 2016

A Multibeam End-Fire Magnetoelectric Dipole Antenna Array for Millimeter-Wave Applications

Yujian Li, *Member, IEEE*, and Kwai-Man Luk, *Fellow, IEEE*

***Abstract*— A novel substrate integrated waveguide (SIW)-fed end-fire magnetoelectric (ME) dipole antenna is proposed. The antenna consisting of an open-ended SIW and a pair of electric dipoles has a simple structure that can be integrated into substrates conveniently. Both the open-ended SIW and the electric dipoles are effectively radiated together. Excellent performance, including a bandwidth of 44%, symmetrical radiation patterns that are almost identical in two orthogonal planes, low backward radiation, low cross polarizations, stable gain of around 5 dBi, and wide beamwidth of around 110°, are also obtained. An 8 x 8 SIW Butler matrix is then designed. Modifications to the geometry of the matrix provide more spacing to locate SIW phase shifters and phase compensation structures with wide bandwidth. By employing the proposed end-fire ME-dipole antenna array and the 8×8 Butler matrix, an eight-beam antenna array is realized. The fabricated prototype demonstrates that wide bandwidth, stable radiation patterns with cross polarizations of less than −28 dB and gain varying from 9 to 12 dBi can be obtained. The proposed multibeam end-fire ME-dipole antenna array would be an attractive candidate for millimeter-wave wireless applications due to its good performance, ease of integration, and low fabrication cost.**

***Index Terms*— 60 GHz, Butler matrix, end-fire antenna, magnetoelectric (ME) dipole, multibeam antenna, substrate integrated waveguide (SIW).**

I. INTRODUCTION

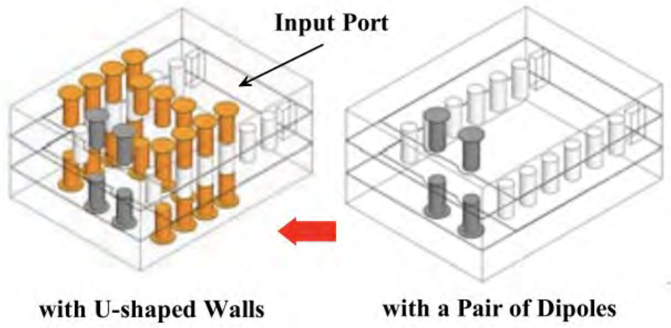
MULTIBEAM antenna arrays with passive beam-forming networks are an attractive candidate for emerging millimeter-wave wireless applications because of their low cost, simple structure, and low power consumption. Several

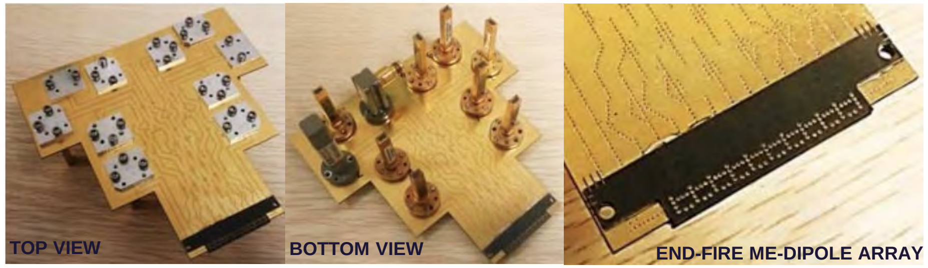
(a) (b)

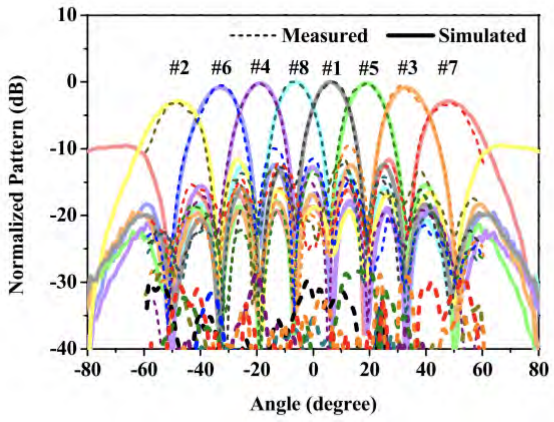
Fig. 1. Cellular phone held in hand. (a) Vertical direction. (b) Horizontal direction.

cellular phones. It is seen that no matter for which position, the major portion of the back side of the cellular phone is covered by the hand. Hence, if an antenna array with multiple broadside beams is mounted on the phone, radiation beams will be obstructed by the hand. The loss from the hand tissue would degrade the performance of the antenna array drastically. On the other hand, it is found that at least two lateral sides of the cell phone are not easy to obstruct by the hand, so an antenna array with multiple end-fire beams is promising to guarantee the quality of 60-GHz millimeter-wave wireless communications. Actually, similar results can also be found for other kinds of portable devices, such as tablets and laptops.

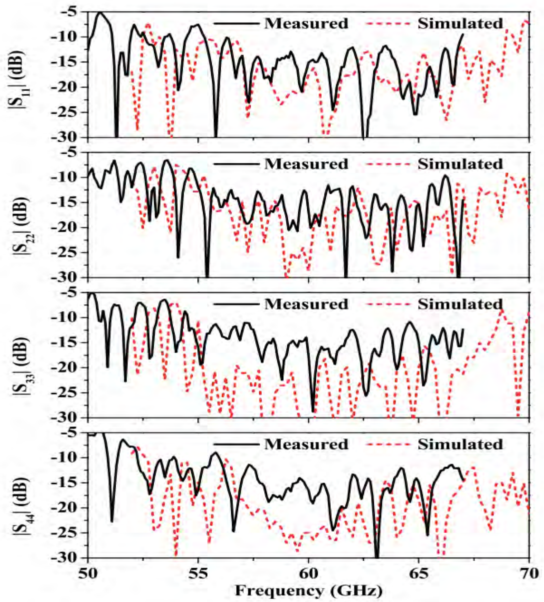
Selection of the radiating element is important to the design







Radiation Patterns at 60 GHz



Simulated and measured S-parameters of the fabricated antenna array

Design Principle:

- Integrate open-end SIW and E-dipoles as ME-dipole antenna
- Additional E-dipole helps to improve matching
- U-shaped walls prevent undesired influence on devices behind the antenna

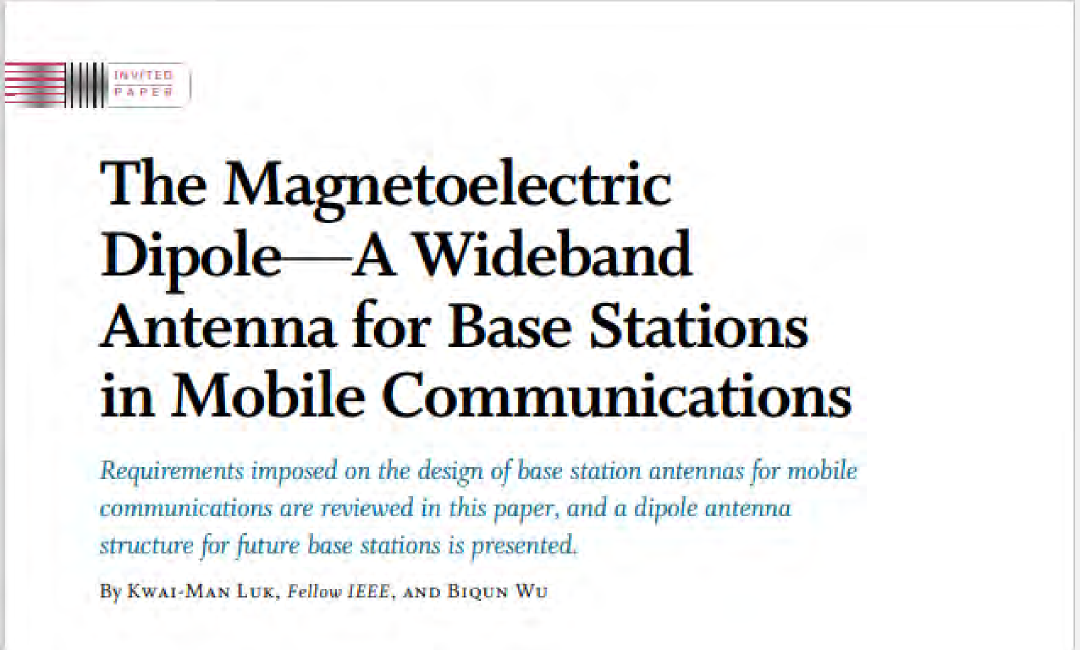
Attractive Features:

- Simple structure
- Ease of integration
- Low costs

Performance:

- f = 60 GHz
- Overlapped BW > 18.2%
- Gain = 9 – 12 dBi
- Directivity > 12 dB
- X-pol. < -28 dB
- Radiation eff. = 45% - 55%

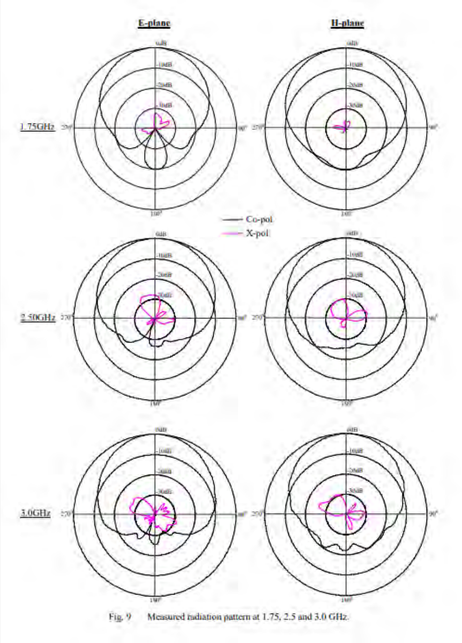
RANK 8 – NO. OF VIEWS 6716


INVITED PAPER

The Magnetoelectric Dipole—A Wideband Antenna for Base Stations in Mobile Communications

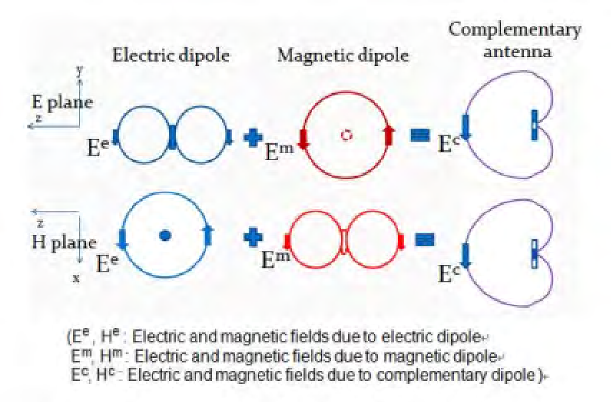
Requirements imposed on the design of base station antennas for mobile communications are reviewed in this paper, and a dipole antenna structure for future base stations is presented.

By Kwai-Man Luk, *Fellow IEEE*, and Biqun Wu



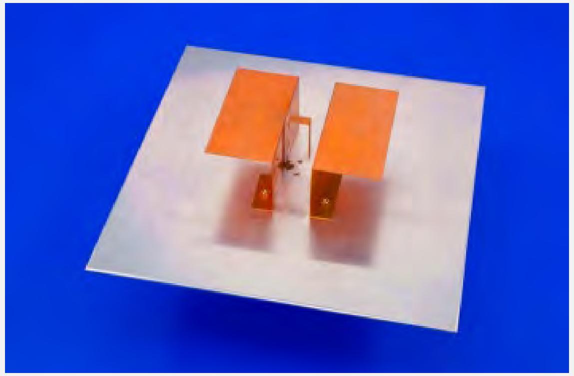
Radiation Patterns at 1.7,2.5,3 GHz

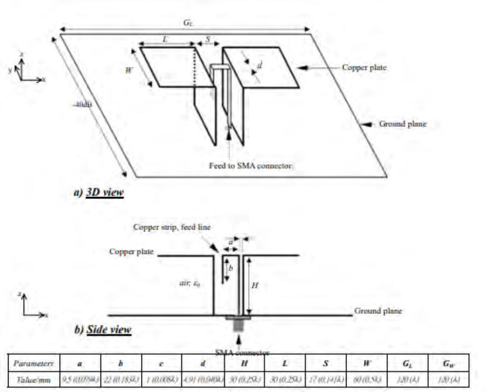
Design Principle:

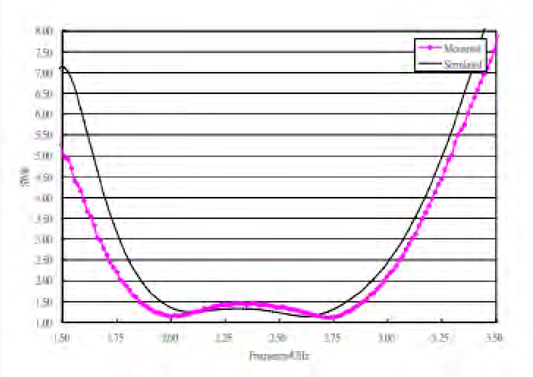


Attractive Features:

- low cross polarization <- 20 dB,
- low back radiation : < -20 dB,
- the beamwidth and rad. pattern are very stable over the operating BW.





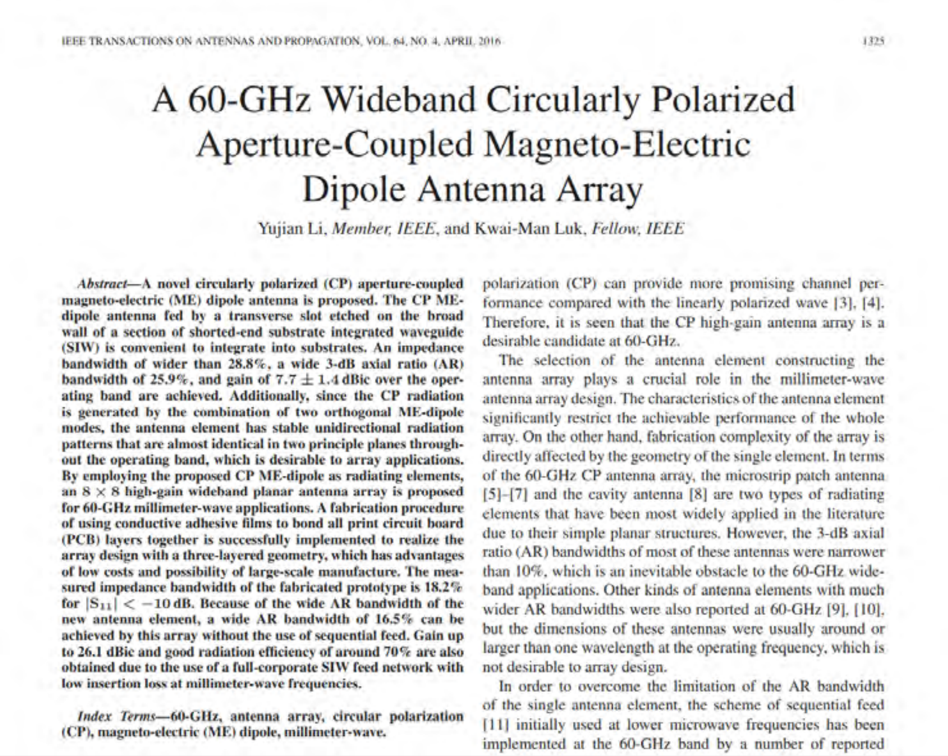


VSWR

Performance:

- f=2.4GHz
- VSWR<1.5 BW = 44% (1.85-2.89)
- Gain = 7.6-8 dBi over the BW
- Size: $0.5\lambda \times 0.5\lambda$

RANK 7 – NO. OF VIEWS 7357


IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 64, NO. 4, APRIL 2016 1325

A 60-GHz Wideband Circularly Polarized Aperture-Coupled Magneto-Electric Dipole Antenna Array

Yujian Li, *Member, IEEE*, and Kwai-Man Luk, *Fellow, IEEE*

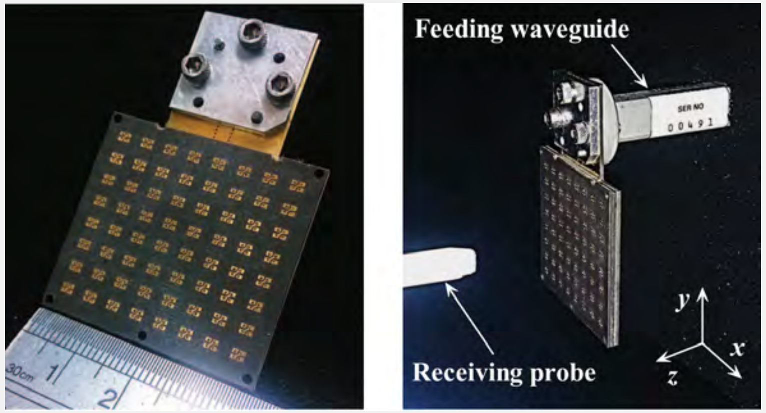
***Abstract*—A novel circularly polarized (CP) aperture-coupled magneto-electric (ME) dipole antenna is proposed. The CP ME-dipole antenna fed by a transverse slot etched on the broad wall of a section of shorted-end substrate integrated waveguide (SIW) is convenient to integrate into substrates. An impedance bandwidth of wider than 28.8%, a wide 3-dB axial ratio (AR) bandwidth of 25.9%, and gain of 7.7 ± 1.4 dBic over the operating band are achieved. Additionally, since the CP radiation is generated by the combination of two orthogonal ME-dipole modes, the antenna element has stable unidirectional radiation patterns that are almost identical in two principle planes throughout the operating band, which is desirable to array applications. By employing the proposed CP ME-dipole as radiating elements, an 8×8 high-gain wideband planar antenna array is proposed for 60-GHz millimeter-wave applications. A fabrication procedure of using conductive adhesive films to bond all print circuit board (PCB) layers together is successfully implemented to realize the array design with a three-layered geometry, which has advantages of low costs and possibility of large-scale manufacture. The measured impedance bandwidth of the fabricated prototype is 18.2% for $|S_{11}| < -10$ dB. Because of the wide AR bandwidth of the new antenna element, a wide AR bandwidth of 16.5% can be achieved by this array without the use of sequential feed. Gain up to 26.1 dBic and good radiation efficiency of around 70% are also obtained due to the use of a full-corporate SIW feed network with low insertion loss at millimeter-wave frequencies.**

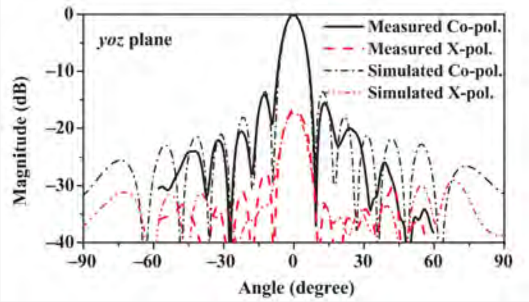
***Index Terms*—60-GHz, antenna array, circular polarization (CP), magneto-electric (ME) dipole, millimeter-wave.**

polarization (CP) can provide more promising channel performance compared with the linearly polarized wave [3], [4]. Therefore, it is seen that the CP high-gain antenna array is a desirable candidate at 60-GHz.

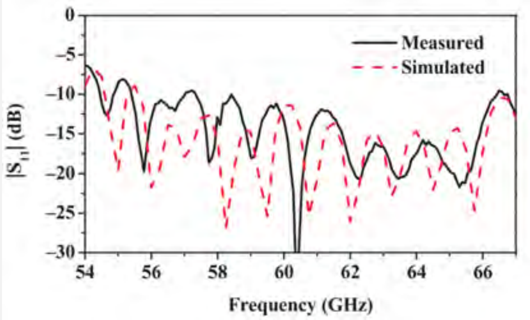
The selection of the antenna element constructing the antenna array plays a crucial role in the millimeter-wave antenna array design. The characteristics of the antenna element significantly restrict the achievable performance of the whole array. On the other hand, fabrication complexity of the array is directly affected by the geometry of the single element. In terms of the 60-GHz CP antenna array, the microstrip patch antenna [5]–[7] and the cavity antenna [8] are two types of radiating elements that have been most widely applied in the literature due to their simple planar structures. However, the 3-dB axial ratio (AR) bandwidths of most of these antennas were narrower than 10%, which is an inevitable obstacle to the 60-GHz wideband applications. Other kinds of antenna elements with much wider AR bandwidths were also reported at 60-GHz [9], [10], but the dimensions of these antennas were usually around or larger than one wavelength at the operating frequency, which is not desirable to array design.

In order to overcome the limitation of the AR bandwidth of the single antenna element, the scheme of sequential feed [11] initially used at lower microwave frequencies has been implemented at the 60-GHz band by a number of reported

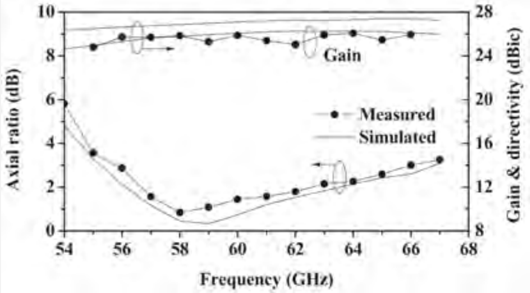




Radiation Pattern at 60 GHz



Measured and simulated $|S_{11}|$ of the fabricated CP antenna array



Measured and simulated AR, gain, and directivity of the CP antenna array

Design Principle:

- A transverse slot for convenient integration
- Two orthogonal ME-dipole modes for CP radiation
- ME-dipole element for a wide AR bandwidth array without the use of sequential feed.

Attractive Features:

- Wide AR bandwidth
- High efficiency

Performance:

- f = 60 GHz
- SWR BW = 18.2%
- Gain = 26.1 dBic
- Size: $6.12\lambda \times 6.8\lambda$
- AR BW = 16.5%
- Efficiency = 72.2%

Rank 6 - No. of Views 7539

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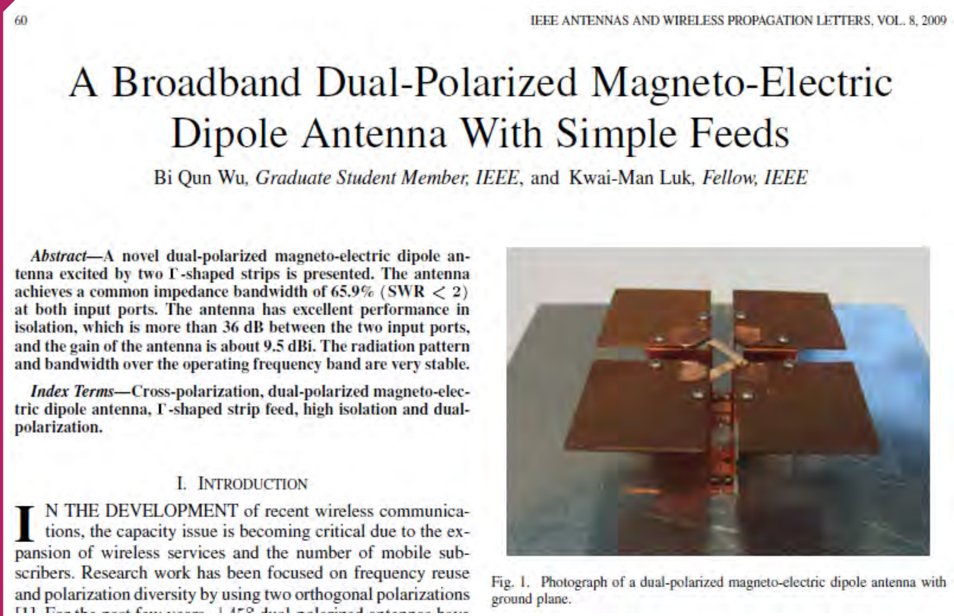

60 IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 8, 2009

A Broadband Dual-Polarized Magneto-Electric Dipole Antenna With Simple Feeds

Bi Qun Wu, *Graduate Student Member, IEEE*, and Kwai-Man Luk, *Fellow, IEEE*

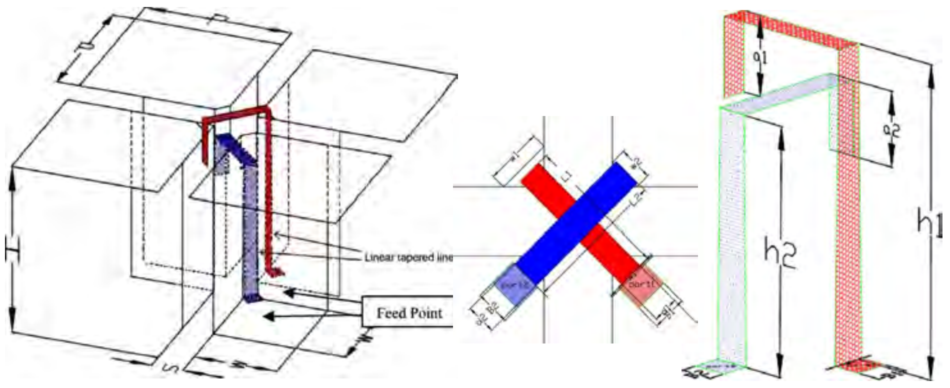
Abstract—A novel dual-polarized magneto-electric dipole antenna excited by two Γ-shaped strips is presented. The antenna achieves a common impedance bandwidth of 65.9% (SWR < 2) at both input ports. The antenna has excellent performance in isolation, which is more than 36 dB between the two input ports, and the gain of the antenna is about 9.5 dBi. The radiation pattern and bandwidth over the operating frequency band are very stable.

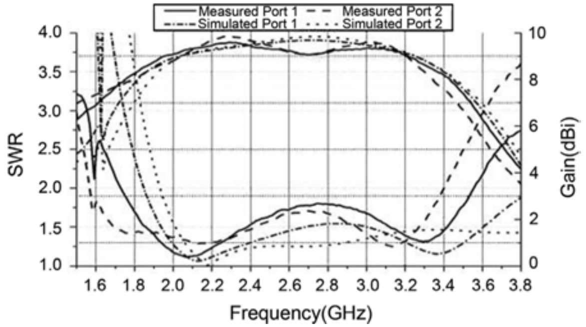
Index Terms—Cross-polarization, dual-polarized magneto-electric dipole antenna, Γ-shaped strip feed, high isolation and dual-polarization.

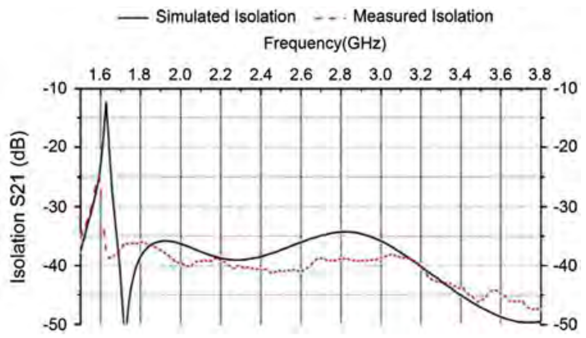
I. Introduction

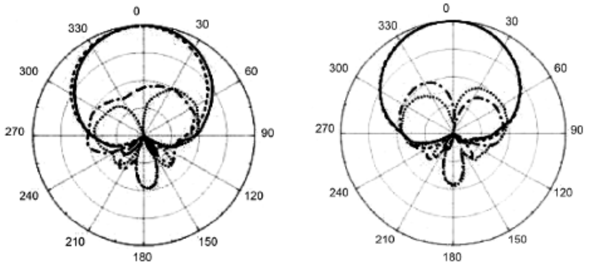
In THE DEVELOPMENT of recent wireless communications, the capacity issue is becoming critical due to the expansion of wireless services and the number of mobile subscribers. Research work has been focused on frequency reuse and polarization diversity by using two orthogonal polarizations

Fig. 1. Photograph of a dual-polarized magneto-electric dipole antenna with ground plane.









Rad. Pat. at 2.701 GHz of Port 1 and Port 2

Design Principle:

- Two Γ-shaped feeds of different heights without touching the metallic parts

Attractive Features:

- Wideband
- High isolation
- High gain

Performance:

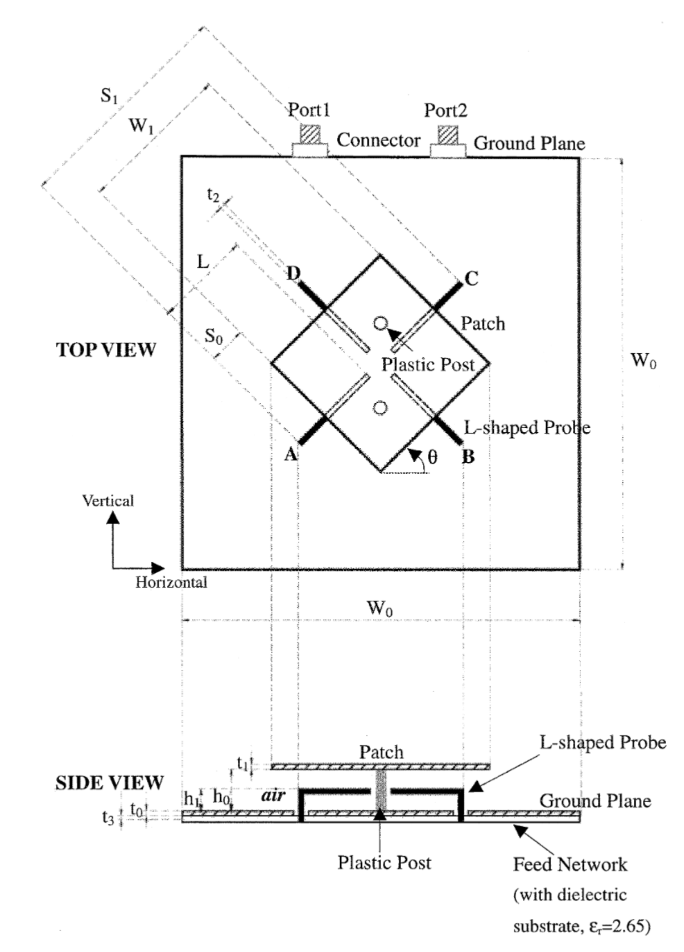
- f = 2.565 GHz
- SWR BW = 67%, Iso. > 36 dB
- Gain = 9.5 dBi
- Size: 0.51λ ×0.51λ ×0.23λ

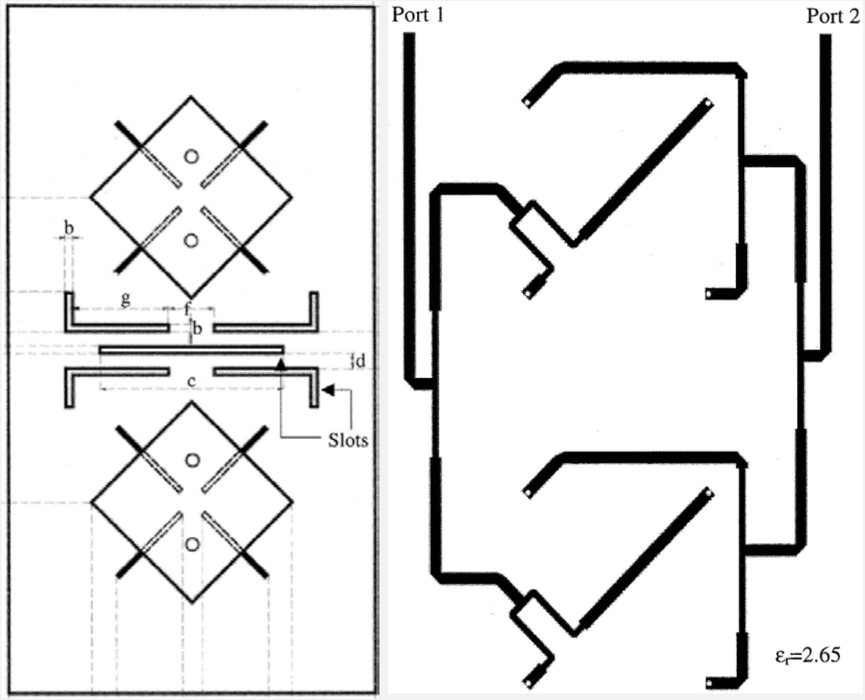
B. Q. Wu and K. Luk, "A Broadband Dual-Polarized Magneto-Electric Dipole Antenna With Simple Feeds," IEEE Antennas and Wireless Propagation Letters, vol. 8, pp. 60-63, 2009.

RANK 5 – NO. OF VIEWS 7709

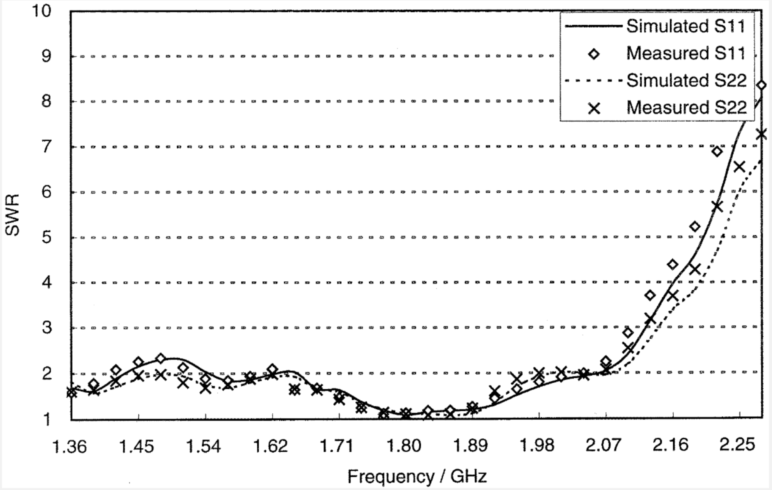
Design of Dual-Polarized L-Probe Patch Antenna Arrays With High Isolation

Hang Wong, *Member, IEEE*, Ka-Leung Lau, and Kwai-Man Luk, *Fellow, IEEE*

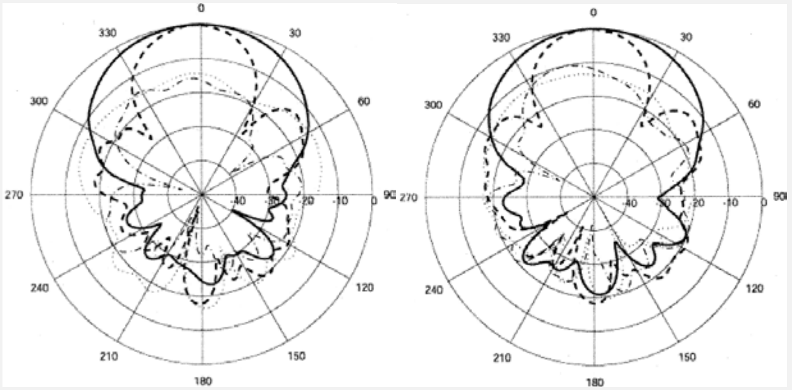




Antenna array and the feed network



SWR of two ports



Radiation Patterns at 1.8 GHz

Performance:

- f = 1.8 GHz
- SWR BW = 20.8%
- Array Gain = 11 dB
- Isolation over 30dB

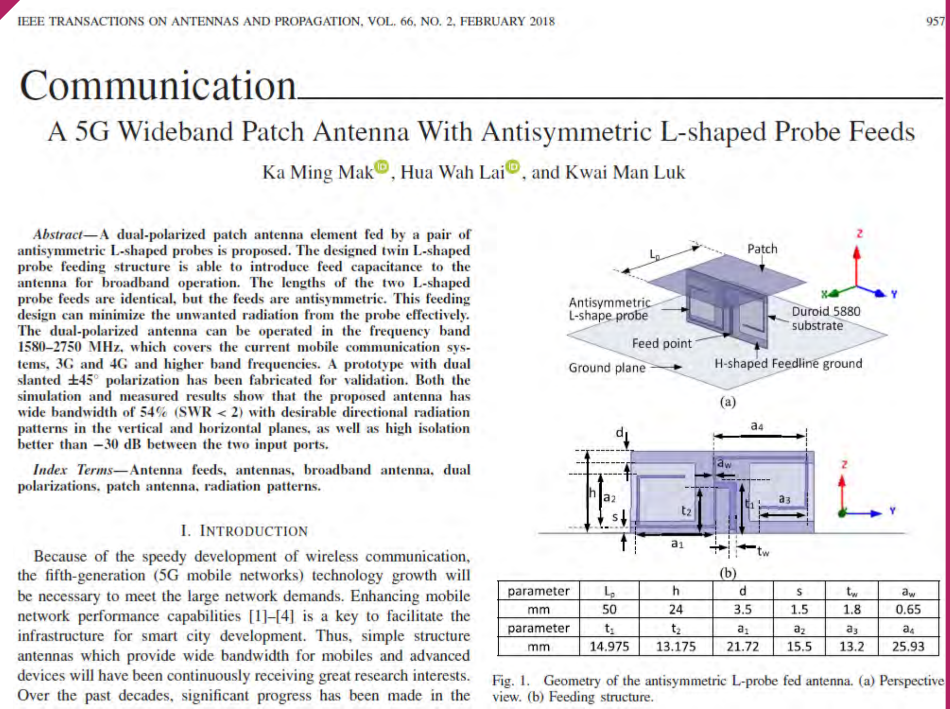
Attractive Features:

- High isolation
- Large overlapping impedance and SWR bandwidth

Design Principle:

- The "dual-feed" design for improving isolation
- L-probe for improving bandwidth

Rank 4 - No. of Views 8208



Communication

A 5G Wideband Patch Antenna With Antisymmetric L-shaped Probe Feeds

Ka Ming Mak, Hua Wah Lai, and Kwai Man Luk

Abstract—A dual-polarized patch antenna element fed by a pair of antisymmetric L-shaped probes is proposed. The designed twin L-shaped probe feeding structure is able to introduce feed capacitance to the antenna for broadband operation. The lengths of the two L-shaped probe feeds are identical, but the feeds are antisymmetric. This feeding design can minimize the unwanted radiation from the probe effectively. The dual-polarized antenna can be operated in the frequency band 1580–2750 MHz, which covers the current mobile communication systems, 3G and 4G and higher band frequencies. A prototype with dual slanted ±45° polarization has been fabricated for validation. Both the simulation and measured results show that the proposed antenna has wide bandwidth of 54% (SWR < 2) with desirable directional radiation patterns in the vertical and horizontal planes, as well as high isolation better than −30 dB between the two input ports.

Index Terms—Antenna feeds, antennas, broadband antenna, dual polarizations, patch antenna, radiation patterns.

I. INTRODUCTION

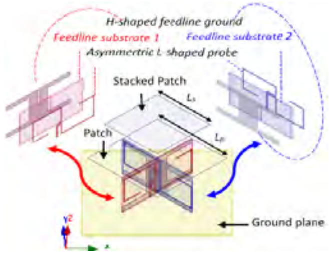
Because of the speedy development of wireless communication, the fifth-generation (5G mobile networks) technology growth will be necessary to meet the large network demands. Enhancing mobile network performance capabilities [1]–[4] is a key to facilitate the infrastructure for smart city development. Thus, simple structure antennas which provide wide bandwidth for mobiles and advanced devices will have been continuously receiving great research interests. Over the past decades, significant progress has been made in the

parameter	L_p	h	d	s	t_w	a_w
mm	50	24	3.5	1.5	1.8	0.65
parameter	t_1	t_2	a_1	a_2	a_3	a_4
mm	14.975	13.175	21.72	15.5	13.2	25.93

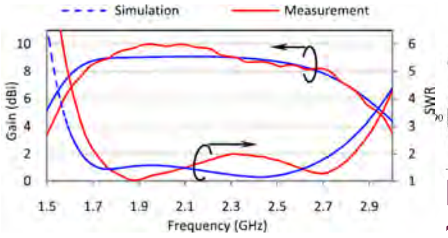
Fig. 1. Geometry of the antisymmetric L-probe fed antenna. (a) Perspective view. (b) Feeding structure.

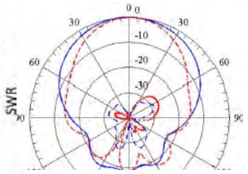
Single linear polarized antenna

Dual polarized antenna



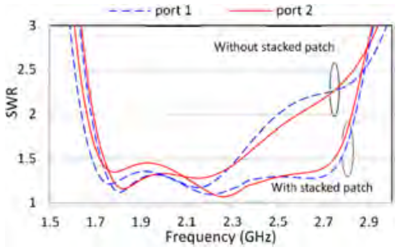
• LP Antenna Performance



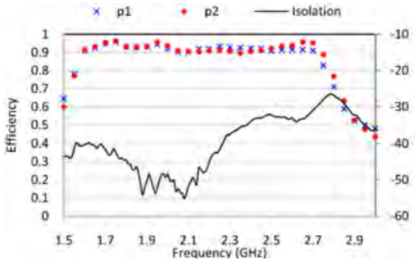


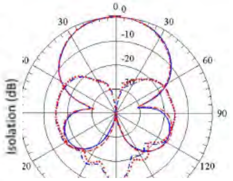
Rad. Pat. at 2.2 GHz

• DP Antenna Performance



Comparison of simulated SWR BW with/ without stacked patch





Rad. Pat. at 2.2 GHz of Port 1

Design Principle:

- Antisymmetric L-shaped probe for broadband and low X-pol.
- For DP, a parasitic patch for retaining wideband operation

Attractive Features:

- Compact and simple structure
- Wideband and high isolation
- High efficiency
- Low x-pol. and stable gain

Performance:

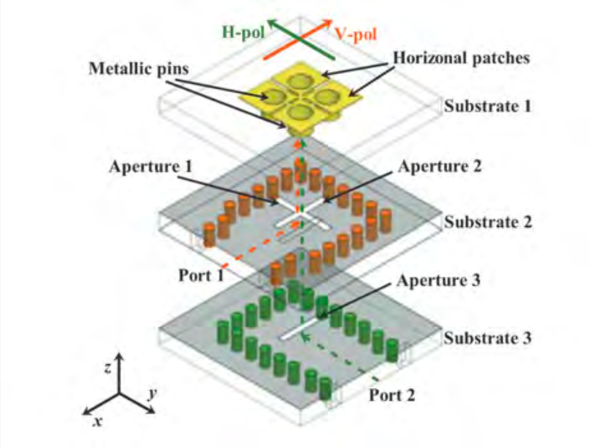
	f (GHz)	SWR BW	Gain (dBi)
LP	2.270	49.3%	10
	Size: 0.38λ ×0.38λ ×0.18λ		
DP	2.173	54% (Iso.>30dB)	9.5
	Size: 0.38λ ×0.38λ ×0.23λ		

K. M. Mak, H. W. Lai and K. M. Luk, “A 5G Wideband Patch Antenna With Antisymmetric L-shaped Probe Feeds,” IEEE Transactions on Antennas and Propagation, vol. 66, no. 2, pp. 957-961, Feb. 2018.

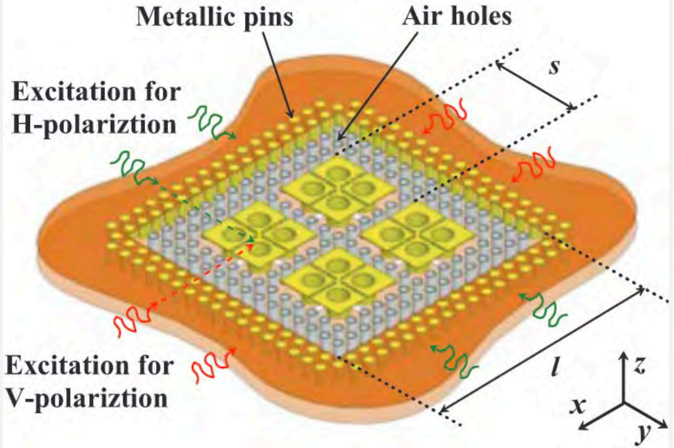
RANK 3 – NO. OF VIEWS 9096

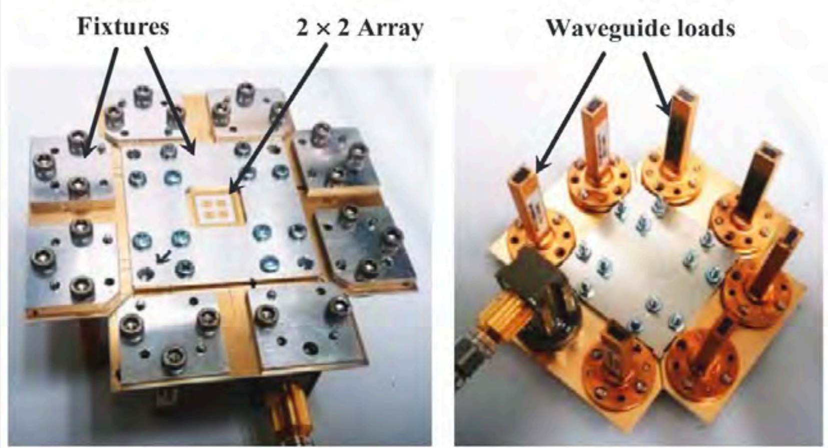
60-GHz Dual-Polarized Two-Dimensional Switch-Beam Wideband Antenna Array of Aperture-Coupled Magneto-Electric Dipoles

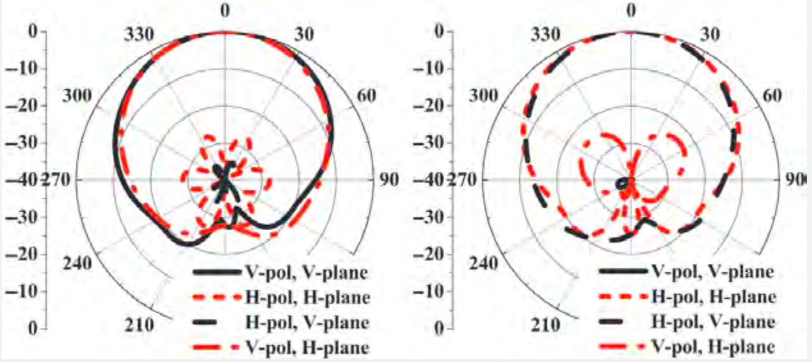
Yujian Li, *Member, IEEE*, and Kwai-Man Luk, *Fellow, IEEE*



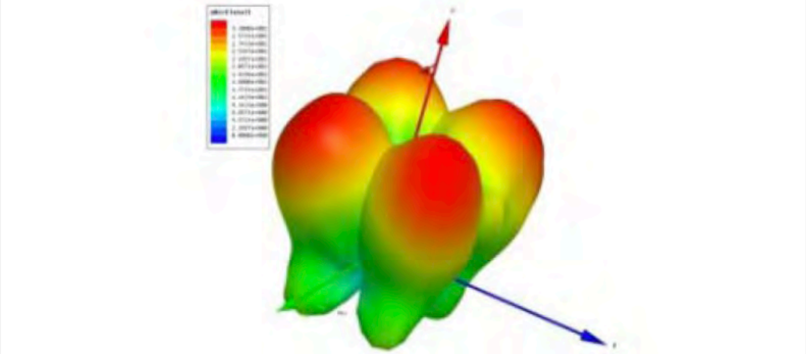
2 × 2 Array







Dual-polarized Radiation Patterns of Antenna Element at 60 GHz



Our simulated tilted beams with same polarization.

Performance:

- f = 60 GHz
- SWR BW = 21%
- Gain = 8 dBi
- Size: 0.6λ×0.6λ

Attractive Features:

- Small size
- Dual-polarized
- High isolation between two ports (over 45 dB)
- Multiple Beams

Design Principle:

- SIW fed for reducing the impact of the feed network.
- Four 90◦ couplers for achieving multiple beams
- Aperture-coupling scheme for improving isolation

RANK 2 – NO. OF VIEWS 10681

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 61, NO. 8, AUGUST 2013 4341

Communications

Single-Layer Single-Patch Dual-Band and Triple-Band Patch Antennas

Wing Chi Mok, Sai Hoi Wong, Kwai Man Luk, and Kai Fong Lee

***Abstract*—Recently, it was shown that a dual- or triple-band patch antenna can be designed by cutting U-slots in the patch of a broadband antenna, and the method was applied to the L-probe fed patch, the M-probe fed patch, coax-fed stacked patches, and aperture coupled stacked patches. All these cases involve either a rather complicated feed, or more than one patch, or more than one layer. In this communication, this method is applied to a broadband U-slot patch antenna. When one additional U-slot patch is cut in the patch, a dual-band antenna results. When two additional U-slot patches are cut in the patch, a triple-band antenna results. The advantages of the resultant configurations are (1) the feed is simple and (2) the structures remain single-layer and single-patch. Both simulation and measurement results are presented to demonstrate the feasibility of this design.**

***Index Terms*—Dual-band antennas, multi-band antennas, patch antennas.**

I. Introduction

In some applications in wireless communications, it is desirable to design a patch antenna covering two or three frequency bands which are close to each other. For example, a base station antenna may be required to simultaneously provide wireless access services for both WCDMA (1.92 ~ 2.17 GHz) and WiMAX (2.50 ~ 2.69 GHz), while rejecting most of the frequencies between the two bands. The ratio of the center frequencies in this example is 1.27. If the antenna is to cover the middle band of WiMAX (3.3–3.7 GHz) as well, a triple band antenna is desirable. The frequency ratios in this second example are 1.27 and 1.71.

patch, two band notches can be introduced and a triple-band antenna results.

In [4], this new method was applied to the cases when the original broadband antennas was (1) a L-probe fed patch; (2) a M-probe fed patch; (3) coax-fed stacked patches; and (4) aperture coupled stacked patches. All these cases involve either relatively complicated feeds or more than one layer or more than one patch.

In this communication, we apply the method to the case when the original broadband antenna is a coax-fed U-slot patch. This design has the advantages of simplicity of the feed as well as having only one layer and only one patch.

II. Simulation Results

We first show simulation results to illustrate the main features of the method. Experimental results are presented in Section III.

The first step in the design is to come up with the U-slot which provides the broadband characteristics, using existing information available in the literature [5], [6]. For the U-slots that provide the notches, the total lengths of the slots are about half the wavelengths of the respective notch frequencies, which was established in [3]. The locations of these U-slots do not affect the notch frequencies, and are chosen to give the best impedance matches arrived at by using the simulation software Mentor Graphics IE3D.

Following the above procedure, we arrive at the geometry of the broadband U-slot patch antenna shown in Fig. 1(a), with the dimensions given in Table I, Antenna 1a. Air is used as the substrate, with the patch supported by the probe. Simulation results of reflection coefficient and gain of this antenna are given by the solid curves in Fig. 2 and Fig. 3 respectively. This antenna has an impedance bandwidth of about 33%.

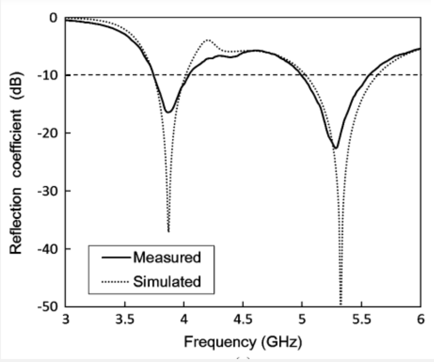
A second U-slot is now cut on the patch (Fig. 1(b)). The purpose

Patch with two slots for dual-band

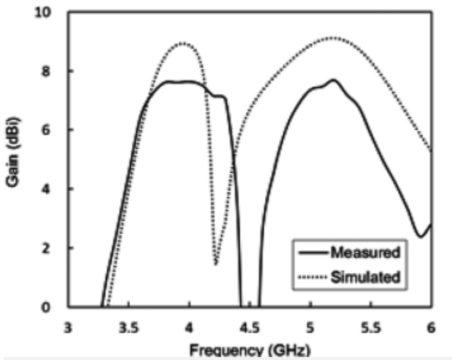
Patch with three slots for triple-band

Dual band

Reflection coefficient

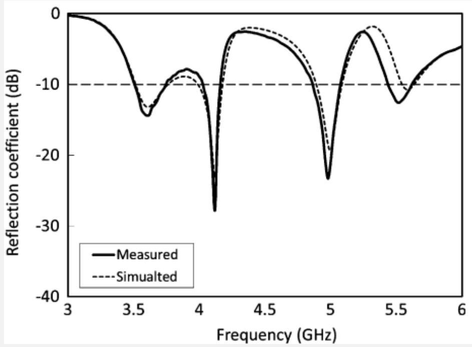


Gain

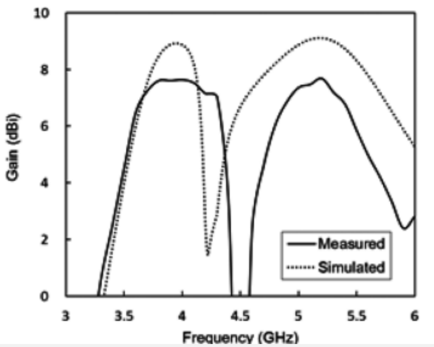


Triple band

Reflection coefficient



Gain



Design Principle:

- The 1st U-slot for wideband matching
- One additional U-slot for dual-band
- Two additional U-slot for triple-band

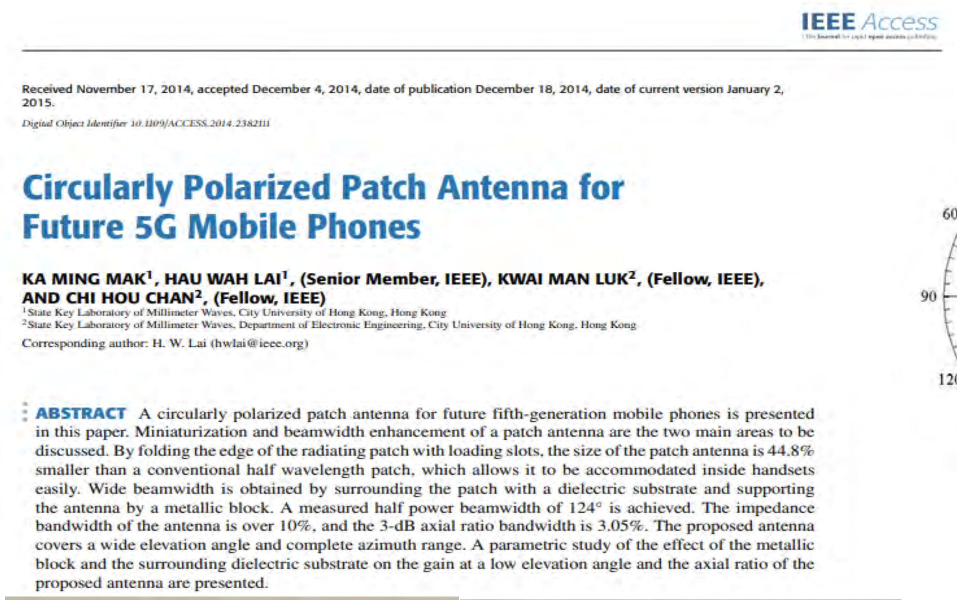
Performance:

- Dual band:
  3.75 – 4.05 GHz
  5.00 – 5.75 GHz
- Triple band:
  3.50 – 3.75 GHz
  4.85 – 5.20 GHz
  5.50 – 5.70 GHz

Attractive Features:

- Simple feed
- Only one patch/one layer
- Easy to fabricate

RANK 1 – NO. OF VIEWS 10919


IEEE Access

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Digital Object Identifier 10.1109/ACCESS.2014.2382111

Circularly Polarized Patch Antenna for Future 5G Mobile Phones

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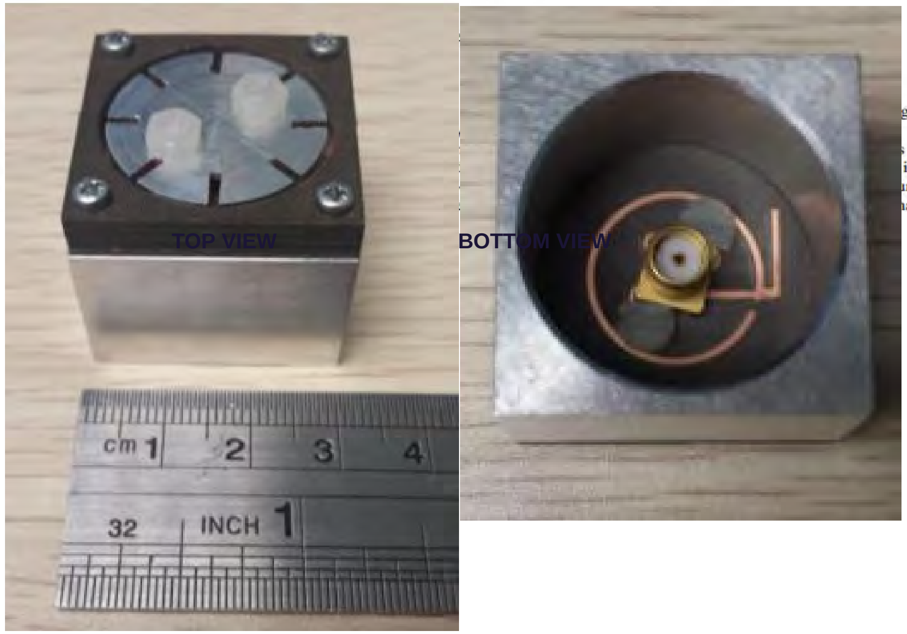
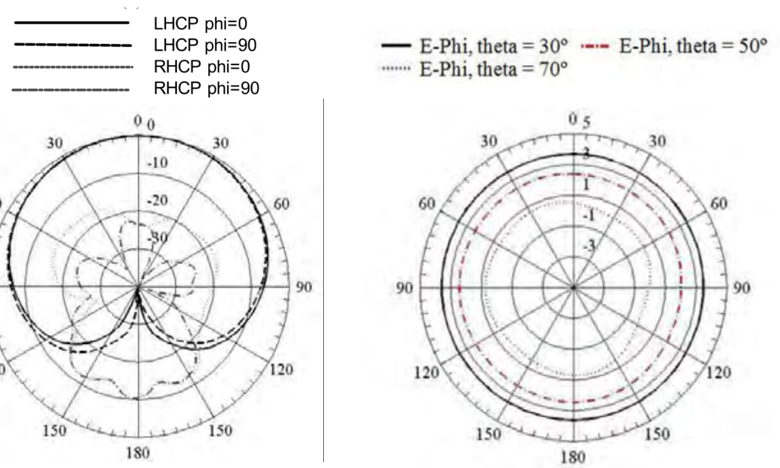
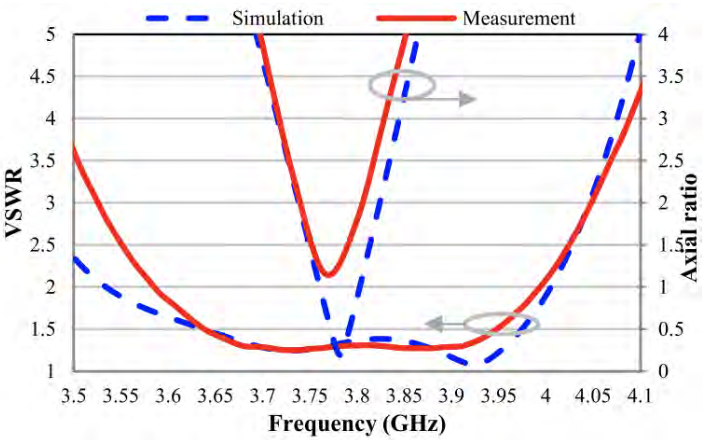
ABSTRACT A circularly polarized patch antenna for future fifth-generation mobile phones is presented in this paper. Miniaturization and beamwidth enhancement of a patch antenna are the two main areas to be discussed. By folding the edge of the radiating patch with loading slots, the size of the patch antenna is 44.8% smaller than a conventional half wavelength patch, which allows it to be accommodated inside handsets easily. Wide beamwidth is obtained by surrounding the patch with a dielectric substrate and supporting the antenna by a metallic block. A measured half power beamwidth of 124° is achieved. The impedance bandwidth of the antenna is over 10%, and the 3-dB axial ratio bandwidth is 3.05%. The proposed antenna covers a wide elevation angle and complete azimuth range. A parametric study of the effect of the metallic block and the surrounding dielectric substrate on the gain at a low elevation angle and the axial ratio of the proposed antenna are presented.





Radiation Patterns at 3.77 GHz



Simulated and measured VSWR and axial ratio

Design Principle:

- Edge of Patch folded down with open slots for size reduction
- Surrounding patch with dielectric substrate for wider beamwidth

Attractive Features:

- Size is 44.8% smaller than a conventional $\frac{\lambda}{2}$ patch
- Cover wide elevation angles & complete azimuth range

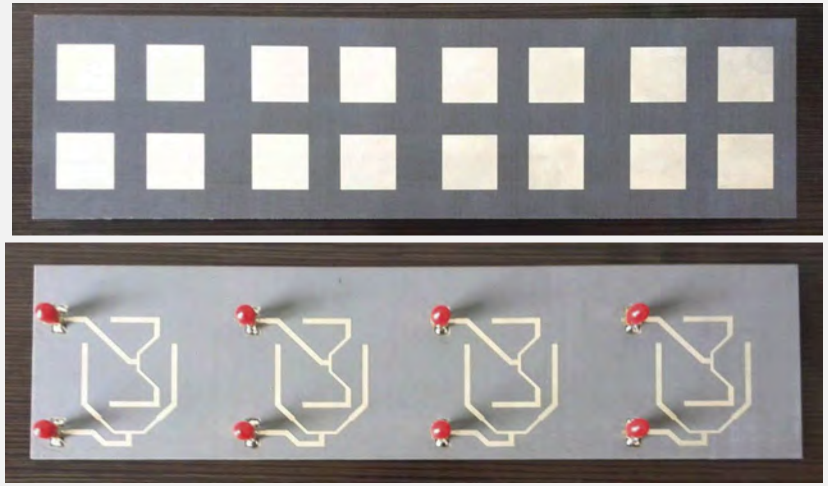
Performance:

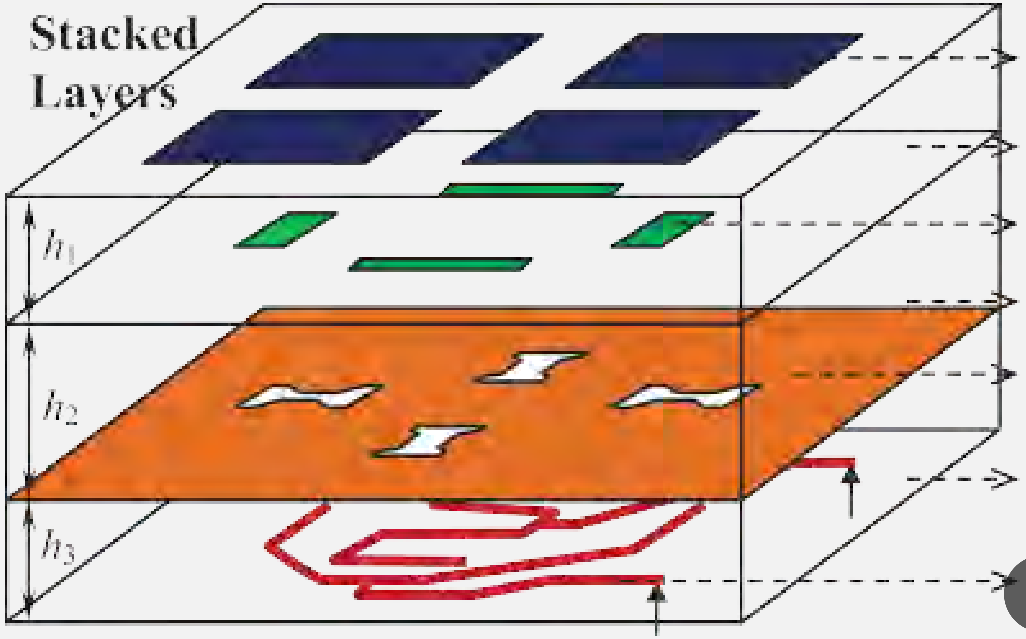
- f = 3.77 GHz
- SWR BW = 11%
- 3-dB axial ratio BW = 3%
- 3-dB beamwidth = 124^0
- Gain = 5 dBic
- Patch length: 0.28λ

A VERY POPULAR PAPER (>100,000 VIEWS)

- Y Gao, R Ma, Y Wang, Q Zhang and Clive Parini, “Stacked patch antenna with dual-polarization and low mutual coupling for massive MIMO,” IEEE Trans on AP, Oct 2016

- Operated at 3.7 GHz
- Isolation over 35 dB
- Innovative feed network designed for dual-polarization radiation

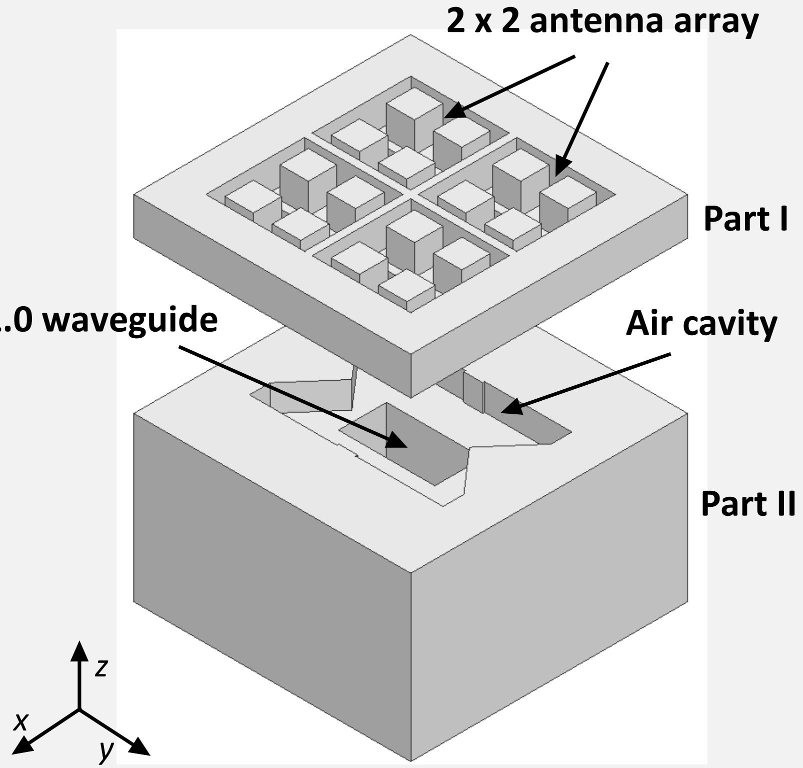


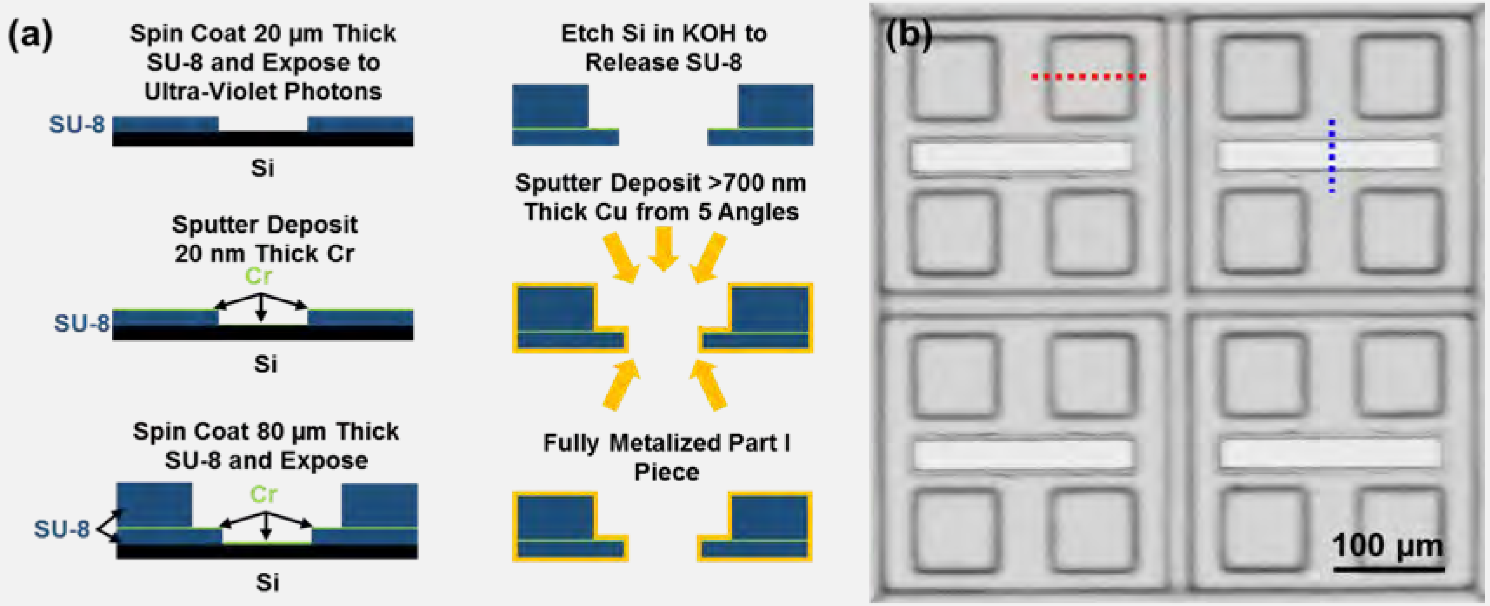


RECENT WORKS ON ME DIPOLES

- THz ME dipole array
- THz open resonator antenna with ME dipole feed
- Low divergence OAM antenna
- A compact linearly-polarized ME dipole array
- A compact Dual-linearly-polarized ME dipole array
- Single-layer Dual-polarized ME dipole array
- Reconfigurable CP ME dipole transmitarray
- Reconfigurable LP ME dipole folded transmitarray
- Wideband low sidelobe ME dipole array
- ME dipole for medical imaging

THZ MAGNETO-ELECTRIC DIPOLE ARRAY





Micro-fabrication process

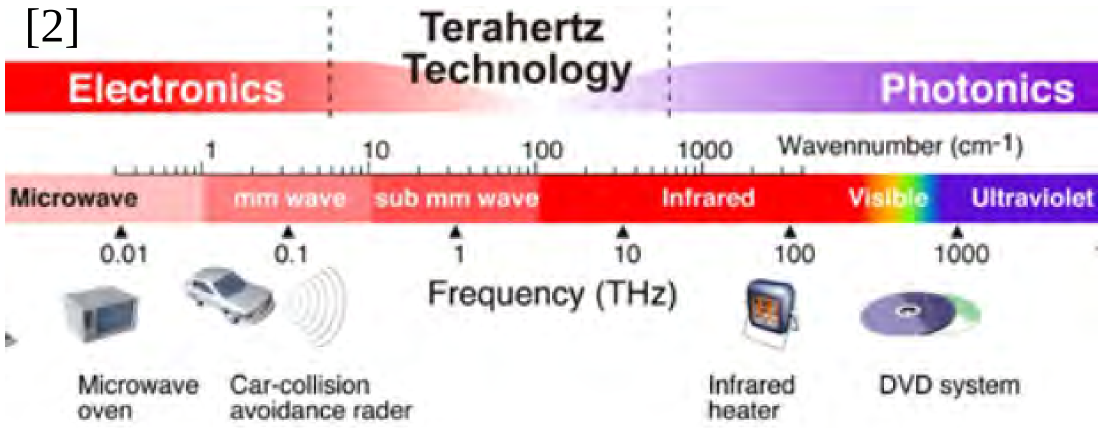
Luk KM, Zhou SF, Li YJ, Wu F, Ng KB, Chan CH, Pang SW, "A microfabricated low-profile wideband antenna array for terahertz communications" Scientific Reports, 7, 11, p.1268, Apr 2017

Microfabricated Terahertz Open Resonator Antenna for Future Ultrahigh Speed Wireless Communication [1]

For **future 6G wireless communication**:
Higher data rate and capacity

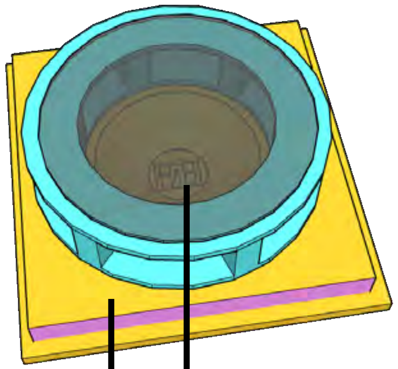
Terahertz band (100 GHz-10 THz)

[2]

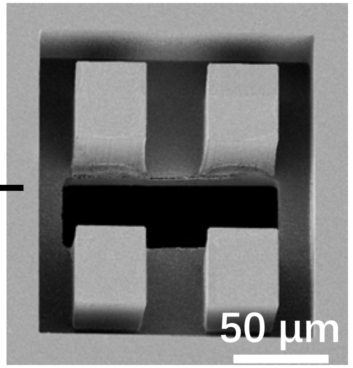


Issues:
- ➢ Large attenuation
- ➢ Low power THz sources

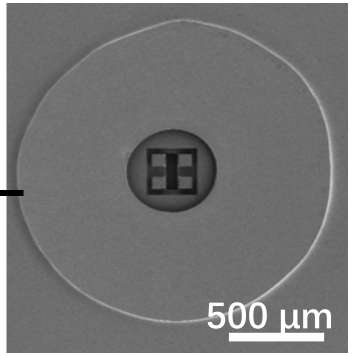
Necessity:
High-gain antennas



Open Resonator antenna:
- High gain: over 20 dBi
- Compact, low profile
- Silicon based: easy to integrate with IC



ME dipole feed:
- Silicon based deep reactive ion etching
- Better radiation pattern, higher gain

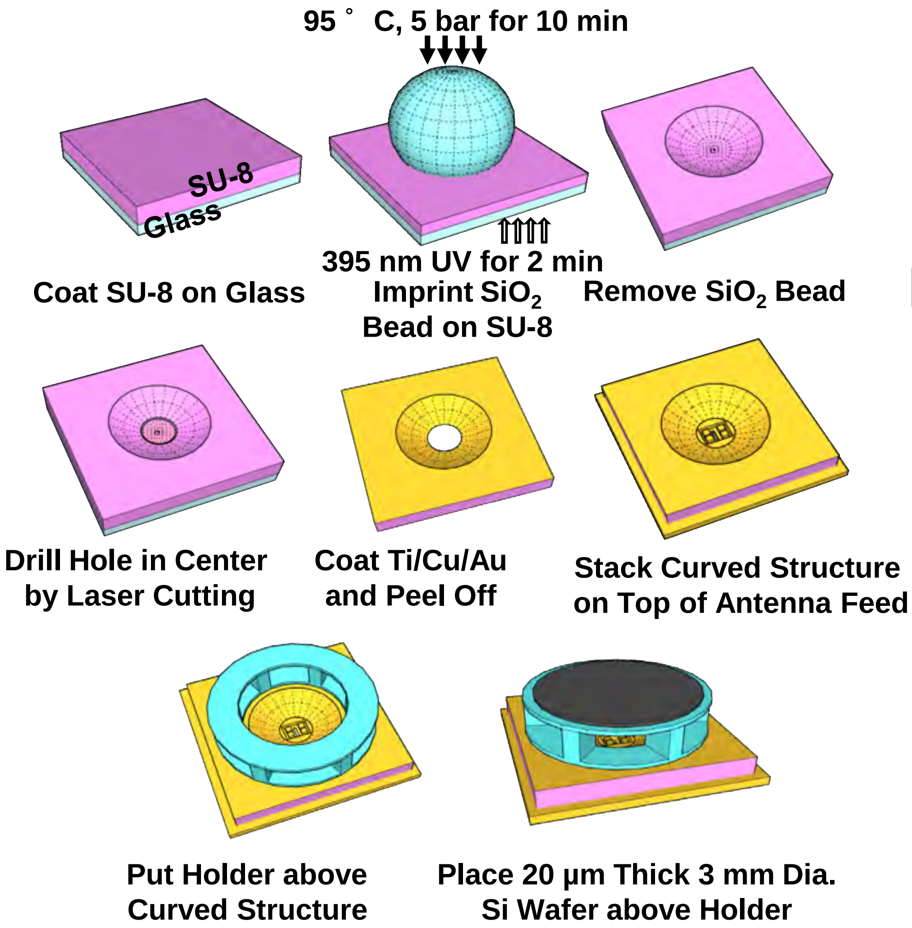


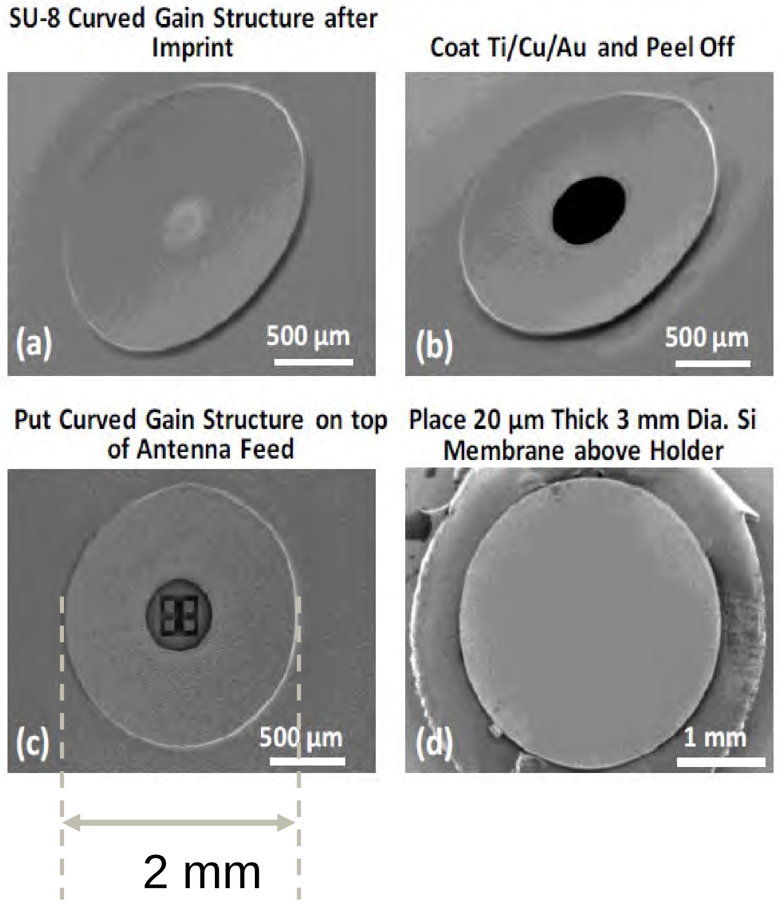
Spherical cavity:
- Polymer based imprinting
- Wider bandwidth, stable gain

[1] Zhu S Y, Li Y L, Luk K M, and Pang S W, Compact high-gain Si-imprinted THz antenna for ultrahigh speed wireless communications, IEEE Transactions on Antennas and Propagation, 2020.

[2] Fukunaga, K., et al. Terahertz imaging systems: a non-invasive technique for the analysis of paintings. O3A: Optics for Arts, Architecture, and Archaeology II, 2009.

Spherical Cavity

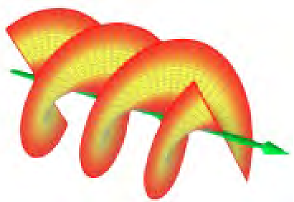




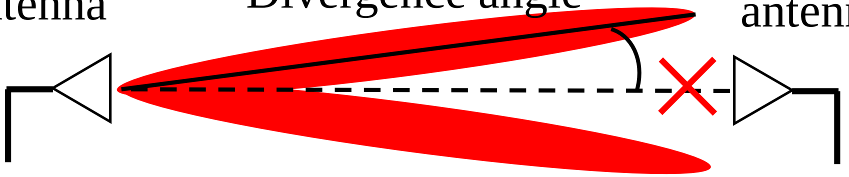
A Low-Divergence OAM Antenna for Future Communication Systems [1]

SAMSUNG 6G white paper
Potential technology: OAM

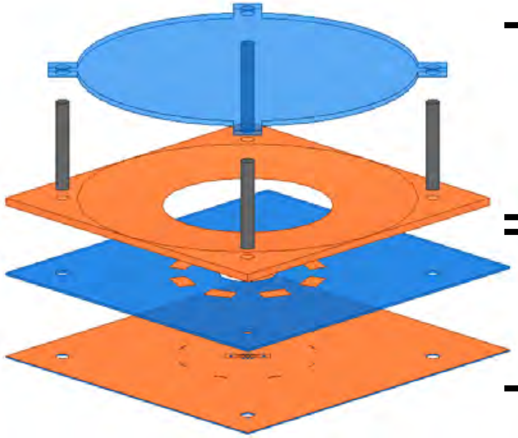
Orbital Angular Momentum

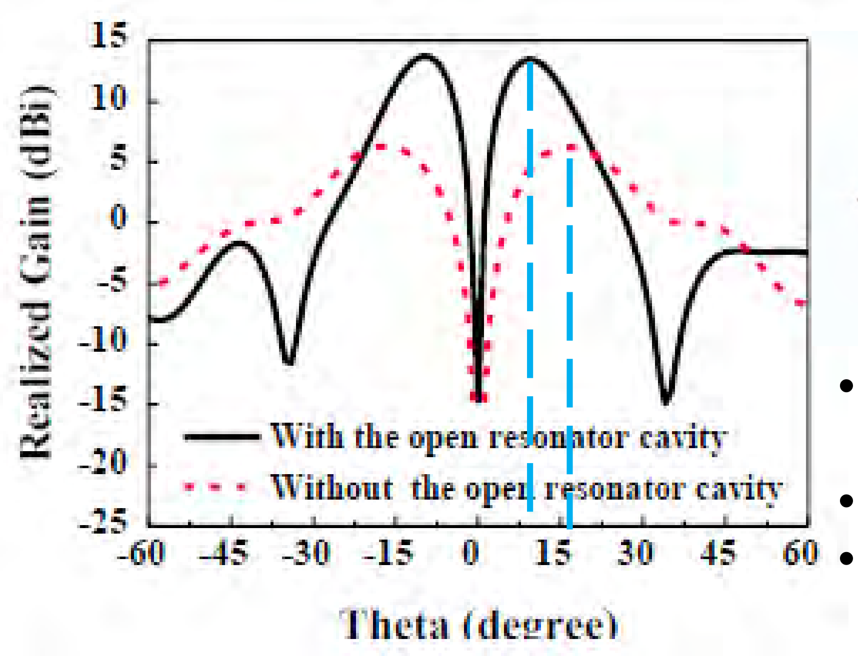


Vortex wave:
- Increase channel capacity
- Realize band multiplexing



Solution:
Antenna with reduced divergence angle

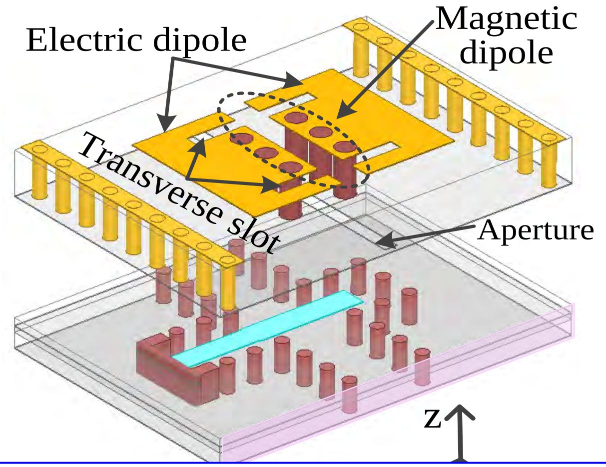


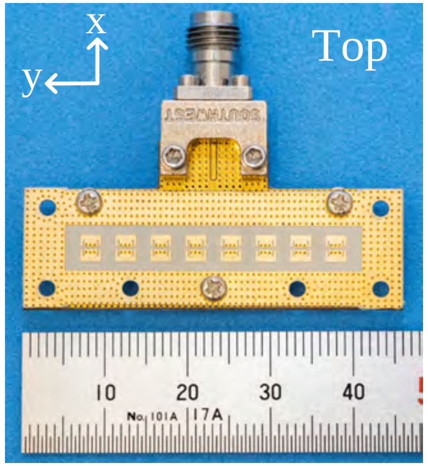


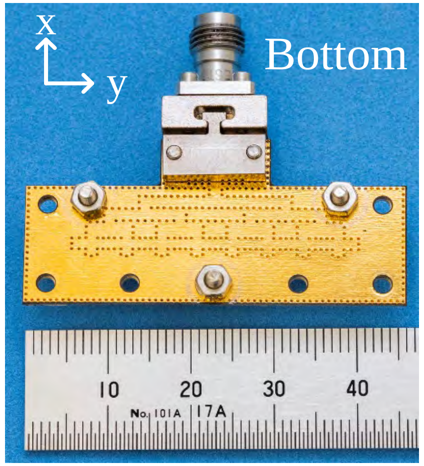
- Divergence angle:
  16° ➡ 9°
- Relatively high gain
- Lower profile

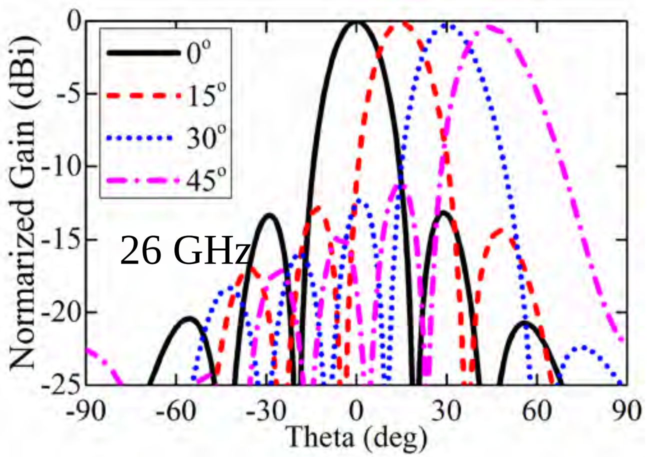
Li Y L, Luk K M. A Low-Divergence Circularly Polarized Dual-Mode OAM Antenna Based on Higher Order Laguerre–Gaussian Modes. IEEE Trans on AP, 2021.

A Wideband Compact Magneto-Electric Dipole Antenna for Millimeter Wave Applications

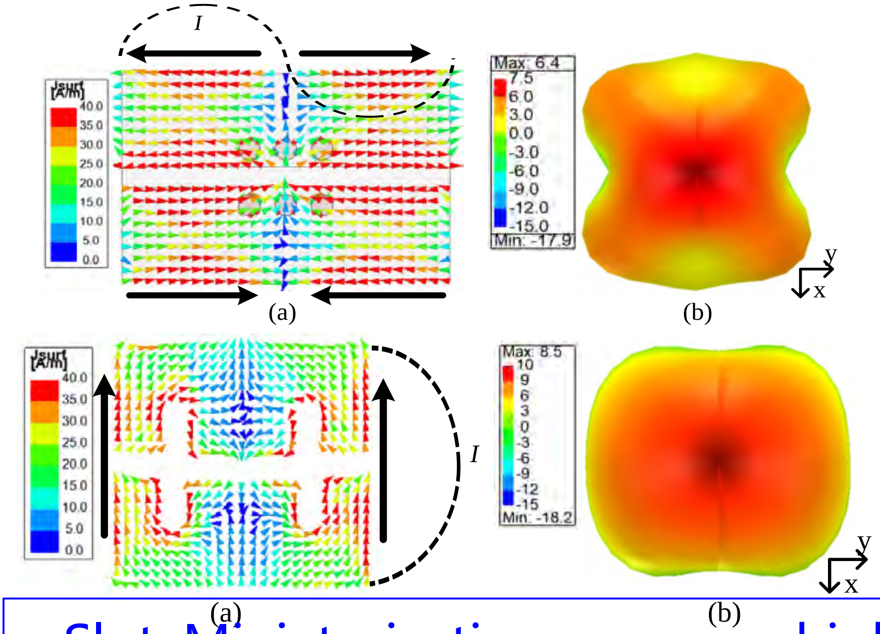


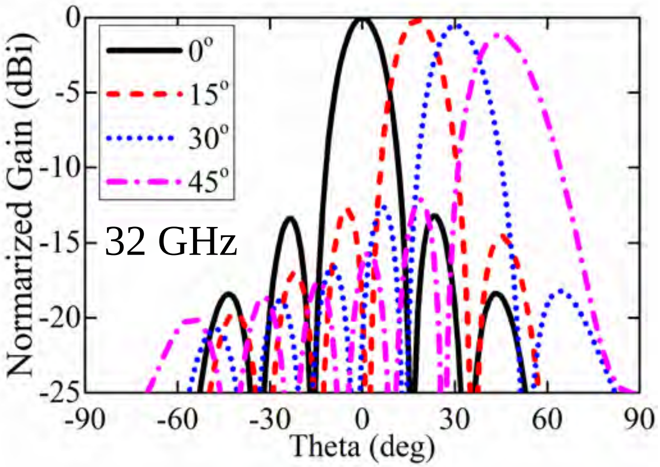


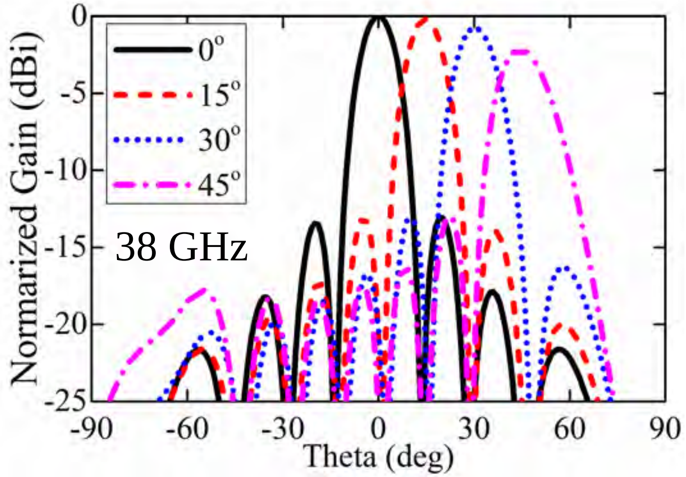




- ME dipole: wide bandwidth





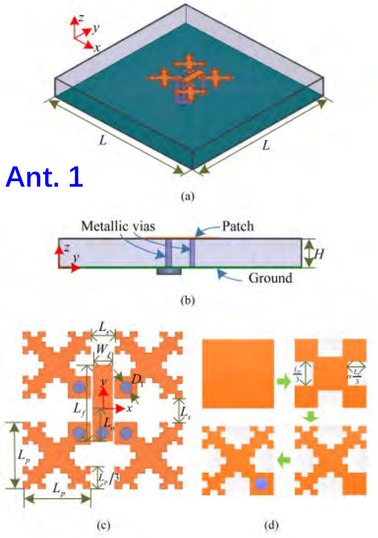


- Scan performance is maintained over a wide operating band

- Slot: Miniaturization, suppress high order mode

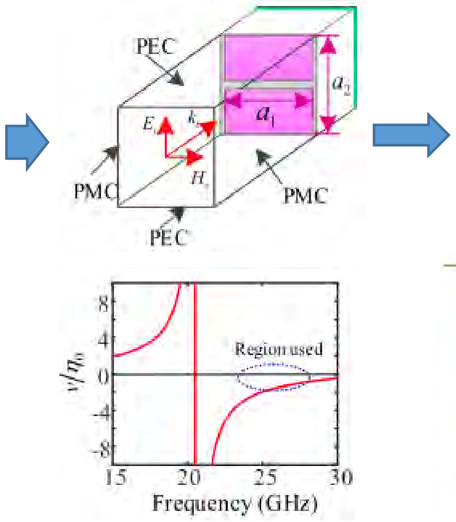
X. Dai, A. Li, K.-M. Luk, "A wideband compact magneto-electric dipole antenna fed by SICL for millimeter wave applications" *IEEE Trans. Antennas Propag.*, vol. 69, no. 9, pp. 5278-5285, Sep. 2021.

Design of an compact DP ME dipole antenna



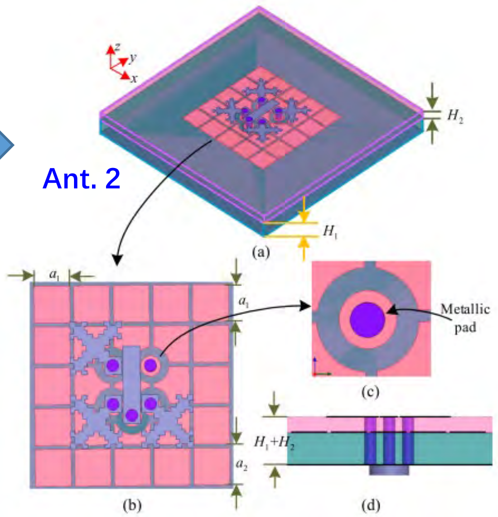
Fractal ME Dipole

Step 1



Reactive Impedance Structure

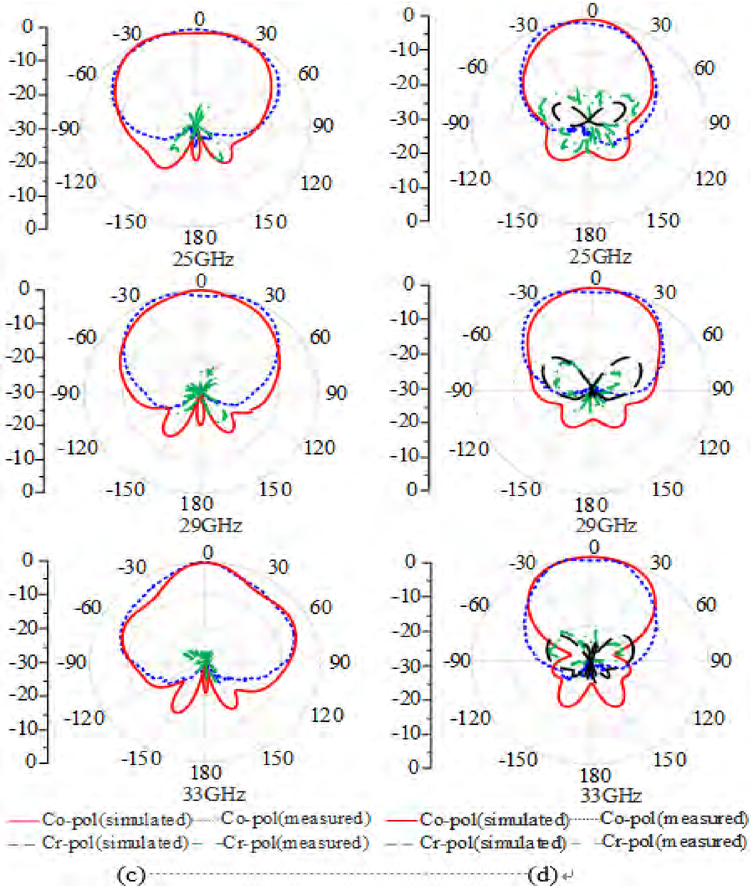
Step 2

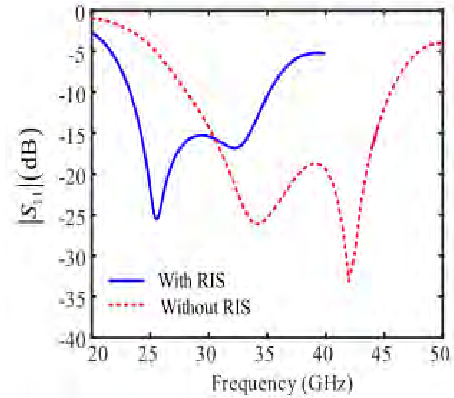


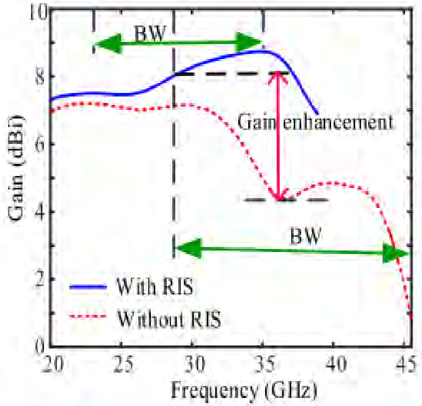
Compact ME Dipole

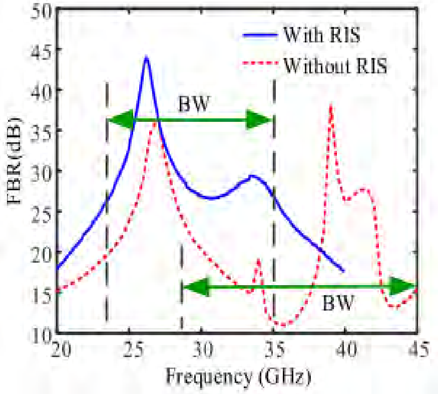
Step 3

Prototype







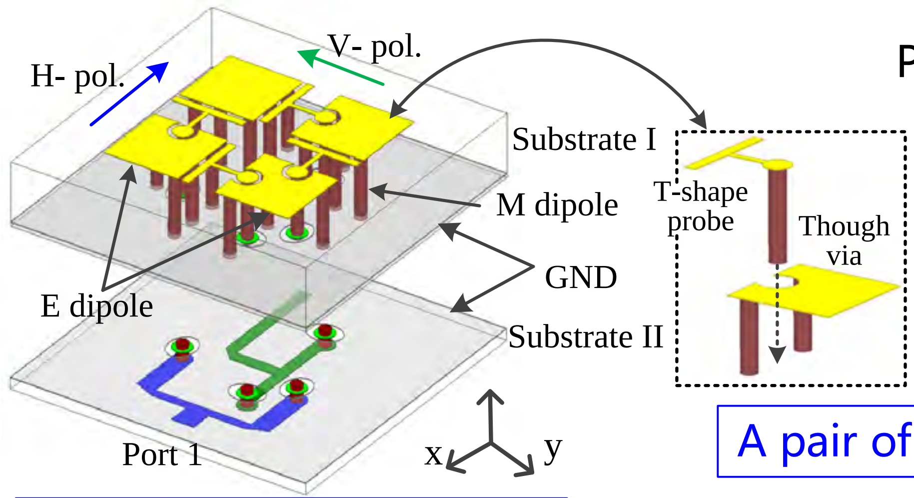


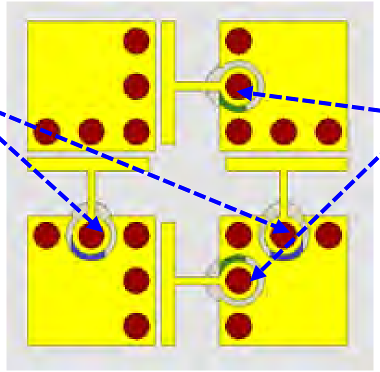
Simulation parameters of the Ant. 1 and Ant. 2

	Size	Gain(dBi)
Ant. 1	0.38λ0 ×0.38λ0 ×0.14λ0	4.0 (0.9-7.1)
Ant. 2	0.30λ0 ×0.30λ0×0.12λ0	8.2 (7.4-9.0)
	BW(%)	**FRB(dB)**
Ant. 1	46.9%	≥11
Ant. 2	42.7%	≥26

Y. Xu, K, M. Luk, A. Li, J. Sun. “A Novel Compact Magneto-Electric Dipole Antenna for Millimeter-Wave Beam Steering Applications,,” ***IEEE Trans. on Vehicular Tech.***, 2021, vol. 70, no. 11, pp. 11772-11783.

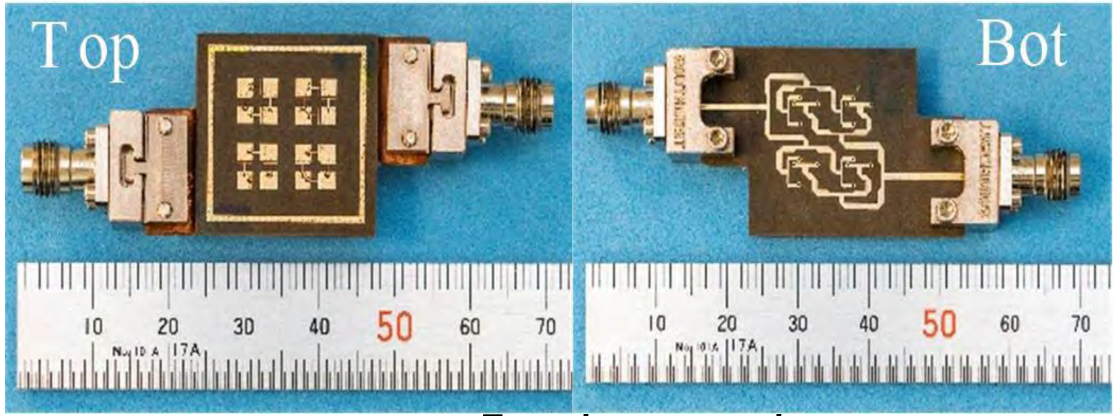
A Single-layer Dual-Polarized ME Dipole Antenna





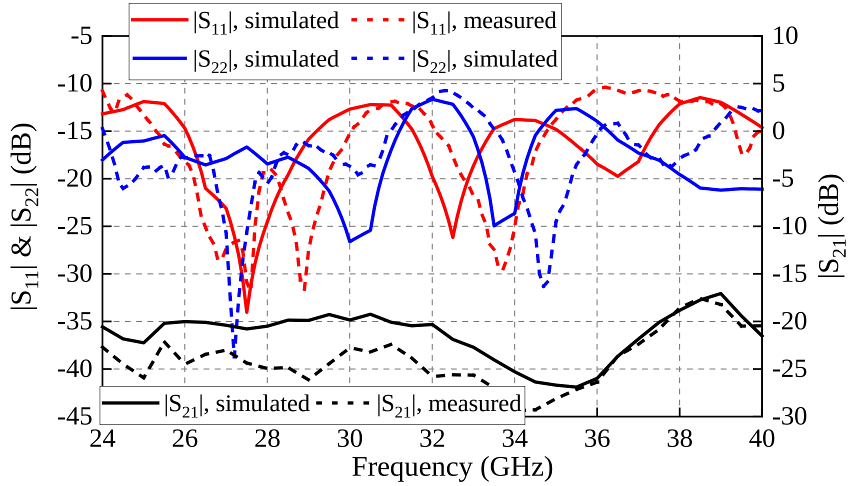
A pair of T-shaped probes for each polarization, avoiding crossover of feeds

ME dipole: wideband



Feed network

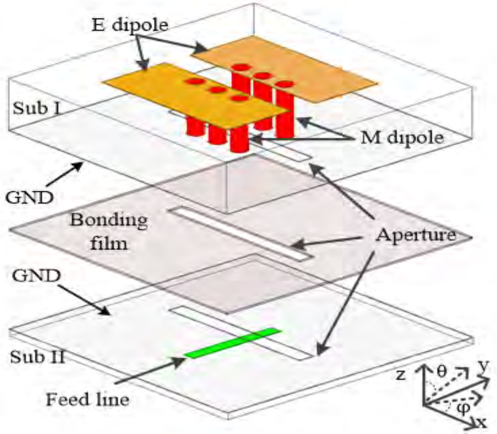
X. Dai, K. -M. Luk, "A wideband dual-polarized antenna for millimeter wave applications" *IEEE Trans on AP*, Apr. 2021.



Performance summary:

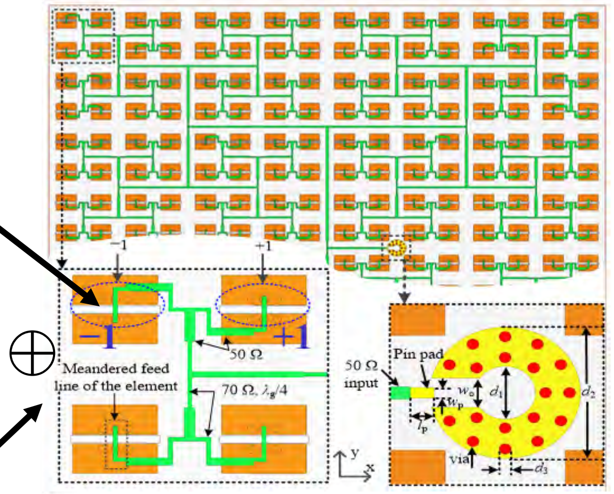
- Bandwidth: 50 % (24-40 GHz)
- Isolation: > 17.5 dB.

Wideband mmWave Antenna Array With Low Side Lobe Using ‘±1’ Excitations

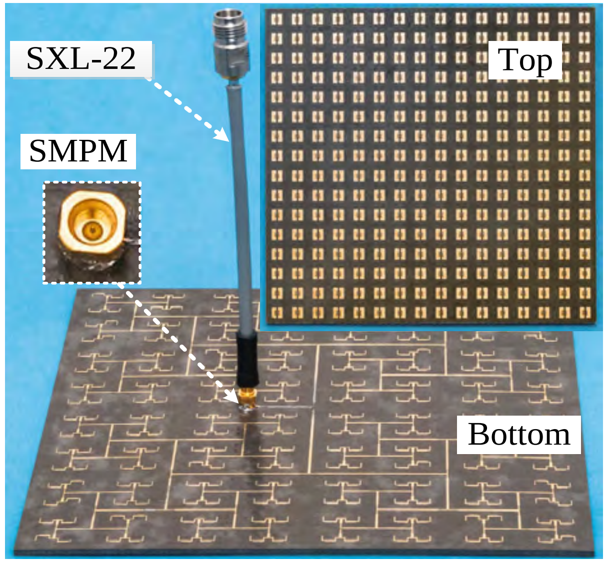


Element geometry

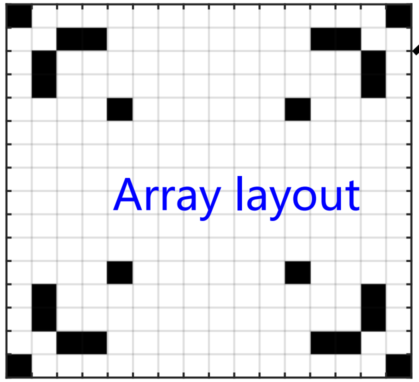
16×16 Array design



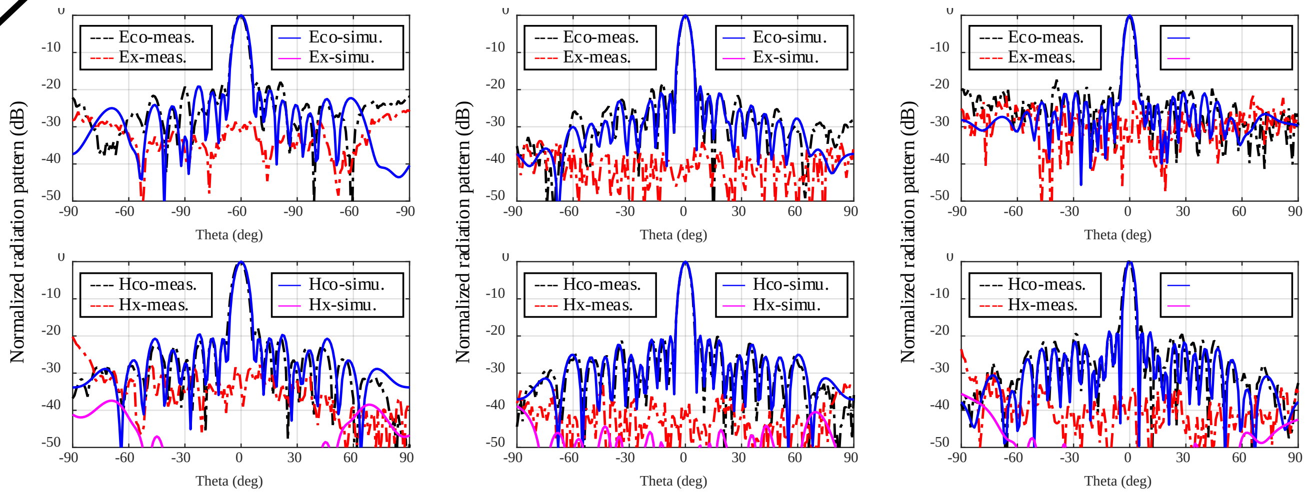
Configuration of the proposed array



- Sidelobe can be suppressed by setting some of the elements feed with reversed directions.



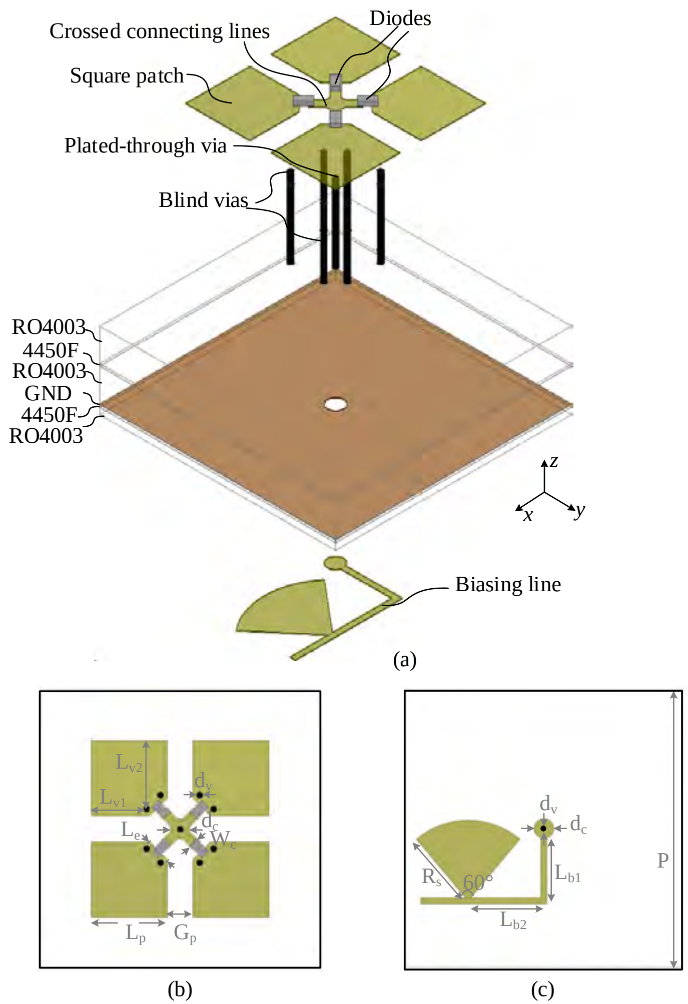
Black box: －1;
White box: ＋1

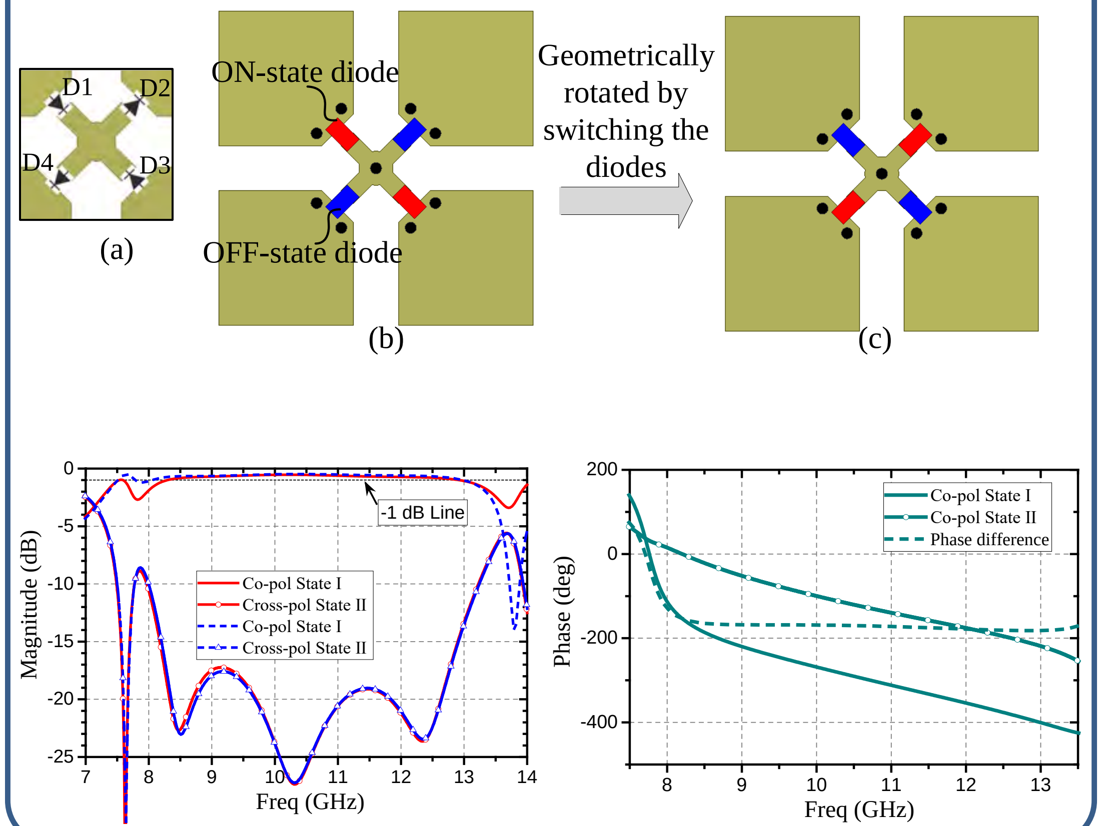


- Low SLLs (<-18 dB) could be maintained over a wide range

X. Dai, X. Li, K. -M. Luk, “A planar wideband millimeter-wave antenna array with low side lobe using ‘±1’ excitations” *IEEE Trans on AP*, Oct. 2021.

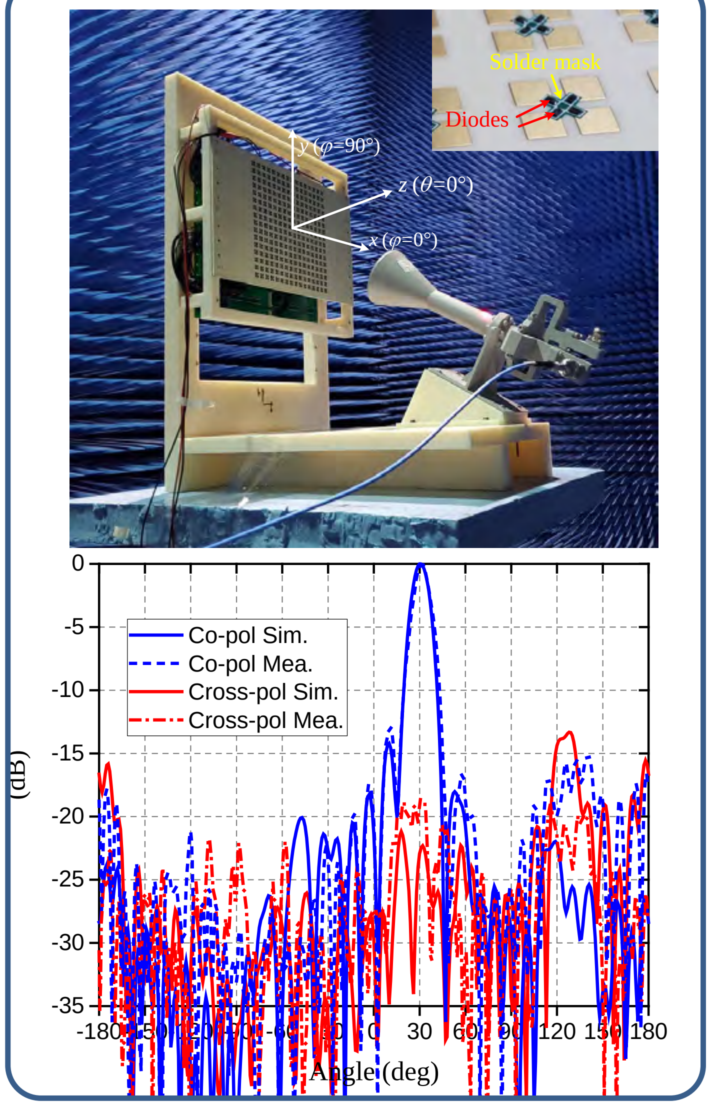
Reconfigurable CP ME-Dipole and Microstrip Reflectarrays

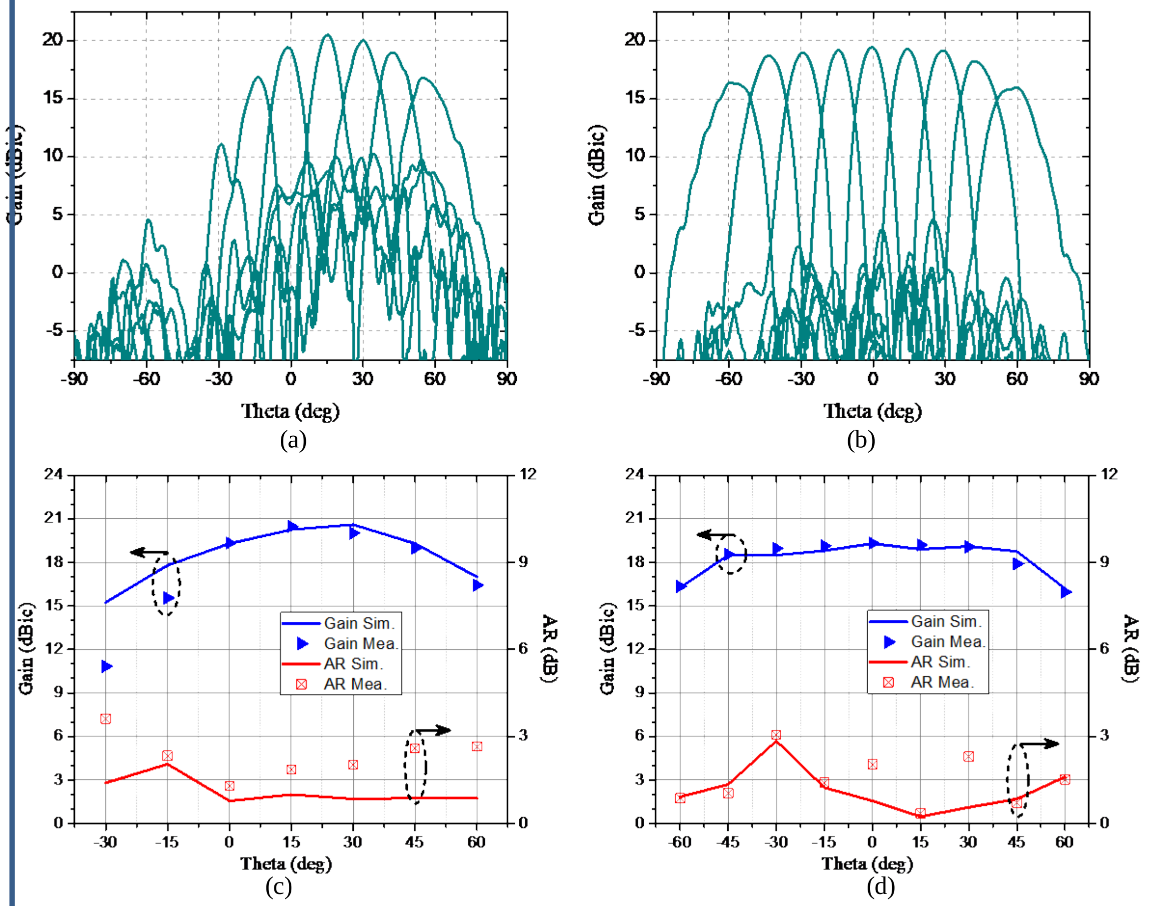




- ➢ Adjustable reflection phase of 1-bit resolution is achieved using the reconfigurable perturbation introduced at the connecting lines.
- ➢ A 1.5-dB and 3-dB AR element bandwidth of 37% and 42% are verified.

Reconfigurable CP ME-Dipole Reflectarrays

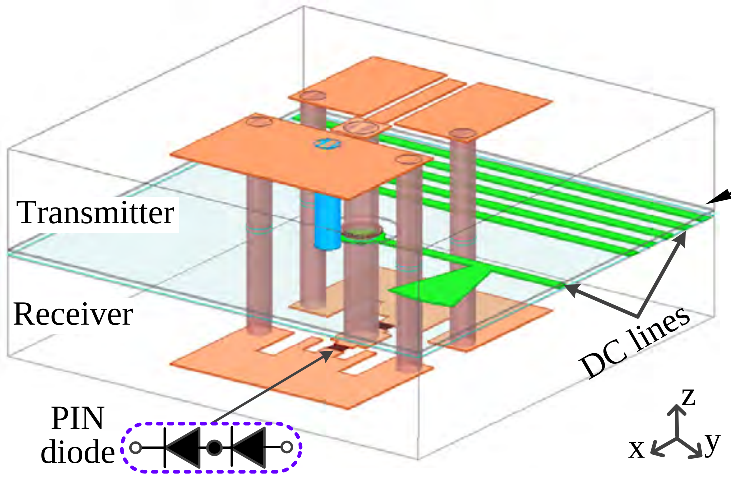


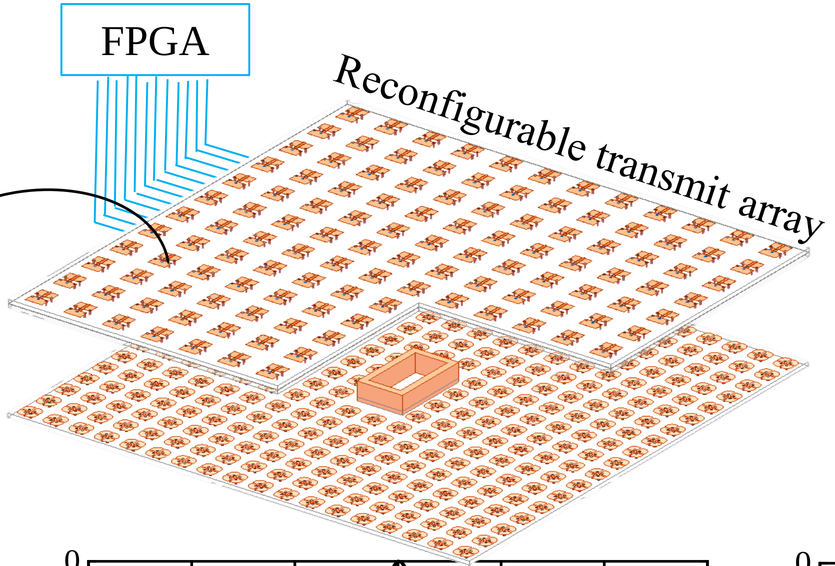


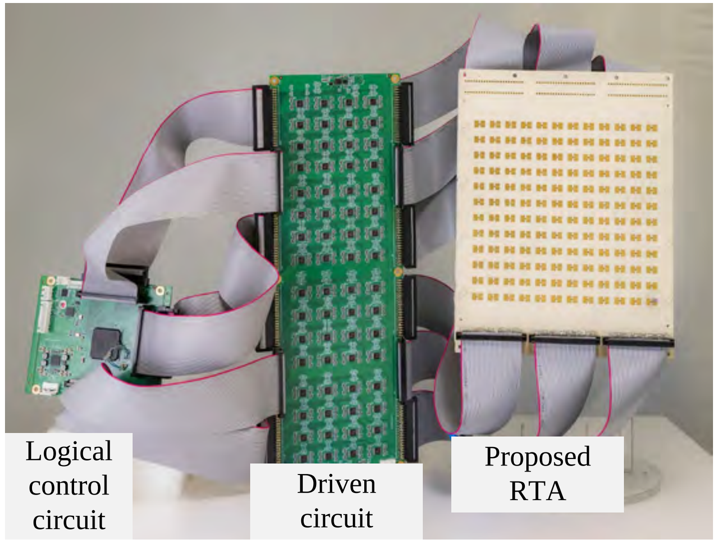
Measured array bandwidth reaches 32%. Very good scanning performance in the azimuth plane (scanning loss of 3.1 dB at ±60°).

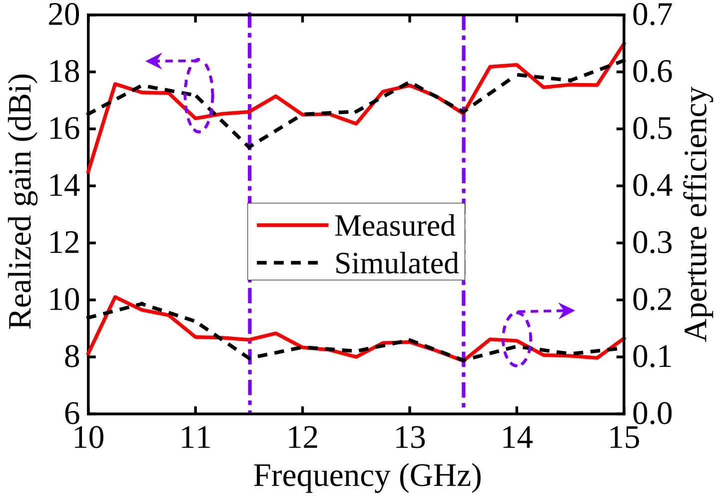
F. Wu, R. Lu, J. Wang, Z. H. Jiang, W. Hong, K. -M. Luk, ***IEEE AWPL*** , 2022

A Wideband Folded Reconfigurable Transmitarray

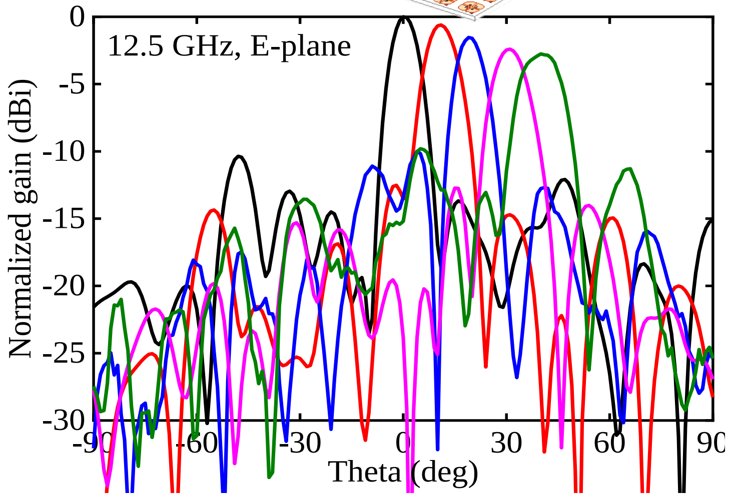


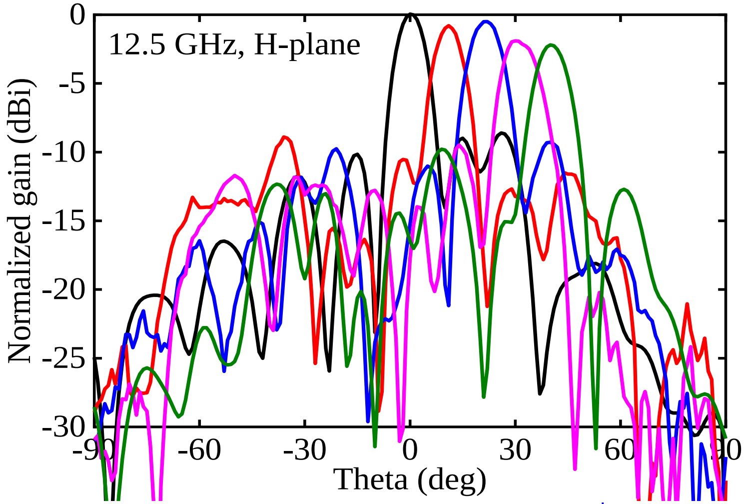






Broadside gain and AE

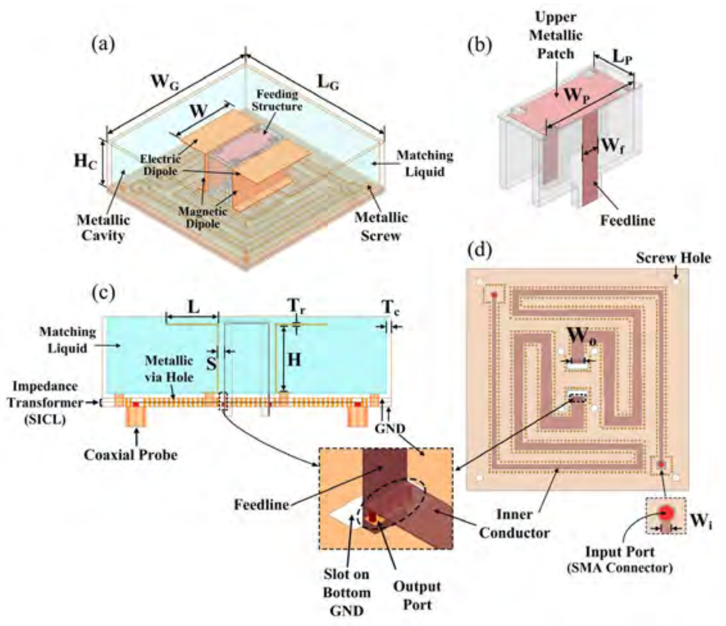




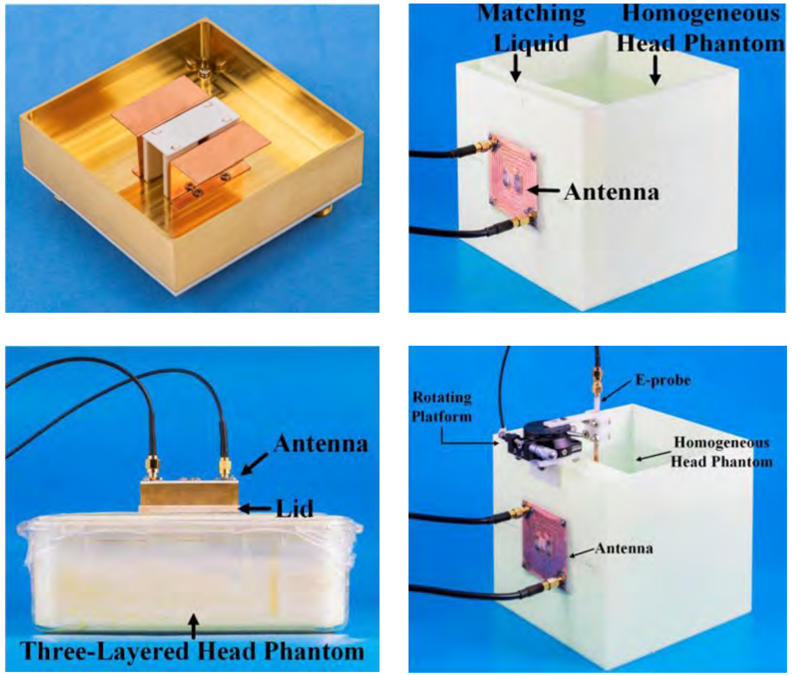
Height 38.5 mm, H/D=0.28; 3-dB gain BW: 37.6%; Aperture efficiency: 20.5%; Beam scanning: ±40°

X. Dai, G.-B. Wu and K.-M. Luk, “A wideband low-profile reconfigurable transmitarray using magnetoelectric dipole elements”, submitted to *IEEE Trans. Antennas Propag.*

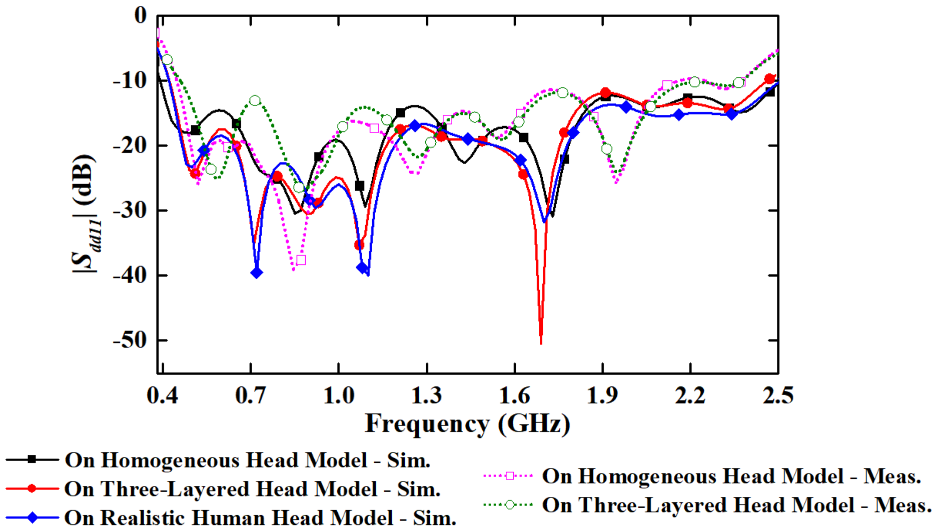
Magneto-Electric Dipole Antenna for Medical Imaging



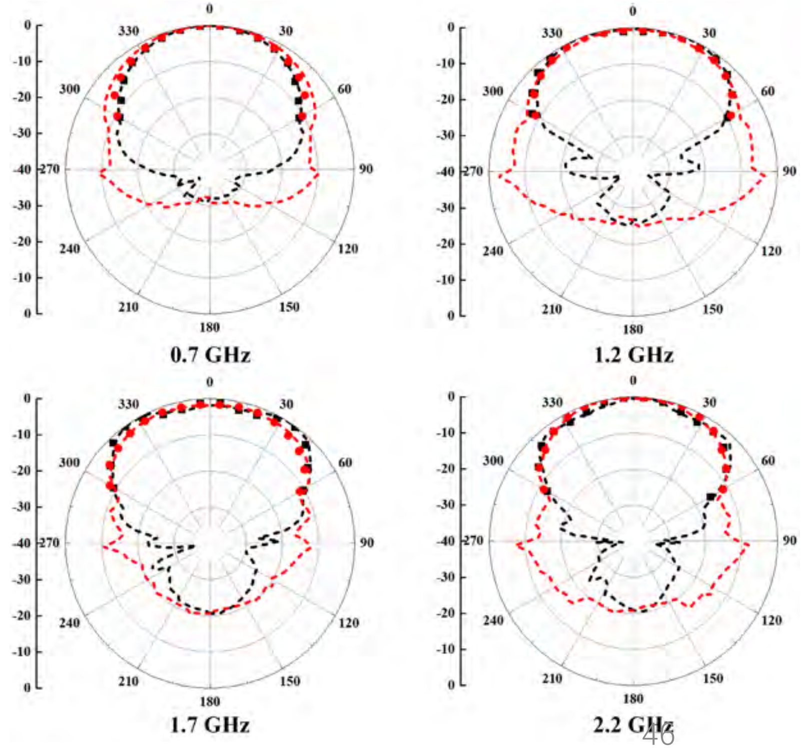
Antenna element

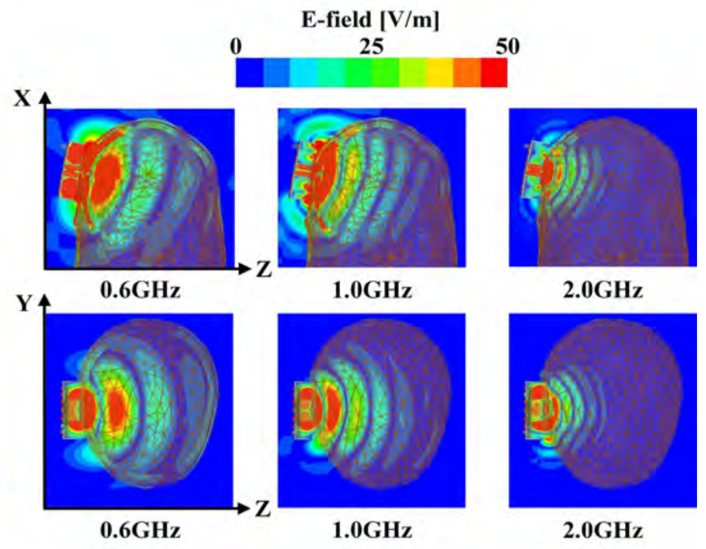


Measurement for antenna element

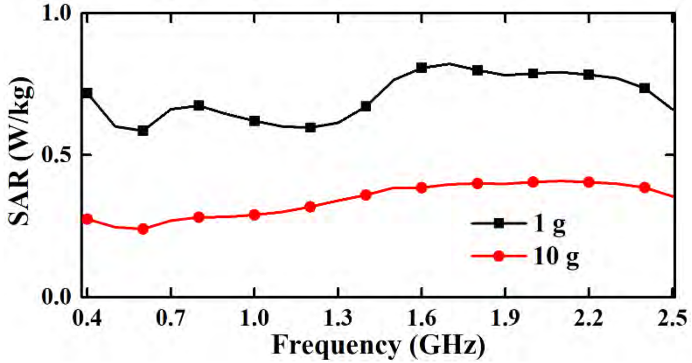


Simulated and measured $|S_{dd11}|$



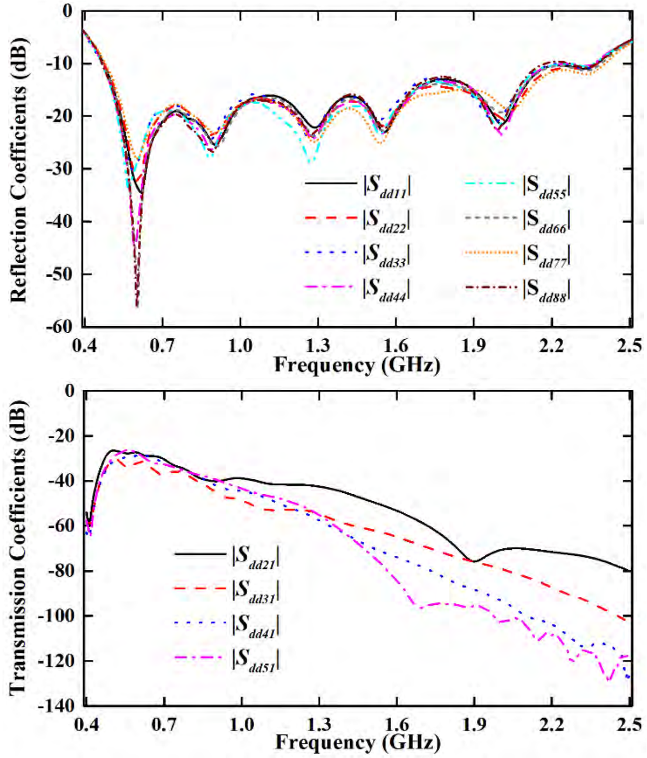


E-field distributions inside head model

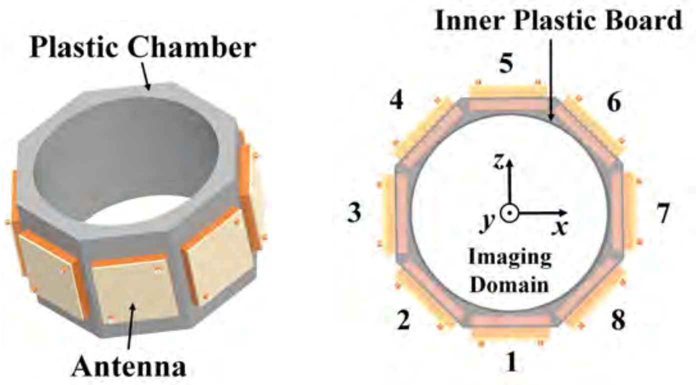


Maximum SAR values inside head model

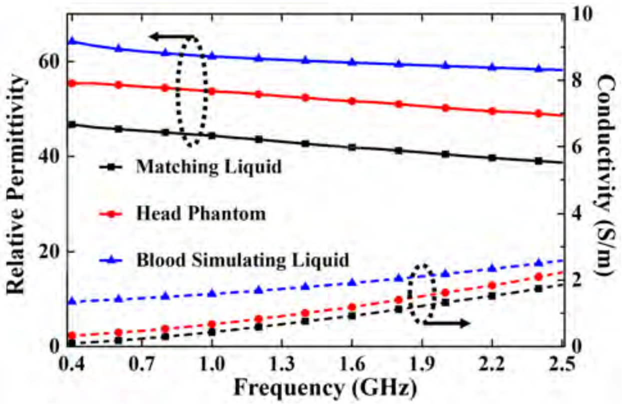
Simulated and measured near-field radiation patterns



S-parameters for antenna array

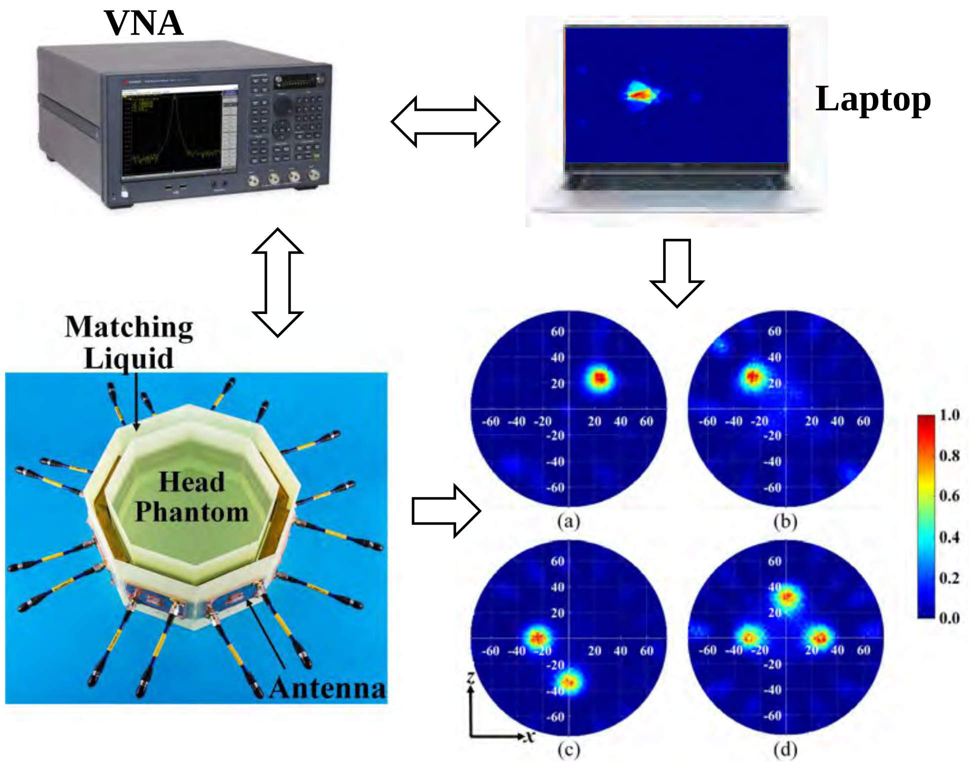


Head imaging system



Dielectric properties

Images reconstruction process



Fabricated prototype

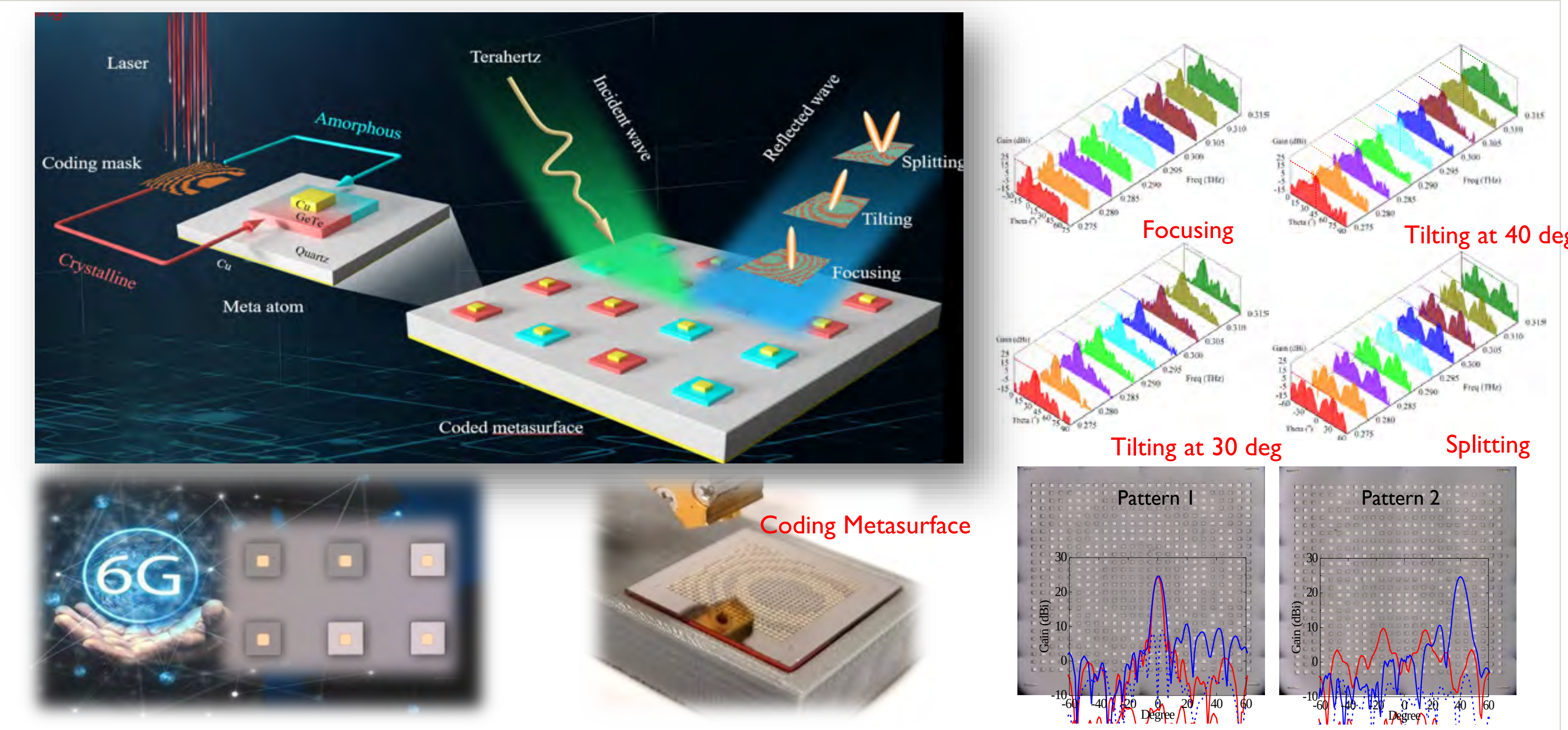
Reconstructed images (Delay-Multiply-and-Sum Algorithm)

Comparison with state-of-the-art on-body matched antennas for the head imaging system

Ref.	Size (L*W*H) λ_0	Frequency Band (GHz)	Bandwidth (%)	Min. FBR (dB)	Stable Main Beam Direction	Quality of Images in Experiments	Min. Radius of the Detected Bleeding Area in Experiments (mm)
[1]	0.117*0.117*0.173	1.0-9.0	160	7.5	√	-	-
[2]	0.05*0.05*0.004	0.5-2.0	120	3.5	√	-	-
[3]	0.117*0.087*0.122	1.0-7.0	150	2.5	√	Bad	5
[4]	0.23*0.23*0.04	1.0-1.7	52	17	×	-	-
[5]	0.167*0.134*0.019	1.0-4.3	124	-	-	Medium	15
[6]	0.187*0.133*0.133	0.8-1.2	40	-	×	-	-
[7]	0.067*0.036*0.006	0.45-3.6	155	9	×	Medium	12.5
This work	0.09*0.09*0.026	0.45-2.4	137	18	√	Good	5

Functional-Material Antennas – Dr Steve H. Wong

Active Terahertz Reconfigurable Coding Metasurface

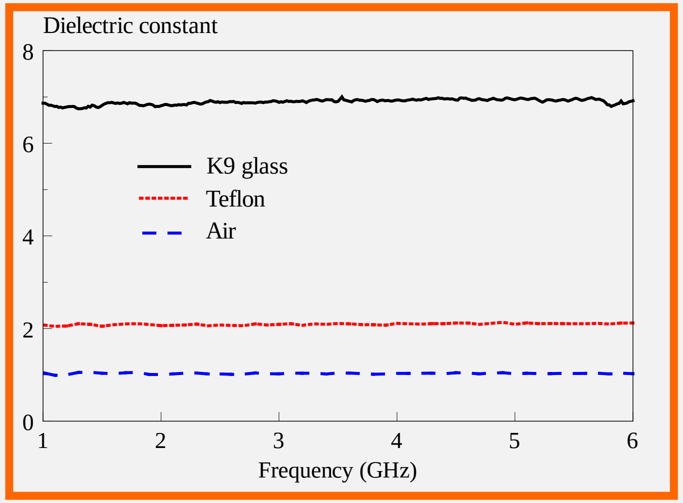


- Integrating GeTe material with cupper to create meta atom
- Using optical approach to select the state of the meta atom either crystalline or amorphous
- This smart surface is the world first experiment to prove a reconfigurable terahertz metasurface at 300 GHz for 6G communications
- Beam manipulations with stable performance over wide operating bandwidth

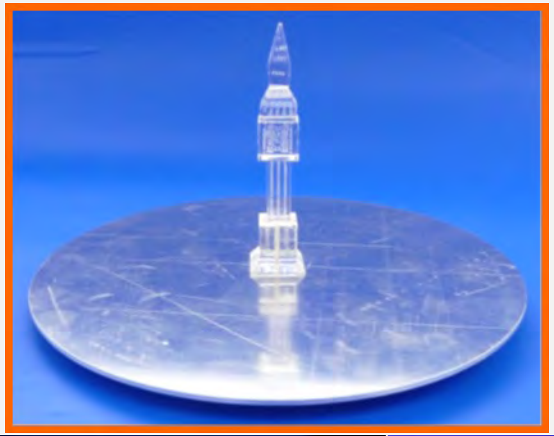
QW Lin, H Wong, L Huitema, A Crunteanu, "Coding Metasurfaces with Reconfiguration Capabilities Based on Optical Activation of Phase-Change Materials for Terahertz Beam Manipulations", *Advanced Optical Materials, 2101699.*

Glass Antennas – Invented by Prof K W Leung

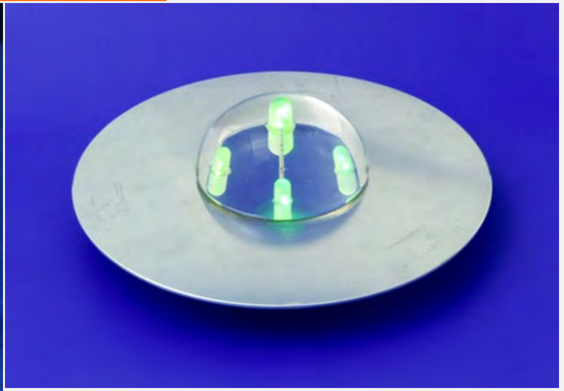
- $n \sim 1.5$ ($\varepsilon_r \sim 2.25$) is for optical frequency only
- ε_r can be very different at microwave frequency



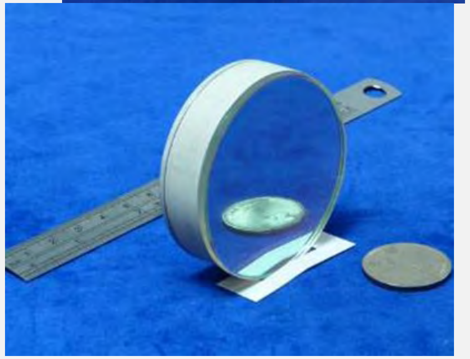
Measured dielectric constants of air, Teflon, and K9 glass by using Agilent 85070D Dielectric Probe Kit, verifying the K9 glass result



Decorative glass Antenna



Light-cover antenna

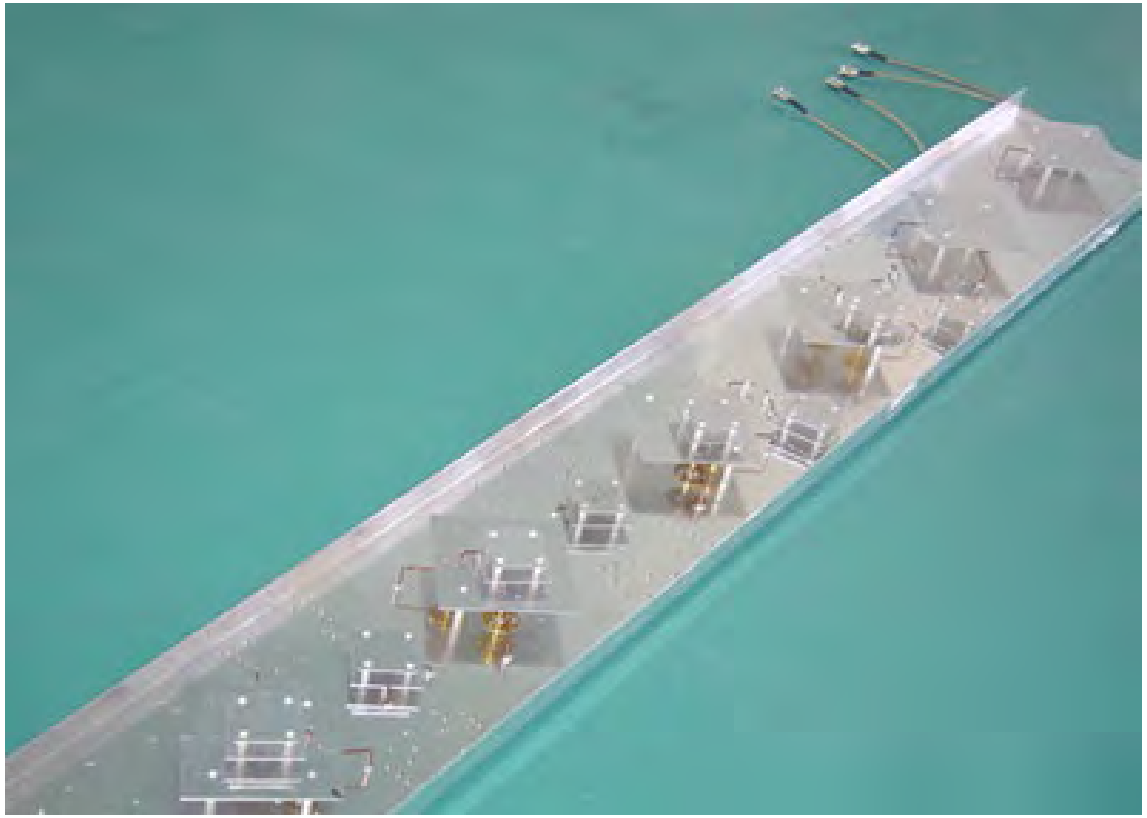


Mirror-integrated antenna (glass used as loading layer)

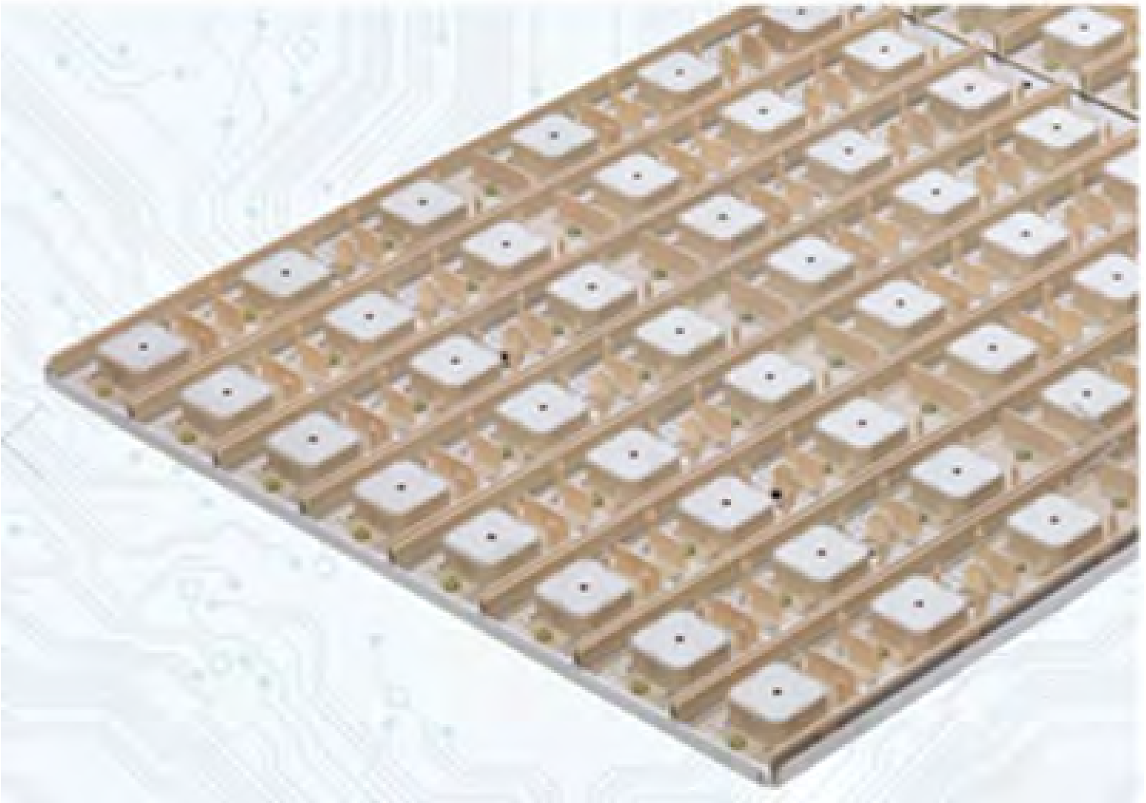
Work done by alumni and others

- Patents on basic designs of L-probe patch antenna and ME dipole are expired.
- The technologies are now open to public.
- Researchers and scholars from many universities, research institutes and companies in China has adopted ME dipoles in their new designs.
- Researchers working on ME dipole enhancements and applications are found from Korea, Taiwan, Singapore, Canada, India, Malaysia, France, Sweden, UK, Italy, and so on.

Products based on L-probe patch antenna



3G Base Station Antenna

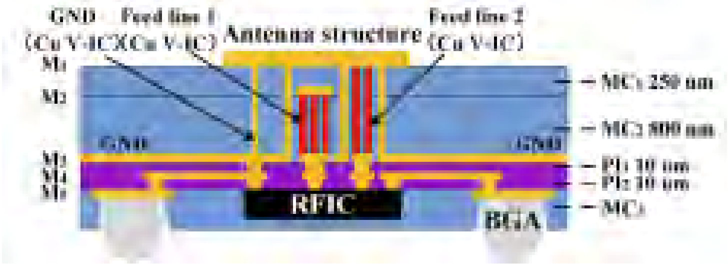


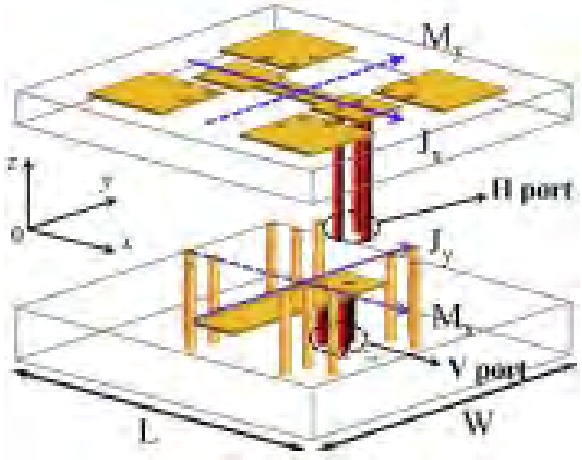
5G MIMO Base Station Antenna

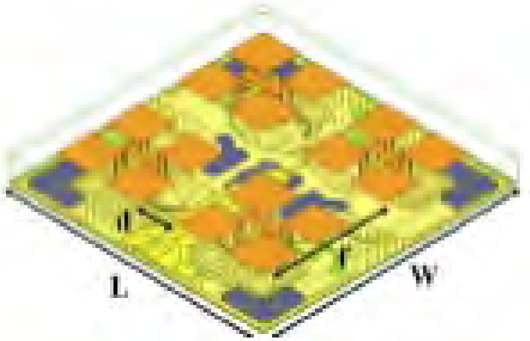
Product based on ME Dipole

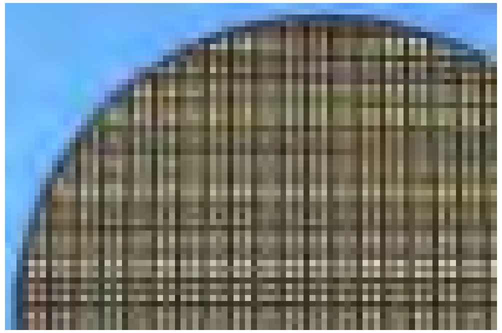
B Yu, Z Qian, C Lin, J Lin, Y P Zhang, G Yang and Y Luo, " A wideband mmWave antenna in fan-out wafer level packaging with tall vertical interconnects for 5G wireless communication," IEEE Trans. on AP, Oct 2021

- Antenna in Package for mmWave 5G
- Dual-polarized design
- Wide bandwidth: 25 to 43 GHz range





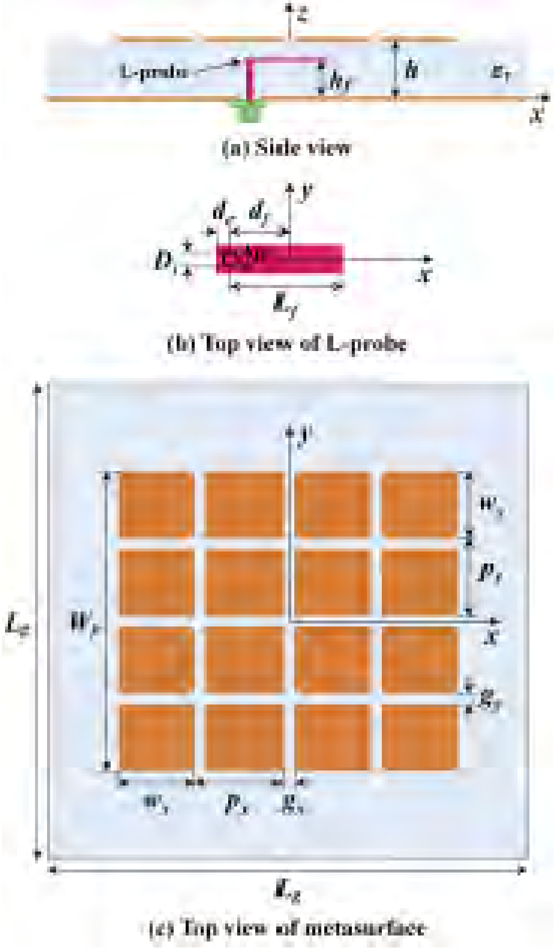


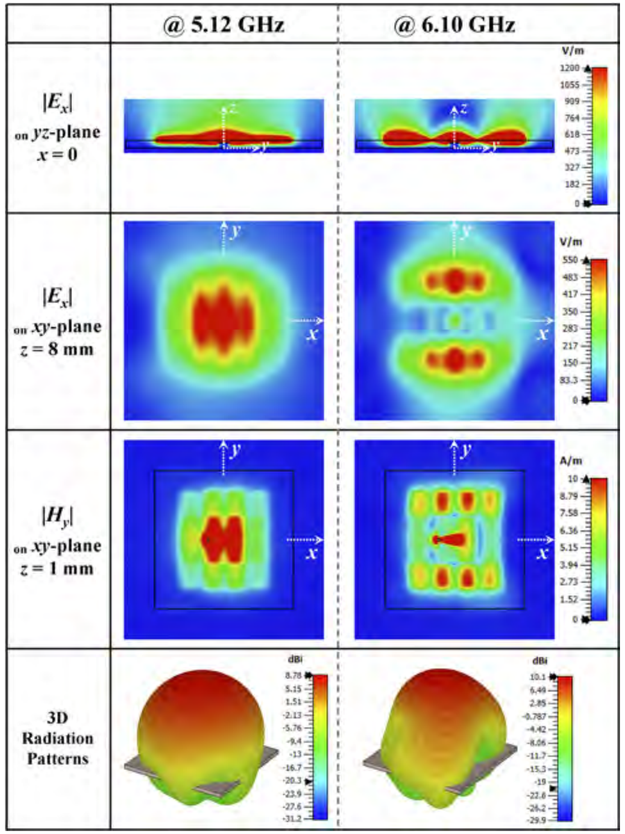


L-probe fed metasurface antenna

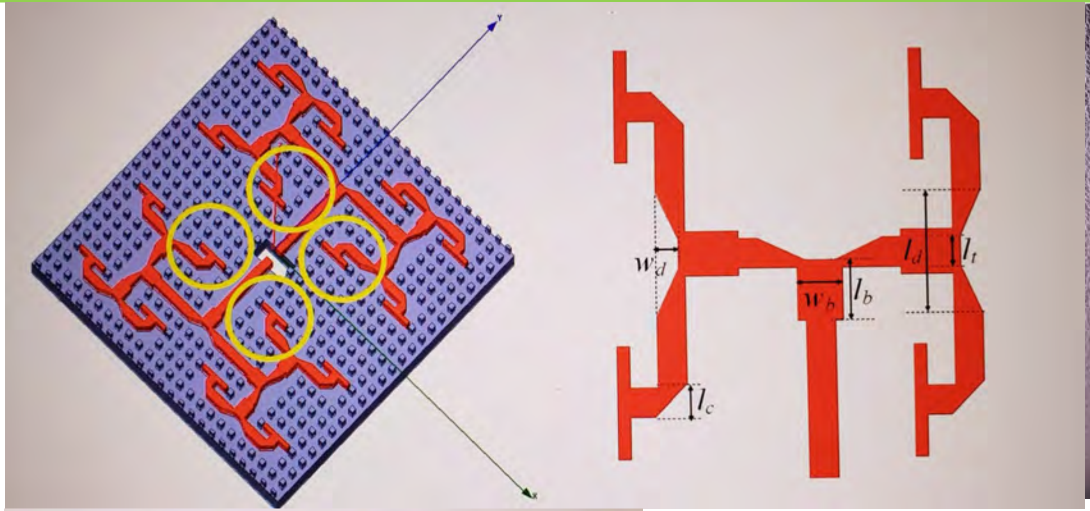
W E I Liu, Zhi Ning Chen, Xianming Qing, “Broadband low-profile L-probe fed metasurface antenna with TM leaky wave and TE surface wave resonances,”IEEE Trans on AP, March 2020

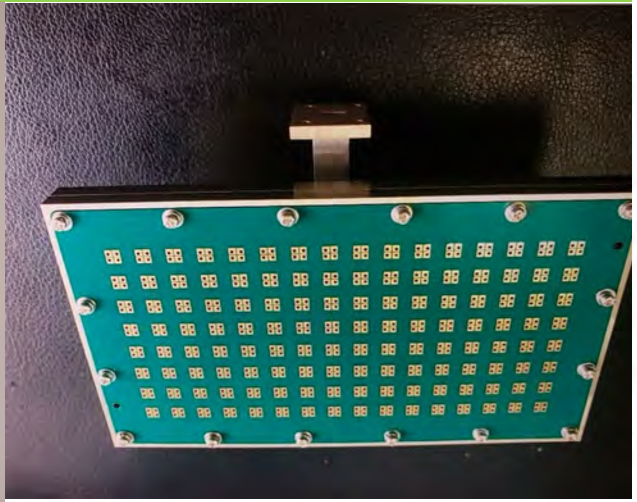
- TM leaky wave and TE surface wave resonances are excited
- Bandwidth: 34.5%
- Low-profile: 0.06 wavelength
- Gain: 10.3 dBi

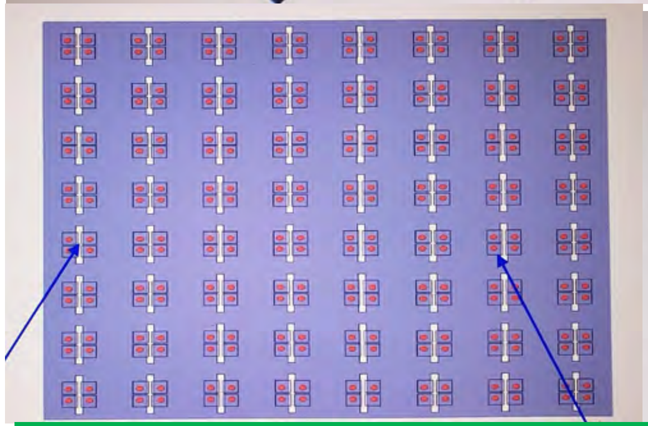


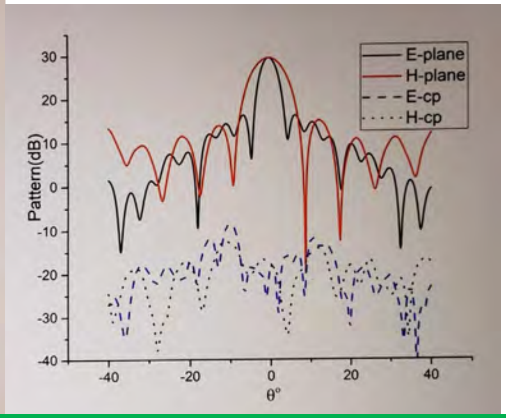


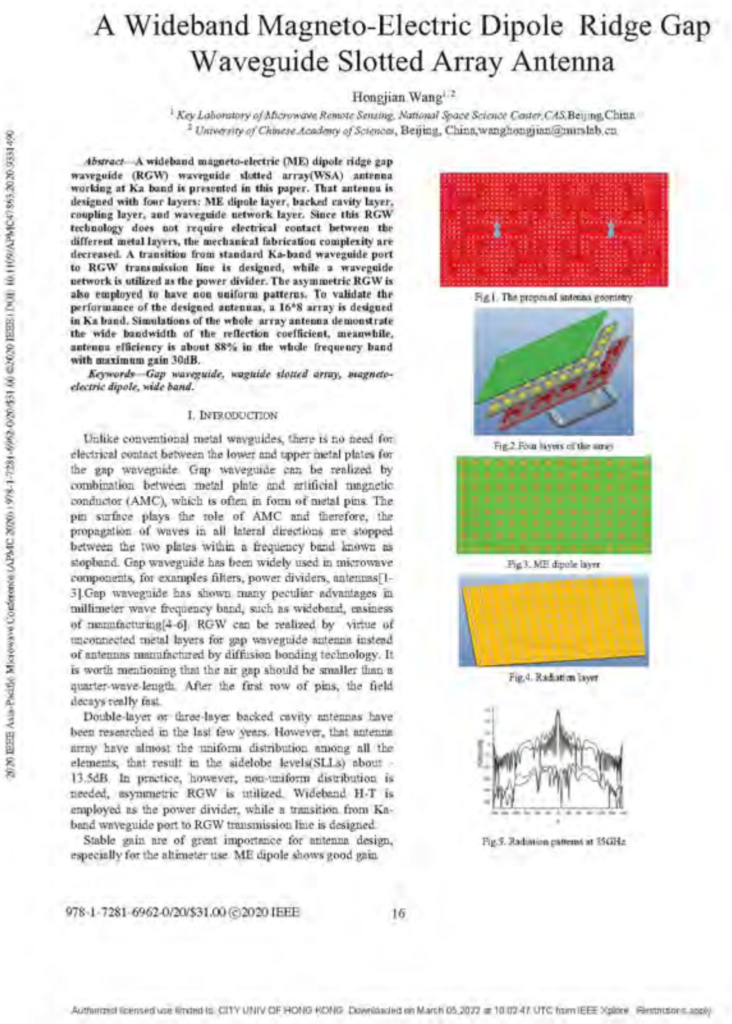
ME Dipole Array for Space Microwave Imaging











A Wideband Magneto-Electric Dipole Ridge Gap Waveguide Slotted Array Antenna

Hongjian Wang[1,2]

[1] Key Laboratory of Microwave Remote Sensing, National Space Science Center, CAS, Beijing, China

[2] University of Chinese Academy of Sciences, Beijing, China, wanghongjian@mirslab.cn

2020 IEEE Asia-Pacific Microwave Conference (APMC 2020) | 978-1-7281-6962-0/20/$31.00 ©2020 IEEE | DOI: 10.1109/APMC47863.2020.9331490

***Abstract*—A wideband magneto-electric (ME) dipole ridge gap waveguide (RGW) waveguide slotted array(WSA) antenna working at Ka band is presented in this paper. That antenna is designed with four layers: ME dipole layer, backed cavity layer, coupling layer, and waveguide network layer. Since this RGW technology does not require electrical contact between the different metal layers, the mechanical fabrication complexity are decreased. A transition from standard Ka-band waveguide port to RGW transmission line is designed, while a waveguide network is utilized as the power divider. The asymmetric RGW is also employed to have non uniform patterns. To validate the performance of the designed antennas, a 16*8 array is designed in Ka band. Simulations of the whole array antenna demonstrate the wide bandwidth of the reflection coefficient, meanwhile, antenna efficiency is about 88% in the whole frequency band with maximum gain 30dB.**

***Keywords*—Gap waveguide, waguide slotted array, magneto-electric dipole, wide band.**

I. INTRODUCTION

Unlike conventional metal wavguides, there is no need for electrical contact between the lower and upper metal plates for the gap waveguide. Gap waveguide can be realized by combination between metal plate and artificial magnetic conductor (AMC), which is often in form of metal pins. The pin surface plays the role of AMC and therefore, the propagation of waves in all lateral directions are stopped between the two plates within a frequency band known as stopband. Gap waveguide has been widely used in microwave components, for examples filters, power dividers, antennas[1-3].Gap waveguide has shown many peculiar advantages in millimeter wave frequency band, such as wideband, easiness of manufacturing[4-6]. RGW can be realized by virtue of unconnected metal layers for gap waveguide antenna instead of antennas manufactured by diffusion bonding technology. It is worth mentioning that the air gap should be smaller than a quarter-wave-length. After the first row of pins, the field decays really fast.

Double-layer or three-layer backed cavity antennas have been researched in the last few years. However, that antenna array have almost the uniform distribution among all the elements, that result in the sidelobe levels(SLLs) about -13.5dB. In practice, however, non-uniform distribution is needed, asymmetric RGW is utilized. Widebend H-T is employed as the power divider, while a transition from Ka-band waveguide port to RGW transmission line is designed.

Stable gain are of great importance for antenna design, especially for the altimeter use. ME dipole shows good gain

Fig.1. The proposed antenna geometry

Fig.2 Four layers of the array

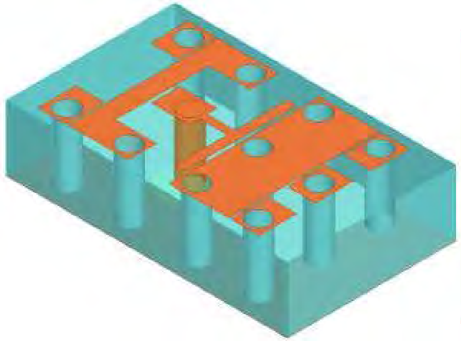
Fig.3. ME dipole layer

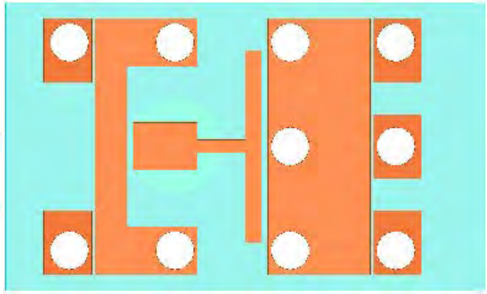
Fig.4. Radiation layer

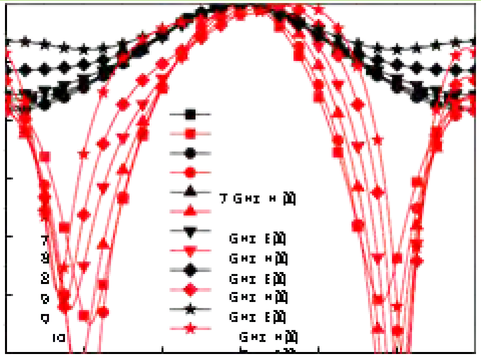
Fig.5. Radiation patterns at 35GHz

- Developed by Prof Hongjian Wang, Key Lab of Microwave Remote Sensing, University of Chinese Academy of Science
- Antenna efficiency: 88%
- Gain: 30 dBi

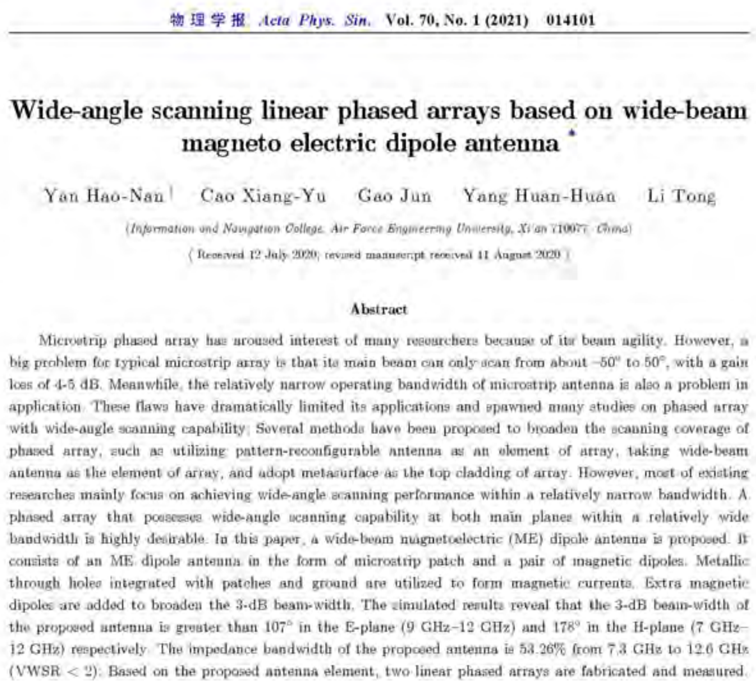
Wide Scan ME Dipole Arrays for X-Band Applications







Element with parasitic shorting vias



物理学报 Acta Phys. Sin. Vol. 70, No. 1 (2021) 014101

Wide-angle scanning linear phased arrays based on wide-beam magneto electric dipole antenna *

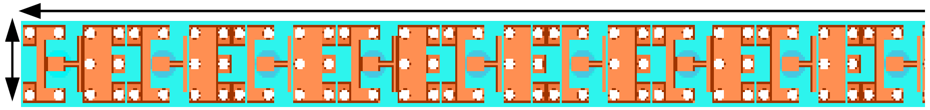
Yan Hao-Nan Cao Xiang-Yu Gao Jun Yang Huan-Huan Li Tong

(Information and Navigation College, Air Force Engineering University, Xi'an 710077, China)

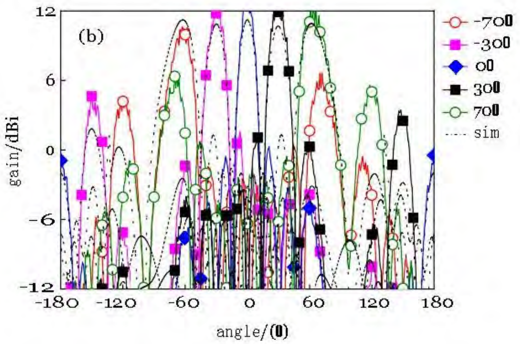
(Received 12 July 2020; revised manuscript received 11 August 2020)

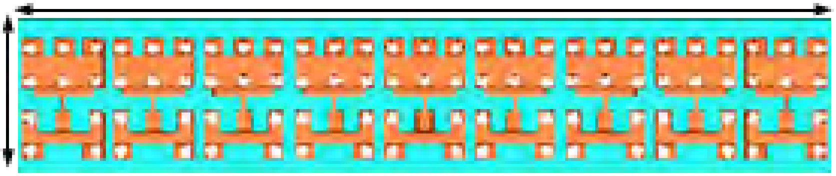
Abstract

Microstrip phased array has aroused interest of many researchers because of its beam agility. However, a big problem for typical microstrip array is that its main beam can only scan from about –50° to 50°, with a gain loss of 4-5 dB. Meanwhile, the relatively narrow operating bandwidth of microstrip antenna is also a problem in application. These flaws have dramatically limited its applications and spawned many studies on phased array with wide-angle scanning capability. Several methods have been proposed to broaden the scanning coverage of phased array, such as utilizing pattern-reconfigurable antenna as an element of array, taking wide-beam antenna as the element of array, and adopt metasurface as the top cladding of array. However, most of existing researches mainly focus on achieving wide-angle scanning performance within a relatively narrow bandwidth. A phased array that possesses wide-angle scanning capability at both main planes within a relatively wide bandwidth is highly desirable. In this paper, a wide-beam magnetoelectric (ME) dipole antenna is proposed. It consists of an ME dipole antenna in the form of microstrip patch and a pair of magnetic dipoles. Metallic through holes integrated with patches and ground are utilized to form magnetic currents. Extra magnetic dipoles are added to broaden the 3-dB beam-width. The simulated results reveal that the 3-dB beam-width of the proposed antenna is greater than 107° in the E-plane (9 GHz–12 GHz) and 178° in the H-plane (7 GHz–12 GHz) respectively. The impedance bandwidth of the proposed antenna is 53.26% from 7.3 GHz to 12.6 GHz (VWSR < 2). Based on the proposed antenna element, two linear phased arrays are fabricated and measured.

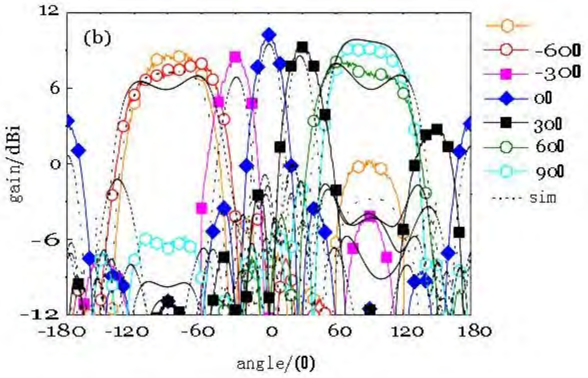


E-plane scan array





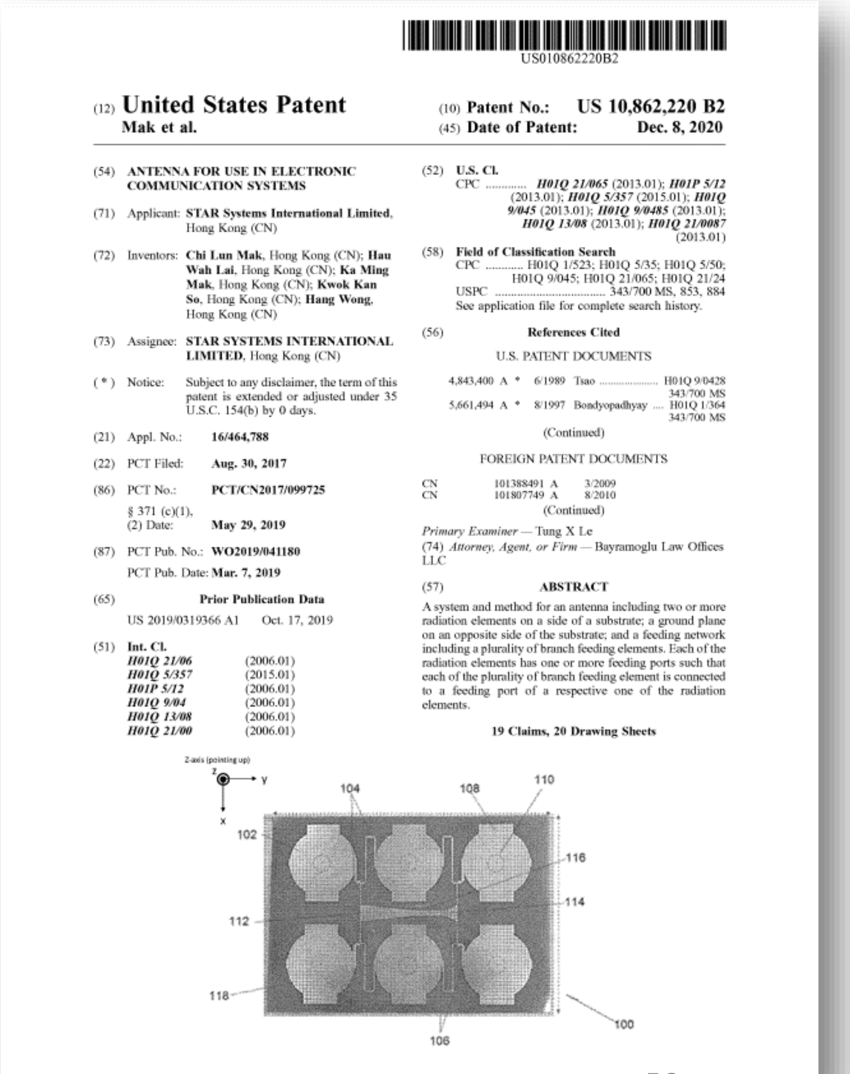
H-plane scan array



- Led by Prof Xiang-Yu Cao, Air Force Engineering University, Xian
- Novel wideband MED with wide beamwidth
- BW: 9 to 12 GHz
- E-plane scanning range: ±70 degree
- H-plane scanning range: ±90 degree

Applications: (R&D to successful commercialization)
Electronic Toll Collection (ETC) - RFID based technology.

- Patent: Antenna for use in electronic communication systems (Granted in 2020) https://patents.google.com/patent/US10862220B2/
- Inventors: **Chi Lun MAK, Hau Wah LAI, Ka Ming MAK, Kwok Kan SO, Hang WONG**
- One of current SSI flagship products.
- Product highlights: High Gain, Small Footprint, Low Cross-pol., etc.



US010862220B2

(12) **United States Patent**
Mak et al.

(10) **Patent No.: US 10,862,220 B2**
(45) **Date of Patent: Dec. 8, 2020**

(54) **ANTENNA FOR USE IN ELECTRONIC COMMUNICATION SYSTEMS**

(71) Applicant: **STAR Systems International Limited**, Hong Kong (CN)

(72) Inventors: **Chi Lun Mak**, Hong Kong (CN); **Hau Wah Lai**, Hong Kong (CN); **Ka Ming Mak**, Hong Kong (CN); **Kwok Kan So**, Hong Kong (CN); **Hang Wong**, Hong Kong (CN)

(73) Assignee: **STAR SYSTEMS INTERNATIONAL LIMITED**, Hong Kong (CN)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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PCT Pub. Date: **Mar. 7, 2019**

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H01Q 5/357 (2015.01)
H01P 5/12 (2006.01)
H01Q 9/04 (2006.01)
H01Q 13/08 (2006.01)
H01Q 21/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 21/065*** (2013.01); ***H01P 5/12*** (2013.01); ***H01Q 5/357*** (2015.01); ***H01Q 9/045*** (2013.01); ***H01Q 9/0485*** (2013.01); ***H01Q 13/08*** (2013.01); ***H01Q 21/0087*** (2013.01)

(58) **Field of Classification Search**
CPC H01Q 1/523; H01Q 5/35; H01Q 5/50; H01Q 9/045; H01Q 21/065; H01Q 21/24
USPC .... 343/700 MS, 853, 884
See application file for complete search history.

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Primary Examiner — Tung X Le
(74) *Attorney, Agent, or Firm* — Bayramoglu Law Offices LLC

(57) **ABSTRACT**

A system and method for an antenna including two or more radiation elements on a side of a substrate; a ground plane on an opposite side of the substrate; and a feeding network including a plurality of branch feeding elements. Each of the radiation elements has one or more feeding ports such that each of the plurality of branch feeding element is connected to a feeding port of a respective one of the radiation elements.

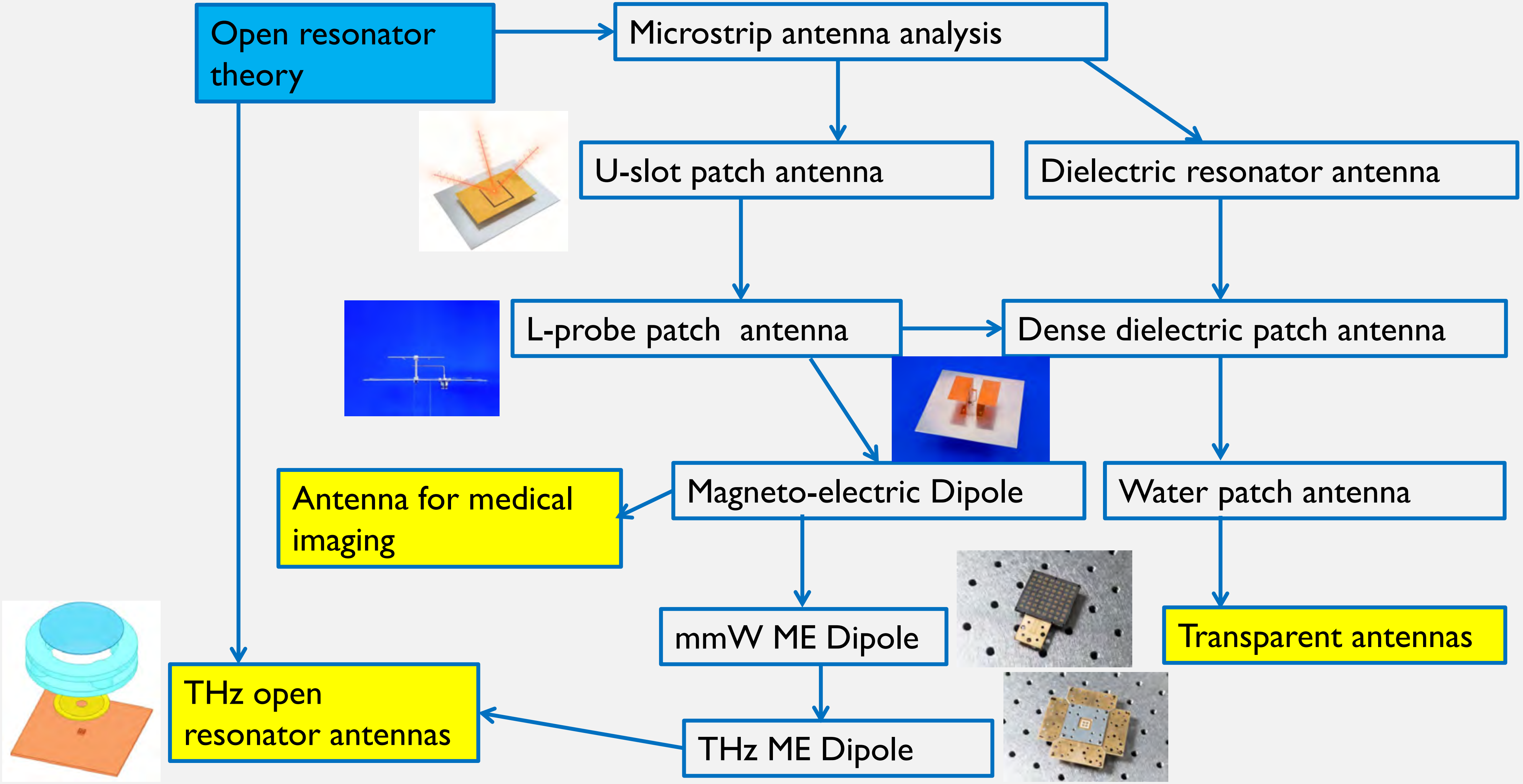
19 Claims, 20 Drawing Sheets

Applications: (R&D to successful commercialization)
Electronic Toll Collection (ETC) - RFID based technology.

E-470 Tollway in Colorado

Deployed successfully in many tollways, many cities, many countries all over the world including Taiwan, Vietnam, Thailand, Malaysia, USA, Colombia, Puerto Rico, India, Hong Kong and Russia (in progress) … and so many to come!

SUMMARY OF RESEARCH ACTIVITIES



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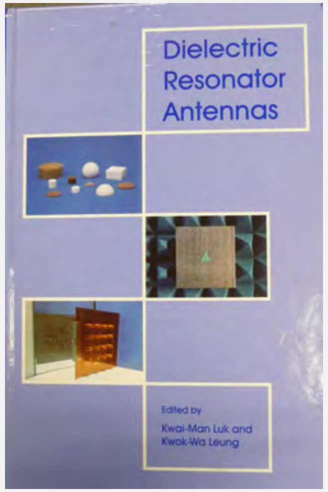

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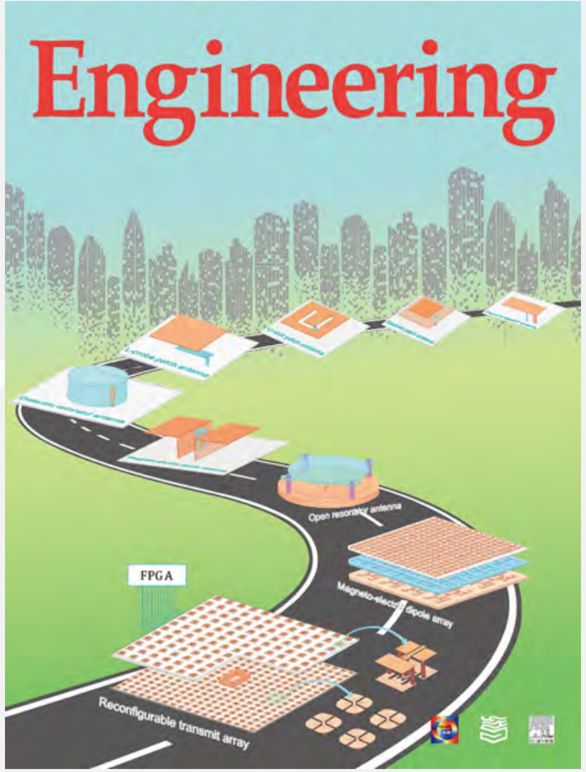

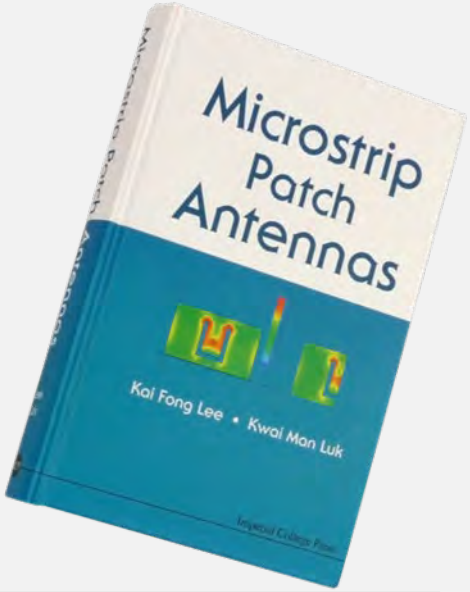

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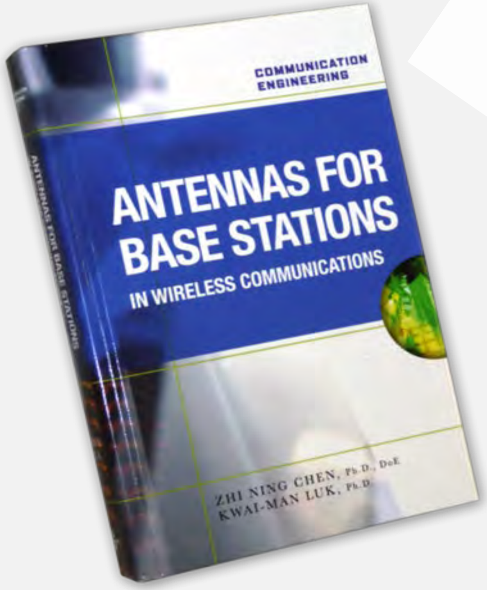

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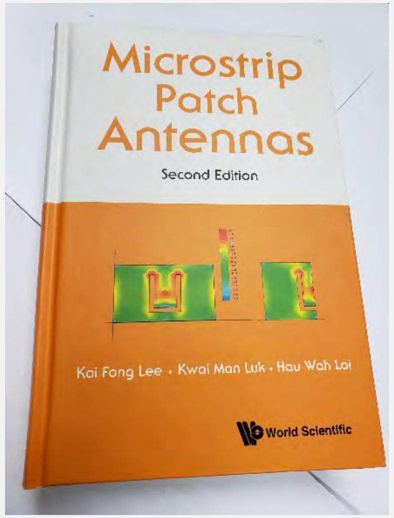

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HONORS AND AWARDS

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Ho Leung Ho Li Prize for Science &Technology Progress (2019)

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ACKNOWLEDGEMENT AND CONCLUDING REMARKS

- Antenna technologies push forward modern wireless connectivity
- Contributed by all creative antenna magicians
- They have made the impossible possible