Some efforts toward the modeling of integrated antennas

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Acknowledgement

I express my heartfelt gratitude to:

- ✓ Karen Olan, M.Sc., for her contribution to this project.
- ✓ Dr. Hiu Yung Wong, Chair of the San Francisco/Santa Clara Valley EDS Chapter, for his kind invitation to be here today.
- ✓ Keysight Technologies, for hosting this meeting.
- ✓ Dr. Wladek Grabinski for having organized this event and for his continued compact modeling efforts through MOS-AK.
- ✓ IEEE EDS, for their funding of the DL Program.
- ✓ CONAHCyT Mexico, for the partial support of this project through Grant # 285199

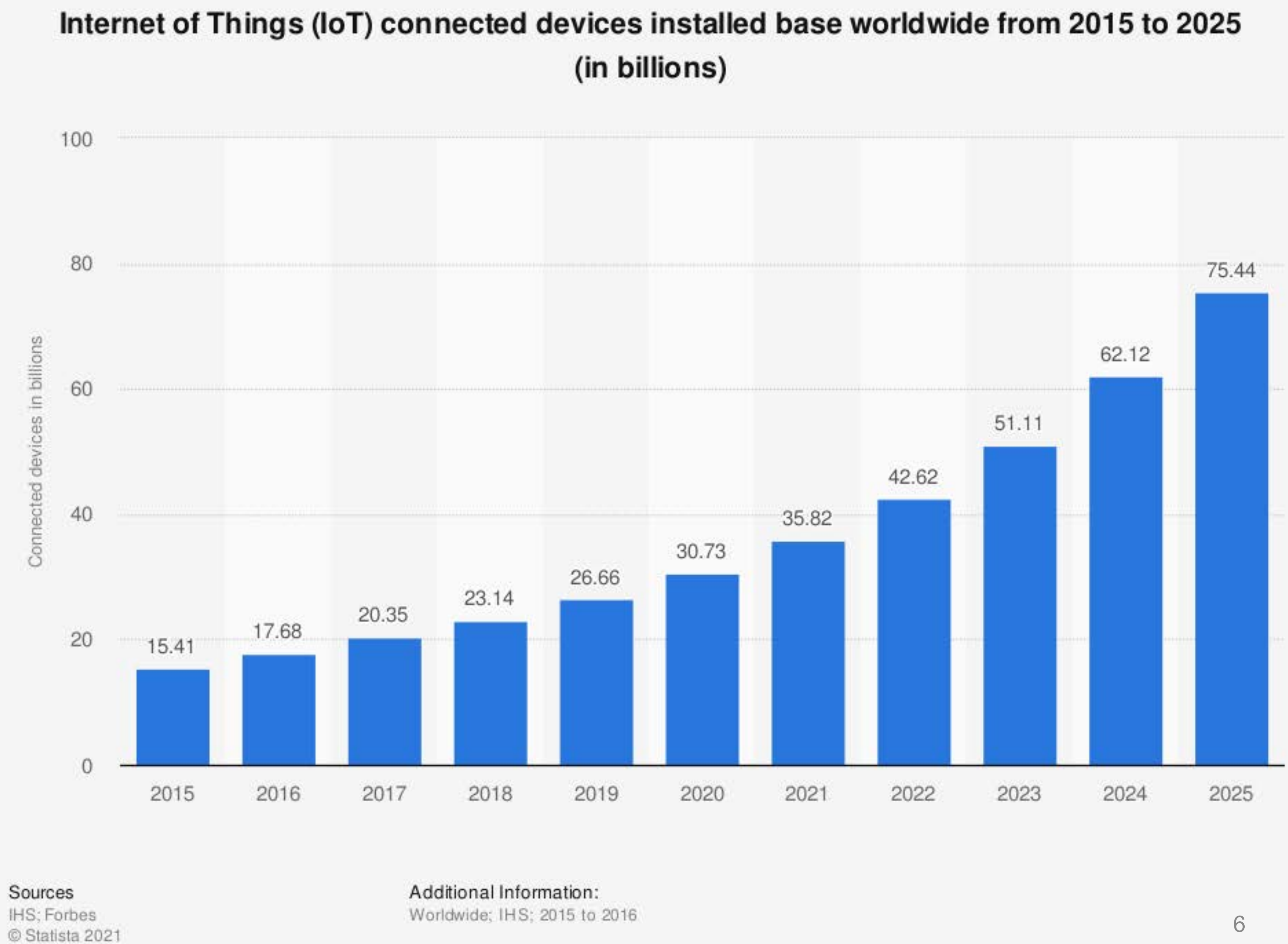
Outline:

- ❖ Motivation
- ❖ Integrated antennas – Early days
- ❖ Integrated antennas – General considerations
- ❖ Ideas on compact modeling of integrated antennas
- ❖ Some efforts toward the modeling of integrated antennas
- ❖ Conclusions

Motivation

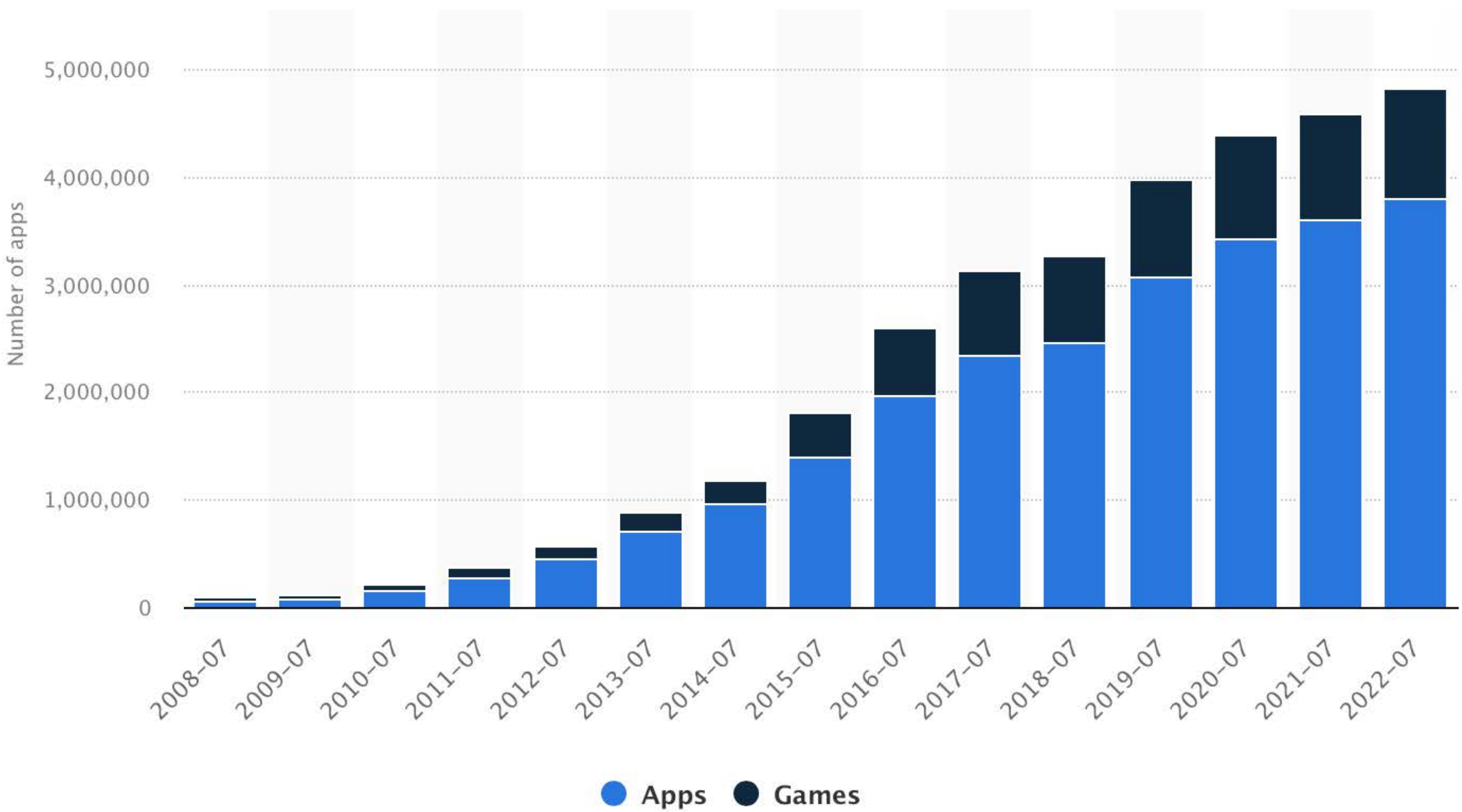
Motivation

- The continuous development of wireless communication devices and systems make integrated antennas desirable.
- There are everyday more and more wireless devices and applications.
- Data rates have to be faster in order to satisfy consumer needs.
- Antennas on-chip are a viable solution.



https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/

Number of available apps in the Apple App Store from 2008 to July 2022



https://www.statista.com/statistics/268251/number-of-apps-in-the-itunes-app-store-since-2008/

IEEE Communications Magazine, vol. 57, no. 8, August 2019.

Opening Terahertz for Everyday Applications

Kenneth K. O, Wooyeol Choi, Qian Zhong, Navneet Sharma, Yaming Zhang, Ruonan Han, Z. Ahmad, Dae-Yeon Kim, Sandeep Kshattry, Ivan R. Medvedev, David J. Lary, Hyun-Joo Nam, Philip Raskin, and Insoo Kim

The authors describe the devices in CMOS and the challenges they pose for implementing terahertz circuits. More importantly, they describe the performance of CMOS terahertz circuits, and their applications in daily life and expected advances that will help to expand the application opportunities.

Abstract

CMOS IC technology has become an affordable means for implementing capable systems operating at 300 GHz and above. CMOS circuits have been used to generate a signal up to 1.3 THz to detect both amplitude and phase of signals up to 1.2 THz, and to detect a signal amplitude up to ~10 THz. Additionally, a transmitter and a receiver operating up to ~300 GHz for electronic smelling using rotational spectroscopy, a 30-Gb/s 300-GHz QPSK transmitter for data communication with −6-dBm output power, and an 820 GHz imaging array fabricated in CMOS have been reported. These results, along with the CMOS circuit performance in the literature, and link analyses suggest that the electronics necessary for everyday life applications in the terahertz band can be affordably realized.

Introduction

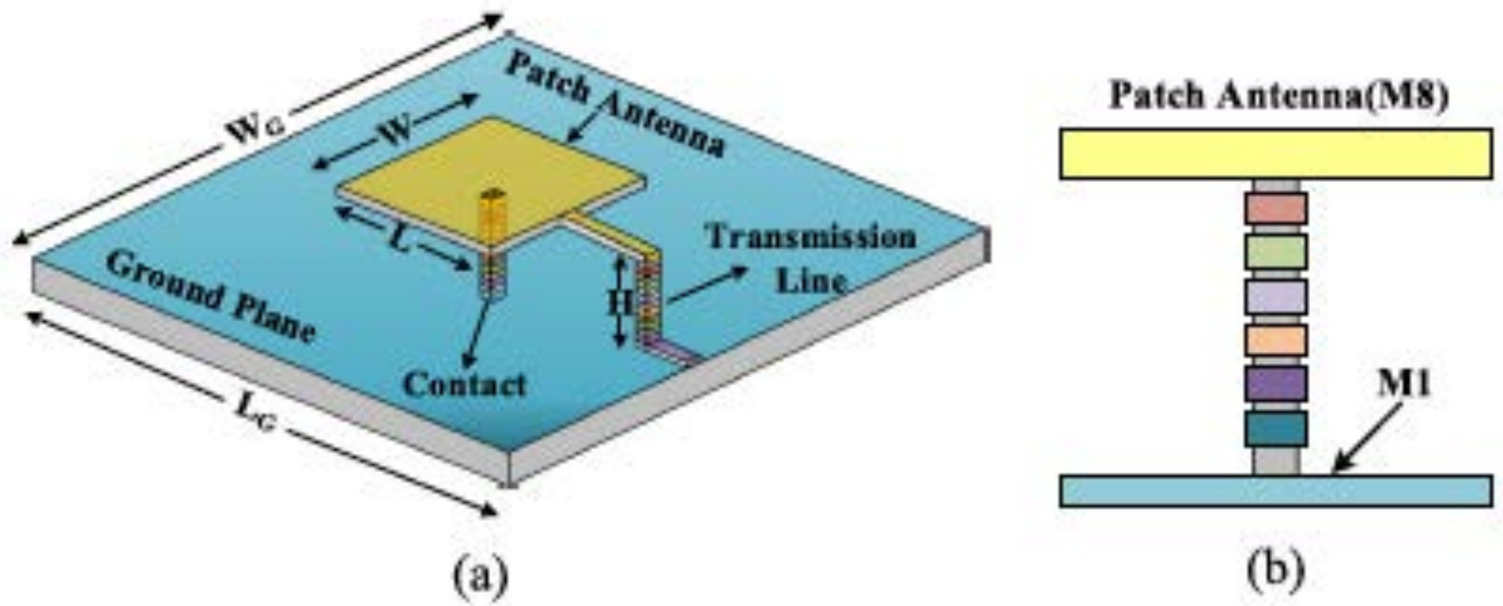
Electromagnetic waves at 300 GHz–3 THz, referred as sub-millimeter or terahertz waves, have a variety of potential everyday applications. They can be used for real-time 3D imaging such as through walls for locating wires and pipes; through decorative pieces to detect

CMOS Integrated Circuit Technology for Terahertz Operation

Realization of terahertz circuits in CMOS is in part enabled by the advances of high frequency capabilities of the active and passive devices in IC technology. The highest unity current gain frequency, f_T, and unity maximum available power gain frequency, f_{max}, of N-channel MOS (NMOS) transistors fabricated in CMOS are 280 and 320 GHz, respectively [6]. These are for transistors, including interconnects to the top metal layer, that increase parasitic capacitance, resistance, and inductance. The highest f_T was achieved using a transistor in 45-nm CMOS (e.g., 45 nm is the minimum feature dimension allowed in the technology), while the highest f_{max} was achieved using a transistor in 32-nm CMOS [6].

The parasitics of metal interconnects for making connections among devices to form circuits significantly impact the terahertz performance. For example, including the metal connections in 45-nm silicon on insulator (SOI) CMOS lowers measured f_{max} from ~400 GHz to 280 GHz [6]. The f_T and f_{max} of the latest technology node using fin field effect transistors (FinFETs) are no longer the highest [6]. Amplification is possible

Example in the THz regime



Parameter	Size (μm)	Parameter	Size (μm)
W_G	66.7	L	24.9
L_G	66.7	H	3.99
W	37.8	W_T	1.86

55 nm CMOS
5.69 dBi gain
>80% efficiency
190 GHz BW
4X8 detector array

"Investigation of Channel Parasitic Effect of CMOS Transistor for High Responsivity 2.58 THz Detector Array with Patch Antennas in Chip", X. Zhang et al., IEEE Transactions on Terahertz Science and Technology, Vol. 13, No. 5, **September 2023**, pp. 464-475. DOI: 10.1109/TTHZ.2023.3286654

Integrated antennas
Early days

Integrated antennas

- The idea of including antennas in an integrated circuit can be traced to the beginnings of this century.
- Many applications for antennas-on-chip (AoC) were initially proposed; several did not mature enough to become commercially viable.
- Antenna size is inversely proportional to frequency; at low GHz frequencies, antennas are huge!

One of the first papers

2000

THIF-31

SI/SIGE HBT ACTIVE INTEGRATED ANTENNA ON HIGH RESISTIVITY SILICON SUBSTRATE

M. M. Kaleja[1], A. Grübl[1], F. X. Sinnesbichler[1,2], G. R. Olbrich[1], K. M. Strohm[3], J.–F. Luy[3], E.M. Biebl[1]

[1]Technische Universität München, 80290 München, Germany
[2]now with Infineon Technologies
[3]DaimlerChrysler Research, Wilhelm–Runge–Str. 11, 89081 Ulm, Germany

ABSTRACT

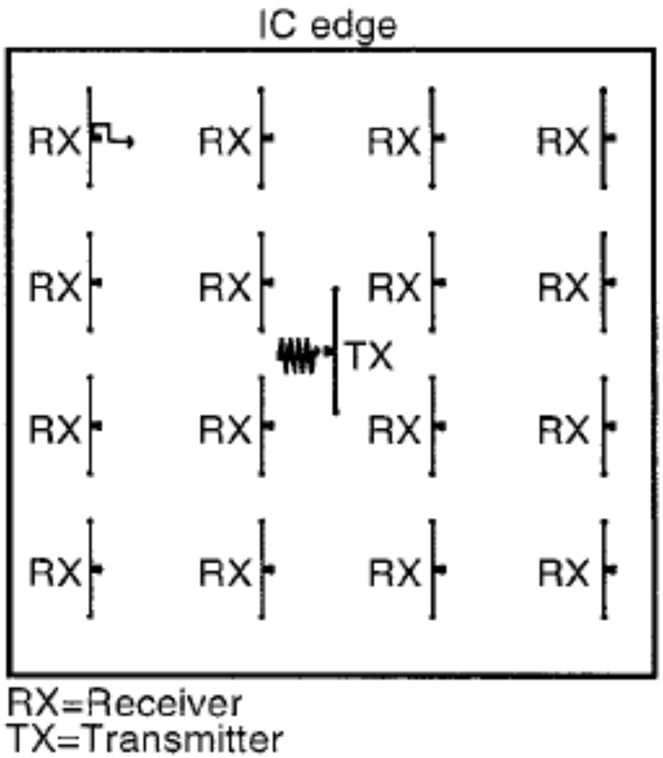
The first active integrated K-band antenna on high resitivity silicon substrate employing a Si/SiGe HBT is presented. Microstrip structures represent the resonating and radiating circuits. Large and small signal modeling was performed to compare the different methods. Several antennas were built and characterized to show the feasibility of this novel approach.

I. INTRODUCTION

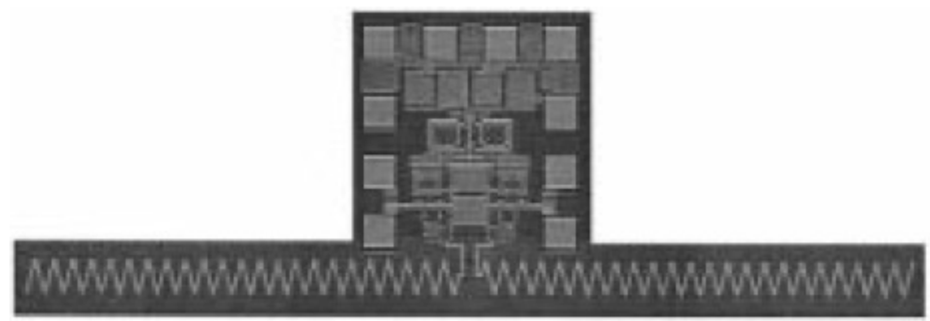
The triumphant advance of AIAs started with the usage of two-terminal elements as IMPATT diodes [2] that are nowadays more and more replaced by three-terminal elements like HEMTs [3] or, as presented in this paper, HBTs [4]. These transistors overcome the problem of the high power dissipation raised by two-terminal devices. This feature enlarges the usability for AIAs based on transistors to battery operated applications e. g. RFID systems [5].
To describe the transistor's behavior as precise as possible, a large signal model has been used for circuit simulation. This model was combined

"Si/SiGe HBT Active Integrated Antenna on High Resistivity Silicon Substrate", M.M. Kaleja et al., 2000 IEEE MTT-S Digest, 11-16 June 2000, Boston, MA, USA, pp. 1899-1902 . DOI: 10.1109/MWSYM.2000.862353

Failed good idea — Intrachip - clock sync



2002



"Intra-Chip Wireless Interconnect for Clock Distribution Implemented with Integrated Antennas, Receivers and Transmitters", B. Floyd et al., IEEE Journal of Solid State Circuits, Vol. 37, No. 5, May 2002, pp. 543-552.

On-Chip Antennas in Silicon ICs and Their Application

Kenneth K. O, *Senior Member, IEEE*, Kihong Kim, Brian A. Floyd, *Member, IEEE*, Jesal L. Mehta, Hyun Yoon, Chih-Ming Hung, *Member, IEEE*, Dan Bravo, Timothy O. Dickson, Xiaoling Guo, Ran Li, Narasimhan Trichy, Jim Caserta, Wayne R. Bomstad, II, Jason Branch, Dong-Jun Yang, Jose Bohorquez, Eunyoung Seok, Li Gao, Aravind Sugavanam, J.-J. Lin, Jie Chen, and J. E. Brewer, *Life Senior Member, IEEE*

2005

Invited Paper

***Abstract*—The feasibility of integrating antennas and required circuits to form wireless interconnects in foundry digital CMOS technologies has been demonstrated. The key challenges including the effects of metal structures associated with integrated circuits, heat removal, packaging, and interaction between transmitted and received signals, and nearby circuits appear to be manageable. This technology can potentially be applied for implementation of a true single-chip radio for general purpose communication, on-chip and inter-chip data communication systems, RFID tags, RF sensors/radars, and others.**

***Index Terms*—BiCMOS, clock distribution, CMOS, data communication, on-chip antenna, silicon, wireless.**

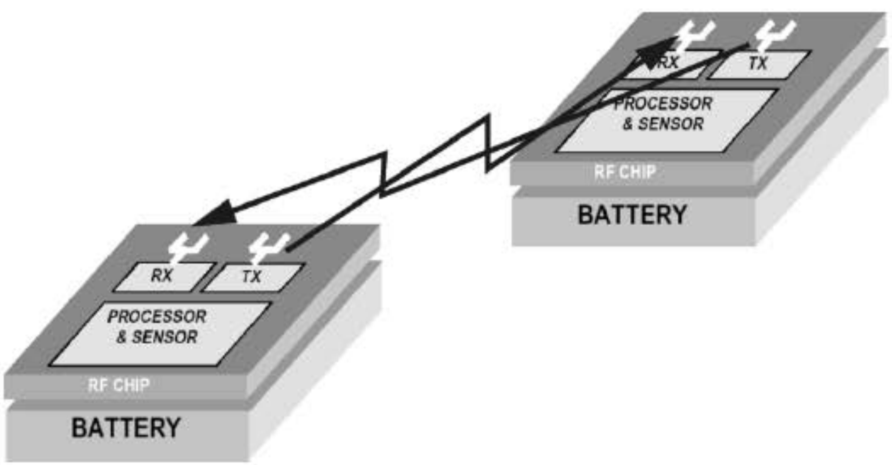


Fig. 1. Conceptual diagram of a μNode.

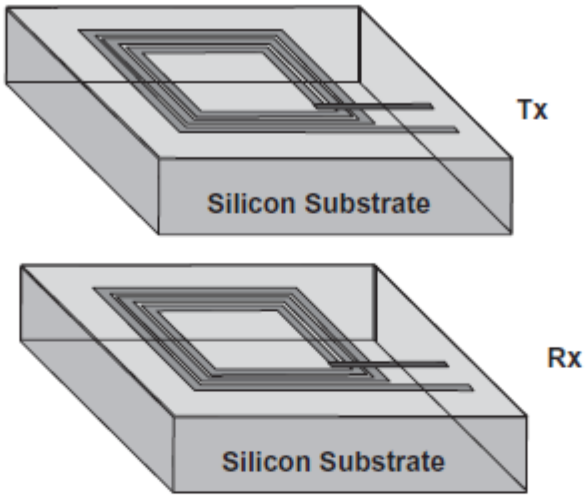
I. Introduction

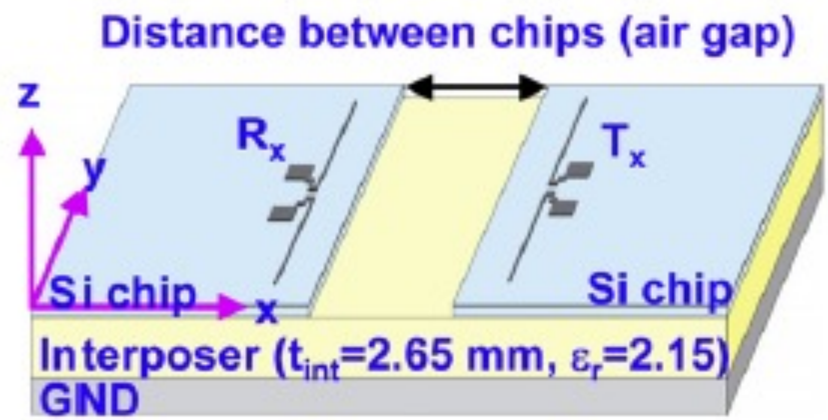
THE SPEED improvements of silicon and SiGe bipolar transistors [1]–[3], and MOS transistors [4]–[6] have

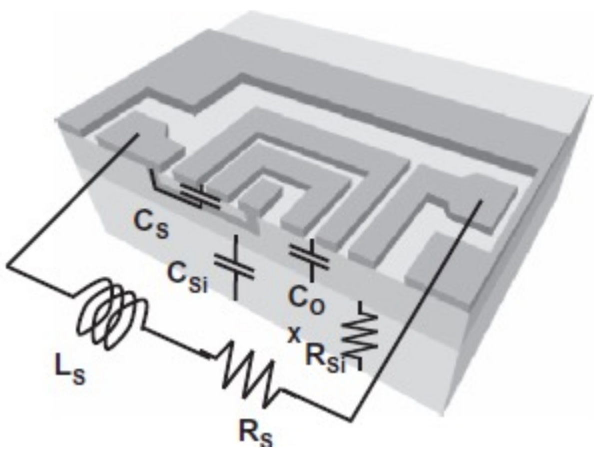
the operating frequencies of circuits. These in conjunction with the increase of chip sizes potentially up to ~ 2.4 cm × 2.4 cm

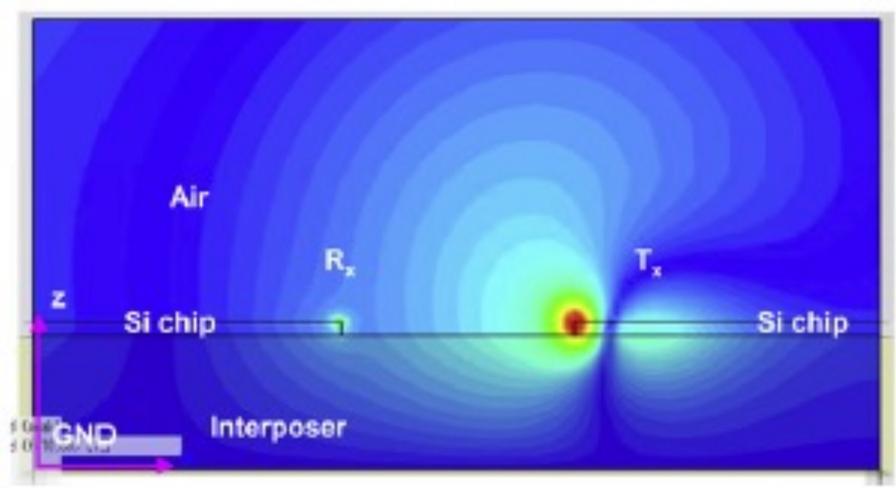
Interchip links

2011









“Wireless Inter-Chip Connects”, T. Kikkawa, Microelectronic Engineering, Vol. 88, 2011, pp. 767-774.

Interesting compilation

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Procedia Chemistry 1 (2009) 513–516

Procedia Chemistry

www.elsevier.com/locate/procedia

2009

Proceedings of the Eurosensors XXIII conference

On-Chip Integrated Antenna Structures for Biomedical Implantable Sensors

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[a]*Department of Information Science, Mathematics, Electronics and Transportations, "Mediterranea" University of Reggio Calabria, Via Graziella, Loc. Feo di Vito – 89122 Reggio Calabria, Italy*

Abstract

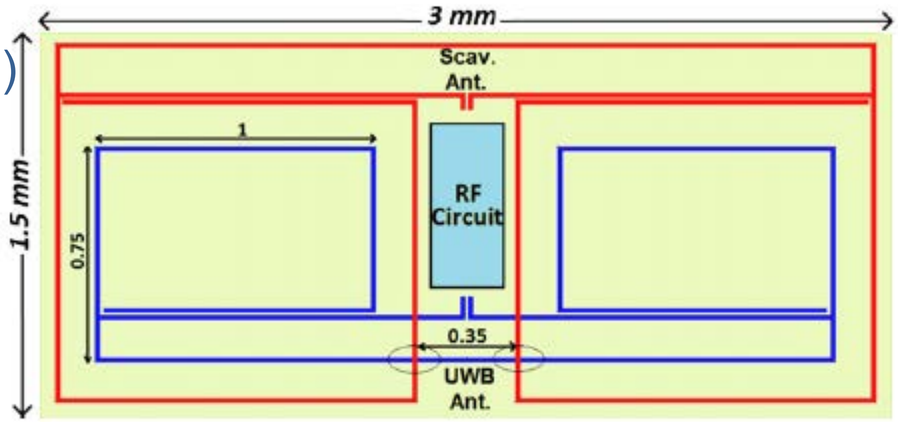
This paper explores some different geometries of integrated antennas in a 0.35 μm CMOS technology for devices operating in the internationally available unlicensed 2.4 GHz band. At this frequency, the wavelength is short enough to implement small antennas with dimensions economically feasible for silicon integration.
Two are the considered different families of structures: spiral and dipole antennas, and some different antenna structures (single-loop, 4-loop, double-4-loop, dipole, bent-dipole, meander-dipole) are examined, all modeled and simulated in Ansoft HFSS. Their inductive and radiation characteristics are compared. Chip dimensions of the order of one square millimetre are considered.

Keywords: temperature sensor; on-chip antenna; wireless sensors; CMOS integrated sensors.

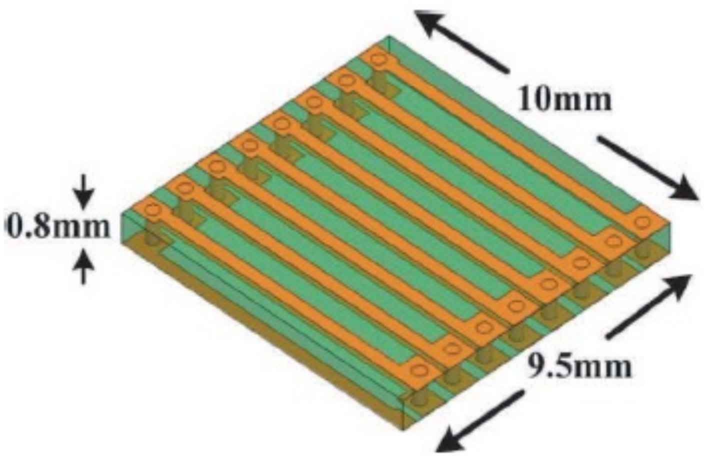
Antenna topologies	Emax [mV/m]	Gain [dB]	Umax [µWatt]	Radiation Efficiency [%]	Input impedance	Average length [mm]	Radiation pattern
	22,2	-50,9	0,60	1,50	11 + j 103	6	
	10,3	-57,5	0,14	0,35	128 - j 139	24	
	8,7	-58,9	0,10	0,24	21 + j 30	50	
	33,4	-47,3	1,50	1,16	689 - j 910	2	
	53,2	-43,3	3,80	2,70	489 - j 599	4	
	36,4	-46,5	1,80	1,40	589 - j 659	2,6	

RFID — Antenna size

(1)

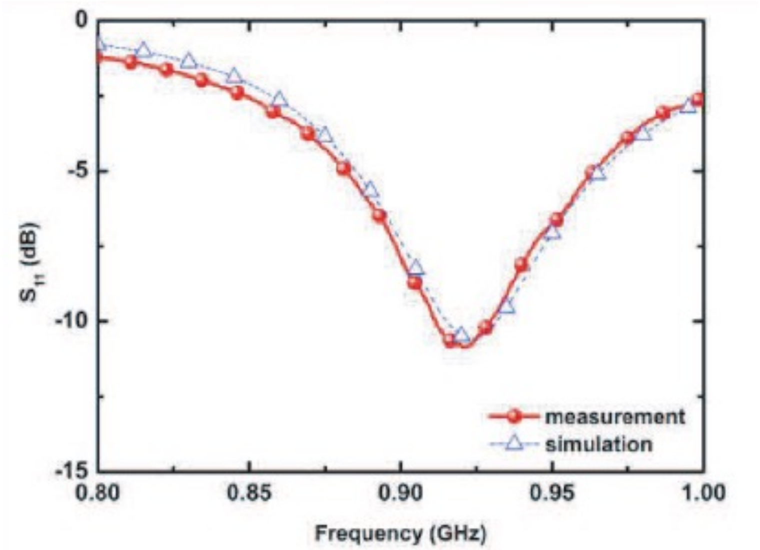


2012



2009

(2)



(1) “Miniaturized Integrated Antennas for Far-Field Wireless Powering”, K. Mohammadpour-Aghdam et al., International Journal of Electronics and Communications, Vol. 66, 2012, pp. 789-796.
(2) “A Miniature Chip Antenna Design for a Passive UHF RFID To be Built in a Portable Device”, Lin et al., PIERS 2009, pp. 1257-1260.

Integrated antennas
General considerations

Integrated antennas

- To overcome the large size of low frequency antennas, meander structures have been proposed.
- The use of metamaterial properties has also been exploited, achieving reduced sizes.
- But nowadays, with higher frequencies of operation, large size is not an obstacle.
- **Small size might become a problem!**

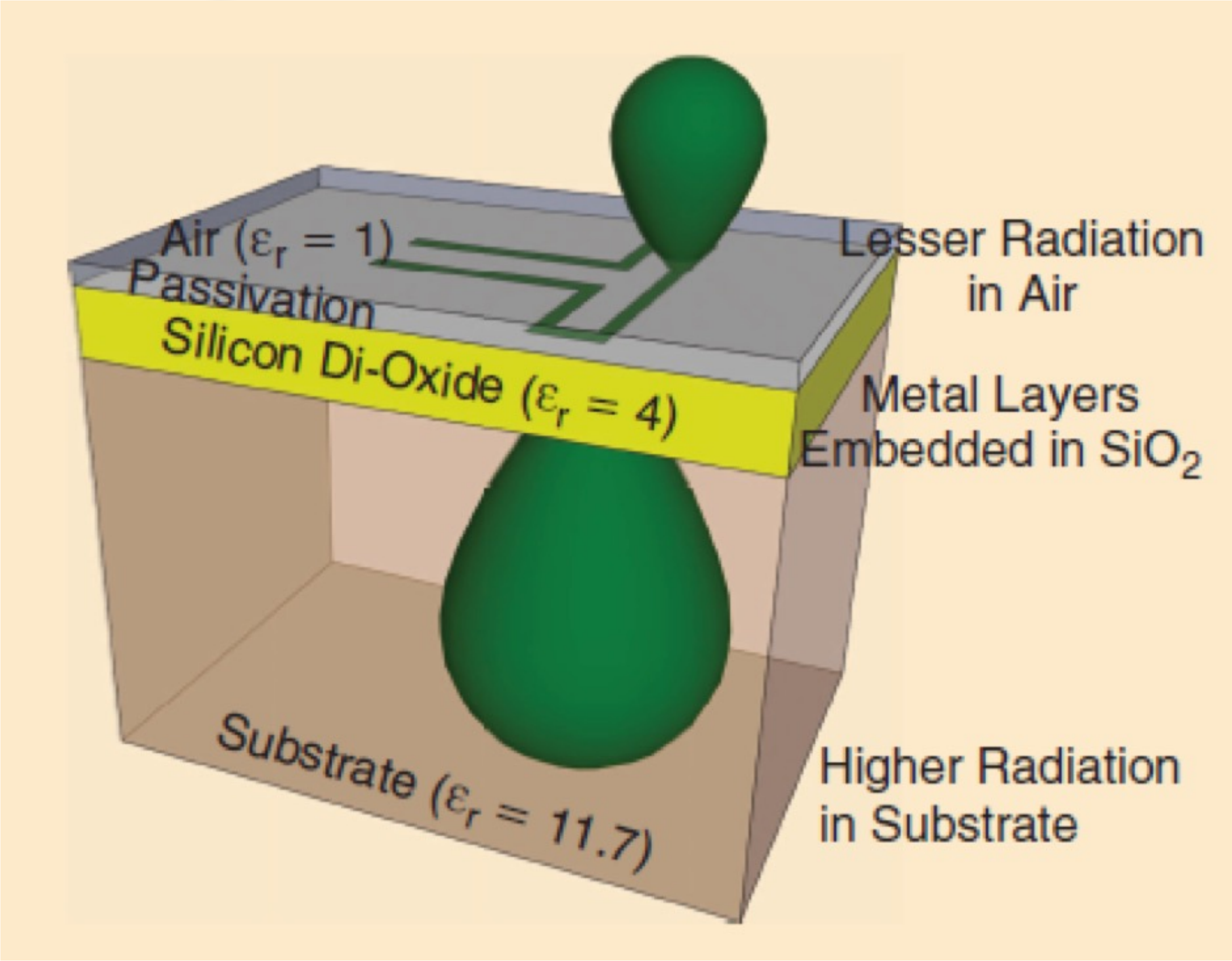
Integrated antennas

- The main impediment to build efficient AoC is the silicon substrate.
- Antennas are more efficient on a low permittivity and high resistivity substrate.
- CMOS ICs are based on a high permittivity and low resistivity substrate, completely the opposite!

Integrated antennas

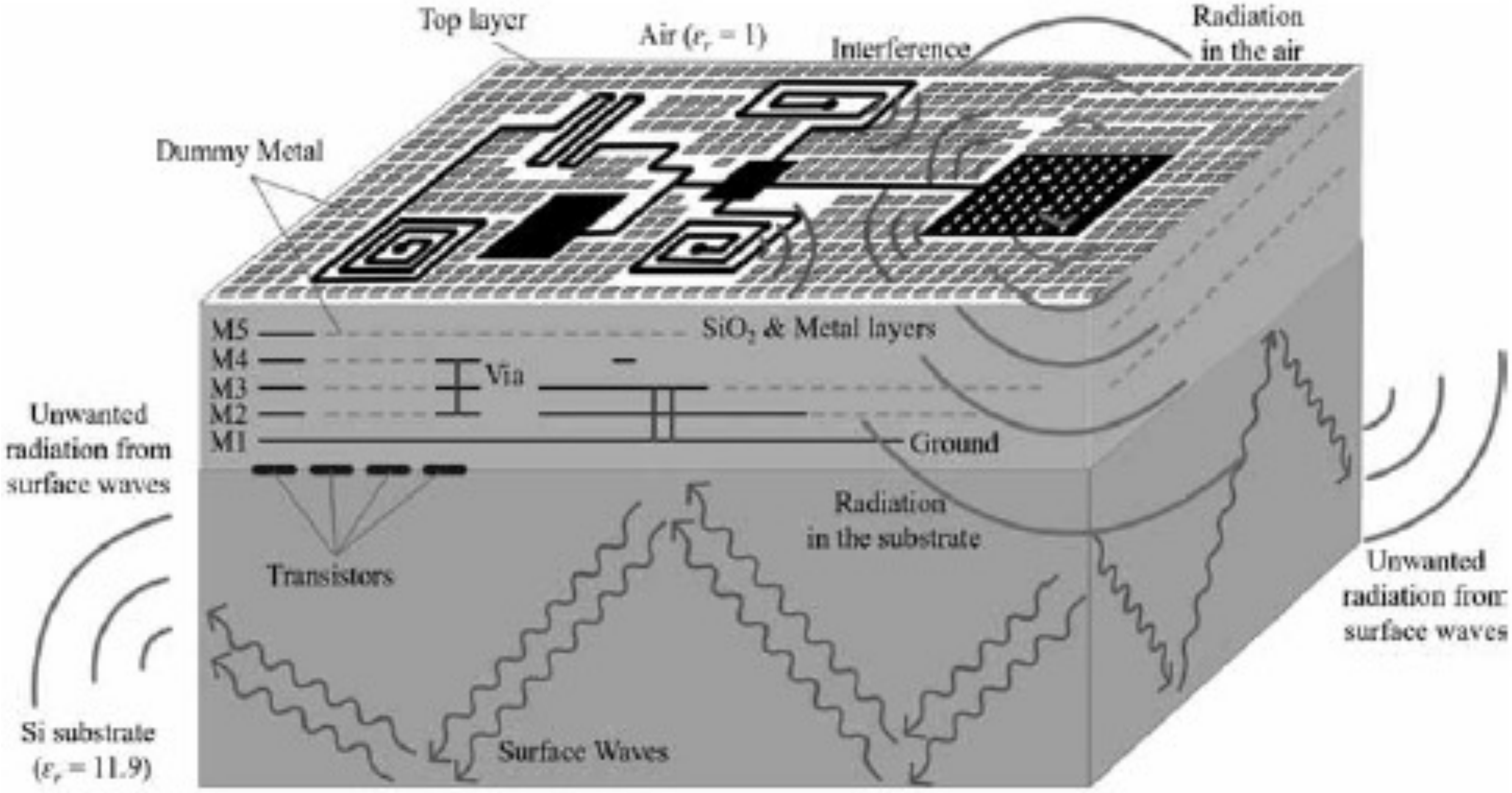
- Moreover, the wave radiated by the antenna can interfere with the circuit's performance — coupling, intermodulation, noise, etc.
- When designing AoC, the user has to be aware of this fact, in order to guarantee signal integrity.
- There are several ways to do so.

Integrated antennas



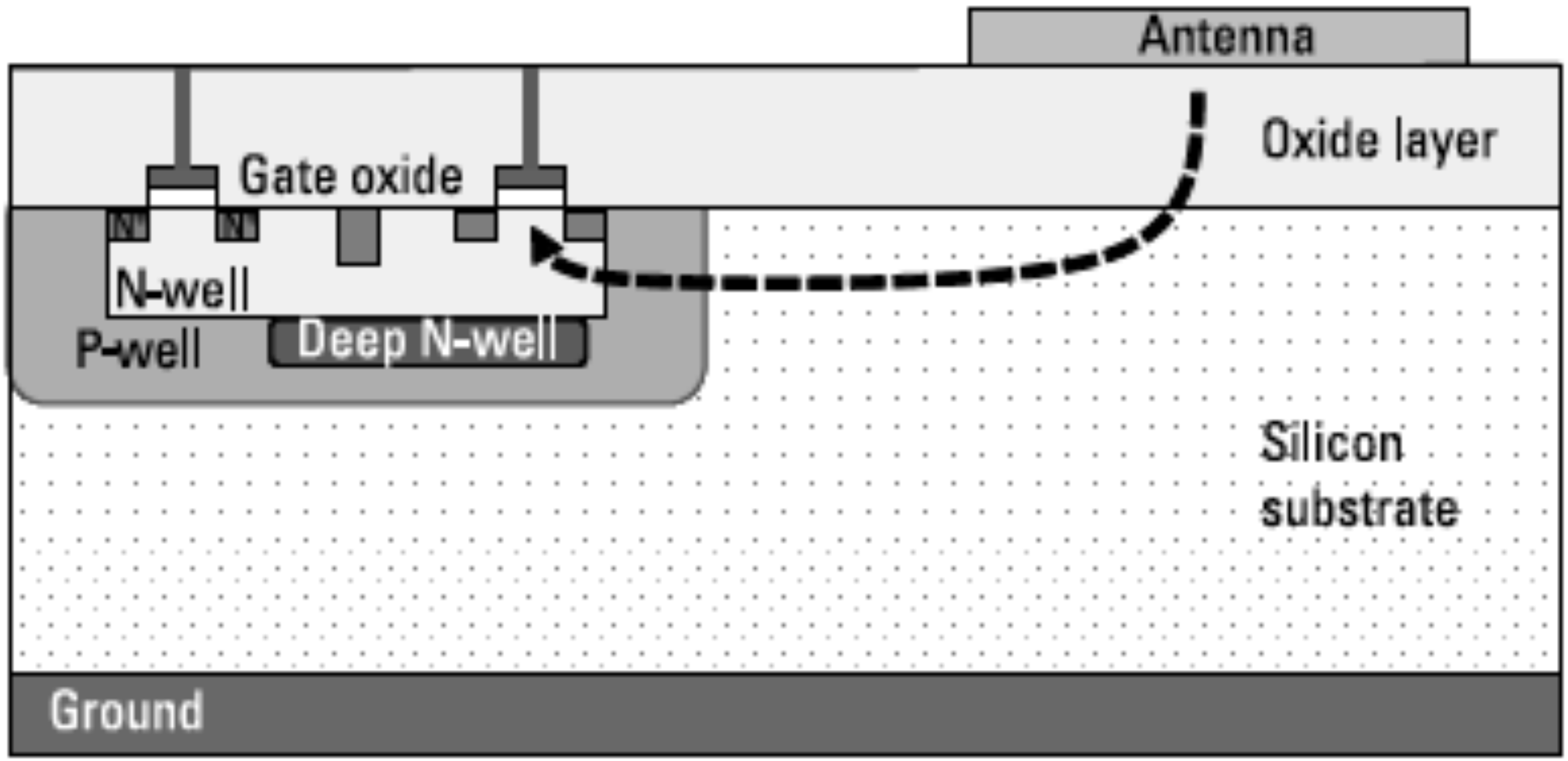
"The Last Barrier", H.M. Cheema, A. Shamin, IEEE Microwave Magazine, Jan/Feb 2013, pp. 79-91.

Integrated antennas



"Antenna-on-Chip, Design, Challenges and Opportunities", H.M. Cheema, F. Khalid, A. Shamin, Artech House, Massachussets, USA, 2021, ISBN 13: 978-1-60807-818-9.

Integrated antennas

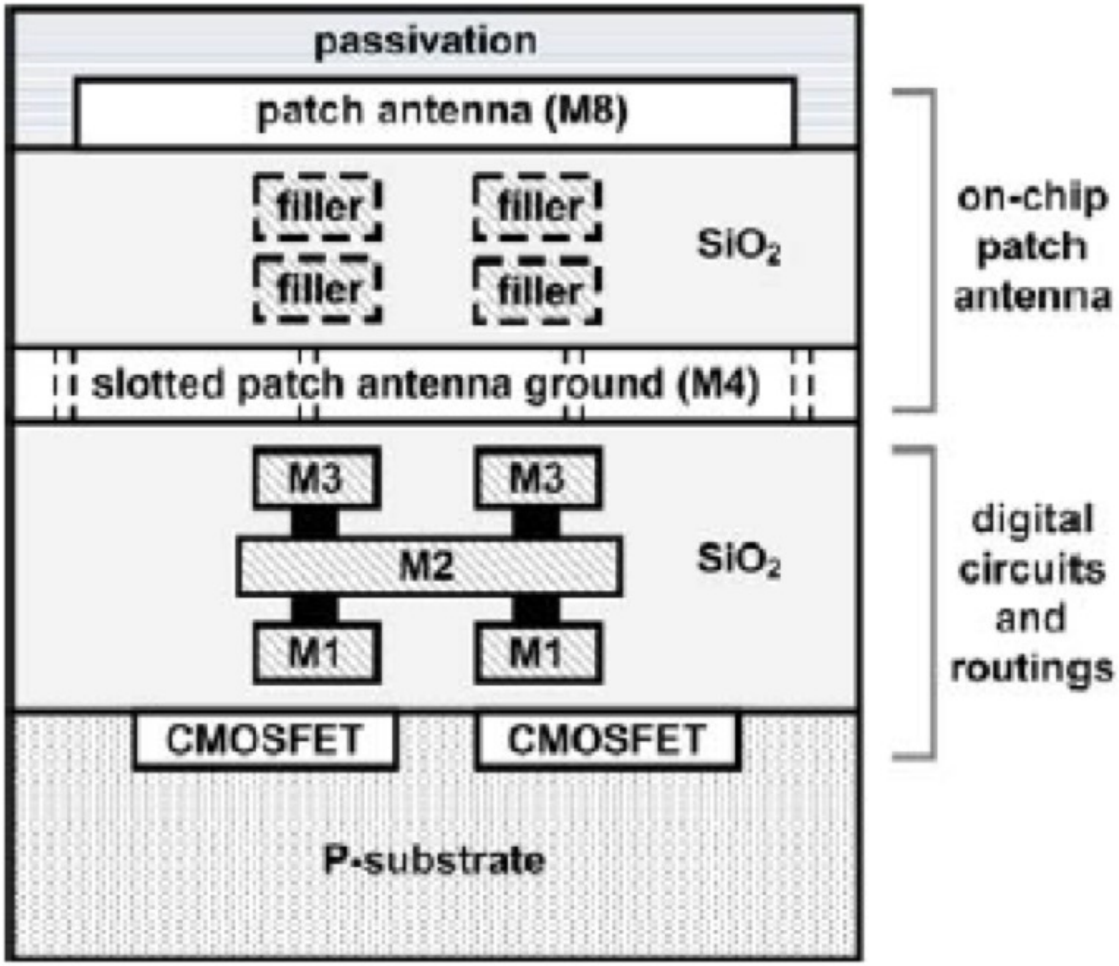


“Antenna-on-Chip, Design, Challenges and Opportunities”, H.M. Cheema, F. Khalid, A. Shamin, Artech House, Massachussets, USA, 2021, ISBN 13: 978-1-60807-818-9.

Integrated antennas

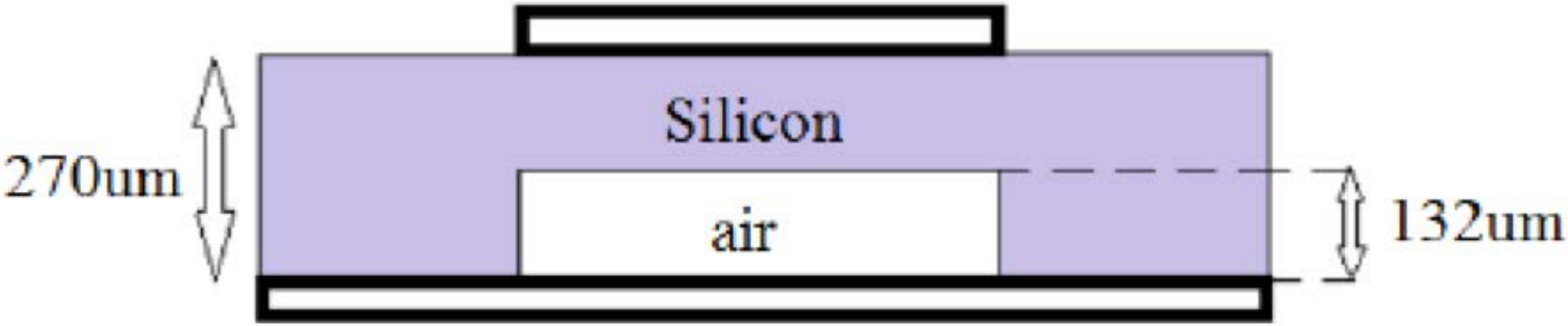
- Many techniques have been studied and exploited to overcome this limitation.
- They involve using:
  - higher-metal-level ground planes;
  - substrate micromachining;
  - high-resistivity regions of the substrate (compensated);
  - many other techniques.

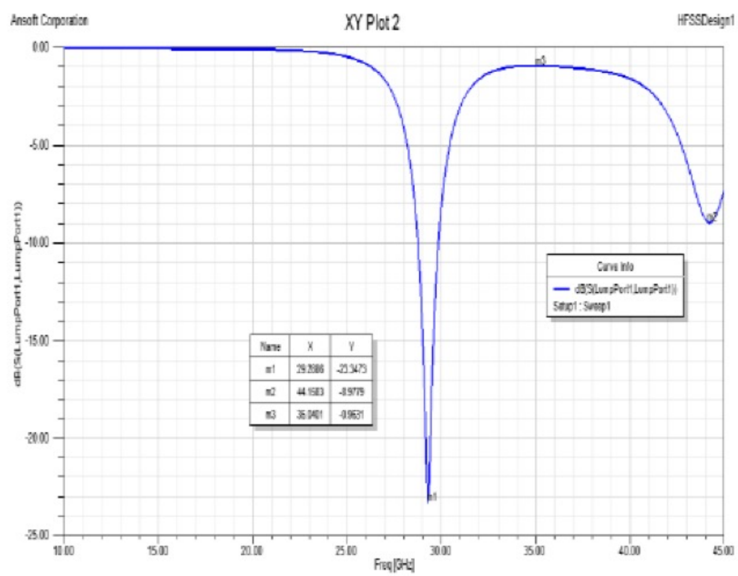
Higher-level ground plane



“60 GHz On-Chip Patch Antenna Integrated in a 0.13-µm CMOS Technology”, K.K. Huang, D.D. Wentzloff, 2010 International Conference on Ultra-Wideband, September 2010, pp.1-4.

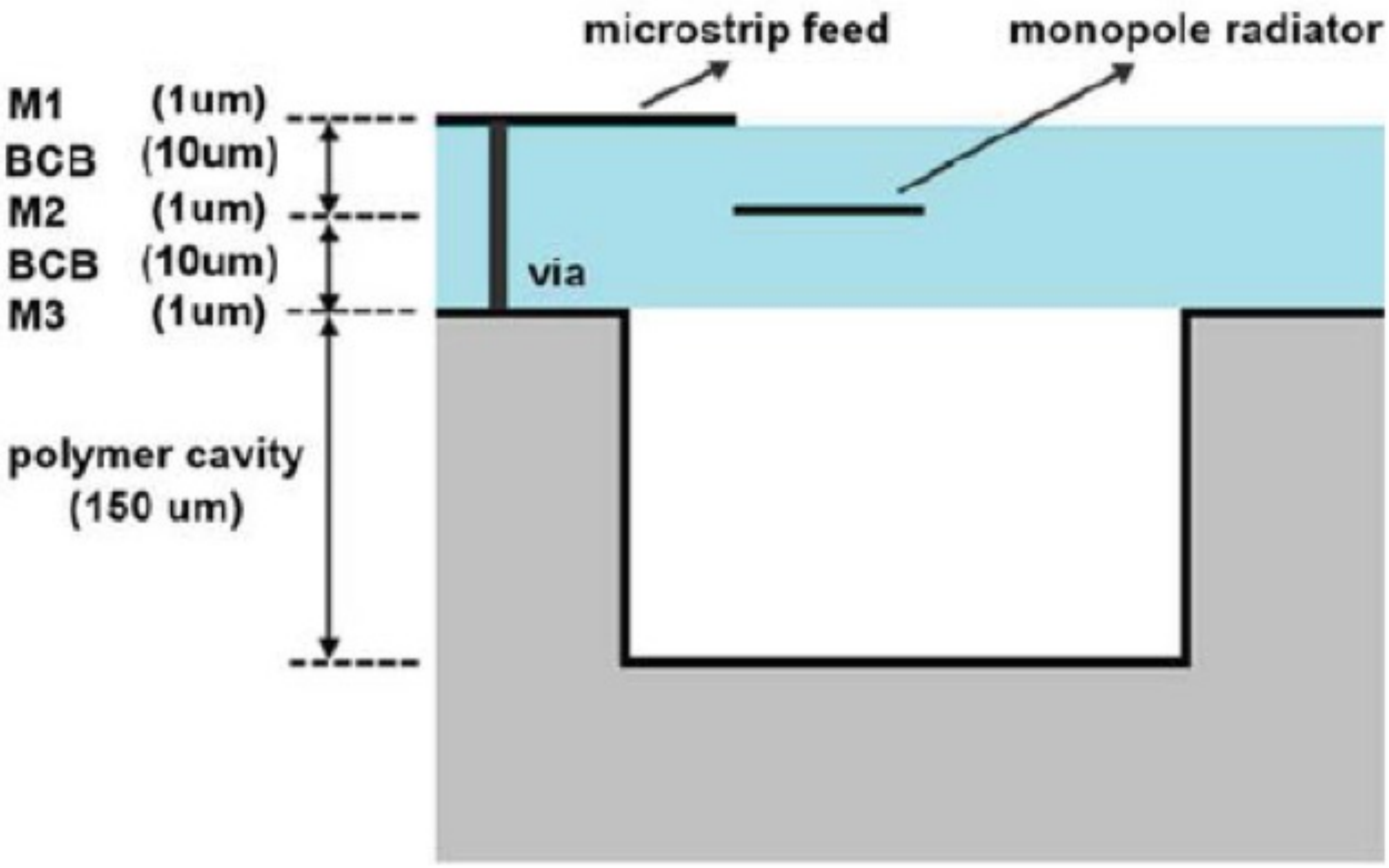
Micromachining





“Design Considerations for Integrated Antennas used in High-Frequency Applications”, L.K. Sandoval, R. Murphy, Proceedings of the XIX International Iberchip Workshop, February 2013, pp. 279-1 – 279-4.

Micromachining



"135-GHz Micromachined On-Chip Antenna and Antenna Array", H. Chu et al., IEEE Transactions on Antennas and Propagation, Vol. 60, No. 10, October 2012, pp. 4582-4588

High resistivity substrate

THIF-31

SI/SIGE HBT ACTIVE INTEGRATED ANTENNA ON HIGH RESISTIVITY SILICON SUBSTRATE

M. M. Kaleja[1], A. Grübl[1], F. X. Sinnesbichler[1,2], G. R. Olbrich[1], K. M. Strohm[3], J.–F. Luy[3], E.M. Biebl[1]

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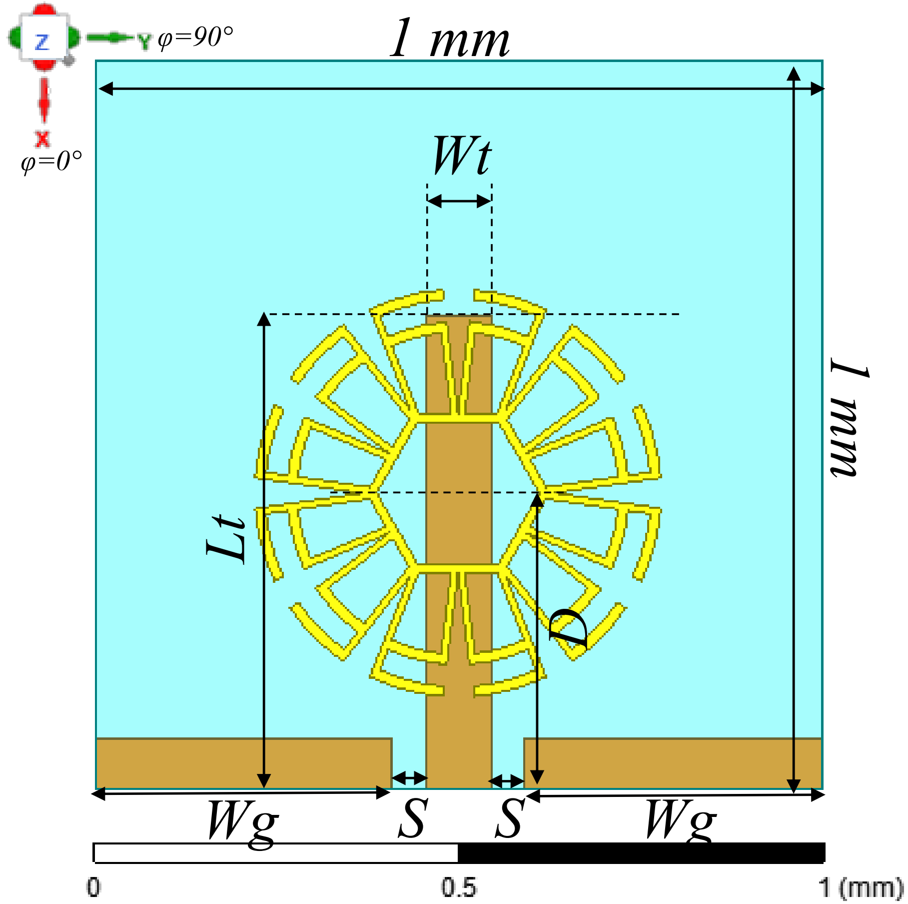
The triumphant advance of AIAs started with the usage of two-terminal elements as IMPATT diodes [2] that are nowadays more and more replaced by three-terminal elements like HEMTs [3] or, as presented in this paper, HBTs [4]. These transistors overcome the problem of the high power dissipation raised by two-terminal devices. This feature enlarges the usability for AIAs based on transistors to battery operated applications e. g. RFID systems [5].
To describe the transistor's behavior as precise as

High resistivity substrate

2022



(a)

“A novel metamaterial-based antenna for on-chip applications for the 72.5-81 GHz frequency range”, K. Olan, R. Murphy, Scientific Reports, Vol. 12, February 2022, pp. 1-9. DOI: 10.1038/s41598-022-05829-0

Ideas on
compact modeling
of integrated antennas

Compact modeling of AoC

- The World has a huge amount of wireless devices (51.11 billion expected in 2023; 75.44 by 2025).
- These have to be connected by antennas.
- Their circuits have to consume the lowest power possible.
- Their footprint must be small.

Compact modeling of AoC

- Hence, wireless devices require AoC.
- At the design level, it would be convenient to have good compact models for a host of antennas.
- These models could then be used during circuit simulation to assess the performance of the circuit.
- But there are some obstacles to achieve this in a reasonable way.

Compact modeling of AoC

- The main problem is the difference in criteria used for antenna design and circuit simulation.
- Antennas are judged with a set of parameters (figures of merit).
- Integrated circuits are designed with a different set of considerations.
- Most of the former parameters do not have a direct correlation with the latter.

Antenna figures of merit

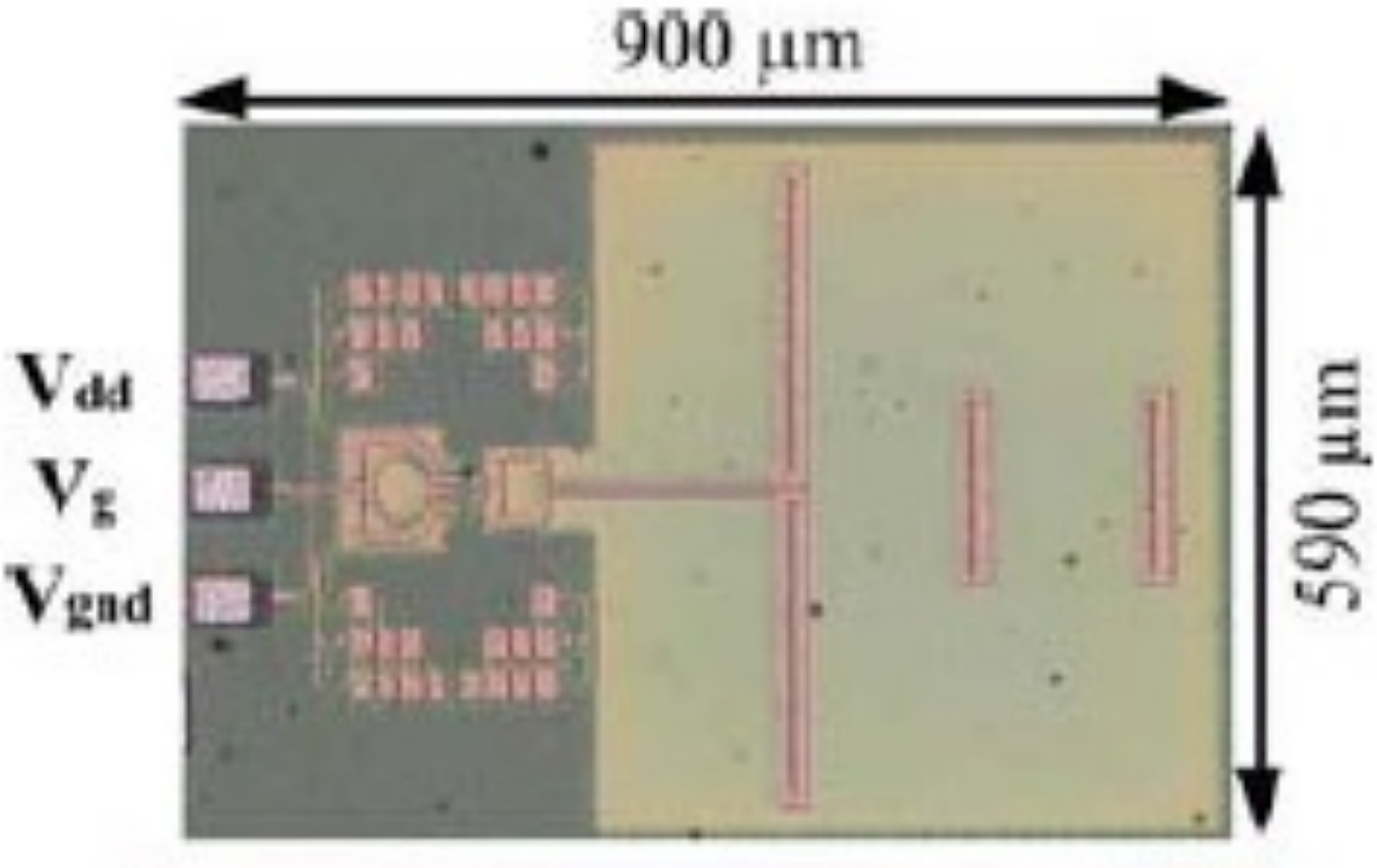
- Radiated power
- Directivity
- Gain
- Efficiency
- Radiation resistance
- Input impedance
- Bandwidth
- Return loss
- Insertion loss
- Polarization
- Co-polarization
- Cross-polarization
- Axial ratio
- Secondary lobes
- Front/Back ratio

Some Efforts Toward the Modeling of Integrated Antennas

Compact modeling of AoC

- Many papers on AoC have been published in the past two decades.
- These mostly highlight the successful integration of the antenna on a chip.
- The frequency range attained on a CMOS process is up to several hundreds of GHz.
- But most articles avoid deriving or presenting a model for the antenna.

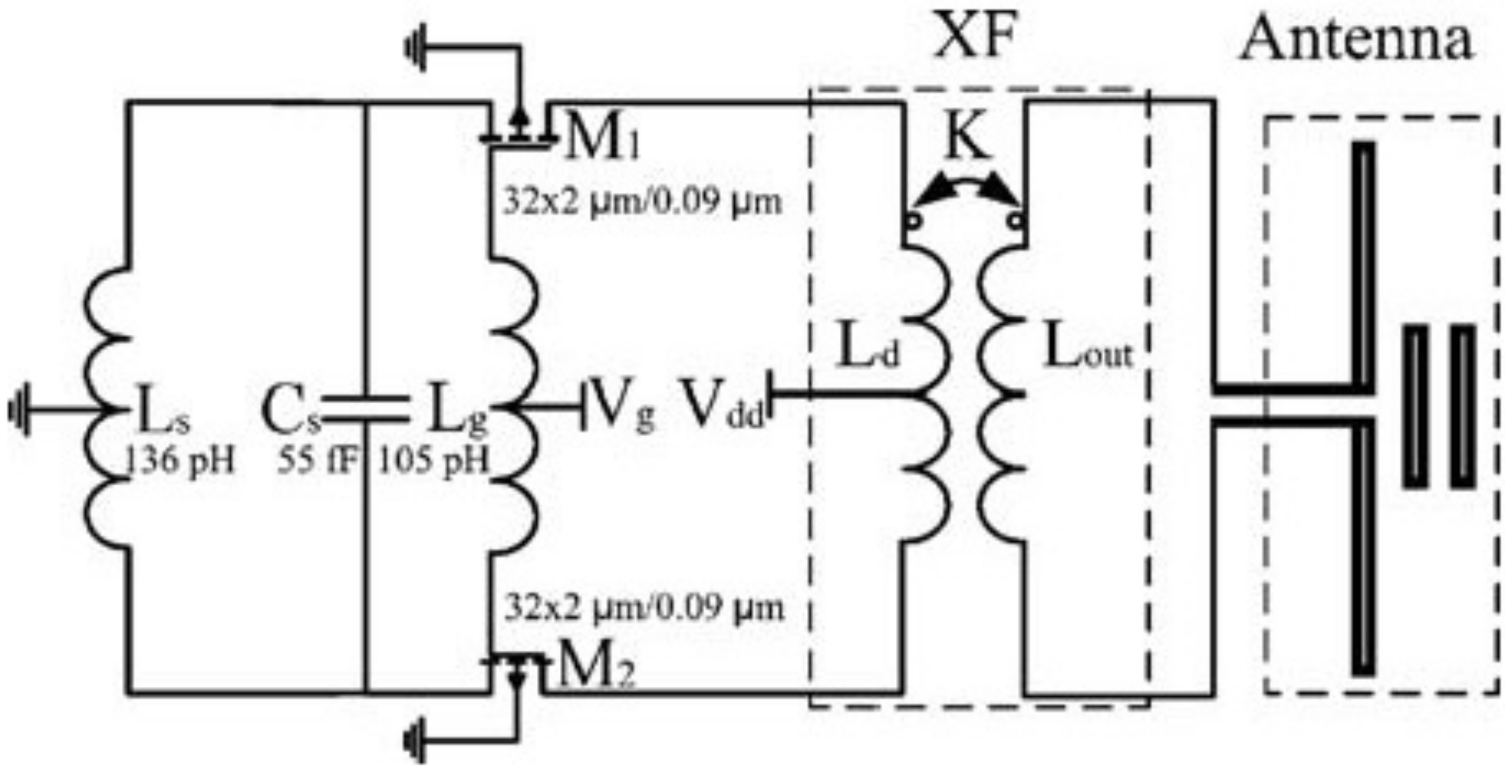
One example:



217 GHz
90 nm CMOS
EIRP=+1.8dBm
BW=17 GHz
(210 GHz to 227 GHz)

"A 210-227 GHz Transmitter With Integrated On-Chip Antenna in 90 nm CMOS Technology", B. Khamaisi et al., IEEE Transactions on Terahertz Science and Technology, Vol. 3, No. 2, March **2013**, pp. 141-147. DOI: 10.1109/TTHZ.2012.2236836

No model for the antenna!



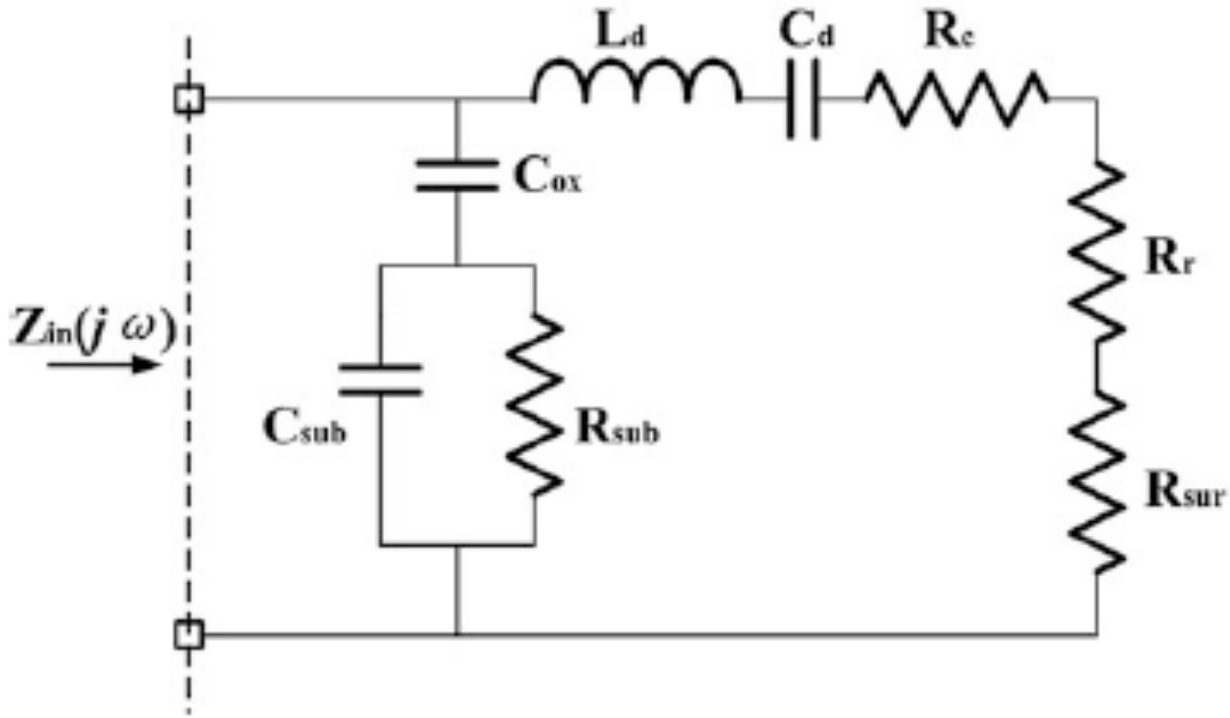
"A 210-227 GHz Transmitter With Integrated On-Chip Antenna in 90 nm CMOS Technology", B. Khamaisi et al., IEEE Transactions on Terahertz Science and Technology, Vol. 3, No. 2, March **2013**, pp. 141-147. DOI: 10.1109/TTHZ.2012.2236836

Compact modeling of AoC

- I have found very few papers which include a SPICE-compatible model for an AoC.
- Most deal with the figures-of-merit outlined before.
- There is no doubt that the task is enormous, but it is also fundamental.
- A few examples are given in the next slides.

Basic model for a dipole AoC

2009



$$Z_{in}(j\omega) = \frac{1 - \omega^2(C_d C_s R_d R_s + C_d L_d)] + j\{\omega[(C_d R_d + C_s R_s(1 - \omega^2 C_d L_d))]\}}{[-\omega^2 C_d C_s(R_d + R_s)] + j[\omega(C_d + C_s - \omega^2 C_d C_s L_d)]}$$

"Antenna-on-Chip and Antenna-in-Package Solutions to Highly Integrated Millimeter-Wave Devices for Wireless Communications", Y.P. Zhang, D. Liu, IEEE Transactions on Antennas and Propagation, Vol. 57, No. 10, October 2009, pp. 2830-2841. DOI: 10.1109/TAP.2009.2029295

Basic model for a dipole AoC

The exact same model appears also in:

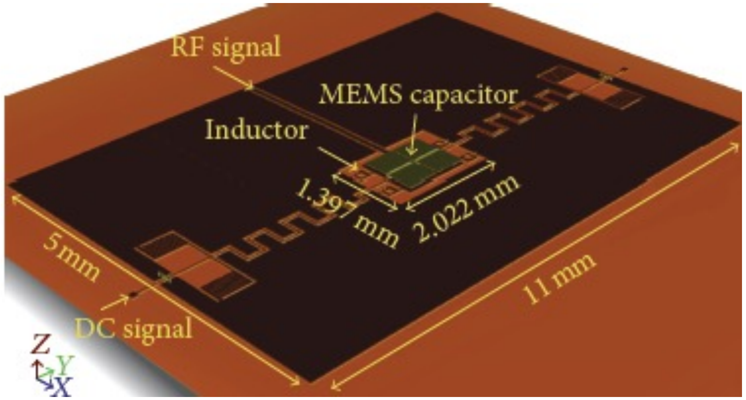
“60GHz Integrated On-chip Antenna on Silicon for High Speed Applications”, D.B. Bereka, Doctoral Dissertation, University of Minnesota, July **2015.**

“On-Chip Antennas”, T. Deng Y.P. Zhang, Chapter in book “Handbook of Antenna Technologies”, Edited by Z.N. Chen, Springer Singapore, ISBN 978-981-4560-44-3, September **2016.**

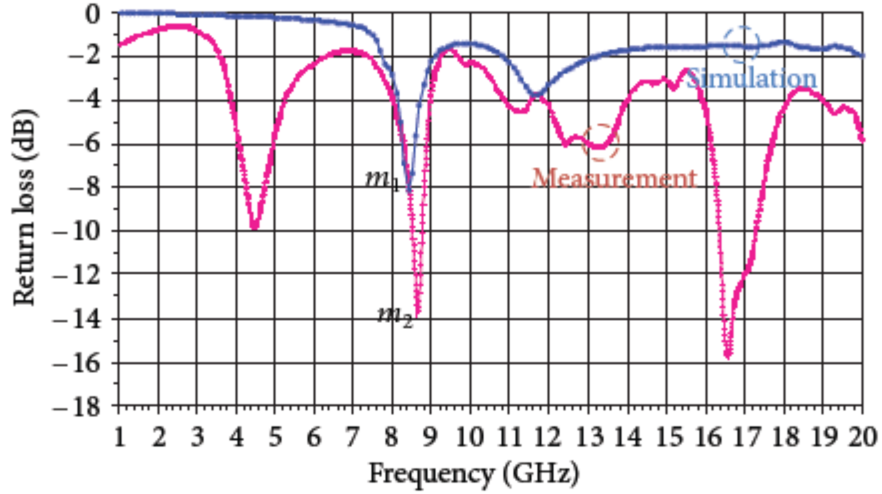
Work done at INAOE

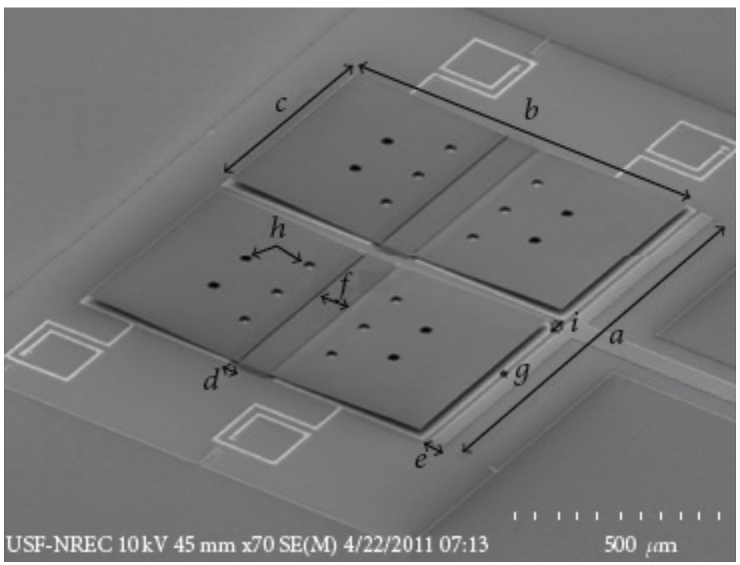
1.- Small Antenna based on MEMS and Metamaterial Properties for Reconfigurable Applications

AoC using MEMs / Metamaterials



2010-2012

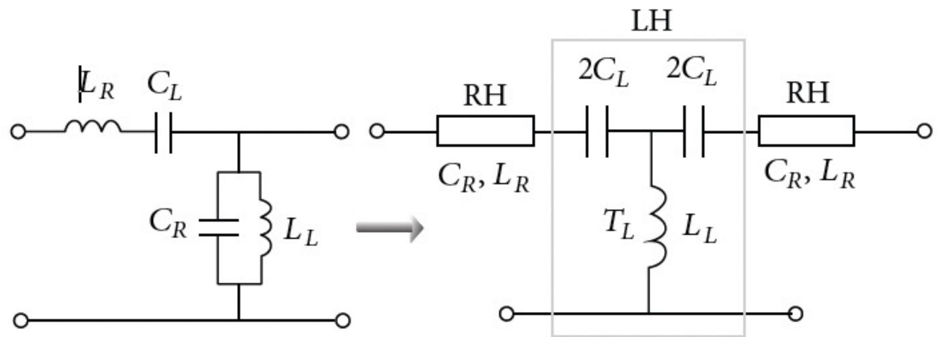




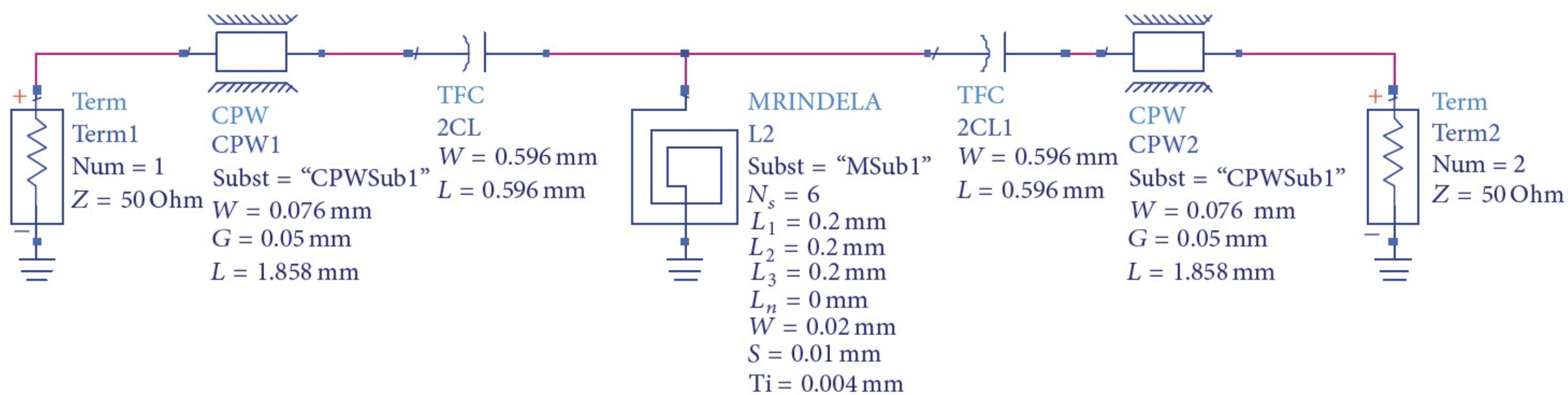
Antenna size is 1.4 mm≈λ/25 (@8.5GHz)

“Small Antenna based on MEMS and Metamaterial Properties for Reconfigurable Applications”, G. Rosas, R. Murphy, W. Moreno, International Journal of Antennas and Propagation, Vol. 2013, January 2013, pp. 1-10.

AoC using MEMs / Metamaterials



Model for the metamaterial cell



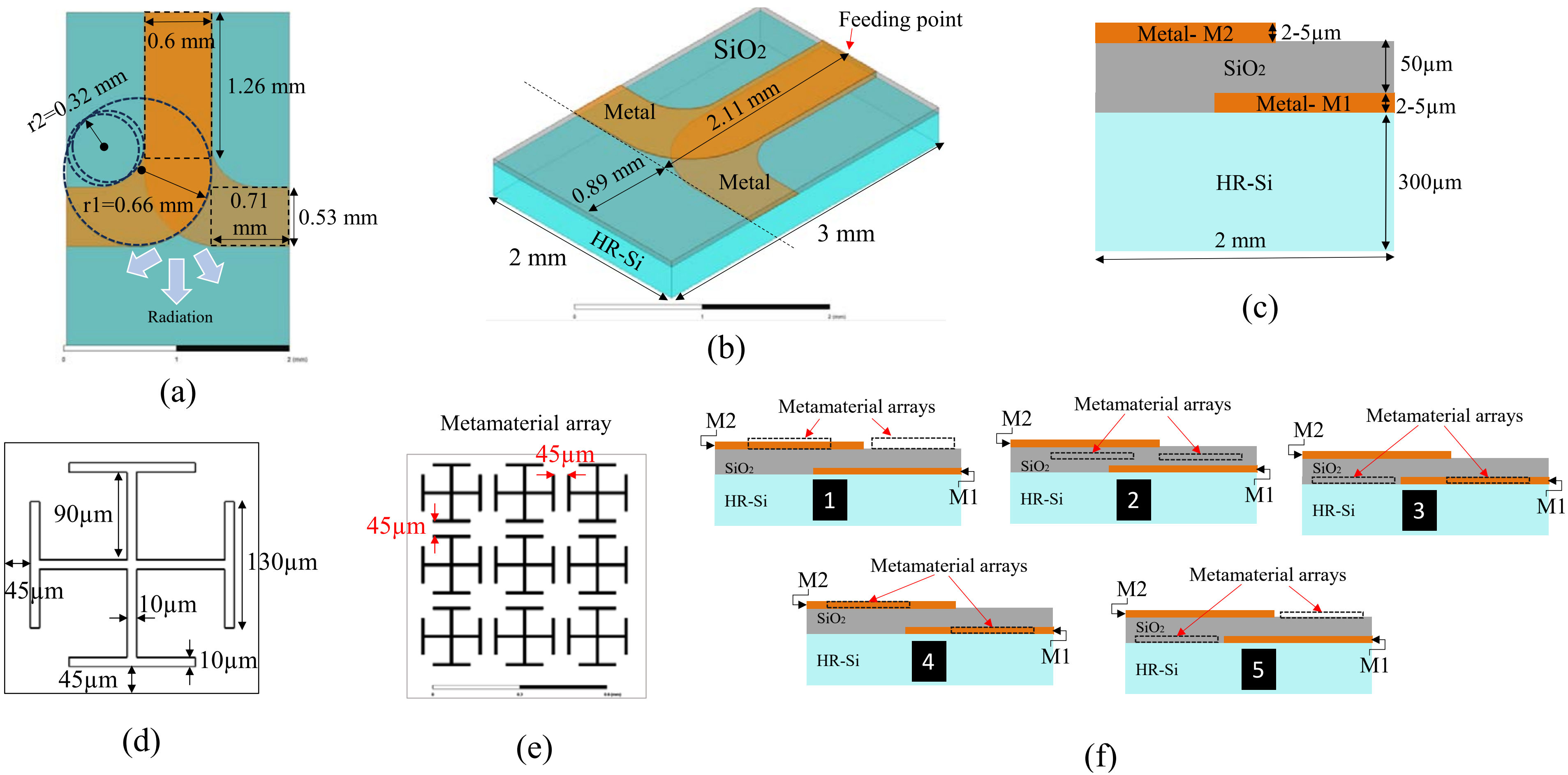
Complete model for the antenna using ADS

"Small Antenna based on MEMS and Metamaterial Properties for Reconfigurable Applications", G. Rosas, R. Murphy, W. Moreno, International Journal of Antennas and Propagation, Vol. 2013, January 2013, pp. 1-10.

Work done at INAOE

2.- Loaded Vivaldi antipodal antenna for E-band applications using metamaterials

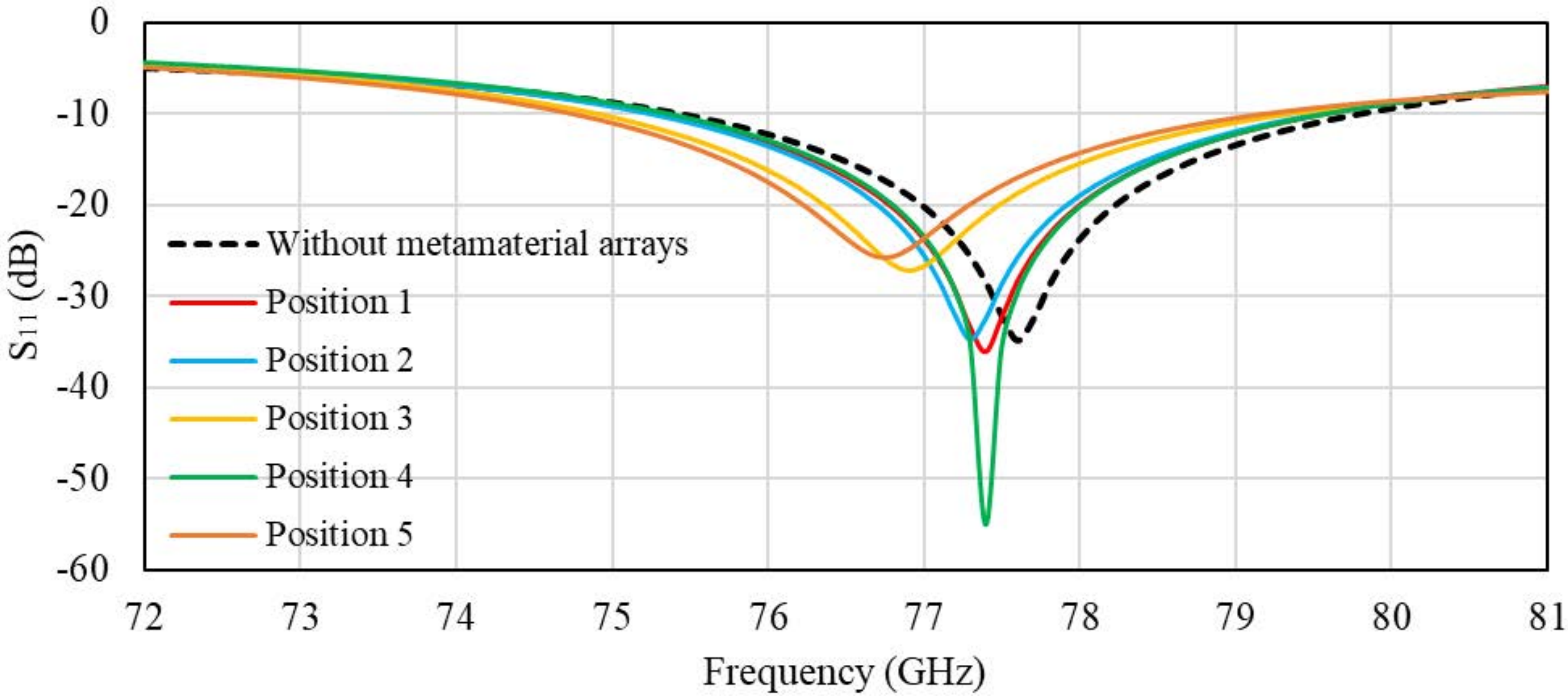
74 GHz—80 GHz AoC 2022



“Metamaterial-Based Antennas for On-Chip Applications in the Millimeter-Wave Range”, K. Olan, R. Murphy, Proceedings of the 2022 IEEE Ap-s/URSI Conference, Denver, CO, USA, July 10-15, 2022, pp. 1016-1017. DOI:10.1109/AP-S/USNC-URSI47032.2022.9886267

74 GHz—80 GHz AoC

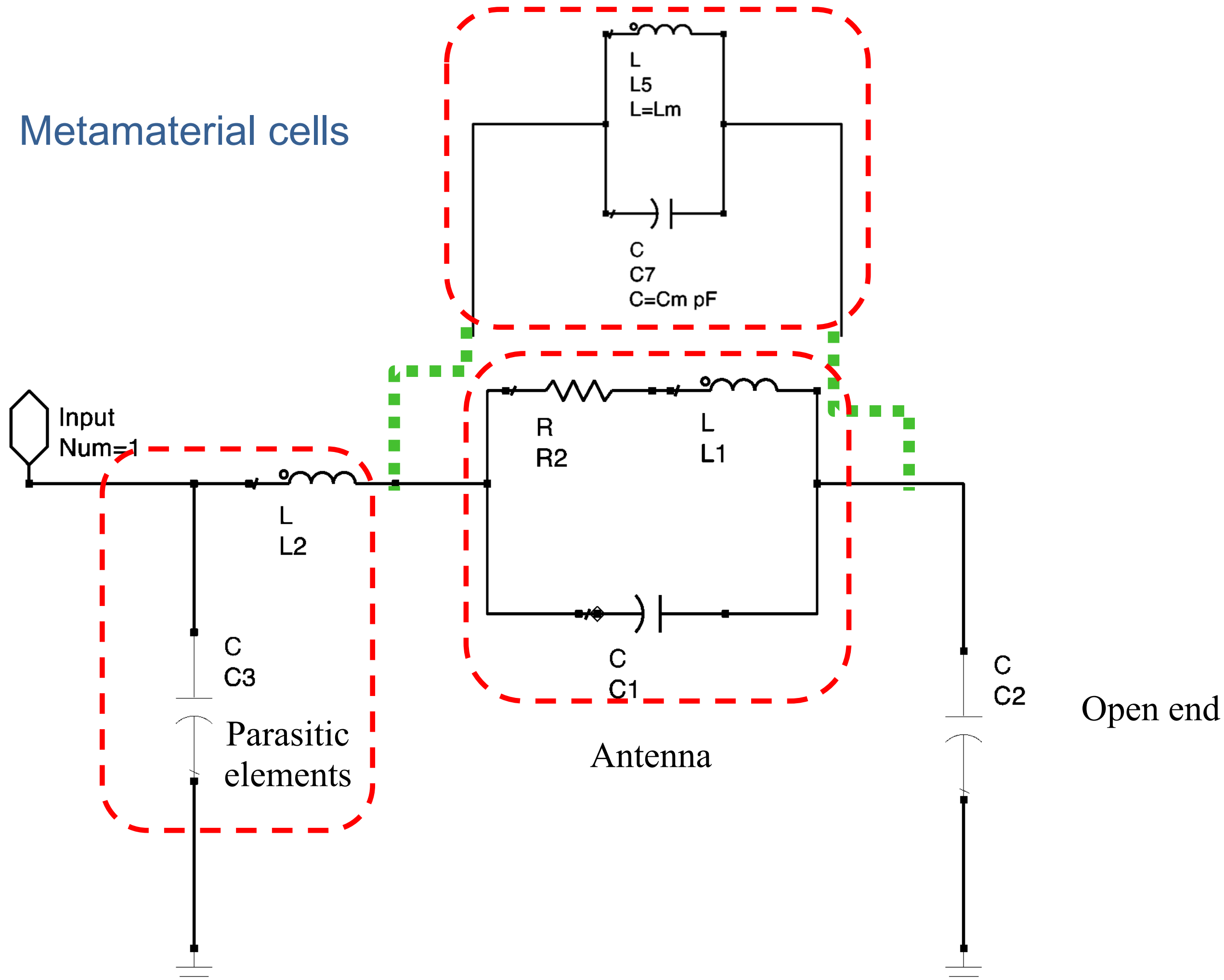
2022



“Metamaterial-Based Antennas for On-Chip Applications in the Millimeter-Wave Range”, K. Olan, R. Murphy, Proceedings of the 2022 IEEE Ap-s/URSI Conference, Denver, CO, USA, July 10-15, 2022, pp. 1016-1017. DOI:10.1109/AP-S/USNC-URSI47032.2022.9886267

74 GHz—80 GHz AoC

2022



"Metamaterial-Based Antennas for On-Chip Applications in the Millimeter-Wave Range", K. Olan, R. Murphy, Proceedings of the 2022 IEEE Ap-s/URSI Conference, Denver, CO, USA, July 10-15, 2022, pp. 1016-1017. DOI:10.1109/AP-S/USNC-URSI47032.2022.9886267

74 GHz—80 GHz AoC

2022

Param	Value	Param	Value
L2	0.21 fH	L1	1.397 pH
C3	0.0324 pF	C1	0.2654 pF
R2	0.637 Ω	C2	0.1571 pF

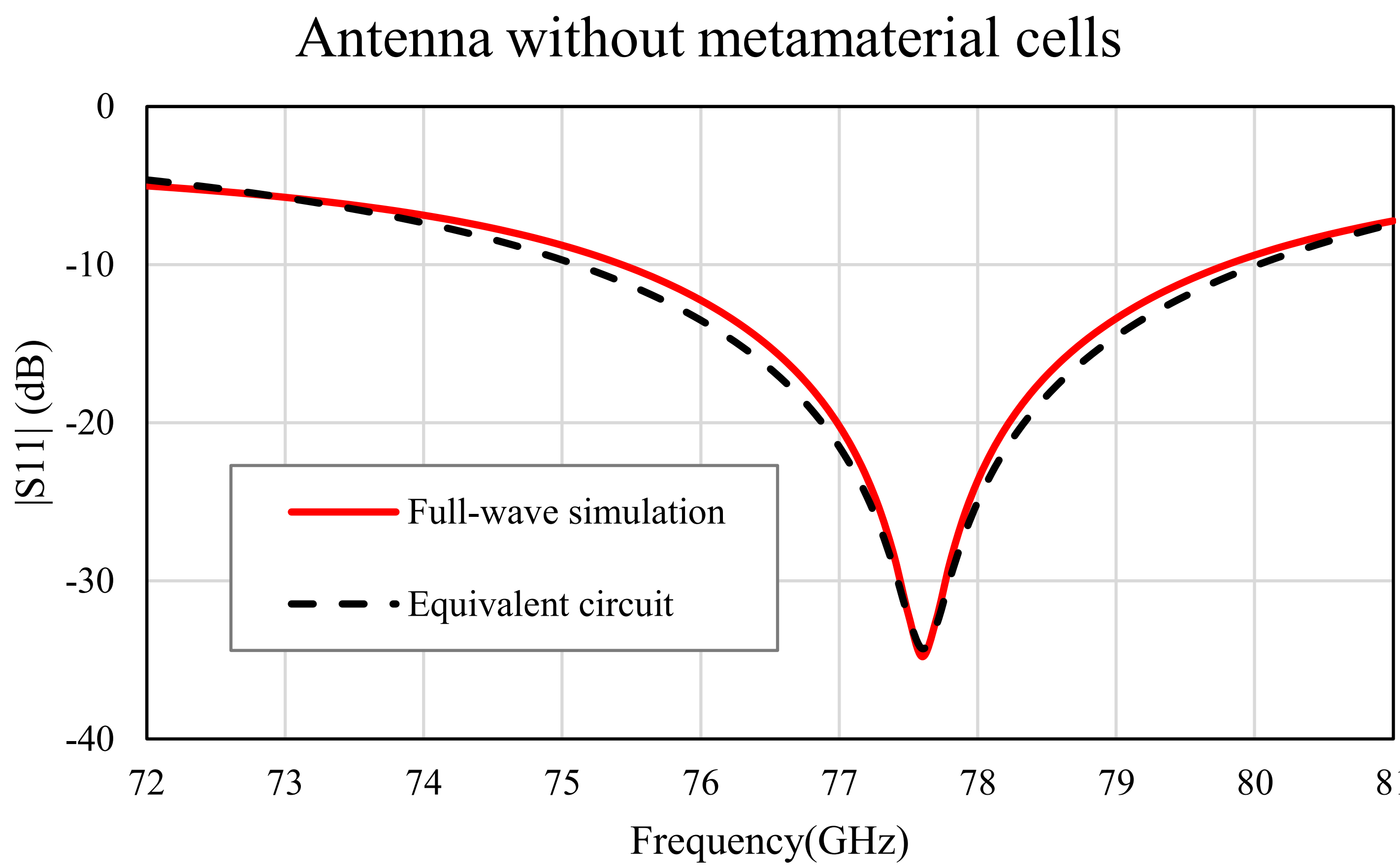
Param	Position 1	Position 2	Position 3	Position 4	Position 5
Lm	0.2232 nH	0.2232 nH	0.2232 nH	0.2232 nH	0.2232 nH
Cm	0.00155 pF	0.00225 pF	0.024505 pF	0.0015 pF	0.0063 pF

"Cm" controls the displacement of the resonant central frequency.

"Metamaterial-Based Antennas for On-Chip Applications in the Millimeter-Wave Range", K. Olan, R. Murphy, Proceedings of the 2022 IEEE Ap-s/URSI Conference, Denver, CO, USA, July 10-15, 2022, pp. 1016-1017. DOI:10.1109/AP-S/USNC-URSI47032.2022.9886267

74 GHz—80 GHz AoC

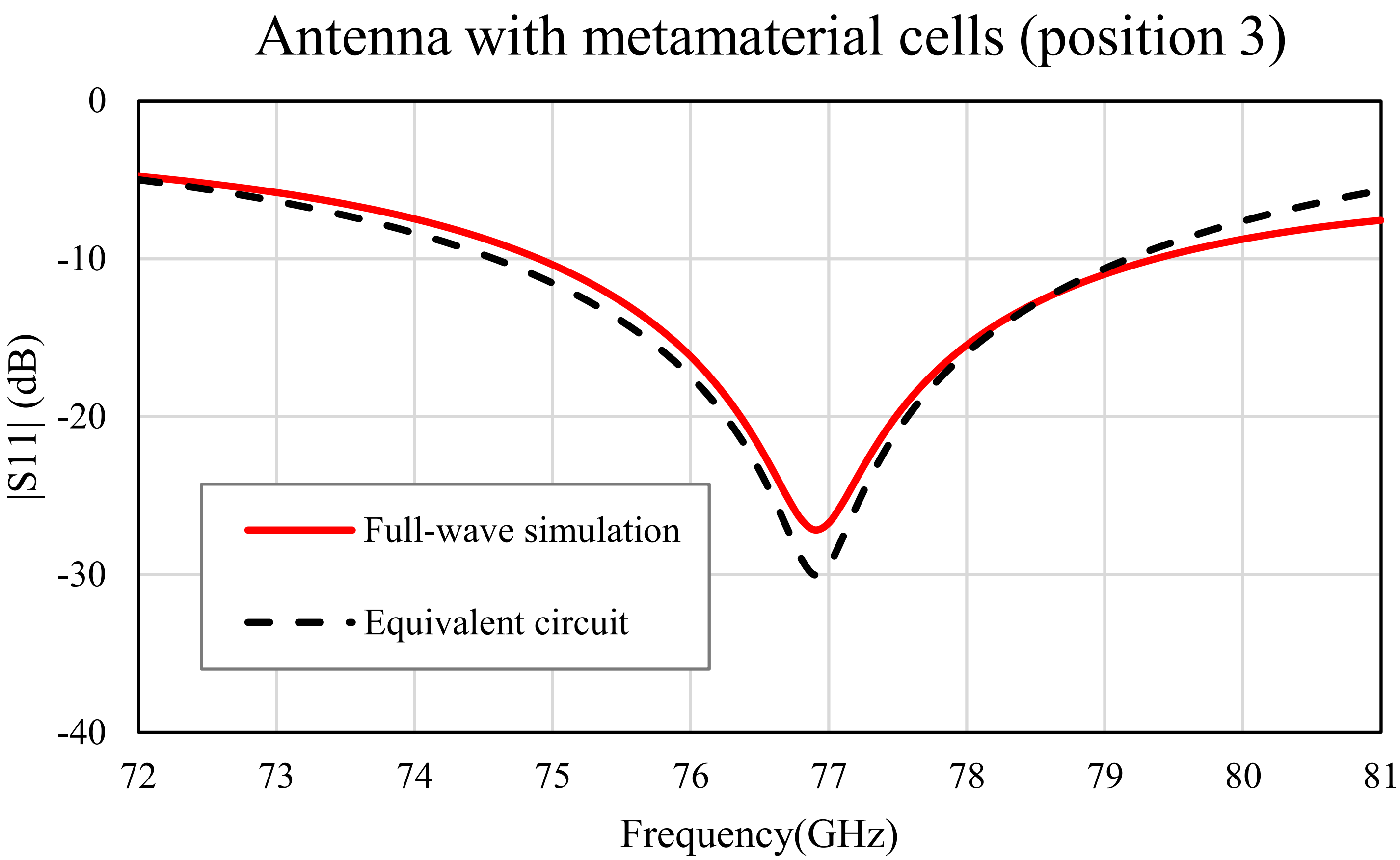
2022



Lm=0; Cm=0

“Metamaterial-Based Antennas for On-Chip Applications in the Millimeter-Wave Range”, K. Olan, R. Murphy, Proceedings of the 2022 IEEE Ap-s/URSI Conference, Denver, CO, USA, July 10-15, 2022, pp. 1016-1017. DOI:10.1109/AP-S/USNC-URSI47032.2022.9886267

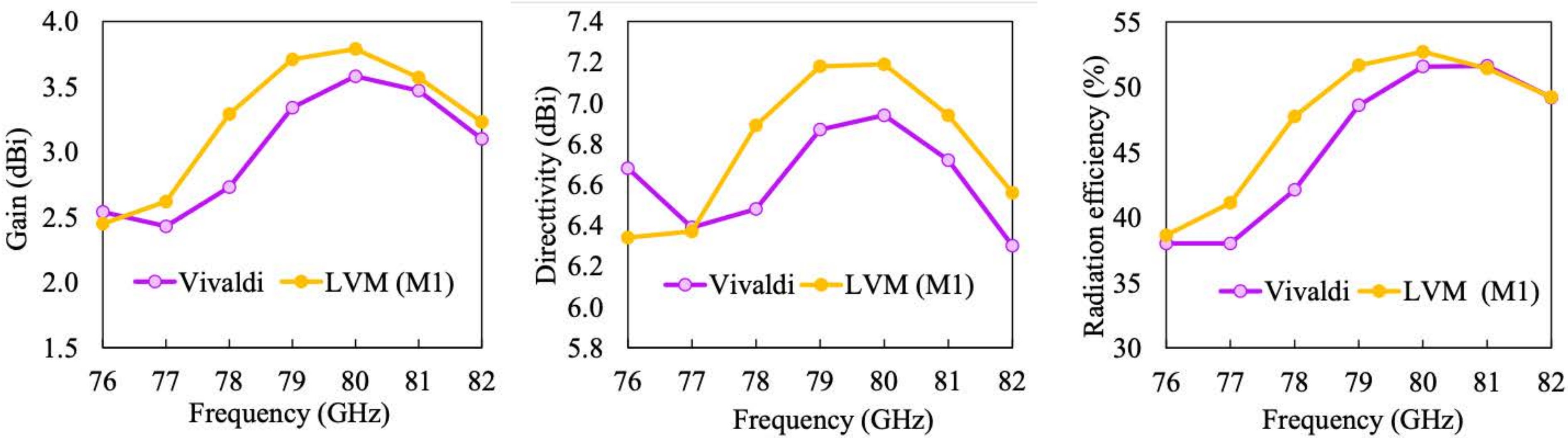
74 GHz—80 GHz AoC 2022



"Metamaterial-Based Antennas for On-Chip Applications in the Millimeter-Wave Range", K. Olan, R. Murphy, Proceedings of the 2022 IEEE Ap-s/URSI Conference, Denver, CO, USA, July 10-15, 2022, pp. 1016-1017. DOI:10.1109/AP-S/USNC-URSI47032.2022.9886267

74 GHz—80 GHz AoC

2022



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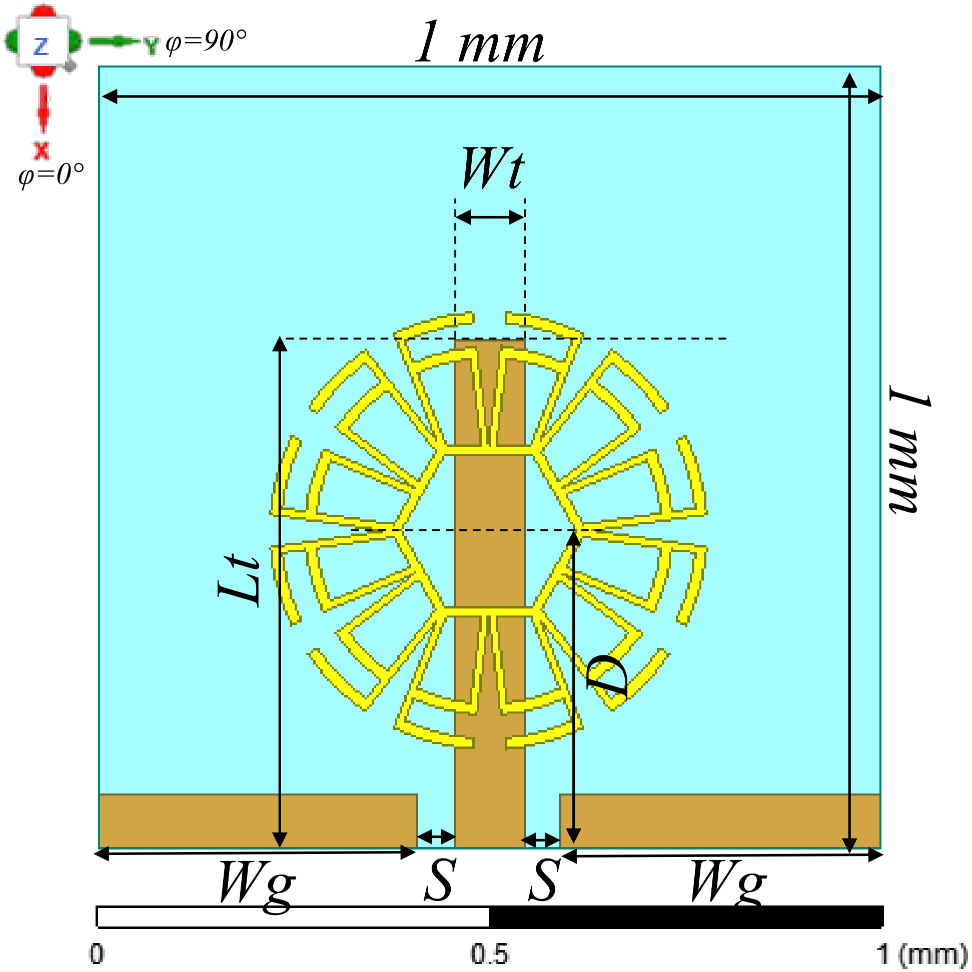
Work done at INAOE

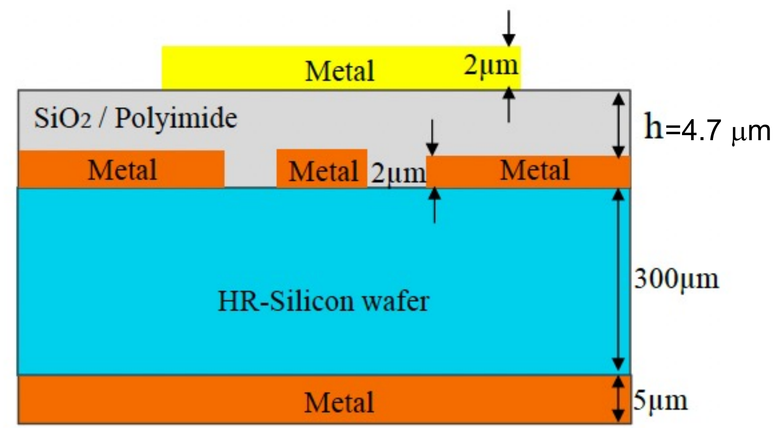
3.- Metamaterial-based antenna for on-chip applications for the 72.5-81 GHz frequency range

72.5 GHz—81 GHz AoC

2021-2023

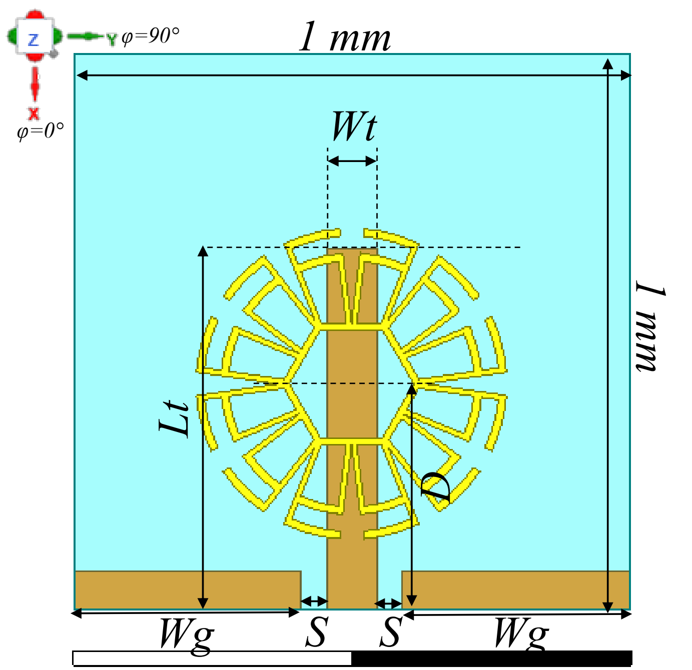


(a)

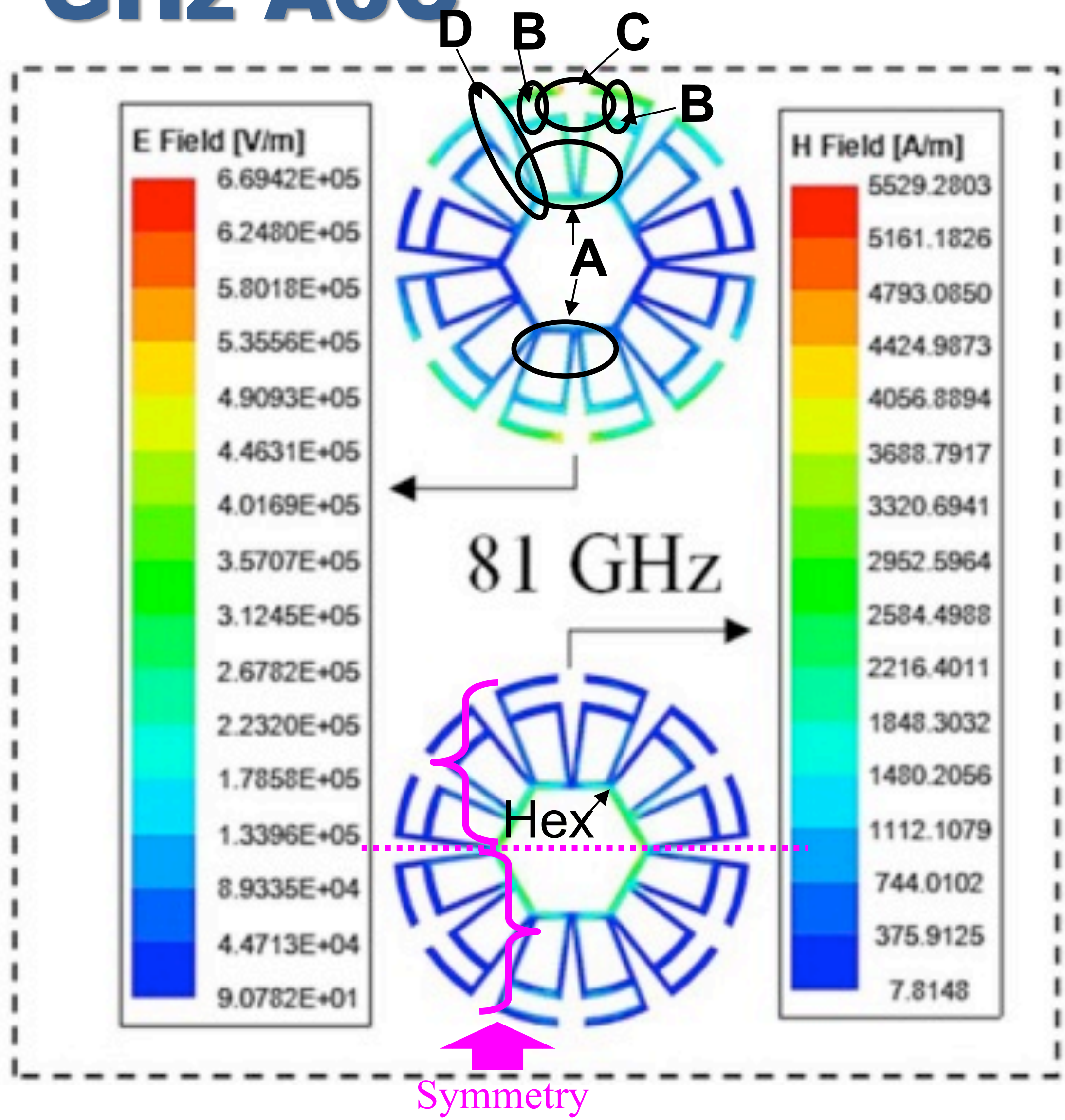


“A novel metamaterial-based antenna for on-chip applications for the 72.5-81 GHz frequency range”, K. Olan, R. Murphy, Scientific Reports, Vol. 12, February **2022**, pp. 1-9. DOI: 10.1038/s41598-022-05829-0

72.5 GHz—81 GHz AoC

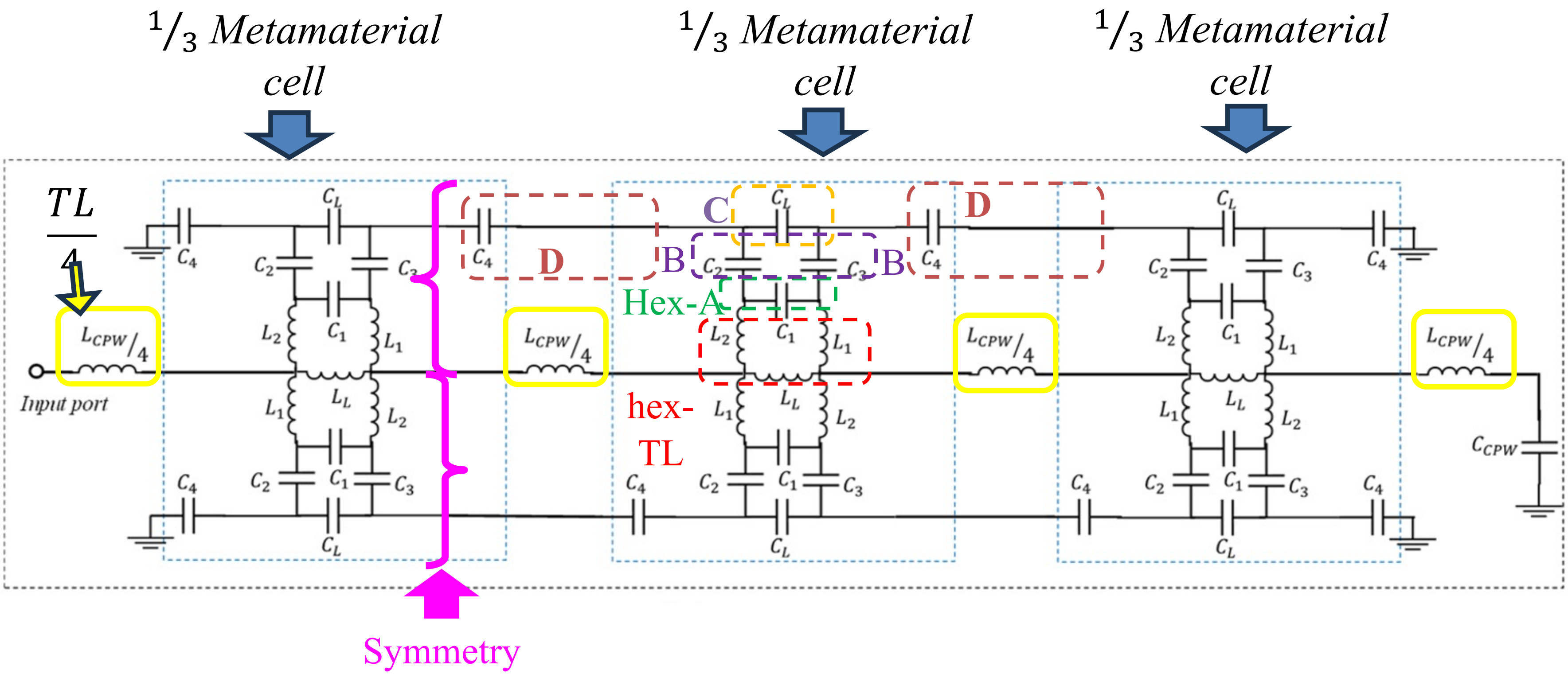


(a)



"A novel metamaterial-based antenna for on-chip applications for the 72.5-81 GHz frequency range", K. Olan, R. Murphy, Scientific Reports, Vol. 12, February **2022**, pp. 1-9. DOI: 10.1038/s41598-022-05829-0

72.5 GHz—81 GHz AoC



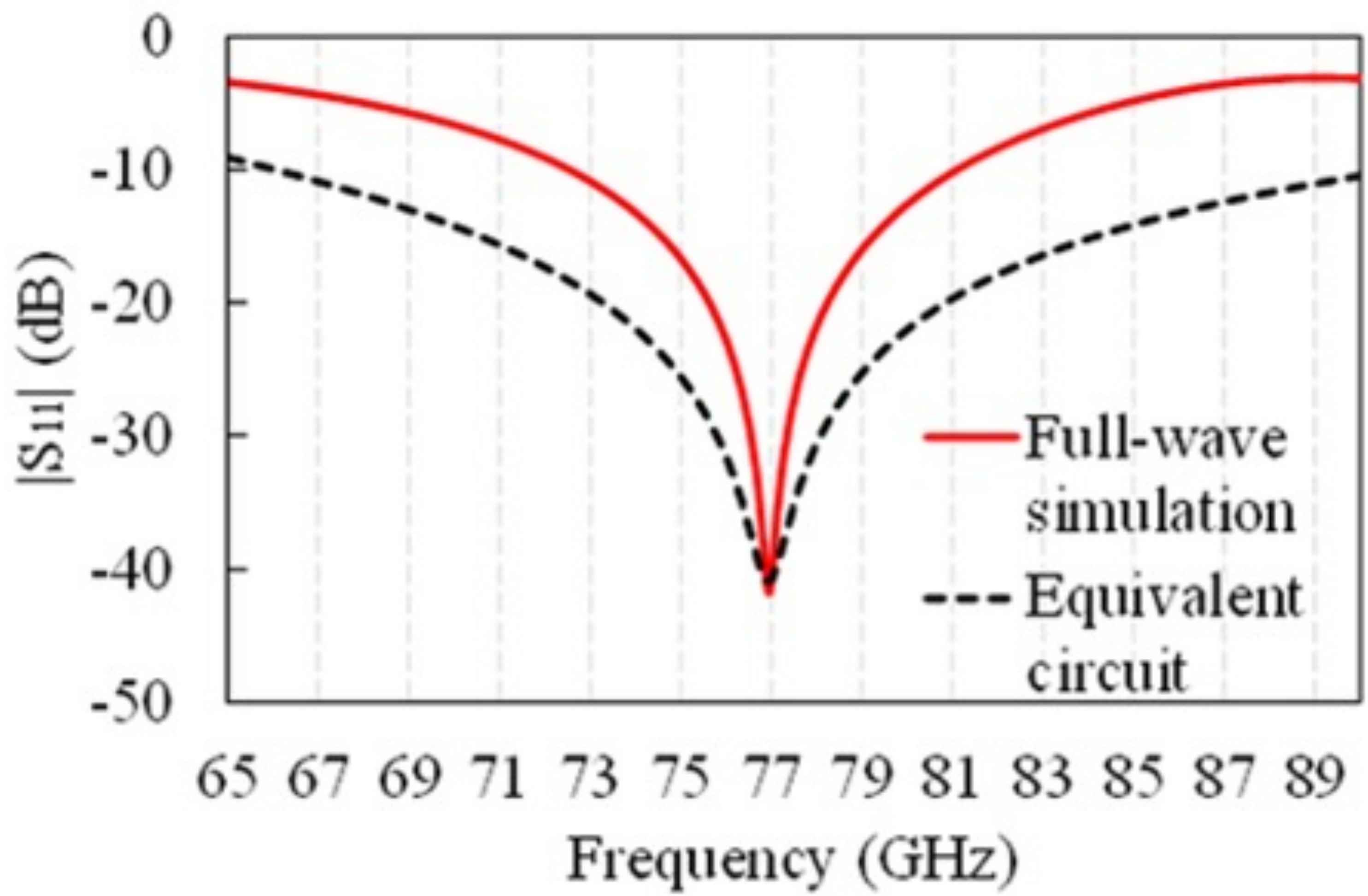
"A novel metamaterial-based antenna for on-chip applications for the 72.5-81 GHz frequency range", K. Olan, R. Murphy, Scientific Reports, Vol. 12, February **2022**, pp. 1-9. DOI: 10.1038/s41598-022-05829-0

72.5 GHz—81 GHz AoC

Param	Value	Param	Value
L_L	1.56 pH	$C_2 = C_3$	66 pF
C_L	2.53 pF	C_4	0.1 fF
$L_1 = L_2$	10.1 fH	C_{cpw}	24.8 fF
C_1	20 fF	$L_{cpw}/4$	44.45 pH

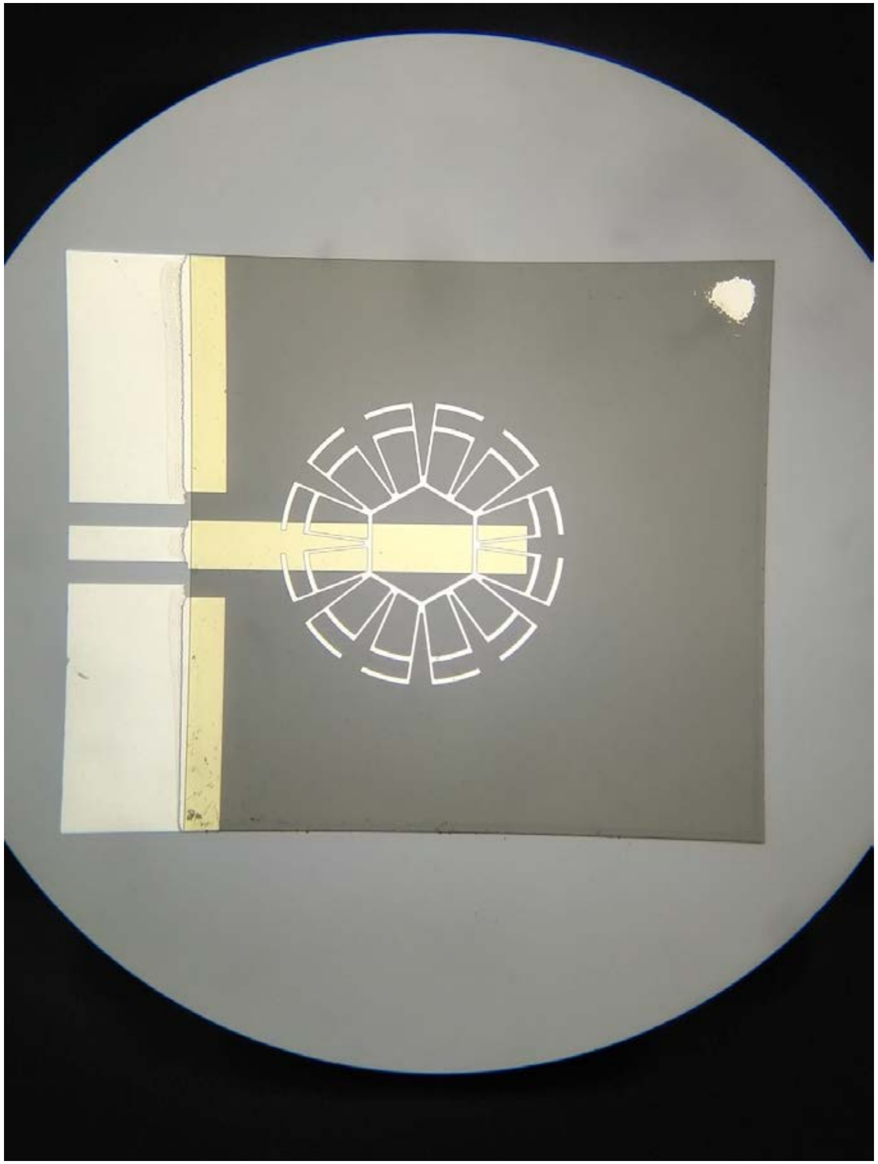
"A novel metamaterial-based antenna for on-chip applications for the 72.5-81 GHz frequency range", K. Olan, R. Murphy, Scientific Reports, Vol. 12, February **2022**, pp. 1-9. DOI: 10.1038/s41598-022-05829-0

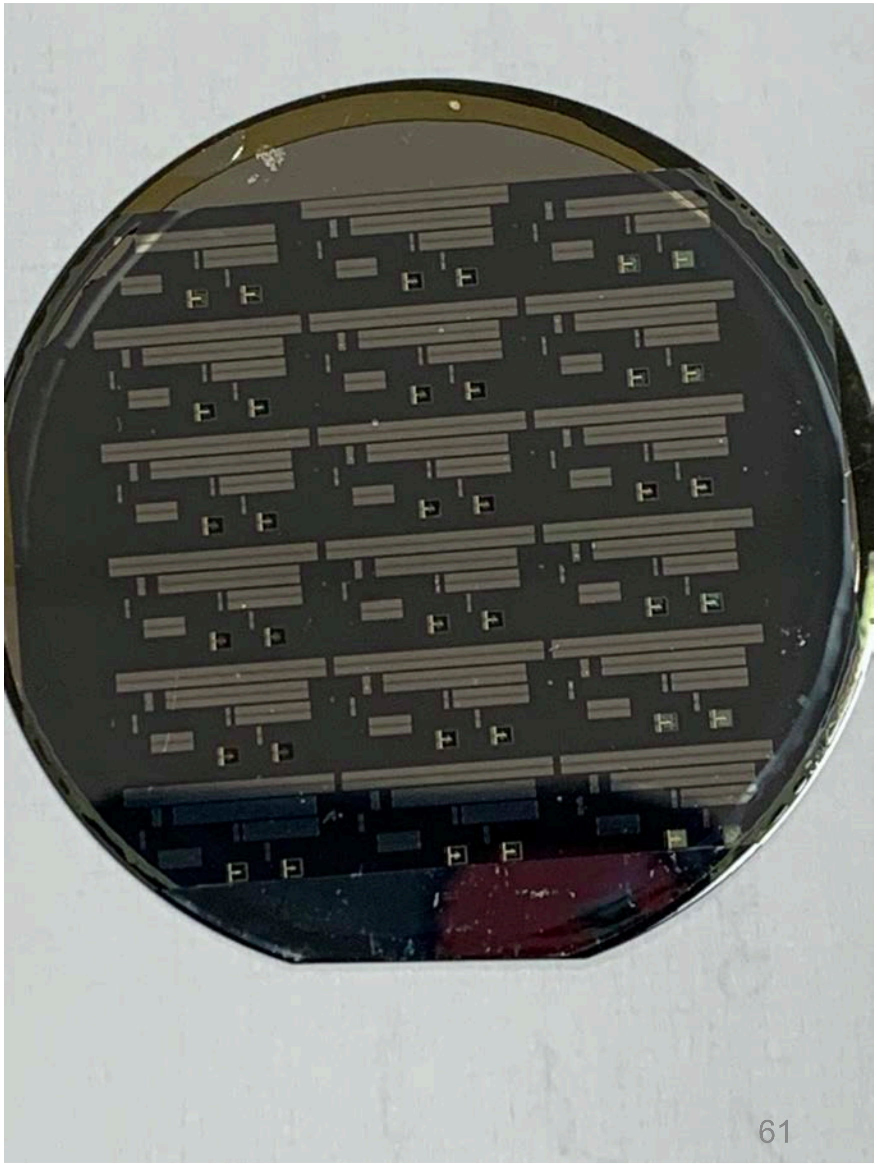
72.5 GHz—81 GHz AoC



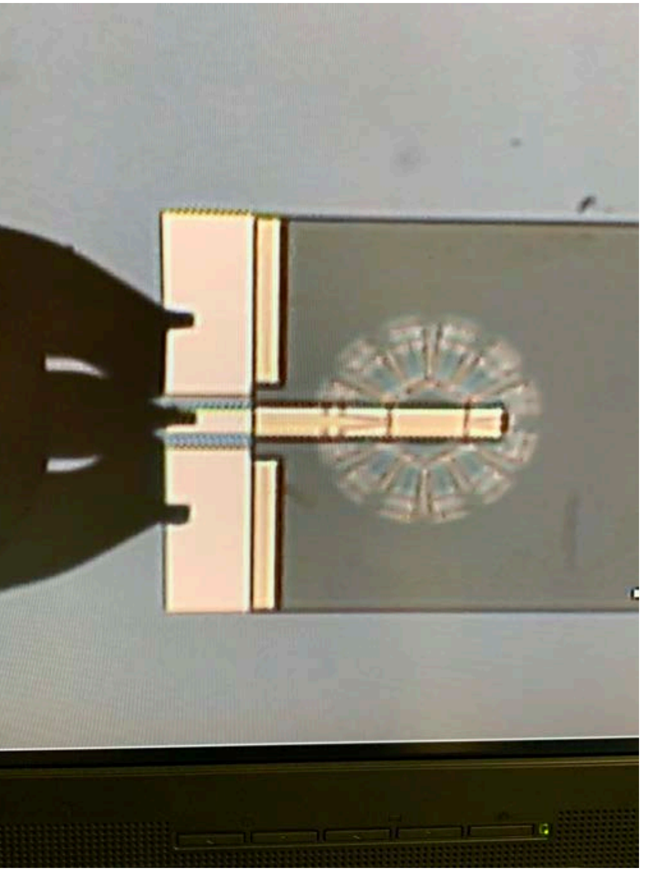
"A novel metamaterial-based antenna for on-chip applications for the 72.5-81 GHz frequency range", K. Olan, R. Murphy, Scientific Reports, Vol. 12, February **2022**, pp. 1-9. DOI: 10.1038/s41598-022-05829-0

Fabricated antenna

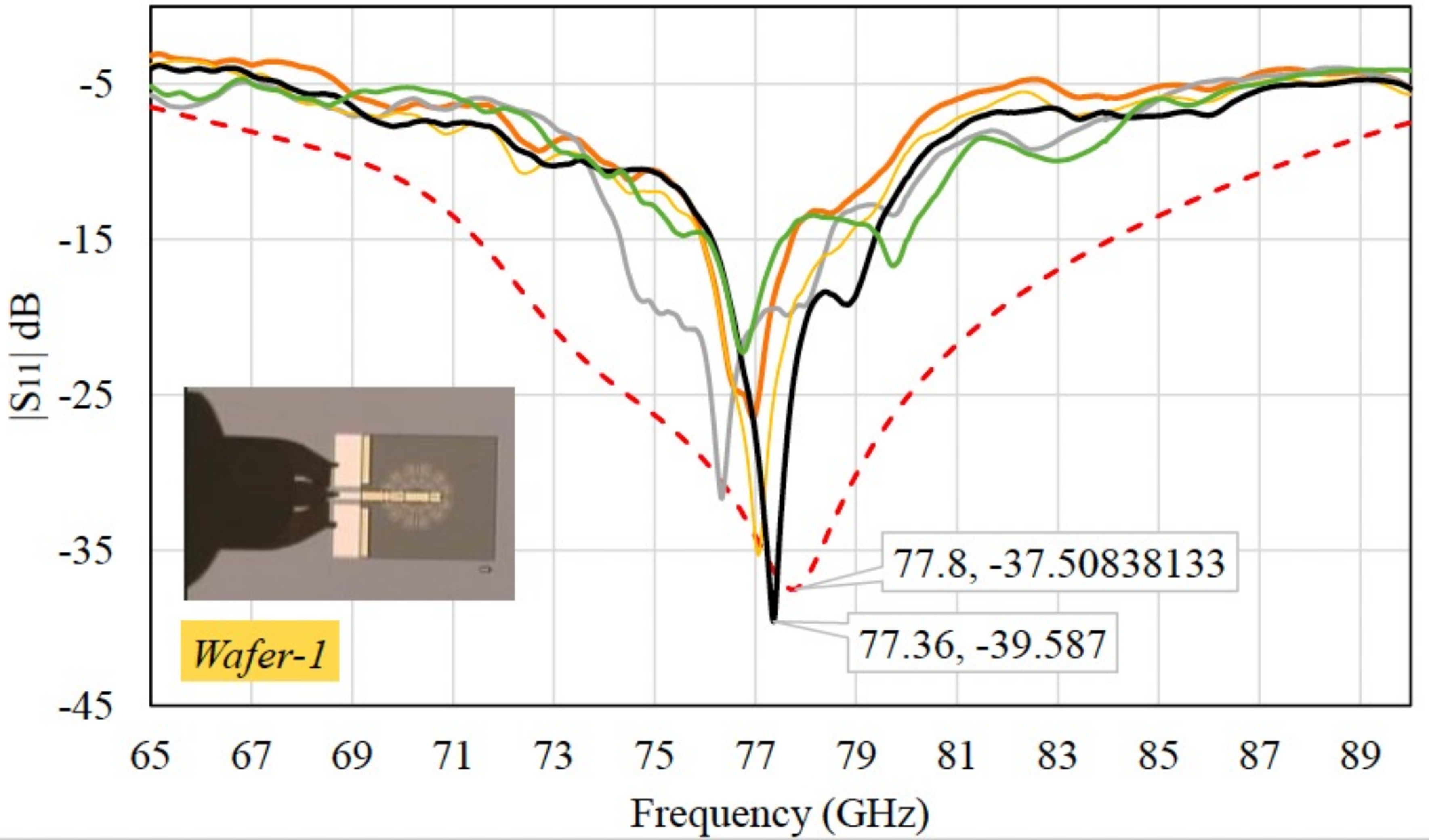




Measurement



Measurement results



“Antennas for Microwave and Millimeter-Wave Applications”, K. Olan, Doctoral Dissertation, INAOE, January 2024.

Conclusions

Conclusions

- On-chip antennas have become ubiquitous.
- There are evermore devices needing them.
- In order to efficiently design and simulate ICs including antennas, compatible compact-models need to be developed.

Conclusions

- Not all the figures-of-merit defined for antennas, however, can be derived from compact models.
- The influence of the radiated wave, among many other effects, has to be taken accurately into consideration.
- On-chip antenna design, and antenna compact modeling, are very dynamic research fields nowadays.

Conclusions

- Impedance, admittance, phase-shift, central frequency, and bandwidth —at least— can be inferred from an electrical model for the antenna, defined in SPICE-like simulators.
- This is a good start, but more has to be done, for instance, to quantify the interference of the radiated wave with the circuitry, among other effects.

Conclusions

- Furthermore, with the advent of 6G technology, it’s imperative to streamline the design and test processes.
- Ideally, we should get to the point of having reliable, trustworthy models for a gamut of antennas on chip that can be called directly at the IC design table.
- I look forward to such a day!

Contact

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