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# Further considerations on RF CMOS compact modeling

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# Acknowledgement

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- **CONACyT, México, for the partial support of these projects through grants # 285199 and 288875, and Scholarships # 455123, 719285 and 852217.**
- **The INAOE, for the partial support of these endeavors.**

# —Agenda—

- Motivation
- MOS Transistor Compact Modeling
- Inductors
- Interconnects
- Antennas On-Chip
- Conclusion

# Motivation

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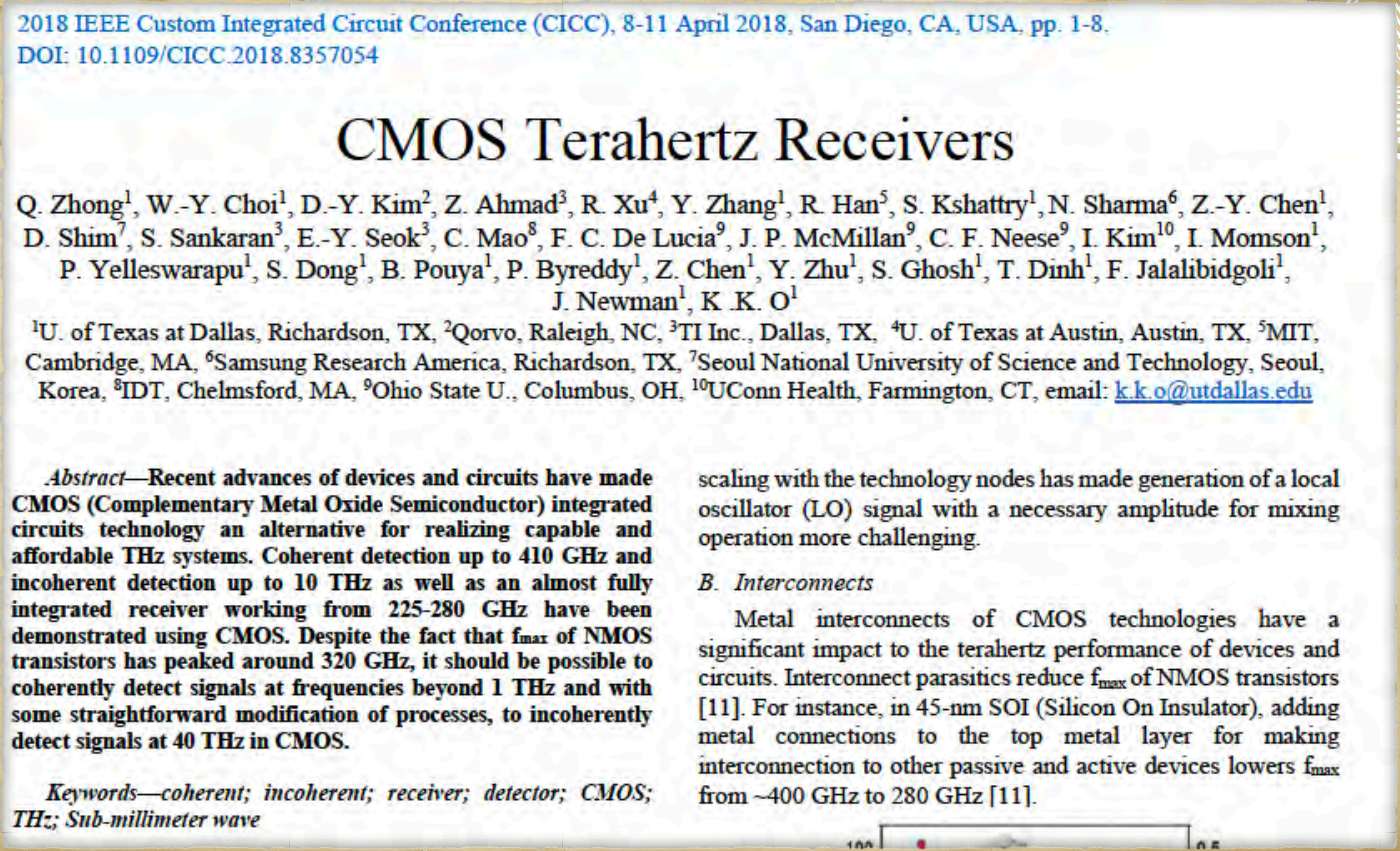
- **Commercial CMOS technology has evolved throughout the years to now become the best alternative for many wireless applications.**
- **It's a mature, well understood, and inexpensive technology.**
- **MOS Transistors have been built to operate at frequencies of hundreds of GHz.**
- **With these, complex ICs have been designed and manufactured, allowing for more on-chip functions than ever before.**
- **This trend will continue for many years, even though we are reaching the physical limits of integration.**

# M1 Microprocessor

- TSMC 5 nm
- Original M1 (2020): 16 billion transistors
- M1 Pro (2020): 34 billion transistors
- M1 Max (2021): 57 billion transistors
- M1 Ultra (2021): 114 billion transistors (two M1 Max)



2018 IEEE Custom Integrated Circuit Conference (CICC), 8-11 April 2018, San Diego, CA, USA, pp. 1-8.
DOI: 10.1109/CICC.2018.8357054

# CMOS Terahertz Receivers

Q. Zhong[1], W.-Y. Choi[1], D.-Y. Kim[2], Z. Ahmad[3], R. Xu[4], Y. Zhang[1], R. Han[5], S. Kshattry[1], N. Sharma[6], Z.-Y. Chen[1],
D. Shim[7], S. Sankaran[3], E.-Y. Seok[3], C. Mao[8], F. C. De Lucia[9], J. P. McMillan[9], C. F. Neese[9], I. Kim[10], I. Momson[1],
P. Yelleswarapu[1], S. Dong[1], B. Pouya[1], P. Byreddy[1], Z. Chen[1], Y. Zhu[1], S. Ghosh[1], T. Dinh[1], F. Jalalibidgoli[1],
J. Newman[1], K .K. O[1]
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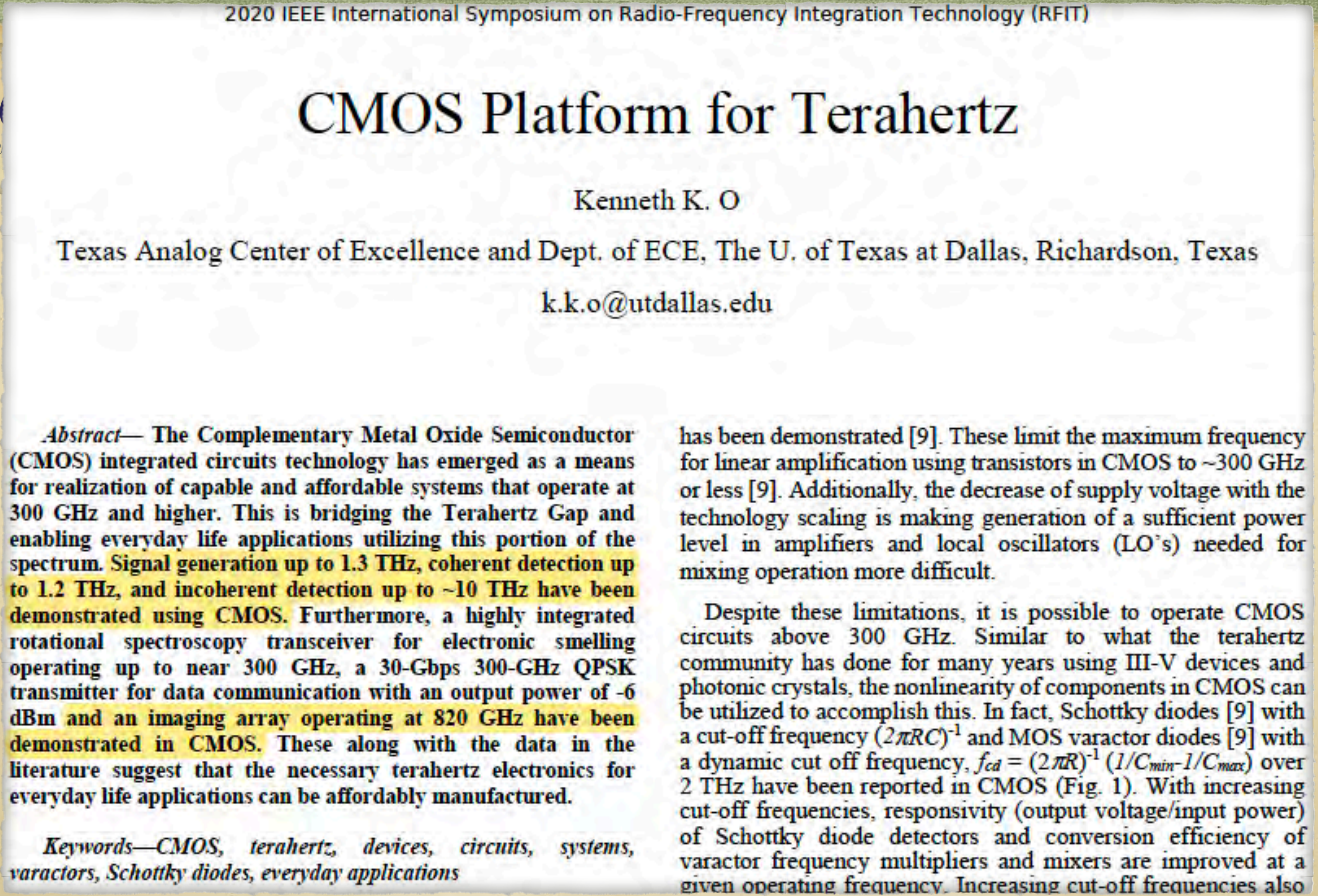
*Abstract*—**Recent advances of devices and circuits have made CMOS (Complementary Metal Oxide Semiconductor) integrated circuits technology an alternative for realizing capable and affordable THz systems. Coherent detection up to 410 GHz and incoherent detection up to 10 THz as well as an almost fully integrated receiver working from 225-280 GHz have been demonstrated using CMOS. Despite the fact that $f_{max}$ of NMOS transistors has peaked around 320 GHz, it should be possible to coherently detect signals at frequencies beyond 1 THz and with some straightforward modification of processes, to incoherently detect signals at 40 THz in CMOS.**

*Keywords—coherent; incoherent; receiver; detector; CMOS; THz; Sub-millimeter wave*

scaling with the technology nodes has made generation of a local oscillator (LO) signal with a necessary amplitude for mixing operation more challenging.

### *B. Interconnects*

Metal interconnects of CMOS technologies have a significant impact to the terahertz performance of devices and circuits. Interconnect parasitics reduce $f_{max}$ of NMOS transistors [11]. For instance, in 45-nm SOI (Silicon On Insulator), adding metal connections to the top metal layer for making interconnection to other passive and active devices lowers $f_{max}$ from ~400 GHz to 280 GHz [11].



2020 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT)

# CMOS Platform for Terahertz

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*Abstract*— **The Complementary Metal Oxide Semiconductor (CMOS) integrated circuits technology has emerged as a means for realization of capable and affordable systems that operate at 300 GHz and higher. This is bridging the Terahertz Gap and enabling everyday life applications utilizing this portion of the spectrum. Signal generation up to 1.3 THz, coherent detection up to 1.2 THz, and incoherent detection up to ~10 THz have been demonstrated using CMOS. Furthermore, a highly integrated rotational spectroscopy transceiver for electronic smelling operating up to near 300 GHz, a 30-Gbps 300-GHz QPSK transmitter for data communication with an output power of -6 dBm and an imaging array operating at 820 GHz have been demonstrated in CMOS. These along with the data in the literature suggest that the necessary terahertz electronics for everyday life applications can be affordably manufactured.**

*Keywords—CMOS, terahertz, devices, circuits, systems, varactors, Schottky diodes, everyday applications*

has been demonstrated [9]. These limit the maximum frequency for linear amplification using transistors in CMOS to ~300 GHz or less [9]. Additionally, the decrease of supply voltage with the technology scaling is making generation of a sufficient power level in amplifiers and local oscillators (LO's) needed for mixing operation more difficult.

Despite these limitations, it is possible to operate CMOS circuits above 300 GHz. Similar to what the terahertz community has done for many years using III-V devices and photonic crystals, the nonlinearity of components in CMOS can be utilized to accomplish this. In fact, Schottky diodes [9] with a cut-off frequency $(2\pi RC)^{-1}$ and MOS varactor diodes [9] with a dynamic cut off frequency, $f_{cd} = (2\pi R)^{-1}\,(1/C_{min}-1/C_{max})$ over 2 THz have been reported in CMOS (Fig. 1). With increasing cut-off frequencies, responsivity (output voltage/input power) of Schottky diode detectors and conversion efficiency of varactor frequency multipliers and mixers are improved at a given operating frequency. Increasing cut-off frequencies also

See also: "Opening Terahertz for Everyday Applications", K.O. Kenneth et al., IEEE Communications Magazine, August 2019, pp. 70-76. DOI: 10.1109/MCOM.2019.1800909

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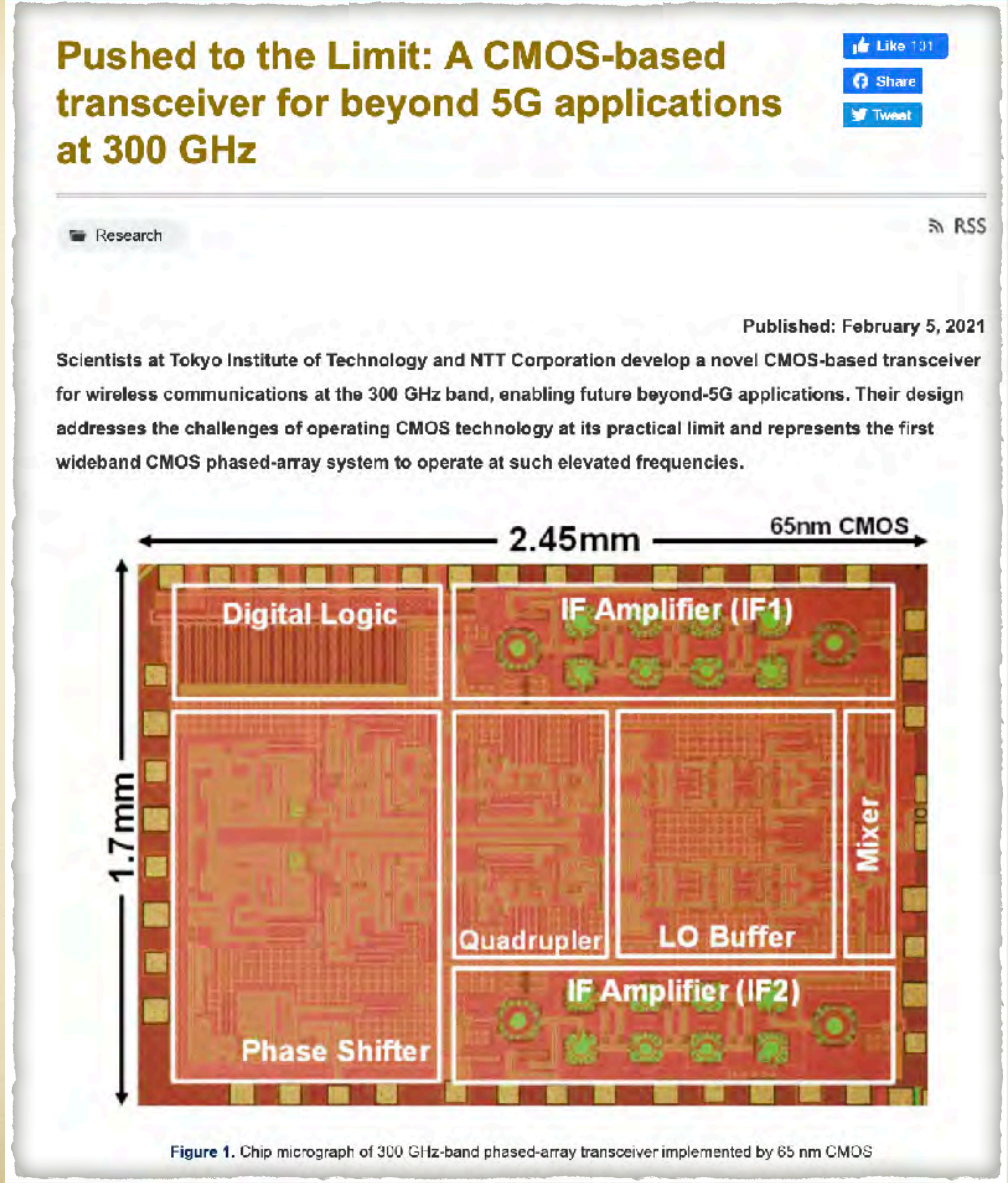
Tokyo Tech News
https://www.titech.ac.jp/english/news/2021/048934.html



# Pushed to the Limit: A CMOS-based transceiver for beyond 5G applications at 300 GHz

Published: February 5, 2021

Scientists at Tokyo Institute of Technology and NTT Corporation develop a novel CMOS-based transceiver for wireless communications at the 300 GHz band, enabling future beyond-5G applications. Their design addresses the challenges of operating CMOS technology at its practical limit and represents the first wideband CMOS phased-array system to operate at such elevated frequencies.

**Figure 1.** Chip micrograph of 300 GHz-band phased-array transceiver implemented by 65 nm CMOS

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“Terahertz Wireless Communications”, H.J. Song, IEEE Microwave Magazine, Vol. 22, No. 5, May 2021, pp. 88-99. DOI: 10.1109/ MMM.2021.3056935

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# Terahertz Wireless Communications

Ho-Jin Song

Nowadays, it is hard to imagine daily life without connecting to cellular communications or wireless local area

cations systems rely primarily on massive signal processing for orthogonal frequency division multiplexing and channel estimation/calibration, which has result-

- But CMOS ICs are not only made of transistors!
- To connect these, interconnect lines are necessary.
- To reach the external world, also.
- To implement filters, capacitors and inductors are needed.
- To convert voltages to currents, resistors are used.
- All these passive devices play an important role in circuit structure.
- In fact, in a complex IC, we might find hundreds of thousands of these.
- They all have an influence on the overall behavior of the circuit.
- Hence, they have to be studied, modeled, and characterized.

# The High Frequency Laboratory of INAOE

- For the last three decades, we have dedicated our research efforts to the modeling, measurement and characterization of active and passive devices used for wireless communications, mostly CMOS.
- But our work also involves HF effects on PCBs, antennas, and antenna arrays for communications and energy harvesting.
- Here we present just a few aspects of the work needed in this continuously expanding field of endeavor.

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# MOS Transistor Compact Modeling

## The modeling of the MOS Transistor

- The MOS transistor is probably the most studied and modeled device by humankind.
- Models are defined by a slew of techniques, methods, approaches, basis, science, principles,…
- They can be physical, mathematical, electrical, empirical…
- But the best combinations are “compact models”, as they are physically based, intuitive, simple, and sufficiently accurate.

- **As fabrication processes evolve, smaller features are attained, more “second order” effects become present, higher frequencies are achieved; thus more complex models are needed.**

- **Therefore, the field of compact modeling is a dynamic research area, and it will continue to be so as long as fabrication technologies reach new frontiers.**

- **MOS-AK is a pioneer in the field of compact modeling, and as we see from the talks in this —and other issues of the workshop — there is always something new under the sun.**

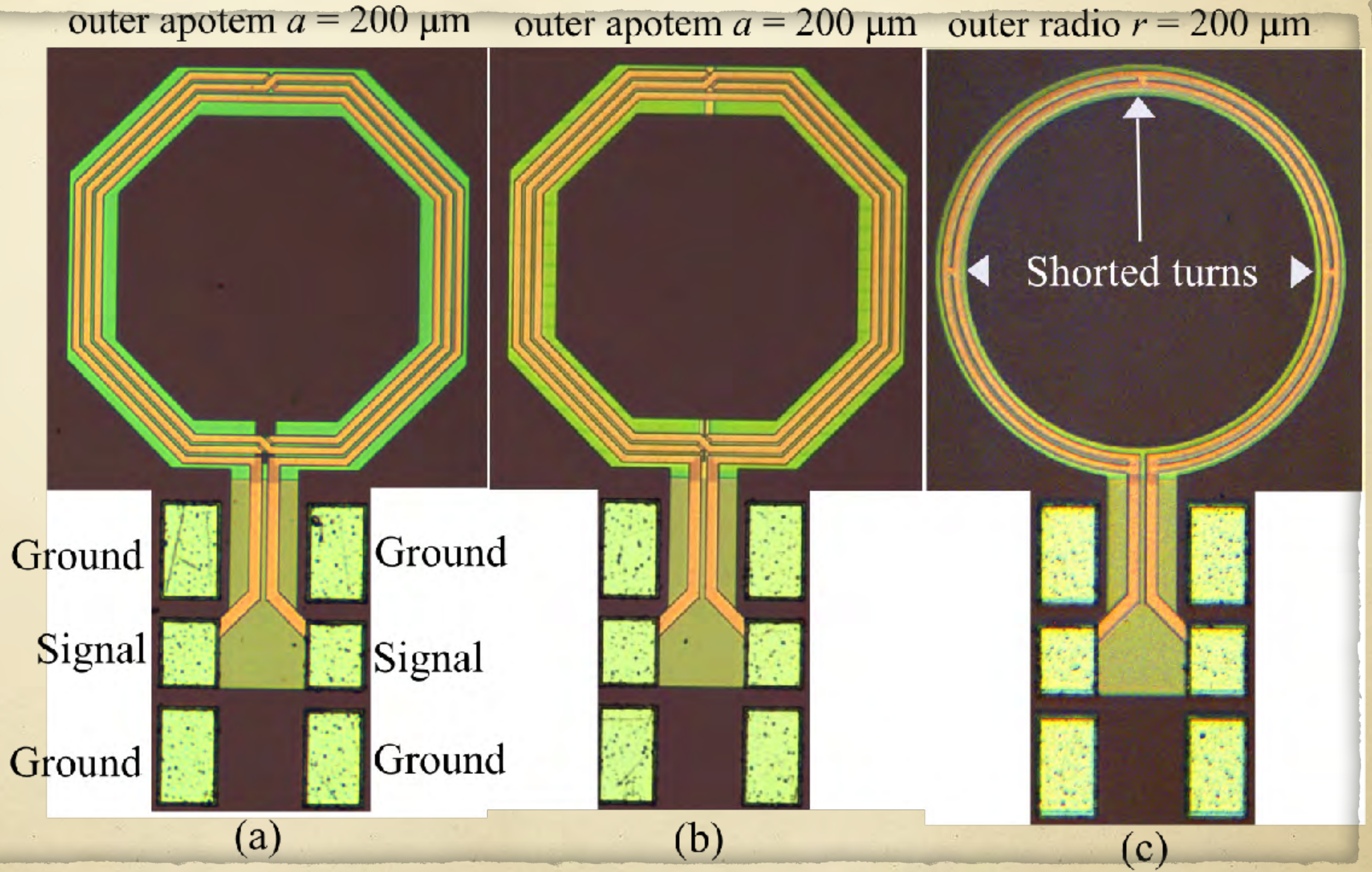
- **And in spite of having many books and journal articles on the field, we must continue delving deeper into the matter to advance the state-of-the-art.**

- **The focus of this talk is highlighting some aspects of importance in the future development of CMOS compact modeling for high-frequency applications.**
- **These include a host of effects which have to be taken into account in order to design and simulate a circuit trustworthily.**
- **Furthermore, antennas have become commonplace in integrated circuits —antennas on-chip— and compact models for these have to be included in circuit simulators to effectively incorporate their effects during simulation.**

# Inductors

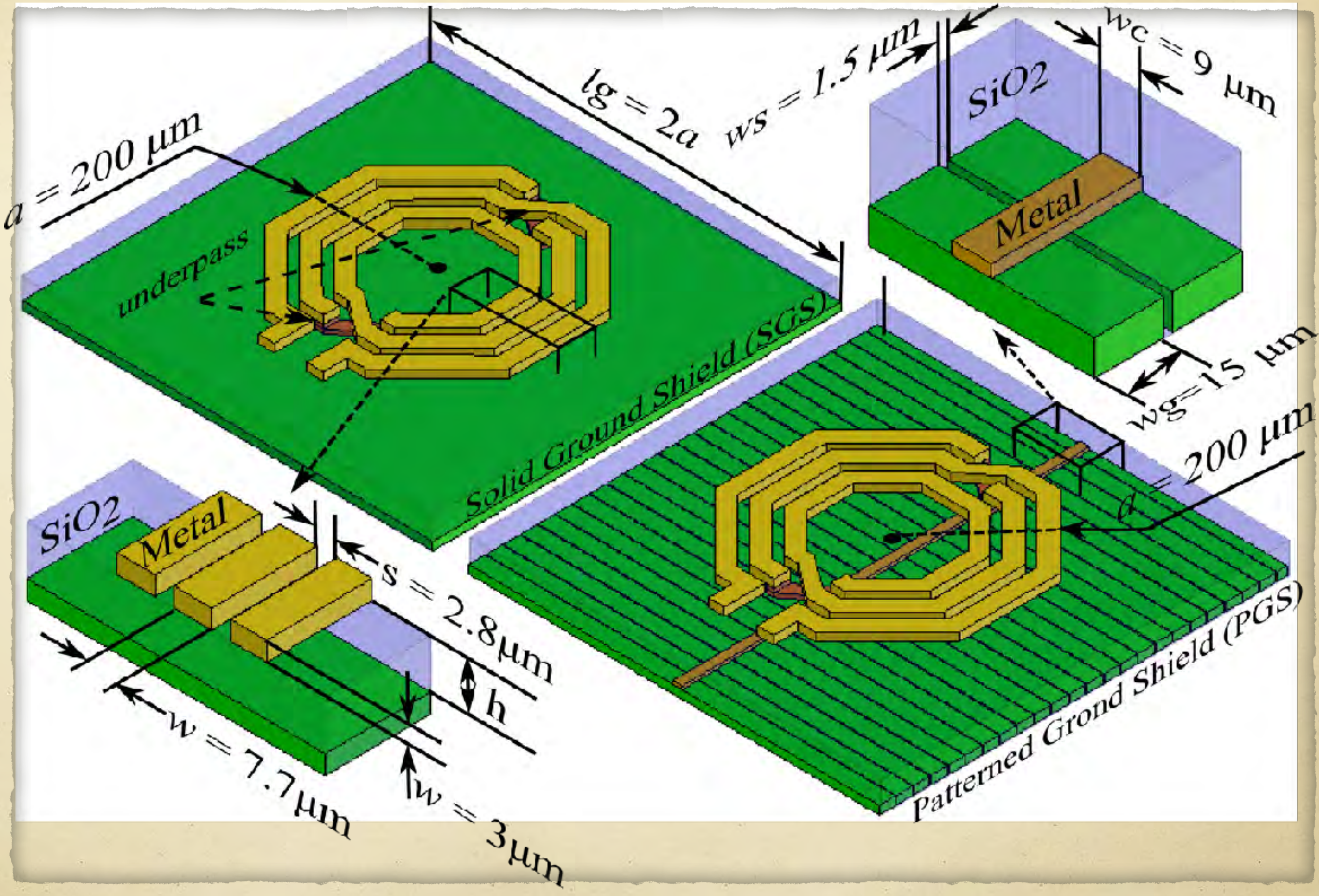
- Inductors are probably the most important passive devices used in radio frequency ICs.
- An important figure of merit for inductors is the Quality Factor (Q).
- The value of Q strongly depends on the losses associated with eddy-currents on the ground path.
- To reduce these losses, ground shields are used underneath the inductors.
- These can be solid (SGS) or patterned (PGS).
- Shields can be built with metal, polysilicon, or low resistivity buried layers.
- A variety of inductors, from IMEC, were available for this study.

# Micrograph of some of the fabricated inductors



“Modeling Ground-Shielded Integrated Inductors Incorporating Frequency-Dependent Effects and Considering Multiple Resonances”, J. Valdés, R. Torres, R. Murphy, G. Álvarez, IEEE Transactions on Microwave Theory and Techniques, Vol. 67, No. 4, April 2019, pp. 1370-1378. DOI: 10.1109/TMTT.2019.2895579

# Schematic showing SGS and PGS



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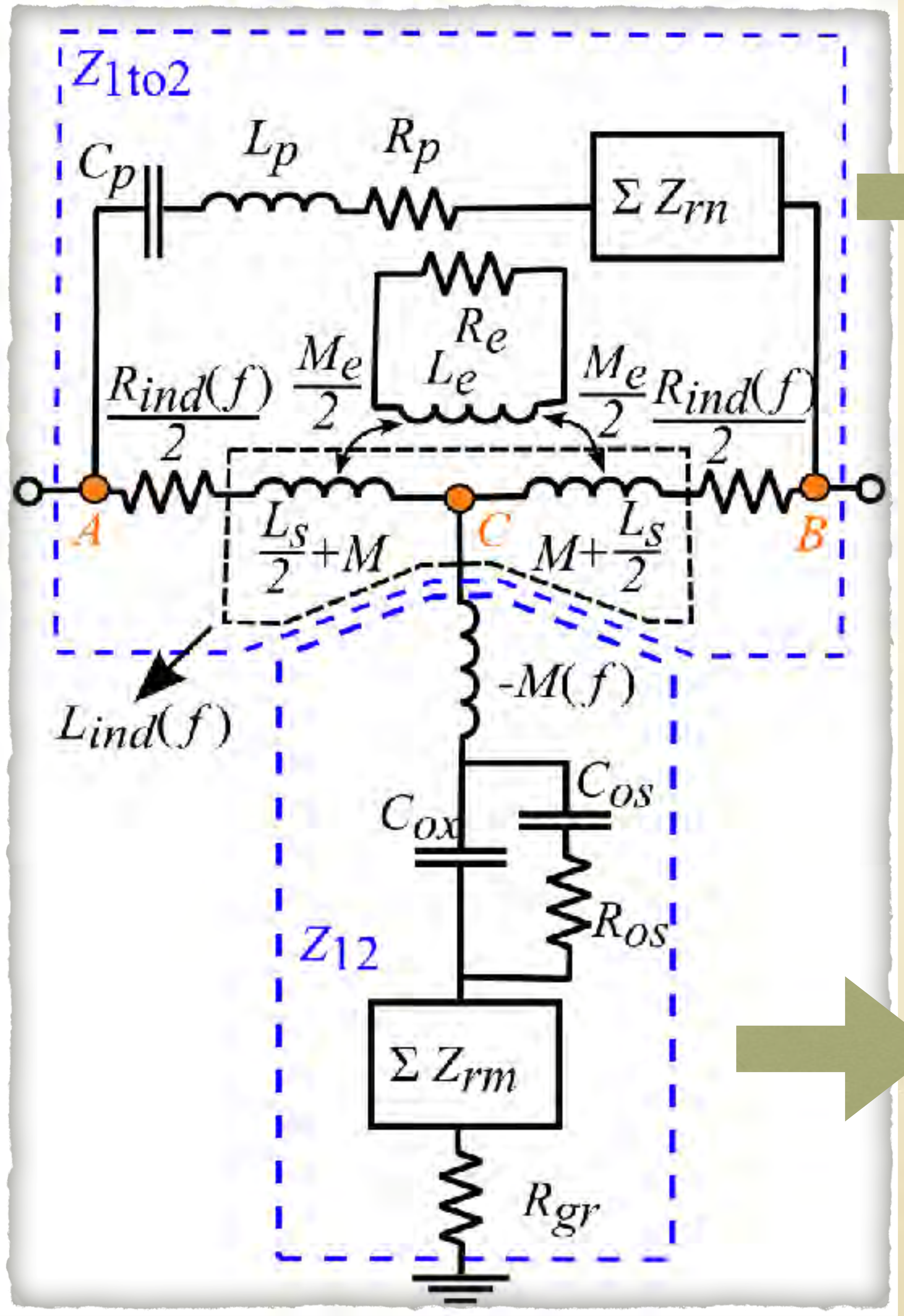
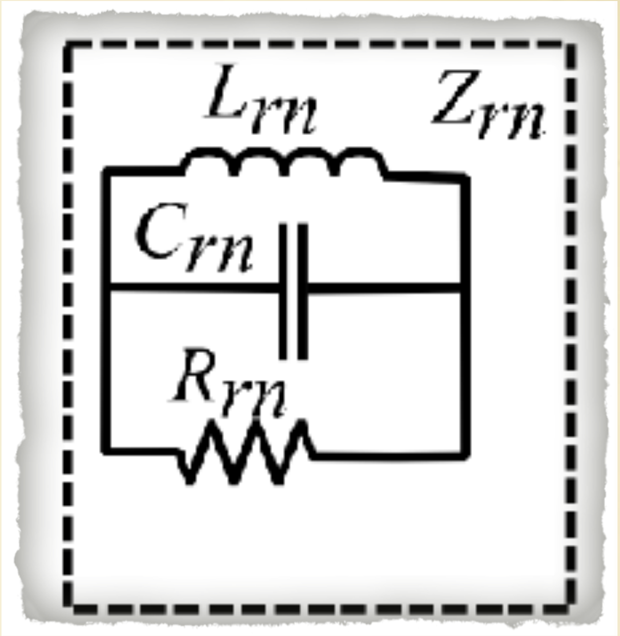
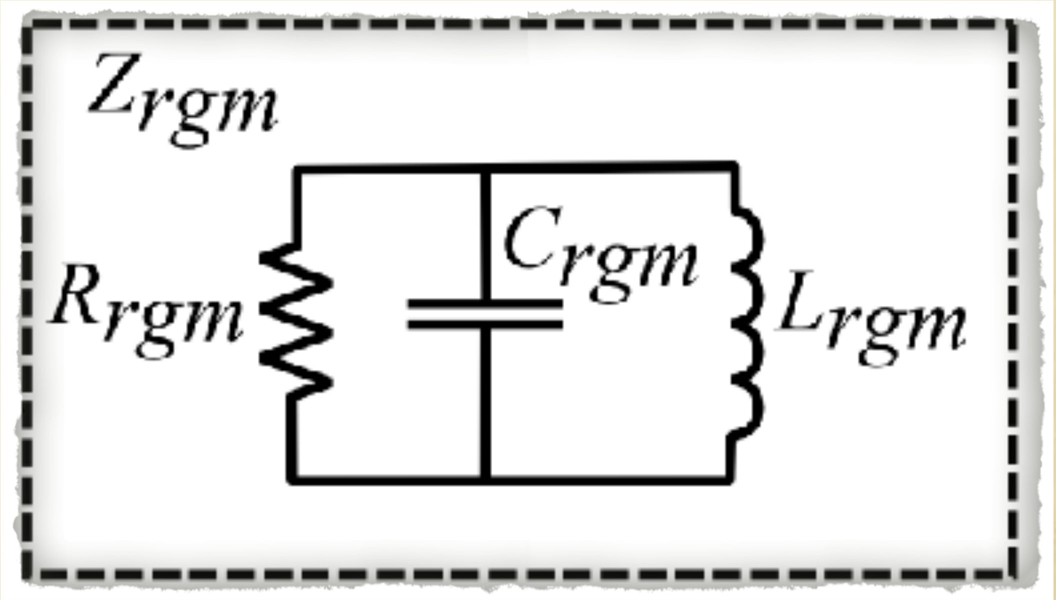
# Proposed Model







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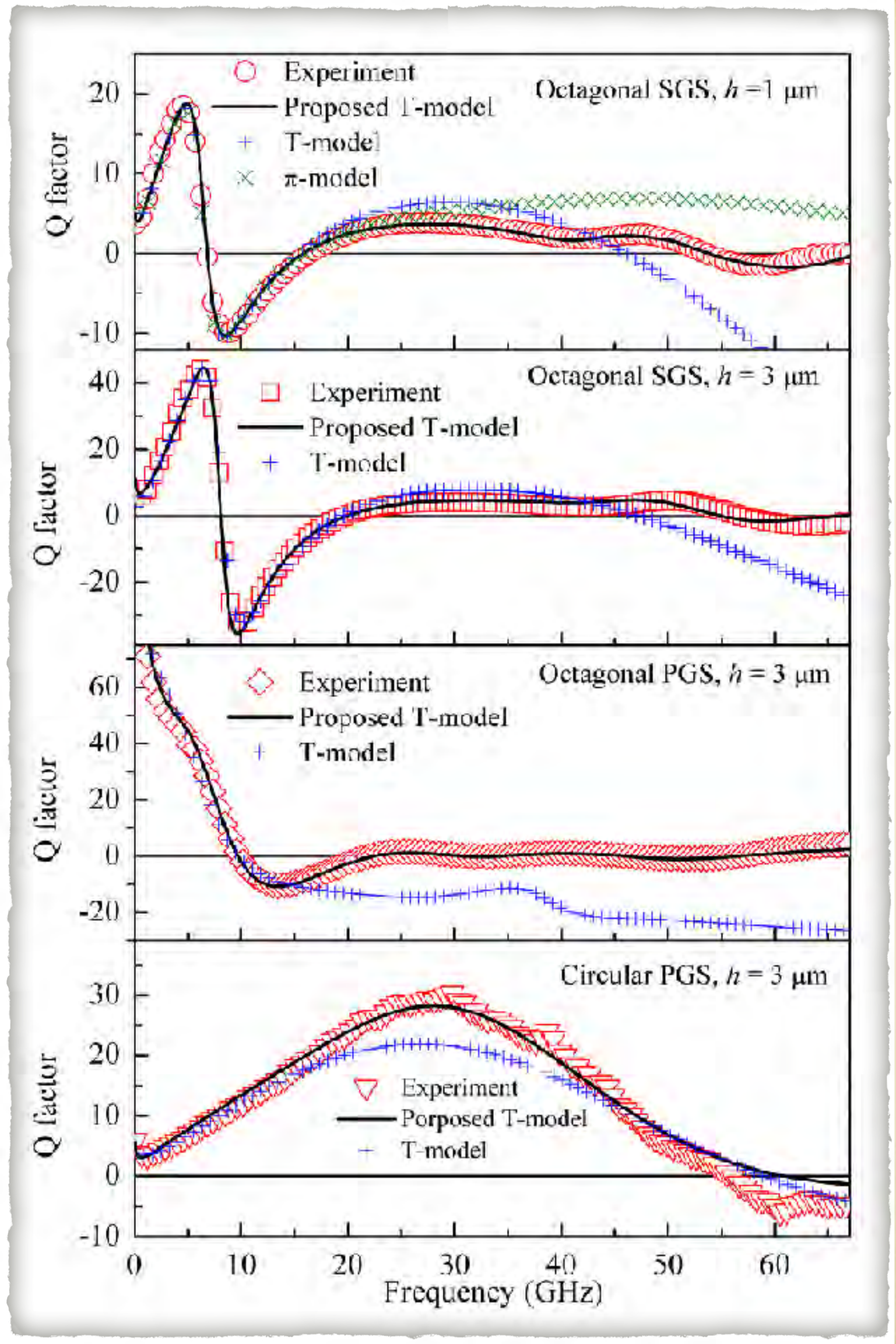

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- **An important factor taken into consideration for the model is the frequency dependence of resistance and inductance:**

$$R_{ind} = R_{ind0} + k_s\sqrt{f}$$

$$L_{ind} = L_{\infty} + \frac{k_s}{2\pi\sqrt{f}}$$

- **Thus, the skin effect is satisfactorily taken into account.**
- **Proximity effects are also considered.**

# Interconnects

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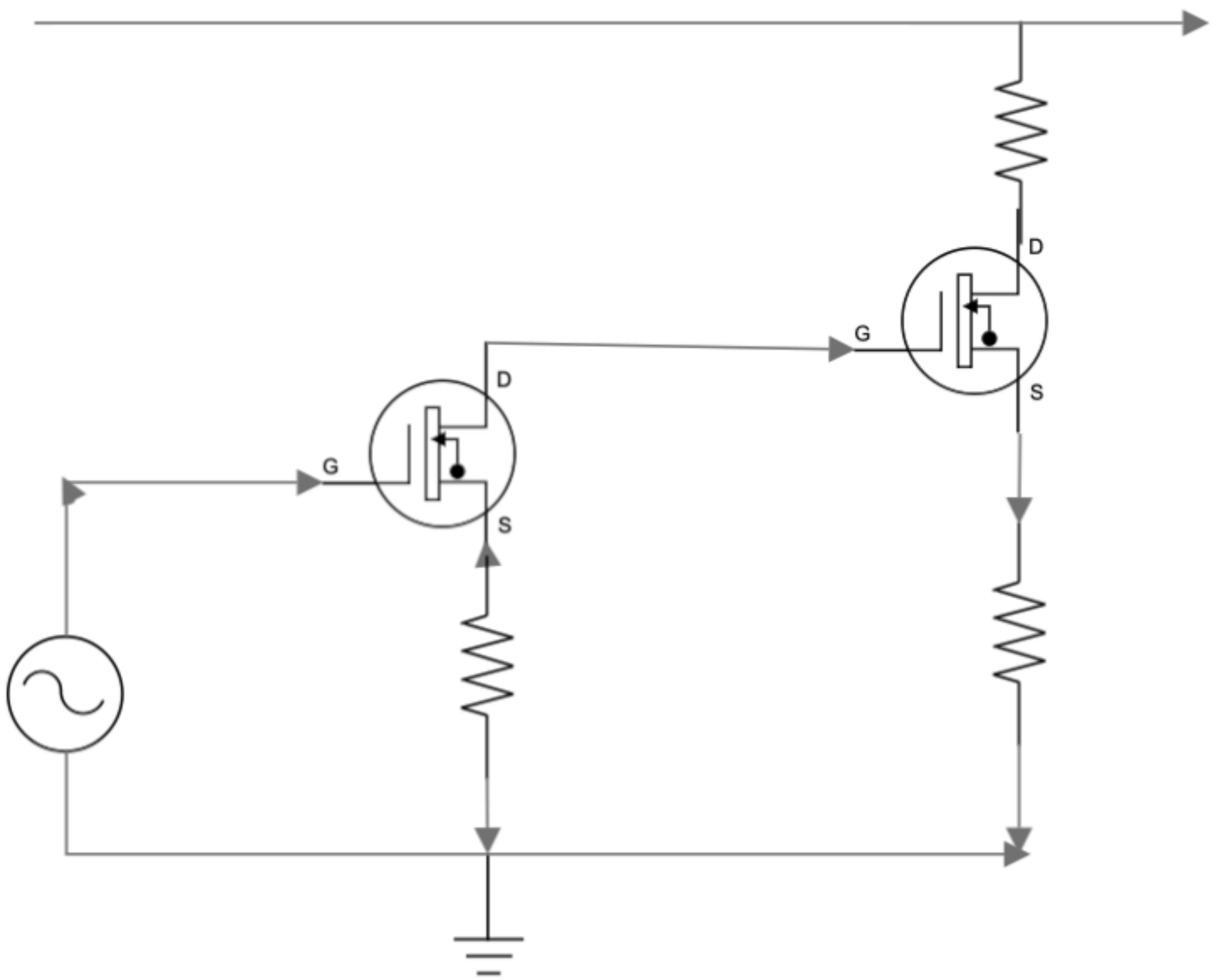
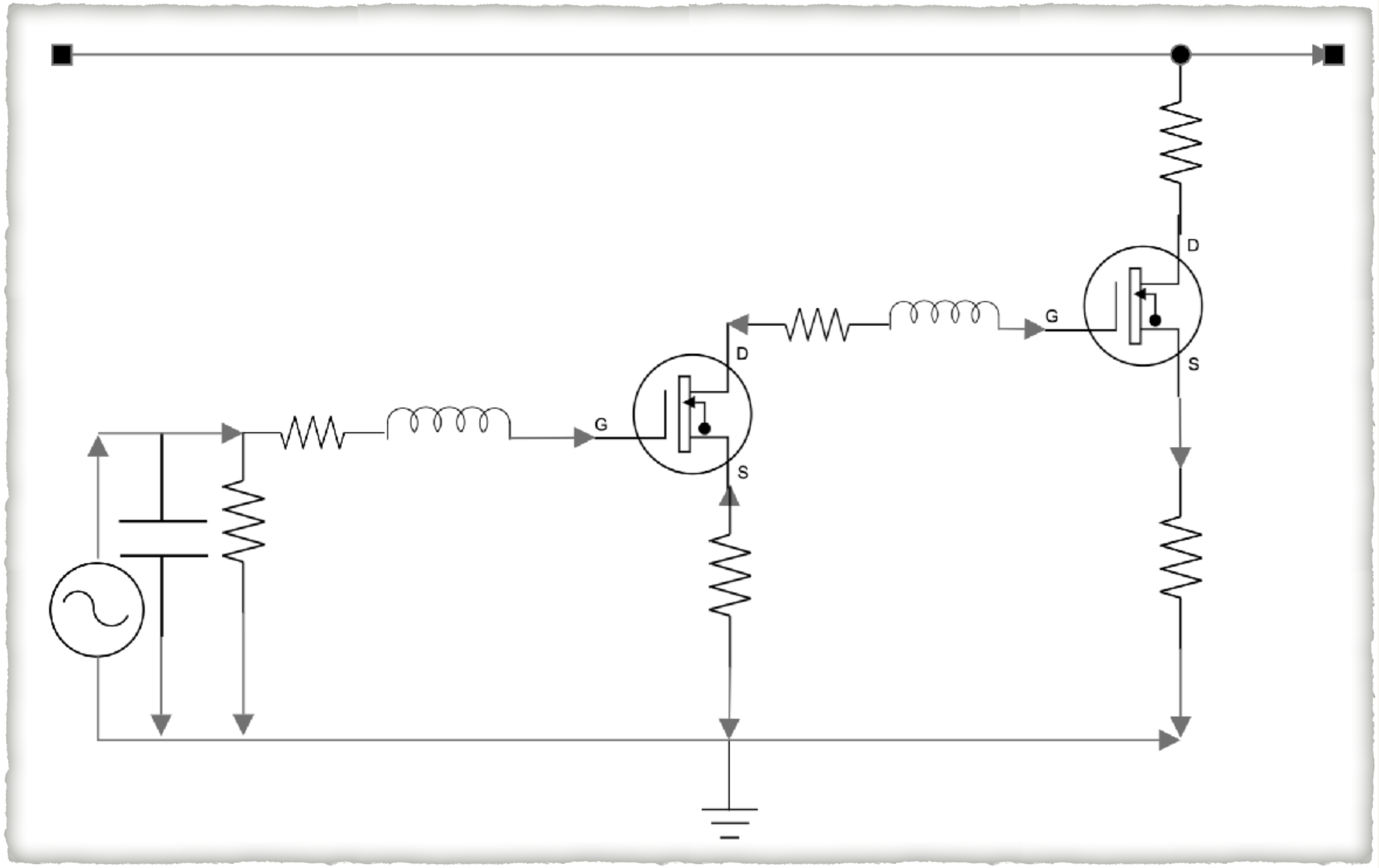
- Interconnects are a fundamental element of any integrated circuit.
- These present transmission line effects when operating in high-frequency.
- As such, they have to be taken into consideration to account for signal delay and losses.
- As mentioned before, however, resistance and inductance are also frequency dependent.
- Furthermore, models can be made more complex to account for second-order effects.

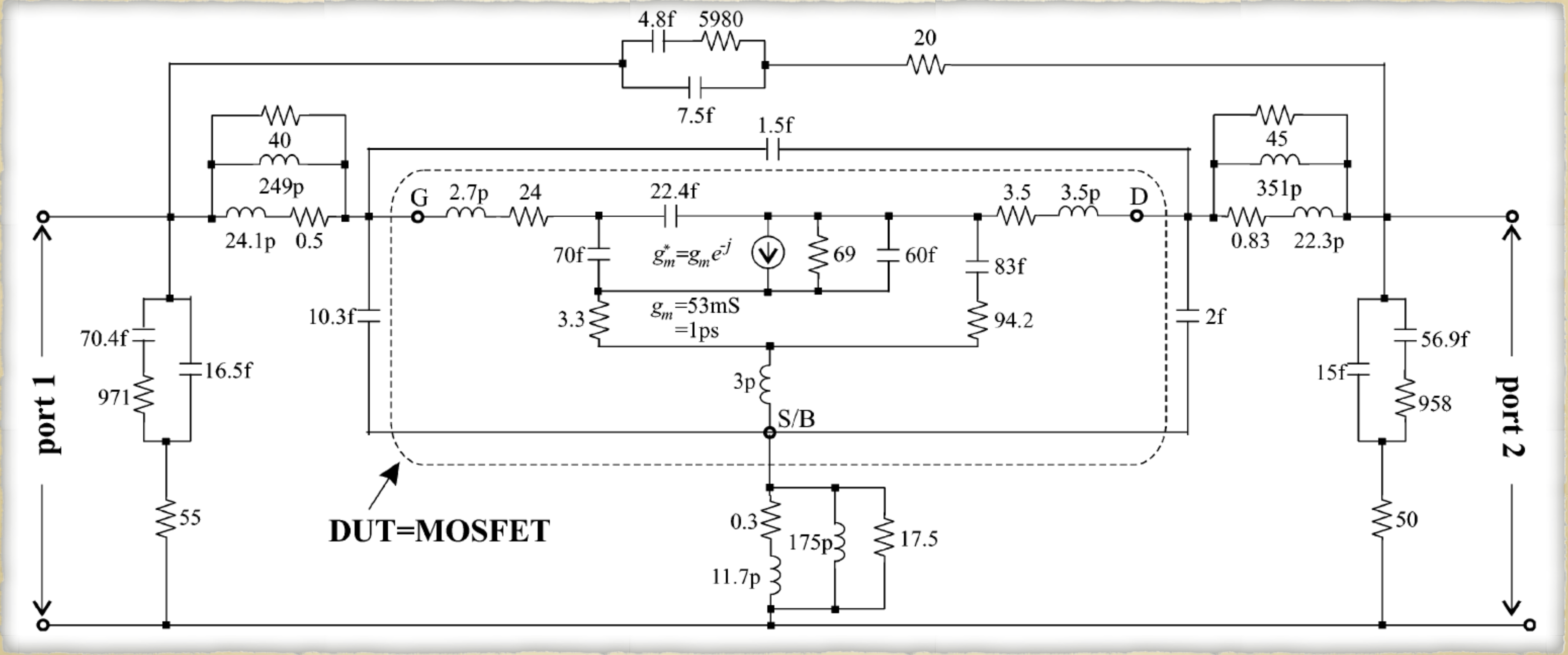
A simple model neglecting the physical nature of interconnects.





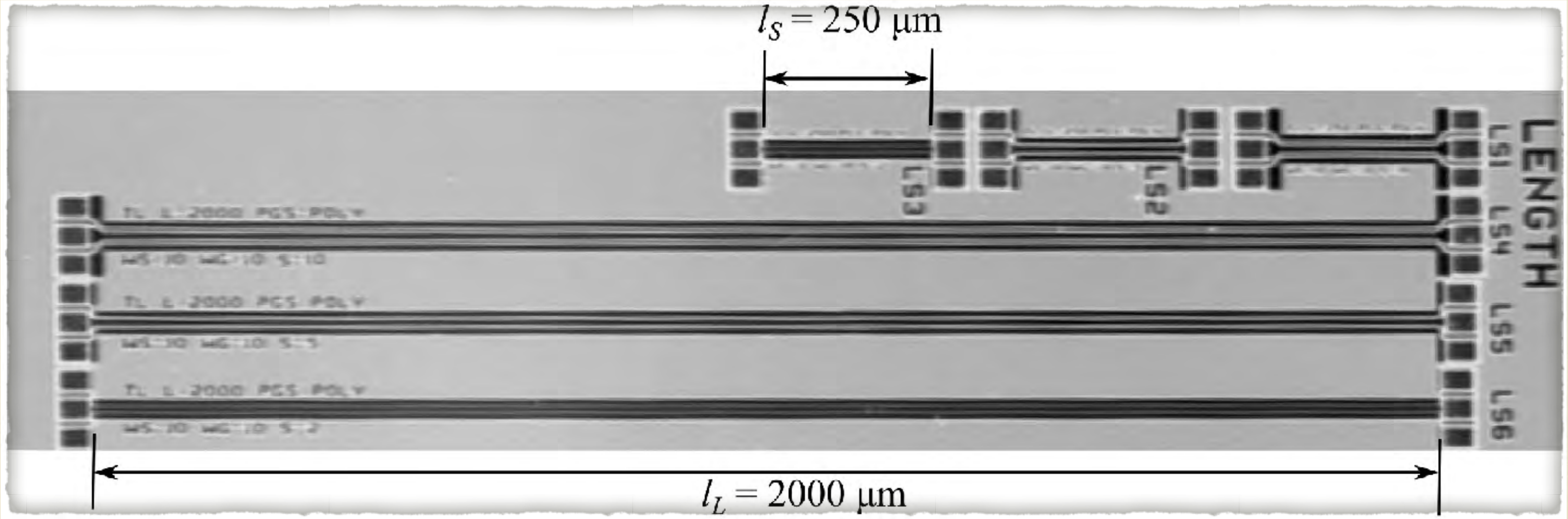
A somewhat more elaborate model considering interconnects and pads.

# A complete model including interconnects and pads

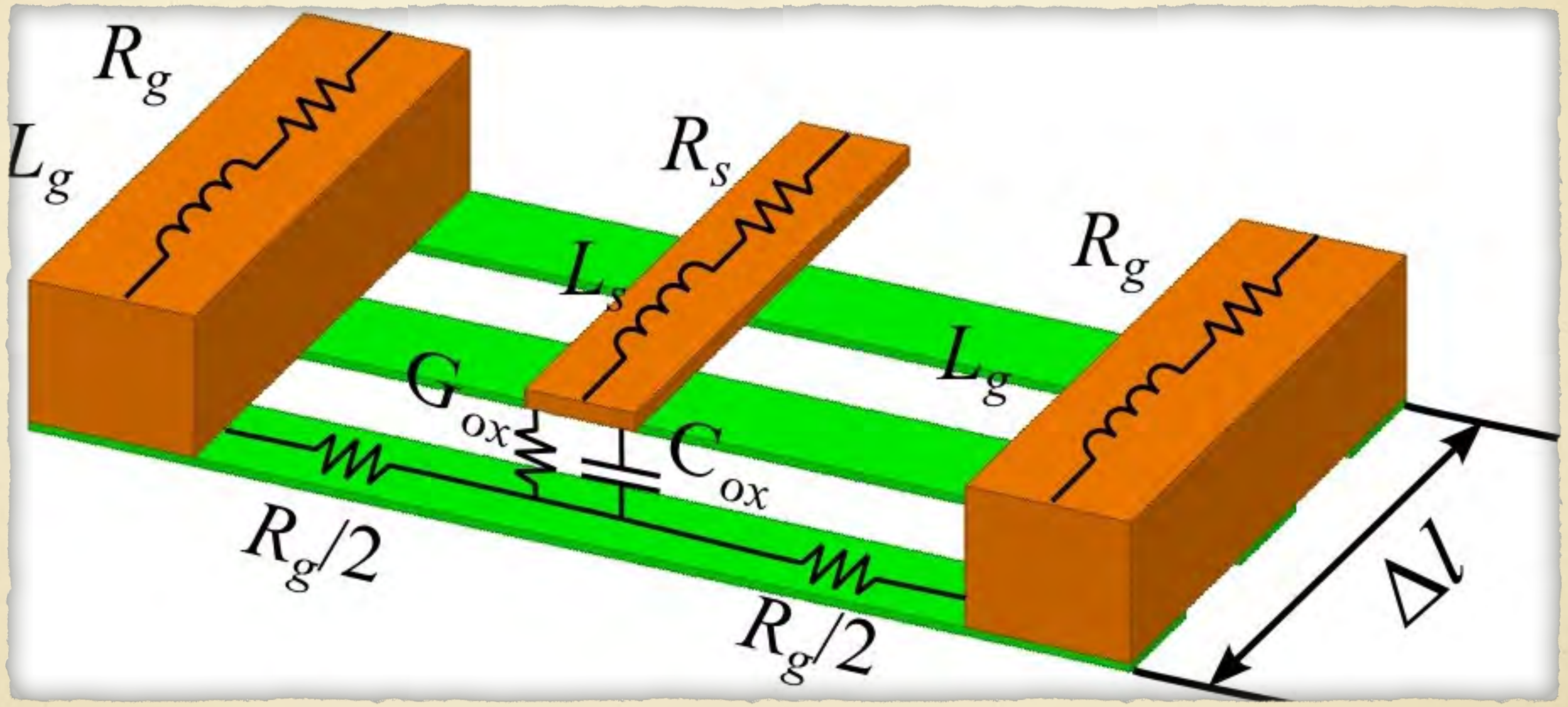


“Analytical Model and Parameter Extraction to Account for the Pad Parasitics in RF-CMOS”, R. Torres, R. Murphy, A. Reynoso, IEEE Transactions on Electron Devices, Vol. 52, No. 7, July 2005, pp. 1335-1342. DOI: 10.1109/TED.2005.850644

# Coplanar waveguides



“Determination of the Contribution of the Ground-Shield Losses to the Microwave Performance of On-Chip Coplanar Waveguides”, J. Valdés, R. Murphy, R. Torres, IEEE Transactions on Microwave Theory and Techniques, Vol. 69, No. 3, March 2021, pp. 1594-1601. DOI: 10.1109/TMTT.2021.3053548



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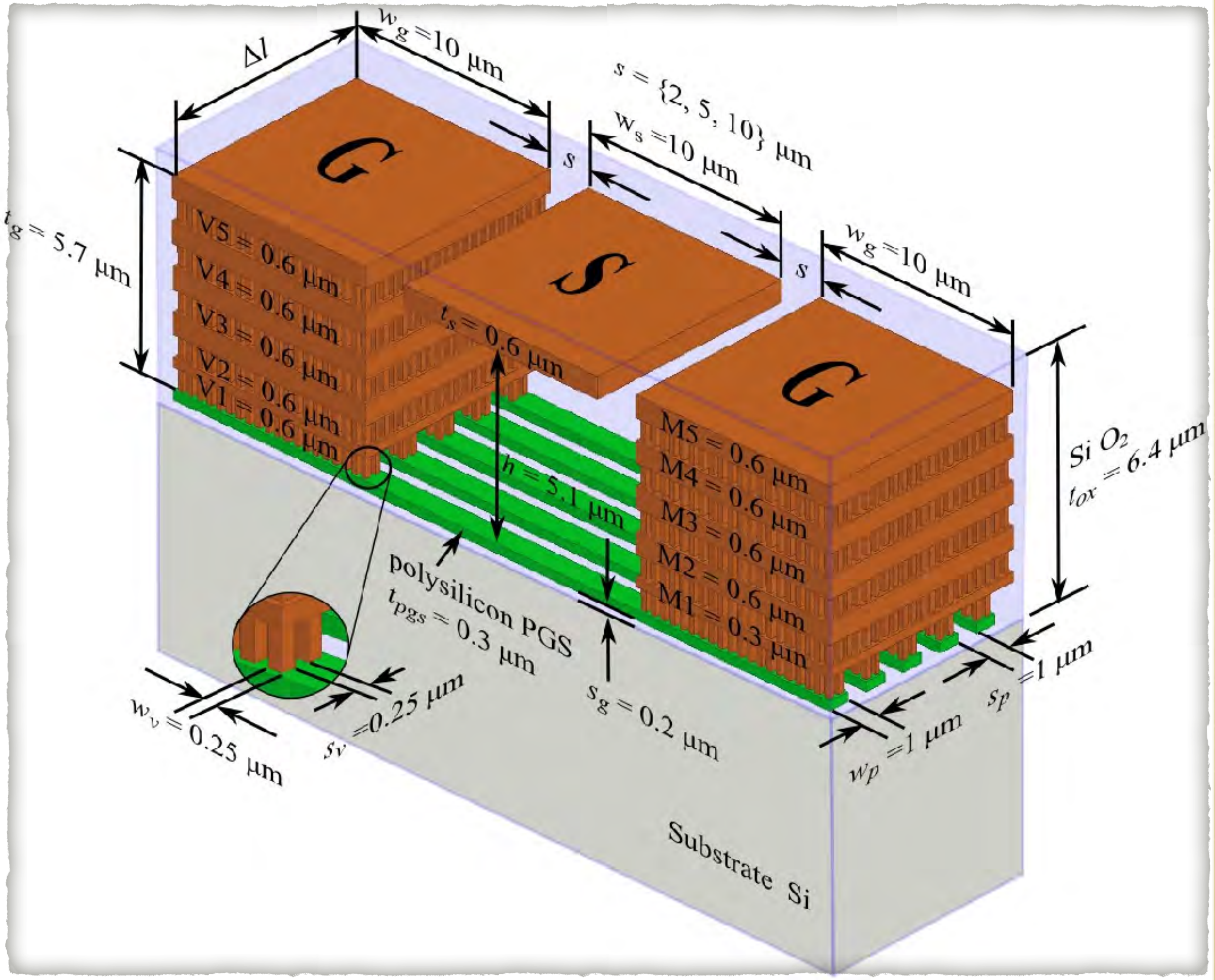

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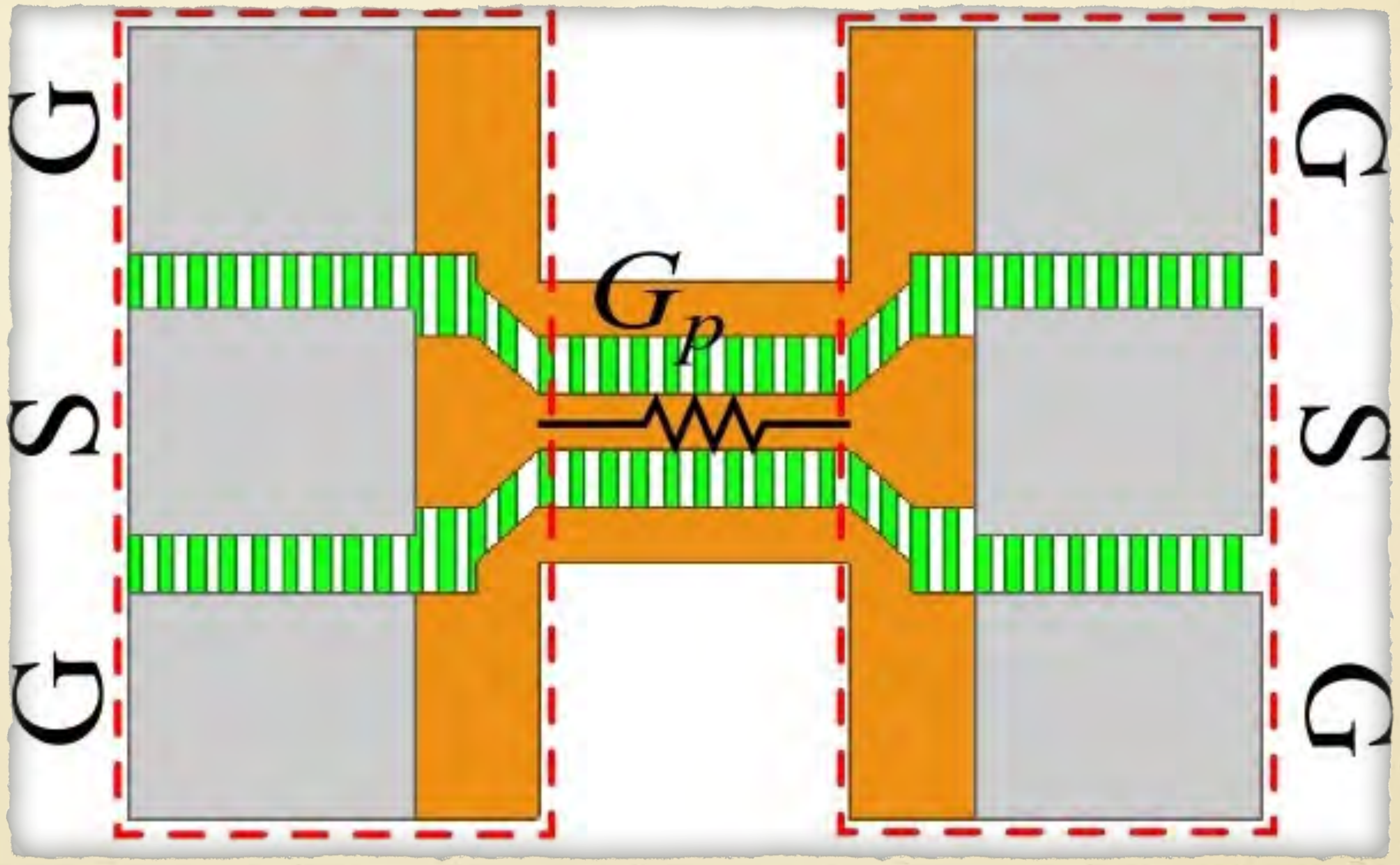
# Input-output coupling for “short” lines (250 μm)



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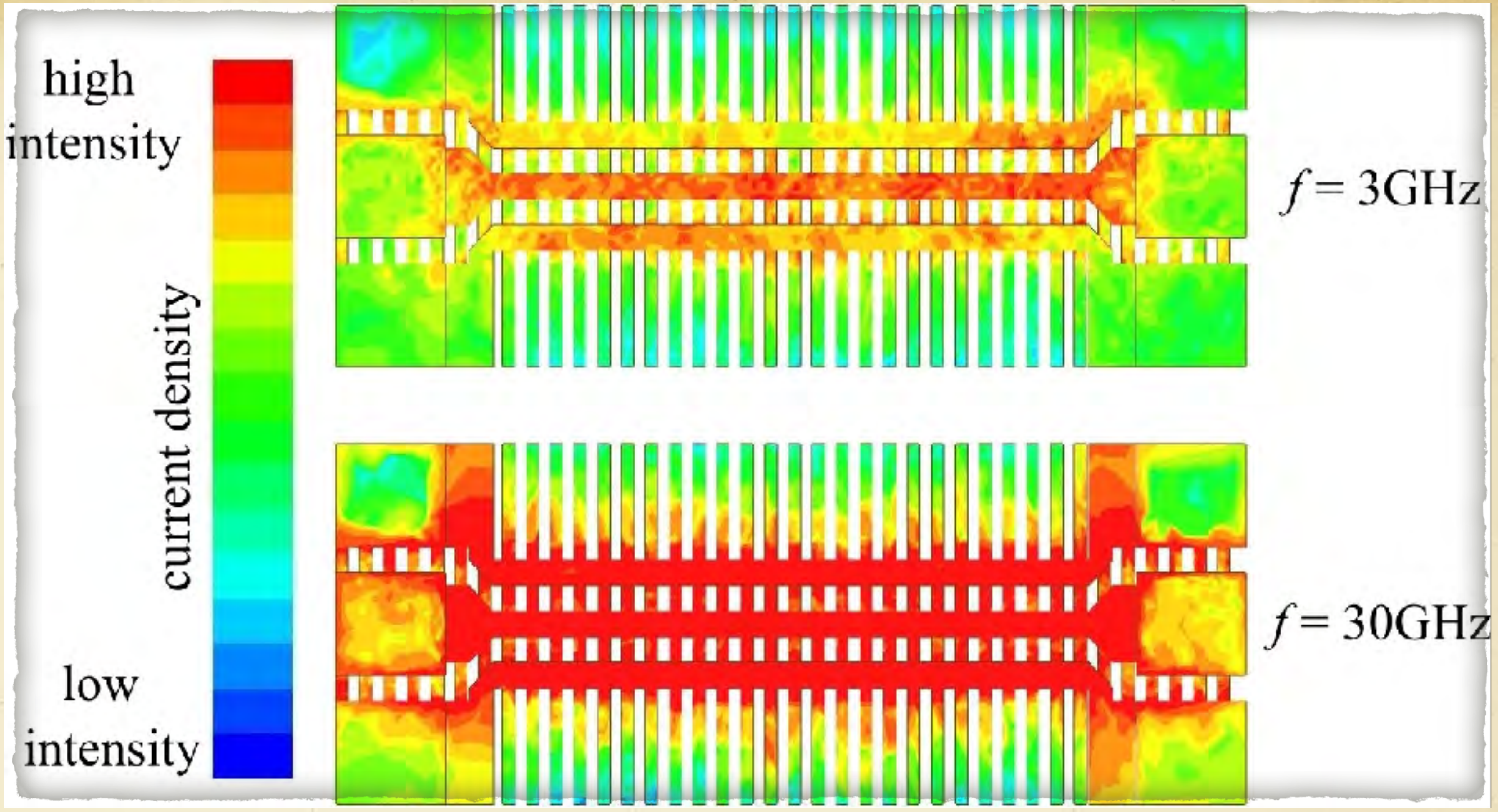
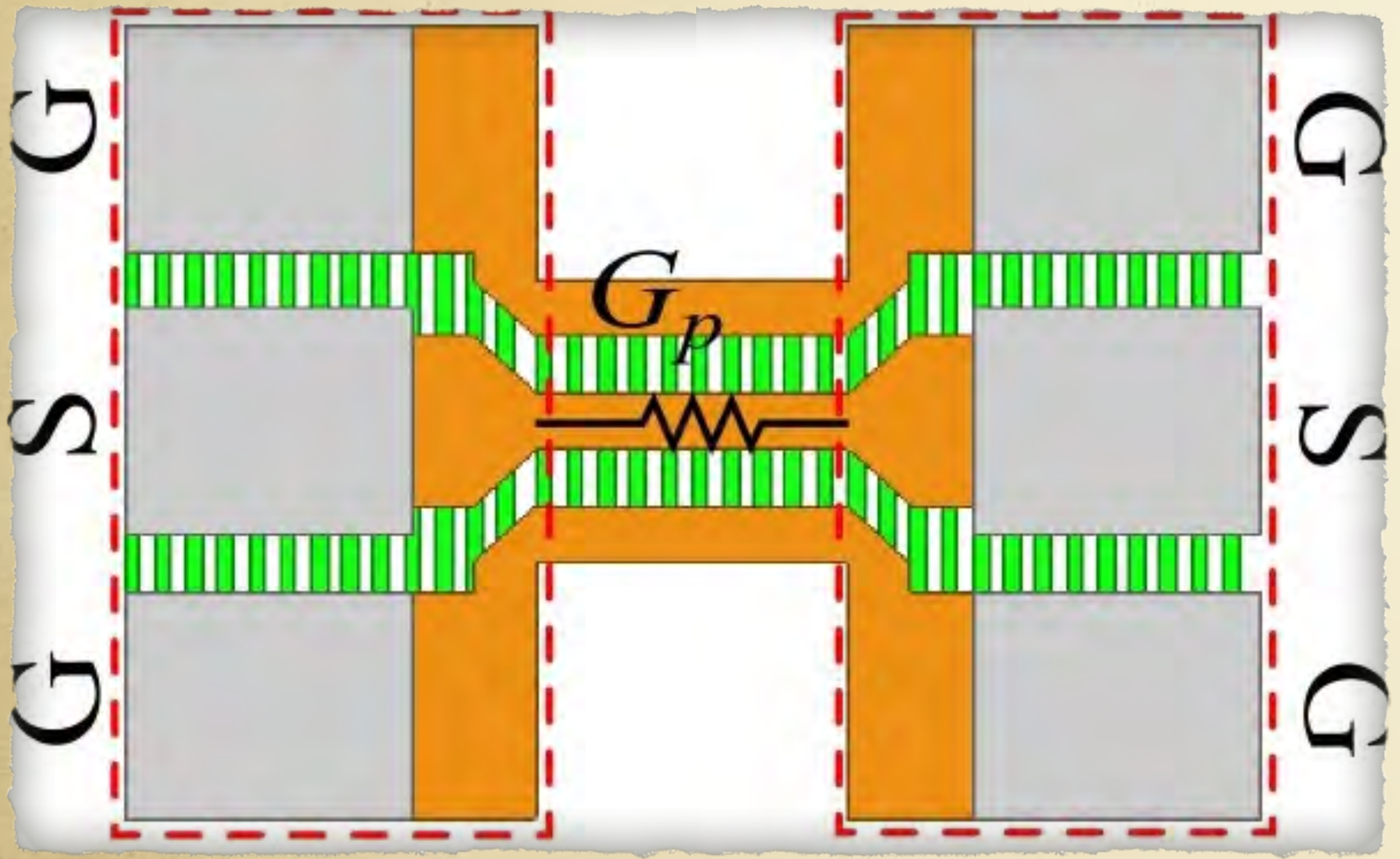
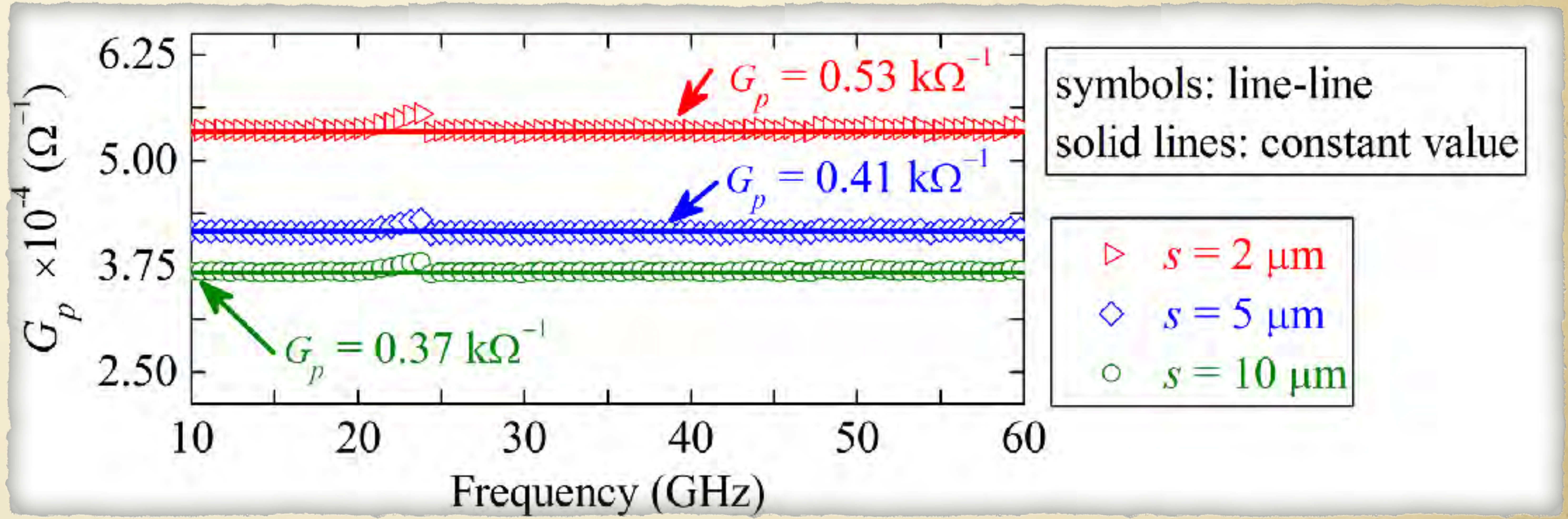


- **Current density substantially increases in the PGS at high frequencies.**
- **The impedance of the shield is reduced with frequency, forming a path in the direction of propagation.**
- **This increases current flow through the shield, and promotes an undesired coupling of the CPW's input and output ports.**

"Determination of the Contribution of the Ground-Shield Losses to the Microwave Performance of On-Chip Coplanar Waveguides", J. Valdés, R. Murphy, R. Torres, IEEE Transactions on Microwave Theory and Techniques, Vol. 69, No. 3, March 2021, pp. 1594-1601. DOI: 10.1109/TMTT.2021.3053548

# The effect is also a function of path separation (gap)





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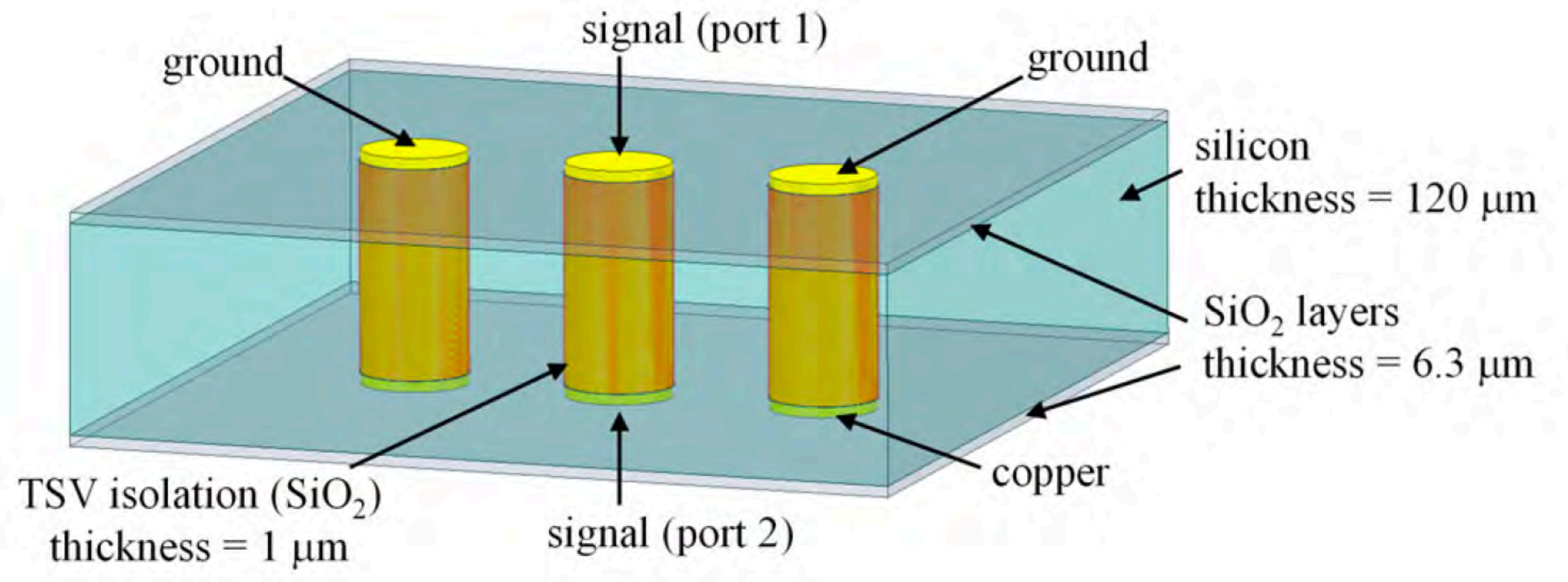
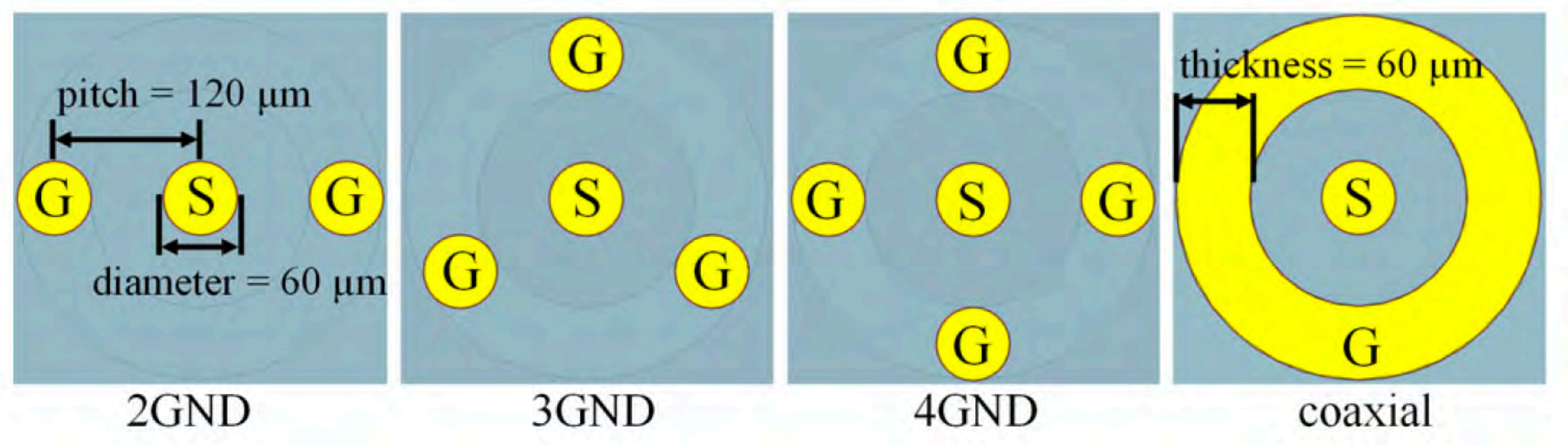
# Trough Silicon Vias (TSVs)



“Assessment of through-silicon-vias with different configurations of ground vias and accounting for substrate losses”, Y. Rodríguez, R. Murphy, R. Torres, International Journal of RF and Microwave Computer-Aided Engineering, July 2021, pp. 1-9. DOI: 10.1002/mmce.22811

# Trough Silicon Vias (TSVs)



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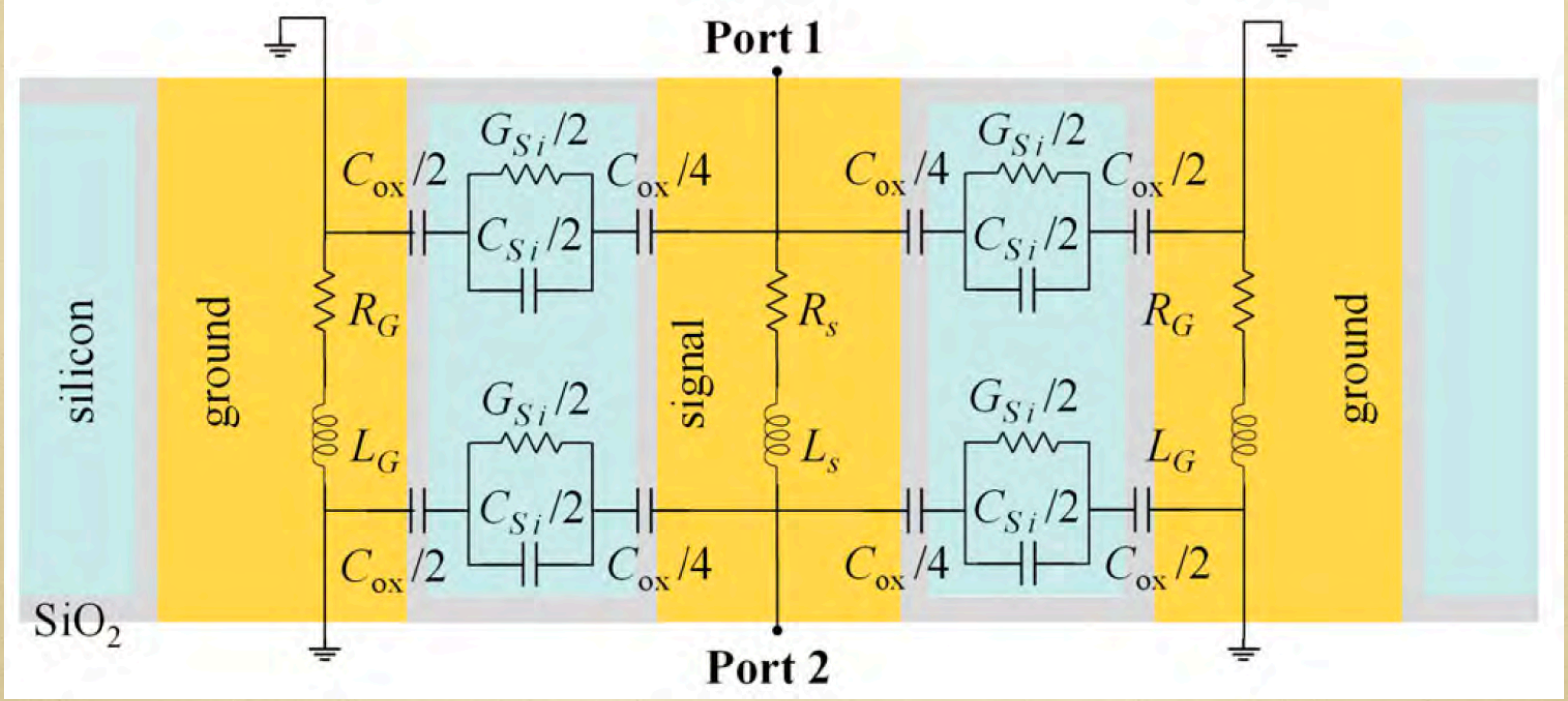

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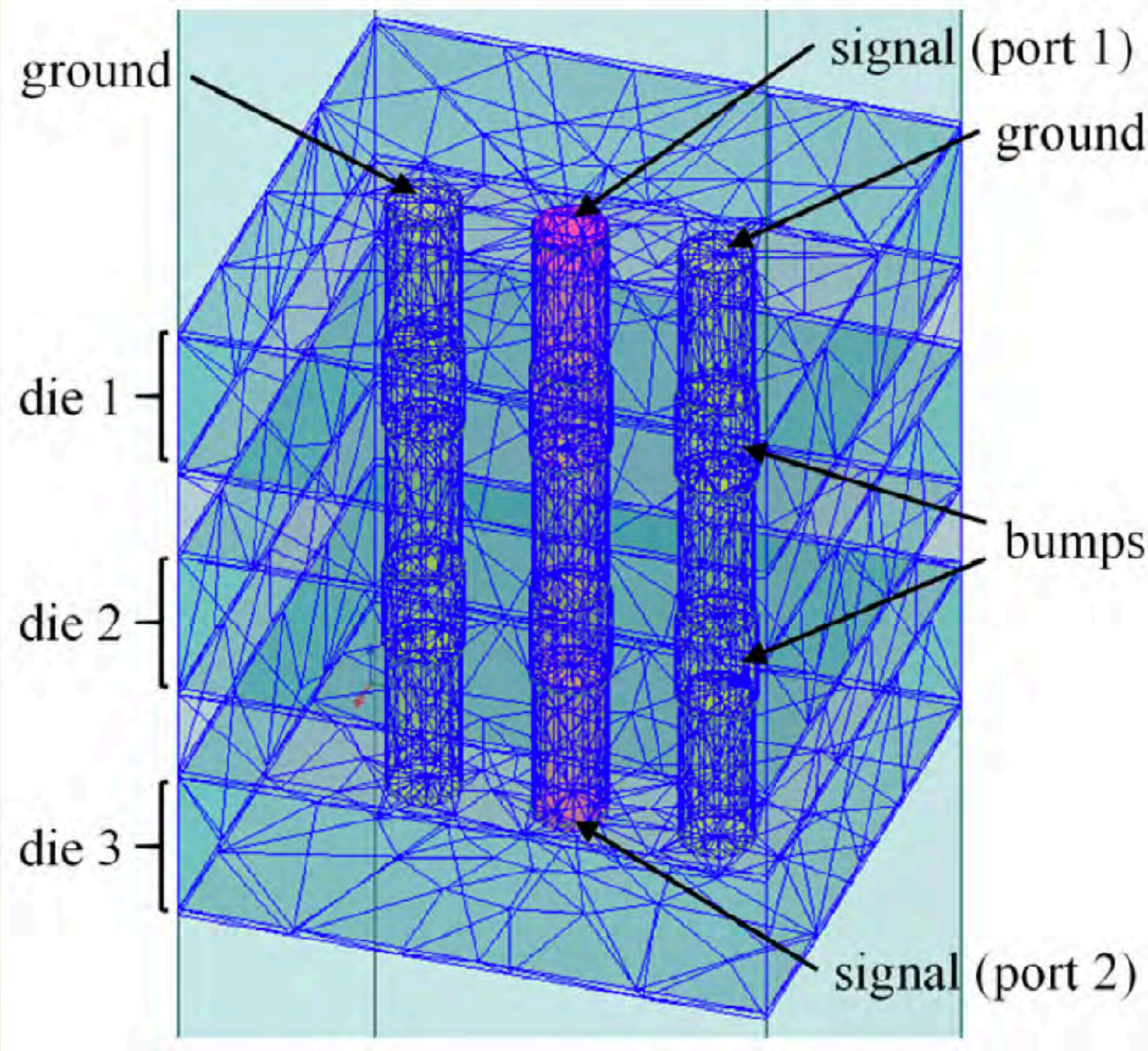
# Multi-stacked chips



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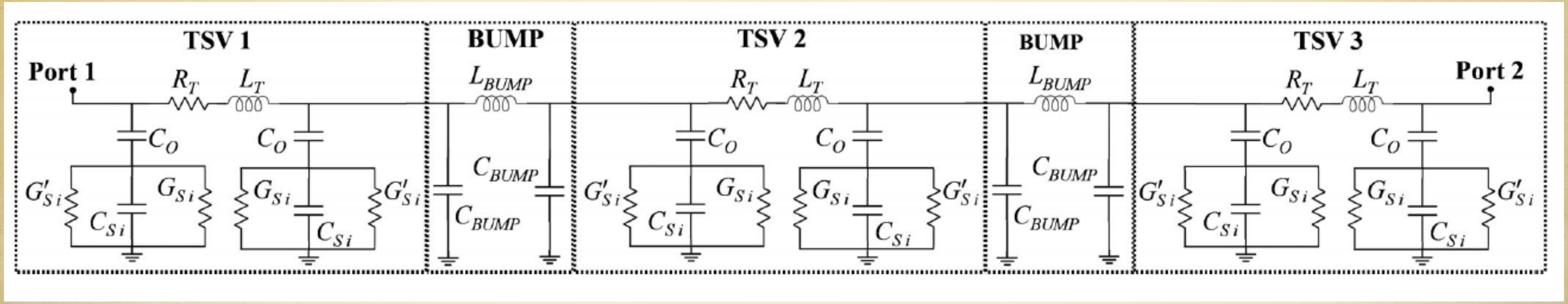
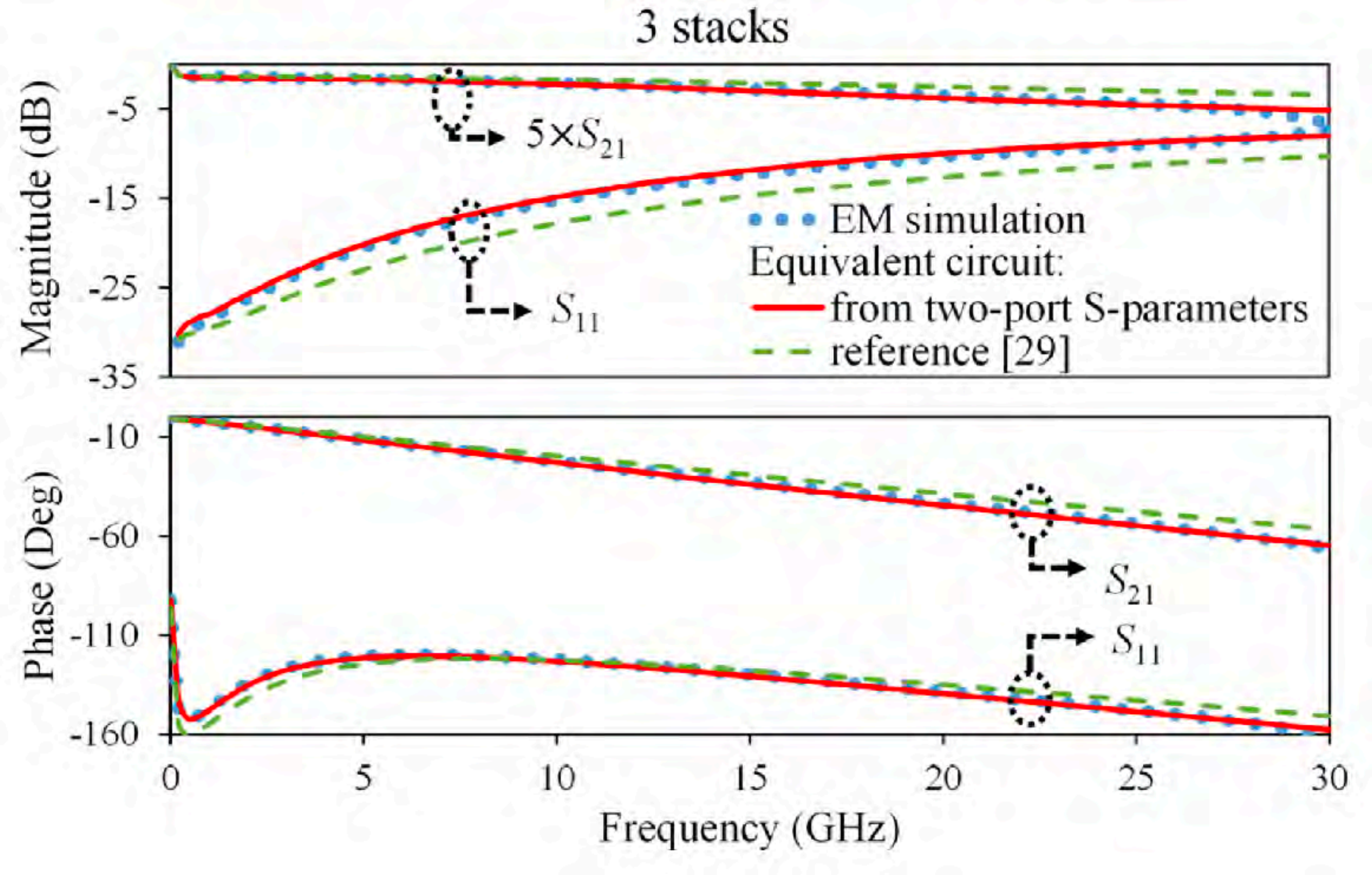


**SPICE compatible model for interconnects to three chips, including solder bumps.**

“Assessment of through-silicon-vias with different configurations of ground vias and accounting for substrate losses”, Y. Rodríguez, R. Murphy, R. Torres, International Journal of RF and Microwave Computer-Aided Engineering, July 2021, pp. 1-9. DOI: 10.1002/mmce.22811

# Model comparison to EM simulations and reported data.



[29] Lu KC, Horng TS, Li HH, Fan KC, Huang TY, Lin CH. Scalable modeling and wideband measurement techniques for a signal TSV surrounded by multiple ground TSVs for RF/high-speed applications. Proc 62nd Electron Comp Technol Conf. 2012; 1023-1026.

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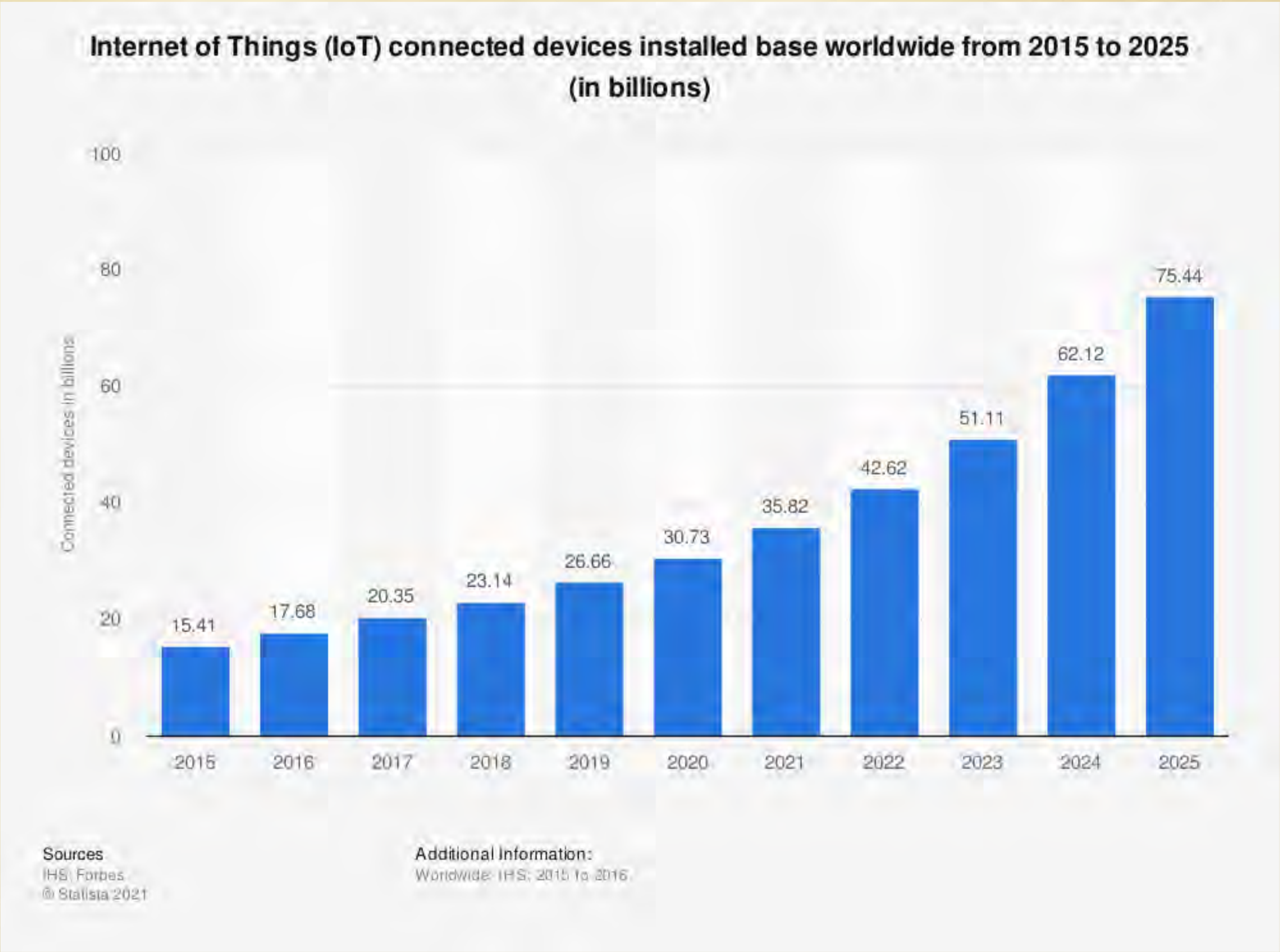
# Antennas On-Chip
# (On-Chip Antennas)

# IoT connected devices. 42.62 billion in 2022; 75.44 billion predicted for 2025.

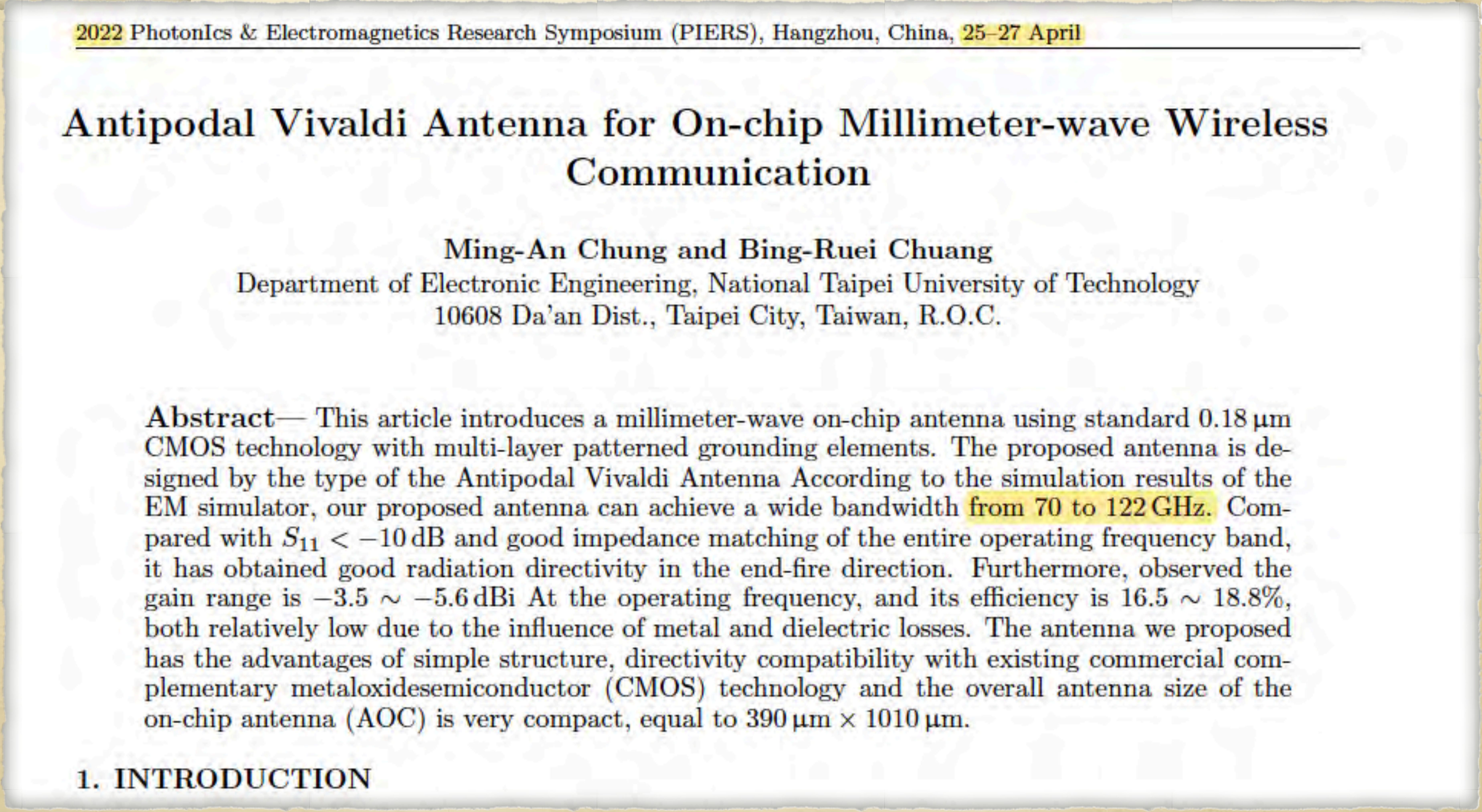


Internet of Things (IoT) connected devices installed base worldwide from 2015 to 2025 (in billions)

Sources
IHS; Forbes
© Statista 2021

Additional Information:
Worldwide; IHS; 2015 to 2016

# On-chip antennas



2022 PhotonIcs & Electromagnetics Research Symposium (PIERS), Hangzhou, China, 25–27 April

## Antipodal Vivaldi Antenna for On-chip Millimeter-wave Wireless Communication

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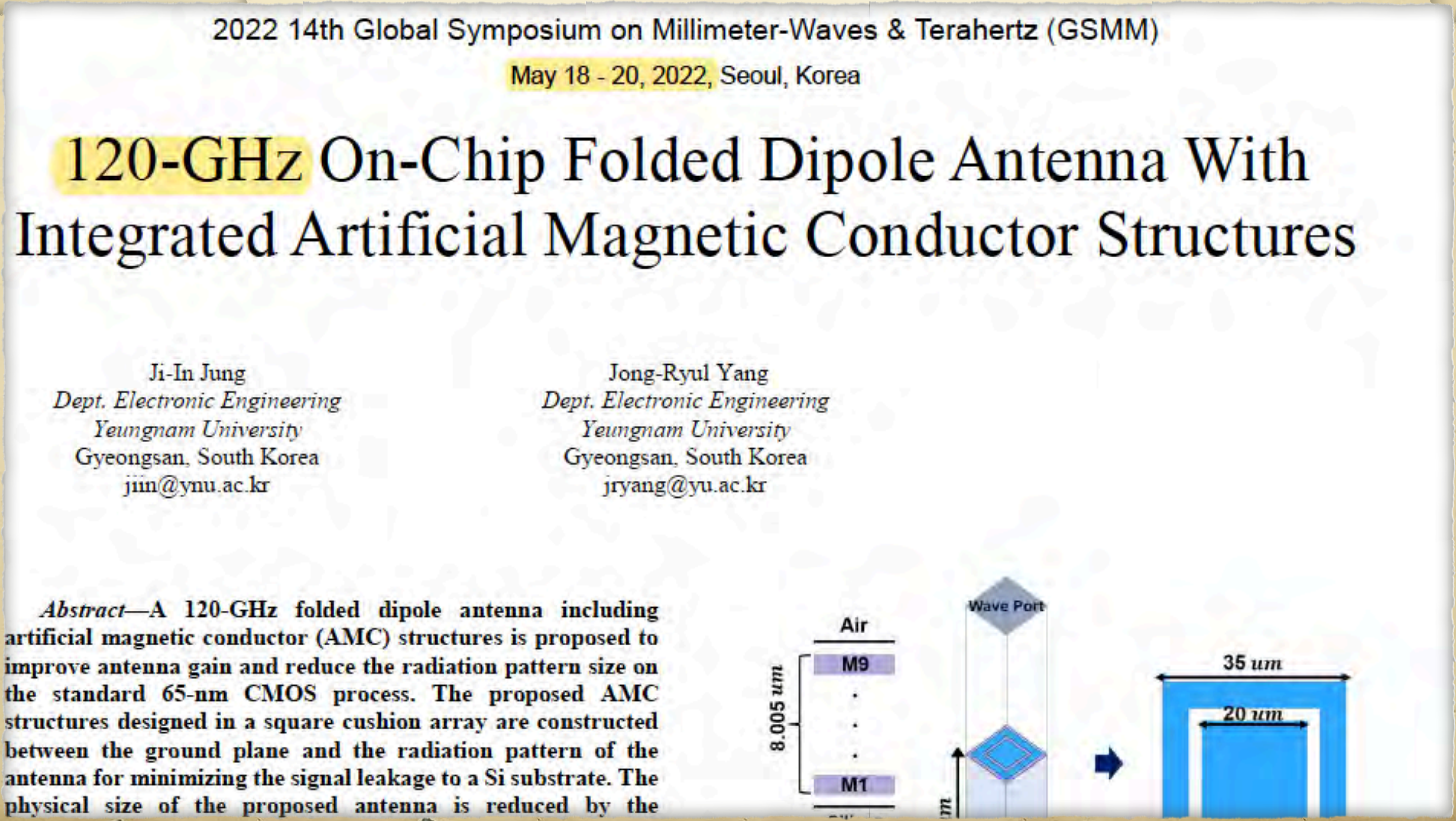
**Abstract**— This article introduces a millimeter-wave on-chip antenna using standard 0.18 µm CMOS technology with multi-layer patterned grounding elements. The proposed antenna is designed by the type of the Antipodal Vivaldi Antenna According to the simulation results of the EM simulator, our proposed antenna can achieve a wide bandwidth from 70 to 122 GHz. Compared with $S_{11} < -10\,\mathrm{dB}$ and good impedance matching of the entire operating frequency band, it has obtained good radiation directivity in the end-fire direction. Furthermore, observed the gain range is $-3.5 \sim -5.6\,\mathrm{dBi}$ At the operating frequency, and its efficiency is $16.5 \sim 18.8\%$, both relatively low due to the influence of metal and dielectric losses. The antenna we proposed has the advantages of simple structure, directivity compatibility with existing commercial complementary metaloxidesemiconductor (CMOS) technology and the overall antenna size of the on-chip antenna (AOC) is very compact, equal to 390 µm × 1010 µm.

## 1. INTRODUCTION

# On-chip antennas



2022 14th Global Symposium on Millimeter-Waves & Terahertz (GSMM)
May 18 - 20, 2022, Seoul, Korea

## 120-GHz On-Chip Folded Dipole Antenna With Integrated Artificial Magnetic Conductor Structures

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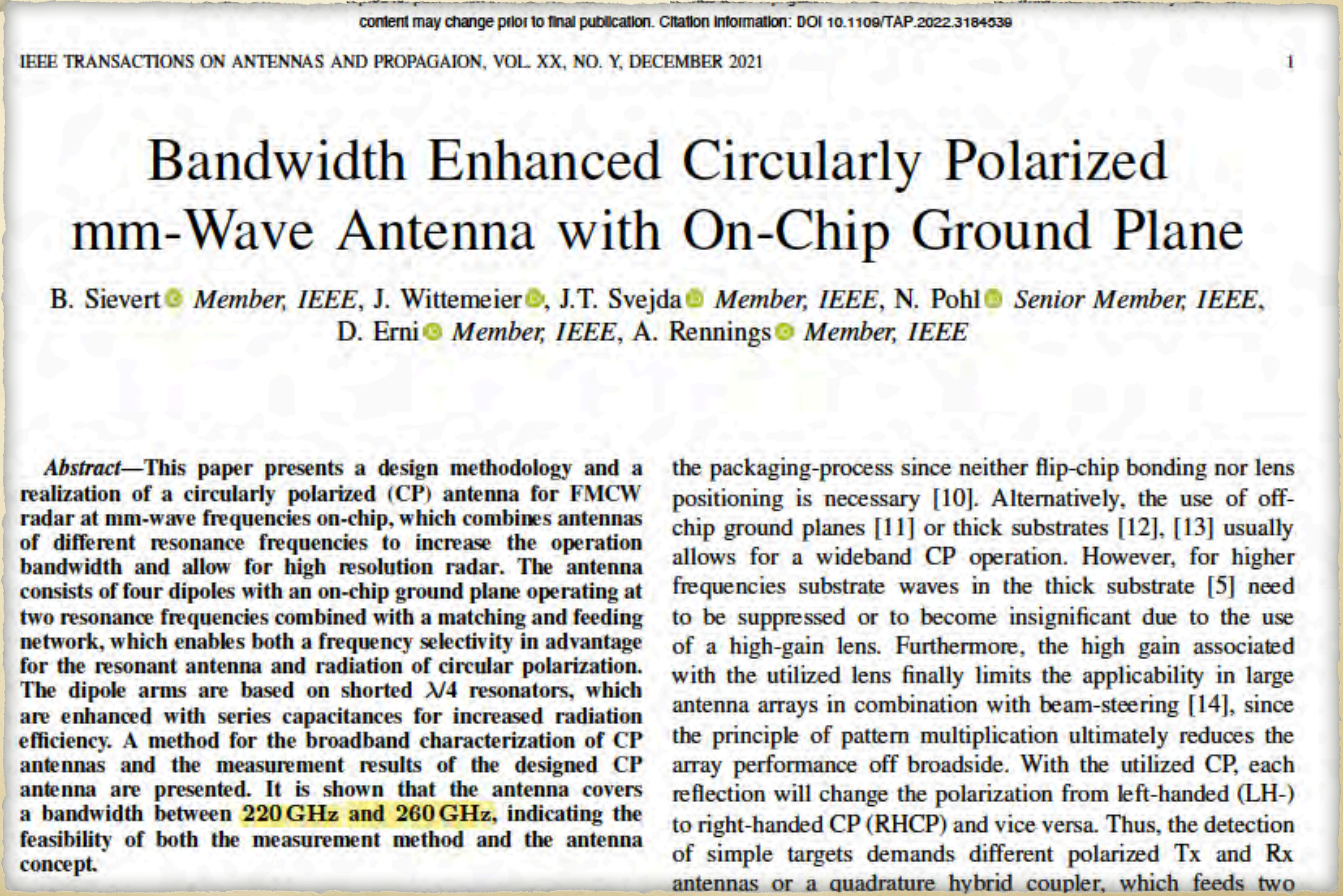
***Abstract*—A 120-GHz folded dipole antenna including artificial magnetic conductor (AMC) structures is proposed to improve antenna gain and reduce the radiation pattern size on the standard 65-nm CMOS process. The proposed AMC structures designed in a square cushion array are constructed between the ground plane and the radiation pattern of the antenna for minimizing the signal leakage to a Si substrate. The physical size of the proposed antenna is reduced by the**

# On-chip antennas



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IEEE TRANSACTIONS ON ANTENNAS AND PROPAGAION, VOL. XX, NO. Y, DECEMBER 2021 1

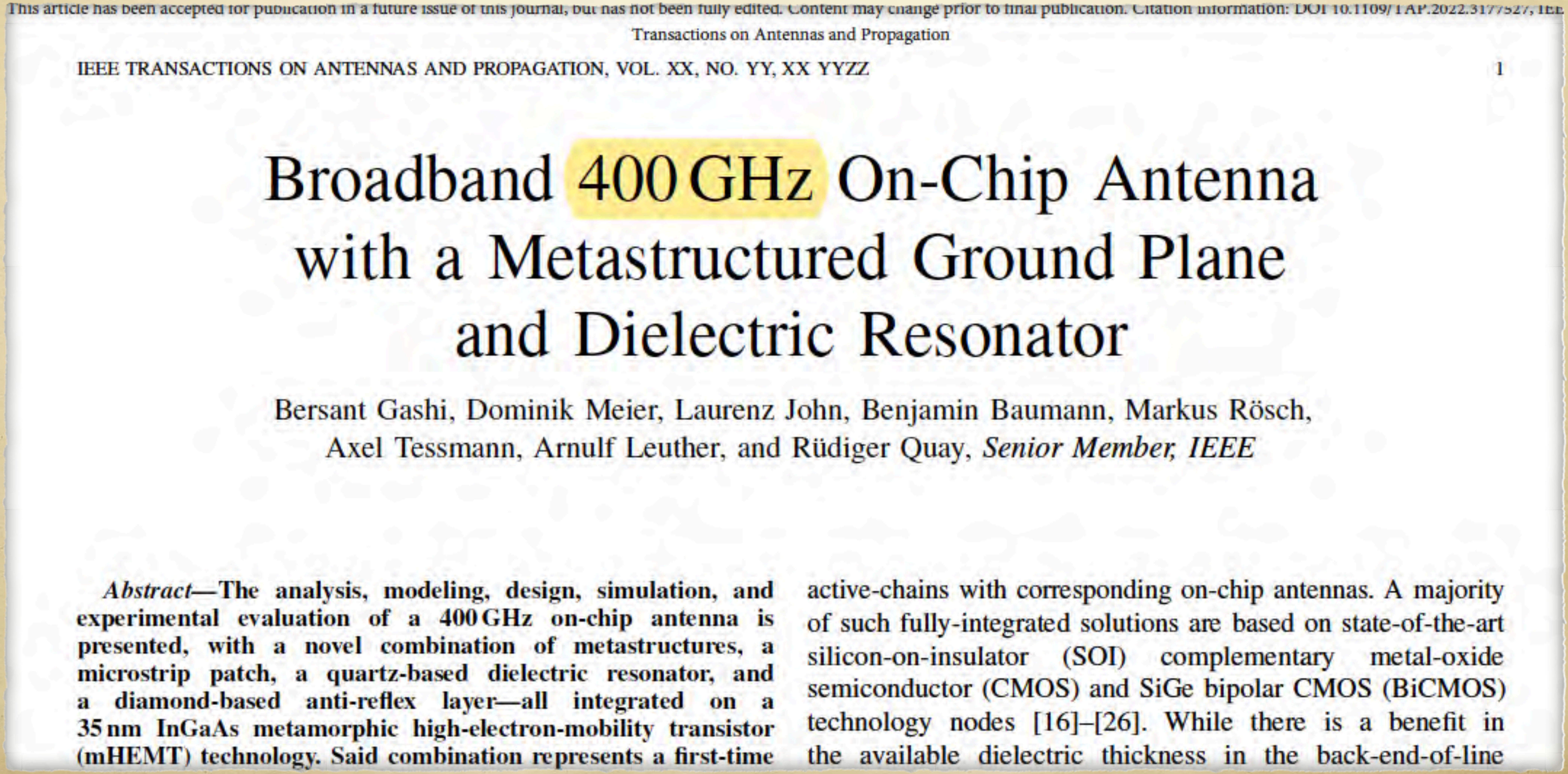
## Bandwidth Enhanced Circularly Polarized mm-Wave Antenna with On-Chip Ground Plane

B. Sievert *Member, IEEE*, J. Wittemeier, J.T. Svejda *Member, IEEE*, N. Pohl *Senior Member, IEEE*,
D. Erni *Member, IEEE*, A. Rennings *Member, IEEE*

***Abstract*—This paper presents a design methodology and a realization of a circularly polarized (CP) antenna for FMCW radar at mm-wave frequencies on-chip, which combines antennas of different resonance frequencies to increase the operation bandwidth and allow for high resolution radar. The antenna consists of four dipoles with an on-chip ground plane operating at two resonance frequencies combined with a matching and feeding network, which enables both a frequency selectivity in advantage for the resonant antenna and radiation of circular polarization. The dipole arms are based on shorted $\lambda/4$ resonators, which are enhanced with series capacitances for increased radiation efficiency. A method for the broadband characterization of CP antennas and the measurement results of the designed CP antenna are presented. It is shown that the antenna covers a bandwidth between 220 GHz and 260 GHz, indicating the feasibility of both the measurement method and the antenna concept.**

the packaging-process since neither flip-chip bonding nor lens positioning is necessary [10]. Alternatively, the use of off-chip ground planes [11] or thick substrates [12], [13] usually allows for a wideband CP operation. However, for higher frequencies substrate waves in the thick substrate [5] need to be suppressed or to become insignificant due to the use of a high-gain lens. Furthermore, the high gain associated with the utilized lens finally limits the applicability in large antenna arrays in combination with beam-steering [14], since the principle of pattern multiplication ultimately reduces the array performance off broadside. With the utilized CP, each reflection will change the polarization from left-handed (LH-) to right-handed CP (RHCP) and vice versa. Thus, the detection of simple targets demands different polarized Tx and Rx antennas or a quadrature hybrid coupler, which feeds two

# On-chip antennas



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Transactions on Antennas and Propagation

## Broadband 400 GHz On-Chip Antenna with a Metastructured Ground Plane and Dielectric Resonator

Bersant Gashi, Dominik Meier, Laurenz John, Benjamin Baumann, Markus Rösch,
Axel Tessmann, Arnulf Leuther, and Rüdiger Quay, *Senior Member, IEEE*

***Abstract*—The analysis, modeling, design, simulation, and experimental evaluation of a 400 GHz on-chip antenna is presented, with a novel combination of metastructures, a microstrip patch, a quartz-based dielectric resonator, and a diamond-based anti-reflex layer—all integrated on a 35 nm InGaAs metamorphic high-electron-mobility transistor (mHEMT) technology. Said combination represents a first-time**

active-chains with corresponding on-chip antennas. A majority of such fully-integrated solutions are based on state-of-the-art silicon-on-insulator (SOI) complementary metal-oxide semiconductor (CMOS) and SiGe bipolar CMOS (BiCMOS) technology nodes [16]–[26]. While there is a benefit in the available dielectric thickness in the back-end-of-line

# On-chip antennas

- As we see from the previous slides, on-chip antennas are a reality.
- As operating frequency increases, more design considerations have to be taken into account, principally signal integrity and electromagnetic compatibility; these are difficult to include at circuit level.
- Thus far, antennas are designed “out-of chip”, and then incorporated to an IC.
- It is clear that there’s an evident need to have compact models for antennas that can be included as a part of the IC design and simulation process.

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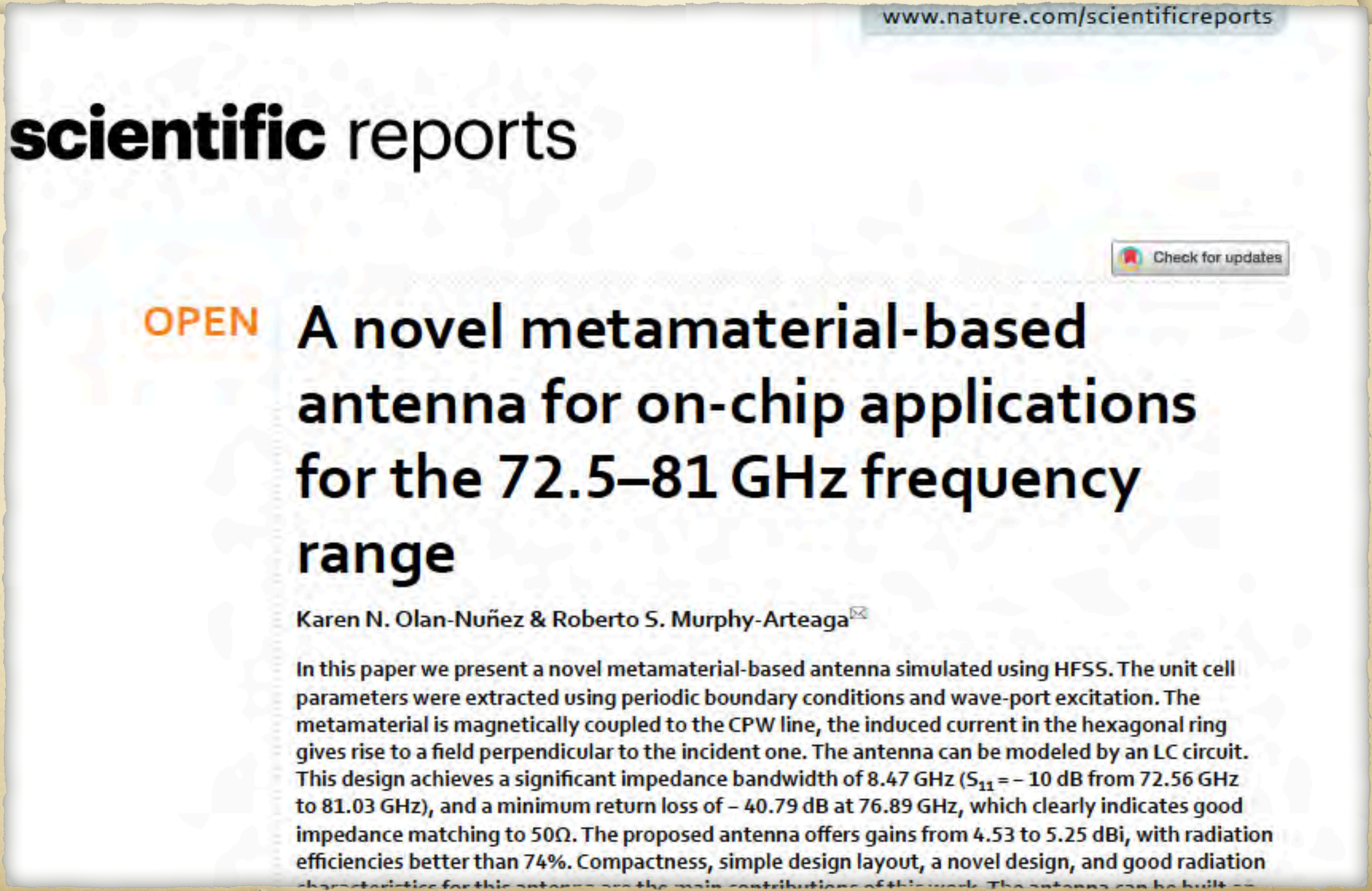

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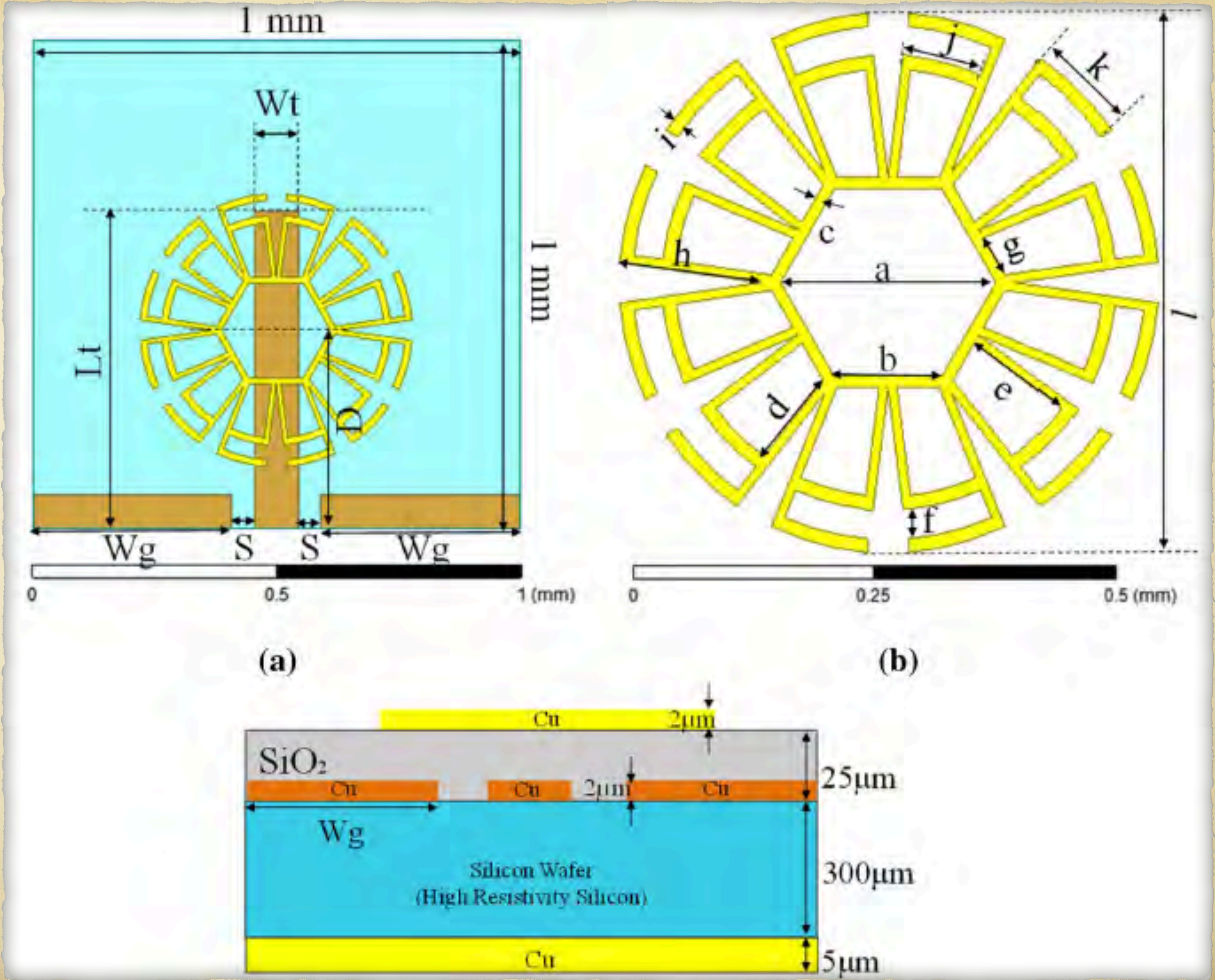
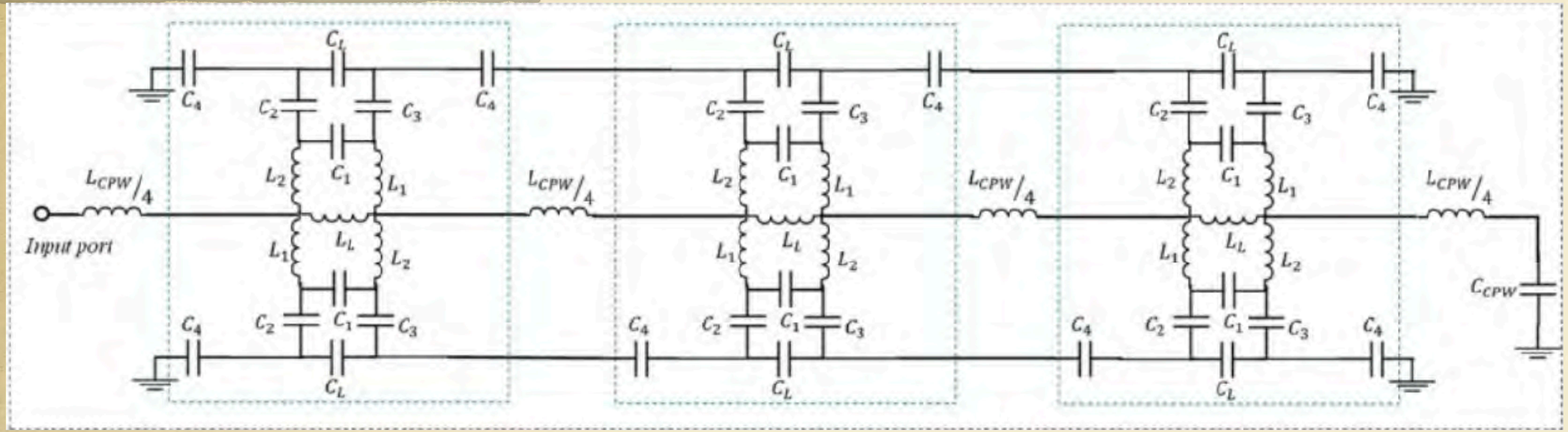
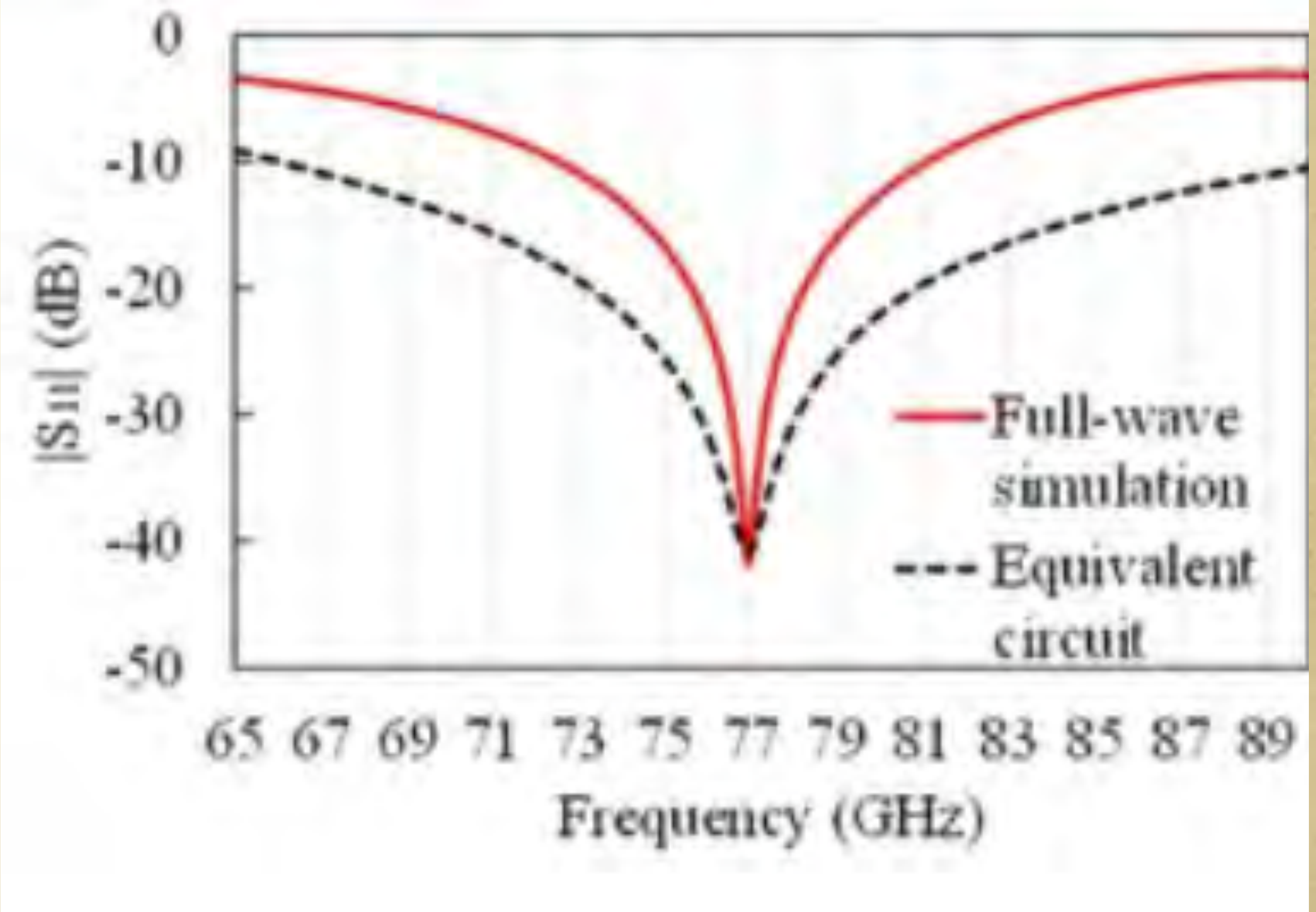
# A novel metamaterial-based antenna for on-chip applications for the 72.5–81 GHz frequency range

Karen N. Olan-Nuñez & Roberto S. Murphy-Arteaga✉

In this paper we present a novel metamaterial-based antenna simulated using HFSS. The unit cell parameters were extracted using periodic boundary conditions and wave-port excitation. The metamaterial is magnetically coupled to the CPW line, the induced current in the hexagonal ring gives rise to a field perpendicular to the incident one. The antenna can be modeled by an LC circuit. This design achieves a significant impedance bandwidth of 8.47 GHz ($S_{11}$ = – 10 dB from 72.56 GHz to 81.03 GHz), and a minimum return loss of – 40.79 dB at 76.89 GHz, which clearly indicates good impedance matching to 50Ω. The proposed antenna offers gains from 4.53 to 5.25 dBi, with radiation efficiencies better than 74%. Compactness, simple design layout, a novel design, and good radiation characteristics for this antenna are the main contributions of this work. The antenna can be built


1 mm
Wt
Lt
D
1 mm
Wg
S
S
Wg
0
0.5
1 (mm)
(a)
j
k
i
c
h
a
g
l
b
d
e
f
0
0.25
0.5 (mm)
(b)
Cu
2μm
SiO₂
Cu
Cu
2μm
Cu
25μm
Wg
Silicon Wafer
(High Resistivity Silicon)
300μm
Cu
5μm





“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

# Conclusion

- **The field of compact modeling grows in importance day by day, as ever more devices can be fit into an IC.**
- **Besides active devices, passive ones have to also be modeled in order to guarantee the correct response of the circuit, first at the simulation level, and then in practice.**
- **Good models also give insight into the physical behavior of the device, circuit or system.**
- **As technology progresses, the need for more sophisticated ICs arises.**
- **Thus, compact modeling continues to be a very fertile and promising field of endeavor.**

- **Technological evolution has made it possible to include antennas on the same chip, covering a host of applications for wireless communications.**
- **The use of metamaterial properties is becoming the norm in the design and manufacture of on-chip antennas.**
- **These techniques make it possible to overcome the limitations in antenna design inherent to a silicon substrate.**
- **These facts reinforce the need for further development of compact models to include a slew of additional components to satisfactorily model, design, simulate and manufacture silicon-based RF integrated circuits.**

# Thank you for your kind attention!

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