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Propagation Channel in Silicon in the Sub-THz Band for MPSoC

Ihsan EL MASRI, Student Member, IEEE,
Thierry LE GOUGUEC, Member, IEEE,
Pierre-Marie MARTIN, Member, IEEE,
Rozenn ALLANIC, Member, IEEE,
Cedric QUENDO, Senior Member, IEEE

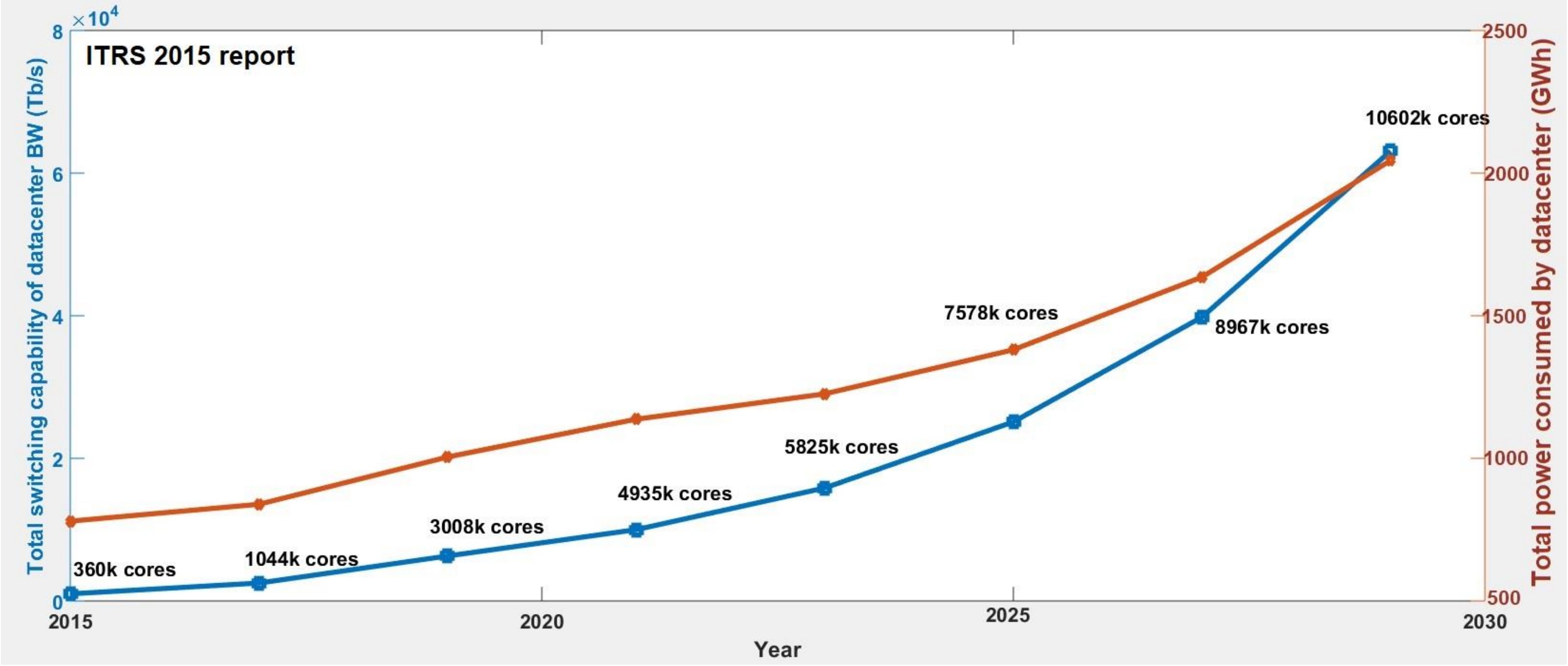
Plan

- Introduction
- Propagation channel in V band
- Propagation channel in the Sub-THz band
- Conclusion

Introduction

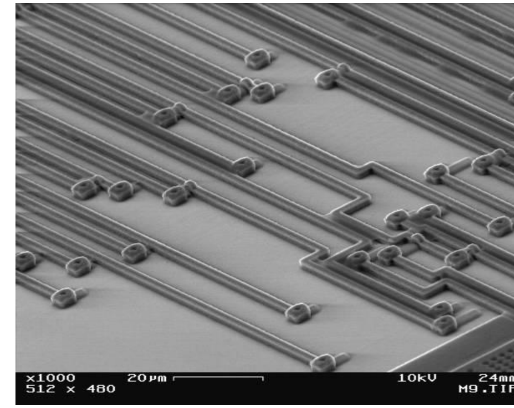
- **Multi processor system-on chip (MPSoC):**
  -> new applications :

Defense & Cyber-security | Artificial Intelligence (AI) | Multimedia applications | Internet of things (IoT)



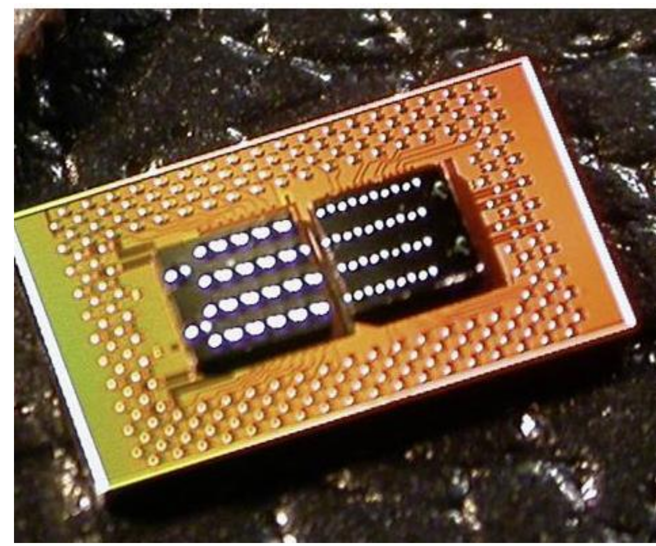
Introduction

- The classical metal interconnects constraints:
  a) High latency.
  b) High power consumption.
  c) Routing complexities.



Classical metal interconnects (Intel)

- Proposed alternatives :
  1. 3D interconnections.
  2. Optical interconnections.
  3. Carbone Nano-Tubes (CNT).
  4. RF interconnections .
  5. **Wireless interconnections.**



Optical interconnections (IBM)

IEEE Région Bretagne CominLabs UNIVERSITE BRETAGNE LOIRE UBO Université de Bretagne Occidentale Lab-STICC cnrs

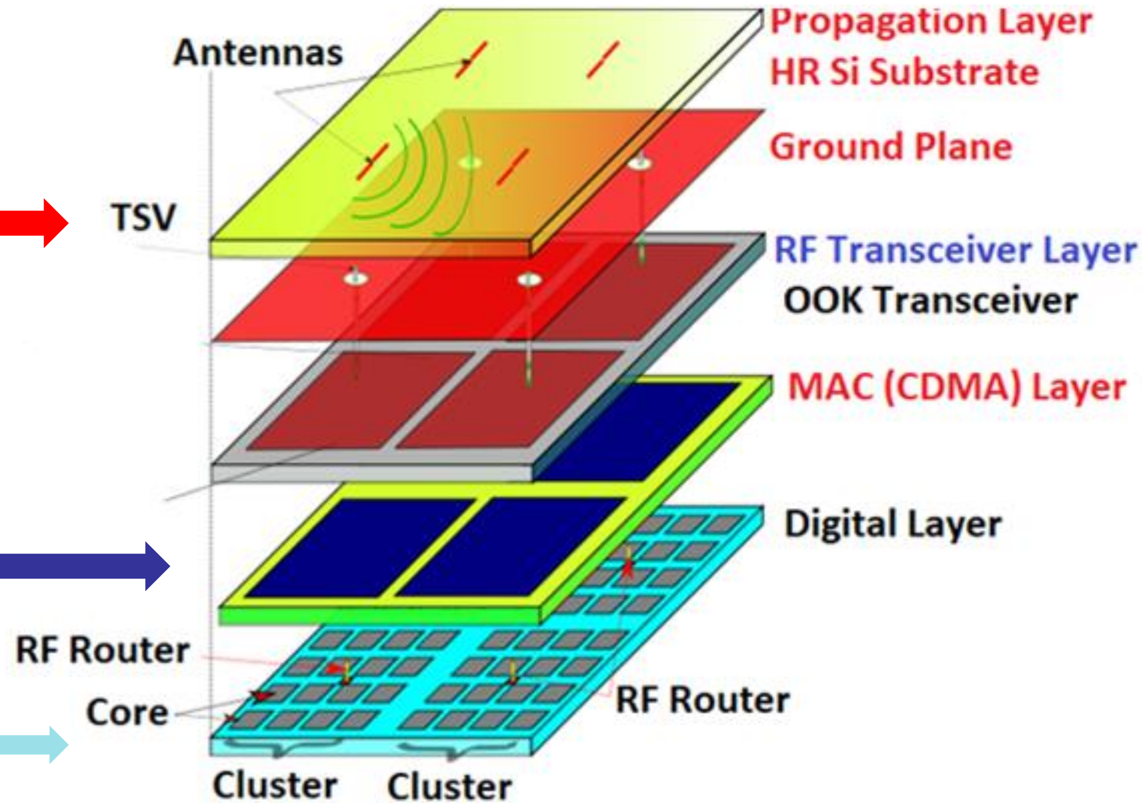
Introduction

- **BBC** project (on-chip wireless **B**roadcast-**B**ased parallel **C**omputing)
  -> **W**ireless **I**nterconnects **N**etwork-**O**n-**C**hip **(WiNoC):**

1) Physical layer:
Propagation channel/ Antennas/ Transceivers

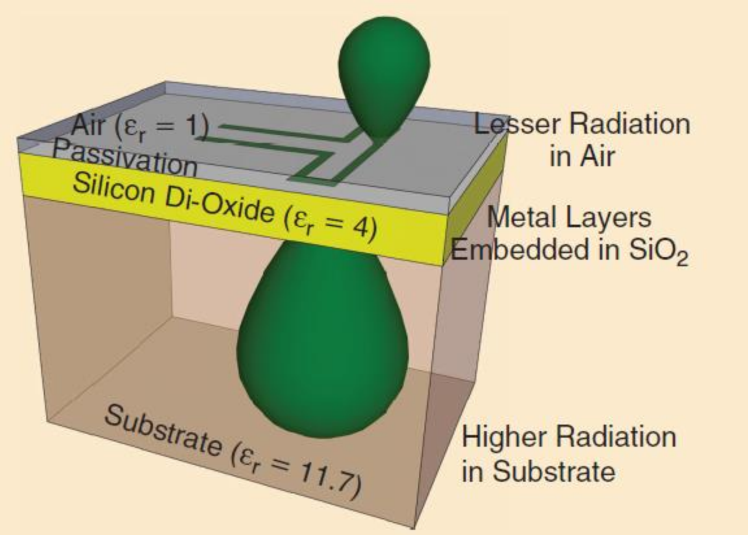
2) Data link (MAC) layer:
Coding (CDMA)

3) Network layer :
Routing algorithm



Introduction

- WiNoC applications => **CMOS technology => Silicon substrate**
- Problems due to the Silicon substrate:
  1. $\varepsilon_{r-\mathrm{Si}} = 11{,}9$ & LR-Si*: ρ = 10 Ω.cm => low antenna efficiency
  2. $\varepsilon_{r-\mathrm{Si}} = 11{,}9$ **>>** $\varepsilon_{\mathrm{air}} = 1$ => reflections on **PMC**** walls and a **resonant cavity**.



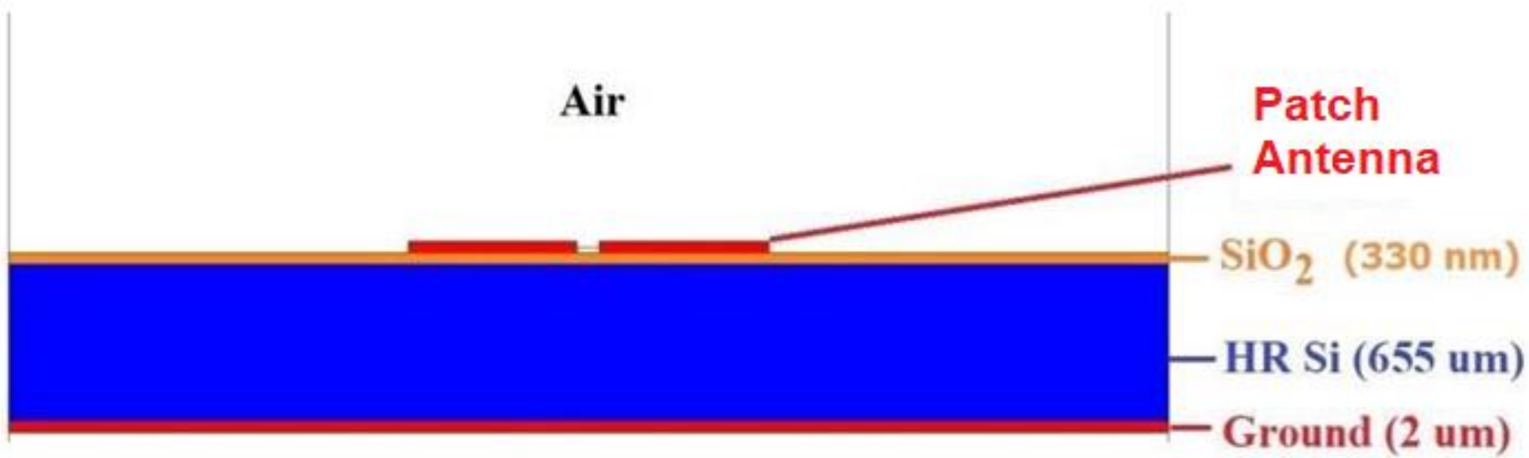
A radiation pattern for a typical integrated antenna on Silicon [1]

* LR-Si: Low resistivity Silicon; ** PMC : Perfect Magnetic Conductor

[1] H. M. Cheema and A. Shamim, "The last barrier: on-chip antennas," *IEEE Microwave Magazine*, vol. 14, no. 1, pp. 79–91, Jan. 2013.

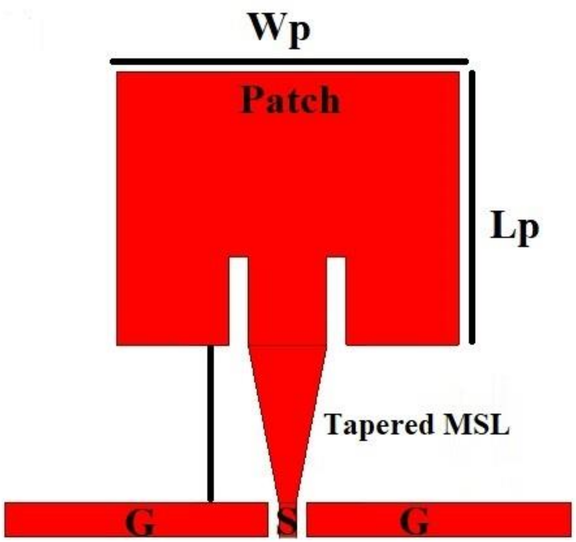
Propagation channel in V band

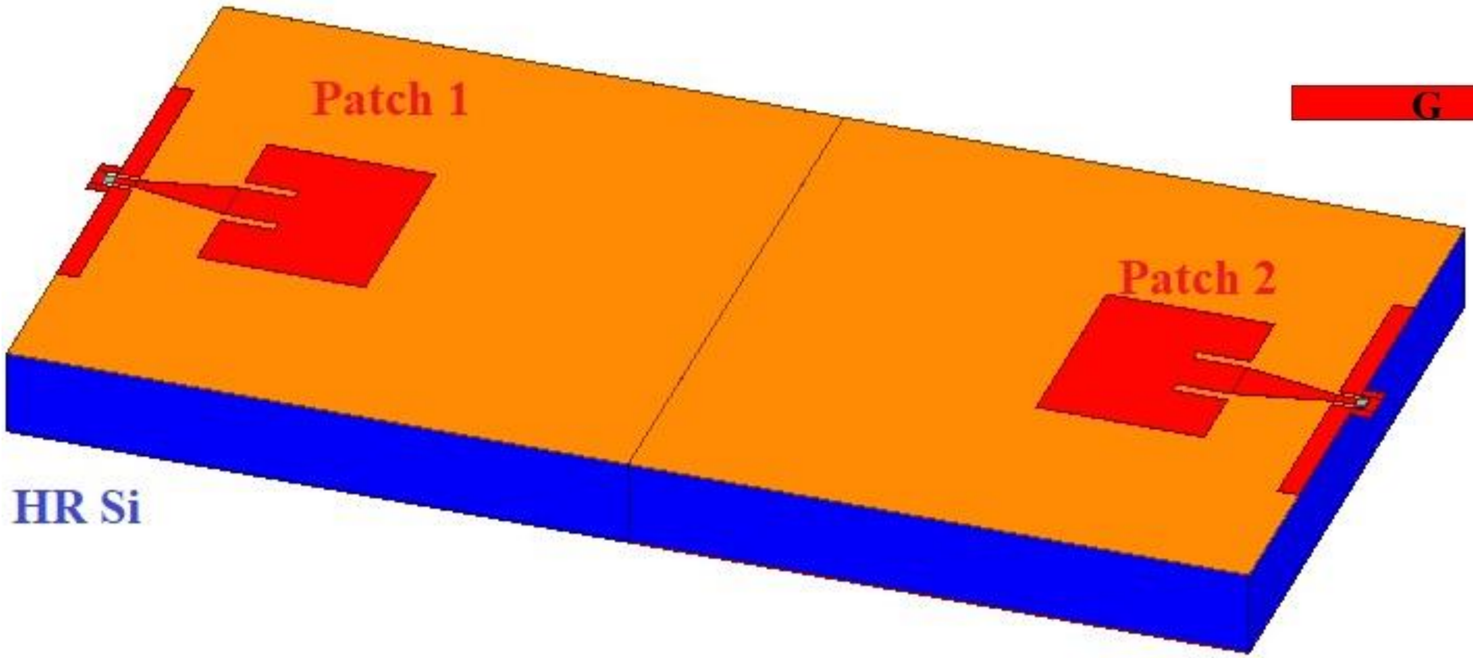
- EM simulation (HFSS) and realization **structure:**
  - High-Resistivity Silicon **(HR-Si)** $(\varepsilon_{Si} = 11,9,\ H_{sub} = 655\ \mu m)$
  - A layer of 330 nm height of SiO_2 $(\varepsilon_{SiO2} = 4)$.



Propagation channel in V band

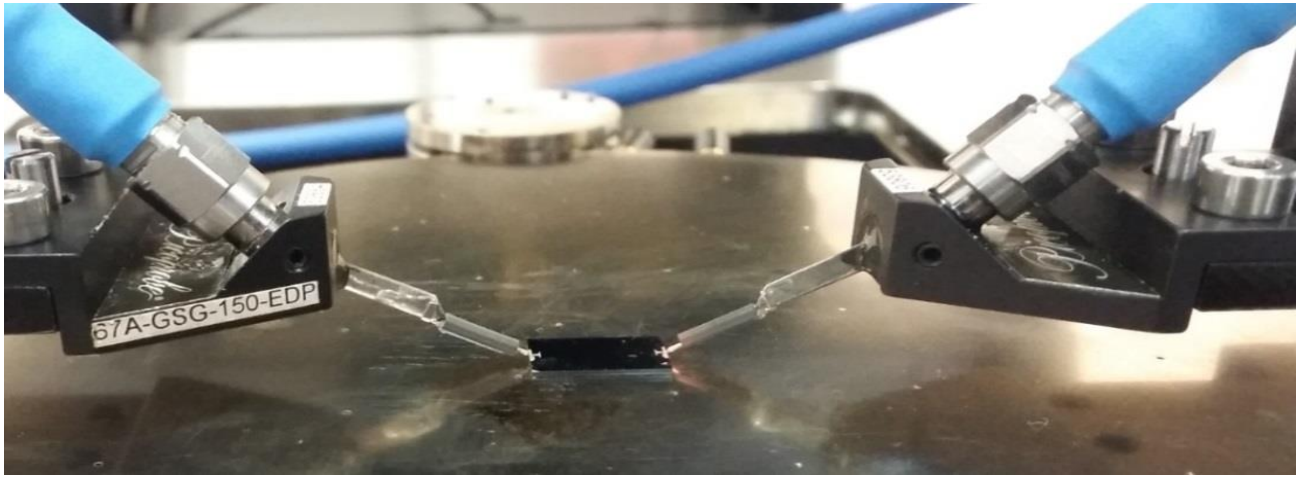
- Propagation channel between 2 patch antennas





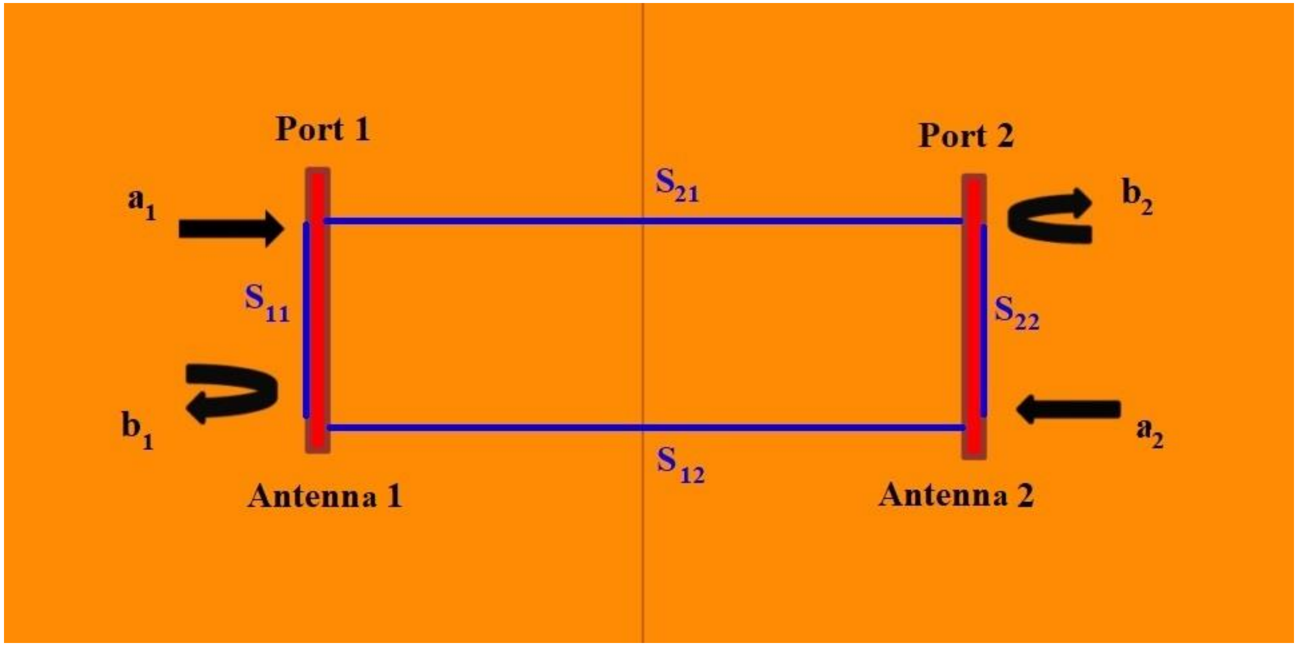
Propagation channel in V band

- First prototype in **V band (40-75 GHz)**.
  - Realization @ GREMAN Laboratory -Tours.
  - Measurement with **GSG probes @ Lab-STICC – BREST**



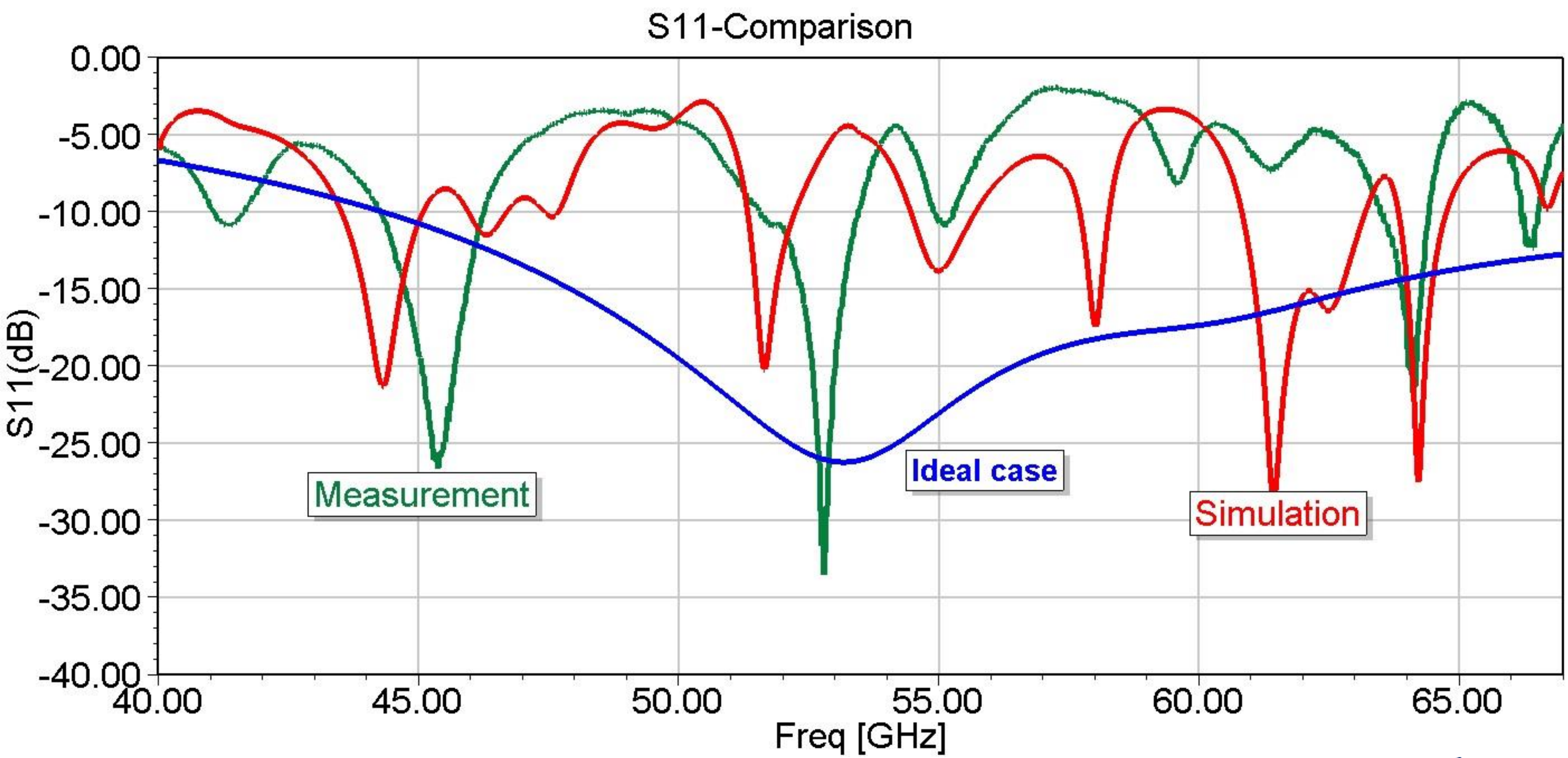
Propagation channel in V band

- Characterization through the S parameters:
  - Reflection: S_{11} or S_{22} : $\boldsymbol{BW_{-10\,dB}(Hz)} \rightarrow \boldsymbol{Matching\ bandwidth}$
  - Transmission: S_{21} or S_{12} : $\boldsymbol{BW_{-3\,dB}(Hz)} \rightarrow \boldsymbol{Transmission\ bandwidth}$



Propagation channel in V band

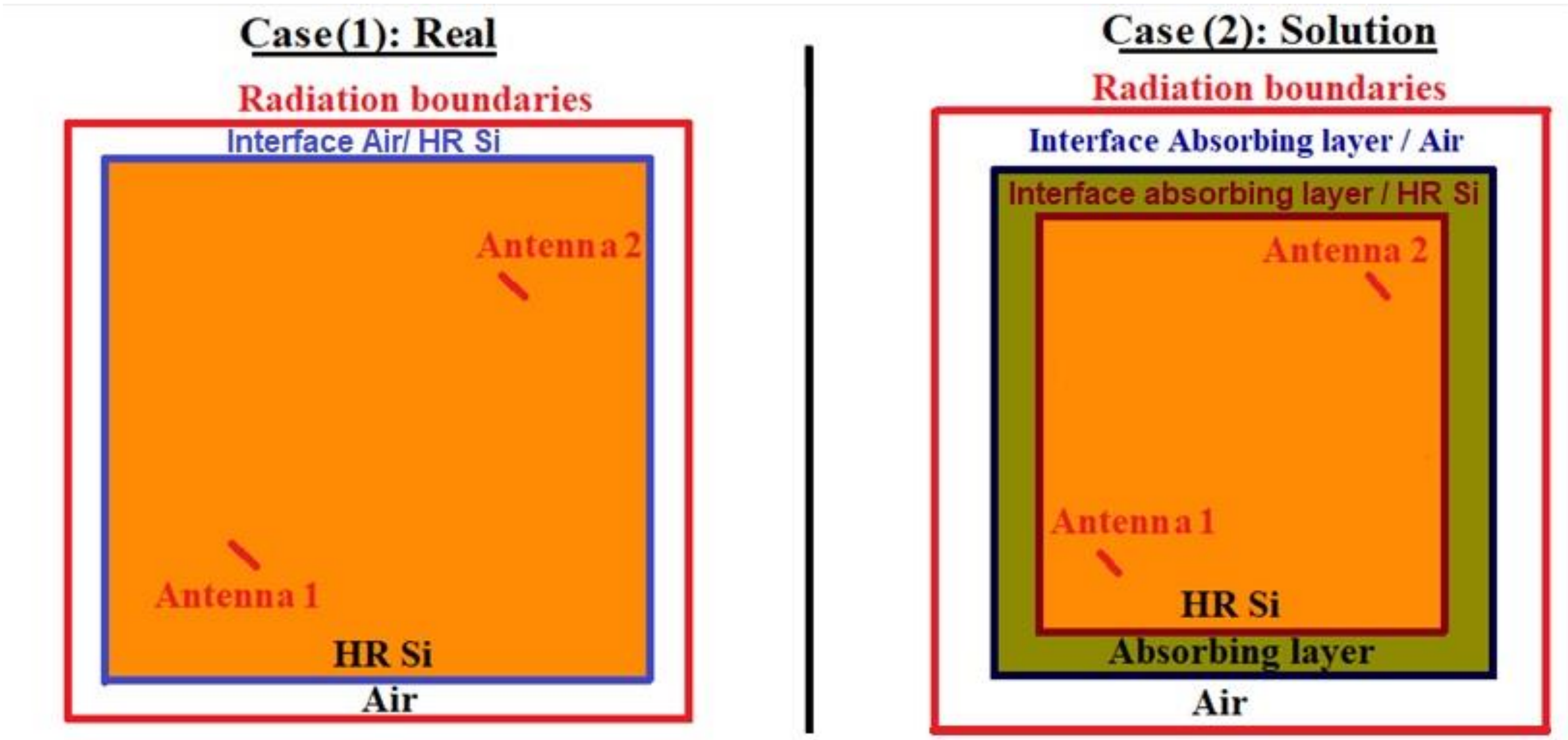
- **Reflection coefficient (S_{11}): Simulated vs. Measured:**
  - Multiple resonances.
  - Cause: cavity effects and multiple substrate modes.



Propagation channel in V band

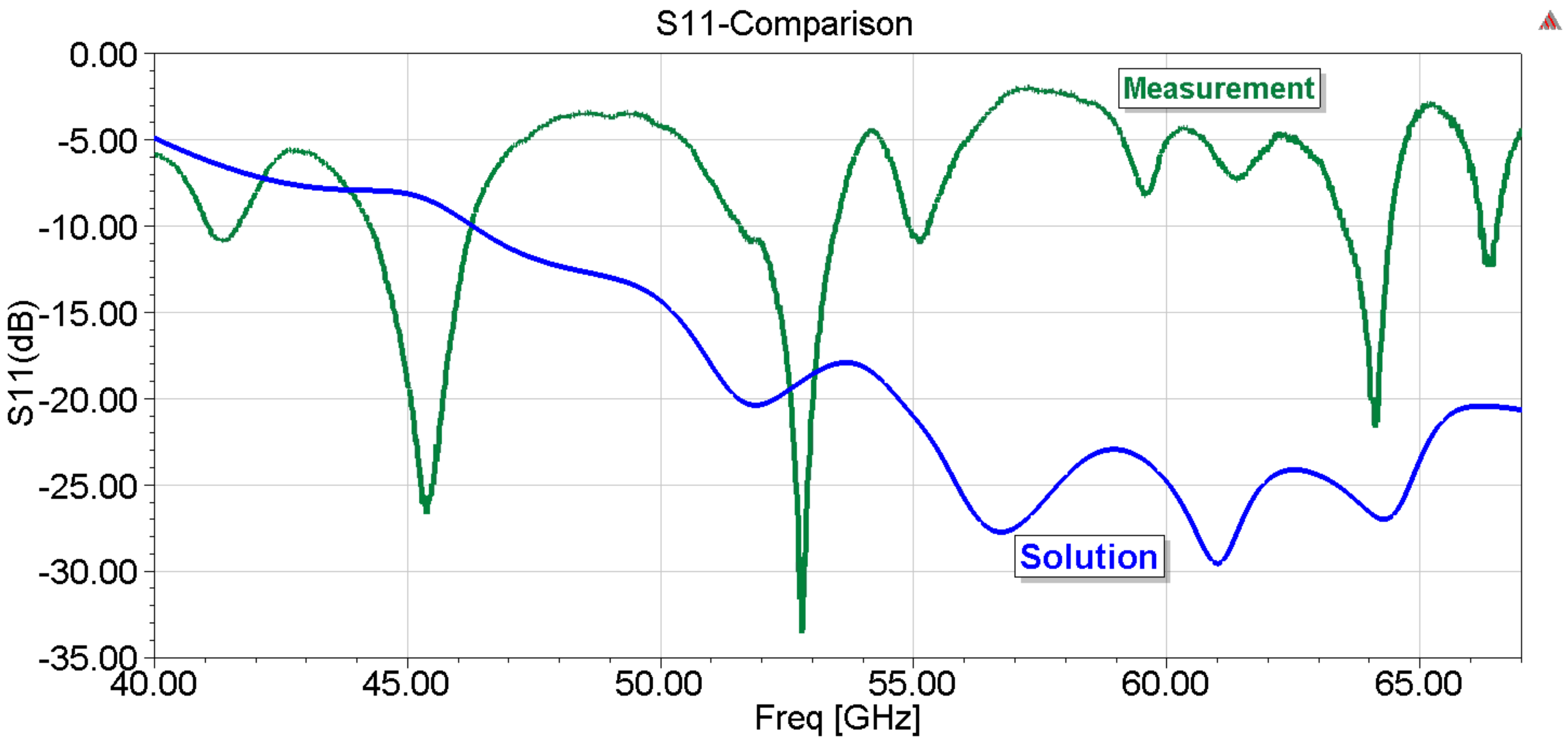
- Solution to the cavity problem and the reflection on the air / Si interface :

  -> Absorbing layer surrounding the Si



Propagation channel in V band

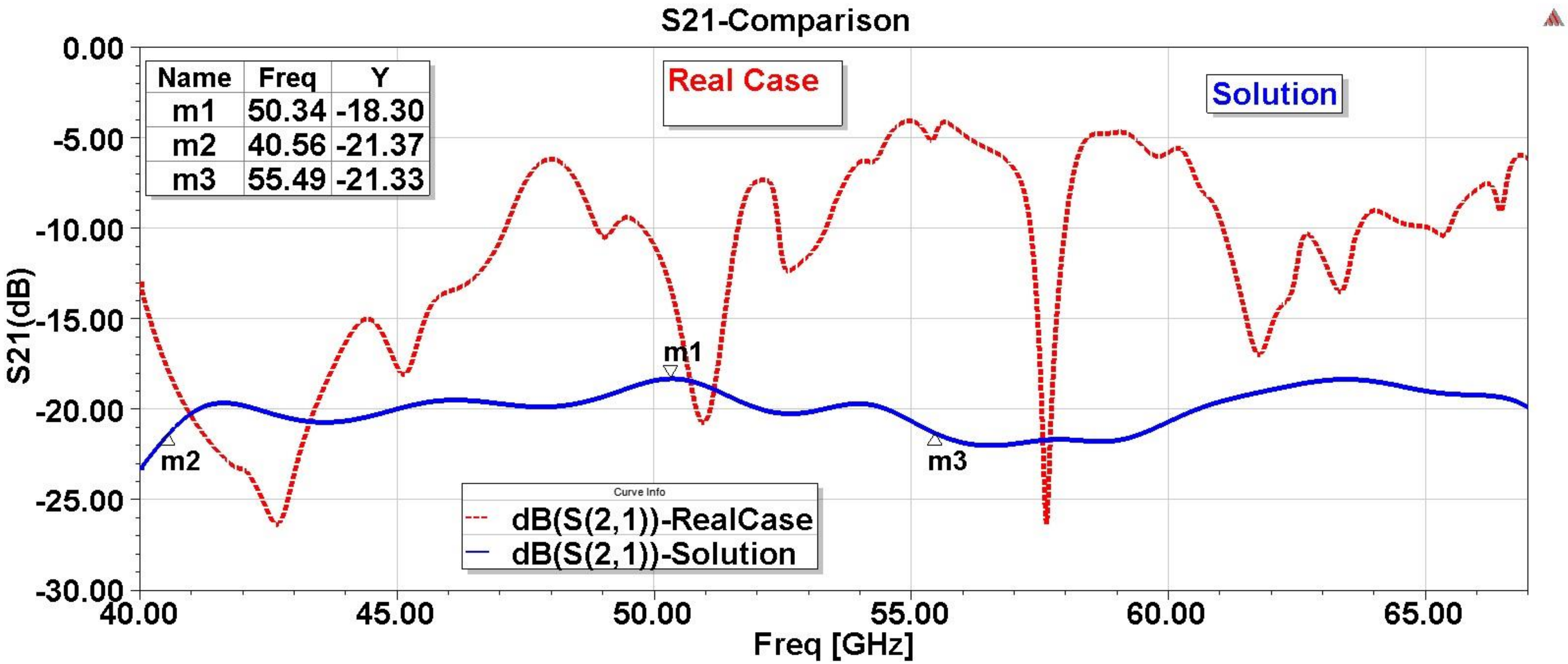
- **Reflection coefficient (S_{11}): Measured vs. Simulated :**
  - Multiple resonances -> Single resonance over a large matching BW.



Propagation channel in V band

- **Transmission coefficient (S_{21}): Simulated :**
  - Multiple transmission zeroes ->

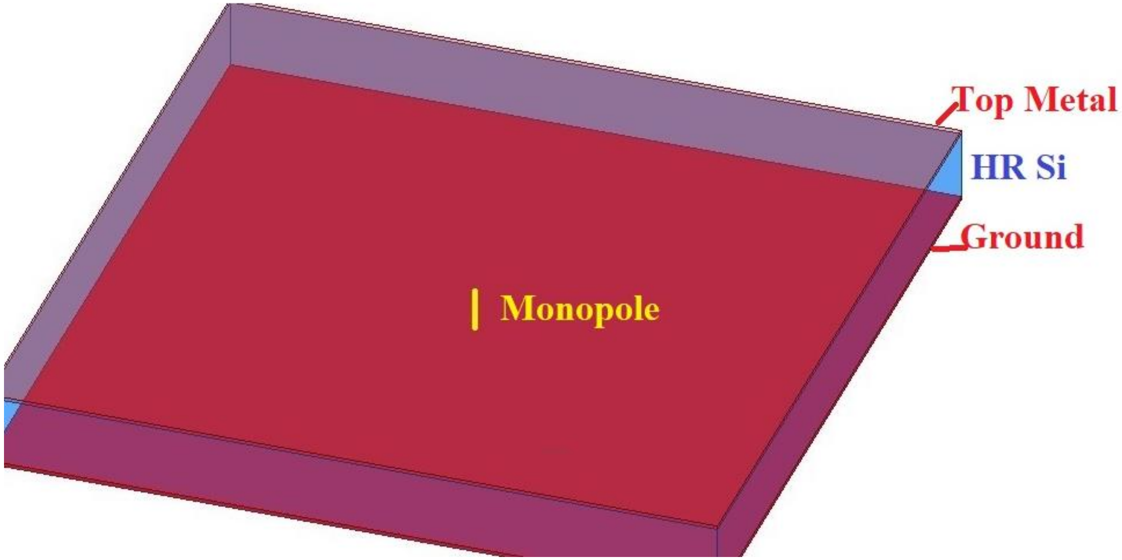
    Stable transmission over a large -3 dB BW .

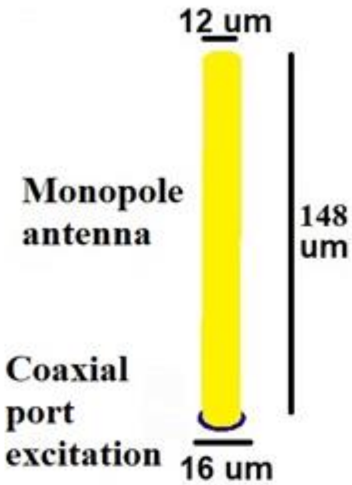


Propagation channel in the Sub-THz band

- **Sub-THz band (30-300 GHz) =>**
  1. High bandwidths : **10% = 20 GHz @ 200 GHz**
  2. Reduced size of the antennas:

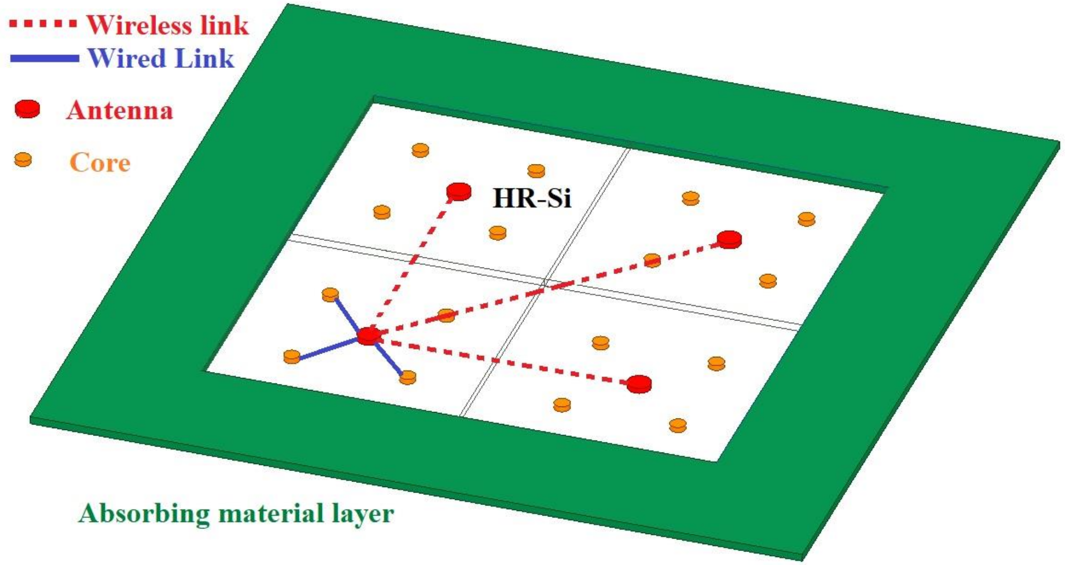
  λ ≈ 435µm @ 200 GHz on Si **-> Vertical monopoles** embedded in the substrate **-> Multicast + Broadcast**





Propagation channel in the Sub-THz band

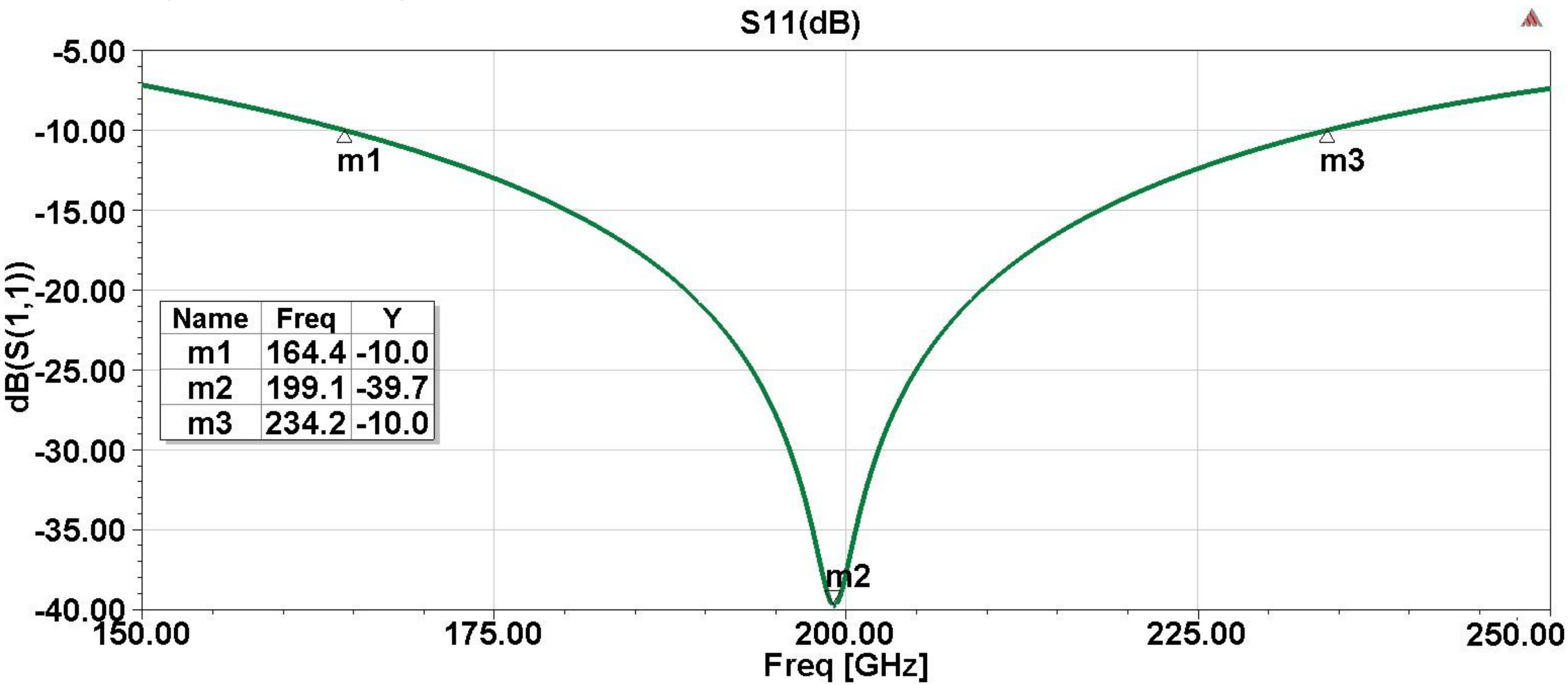
- **Surrounding absorbing layer => No cavity** problem



- **Two metallic planes** (top and bottom)=> HR Si as a **2D guiding media** + **No EMC** problem

Propagation channel in the Sub-THz band

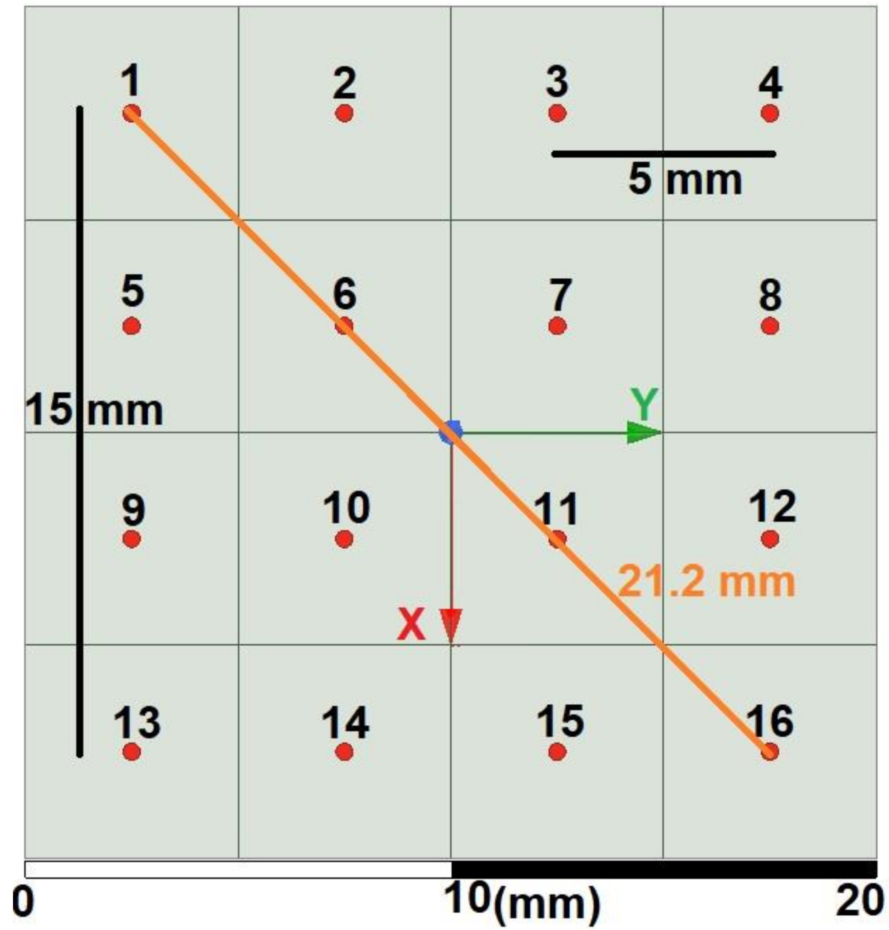
- **Reflection coefficient (S_{11}): Simulated :**
  - Single resonance.
  - Large matching BW : 70 GHz (≈ 35 %)



Propagation channel in the Sub-THz band

- **A realist Many-Core scenario:**
  a) Squared mesh with 16 monopoles
  b) 1 Antenna per cluster
  c) 8 cores per cluster => 128 cores

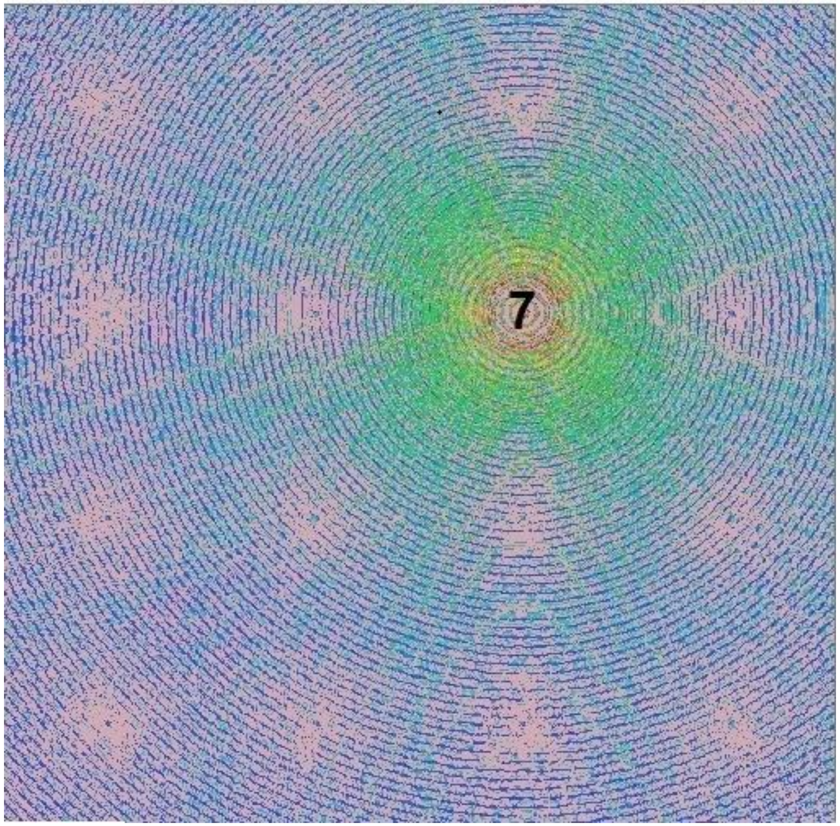
  (Used by: Intel, NVIDIA, Tilera …)



Propagation channel in the Sub-THz band

Electric field distribution of the antenna #7

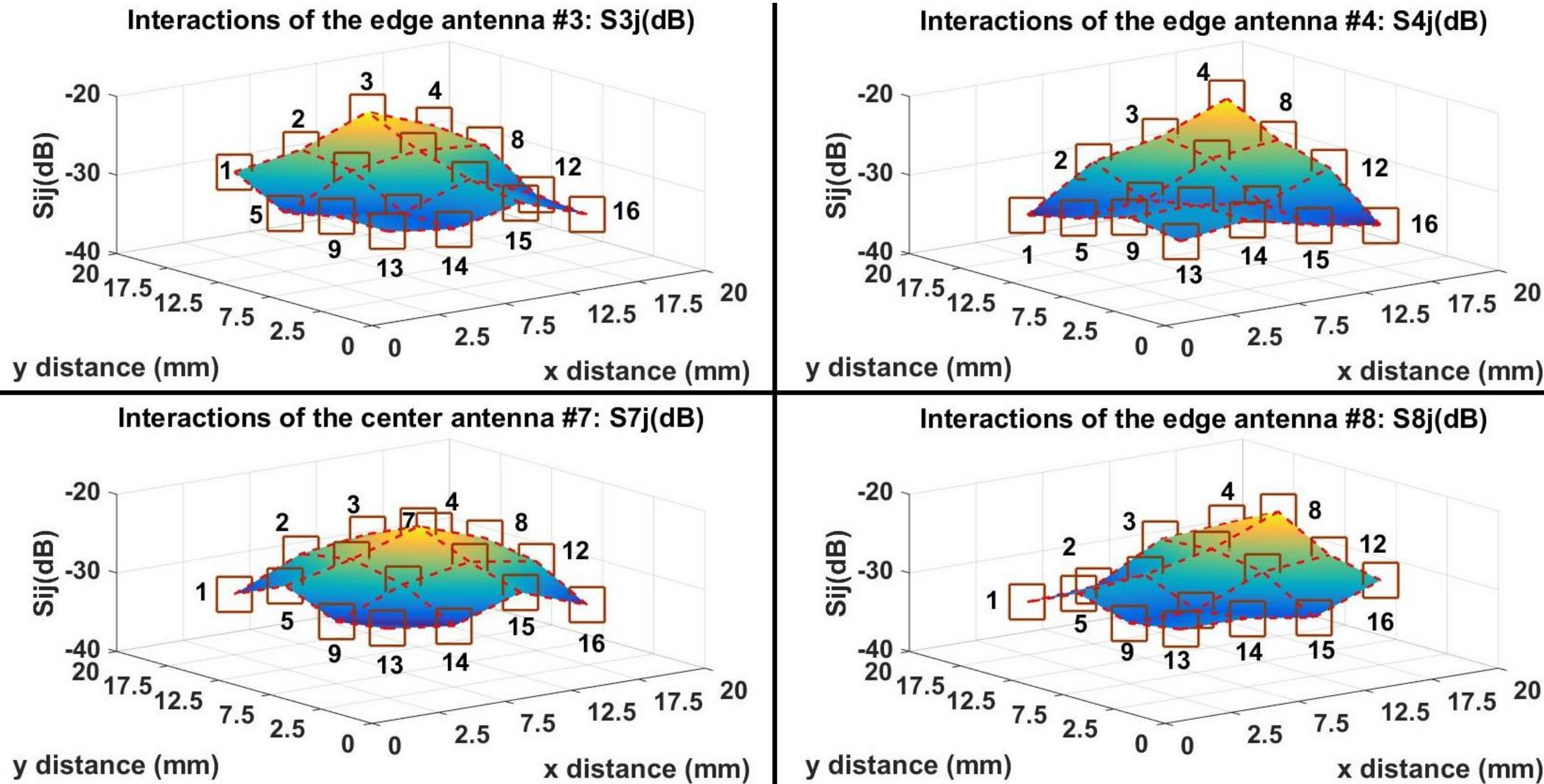
@200 GHz



1. **Convenient for Broadcast /Multicast**
2. Dependence on the **antennas placement and the distance** of separation

Propagation channel in the Sub-THz band

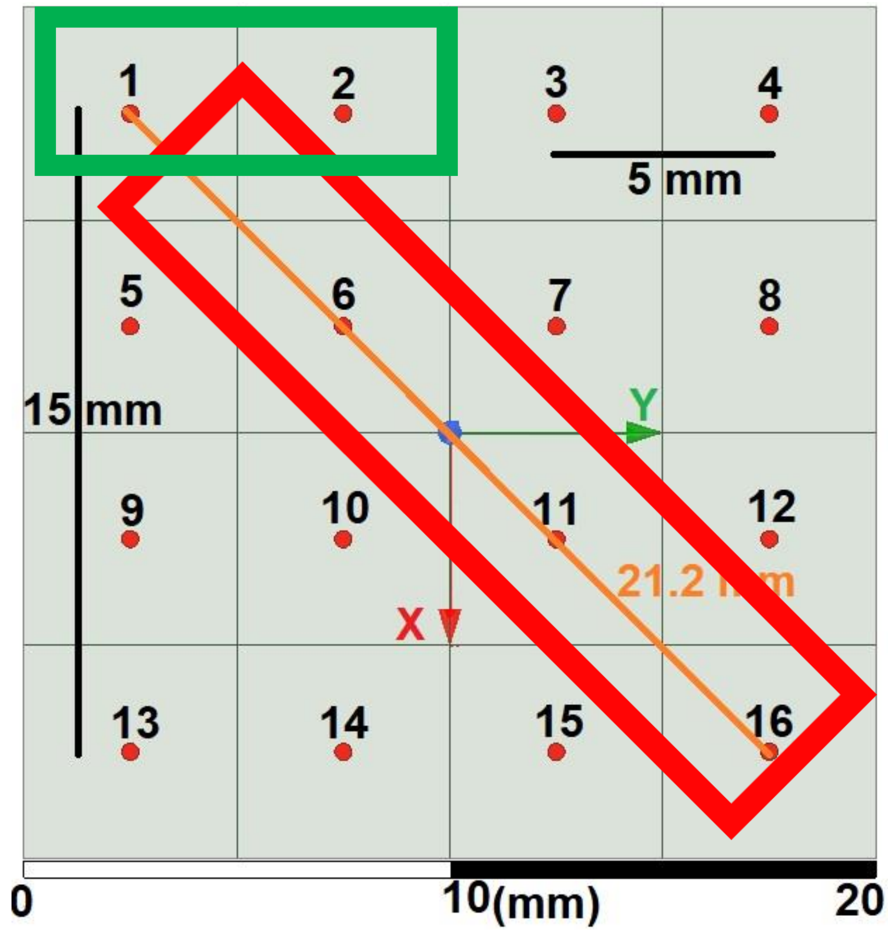
Effect of the antennas placement and the distance on the signal intensity



Propagation channel in the Sub-THz band

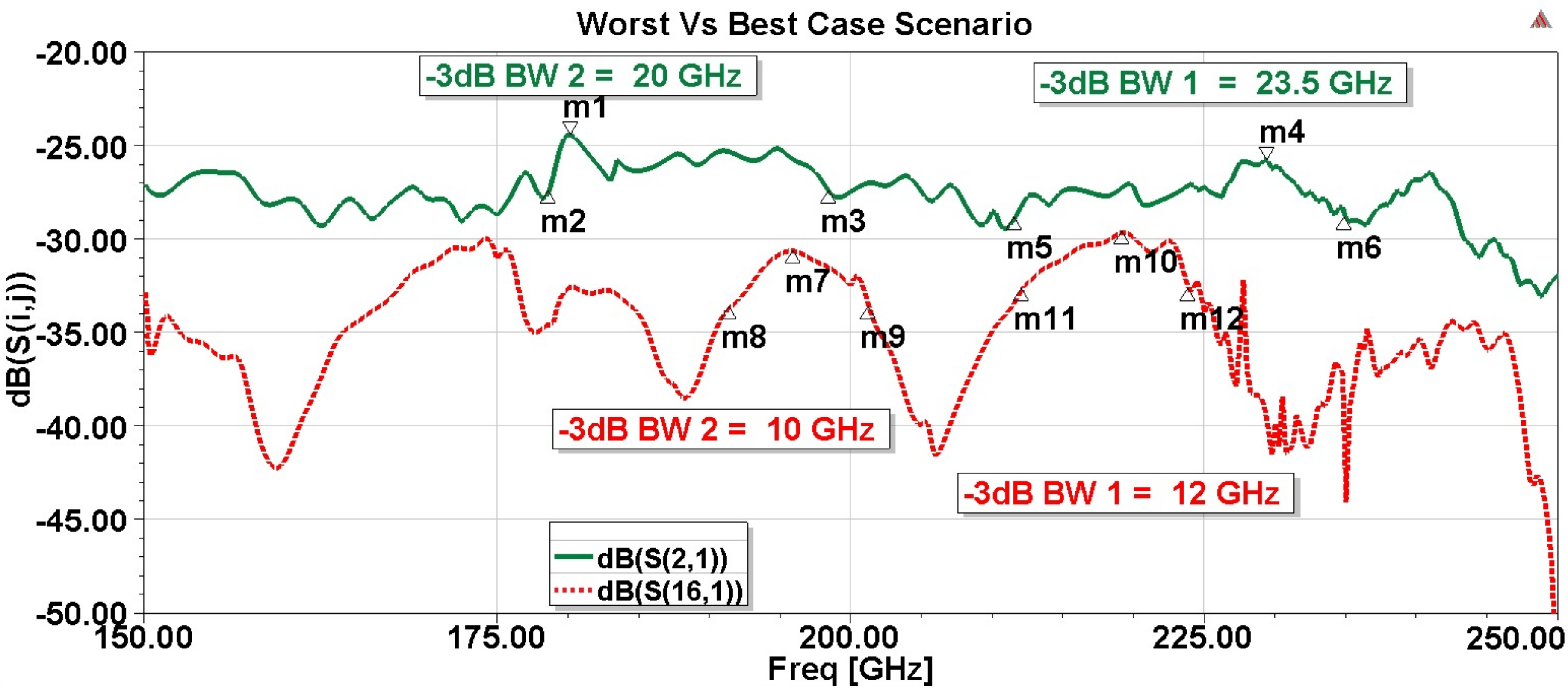
Best Case scenario : highest levels and largest -3dB-BW between the closest antennas (ex. 1 & 2 or equivalent) with a distance of separation of 5 mm.

Worst-case scenario: between the farthest antennas i.e. on the diagonals (1 & 16 or 4 & 13) with a distance of separation of 21.2 mm.



Propagation channel in the Sub-THz band

Transmission coefficient (S_{ij}): Simulated :



-3dB BW 2 = 20 GHz -3dB BW 1 = 23.5 GHz -3dB BW 2 = 10 GHz -3dB BW 1 = 12 GHz

Name	Freq	Y	Name	Freq	Y	Name	Freq	Y	Name	Freq	Y
m1	180.25	-24.47	m4	229.50	-25.86	m7	196.00	-30.66	m10	219.25	-29.65
m2	178.65	-27.47	m5	211.60	-28.86	m8	191.47	-33.66	m11	212.14	-32.65
m3	198.46	-27.47	m6	234.98	-28.86	m9	201.31	-33.66	m12	223.91	-32.65

Propagation channel in the Sub-THz band

- **Data rate comparable to the state of the art of the WiNoC**
- **Coding can be optimized in both cases**

Case	-3dB BW1 (GHz)	-3dB BW2 (GHz)	Possible data rate (Gbps) For both BW *	Possible data rate (Gbps) For BW1 only **
Best Case Scenario	23,5	20	> 32	> 16
Worst Case Scenario	12	10	> 16	> 8

*** By a frequency multiplexing, possible benefit of both bandwidths**

**** Using only the largest bandwidth**

Conclusion

1. The advantages of the WiNoC antennas in the EHF band: **high bandwidth** with a **minimal size**.

2. **The cavity** problems : **Multiple resonances** and **transmission zeros.**

3. **Proposed solutions:**
   A. Addition of an **absorption layer**
   B. Two metallic planes to avoid **EMC influences**
   C. HR-Si as a **propagation medium**
   D. Additional improvement through the vertical **monopole antennas.**

Perspectives

1. Proof of concept: Measurement of the realized **absorbing layer circuits** in **Q** and **V band.**

2. **Task Mapping** at the **coding/routing** levels based on the **attenuation maps.**

3. Combination of **RF models and digital techniques** and evaluation of the **complete proposed WiNoC solution.**

Thank you for your attention

Work performed on the High Performance Computing Cluster(HPC) at Lab-STICC:

https://www.univ-brest.fr/plateformes-technologiques/menu/nos-plates-formes/TECHYP