What causes the fluctuations in f_{max} with respect to frequency?

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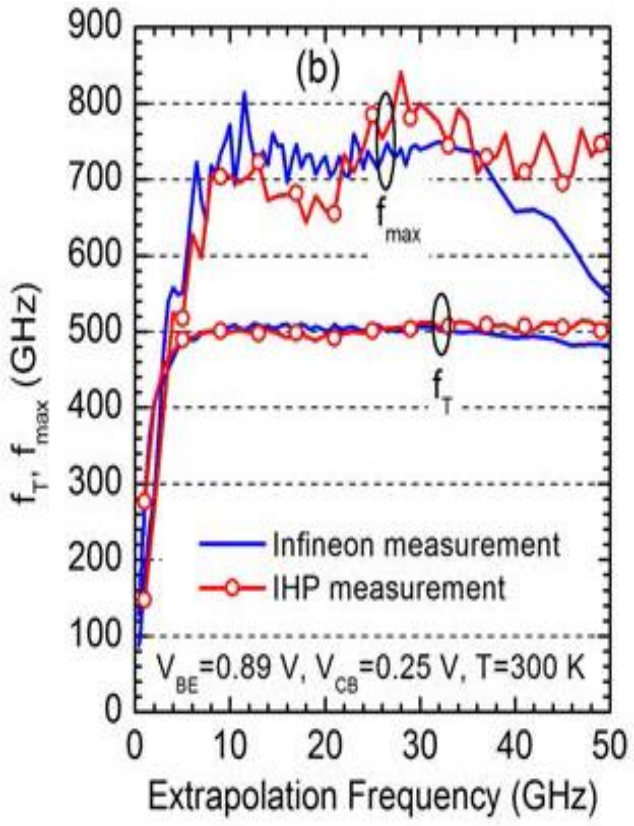
Impact of test structure and probes on calibration ?

Impact of calibration/probes on FOM measurement

- f_{MAX} is a FOM that is difficult to measure : same device measured at IHP and Infineon

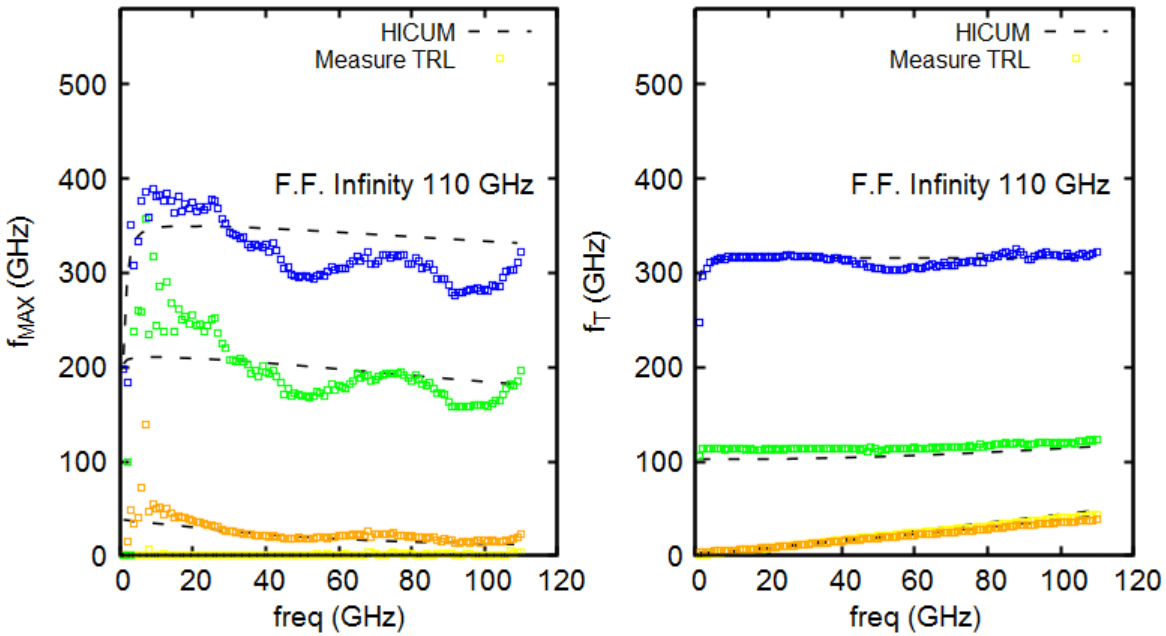


B. Heinemann *et al.*, « SiGe HBT with fx/fmax of 505 GHz/720 GHz », in *2016 IEEE IEDM*, déc. 2016

Impact of test structure and probes on calibration ?

Impact of calibration/probes on FOM measurement

- f_{MAX} is a FOM that is difficult to measure : same device measured at IHP and Infineon
- What about our result on STMicroelectronics B55 technology



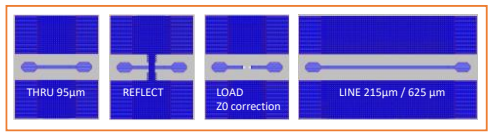
How to analyse the results ?

See Fregonese et al., IEEE TED

Impact of test structure and probes on calibration ?

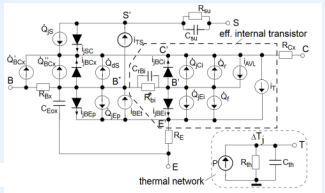
Simulation methodology => reproduce the measurement procedure

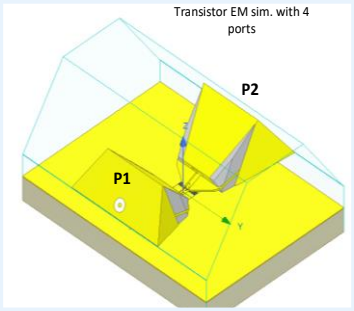
T R L

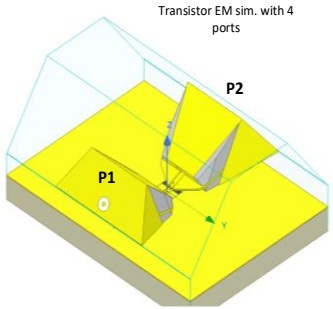


TRANSISTOR

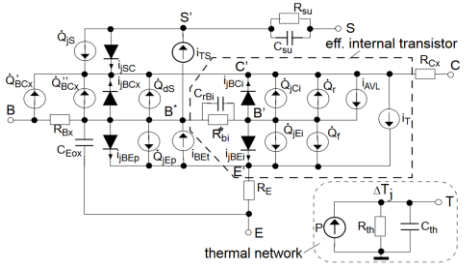
EM sim. + SPICE simulation







open / short



TRL

De-embedding OS / SO

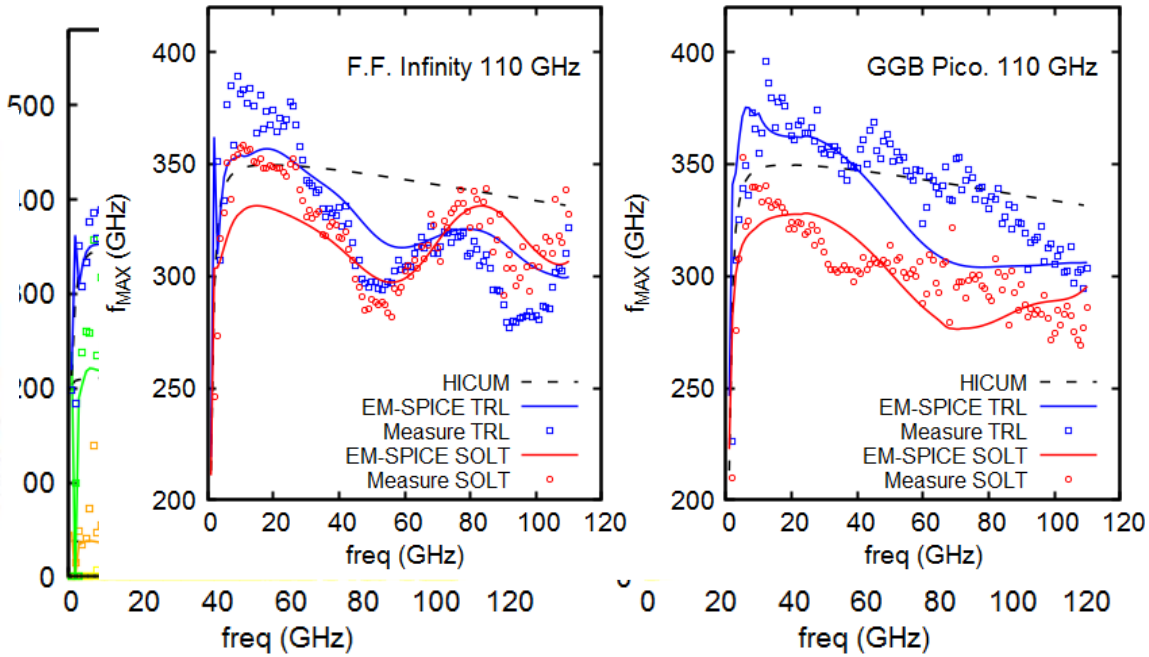
comparison

Does cal. + deemb. allows to recover intrinsic characteristics ?

Impact of test structure and probes on calibration ?

Impact of calibration/probes on FOM measurement

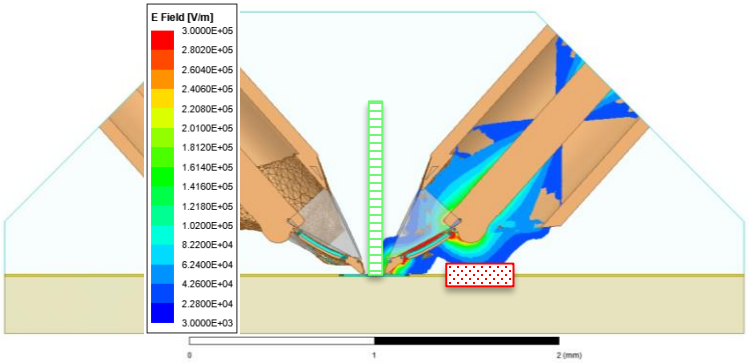
- f_{MAX} is a FOM that is sensitive to calibration accuracy
- Example of TRL calibration result on STMicroelectronics B55 technology



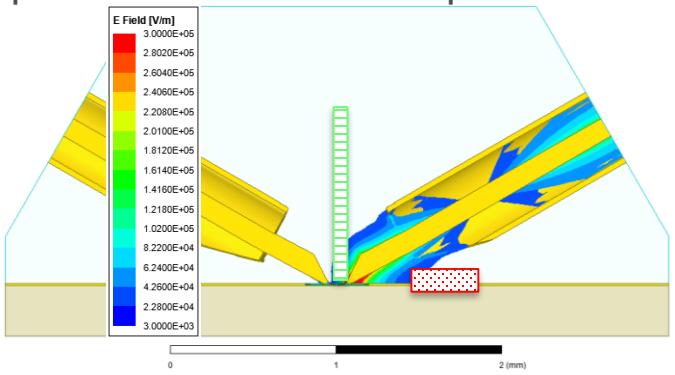
Impact of test structure and probes on calibration ?

Impact of calibration/probes on FOM measurement

Example of probe crosstalk with inter-probe distance of ~140µm

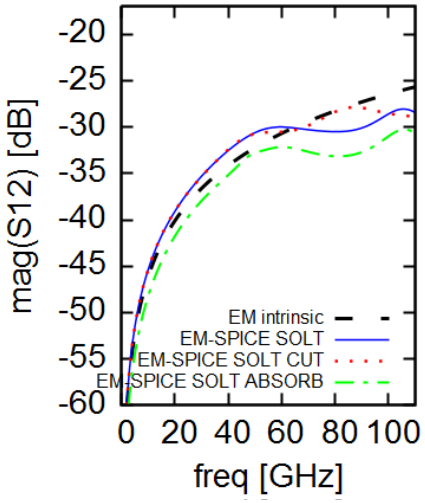


Infinity probe (100µm pitch)
on a trans-open, freq = 60 GHz

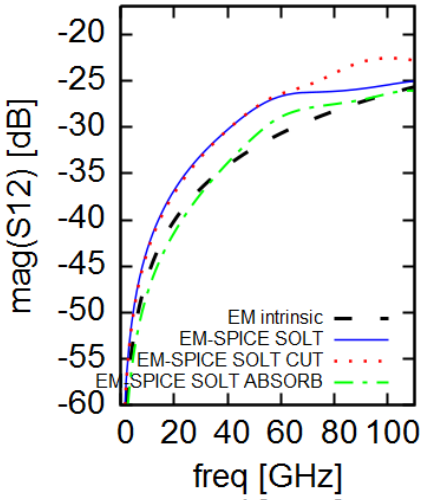


Pico-probe (100µm pitch)
on a trans-open, freq = 60 GHz

F. F. Infinity 110 GHz



GGB Pico. 110 GHz



⇒ probe couplings has a strong impact ! (not corrected by SOLT / TRL)

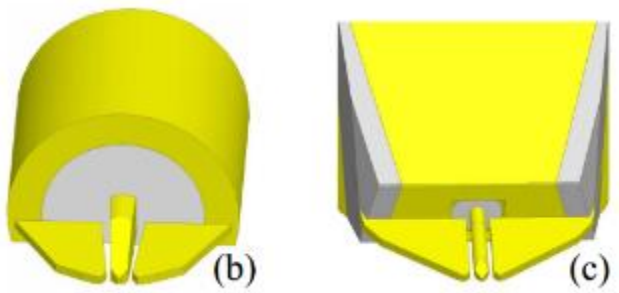
Where is the way out?

- All S-parameters above 30 GHz are wrong, that is to say, they are affected by not-corrected coupling
- How to solve the issue
  - New probes with appropriate test-structures
  - New calibration method with appropriate test-structures

Impact of test structure and probes on calibration ?

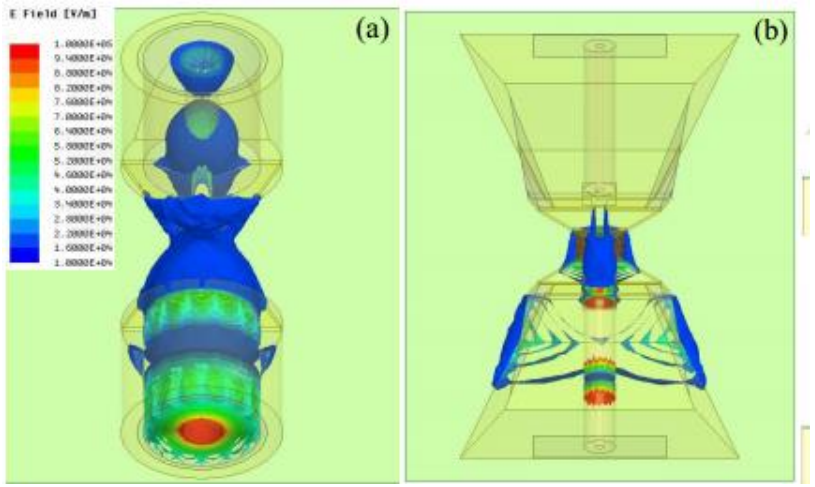
Impact of calibration/probes on FOM measurement : measurement up to 500 GHz & discontinuities

- Advanced probe models are required to understand measurement imperfections

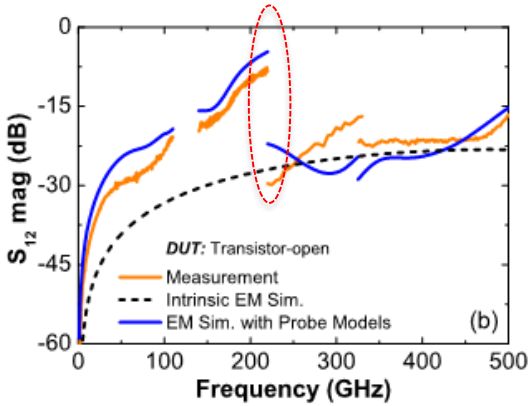


140-220 GHz 220-325 GHz

@ 220 GHz



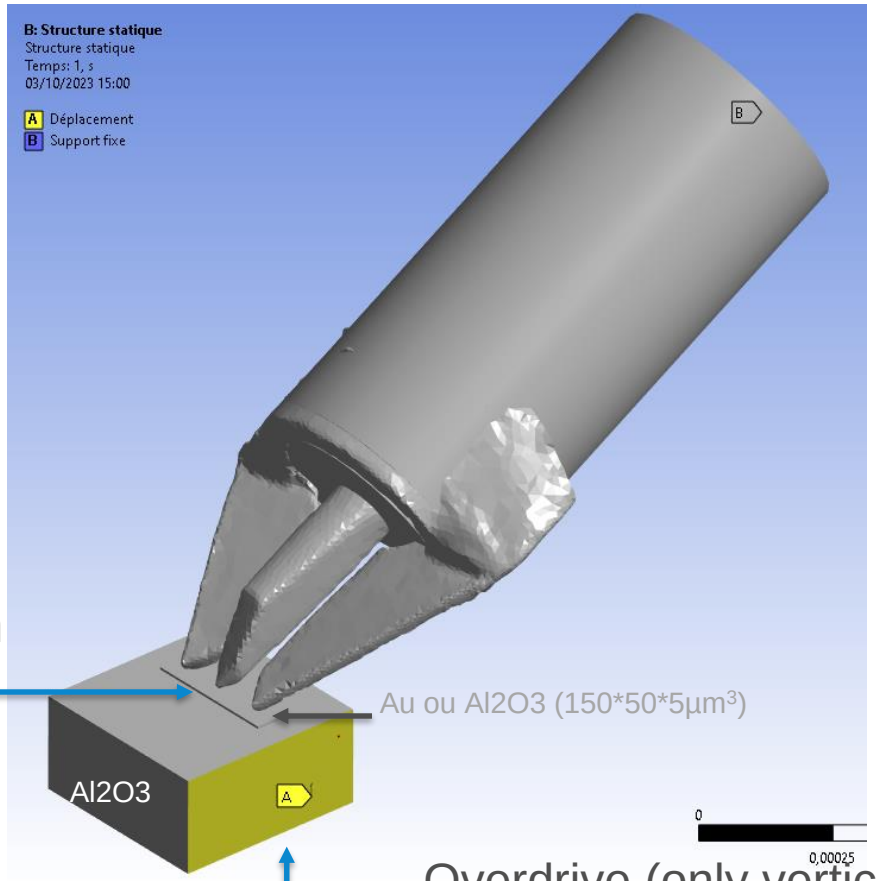
Electric field (E-field) distribution (top and side views) in the transistor-open at 220 GHz using two probe models



- **Inter-pad distance needs to be increased**
- Probes need to be downscaled to reduce the probe to substrate coupling

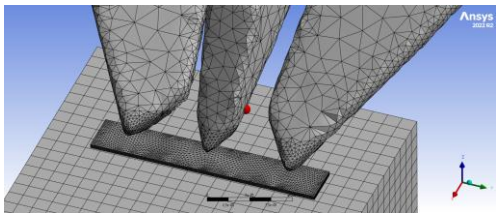
Mechanical Simulation: boundary condidtion

- Ex: GGB pico 110 GHz



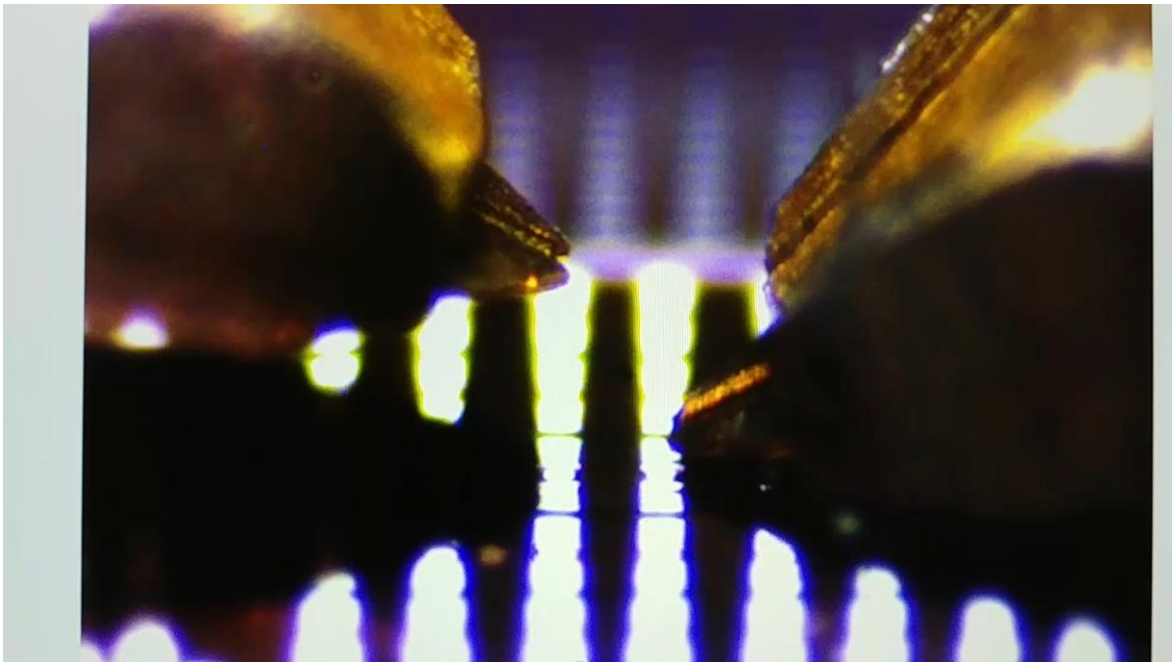
Sliding link between probe and Au

3D model

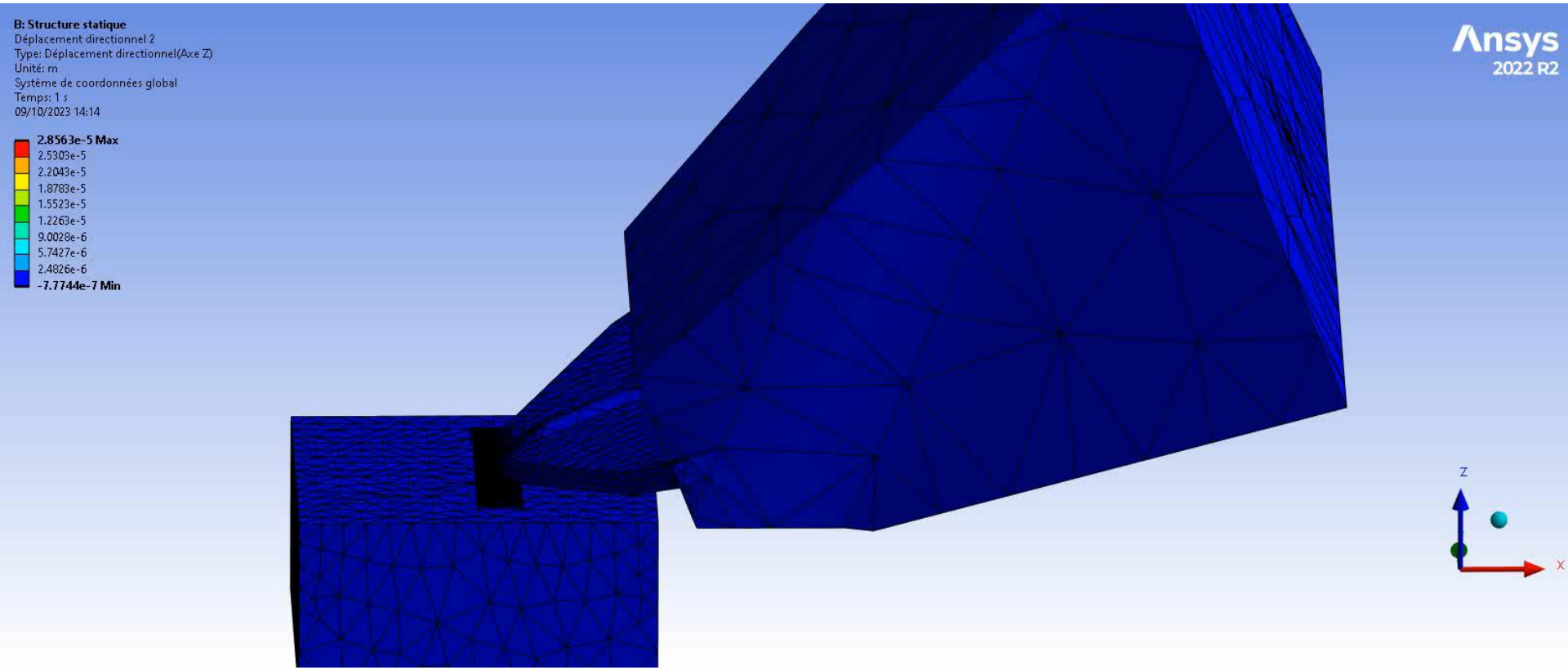


Overdrive (only vertical direction)

Side view movie showing skating and probe bending: GGB 325 GHz probe



Side view simulation showing skating and probe bending: GGB 325 GHz



New probe design (ANR Precise)

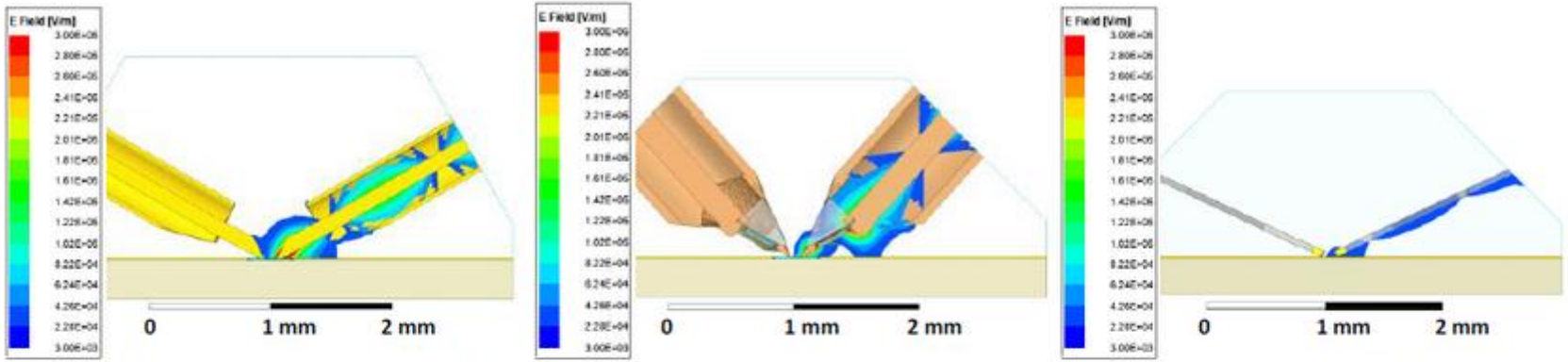


Fig. 6 Field distribution highlighting probe to substrate coupling @ 60 GHz (phase of Efield showing strongest coupling) on a load – same scale is used for each simulation (Picoprobe, Infinity, our solution)

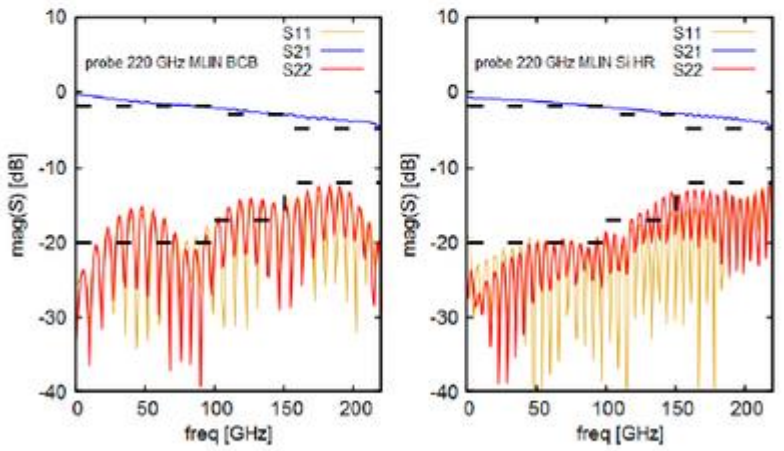


Fig. 7a : Simulation results of probe

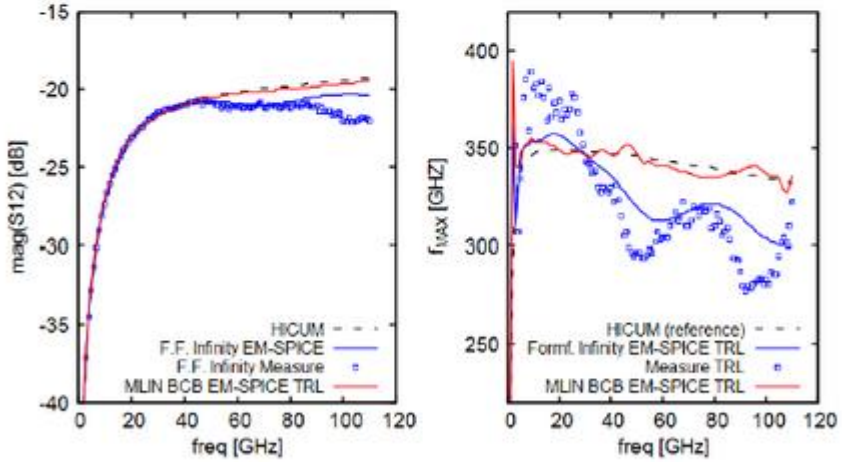


Fig. 7b: Emulation of measurement of a B55 transistor (BiCMOS 55nm) using Infinity probe and our probe

Conclusion

- Coupling is a show stopper for accurate S-parameter measurements
- Two types of coupling
  - Probe-to-probe
  - Probe-to-substrate
- Coupling can be decreased by appropriate test-structure design and layout
  - Chess-pattern of different structures on the chip
  - Appropriate distance between structures: not too dense
  - Appropriate distance between port 1 and port 2
  - etc.
- Invent new probe-tip with reduced coupling, work is on-going (results next year ?)
- Revisit 16 terms error-model: very promising results (not shown in public version)!

Acknowledgements

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