# Accuracy investigations of calibration and de-embedding technics

Manuel Potereau, Sebastien Fregonese, Arnaud Curutchet and Thomas Zimmer

- IMS laboratory, France -

# Introduction

- New imaging and security applications need THz solutions
- Integrated technologies improvement allows development of new transistors architecture
  - Working near the THz frequency range
  - Size of device and input capacitance decrease
  - BEOL is more complex
- Standard measurement calibration and de-embedding methods needs to be enhanced to address this range of frequency
- SOLT and TRL calibration technics are the more widely used but shows some limitations
- TRL improvement method is proposed in this presentation

# Outline

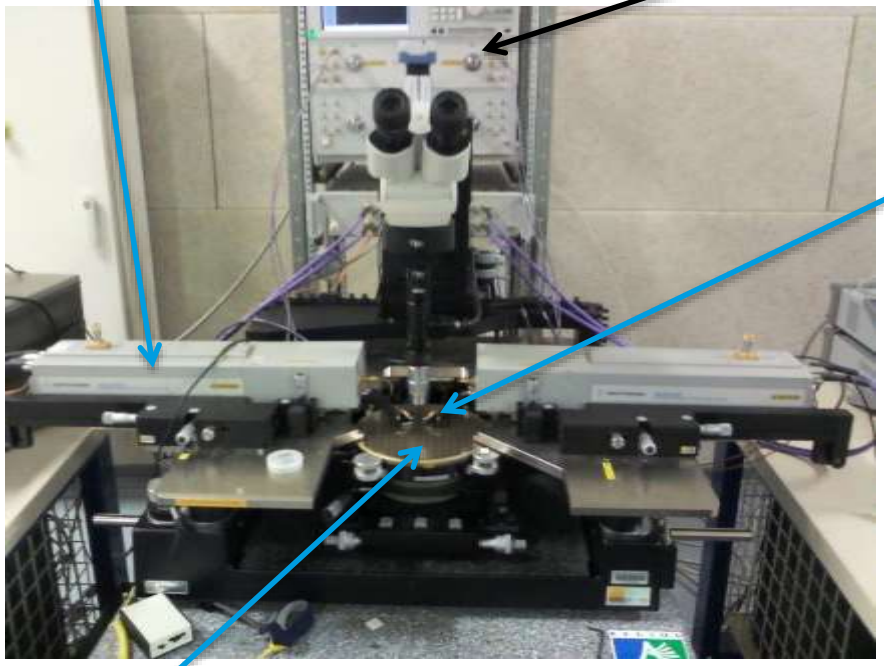
- Introduction
- Measurement instruments limitations
  - Input power
  - Average
  - Intermediate frequency bandwidth
  - Instrument shift with time
- TRL calibration
  - About TRL calibration
  - Enhancement proposal and validation
- Conclusion and further work

# Test bench description

Vector Network Analyzer (VNA)

- ZVA-67 Rhodes et Schwarz
- PNA E8361A Agilent

Millimeter heads

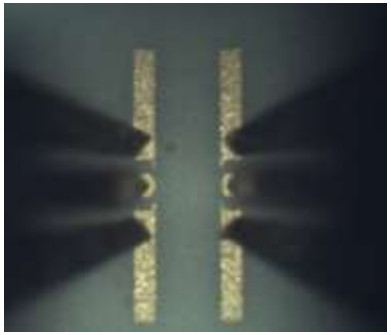


RF probes

Device Under Test (DUT) on wafer

Cascade infinity 67GHZ pitch 100µm

CS-5 Calibration kit



Z-probe 110GHz pitch 100µm

CSR-8 Calibration kit

# Input power influence

➔ Working hypothesis:

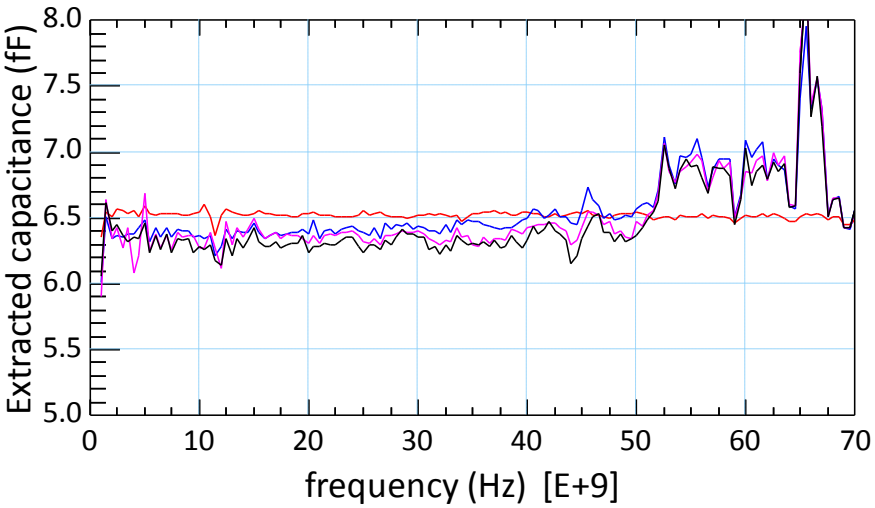
- NWA is mainly composed of quasi linear devices.
- The higher the input power is, the lower the noise contribution is.

Calibration is performed at high power (and low noise) and measurement power is adjusted depending of the active device.

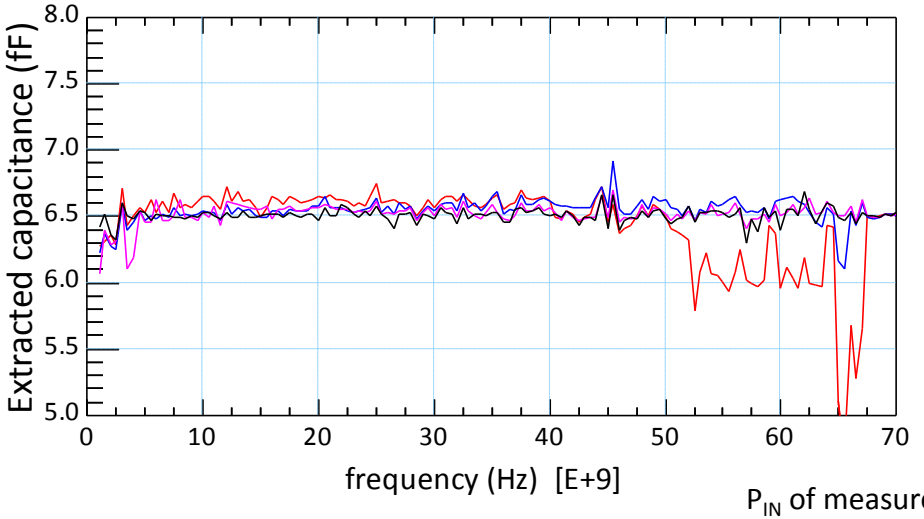
➔ Verification of this hypothesis

1. Calibration at an given input power $P_{IN(Cal)}$
2. Measurement of an open structure at different input power $P_{IN(Meas)}$
3. Extraction of the capacitance and comparison

# Input power influence: during measurement




Calibration at $P_{IN}$=-6dBm




Calibration $P_{IN}$=-25dBm

$P_{IN}$ of measure:

$P_{IN}$=-6dBm

$P_{IN}$=-10dBm

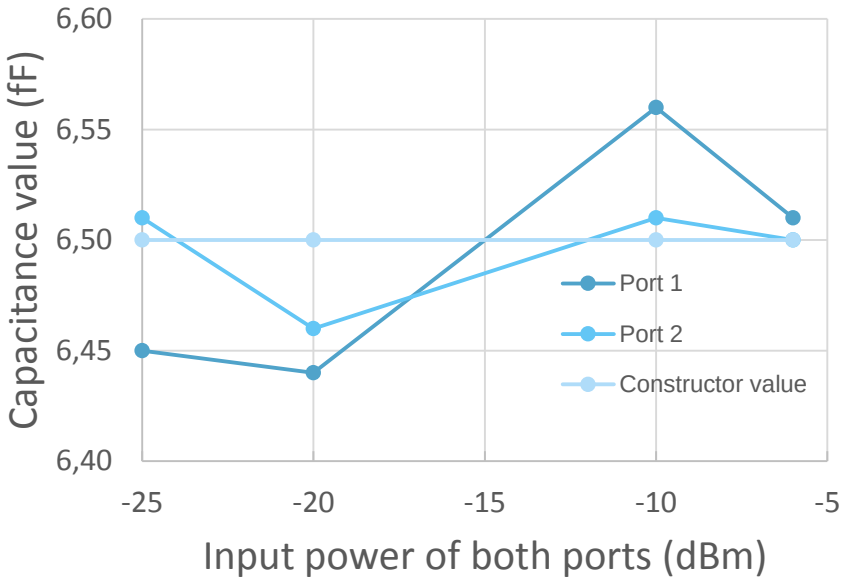
$P_{IN}$=-20dBm

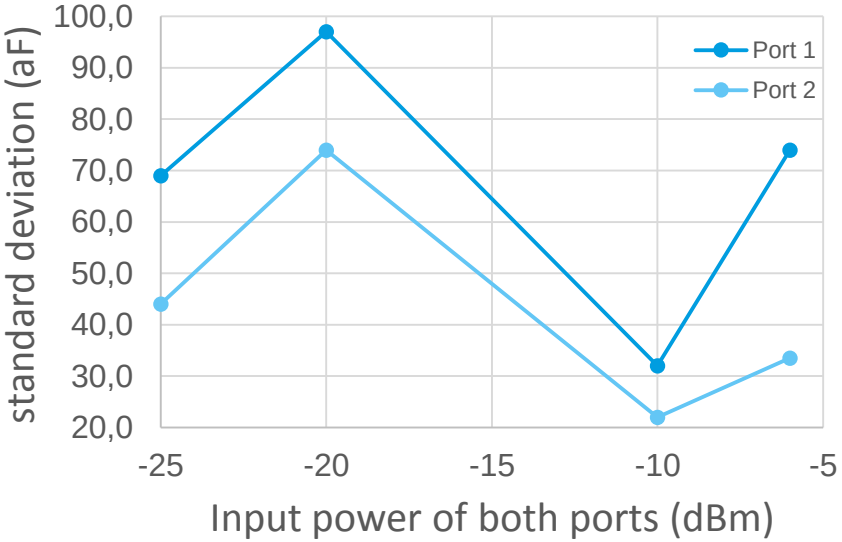
$P_{IN}$=-25dBm

- Measurement accuracy is better when $P_{IN\ Measurement} = P_{IN\ Calibration}$
- Test bench is not linear with the input power

We need to make a calibration at the same input power as the measurement one.

# Input power influence: during calibration

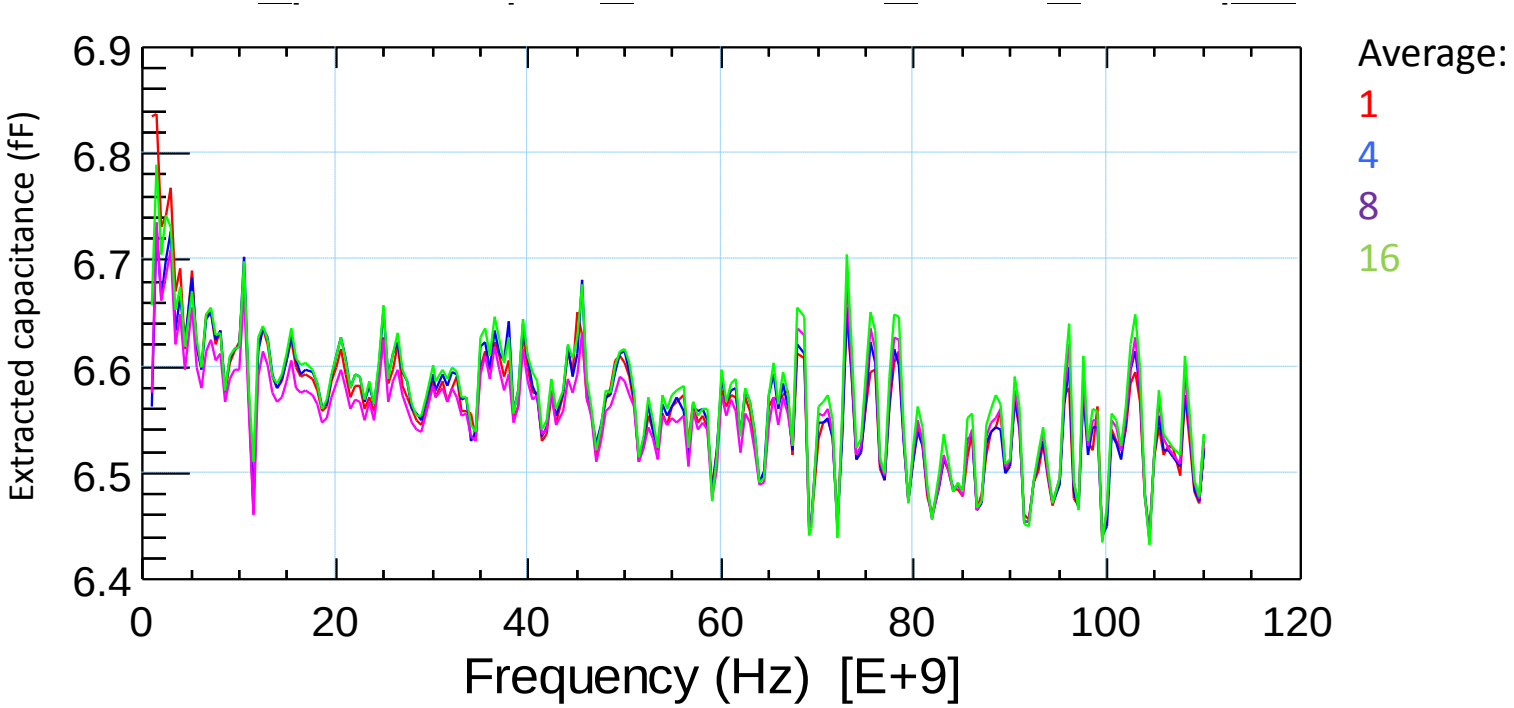



- Calibration is performed at the same input power than the measurement
- 0.1fF of accuracy is achieved without power dependency

# Average: Contribution to noise immunization

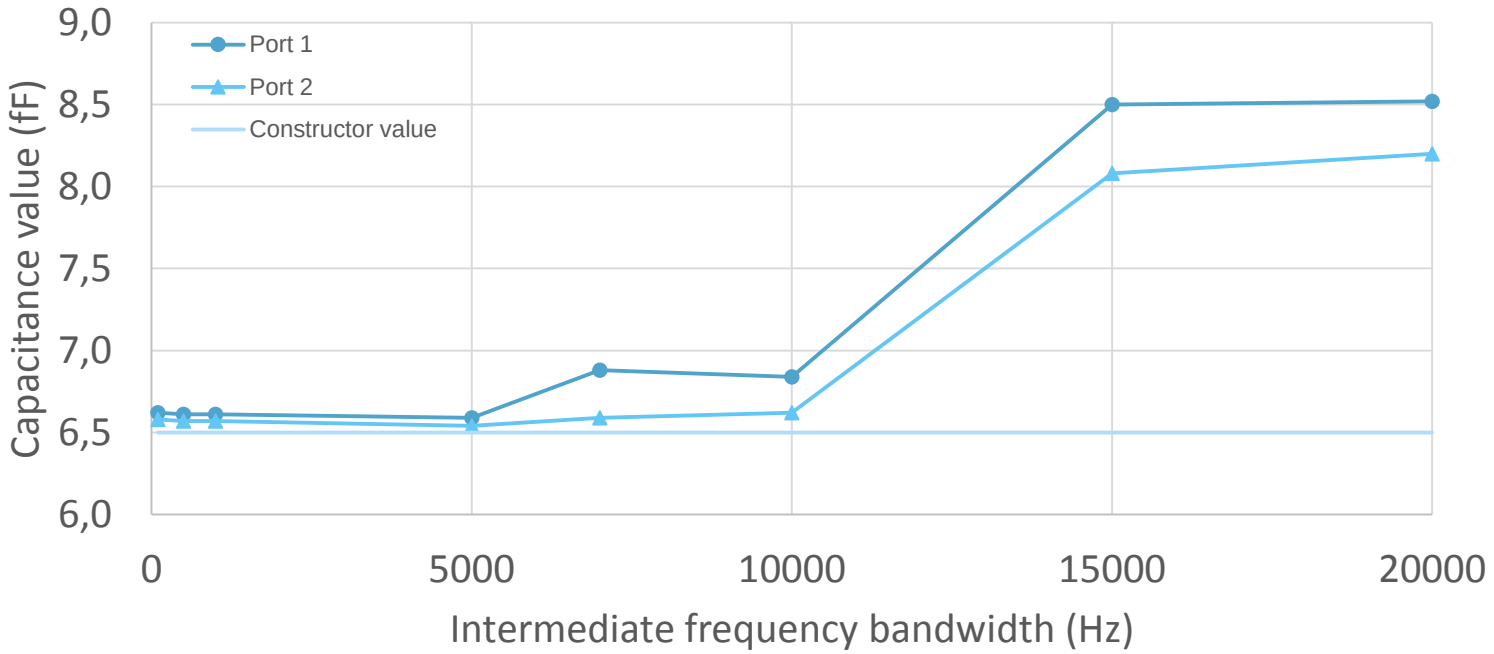
Repeat the same measurement a number of time and take the average of it. In order to reduce the random noise.




- No significant variation between average of 1 and average 16 is observed.
- The random noise is negligible compare to static residual calibration error for this input power (-6dBm)

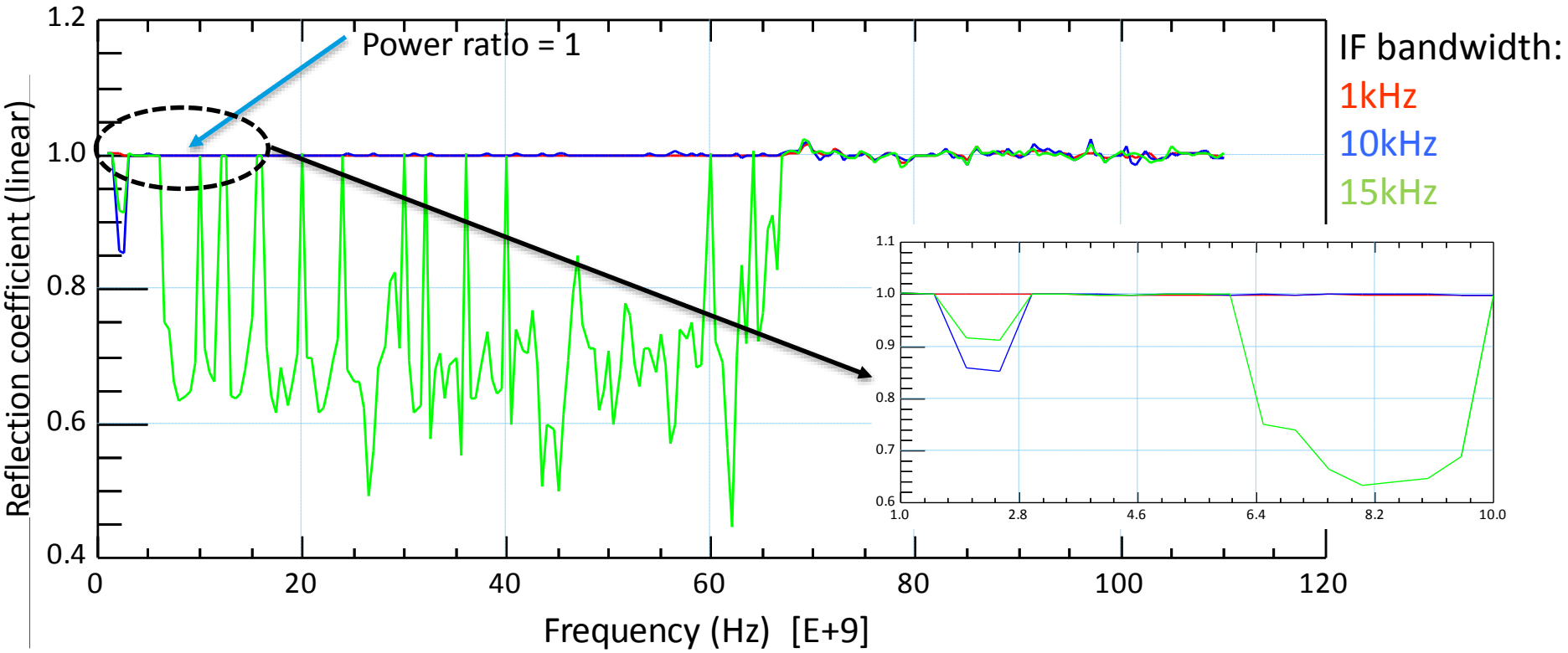
# IF bandwidth: Contribution to noise immunization

Reduce the bandwidth of the intermediate frequency filter to enhance the accuracy.



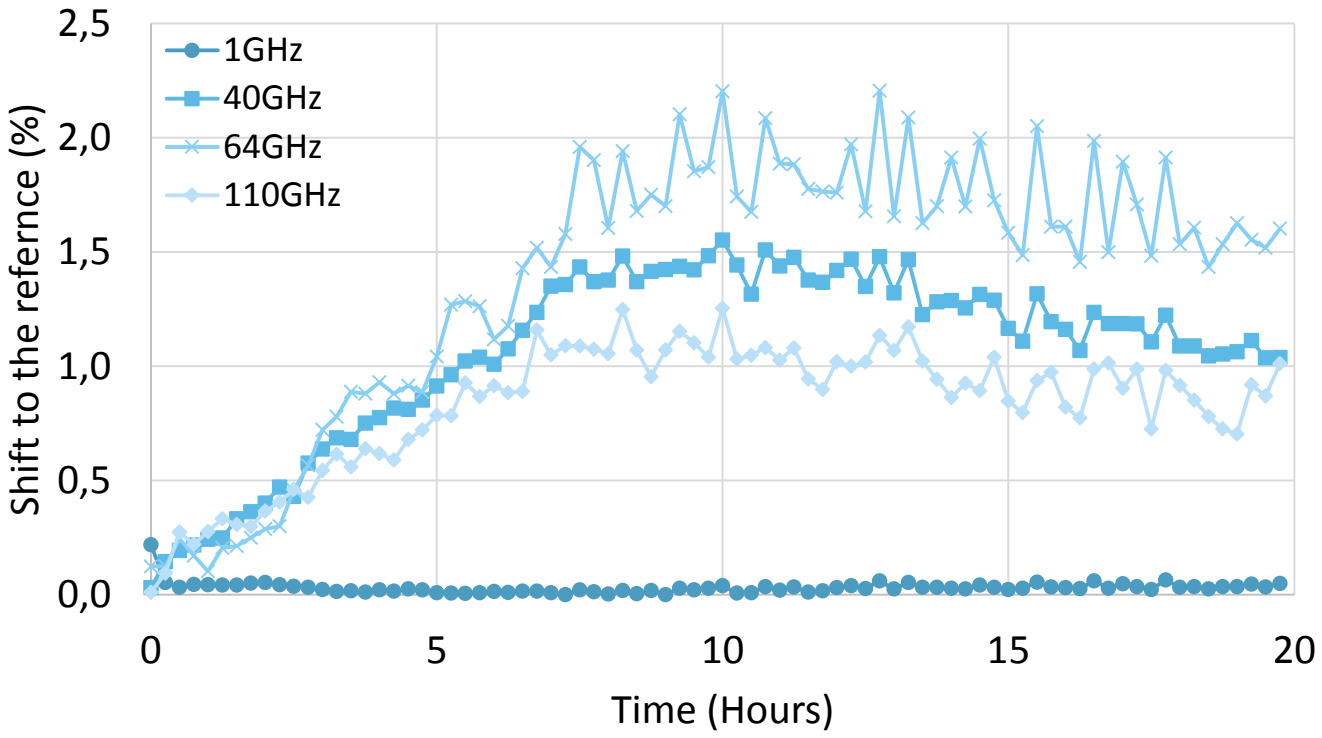

- Error explodes when IF bandwidth reached 5kHz.

# IF bandwidth: Frequency dependency




- The higher the IF bandwidth is, the higher the spike end the frequency is.
- Therefore, a spike or a drop in the capacitance at low frequency highlights a too high IF bandwidth.

# Instruments shift with time




We use the optimal options find previously and use the same set-up.

- The shift increase with frequency. The millimeters head reduce the shift.
- If accuracy higher than 1% is needed, the calibration must be made every 5hours.

# Instrument limitation: summary

- ➔ Input power for calibration and measurement must be exactly the same.
- ➔ Average is not efficient and time consuming at -6dBm.
- ➔ A drop or a peak at low frequencies means that the IF bandwidth is too high.
- ➔ Shift increases with the measurement frequency.

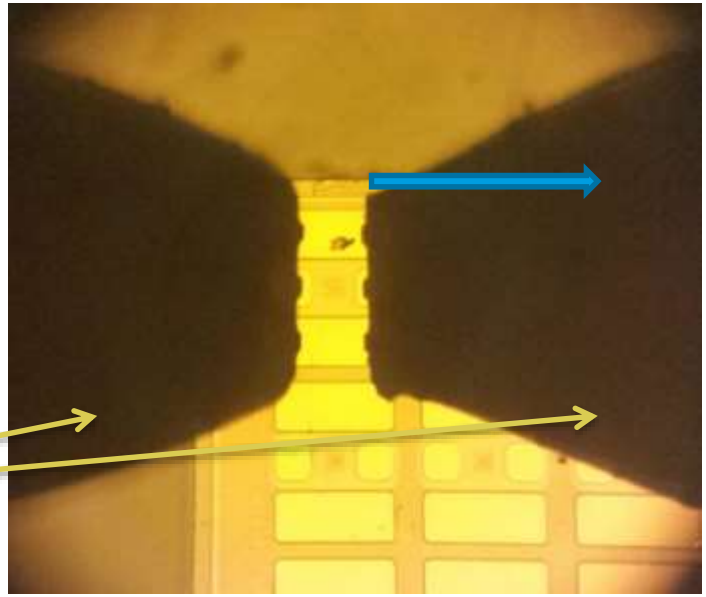
# TRL cal.: About the TRL

- Use 3 standards
  - Through (short transmission line)
  - Reflect
  - Line (long transmission line)

- No physical parameter are needed
  - They can be extract from measurement

- One assumption
  - Physical constants of the transmission line are the same for each line.

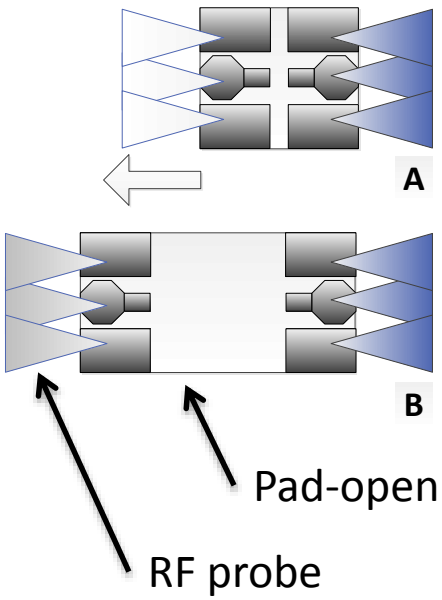
# TRL cal. : Probe movement during calibration




Difference of length between the Line and the Through. At least one probe need to be moved.

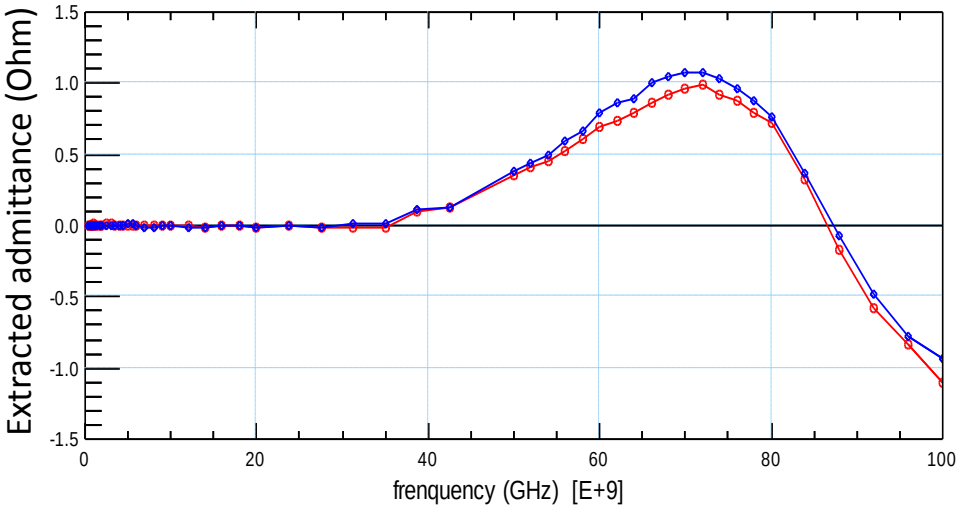
- The environment is altered.
  - Extracted constant can be altered too.

# TRL cal. : Error quantification methodology



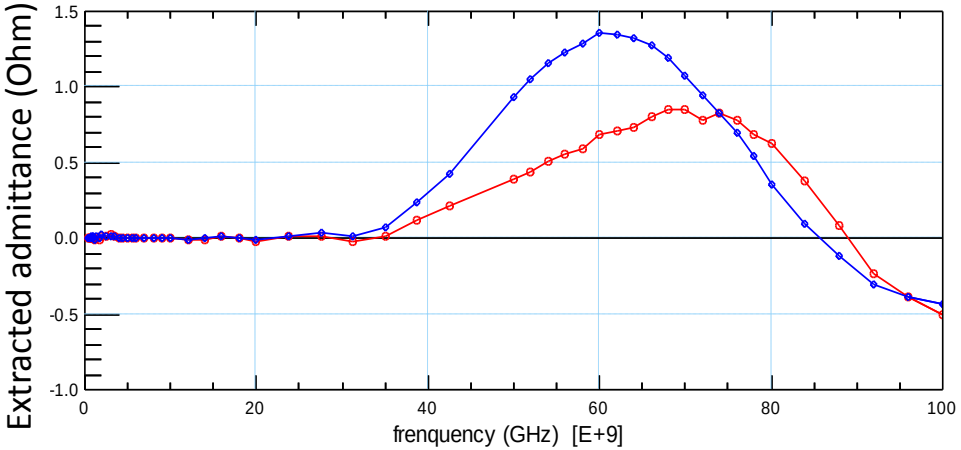

1. Measurement of the pad-open structure A (distance between probes : 130µm)
2. Movement of the left probes
3. Measurement of the pad-open structure B (distance between probes : 230µm)
4. Comparison of the pad admittance before and after the probe movement

# TRL cal. : Experimentation results



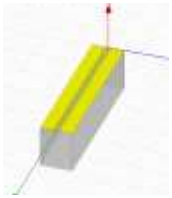

Blue : Impedance of the pad, first measurement
Red : Impedance of the pad second measurement

Probe not moved between the two measurements.
No significant modification



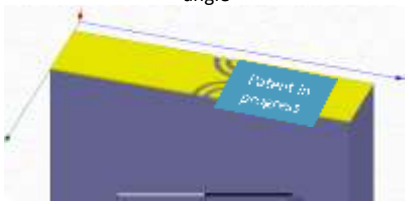

Probe moved between the two measurements.
Significant modification

# TRL cal. : Proposal for method improvement

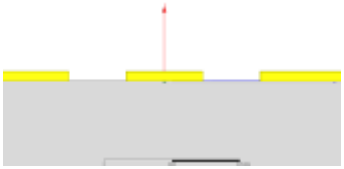


Old line

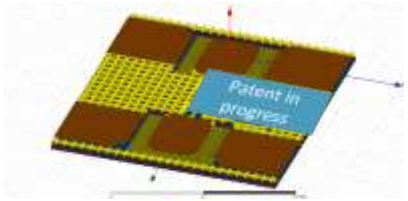

New line in coplanar topology with straight angle



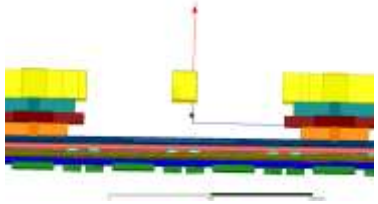

New line in coplanar topology with curved angles



Side view




New line in microstrip topology with ground plane

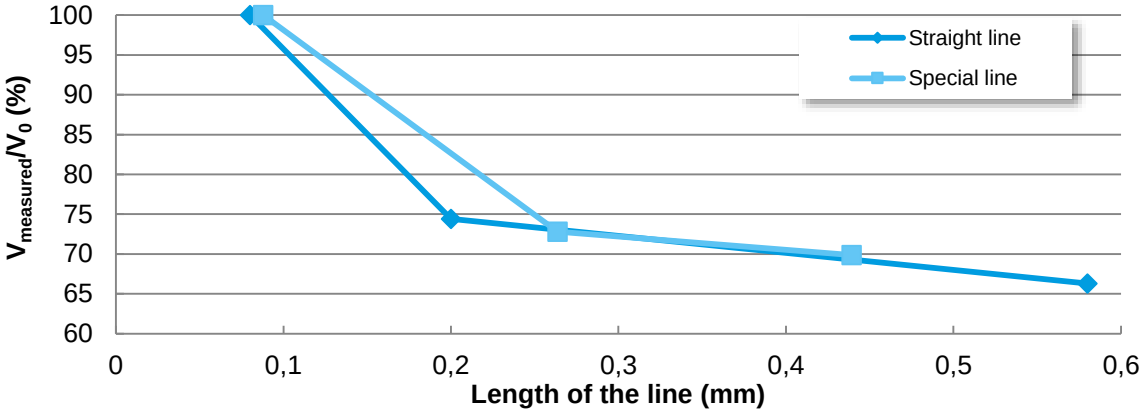


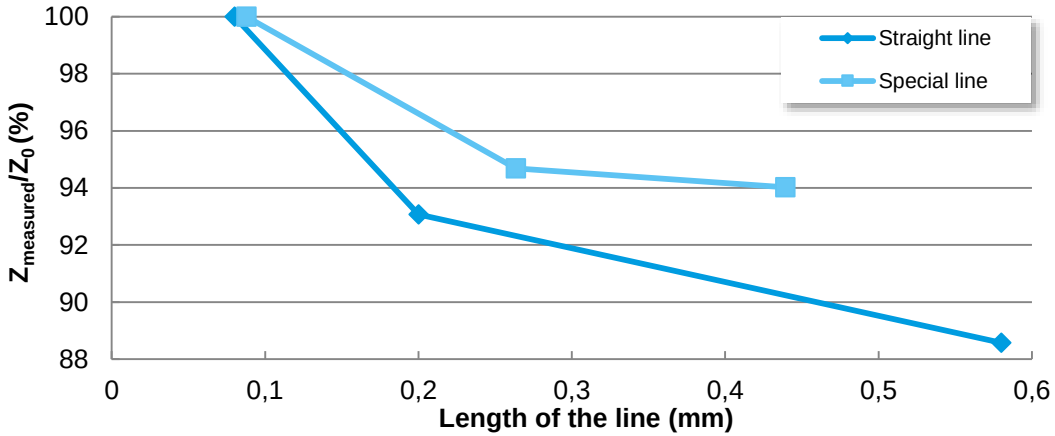
Side view

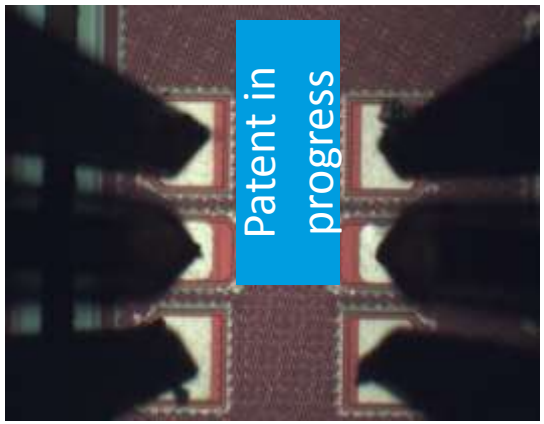
We altered the long line to keep a constant distance between probes.
Three prototypes are displayed

- Two on alumina substrate for “calibration kit” use.
- One on silicon substrate for “on wafer” use.

# TRL cal. : Comparison of extracted physical constant



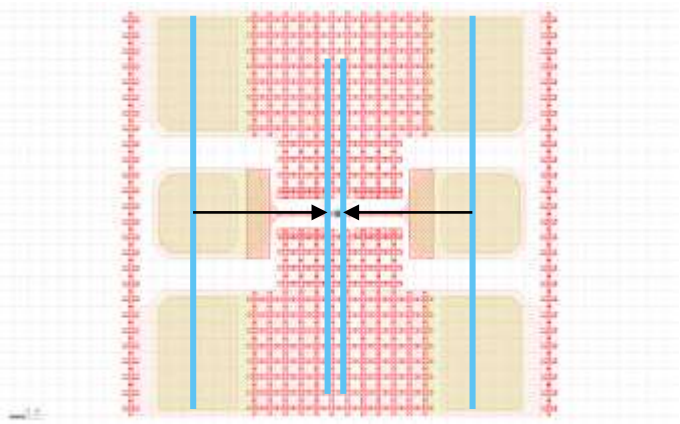




No improvement in the propagation constant.

Notable improvement in the characteristic impedance.

➢ We can expected, at least, same accuracy calibration.

# TRL cal. : Validation of the new calibration

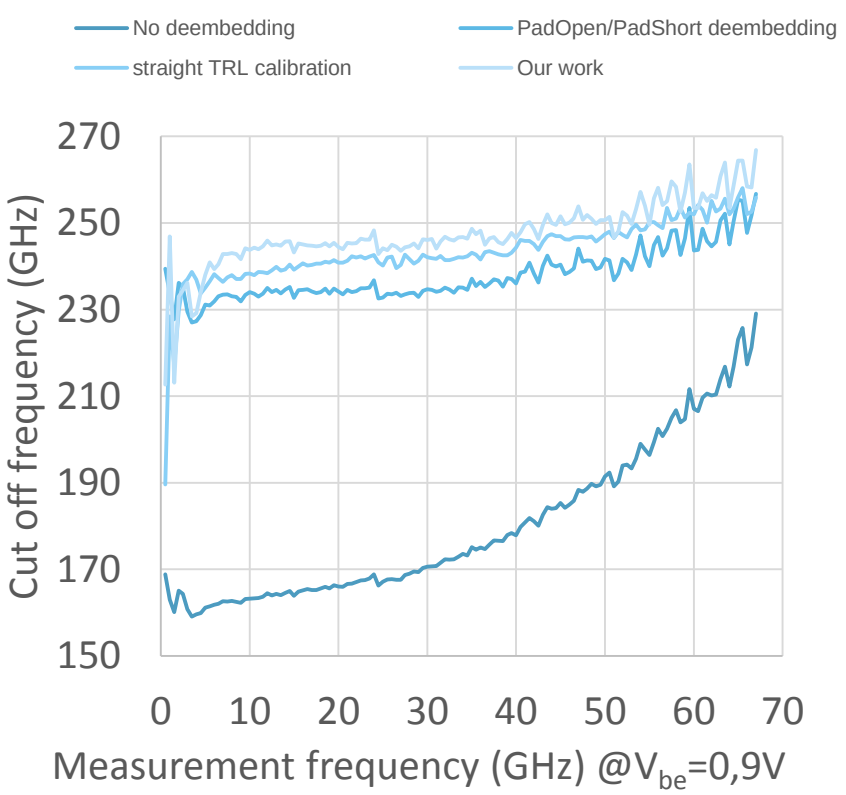


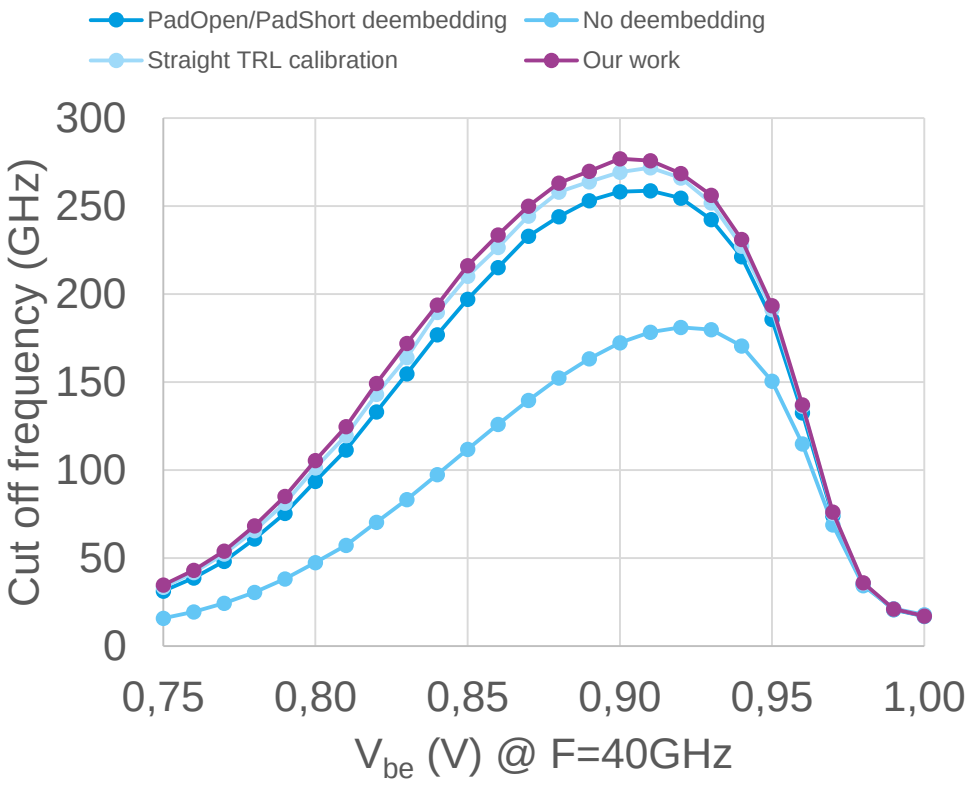
The goal is to move the reference plane from the end of the RF probe to the end of the pad.

Comparison between three methods for the extraction of transistor parameter:

- Pad-Open/Pas-Short deembedding.
- on wafer standard TRL calibration.
- on wafer special TRL calibration.

# TRL cal. : Extraction of standard transistor cut off frequency with different methods




All three methods give result close to each other.
TRL calibration methods give slightly higher result because of the removing of the access line contribution.

# Conclusion and further work

- Measurement station is optimized. The accuracy and shift limitation are known.

- First results in the new special TRL are encouraging. The two over prototypes must be fully characterized.
  - This calibration can be use with automatic prober.

- The same study has to be made at higher frequency with the new measurement station (up to 500GHz).

# Acknowledgment to the dotSeven Program

This project has received funding from the European Union's Seventh Program for research, technological development and demonstration under grant agreement N°316755.