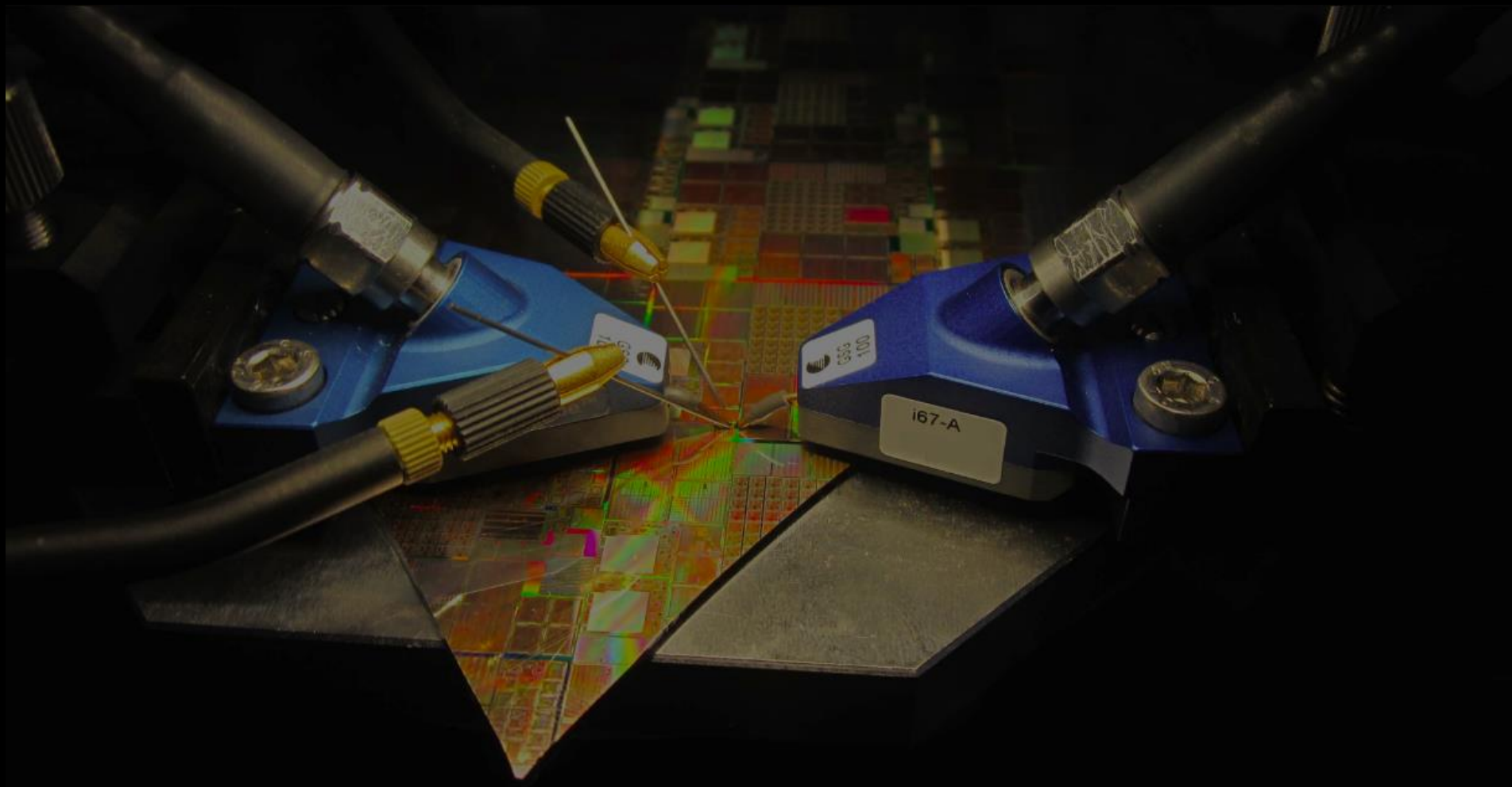

Modeling of 70nm GaAs mHEMT Process for MMIC Amplifier Design up to 220GHz

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微系统与太赫兹研究中心
Microsystem & Terahertz Research Center

Yinhe596 S&T Campus

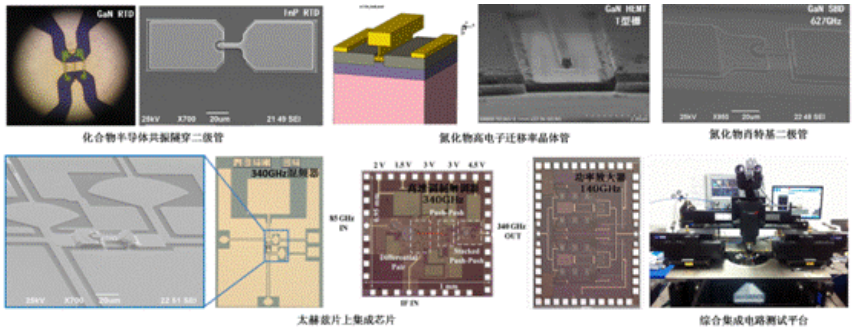
- Location:
  - Shuangliu District, Chengdu
- Strategic new tech research centers:
  - info tech, advanced manufacturing, new materials,…

Microsystem and Terahertz Research Center(MTRC)

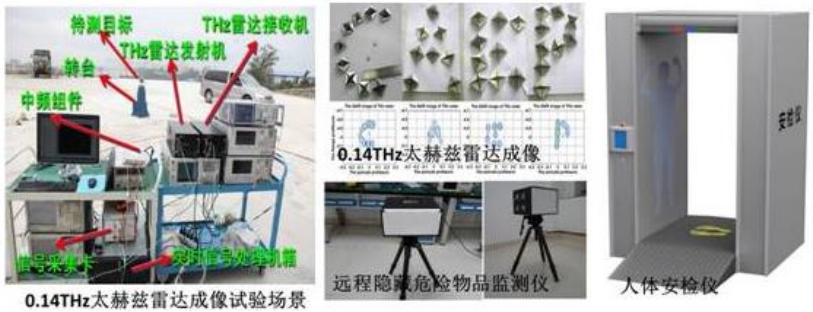
- 4 research labs
- latest EDA platform for design, state of the art THz characterization & measurement equipment
- in-house fabrication facility with 3000+m^2 cleanroom for III-V, MEMS & system integration

MT03: THz Application Technology Research Laboratory

- Yinhe596
  - MTRC
    - MT03



- Active in research fields
  - THz communications, radar, imaging systems
  - THz components, THz ICs, THz microsystems integration



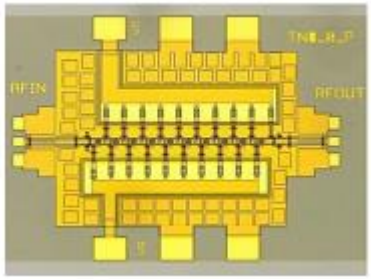
Outline

Modeling of 70nm GaAs mHEMT Process for MMIC Amplifier Design up to 220GHz

- Background & Motivation
- Test chip & Characterization
- Modeling Methodologies & Results
- Summary

Background & Motivation

- THz gap
  - huge bandwidth, high data rate, applications in high speed communication
- III-V transistor speed
  - InP HEMTs with f_{max} >1THz, amplifier even work at 1THz by NGC
  - Few COTS modules available
- Foundry process
  - 70nm GaAs mHEMT
  - f_{max}>400GHz
  - amplifiers beyond 100GHz



1THz TMIC Amplifier by NGC

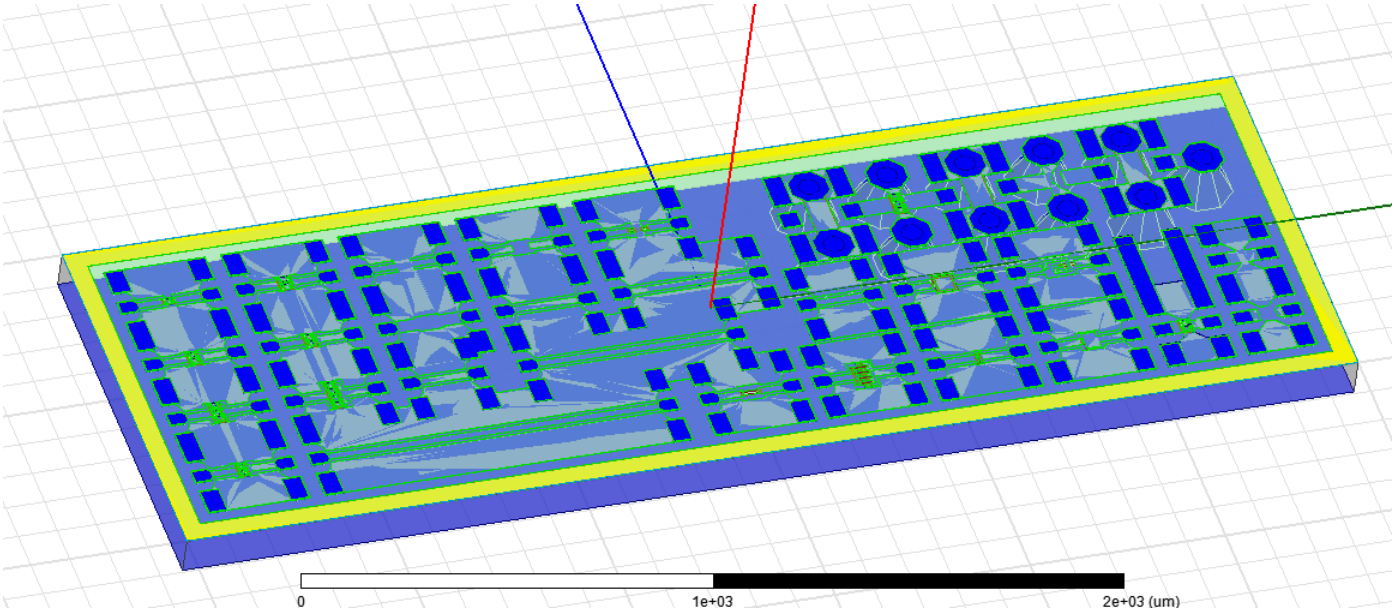
Background & Motivation

- PDK model
  - only verified up to 50GHz
  - unknown uncertainty for THz
  - high risk and costly redesign

- Evaluation of devices is necessary
  - for beyond 100GHz design
    - small components value sensitive to variation and modeling error
  - passives and transistors
    - passives: EM helps but need calibration and verification
    - transistor modeling as an integral part of the amplifier design flow

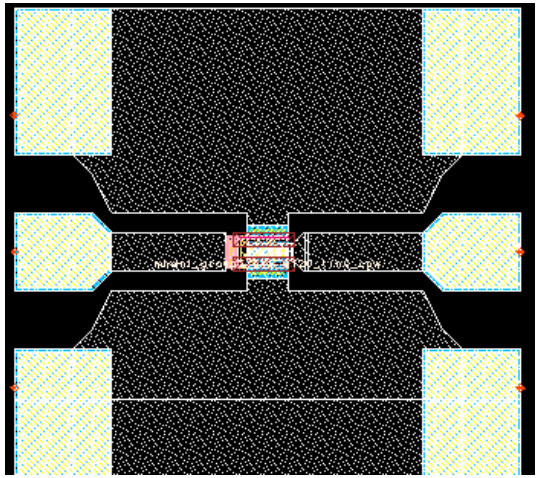
Test Chip

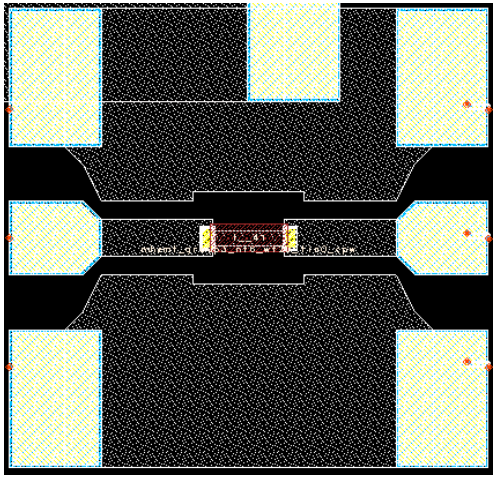
- Test structures for evaluation and modeling
  - compact design
    - 1x3mm^2
  - CPW environment
    - G-G 40um, signal trace 20um for 50Ohm TXL

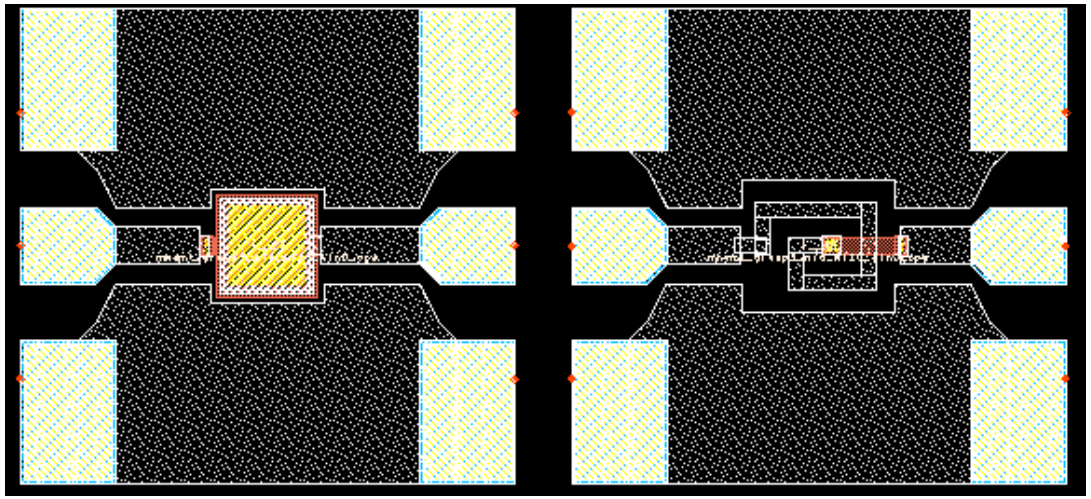


Typical Test Structures

- mHEMTs
- Resistors
- Capacitors
- Inductors
- TXLs…
- GSG pads 75-100um
- 200um separation

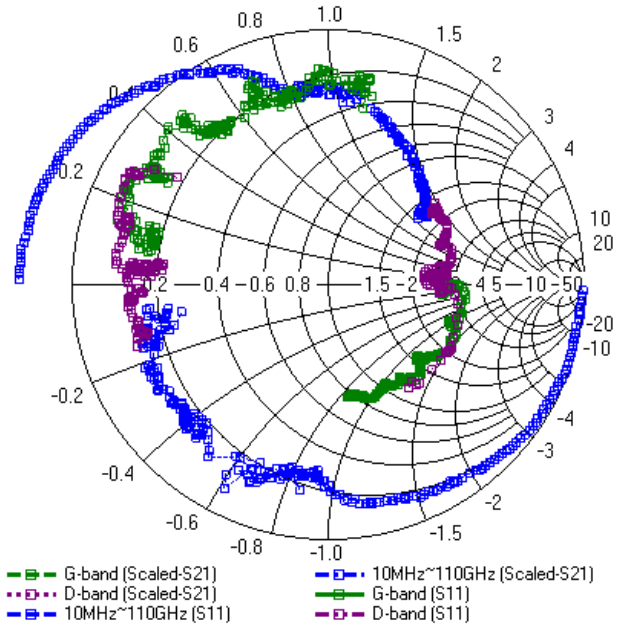






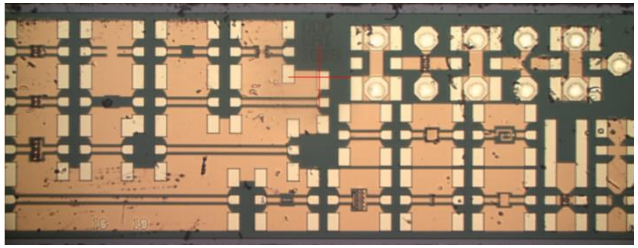
Devices Characterization

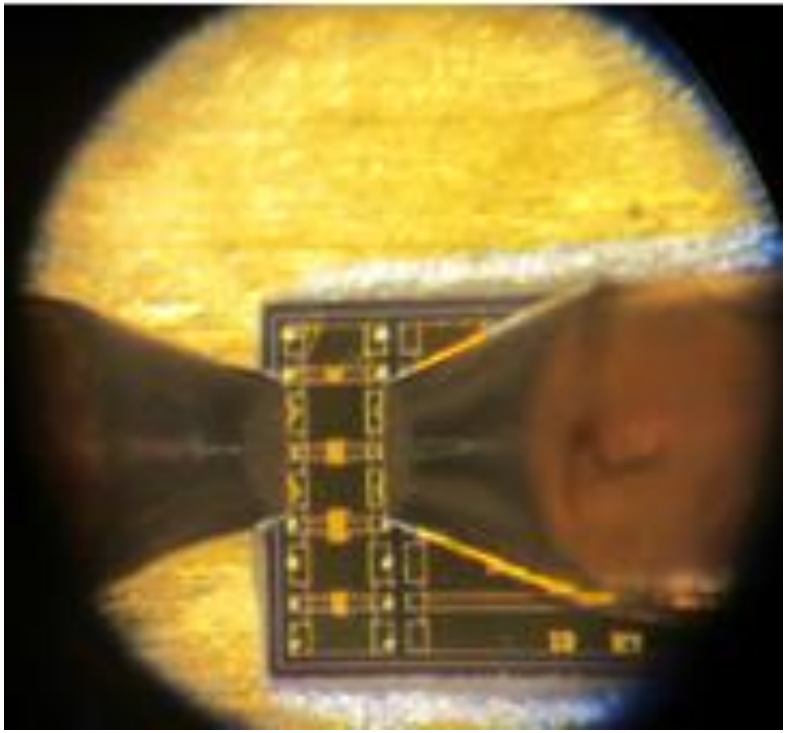
- On-wafer banded s-parameters measurements
  - 100um GSG probes
  - 10MHz~67GHz(x3)
  - VNA frequency extenders
    - 75GHz~110GHz(x2)
    - 10MHz~110GHz
    - D:110GHz~170GH
    - G:140GHz~220GHz
  - 6 setups measurement systems in 5 labs



Devices Characterization

- Measured on probe station with:
  - dies glued on copper carrier by silver epoxy
  - to mimic the targeted working environment

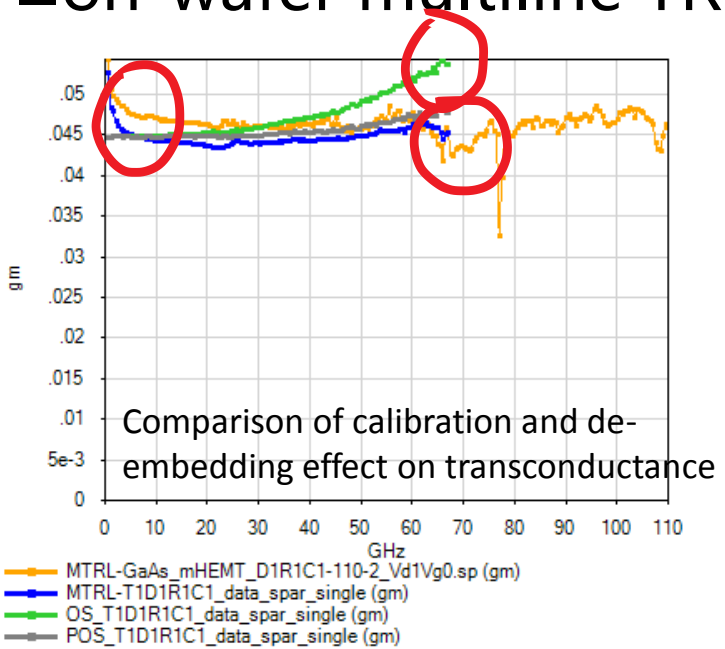


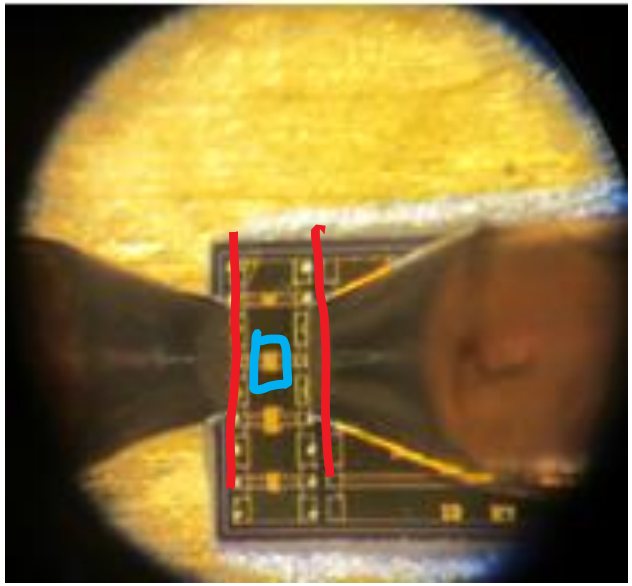


[1]P. Manuel, S. Fregonese, A. Curutchet, et al, EuMC, p.167(2015).

Devices Characterization

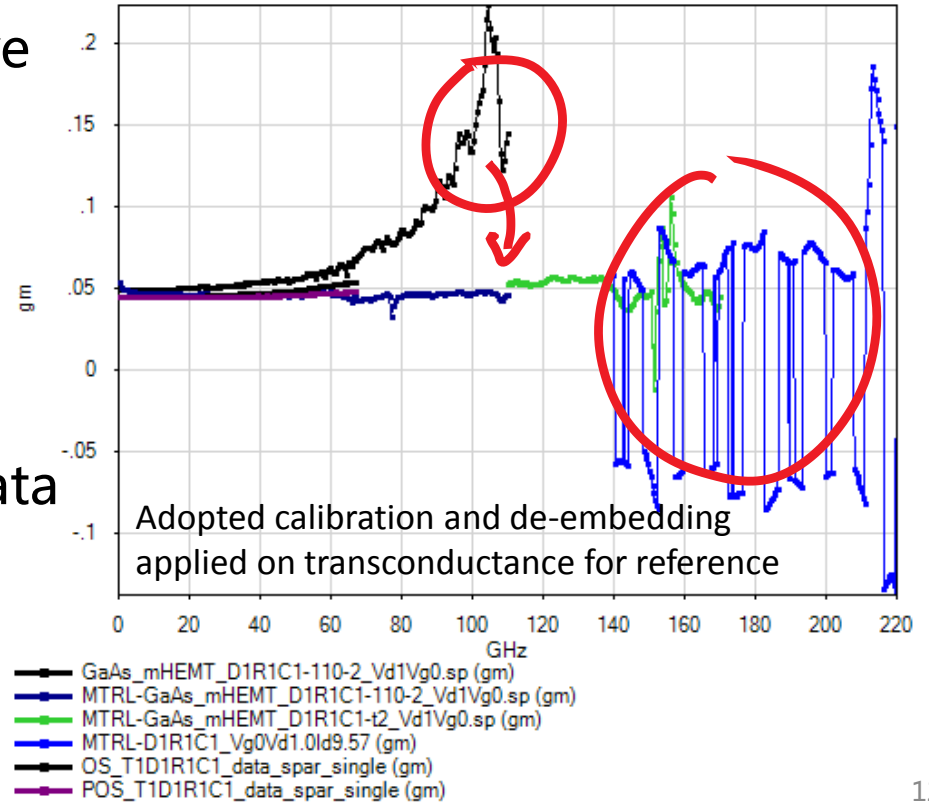
- Calibration and De-embedding[1]
  - 1st tier calibration using LRRM with ISS
  - OPEN/SHORT/PAD dummies for OS, POS de-embedding
  - on-wafer multiline TRL calibration





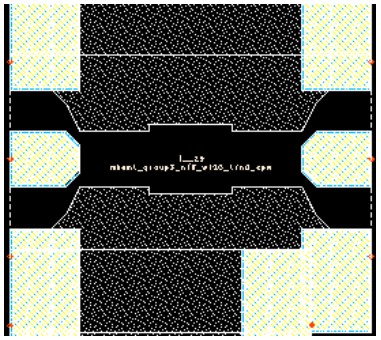
Devices Characterization

- Calibration and De-embedding
  - POS up to 67GHz
  - mTRL is used in other bands
    - generally effective
  - Some problems
    - discontinuities
    - unreal artifacts
    - Incorrect sign
    - originate from data

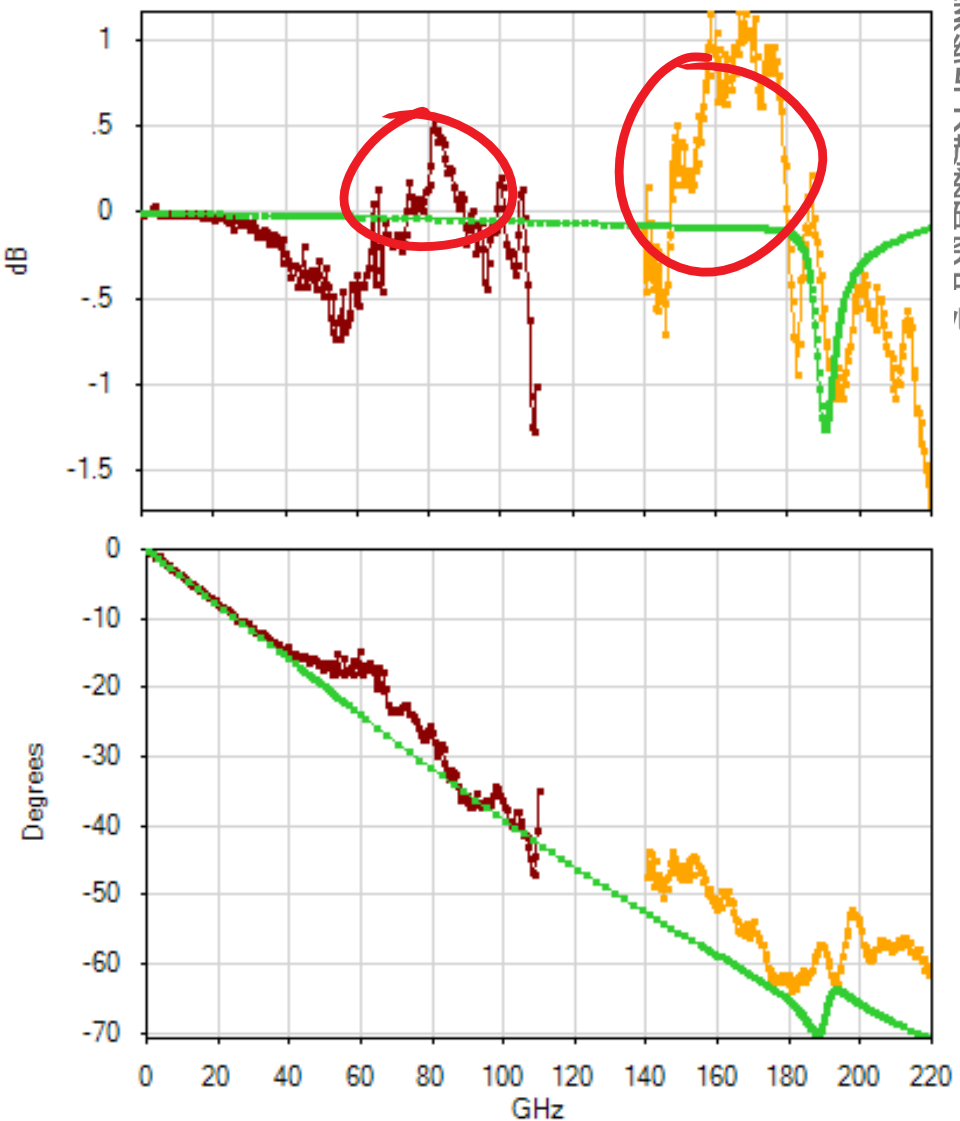


Measurement Non-idealities

- Raw S_{11} of PAD dummy
  - especially obvious for magnitude of s-parameters



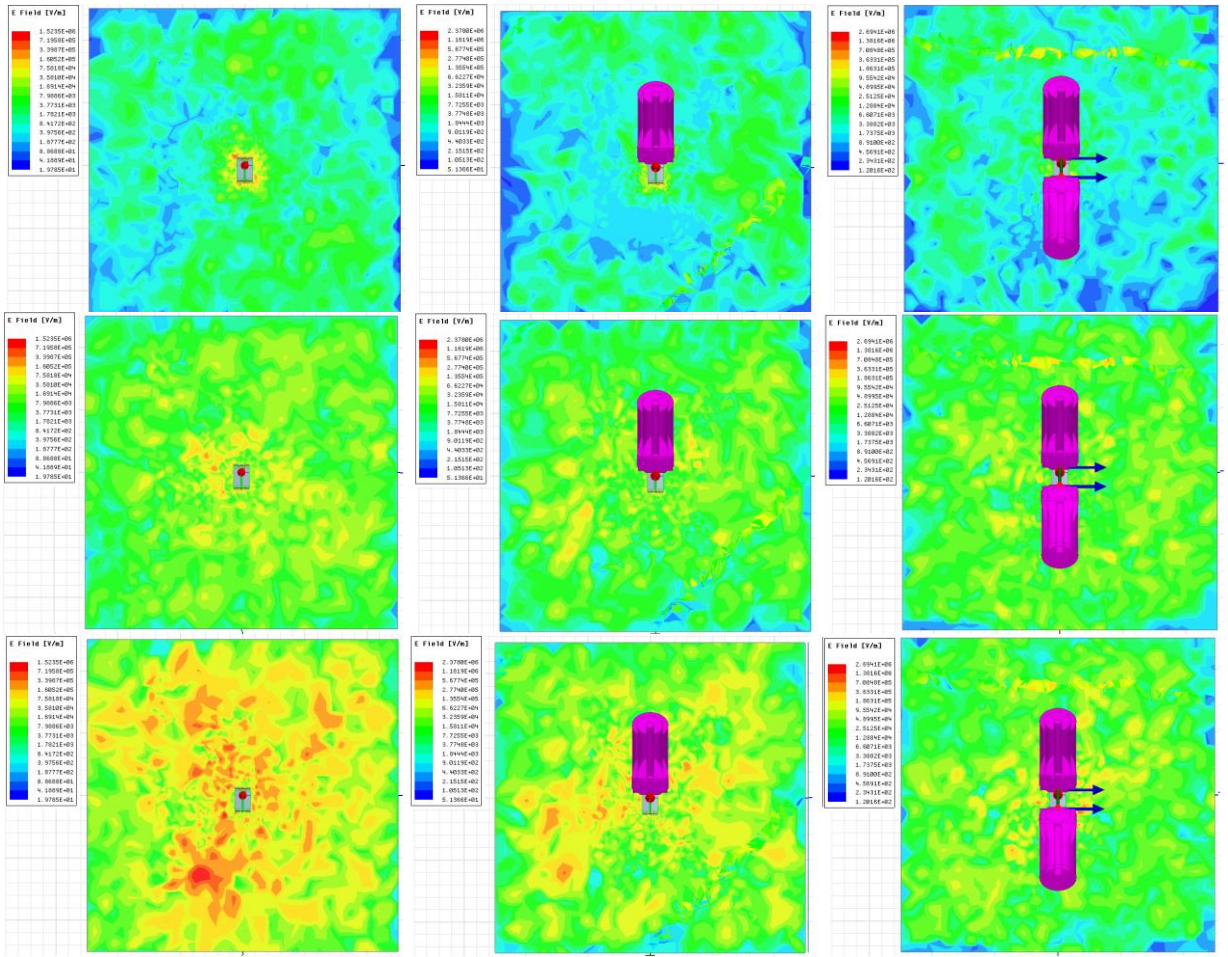
- Ref[2]
  - Parasitic scattering and coupling



[2]M. Seelmann-Eggebert, M. Ohlrogge, R Webber, et al, MTT, 63(7), p.2335(2015).

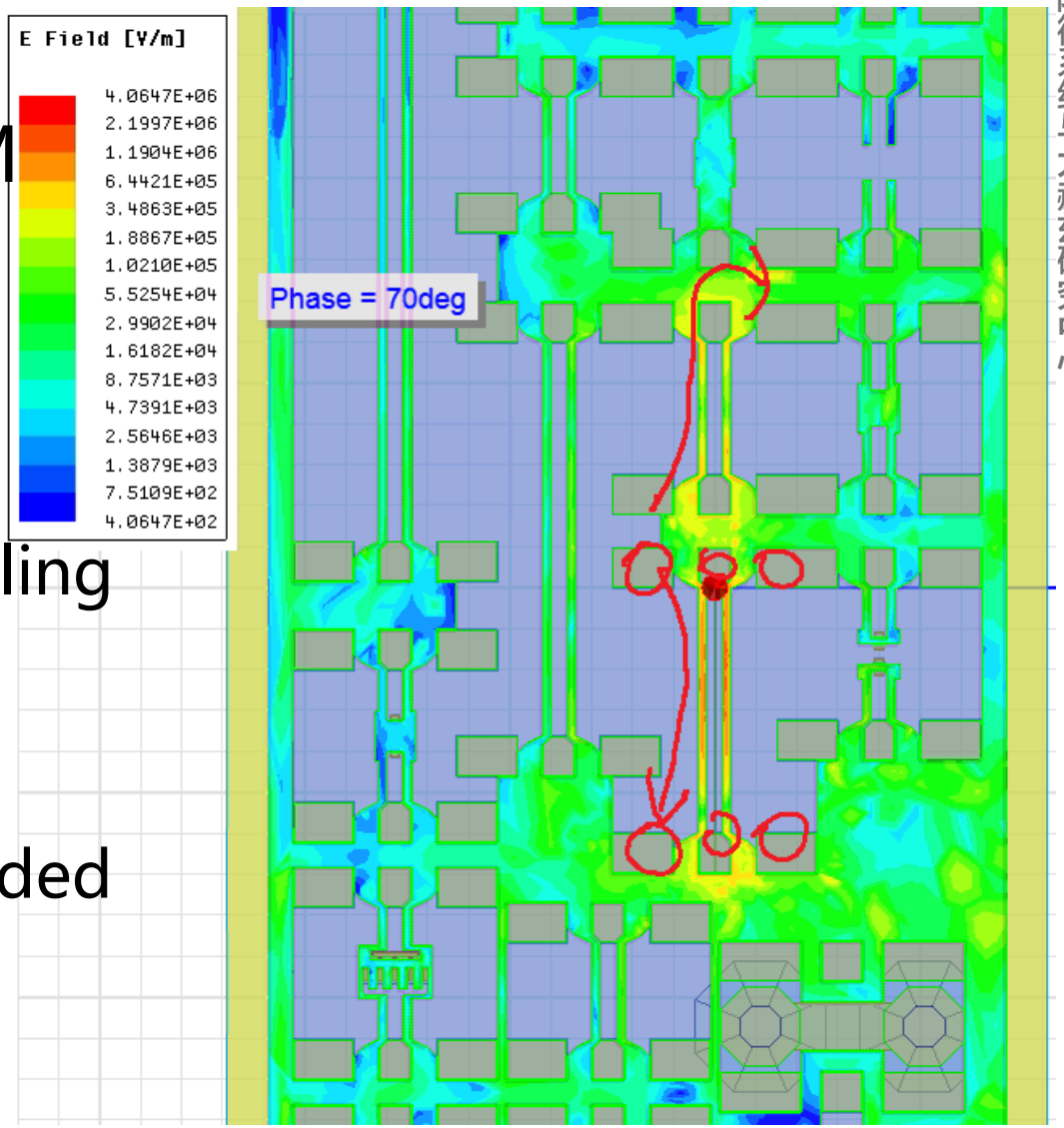
Parasitic Scattering & Coupling

- E-Field distribution for a CPW transmission line
  - 100GHz
  - 200GHz
  - 300GHz



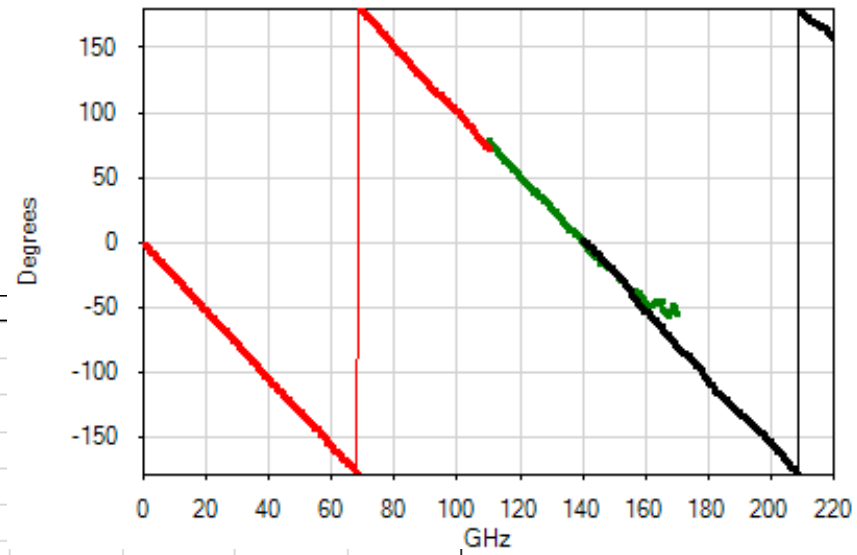
Parasitic Scattering & Coupling

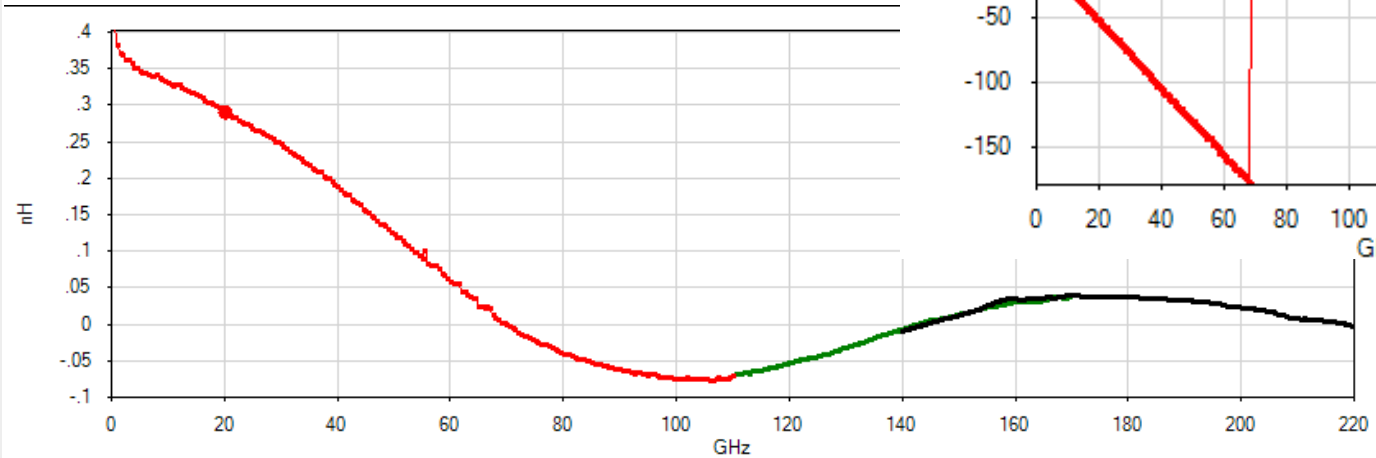
- full test chip EM simulation
  - @200GHz
  - unwanted coupling to adjacent test structures
  - results in degraded data



Parasitic Scattering & Coupling

- Some characteristics and test structures are less sensitive
  - Effective inductance, capacitance, phase of transmission terms
  - long transmission line
    - Effective L, Phase





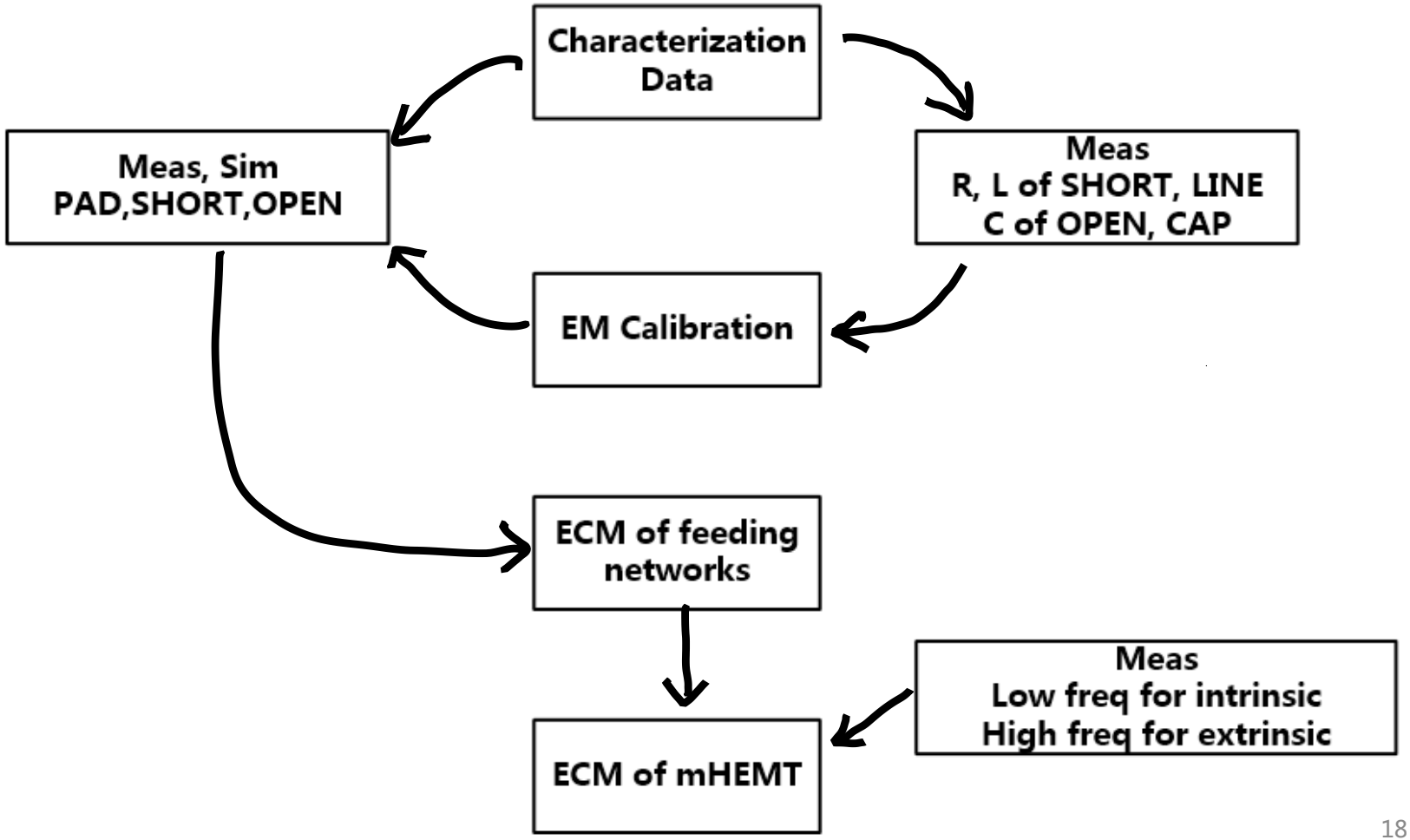
Modeling Methodologies

- Considering the data degradation up to 220GHz
- Following strategies are used:
  - Systematic calibration of EM simulation
    - For parasitics extraction and measurement verification
  - Feeding network modeling
    - replace de-embedding and on-wafer calibration
  - Recursive Modeling[3] of mHEMT
    - previously extracted equivalent circuit model(ECM) used recursively in later extractions

[3]Babak Heydari, Dissertation, UCB/EECS (2008).

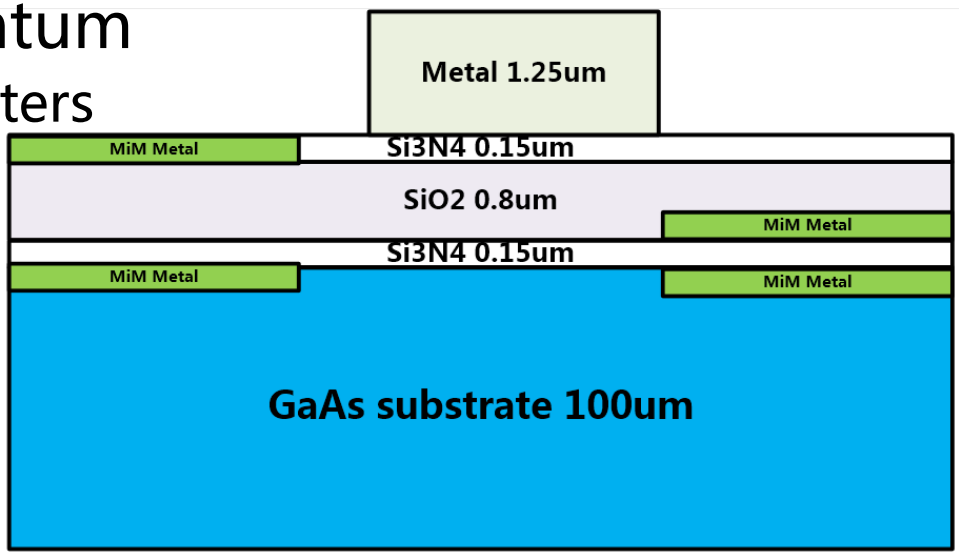
Modeling Methodologies

- Modeling in flowchart



EM Calibration

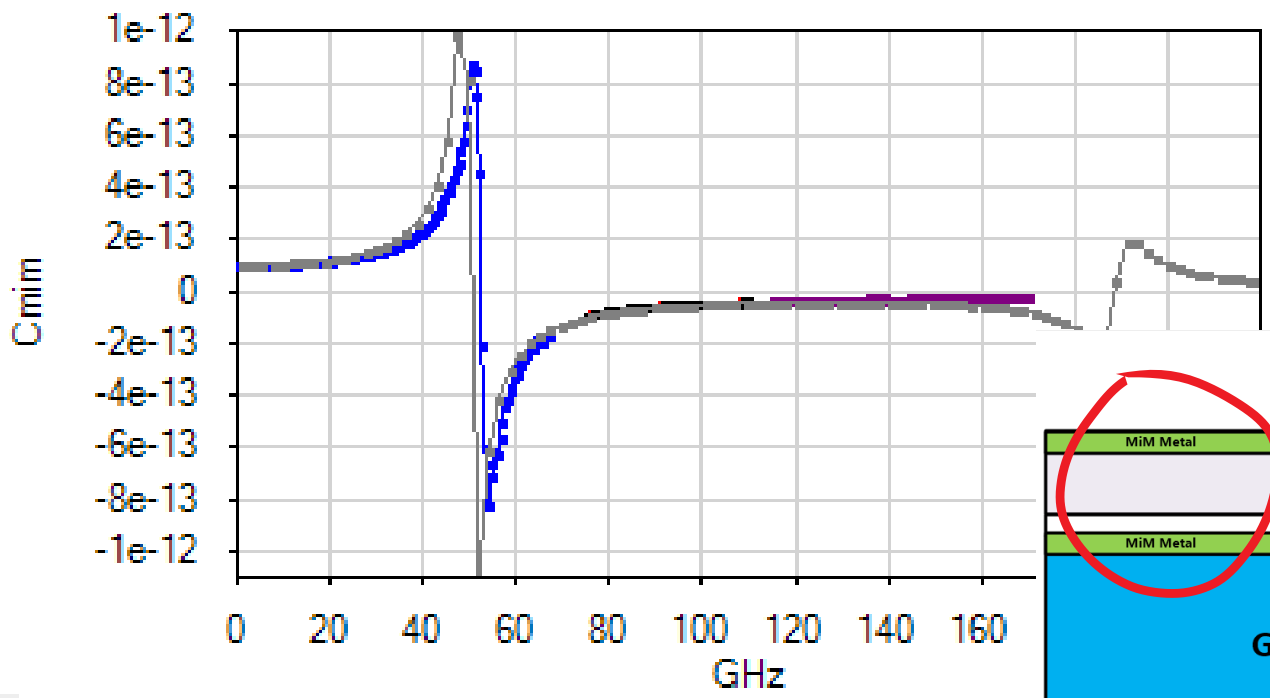
- Systematic EM calibration[4]
  - Simplified process cross-section profile
  - based on measurement data of SHORT, LINEs and Caps structures
  - HFSS and Momentum
    - Materials parameters
    - thickness

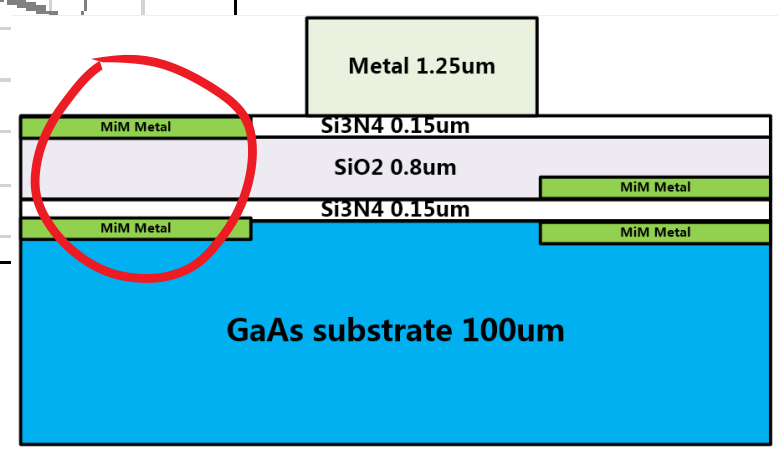


[4]K. Takano, K. Katayama, S. Mizukusa, et al, ICMTS, p. 230 (2015).

EM Calibration Results

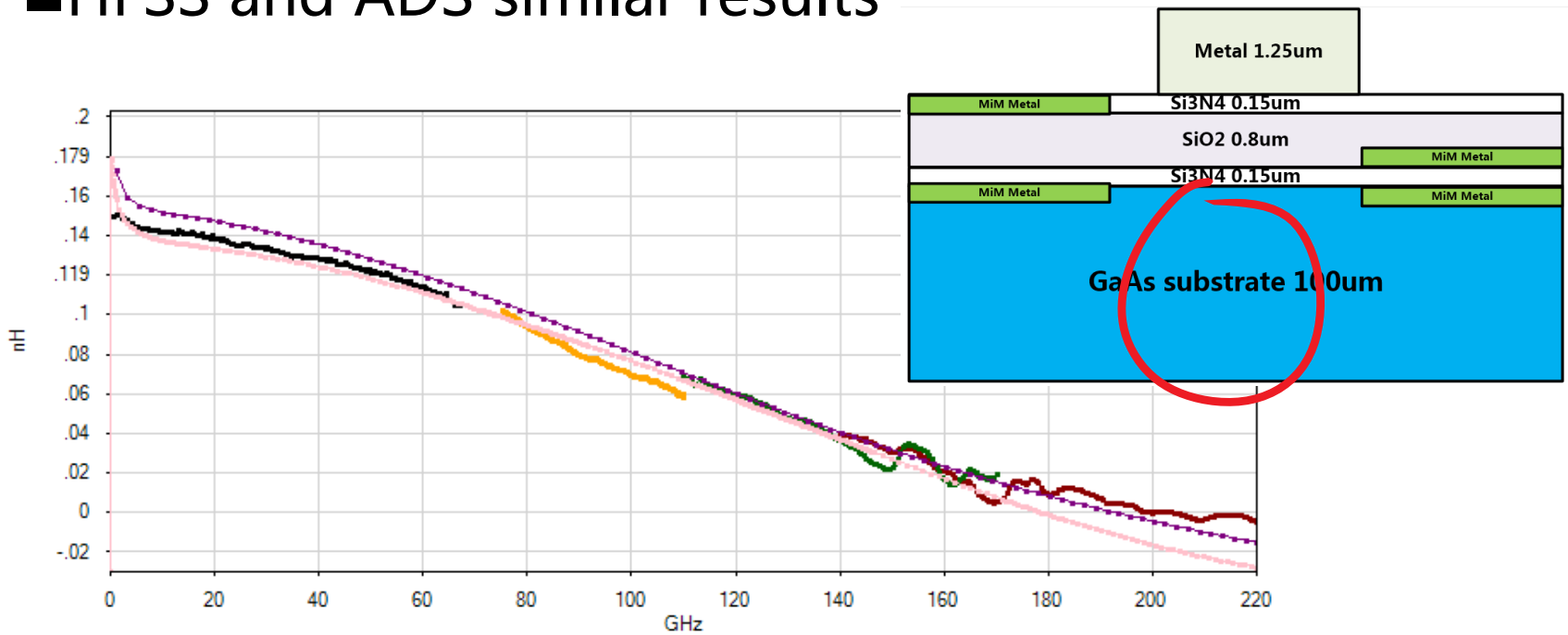
- 100fF C_{mim}
  - Si_3N_4, SiO_2 dielectric from 2 Caps
  - verified up to 170GHz





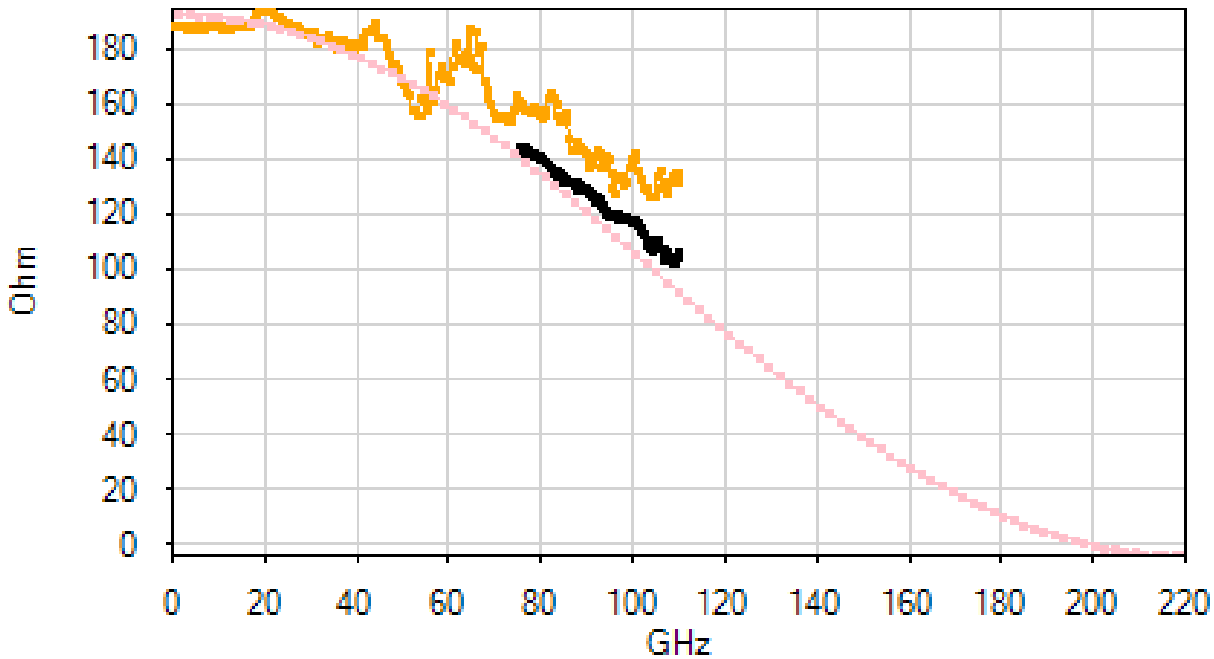
EM Calibration Results

- Transmission lines
  - Conductivity from effective resistance
  - GaAs substrate dielectric from LINEs
  - HFSS and ADS similar results



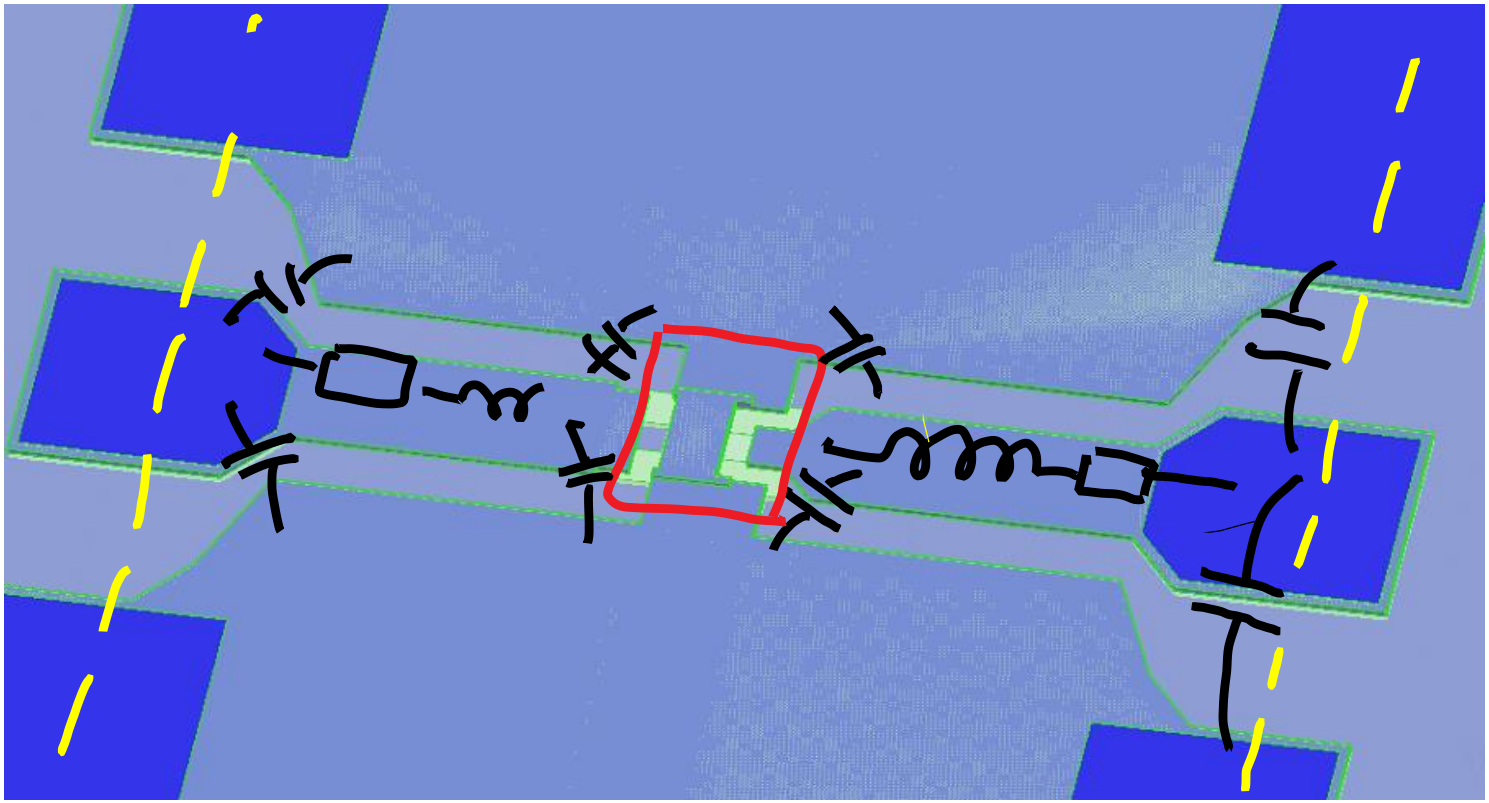
EM Calibration Results

- 200Ohm Resistor
  - Thin film metal resistor
  - verified up to 110GHz



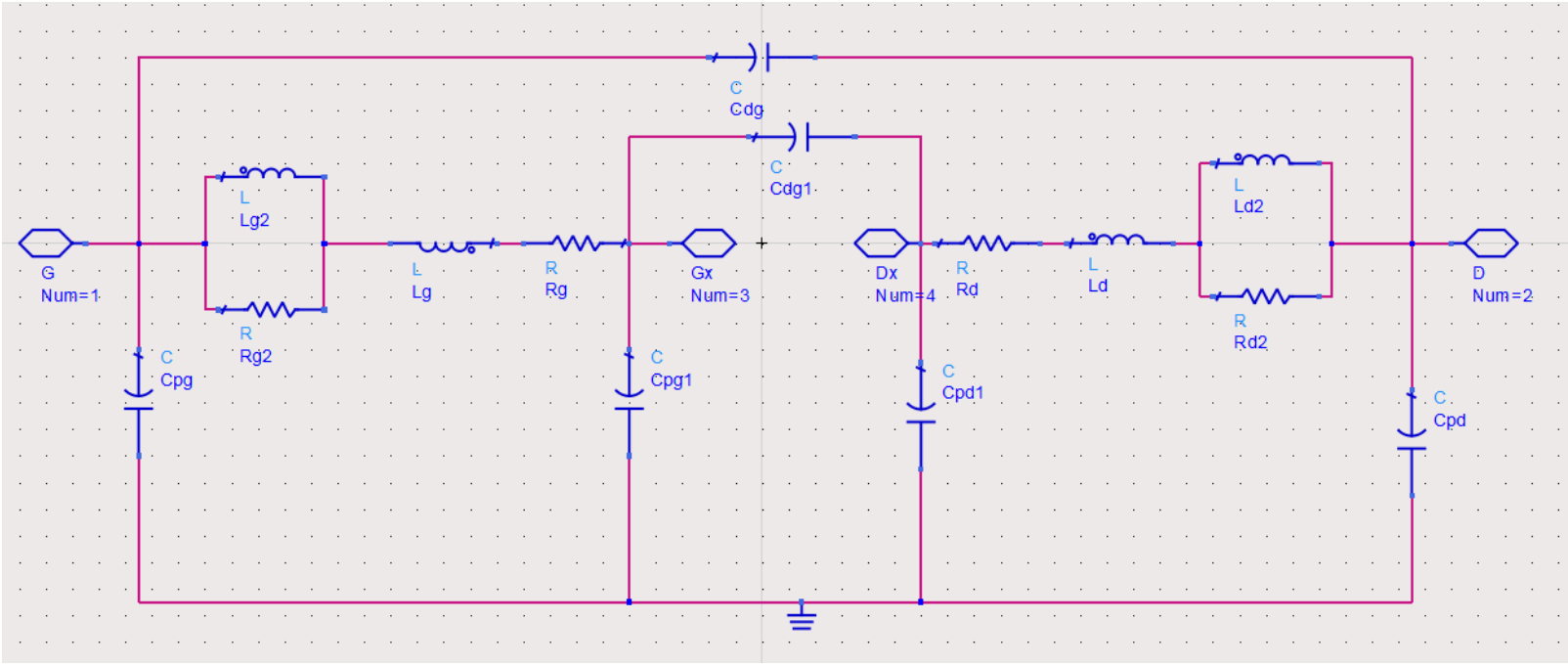
Feeding network modeling

- 2x20um mHMET with feeding parasitics
  - Reference planes

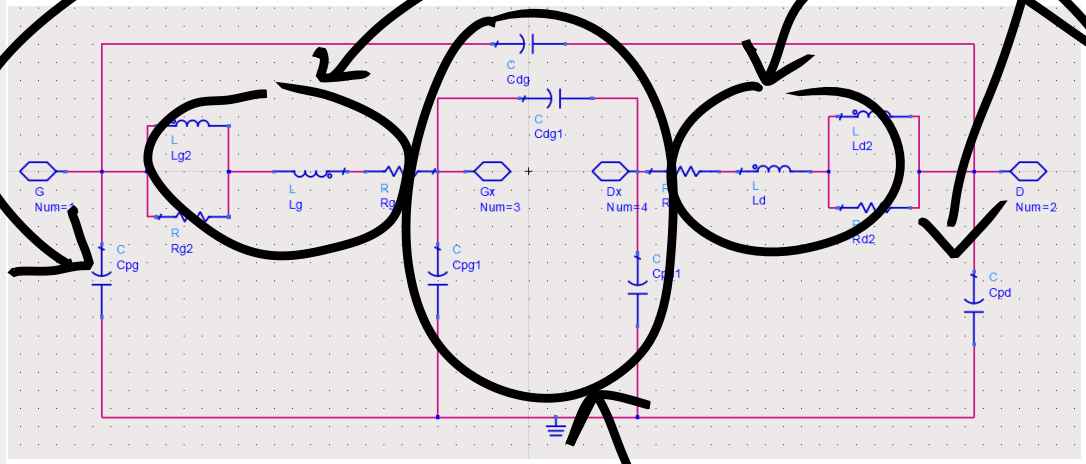


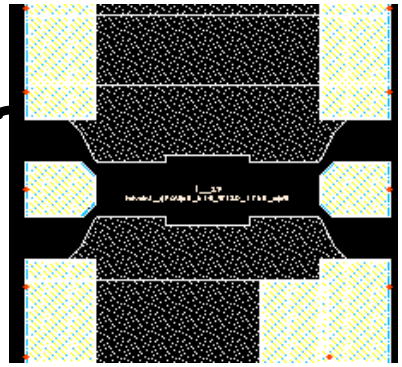
Feeding network modeling

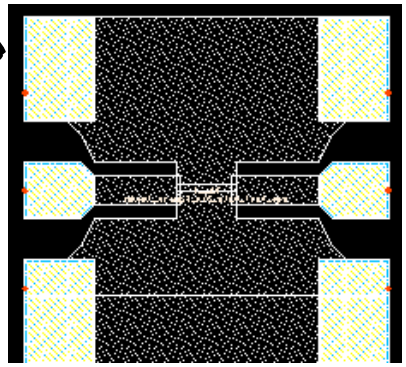
- Feeding network modeling
  - based on PAD, SHORT and OPEN dummy structures

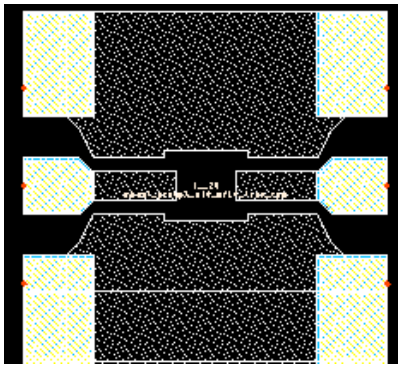


Feeding network modeling





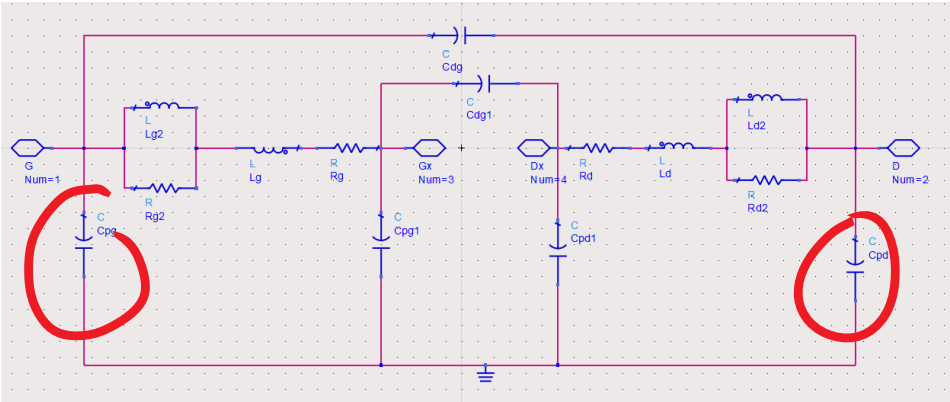


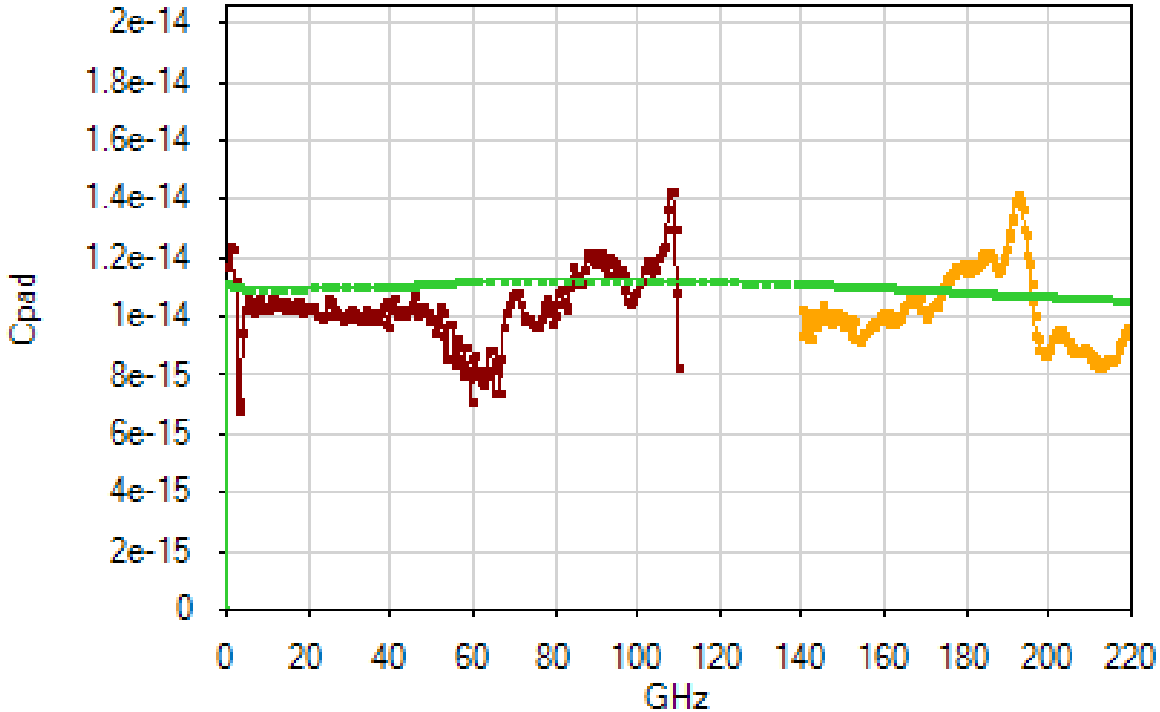


- Extraction recursively
  - Each extracted ECM is used as part of the subsequent ECM
  - PAD→SHORT→OPEN

Feeding Networks Results

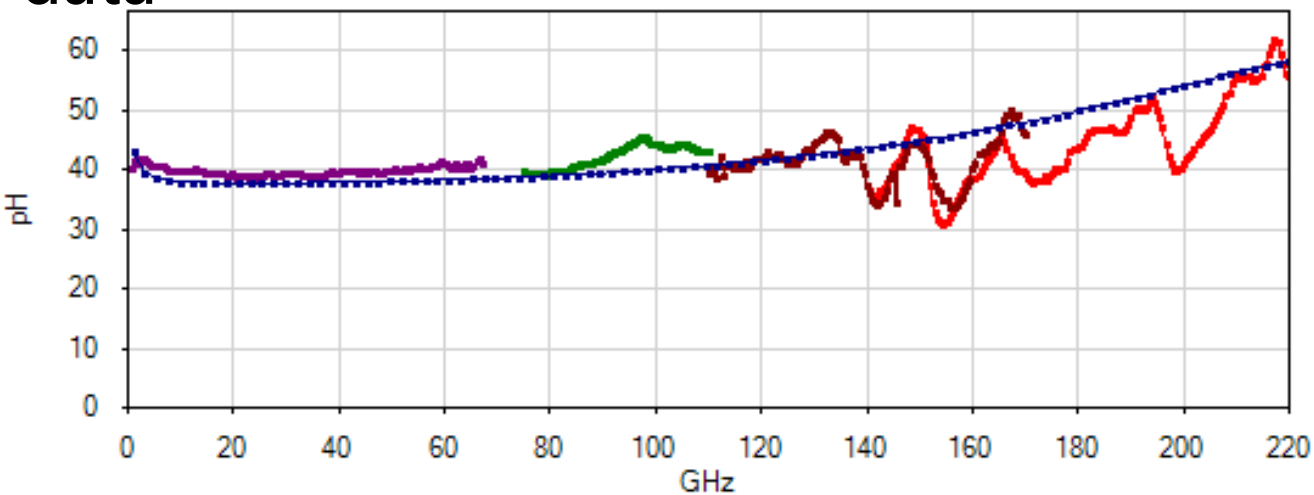
- PAD dummy
  - EM vs. data
  - C_{pg}, C_{pd}

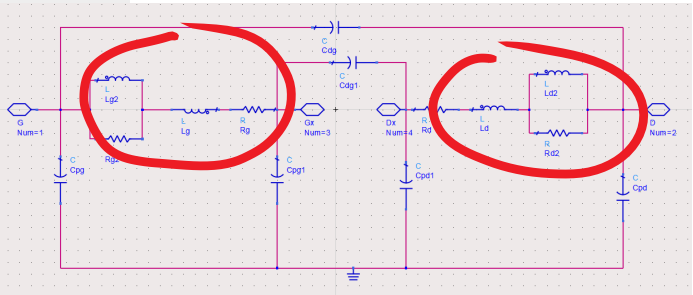


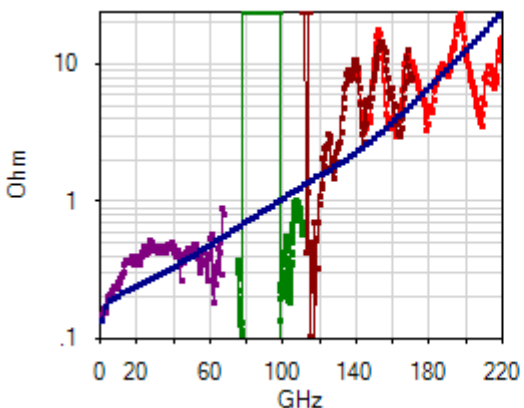


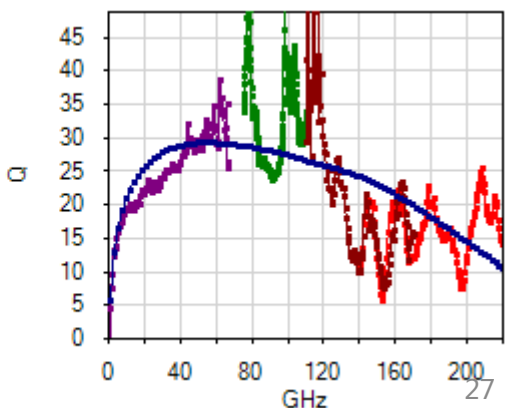
Feeding Networks Results

- SHORT dummy
  - EM vs. data
  - R_g, L_g
  - R_{g1}, L_{g1}
  - R_d, L_d
  - R_{d1}, L_{d1}



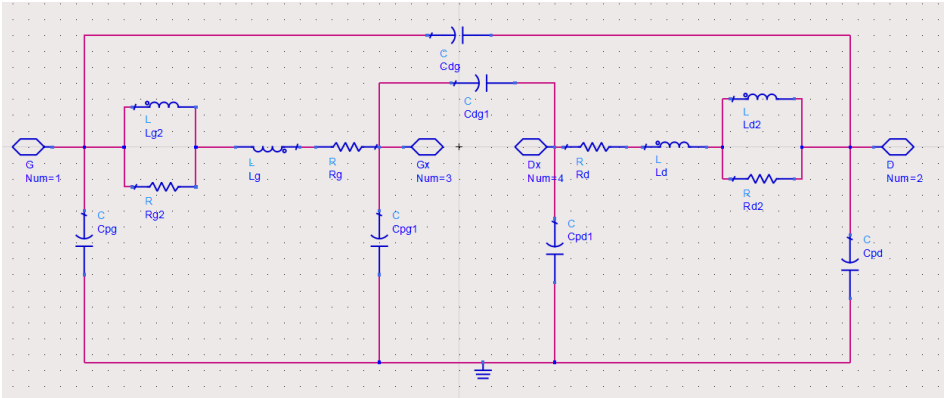


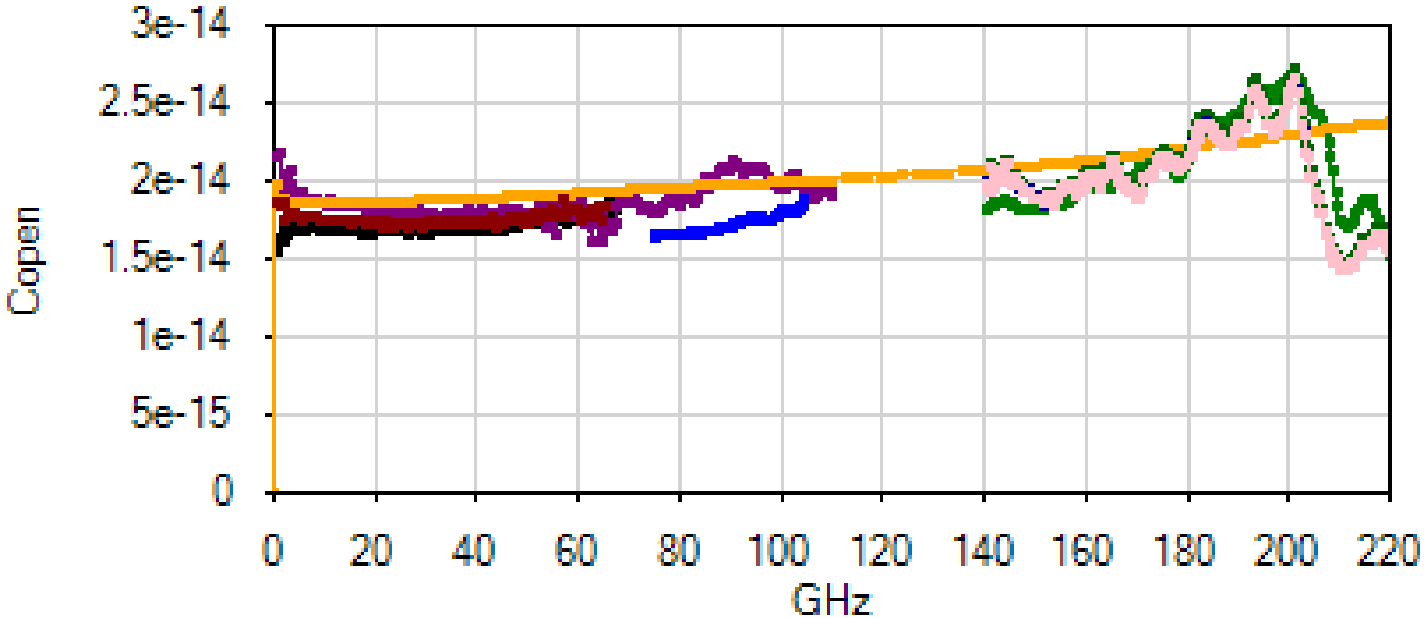




Feeding Networks Results

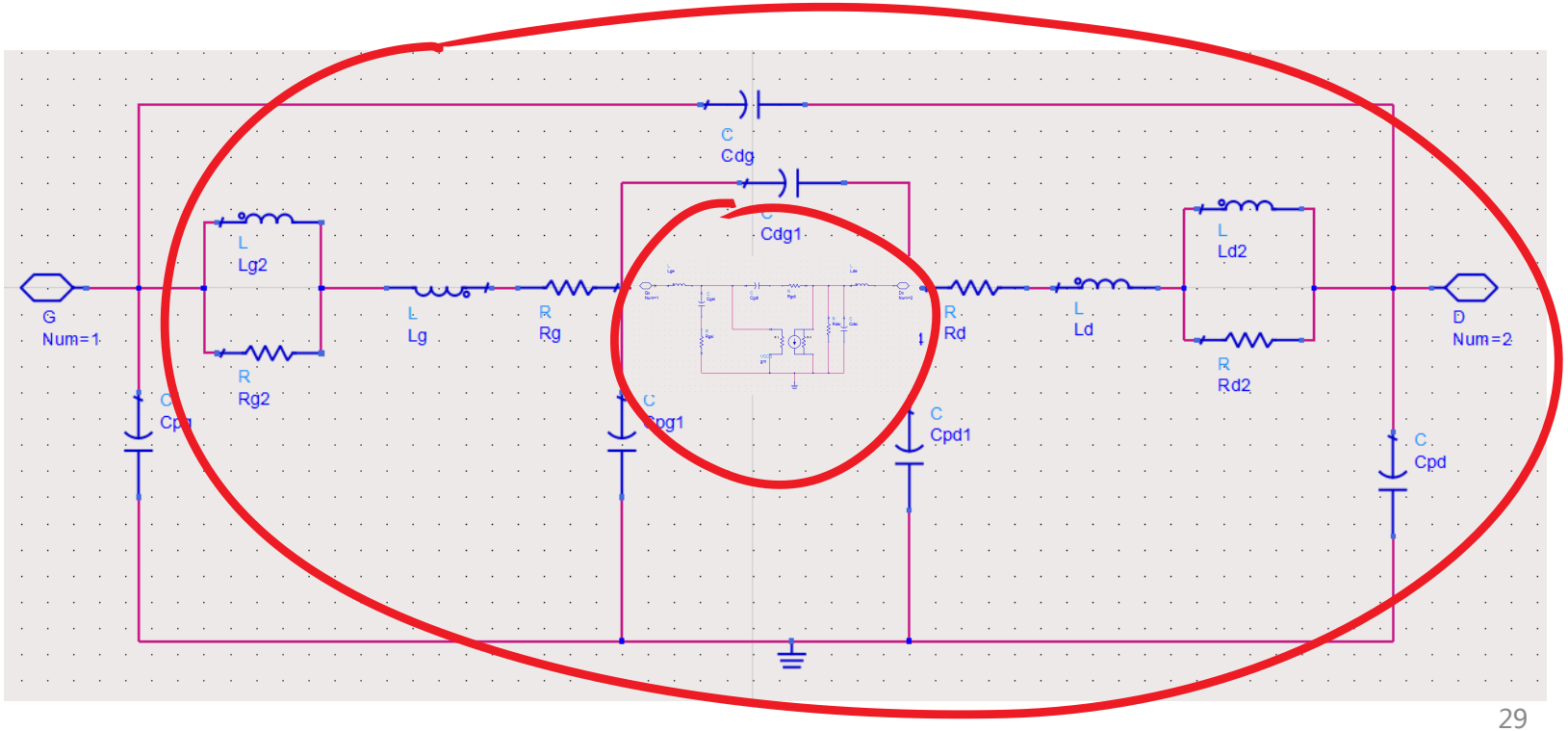
- OPEN Dummy
  - EM vs. data
  - C_{pg1},C_{pg2}
  - C_{dg},C_{dg1}





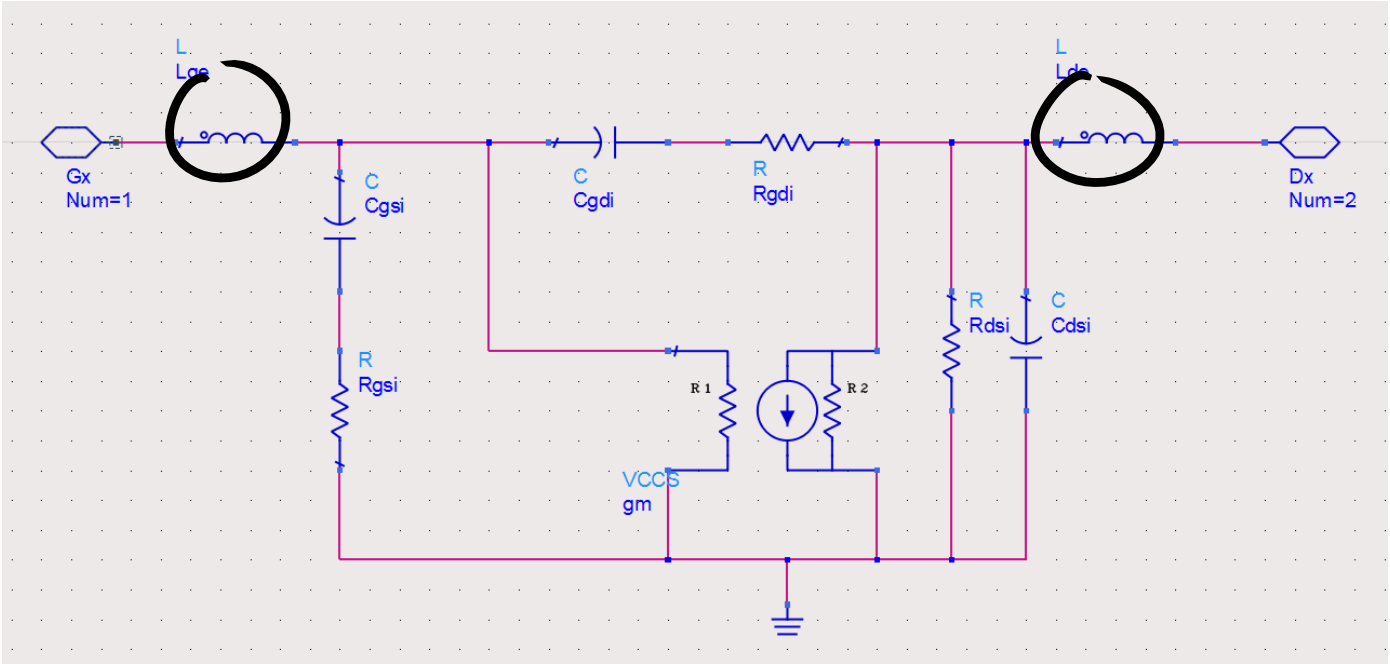
Recursive Modeling

- mHEMT model
  - Pi-network embedded in the feeding ECM
  - used raw measurement data as targets



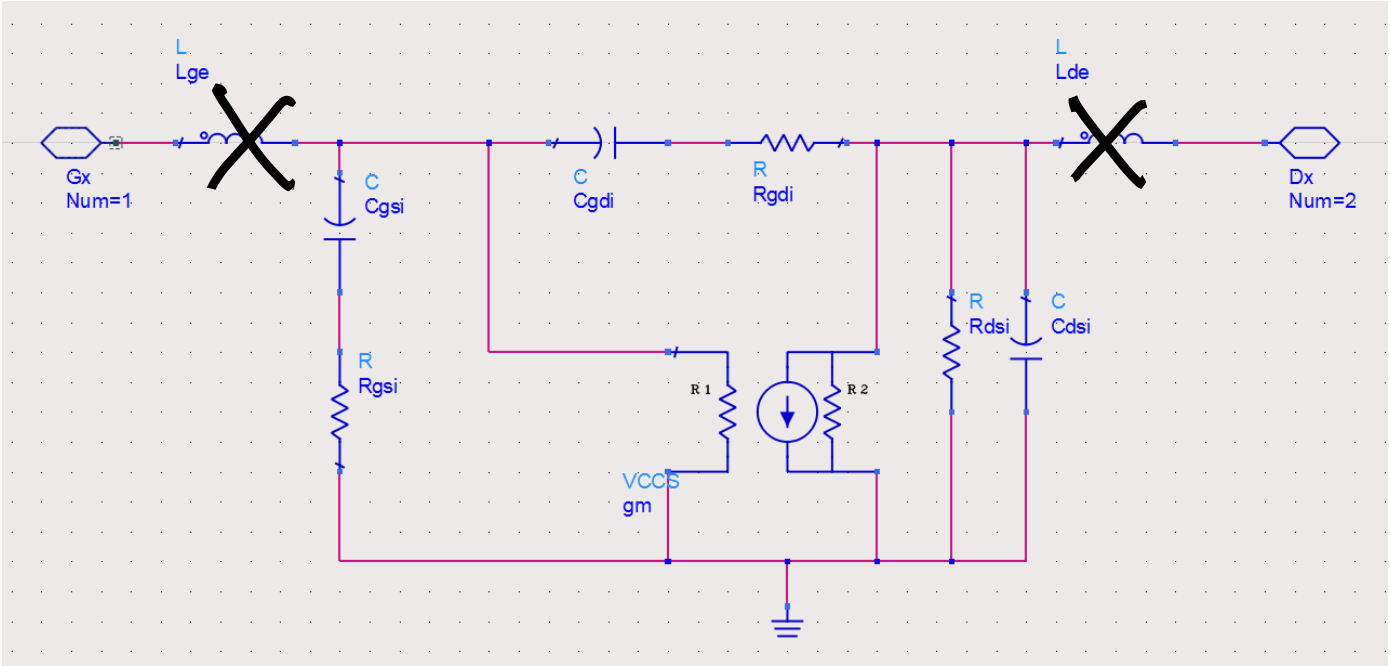
Extrinsic Elements Extraction

- Cold-FET for terminal parasitics
  - source parasitics and res at G,D ignored
- L_{ge}, L_{de}
  - Recursive methods, fitting to raw data(>110GHz)



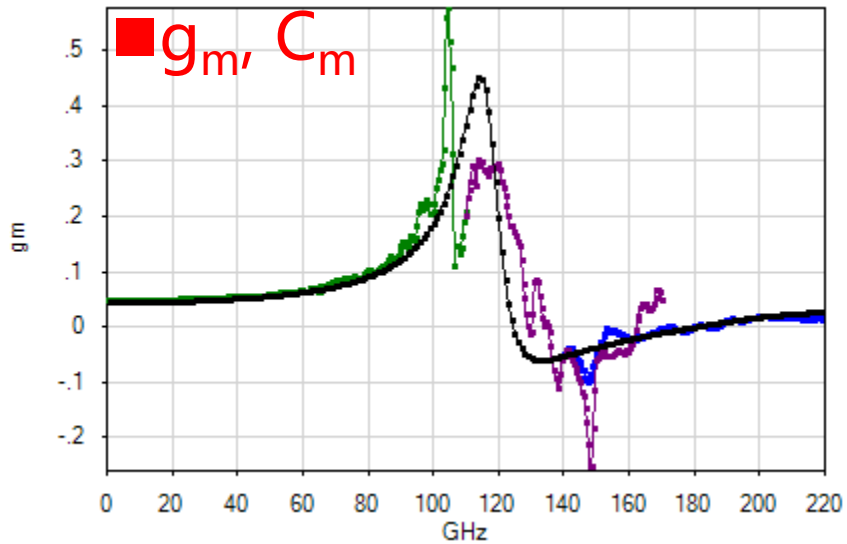
Intrinsic ECM Extraction

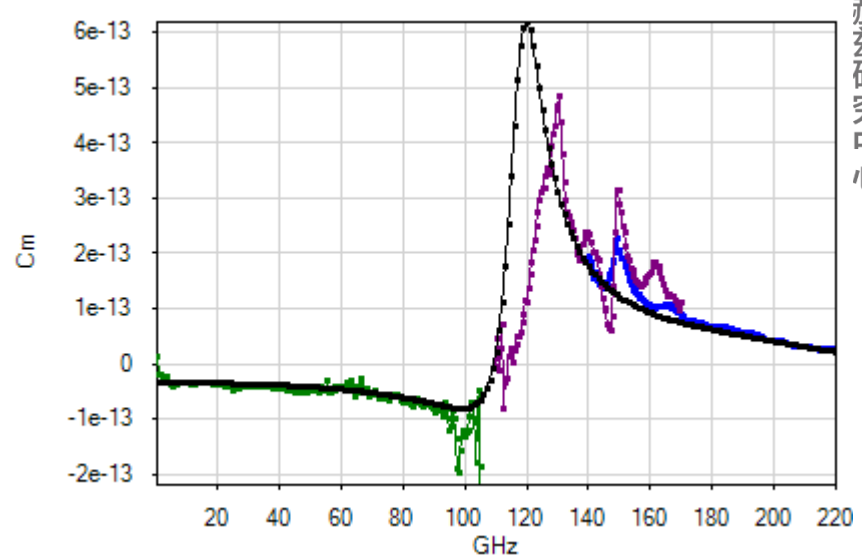
- Intrinsic elements
  - starting value: extracted from low frequency de-embedded data(<110GHz)
  - then fitting together with feeding network ECM

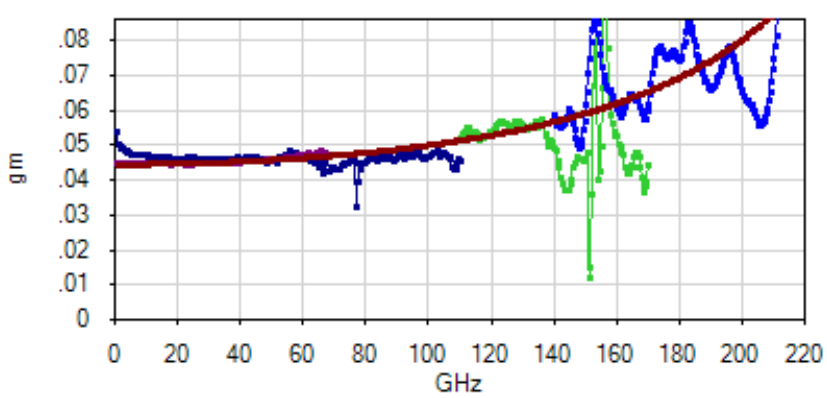


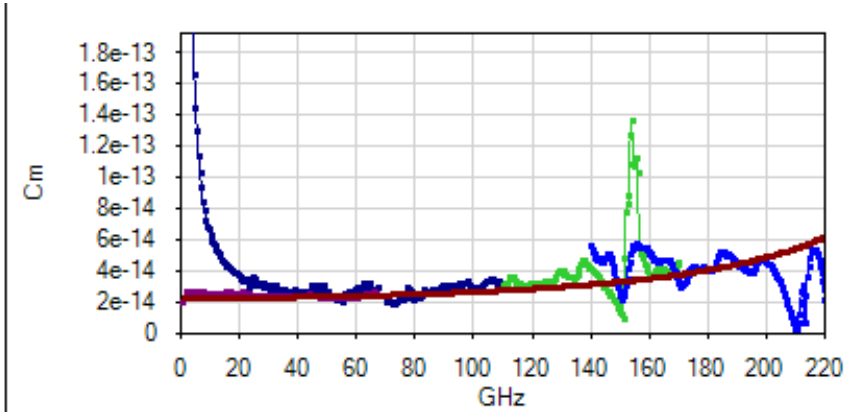
Meas vs. Sim Results

- mHEMT 2x20um V_g=0V V_d=1V(close to peak transconductance)



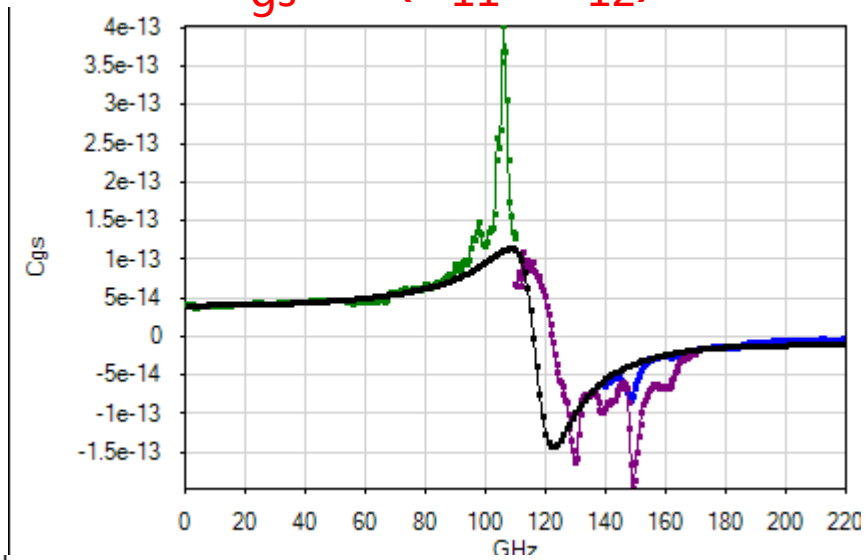


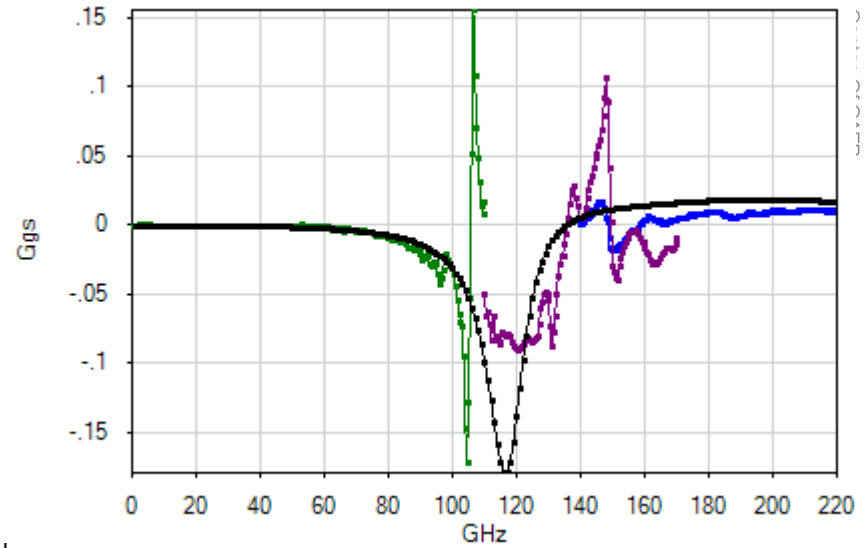


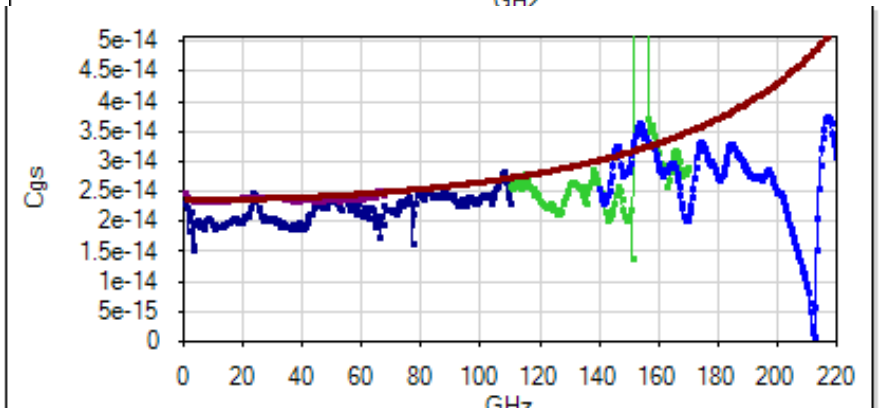


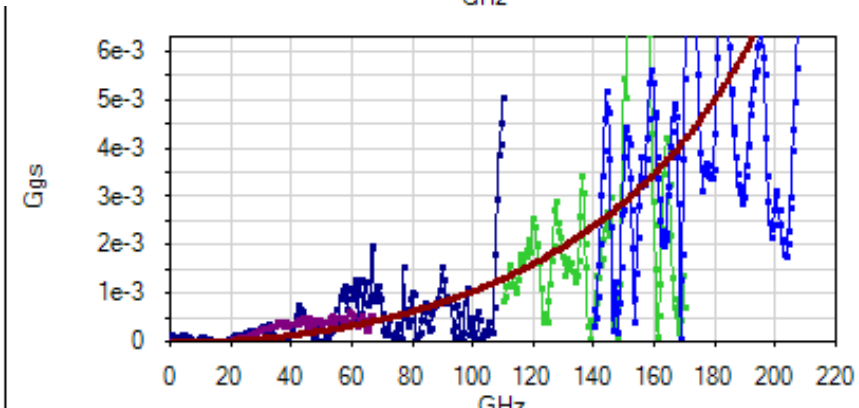
Meas vs. Sim Results

- mHEMT 2x20um V_g=0V V_d=1V
  - C_{gs}, re(Y_{11}+Y_{12})



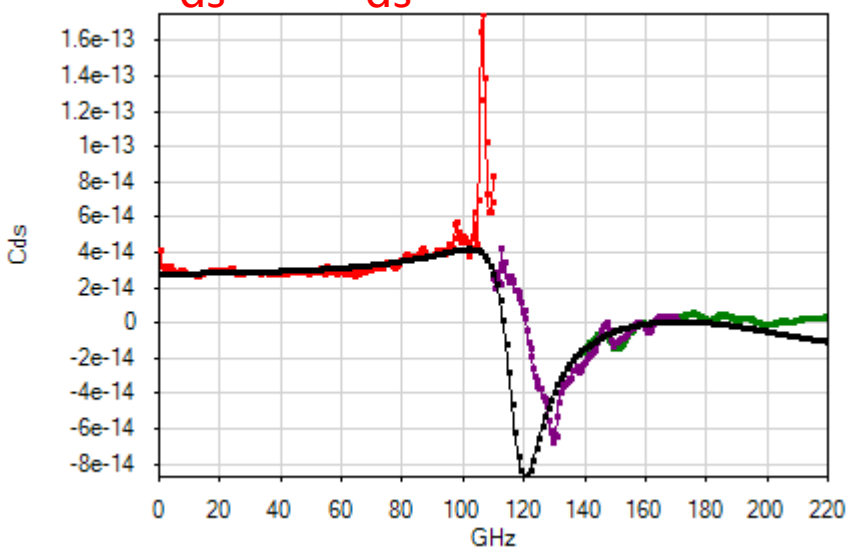


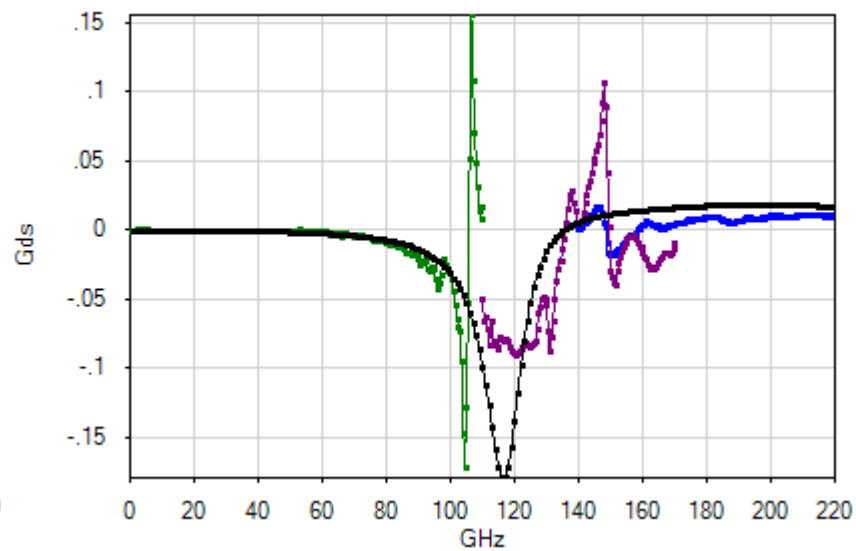


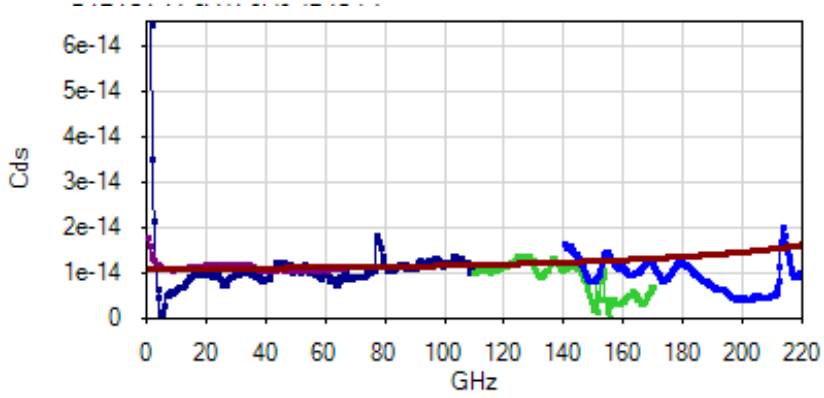


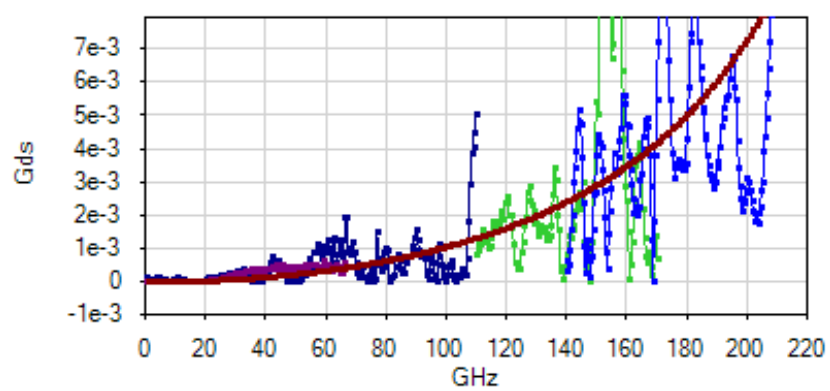
Meas vs. Sim Results

- mHEMT 2x20um V_g=0V V_d=1V
  - C_{ds}, $1/R_{ds}$



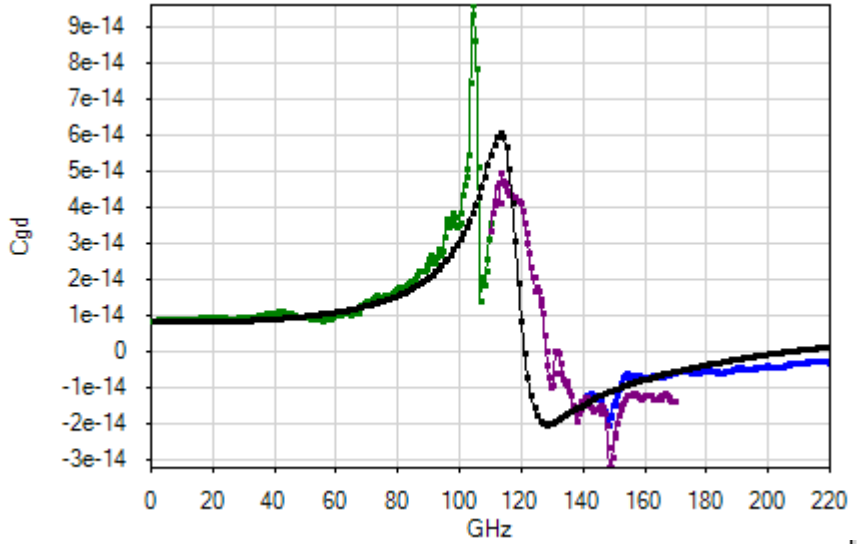


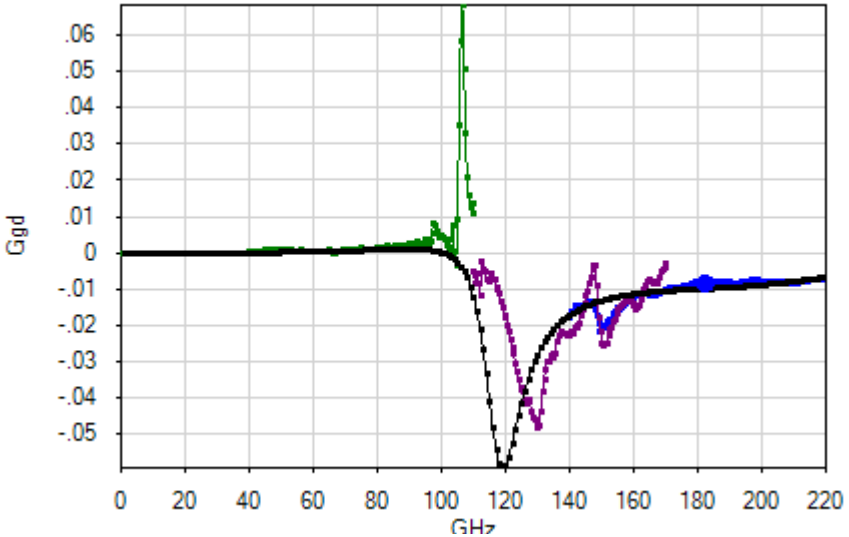


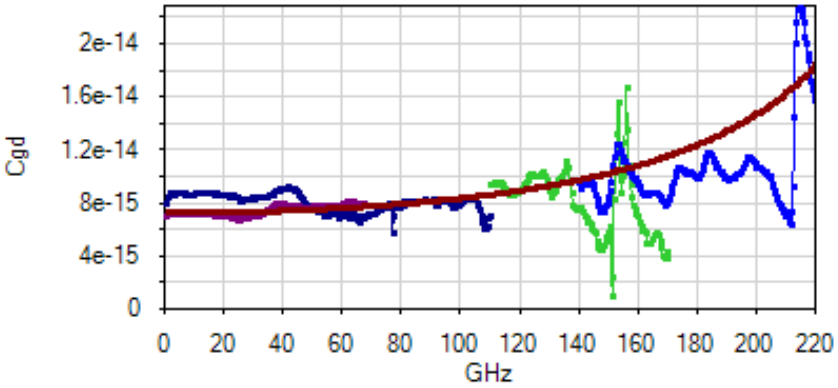


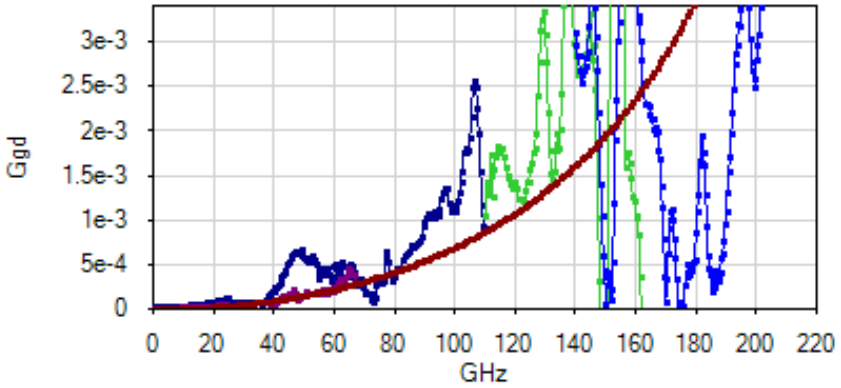
Meas vs. Sim Results

- mHEMT 2x20um V_g=0V V_d=1V
  - C_{gd}, re($1/Y_{12}$)



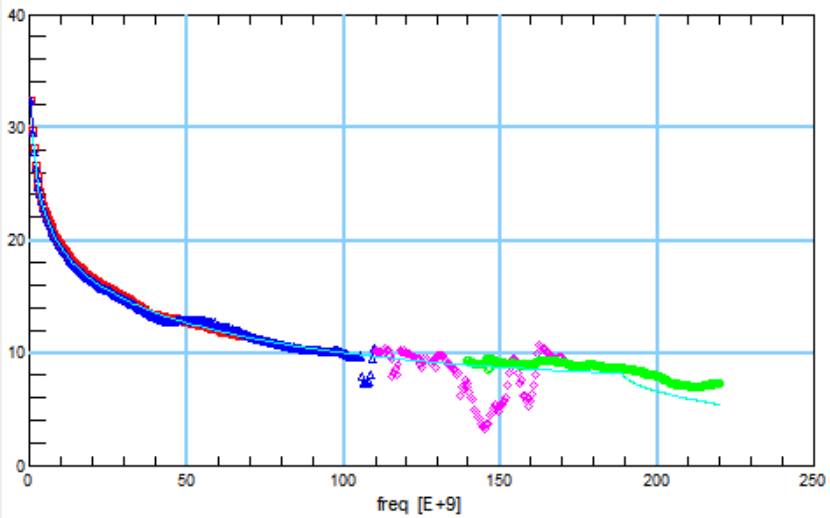


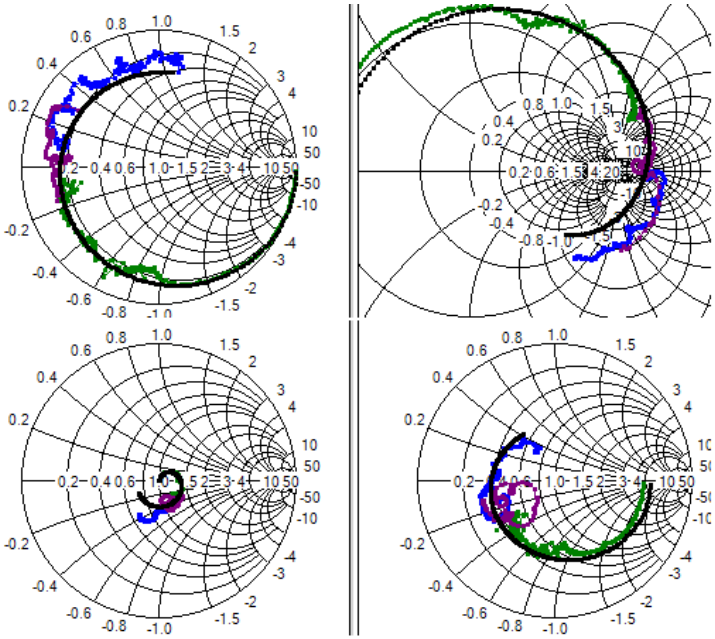




Meas vs. Sim Results

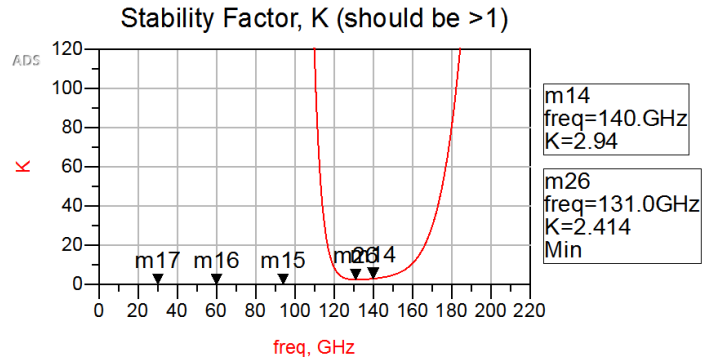
- mHEMT 2x20um V_g=0V V_d=1V
  - MAG
  - S-parameters Smith plots

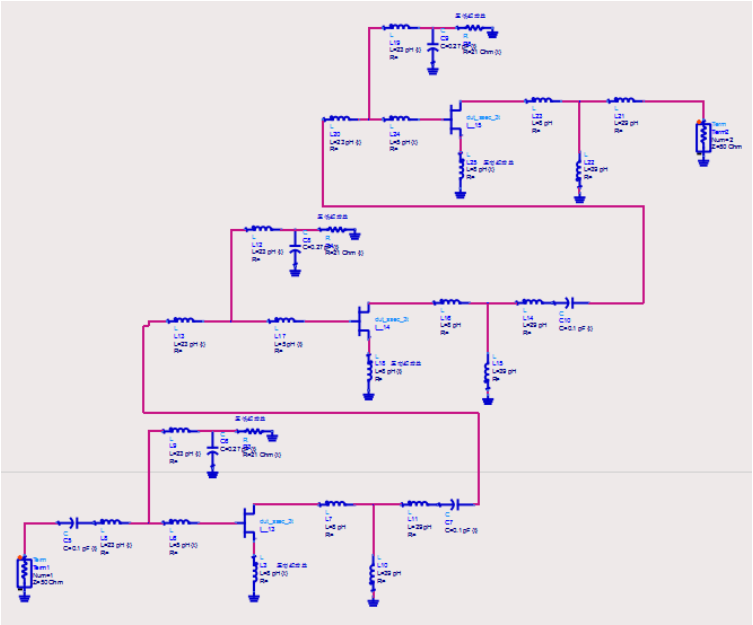


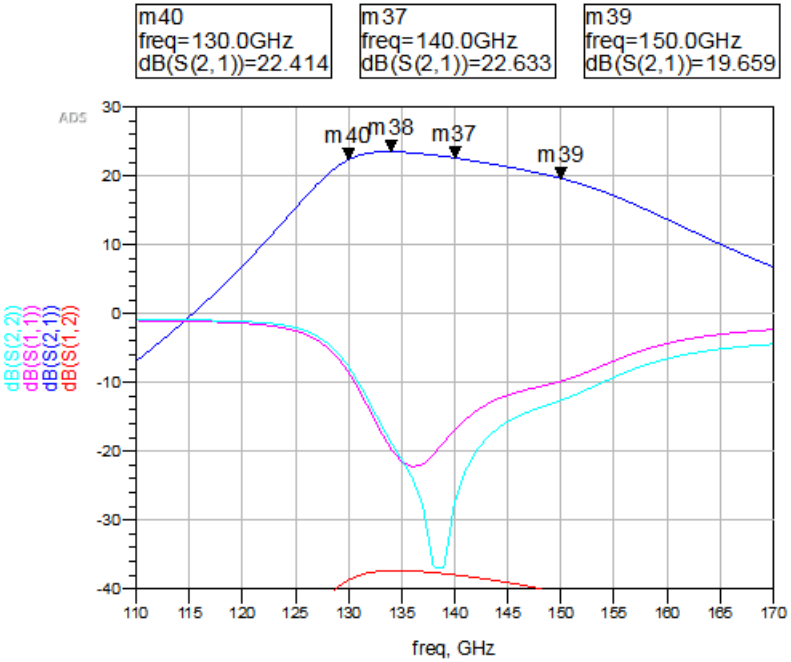


Model Application

- 3-stage CS amplifier
  - T-junction matching
  - Gain>20dB@140GHz







Summary

- Test chip & Characterization
  - Compact, CPW style
  - On-wafer banded measurements with non-idealities

- Modeling Methodologies & Results
  - EM calibration for parasitics extraction and verification of measurement
  - Feeding network modeling instead of de-embedding and calibration
  - Recursive modeling of mHEMT up to 220GHz, to be used in amplifier design

Ref & Acknowledgement

References

- [1]P. Manuel, S. Fregonese, A. Curutchet, et al, EuMC, p.167(2015).
- [2]M. Seelmann-Eggebert, M. Ohlrogge, R Webber, et al, MTT, 63(7), p.2335(2015).
- [3]Babak Heydari, Dissertation, UCB/EECS (2008).
- [4]K. Takano, K. Katayama, S. Mizukusa, et al, ICMTS, p. 230 (2015).

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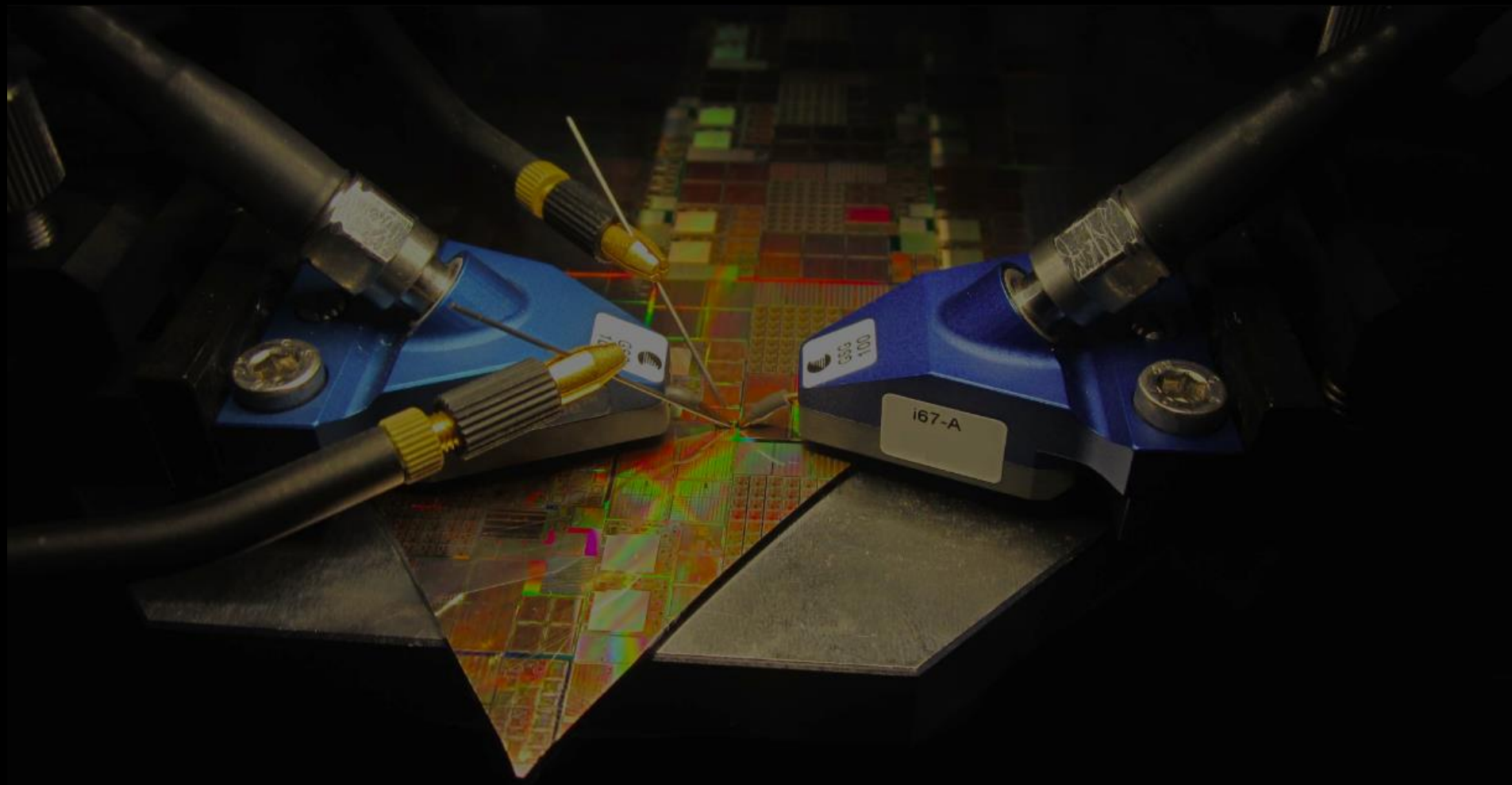

Thanks for your attention.