WM-01 – “Advanced CAD Tools and Techniques for the System Co-Design of Smart Antenna and Transmitter Modules”

Advanced CAD tools for an efficient Antenna / Module co-design

E. Ngoya, S. Mons, T. Reveyrand, C. Menudier, M. Thévenot, J. Lintignat, A. Beaumont

XLIM-Université de Limoges, UMR CNRS 7252, 87068 Limoges, France

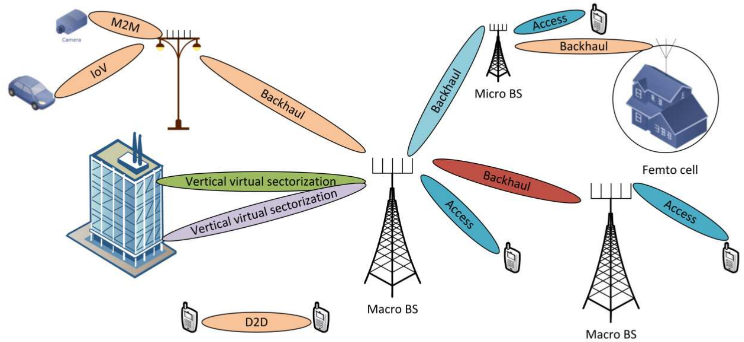
{www.xlim.fr} edouard.ngoya@xlim.fr

Outline

- Context
- Antenna and Radio co-simulation challenges
- XLIM Lab/SCERNE System-level simulation Framework development
- Large array antenna modeling focus
- Power amplifier modeling focus
- Beam steering complexity focus
- Conclusion

Context and objectives for 5G :
Achieve efficient beamforming for mass-market applications

Rafale RBE2 – Thales



I. Ahmed *et al.*, « A Survey on Hybrid Beamforming Techniques in 5G: Architecture and System Model Perspectives », *IEEE Communications Surveys & Tutorials*, 2018.

Cutting-edge historical niche market

Strong know-how since decades
–> high precision and reconfigurability,
BUT ….
The cost and complexity are outstanding, with a reduced overall efficiency !!

Mass market

Requires capabilities close to cutting-edge

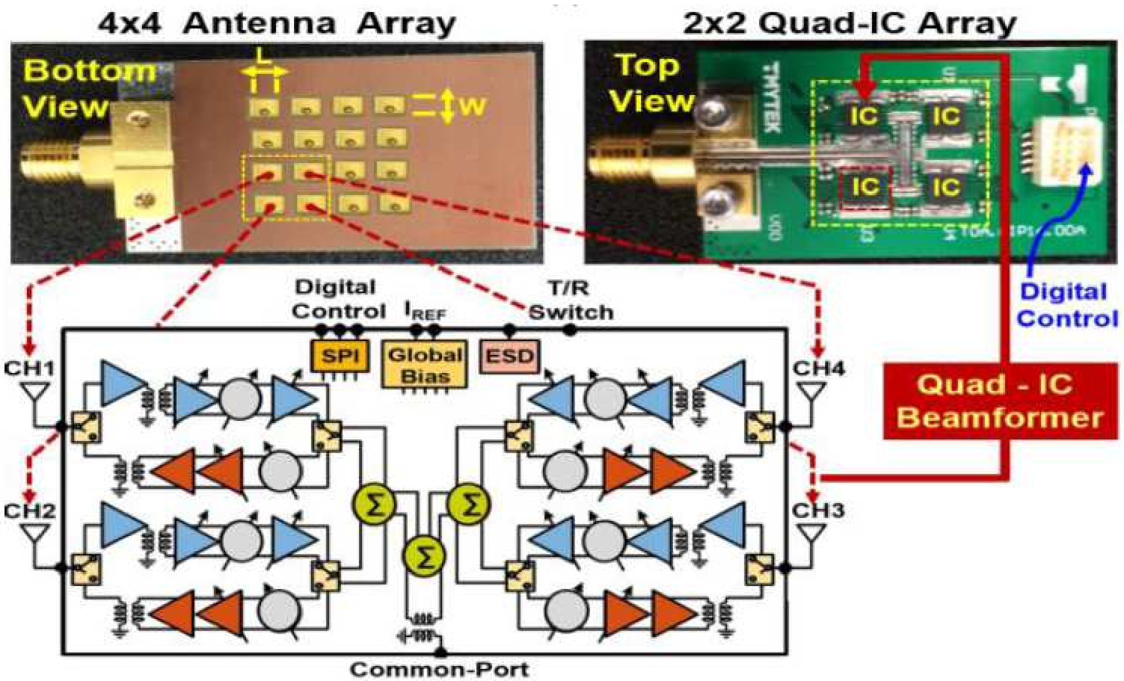
BUT ….
The cost, complexity and efficiency must comply with mass market applications !!

Requires effective system-level CAD tools to allow efficient co-design of Antenna and RF modules

Mass-market application paradigm shift

- High Radio integration density
- No more isolation between Radio and Antenna

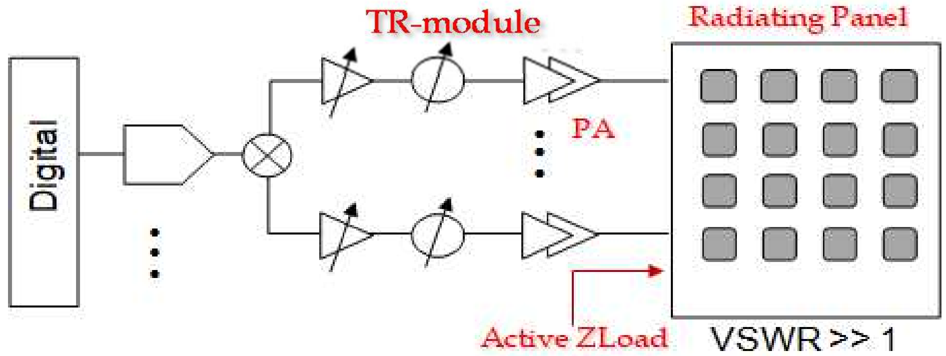
Typical example



"Millimeter-Wave Beamformer Chips with Smart-Antennas for 5G: Toward Holistic RFSOI Technology Solutions including RF-ADCs",
Sidina Wane *et al*, WMCS2019

- Requires Radio and Antenna Co-design
- New modeling and simulation challenges

Antenna and Radio Co-simulation challenges



Radio CAD
Circuit-level simulation tools
ADS, Spectre-RF, AWR, ..

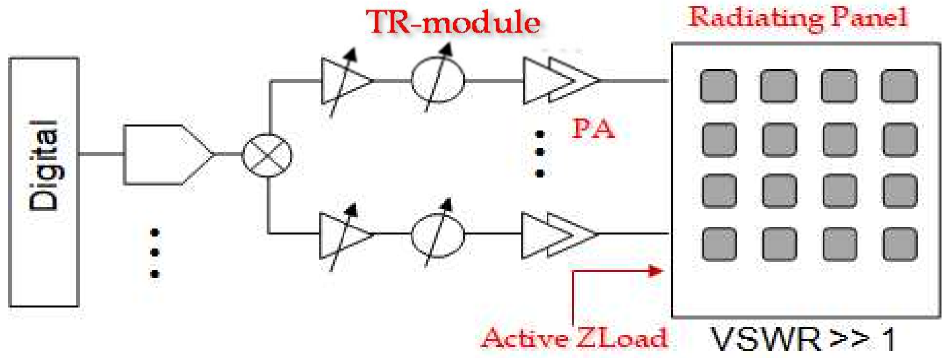
Antenna CAD
EM simulation tools
HFSS, CST, EMPro, ..

Radar beamforming CAD
System-level simulation tools
Matlab-Simulink, Systemvue, VSS, …, In-House tools

Beamforming CAD issues

- Conventional system-level tools are not effective (dataflow simulation type)
  → rely on perfect Radio-Antenna isolation (matched load)
- Effective simulation requires nonlinear Spice type simulation, i.e., Radio CAD type
- Radio CAD are ineffective for beamforming because of the outstanding complexity of the overall system

Antenna and Radio Co-simulation challenges



Radio CAD
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ADS, Spectre-RF, AWR, ..

Antenna CAD
EM simulation tools
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Radar beamforming CAD
System-level simulation tools
Matlab-Simulink, Systemvue, VSS, …, In-House tools

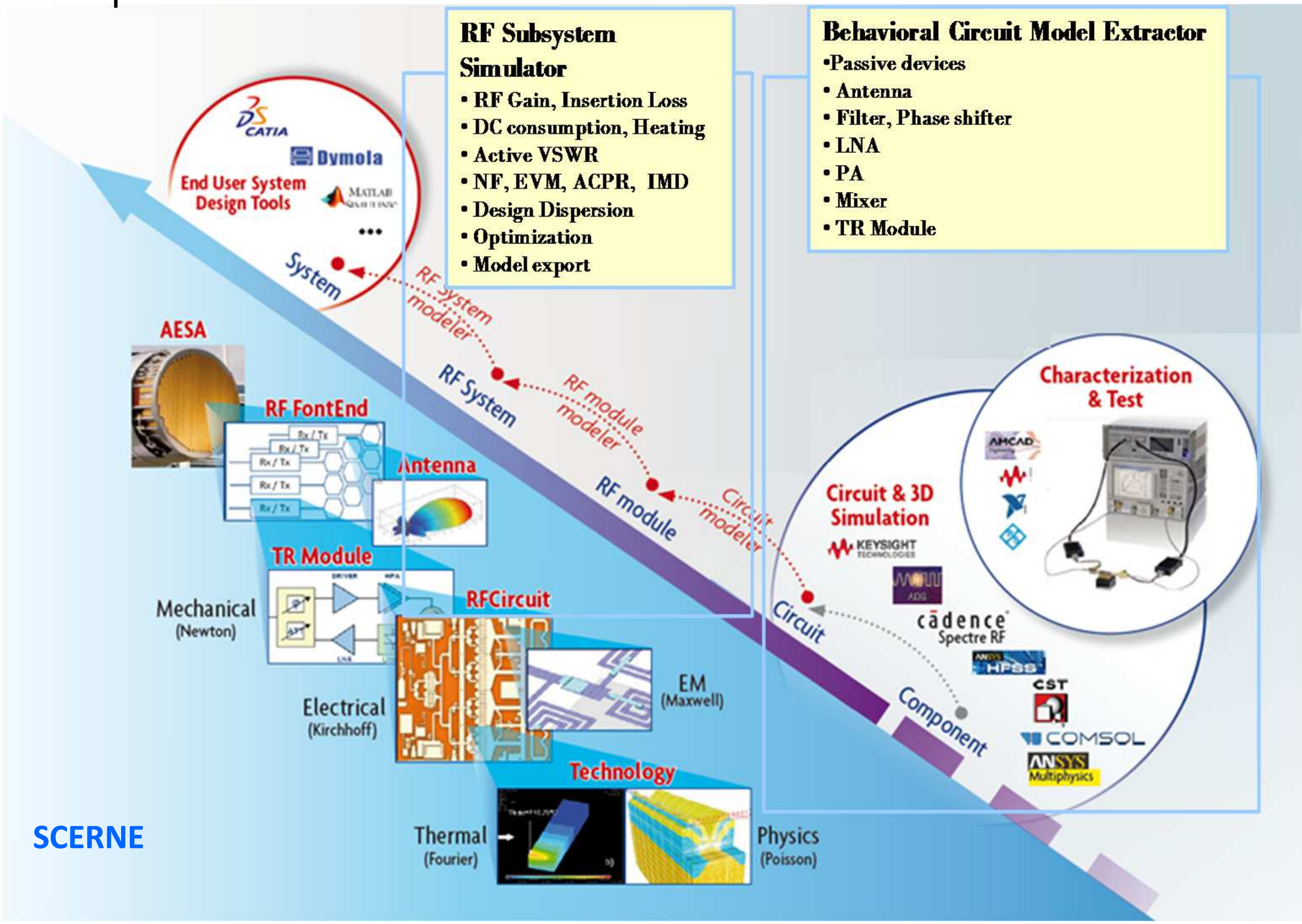
Necessary system-level simulation tools advancements

- Nonlinear, non-impedance matched and parameterized behavioral model for Radio
- Spice type solver within the beamforming loop

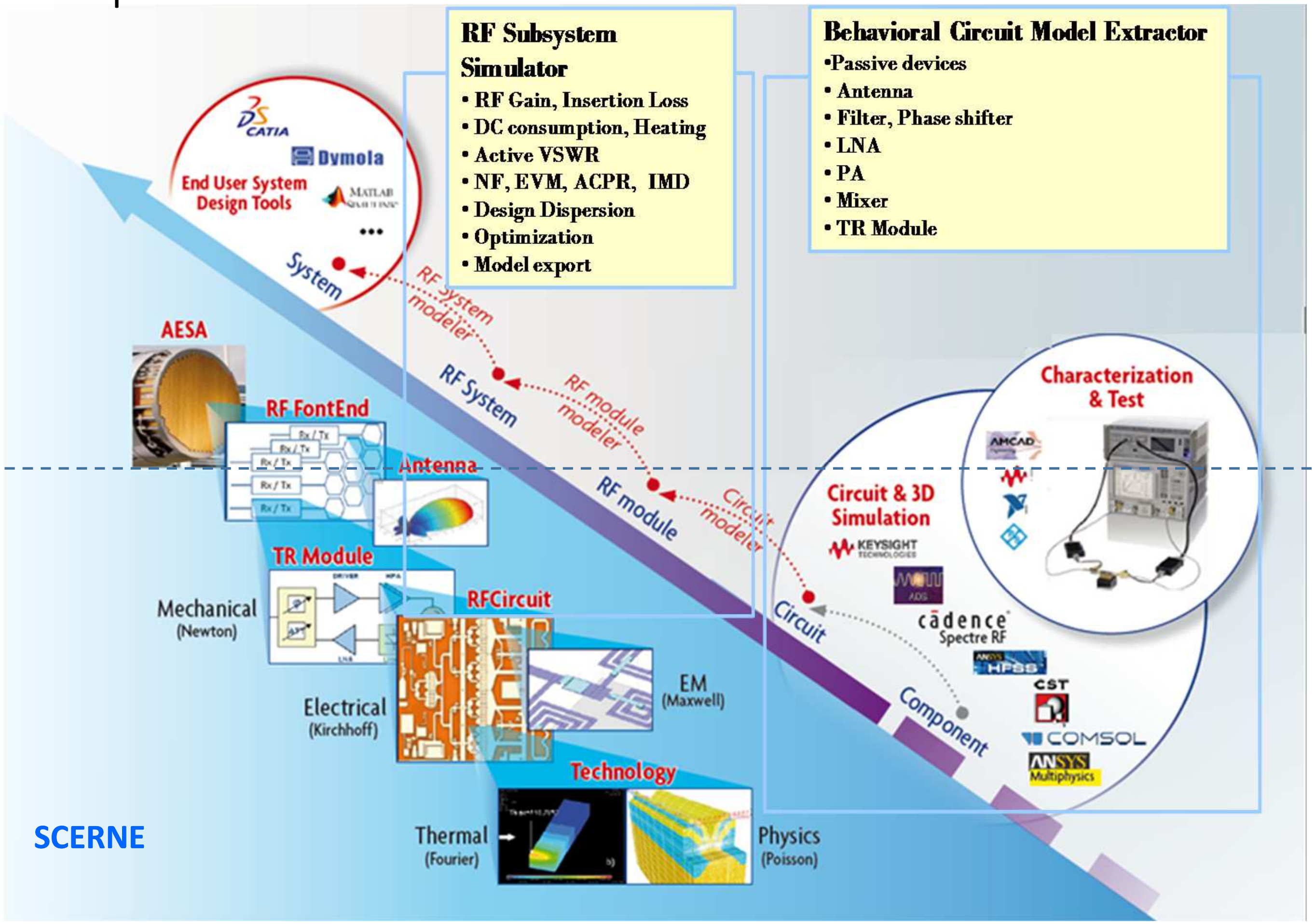
Challenge I : master description heterogeneity/complexity

- Simulation tools/Vendors
  Ansys, CST, Keysight, Cadence, NI, .. , In-House
- Test equipments/Vendors
  Keysight, NI, Rhode-Schwarz, Anritzu, ..
- Hierarchy
  Device-level, Circuit-level, Subsystem-level, Board
- Domain/Formalism
  Mechanical, Thermal, EM, Electrical
- People/expertise/language
  Digital, Analog BB, RF, Antenna, Packaging

XLIM Lab/SCERNE Behavioral modeling and System-level simulation Framework devpt.



XLIM Lab/SCERNE Behavioral modeling and System-level simulation Framework devpt.



- Collaboration with AMCAD Engineering
- Mature functionalities made available in commercial AMCAD/VISION framework

XLIM Lab/SCERNE Behavioral modeling and System-level simulation Framework

Current Focus : 5G Antenna modeling flow

Panel parameters extraction

Full-wave EM / Measurements

[S] Coupling Matrix

[$\Phi_m(\theta,\varphi)$] : element radiation patterns

Multi-objectives, beam synthesis

Antenna: VSWR, Directivity, Axial ratios, ..

Circuit: Linearity, Efficiency, ..

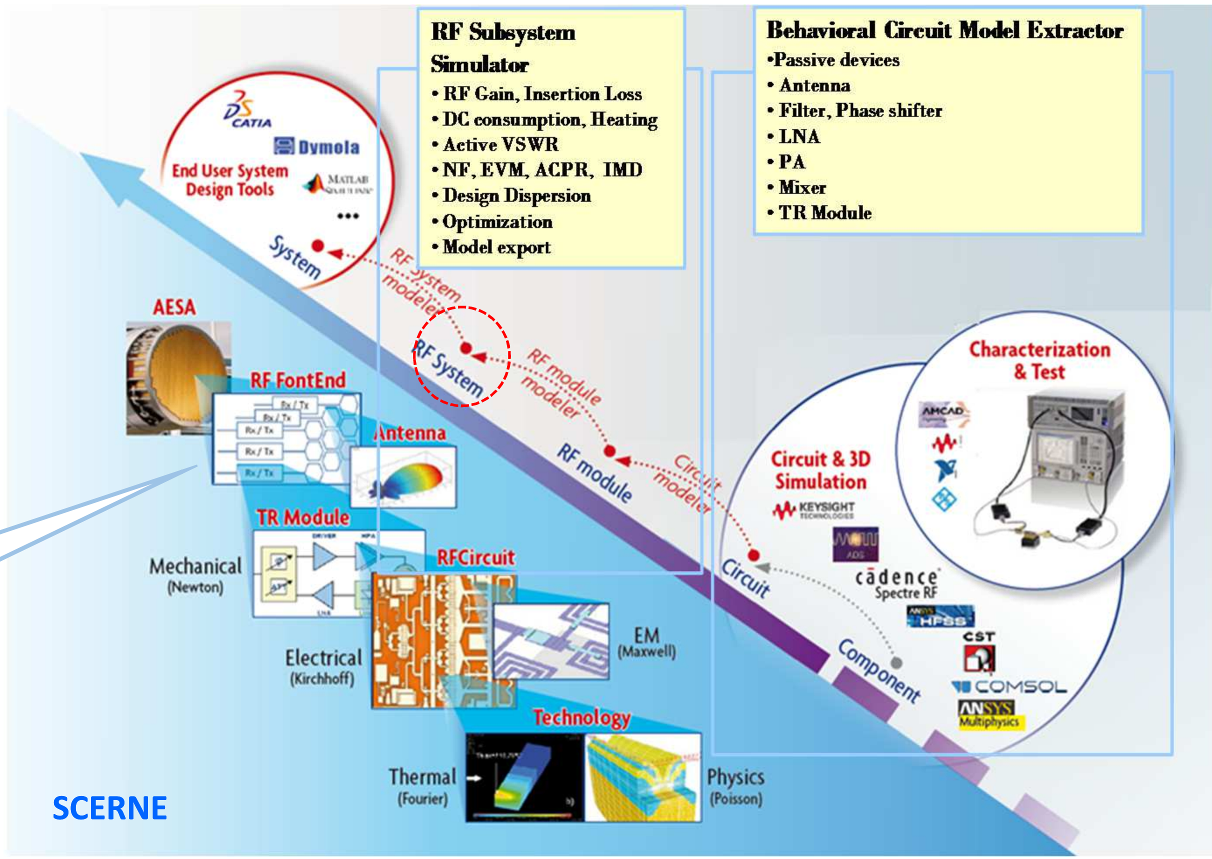
→ Focused optimizer algos + Matlab optim

Post-processing

Antenna EM + RF circuit performances, ..

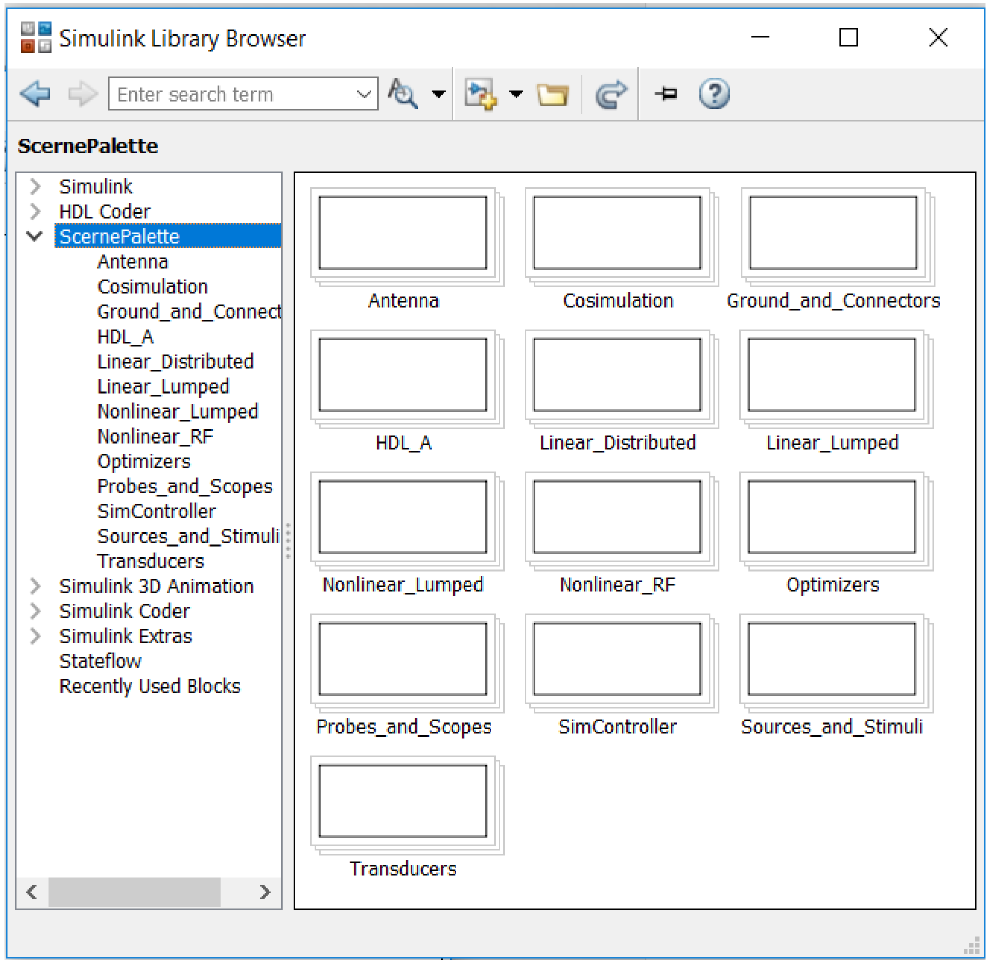
Model Export

Exportation to third-party tools + IP protection

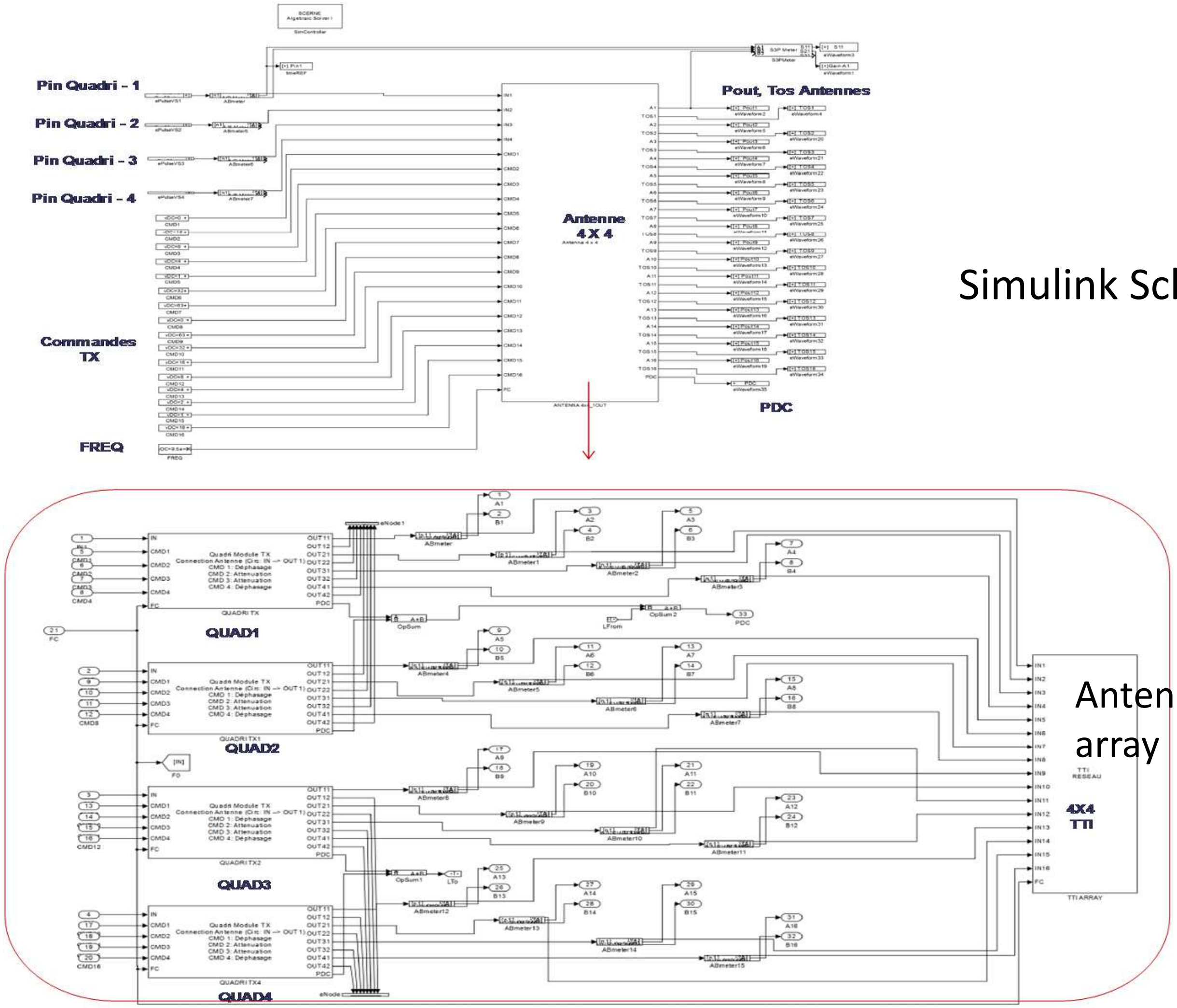


❑ SCERNE Simulator key features

- ✓ Uses Simulink as a schematic capture (opening to Matlab applications)
- ✓ Large palette of behavioral models (LNA, PA, Mixer, SnP, ..), compatible AMCAD/VISION model extractor
- ✓ Performs circuit type (Spice) simulation (notions of current, voltage and impedance)
- ✓ Performs simulation in time domain (envelope-transient analysis) and/or frequency domain (CW) analysis)
- ✓ Complete suite of simulation methods:– swept parameter – statistical analysis – multiple objectives optimization
- ✓ Simple analog HDL language for time and frequency domain device modeling
- ✓ Hidden IP model export mechanism

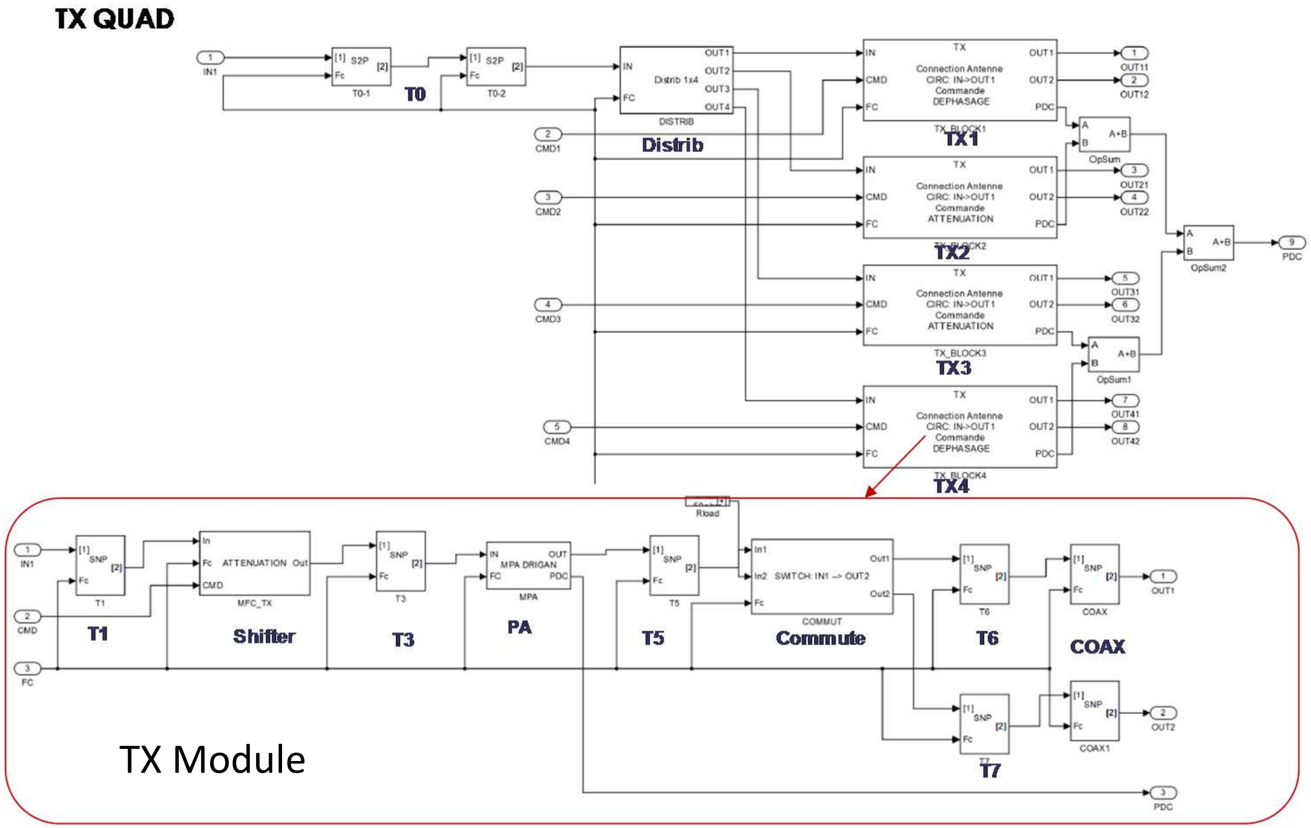


- 4x4 TX module simulation example with SCERNE



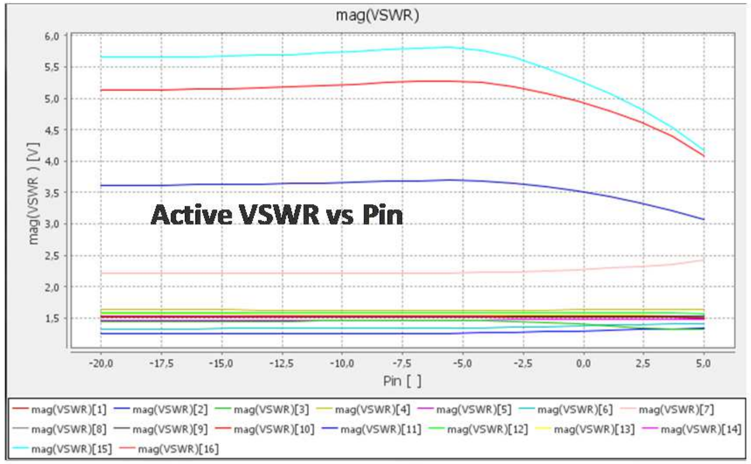
Simulink Schematic

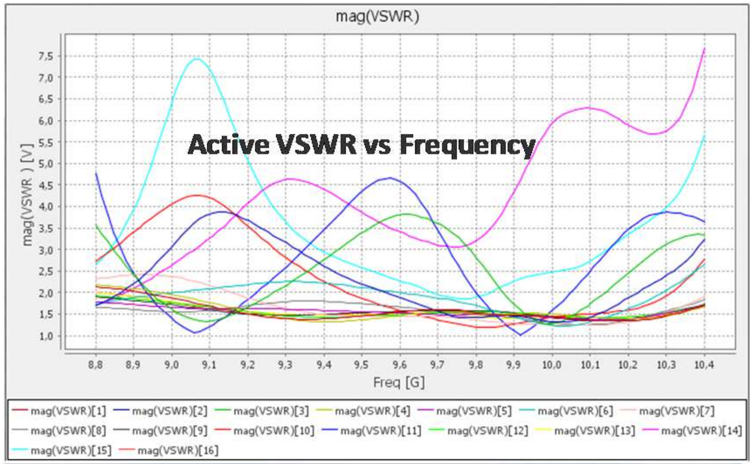
- 4x4 TX module simulation example with SCERNE, Cont.

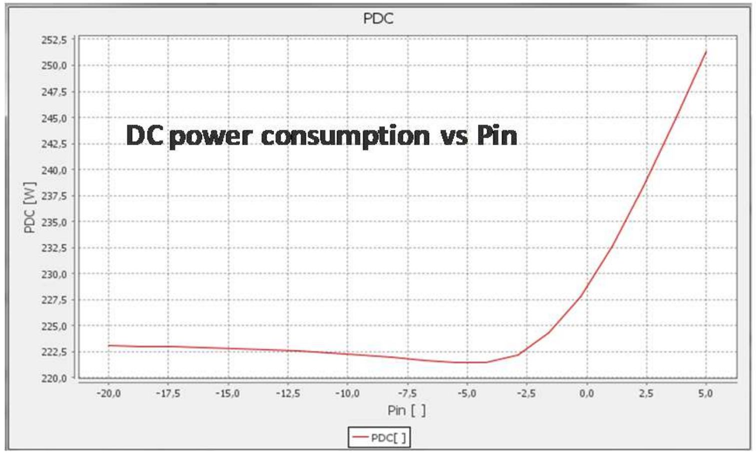


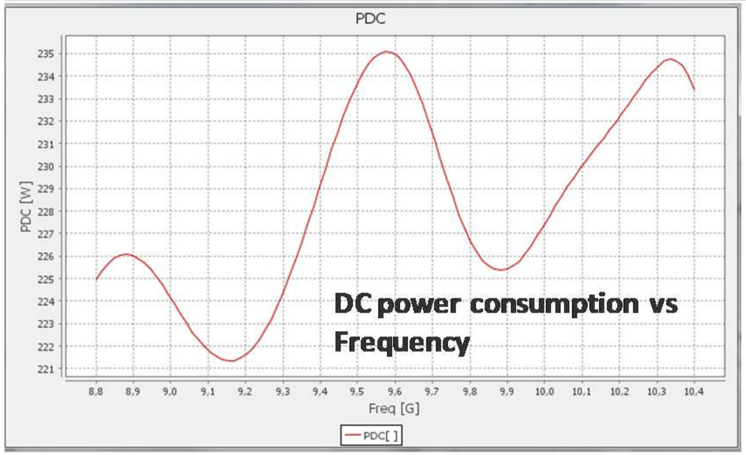
Simulink Schematic

❑ 4x4 TX module simulation example with SCERNE, Cont.









Fast simulation, 16 antennas : 3 sec run time

Challenge II: EM Modeling of large array

- Full-wave EM solver requires outstanding computation resources
- Only affordable by big players
- Expensive and time consuming

There is a need for effective behavioral EM model of antenna array

- Followed approach: Modified Floquet analysis methods

  "A large Antenna Array for Ka-band Satcom-on-the-Move Applications – Accurate Modeling and Experimental Characterization",

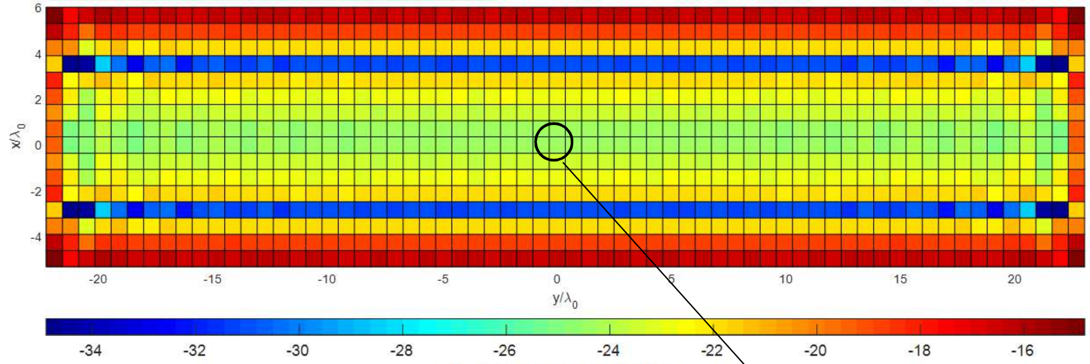
  B. Lesur *et al*, IEEE Trans. Antenn. and Propag., 2018

Challenge II: EM Modeling of large array, cont.

- Modified Floquet analysis

ZODIAC AEROSPACE

16x64 Element array panel



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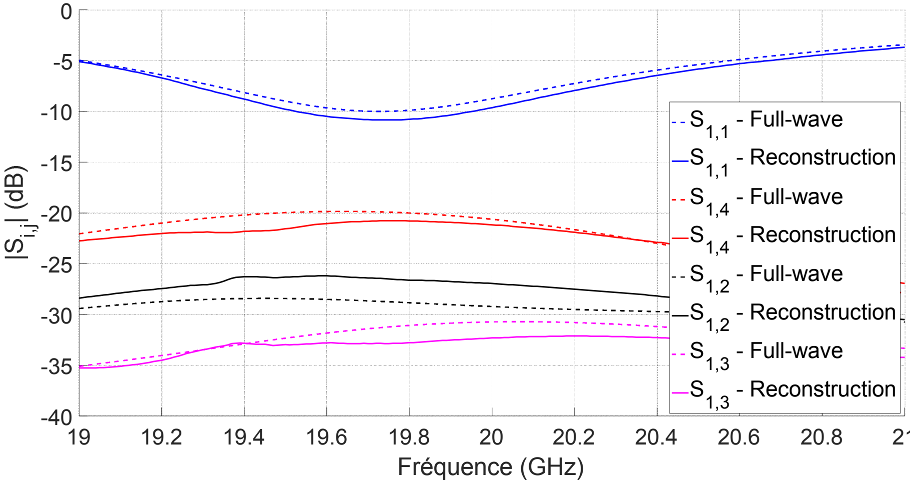
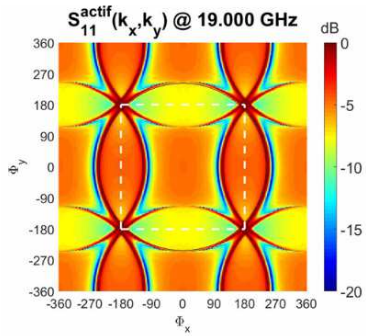
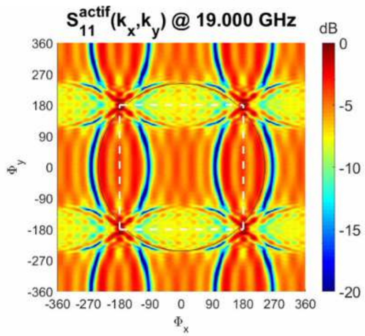
Active reflection coeff (dB)



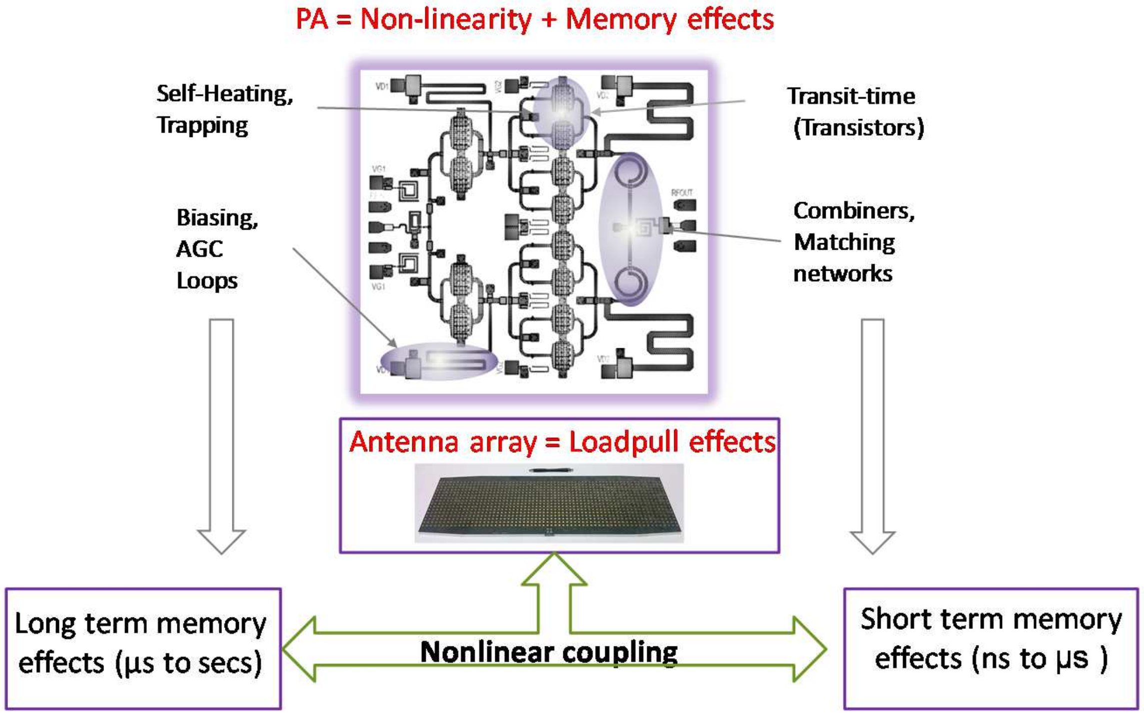


Ideal Floquet



Model

Challenge III: Modeling of wideband PA and DPD



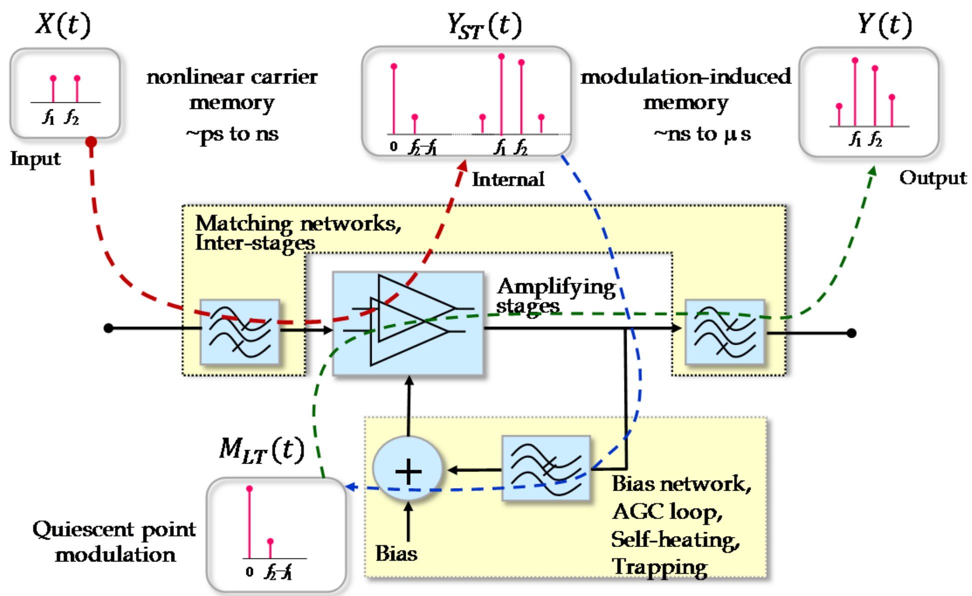
Nonlinearity + memory + antenna loadpull effects severely impact wideband modulation signals, with consequences:

- Deriving PA model is very challenging
- Conventional black-box DPD algorithms do not perform well

Challenge III: Modeling of wideband PA and DPD, cont.

- Grey-box behavioral PA model

  ” Progress for Behavioral Challenges: A Summary of Time-domain Behavioral Modeling of RF and Microwave Subsystems”
  E. Ngoya *et al*, IEEE Microwave Magazine, 2014



TPM model

- Pseudo equivalent network
- Dissociate short and long term memories
- Identify nonlinear integral equations, using two-tone signal and load-pull

$$Y(t) = Y_{ST}(t)[1 + M_{LT}(t)]$$

$$\boldsymbol{Y_{ST}}(t) = \int_0^t h_{ST}(|X(t-\tau)|,\tau)X(t-\tau)d\,\tau$$

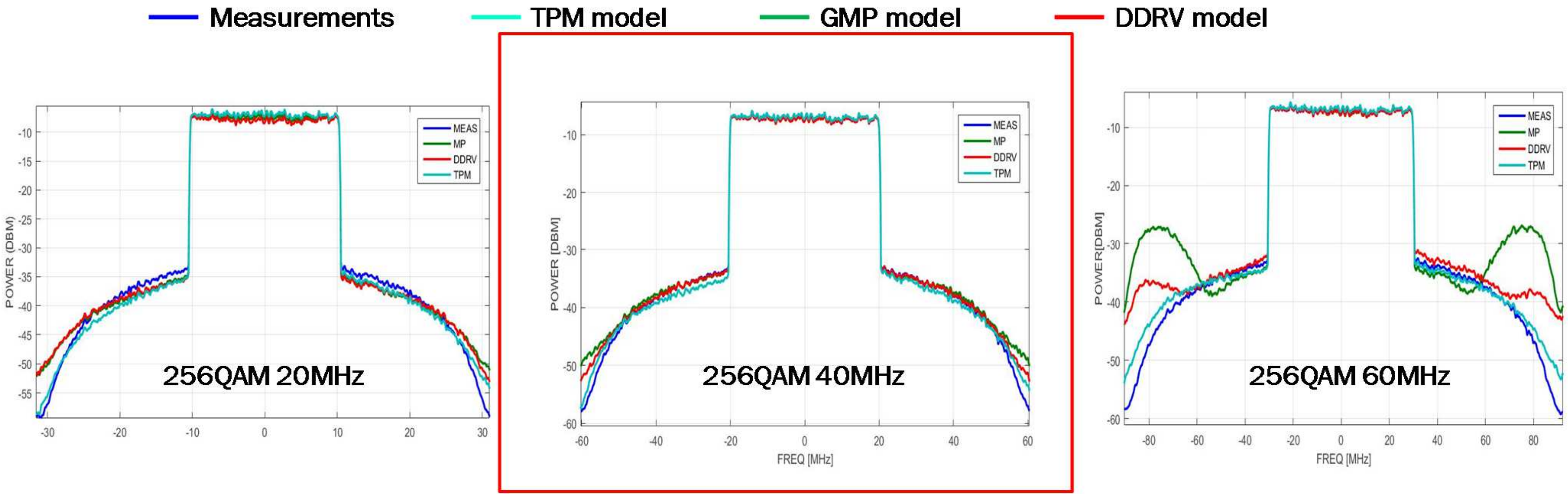
$$\boldsymbol{M_{LT}}(t) = \int_0^t h_{LT1}(|X(t-\tau)|,\tau)|X(t-\tau)|d\tau + \int_0^t h_{LT2}(|X(t-\tau)|,\tau)\frac{d\angle X(t-\tau)}{dt}d\tau$$

Challenge III: Modeling of wideband PA and DPD, cont.

- ❑ Typical comparison with conventional black-box models

12 Watts multistage LDMOS RF-PA – 2.6GHz - NXP/MD7IC2012N

Peak Power = 5dB Gain compression



Learning signal for the conventional models: GMP and DDRV

Challenge III: Modeling of wideband PA and DPD, cont.

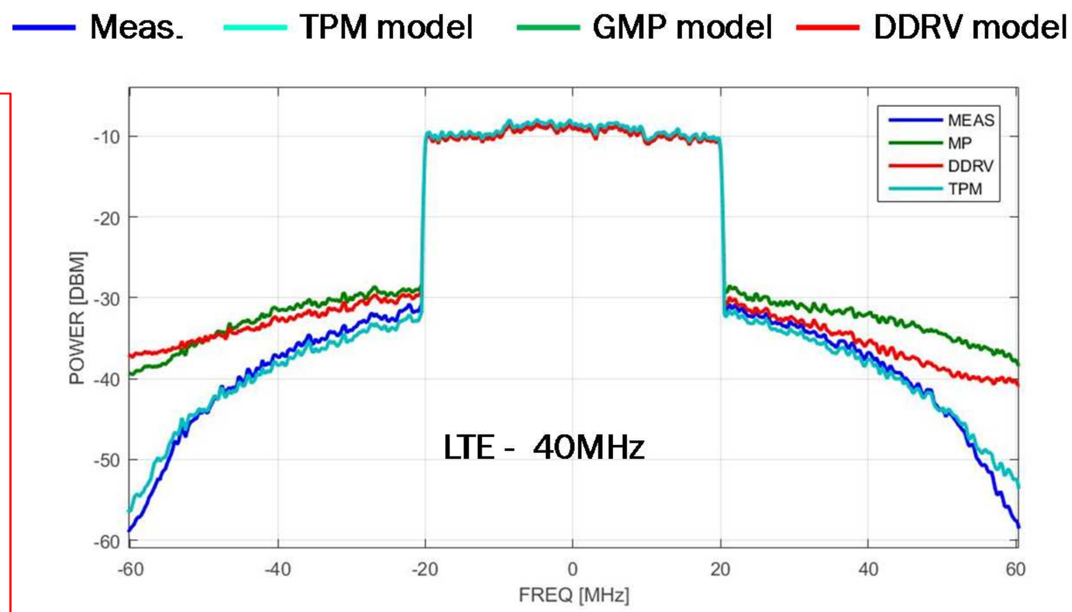
❑ Typical comparison with conventional black-box models

12 Watts multistage LDMOS RF-PA – 2.6GHz - NXP/MD7IC2012N

Peak Power = 5dB Gain compression

✓ *Signal change from 256QAM to LTE, same peak power*

- Conventional models need reconstruction for every signal, bandwidth and power level change
- TPM model is providing a robust PA modeling solution
  - ✓ similar performance for all signal, bandwidth and power level



Challenge IV: Beam steering precision

- Impact of antenna loadpull on the radio make beam steering algorithms and precise system calibration highly challenging

A mitigation approach: Hybrid vs Full Active network

Hybrid steering uses a fraction of passively terminated antenna elements as an artefact to maintain mismatch of active elements low, through mutual coupling.

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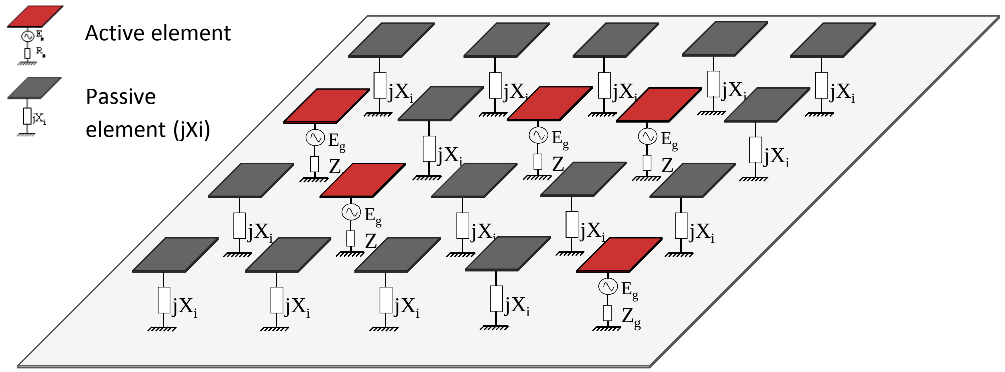
"Optimization of the VSWR of Reconfigurable Antennas with a Coupled Multielement Concept",
A. Alzein, *et al*, Antennas and Propagation (EUCAP), 2018.

Challenge IV: Beam steering precision

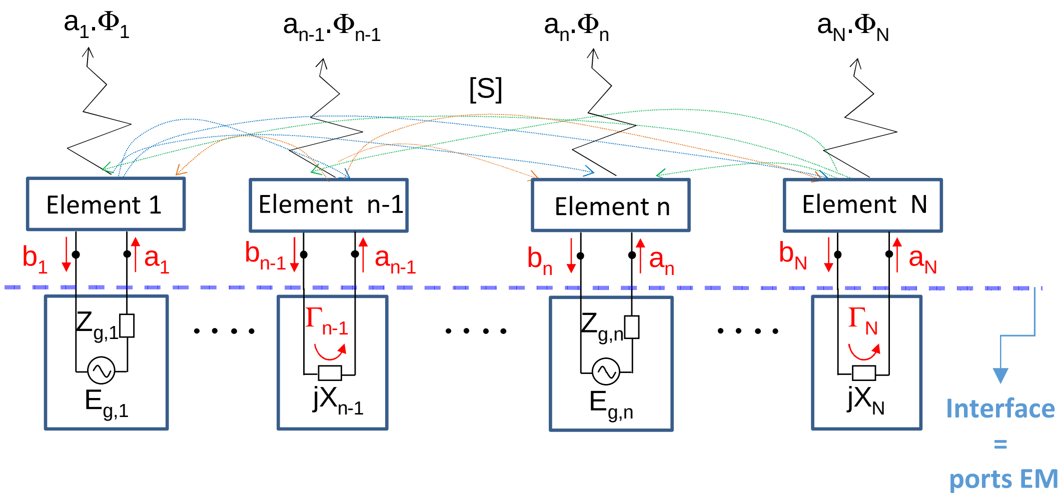
❑ Hybrid steering concept

- Maximize elements' mutual coupling
- Terminate a fraction of elements with passive reactive loads
- Use passive load as a minimizer for active elements' mismatch



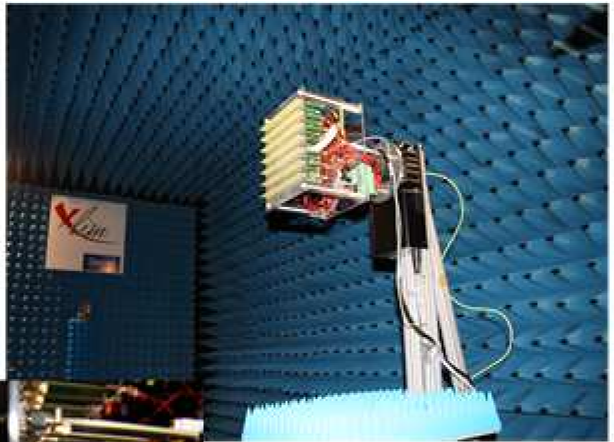
Results in simplification of beamforming network, and reduced active channels

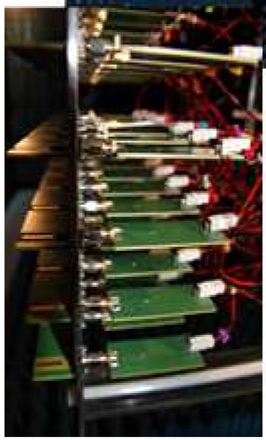
Made possible by Antenna-Circuit co-design



Challenge IV: Beam steering precision

- **Proof of concept: Hybrid network based on monopole lattice @2.45 GHz**

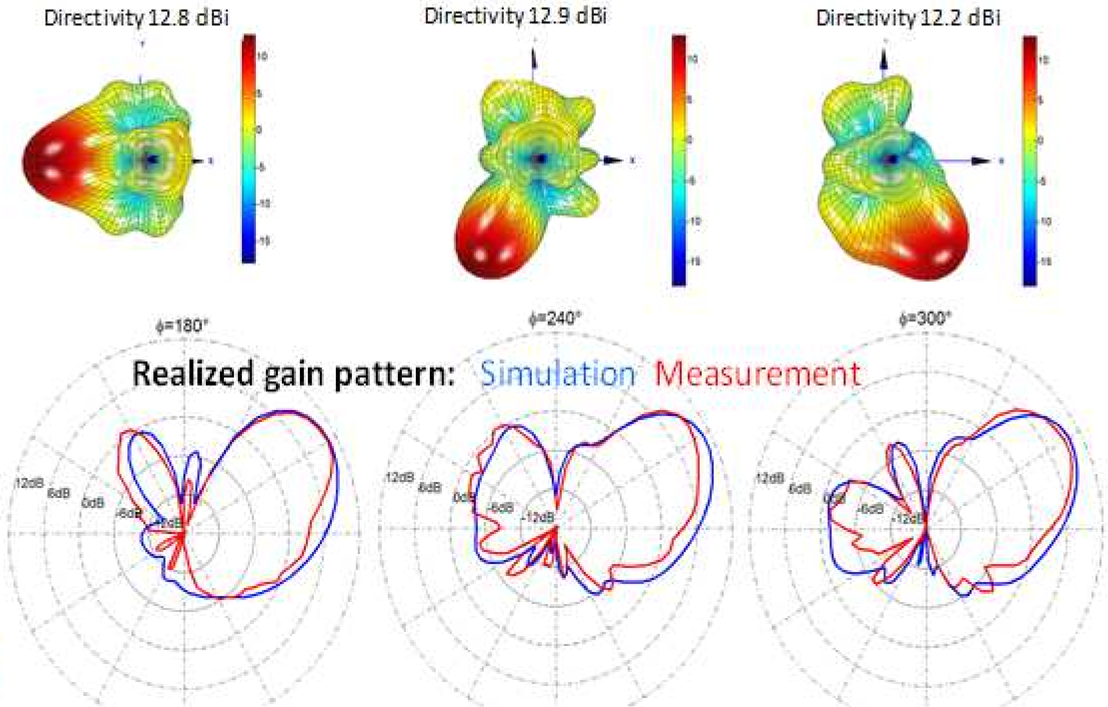




7x7 monopoles connectorized with RTPS @ 2.45 GHz (10% bandwidth)

- ✓ Efficient beamforming with one active element over 49

|Sii|active ≤ -12 dB {2.35-2.5 GHz}



C. Menudier, M. Thevenot, E. Arnaud, A. Oueslati, F. Fezai, T. Monediere, N. Chevalier, S. Reynaud, "Synthesis of a 2D Reconfigurable Parasitic Element Antenna", Proceedings of the 46th European Microwave Conference (EUmC), London, 3-7th October 2016

Summary

- Beamforming for 5G mass-market applications
- Antenna and Radio co-simulation challenges
- XLIM Lab/SCERNE System-level simulation Framework help bridge heterogeneity/complexity gaps in system design
- Proposed solutions for
  - Large array antenna modeling
  - Power amplifier modeling
  - Beam steering complexity reduction

Thank you!