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


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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

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
Antenna and Radio Co-simulation challenges

Radio CAD
\textit{Circuit-level simulation tools}
ADS, Spectre-RF, AWR, ..

Antenna CAD
\textit{EM simulation tools}
HFSS, CST, EMPro, ..

Radar beamforming CAD
\textit{System-level simulation tools}
Matlab-Simulink, Systemvue, VSS, ..., In-House tools

\textbf{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

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Circuit-level simulation tools
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Radar beamforming CAD
System-level simulation tools
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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.
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- Collaboration with AMCAD Engineering
- Mature functionalities made available in commercial AMCAD/VISION framework
Panel parameters extraction
Full-wave EM / Measurements

[ S ] Coupling Matrix
[ Φ_m(θ,ϕ) ] : 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

XLIM Lab/SCERNE Behavioral modeling and System-level simulation Framework
Current Focus : 5G Antenna modeling flow
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

Antenna array
4x4 TX module simulation example with SCERNE, Cont.

Simulink Schematic

TX Module
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”,
Challenge II: EM Modeling of large array, cont.

- Modified Floquet analysis

16x64 Element array panel

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"  

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

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

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

\[
M_{LT}(t) = \int_0^t h_{LT1}(|X(t - \tau)|, \tau)|X(t - \tau)|d\tau + \int_0^t h_{LT2}(|X(t - \tau)|, \tau)\frac{d^2X(t-\tau)}{dt}d\tau
\]
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.*
Challenge IV: Beam steering precision

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A mitigation approach: Hybrid vs Full Active network

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"Optimization of the VSWR of Reconfigurable Antennas with a Coupled Multielement Concept",
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

![Image of monopole lattice]

- **7x7 monopoles connectorized with RTPS @ 2.45 GHz (10% bandwidth)**
  - Efficient beamforming with one active element over 49
  - |Sii| active ≤ -12 dB (2.33-2.5 GHz)

![Directivity plots]

Realized gain pattern: Simulation vs Measurement

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!