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TCAD-based Dynamic Thermal X-parameters for PA Self-Heating Analysis

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Research context and motivation

The widespread deployment of **FinFET devices** for advanced digital applications leads to the exploration of this technology for **analog high-frequency applications**

- f_T>200 GHz in the 22 nm technology node
- Lower cost

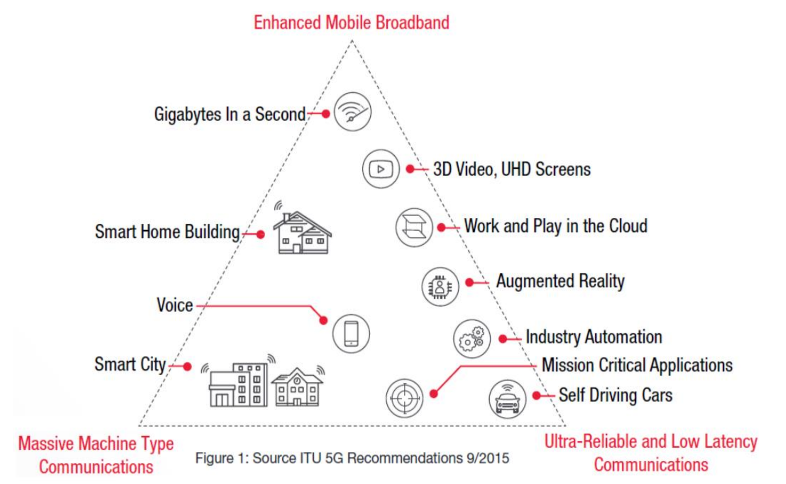
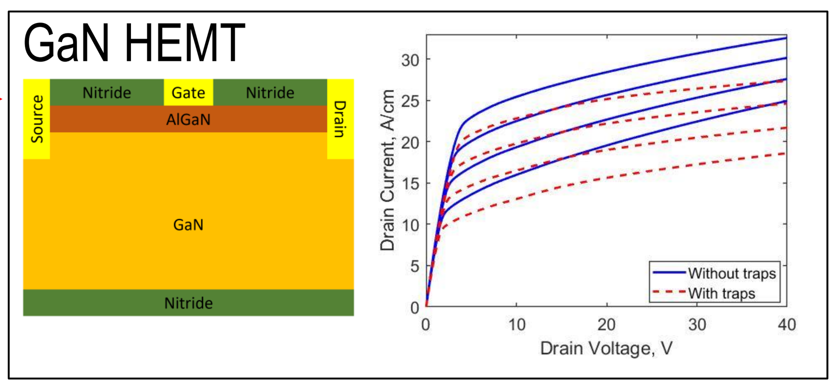


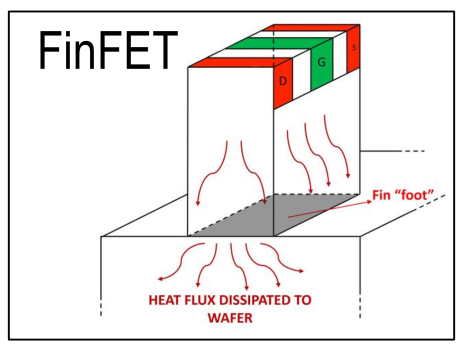
Figure 1: Source ITU 5G Recommendations 9/2015

The peculiar structure of FinFET devices makes the technology very promising in the view of **millimeter-wave phased arrays for 5G/6G**.

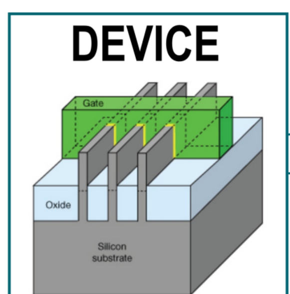
Dispersion effects in semiconductor devices:

- Trapping phenomena
- Temperature dependence





Addressed research questions/problems



3D geometry
multi-finger structures

Promising, but affected by
- Higher parasitic effects
- Pronounced technological variability
- Difficult thermal management

TCAD
- Drift-diffusion (DD) code
- Large-Signal (LS) analysis
- Small-Signal-LS analysis

Harmonic Balance (HB) technique

- Accurate description
- Flexible platform
- High computational cost

BEHAVIORAL MODELS
- Accurate
- Computationally efficient
- Circuit oriented

X-PARAMETER (Xpar)

Temperature dependence

T-DEPENDENT XPAR (T-XPAR)

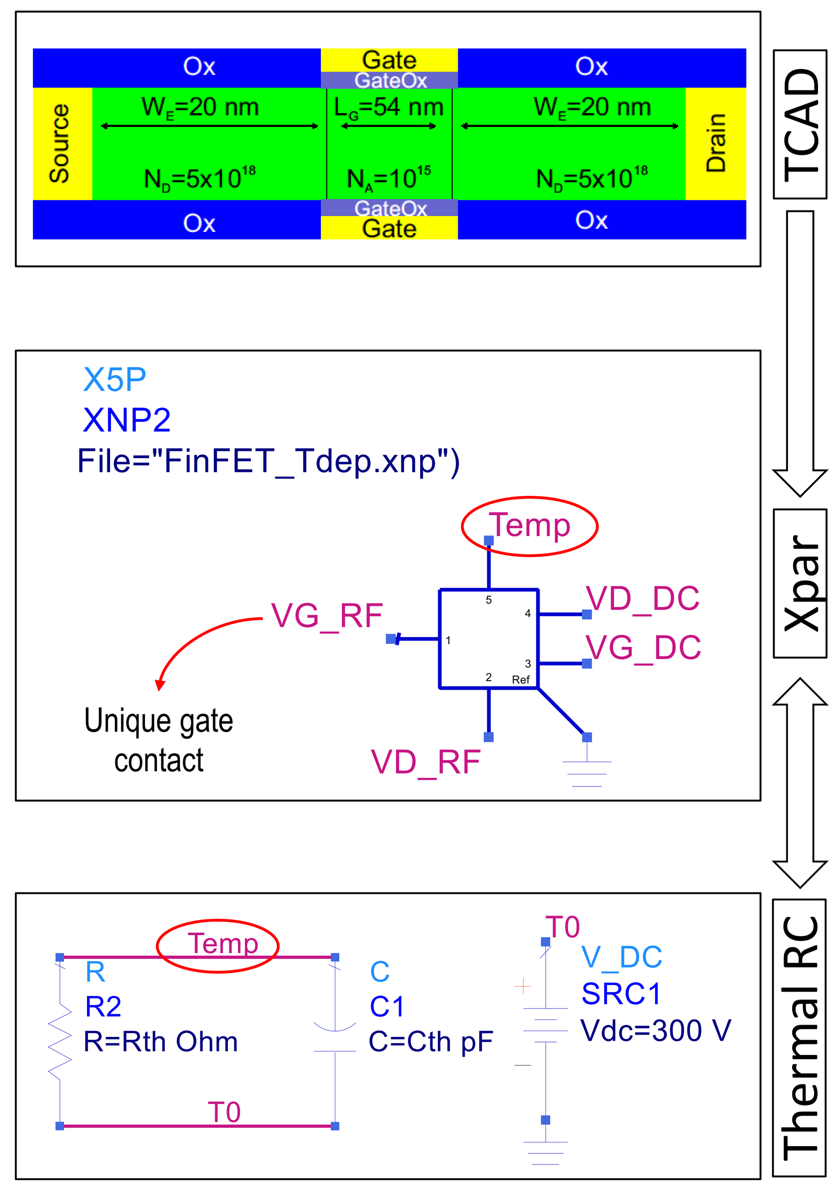
Novel contributions

A multi-bias T-Xpar model of a 54 nm Si FinFET is extracted from **TCAD LS simulations** changing the lattice temperature of the device as an independent parameter. The model is imported into **Keysight ADS** with fictitious DC voltage ports to set the parameter values, aiming at the simulation of the device with varying operating condition from class A to class B. This is an efficient implementation of a **dynamic thermal model** directly extracted from accurate LS TCAD simulations via T-Xpars.

Submitted and published works

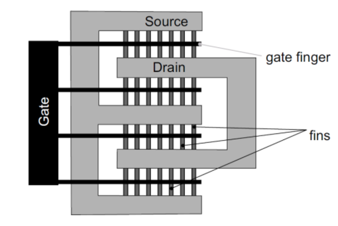
- E. Catoggio et al., "Efficient TCAD Thermal Analysis of Semiconductor Devices", IEEE Trans. El. Dev., vol.68, no.11, 2021, pp.5462-5468.
- E. Catoggio et al., "Efficient TCAD Large-Signal temperature-dependent variability analysis of a FinFET power amplifier", Proc. SISPAD 2021, Dallas (USA), 2021, pp.36-39.
- S. Donati Guerrieri at al., "Bridging the Gap between Physical and Circuit Analysis for Variability-Aware Microwave Design: Modeling Approaches", Electronics, vol.11, no.6, 2022, pp.860-877.
- E. Catoggio et al., "FinFET PAs through temperature-dependent X-parameters extracted from physics-based simulations", Proc. INMMIC 2022, Cardiff (UK), 2022, pp.1-3.
- E. Catoggio et al., "Efficient TCAD Temperature-dependent Large-Signal Simulation of a FinFET Power Amplifier", Proc. EuMIC 2021, 2022, pp.189-192.
- S. Donati Guerrieri et al., "TCAD simulation of microwave circuits: The Doherty amplifier", Solid-State Electronics, vol.197, 2022, pp.108445-108449.
- S. Donati Guerrieri at al., "Bridging the Gap between Physical and Circuit Analysis for Variability-Aware Microwave Design: Power Amplifier Design", Electronics, vol.11, 2022.

Adopted methodologies



Multi-finger FinFET structure:

- H_{fin}=25 nm and W_{fin}=14 nm
- 10 fingers with 30 fins each



T-Xpar extraction from TCAD simulations:

- 50 Ω at both input and output ports
- 70 GHz of operating frequency
- HB simulation with 10 harmonics
- Extraction temperatures: **[300, 340, 380]** K
- Gate bias variation from Class A to Class B

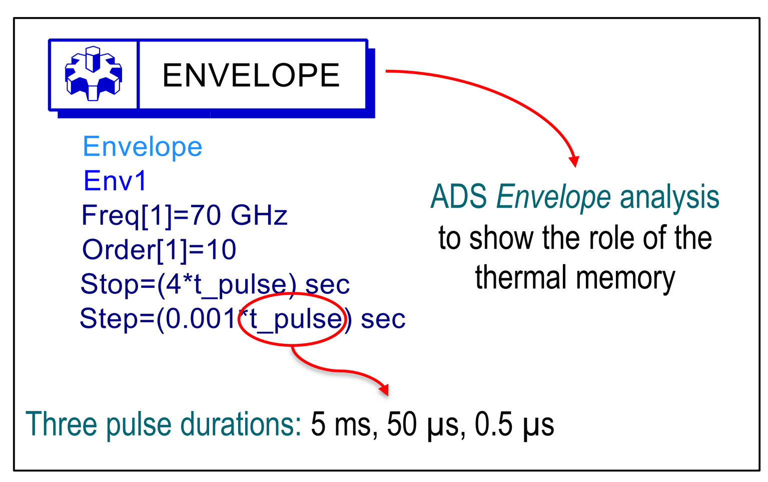
ADS Xpar simulations:

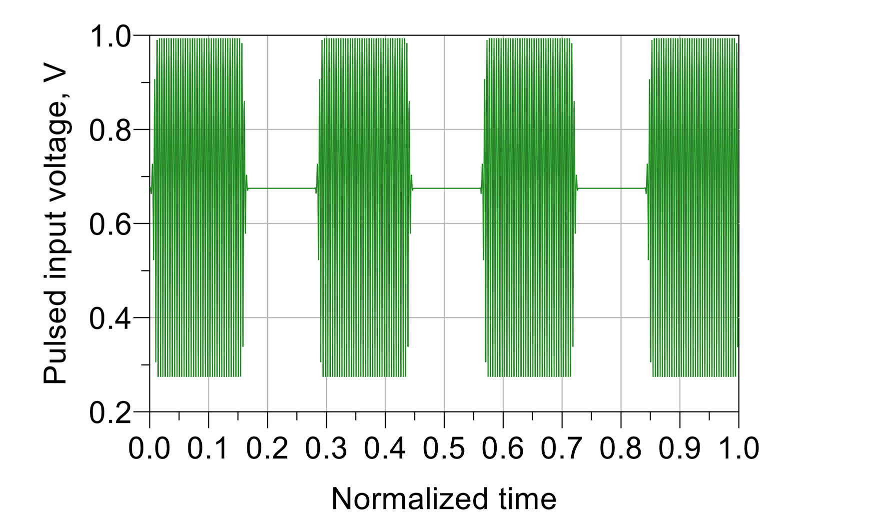
- *Temp* terminal: isolated port representing the device junction temperature (T_j)
- Class A optimum load on the fundamental

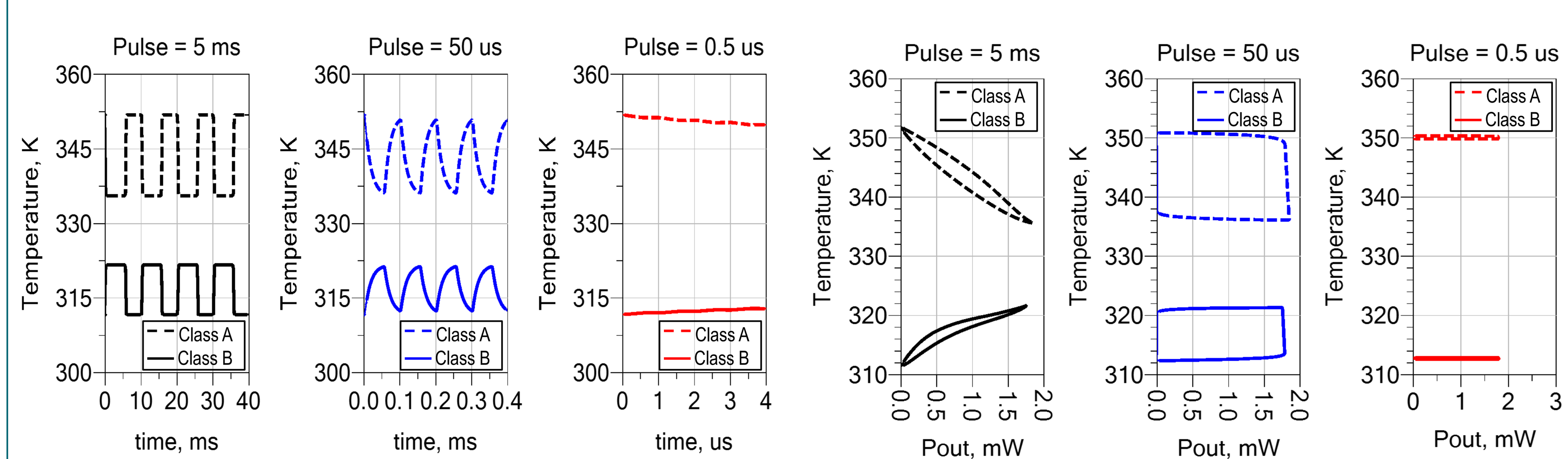
Lumped RC thermal network: coupled to the Xpar model to account for thermal dynamics

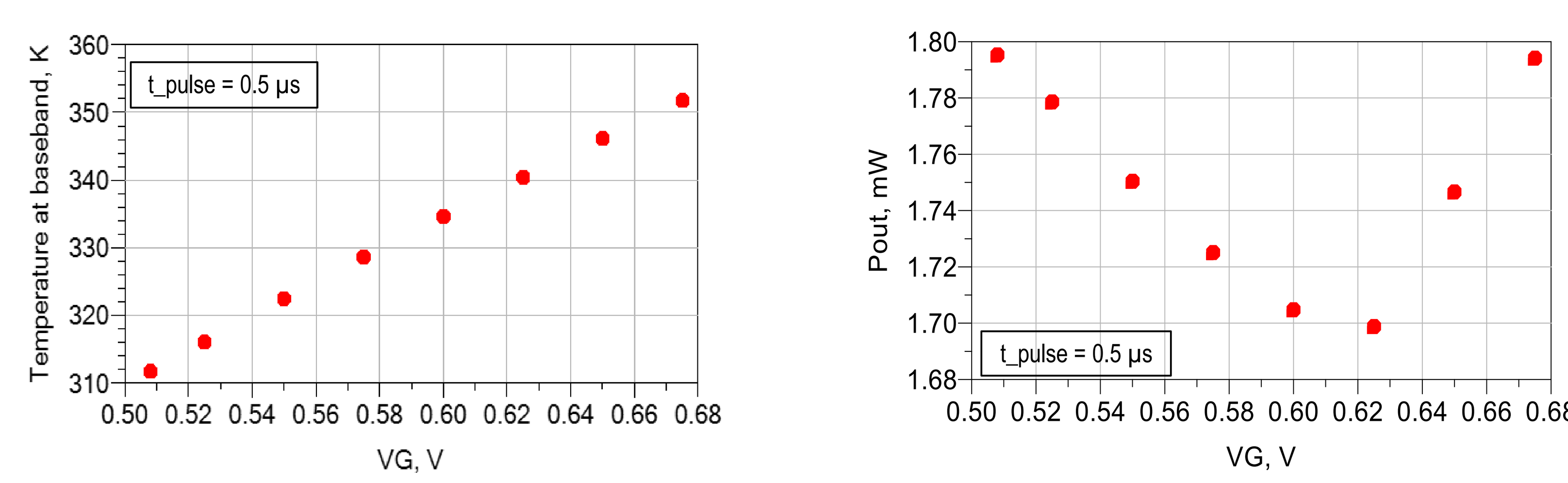
- R_{th}: set to 1 K/μW
- C_{th}: sized to have a thermal cutoff of 10 kHz

Self-heating analysis with **pulsed input power** varying the gate bias from a Class A to a Class B stage.









Future work

- Simulation of power devices based on GaN: Large-Signal analysis of GaN-based electronic devices to highlight the effect of piezoelectric polarization and traps.
- Simulation of 3D devices: the implementation of a three-dimensional version of the current code in order to simulate 3D structures.

List of attended classes

- 01UJGRV – Advanced devices for high frequency applications (27/05/2020, CFU 4)
- 01UAYOQ – CAD of semiconductor devices (14/02/2020, CFU 6)
- 02IUGKG – Il metodo Monte Carlo (04/06/2020, CFU 6)
- 01UIYRV – Physics-based modeling of semiconductor devices (01/04/2020, CFU 3)
- 01SFURV – Programmazione scientifica avanzata in matlab (25/05/2020, CFU 4)