

# Active Microwave Components for Next Generation Airborne Sensor and Communication Systems

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# Background



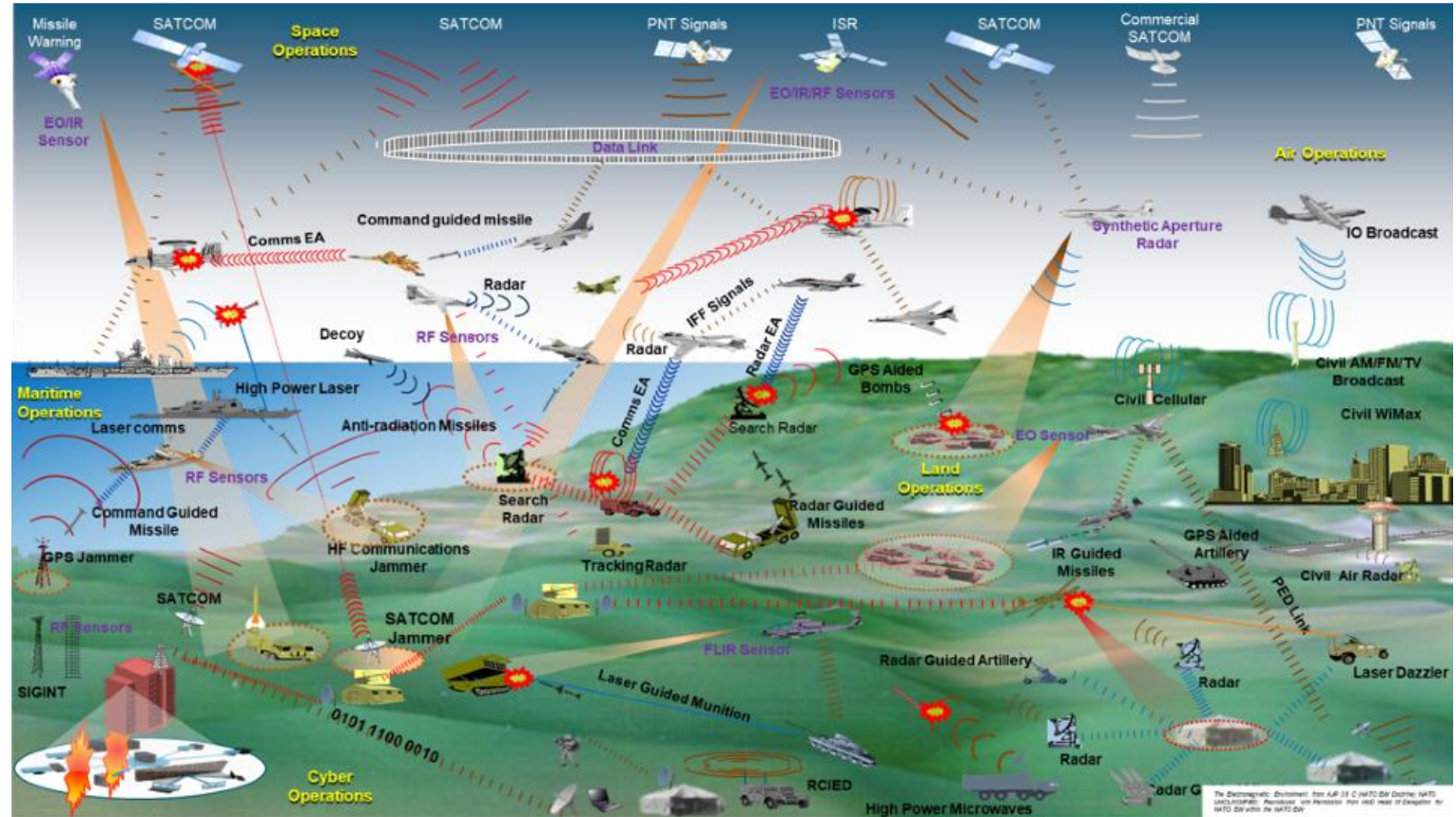
- Two Granted NFFP8 Call 1 Projects (2023 - 2024)
- Project 1: Linear Receivers for a Congested and Contested Electromagnetic Domain
  - Saab and Chalmers University
  - Strong collaboration with Vinnova C3NiT center and Linköping University
- Project 2 Reconfigurable Transmit/Receive Front-End for Multi-functional Sensors
  - Saab and Chalmers University
  - Strong collaboration with Vinnova WiTECH center

Keeping people and society safe

# Electromagnetic Domain



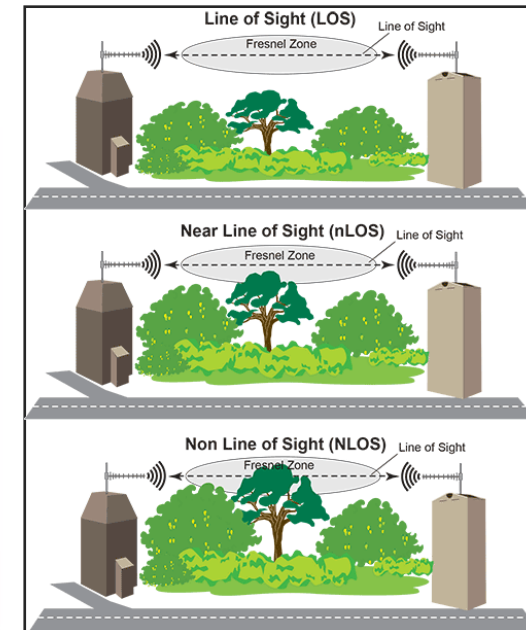
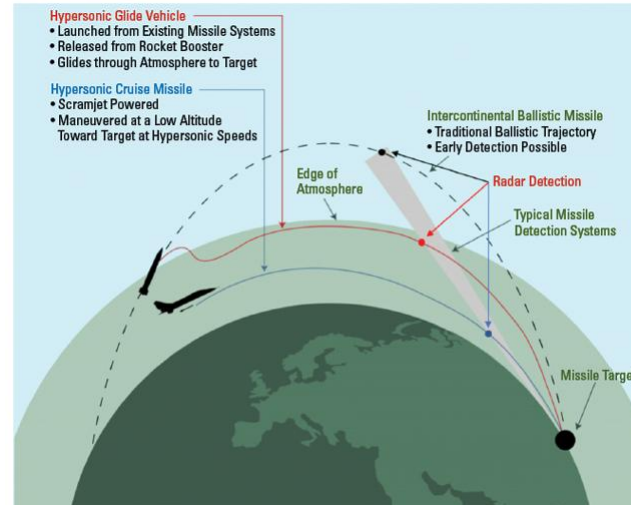
- Congested and Contested
  - No unused frequency bands
- Intentional and unintentional jamming
- Applications:
  - Surveillance
  - Communication
  - Intelligence
  - Electronic Warfare
- HPM survivability
- Wideband operation
  - Multi-functional systems
  - Monitor all activities



# Airborne Sensors



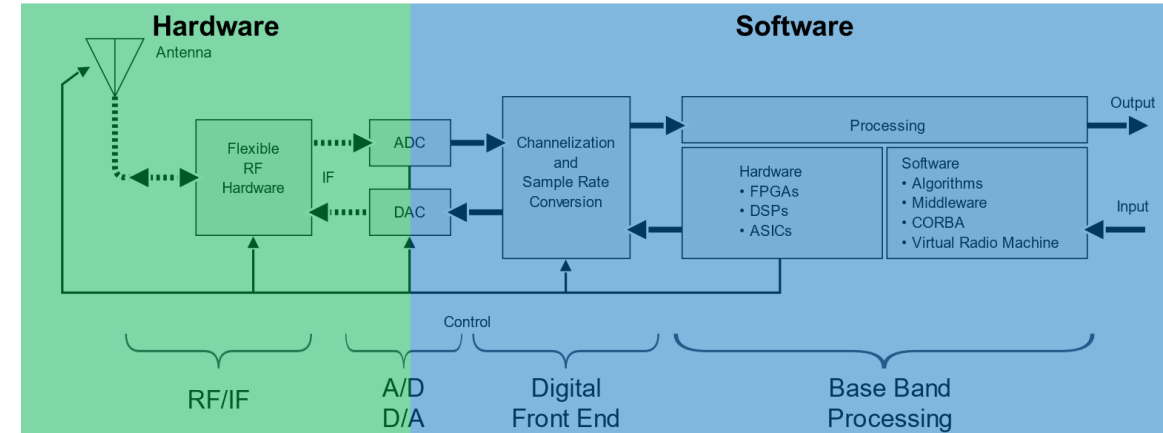
- Low Size, Weight, and Power consumption (SWaP)
- Many different platforms
  - From small Drones to AEW
- Operate in direct line of sight
  - High altitude for long range detection
  - Susceptible to all incoming signals
  - Operation behind enemy lines



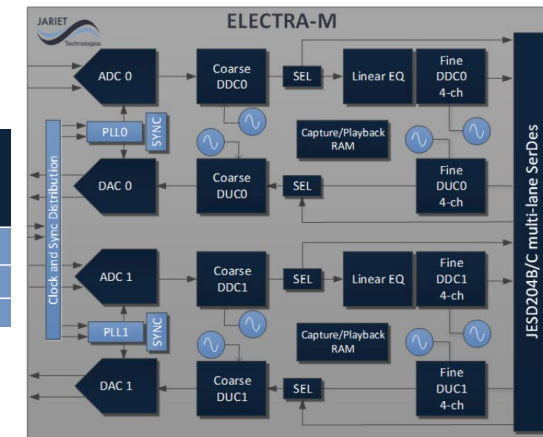
# Software Defined Radio



- One radio for multiple applications
  - Digital parts quickly reprogrammable
- New mixed signal solutions cover extreme bandwidths
  - Up to 64GSPS
  - Detect all signals in a congested EM domain
- Combine with RF front-end for high power levels
- Susceptible to signals over a wide bandwidth
  - High noise level
  - Linearity issues
  - Jamming
  - Need for filtering

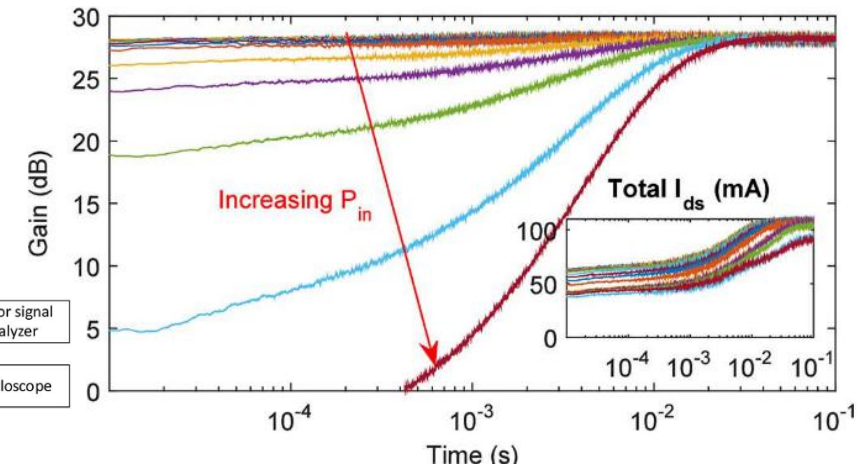
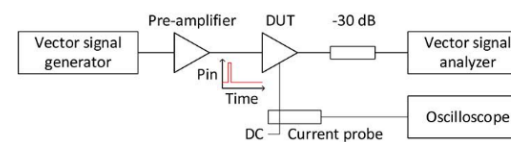
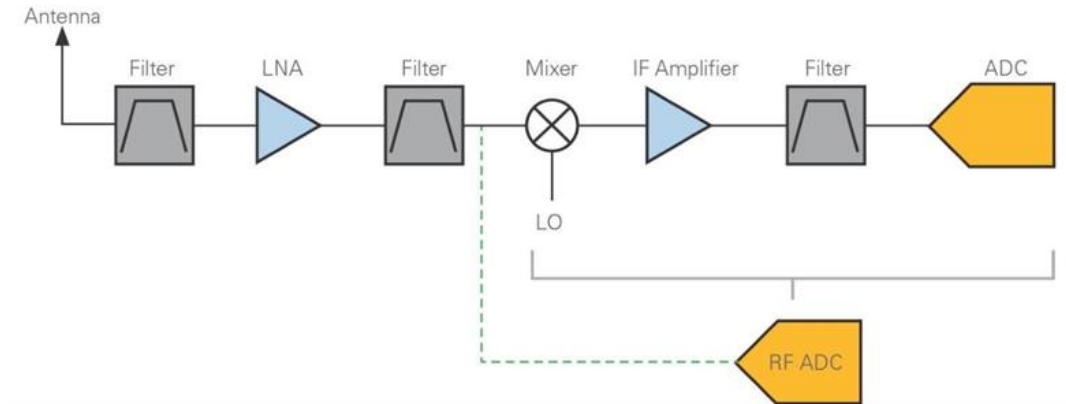


Electra Family	Channels	RF (GHz)	Sample Rate (GSPS)	Min Dec/Int	Max IBW (GHz)	Tuners/ch	BGA Package	Status
Electra-MA	2T2R	0.1-36	40 to 64	8	6.4	4	25 x 25mm	Production
Electra-MK		0.1-22	40 to 58	16	2.9	2		Production
Electra-MX		0.1-12	40 to 51.2	32	1.28	2		Production



# RF Front-end Requirements

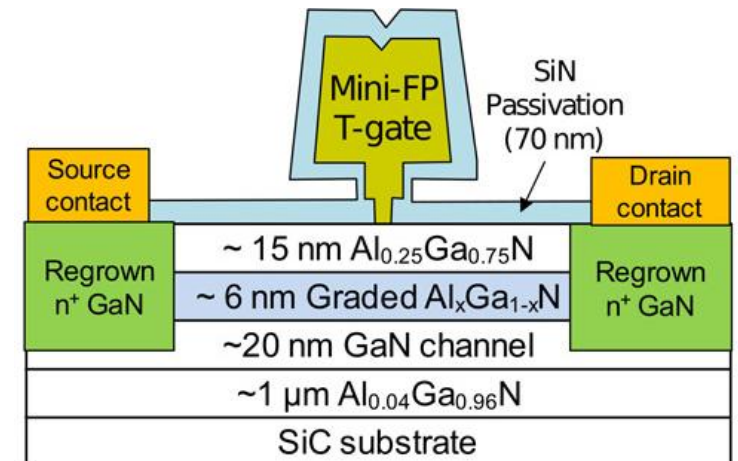
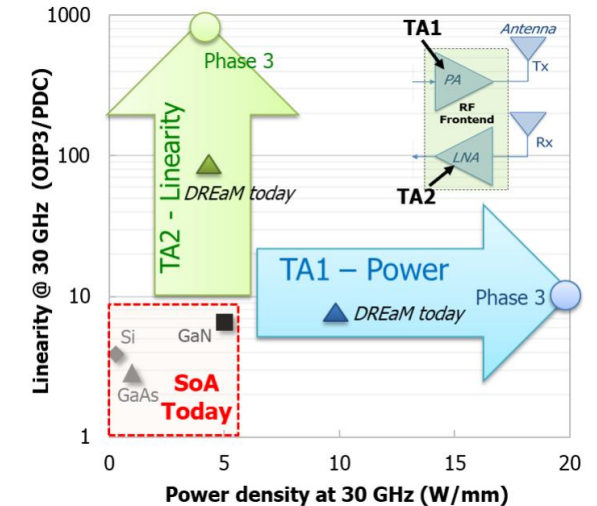
- Wideband ADC/DAC enable direct sampling without mixer
- Frequency selectivity options
  - Digital filtering in ADC
    - Highly linear LNA
  - Tunable Front-end filter
    - High-Q tunable components
  - Switchable filter banks
    - Low loss switches
- Requirements for airborne sensors
  - High survivability and linearity of LNA
    - Instant recovery of Gain
  - Band select filters
  - Low SWaP



# Linear Receivers for a Congested and Contested Electromagnetic Domain

## Motivation

- Highly linear Low Noise Amplifiers needed for airborne sensors
  - While keeping power consumption low  $OIP3/P_{DC}$
- DARPA DREaM aimed at 20dB increase in FoM
  - Graded AlGaN channel HEMT is State of the Art
- Graded AlGaN channel HEMT
  - Thin layer between channel and barrier with increasing Al content
  - Tailoring the  $g_m$  curvature
  - Challenging material growth with fast and accurate control

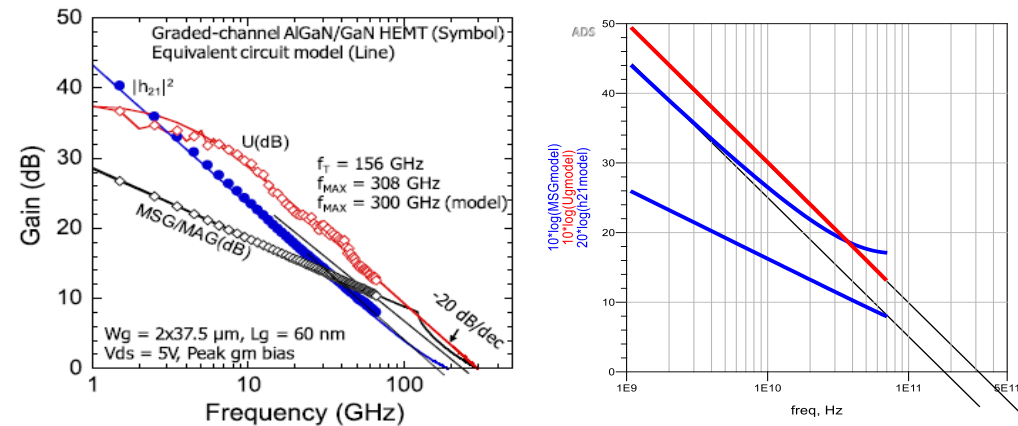
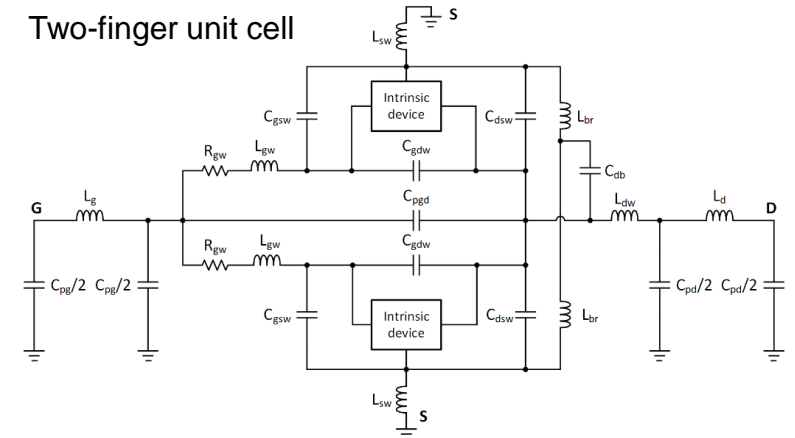


# TCAD Calibration using State of the Art

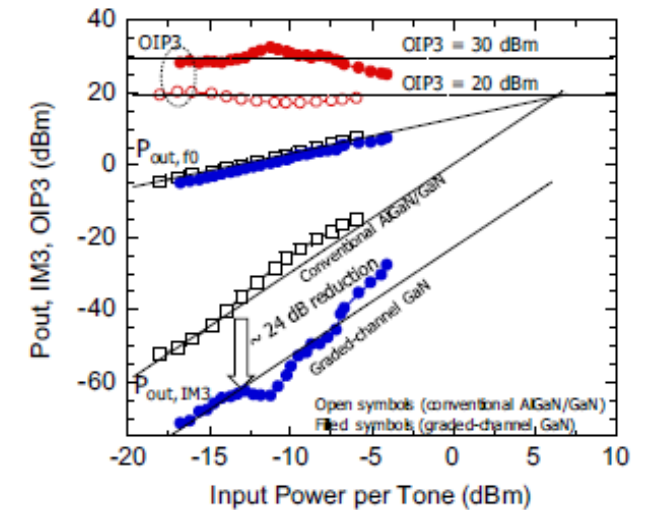


## Simulation and Optimization Toolbox Creation

- Intrinsic nonlinear core from TCAD
- Extrinsic parasitics from Electro Magnetic simulations
- Excellent prediction of performance from models
- New Toolbox for device optimization



Comparison of  $h_{21}$ ,  $U$ , and  $MSG$  at  $V_{ds}=5$  V and  $I_{ds}=320$  mA/mm from measurement (left) non-linear model with parasitics from EM-simulations added for the non-linear model (no tuning of bias)



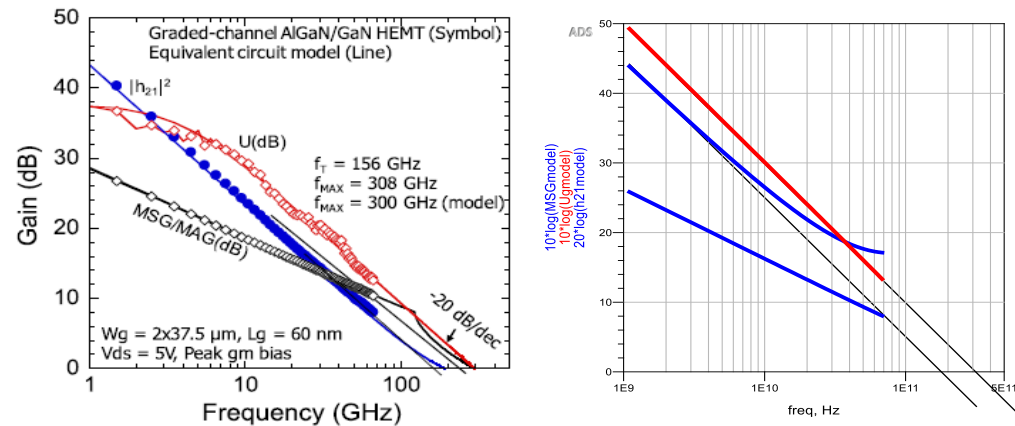
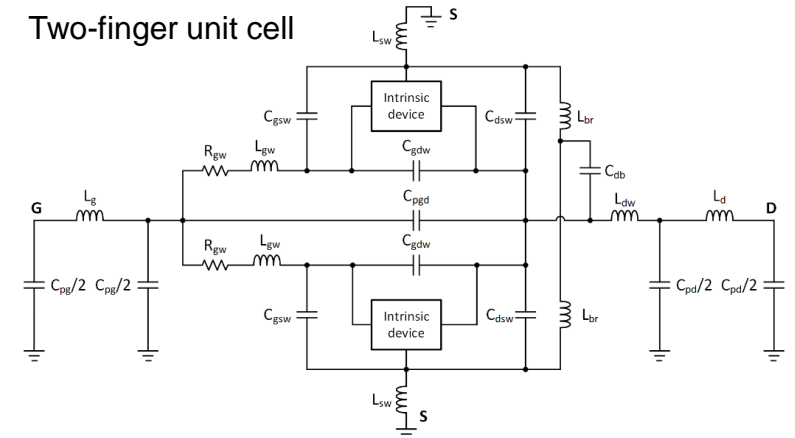
Comparison of  $P_{out}$ ,  $IMD3$  and  $OIP3$  @30 GHz and  $V_{ds}=14$ V for the non-linear model and published data

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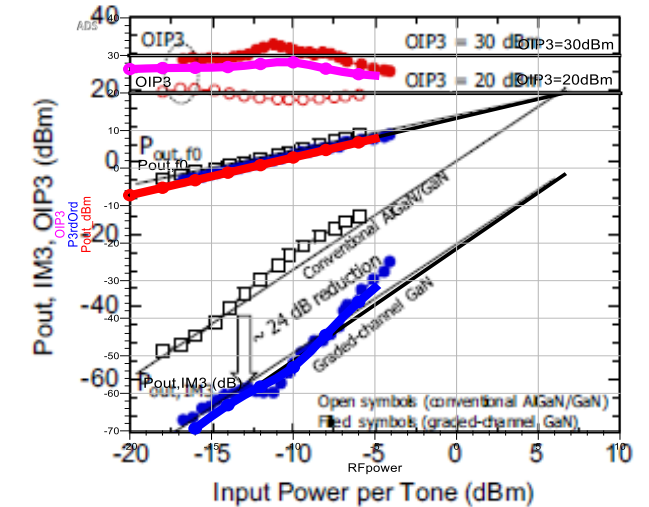


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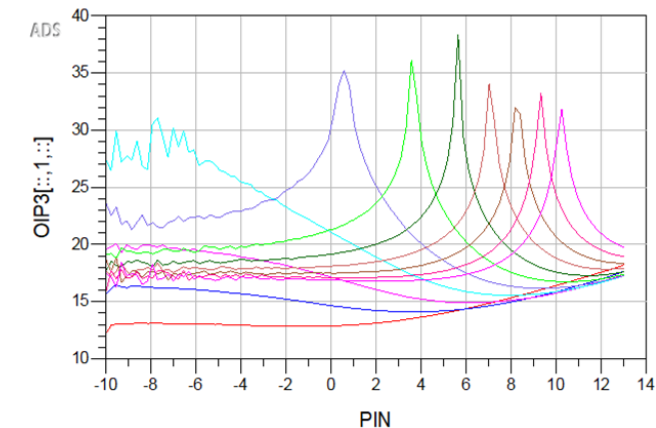
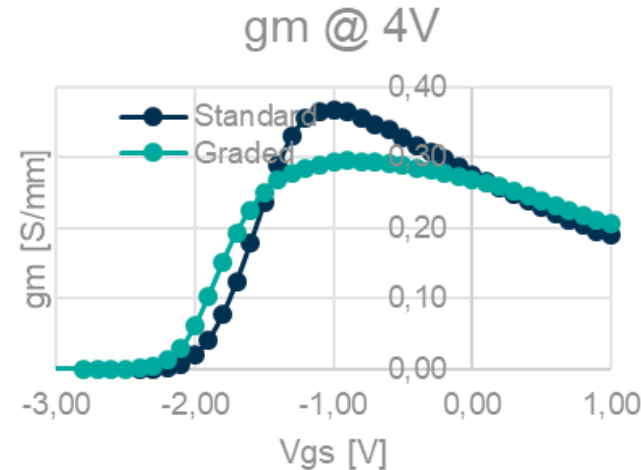
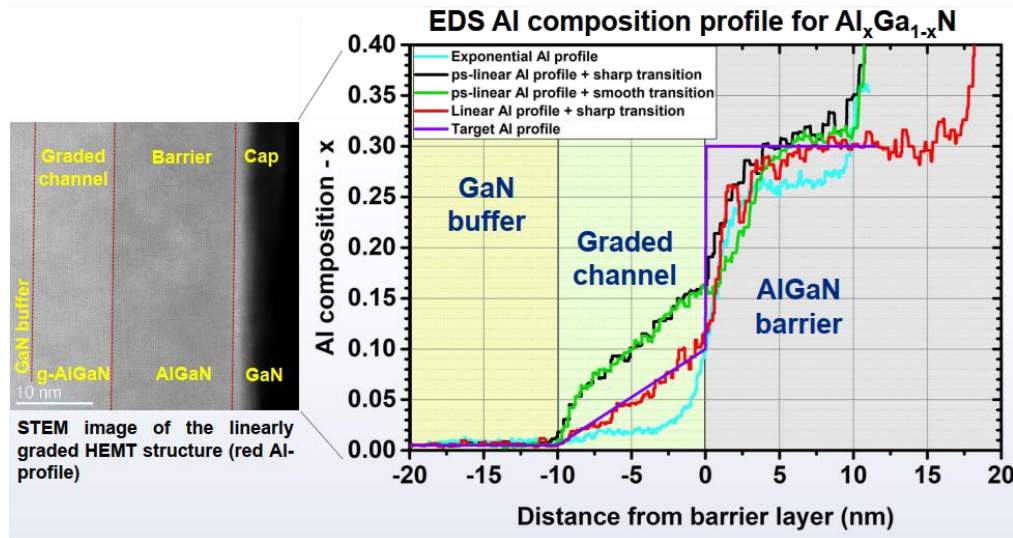
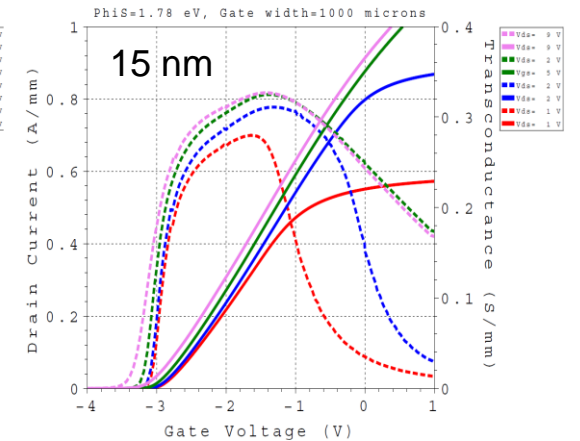
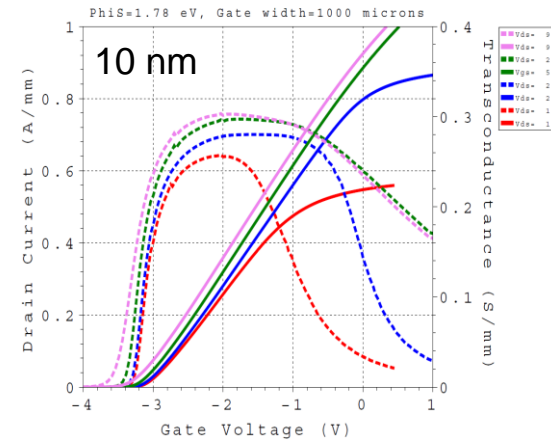
Comparison of  $h_{21}$ , U, and MSG at  $V_{ds}=5$  V and  $I_{ds}=320$  mA/mm from measurement (left) non-linear model with parasitics from EM-simulations added for the non-linear model (no tuning of bias)



Comparison of Pout, IMD3 and OIP3 @30 GHz and  $V_{ds}=14$ V for the non-linear model and published data

# Mastering Material Growth

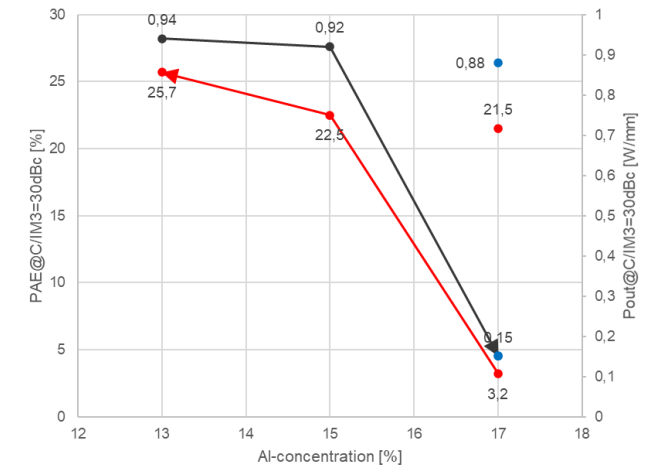
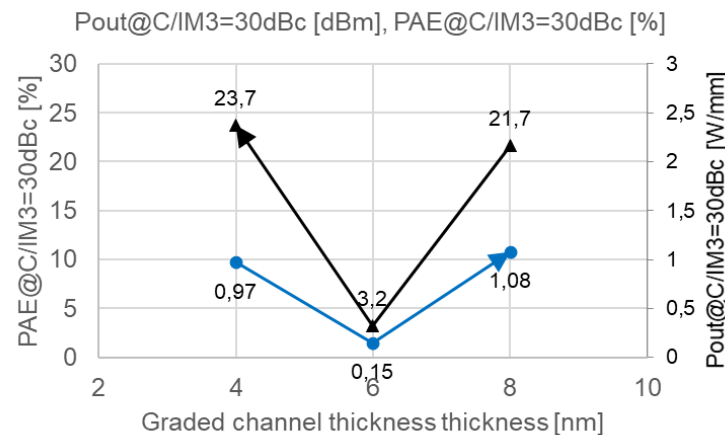
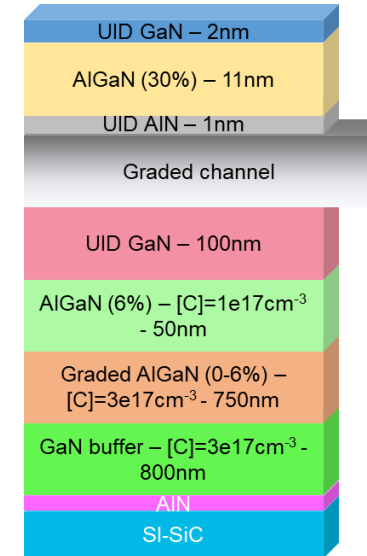
- Physical simulations for initial parameters
  - Large impact on gm profile versus grading profile
- Material growth based upon best parameter
  - **First Swedish Graded AlGa<sub>N</sub> Channel HEMT**
- Excellent Al composition control over very thin layer
- Flatter gm curvature compared to standard channel



# Material Optimization by Growth



- Extrapolation of TCAD results with caution
  - Real experiments needed to calibrate models
- Challenging to quickly alter Al content in MOCVD growth
- Thickness variation from 4nm to 8nm
- Al concentration from 13% to 17%
- Clear trend for Al concentration
- Inconclusive results versus thickness

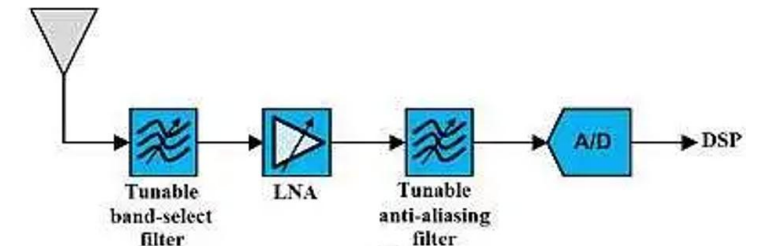


# Reconfigurable Transmit/Receive Front-End for Multi-functional Sensors

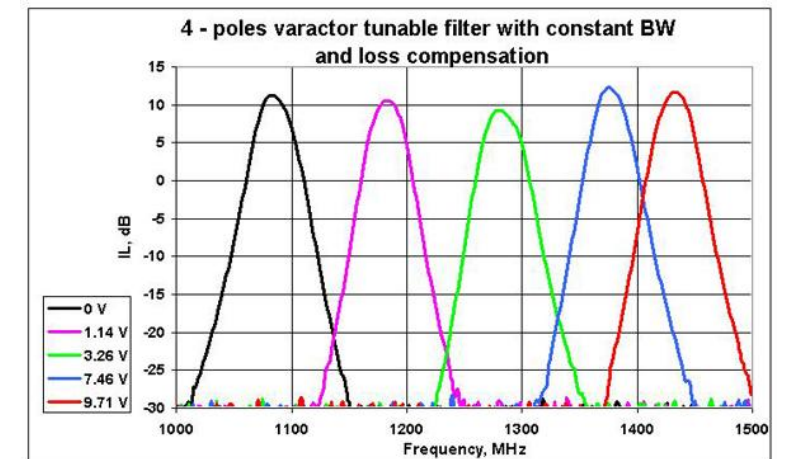
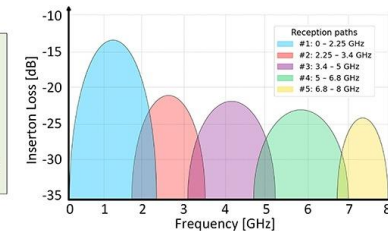
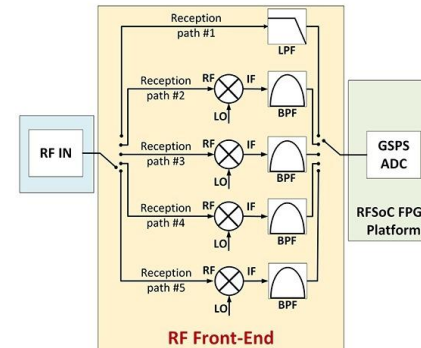


## Motivation

- Fast and reconfigurable RF front-ends needed in contested environments
- Frequency agile RF front-end
  - Tunable filter
  - Filter bank
  - Low loss
  - High linearity
  - Power handling
- Reconfigurable power amplifier
  - Tunable load impedance



Design, Implementation, and RFSoc-Based Validation of a Multi-Path RF Front-End for Wideband Spectrum Analysis



# Choosing the Varactor

Congested and contested airborne environment differ from e.g. telecom / satcom

- High tuning range C(V)
- **High power operation, i.e. large voltage handling**
- High linearity
- Low losses

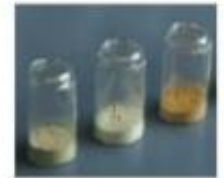
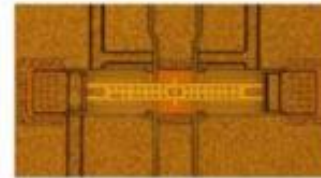
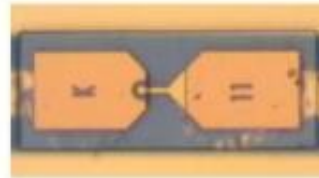
## Materials used in varactors, phase shifting and impedance controlling devices

Semiconductor

Micro-Mechanics

Liquid Crystal

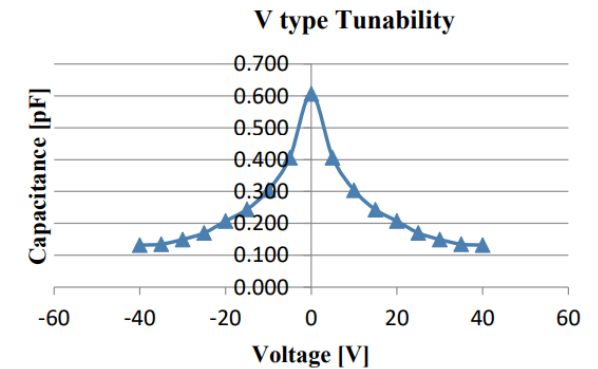
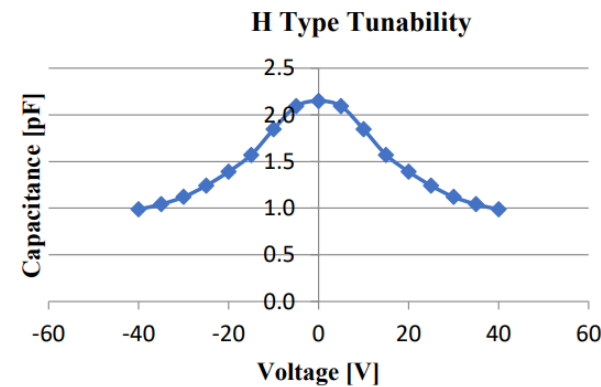
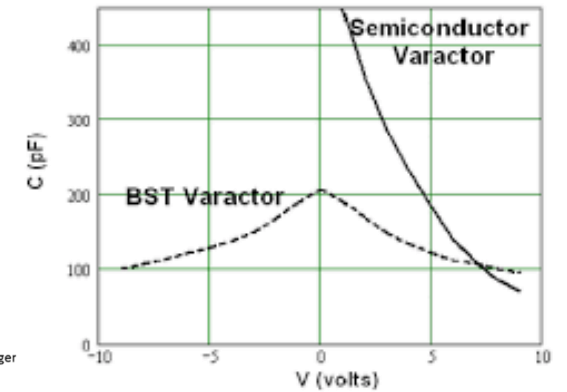
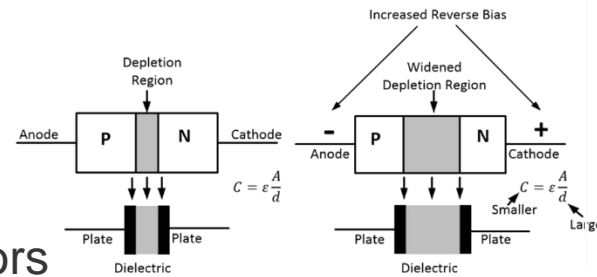
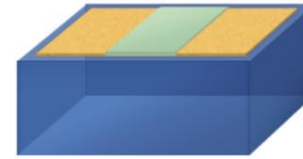
Tunable Dielectrics



	Semiconductor	Micro-Mechanics	Liquid Crystal	Tunable Dielectrics
Tunability	➕ High	➖ Medium	➖ Medium	➕ High
Tuning Voltage	➕ Low	➖ Medium	➖ Medium	➖ High
Switching Speed	➕ High	➕ High	➖ Low	➕ High
Linearity (IP3)	➖ Low	➕ High	➕ High	➕ High
Q Factor/ESR	➖ OK	➖ OK	➕ Good	➕ Good
Reliability	➕ Good	➖ Low	➕ High	➕ High
Production Cost	➖ Medium	➖ Medium	➕ Low	???

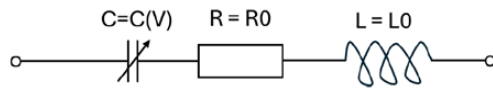
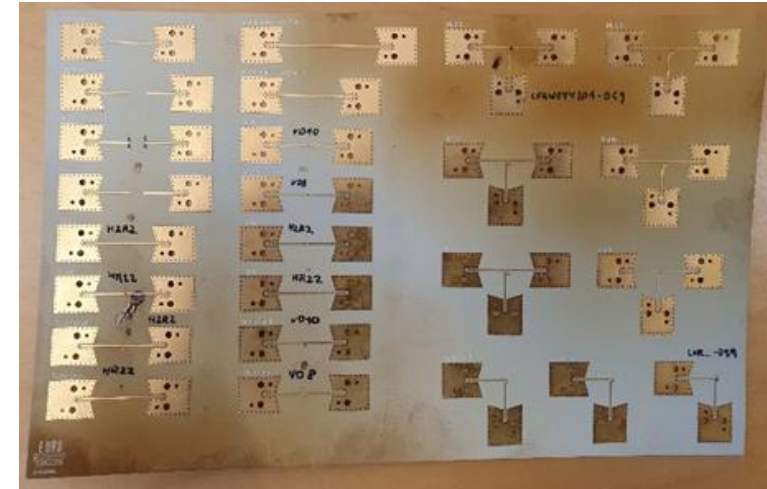
# Varactor Evaluation

- Tunable Dielectric
  - Ferroelectric materials
  - Barium Strontium Titanate (BST)
  - Dielectric properties change with applied voltage
  - Temperature dependence to be considered
- Two variants available
  - V-type optimized to be closer to Schottky varactors
  - H-type show more linear C vs V for large voltage range
  - Very high voltage handling

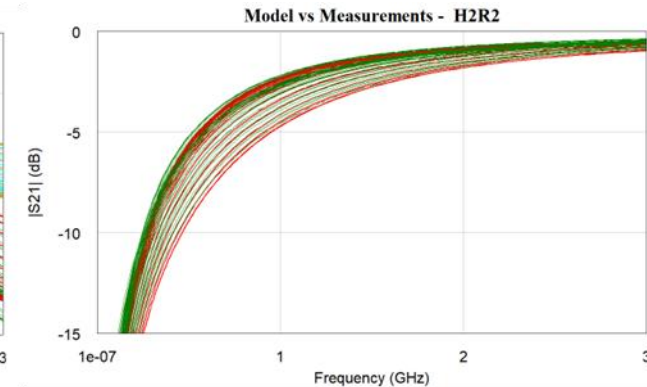
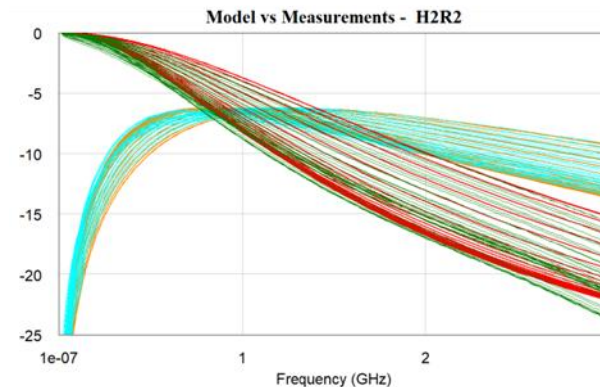
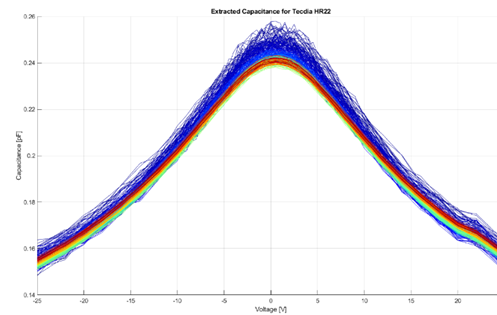


# Characterization and Modeling

- Test board developed to measure several configurations
  - Calibration standards
  - Series configuration
  - Shunt configuration
- Model development and verification
  - Constant series resistance and inductance
  - Polynomial description of capacitance
  - Excellent fit in the measured frequency range



Varactor Model	Tecdia H2R2
$c_4$ (pF/V <sup>4</sup> )	$2.837 \cdot 10^{-6}$
$c_3$ (pF/V <sup>3</sup> )	0
$c_2$ (pF/V <sup>2</sup> )	$-3.123 \cdot 10^{-3}$
$c_1$ (pF/V)	0
$c_0$ (pF)	1.994
$R_0$ ( $\Omega$ )	3.2 $\Omega$
$L_0$ (nH)	0.18
Frequency Range of Model Validity	100 Hz - 3GHz



# Conclusions



- Both project have paved the way towards enabling highly linear receivers
- Graded AlGa<sub>N</sub> channel HEMTs a promising candidate for LNAs
  - Material growth optimization can still improve performance
  - Technology accessible in Sweden
  - Commercialization is pending
- Frequency agile receivers needed in the congested and contested environment
  - Tunable microwave components are enablers
  - BST varactors are promising candidates
  - Filter demonstrator pending
- Both projects terminated after 1 year pre-studies