Modeling and Simulating Otava mmWave Beamformer IC

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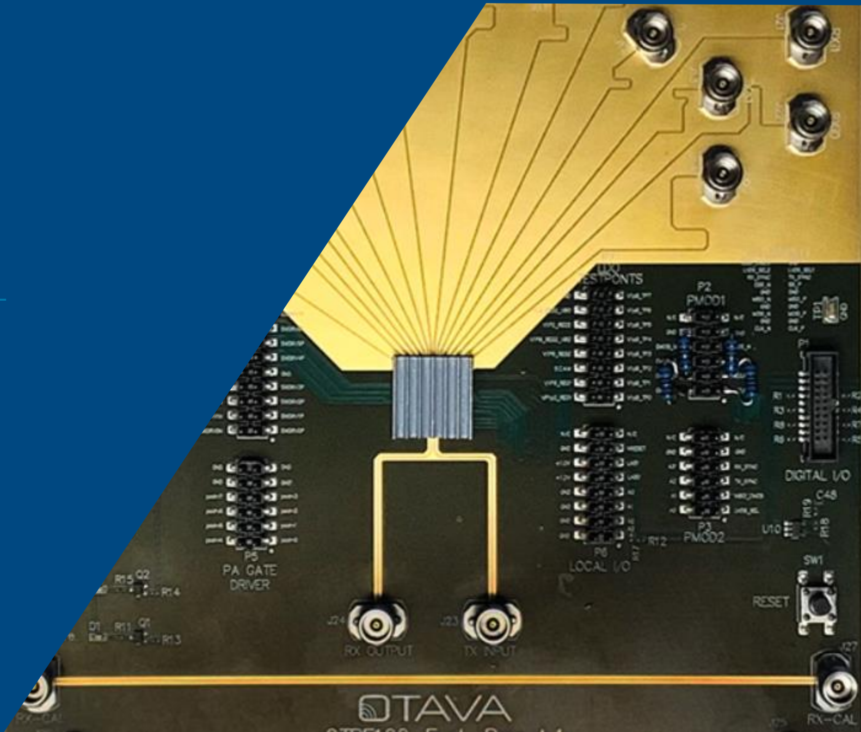
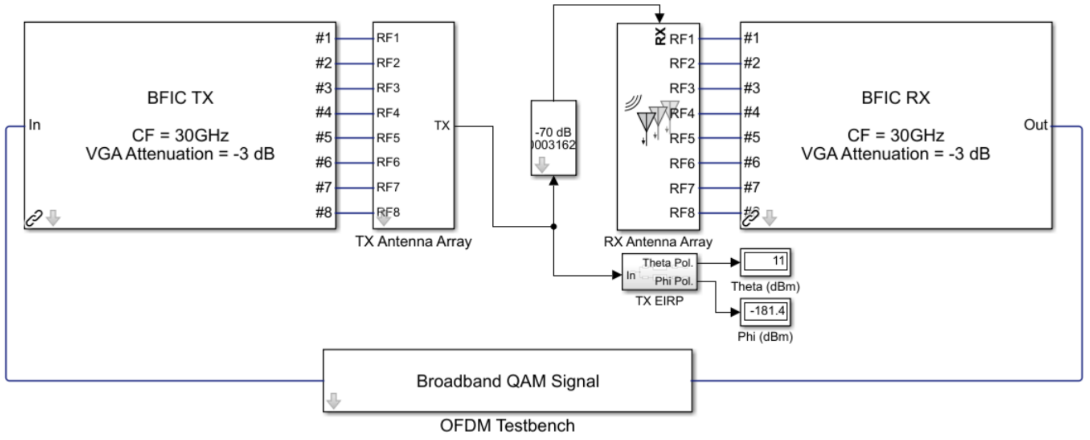
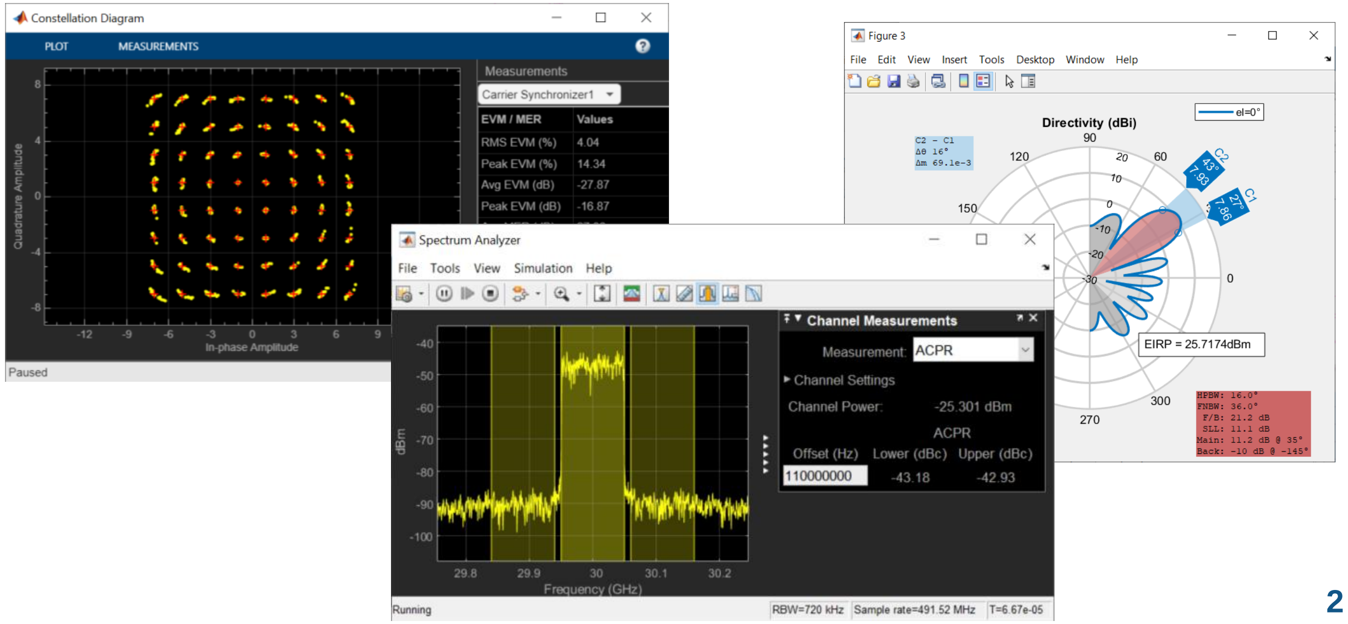
Otava



Agenda

- Introducing Otava Beamformer IC (BFIC)
- Modeling the BFIC in MATLAB: goals and capabilities
- Overview of the model structure
- Using RF characterization data and enabling integration with the antenna array models
- Demos
- Conclusions

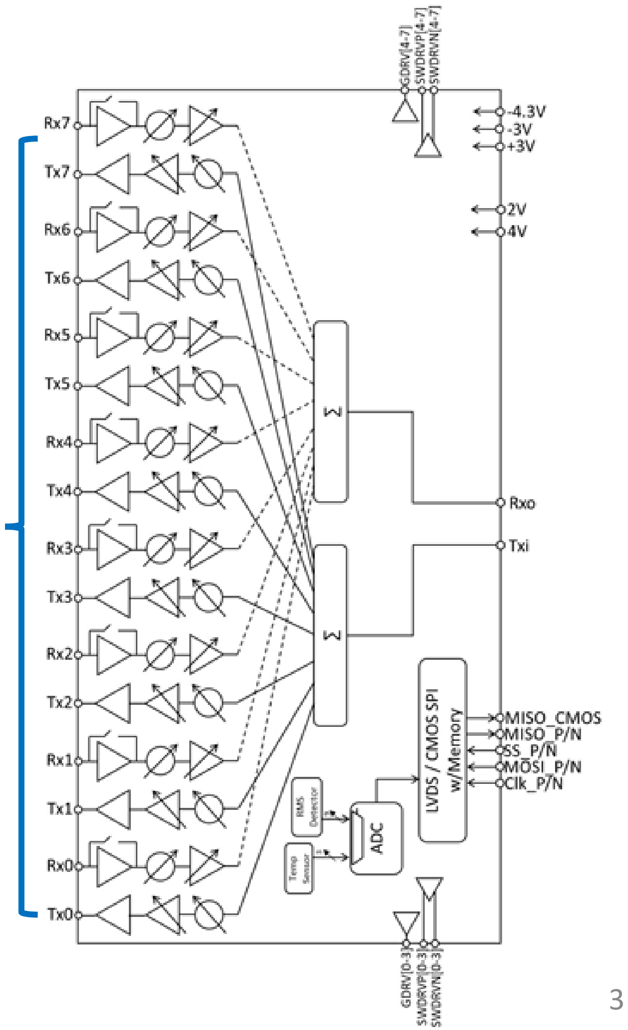




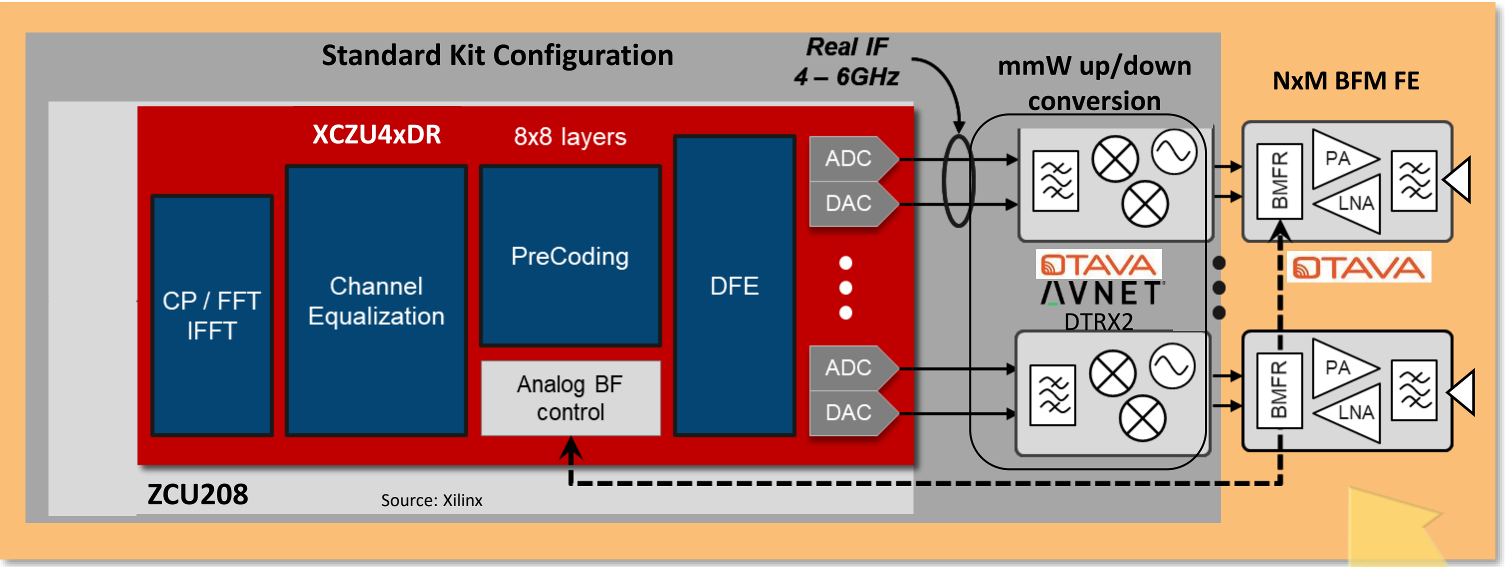
Wideband 24-40GHz Beamforming RFIC *OTBF103*

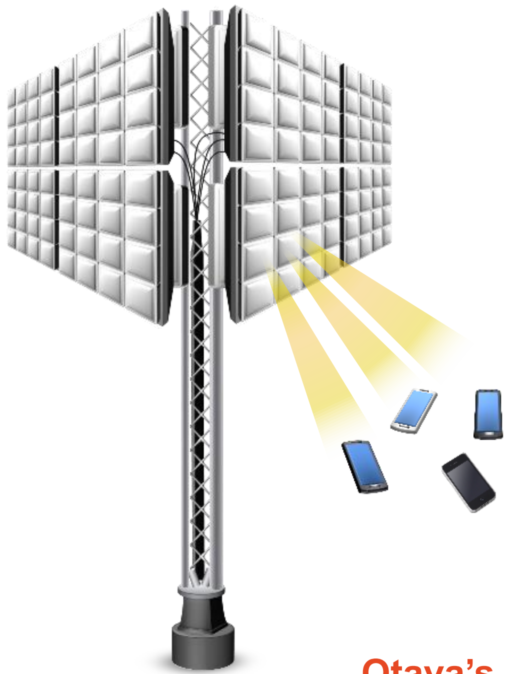
- 24-40GHz mmW Design
  - 8 Rx Inputs to 1 Rx Output
  - 8 Tx Outputs from 1 Tx Input
  - Independent VGA control (20 dB range, 0.5 dB step)
  - Independent Phase control (360 deg coverage, 5.6 deg step)
- Analog Content
  - Temp Sensor / RMS Power Detector capability
  - External Gate Driver operates from -4.3 to +0.3V (x8)
  - External T/R Switch Driver provides +3 and -3V outputs (x8)
- 4-wire Digital SPI Design (LVDS/CMOS Control)
  - SPI operation up to 350MHz for fast on the fly switching of all parameters
  - Integrated memory for fast beam switching (64 states)

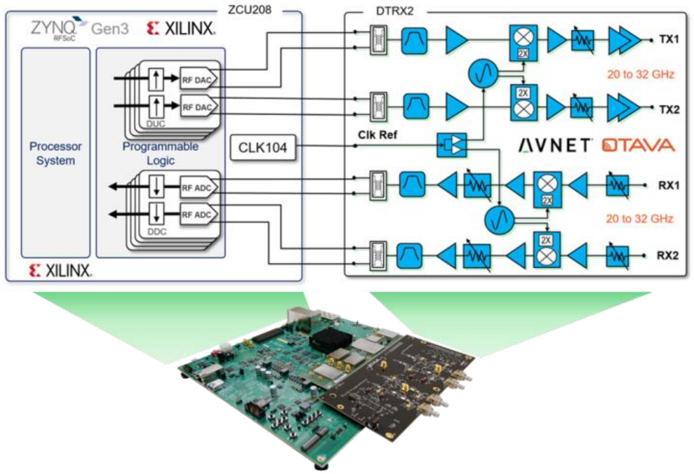
8 Tx ports
8 Rx ports



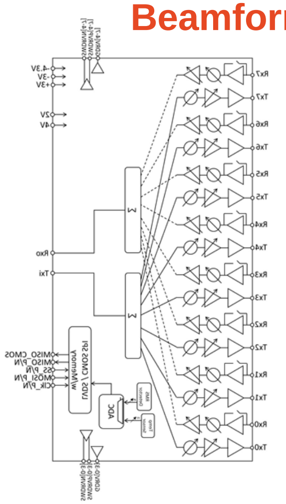
Within the Full RU System







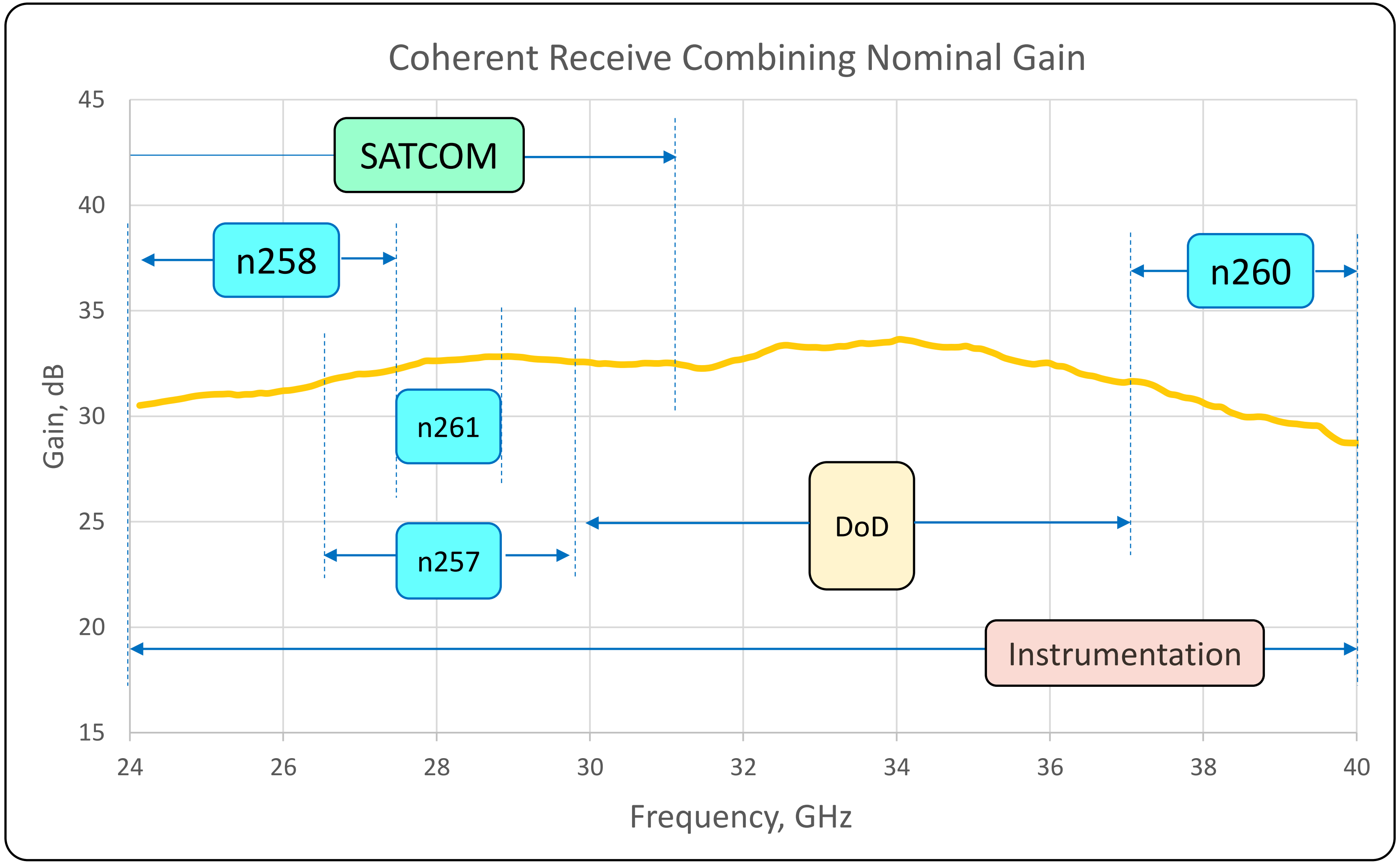
Otava's Beamformer IC



OTBF103 Covers Multiple Bands and Applications

Application Legend

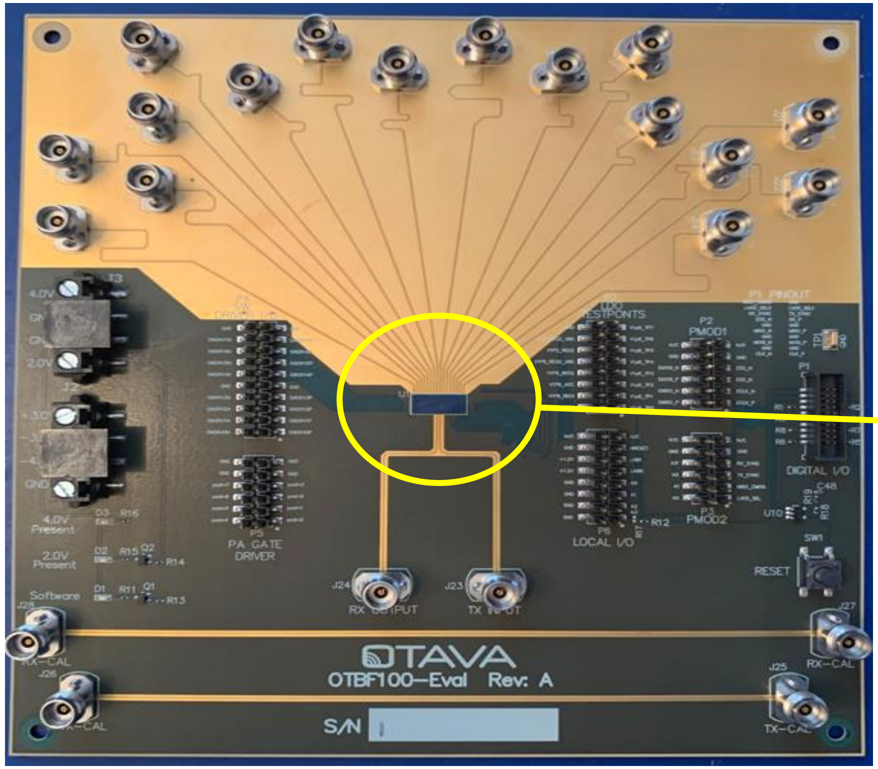
- = 5G NR FR2
- = DoD / Military
- = SATCOM
- = Instrumentation

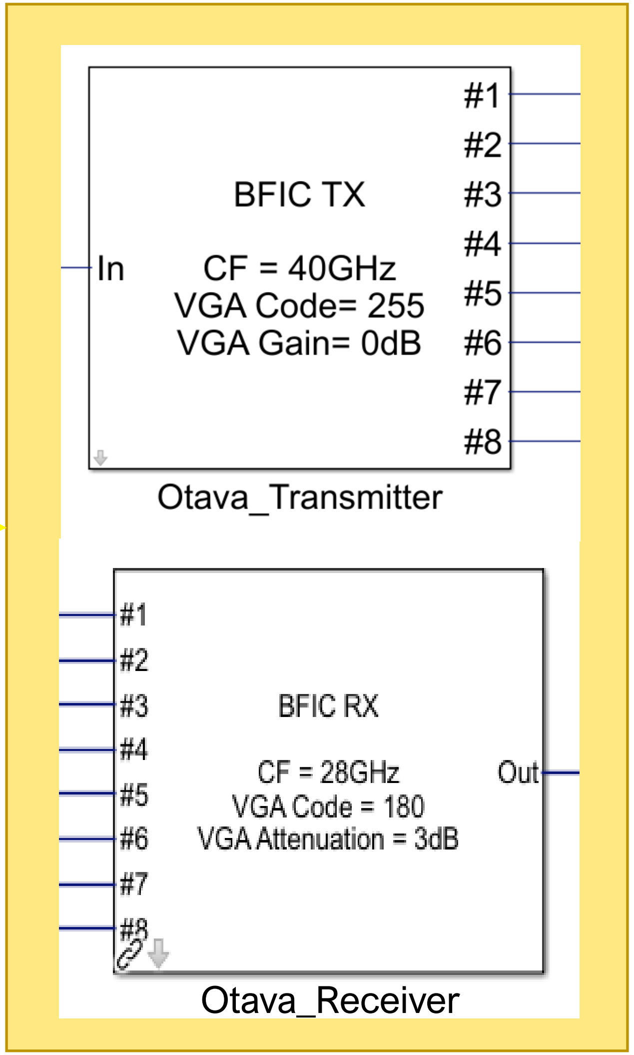


The Design Tools Offered

…. AND the MATLAB model

The Eval Board





Model Goals and Capabilities

- Model built in MATLAB and Simulink, to enable **bits-to-antenna system level simulations**, **RF signal chain optimization** and **algorithm development**

- Specifically tailored for antenna array radio modeling & comprehensive radio design

- Model to **capture the circuit performance** over
  - ✓ RF operating frequency
  - ✓ VGA gain setting
  - ✓ Phase shifter setting
  - ✓ Input/output power level

- The model is **based on actual measured data** and captures key RF performance as well as measured residual Amplitude and Phase errors as a function of the operating point

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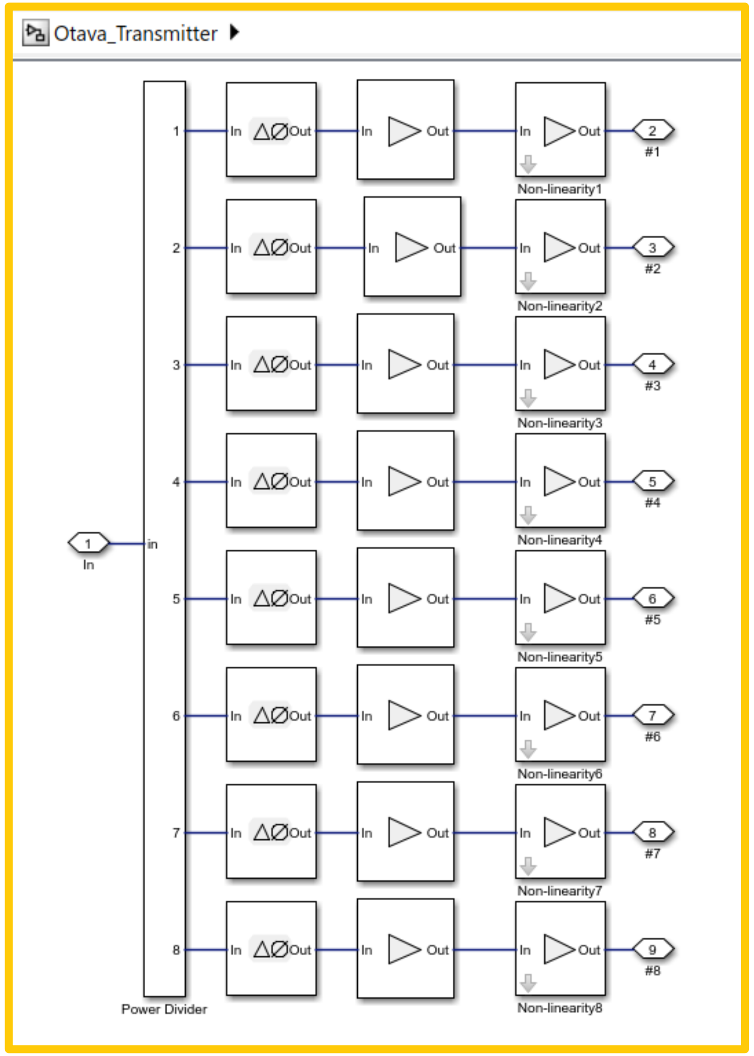
What Does the Model Capture?

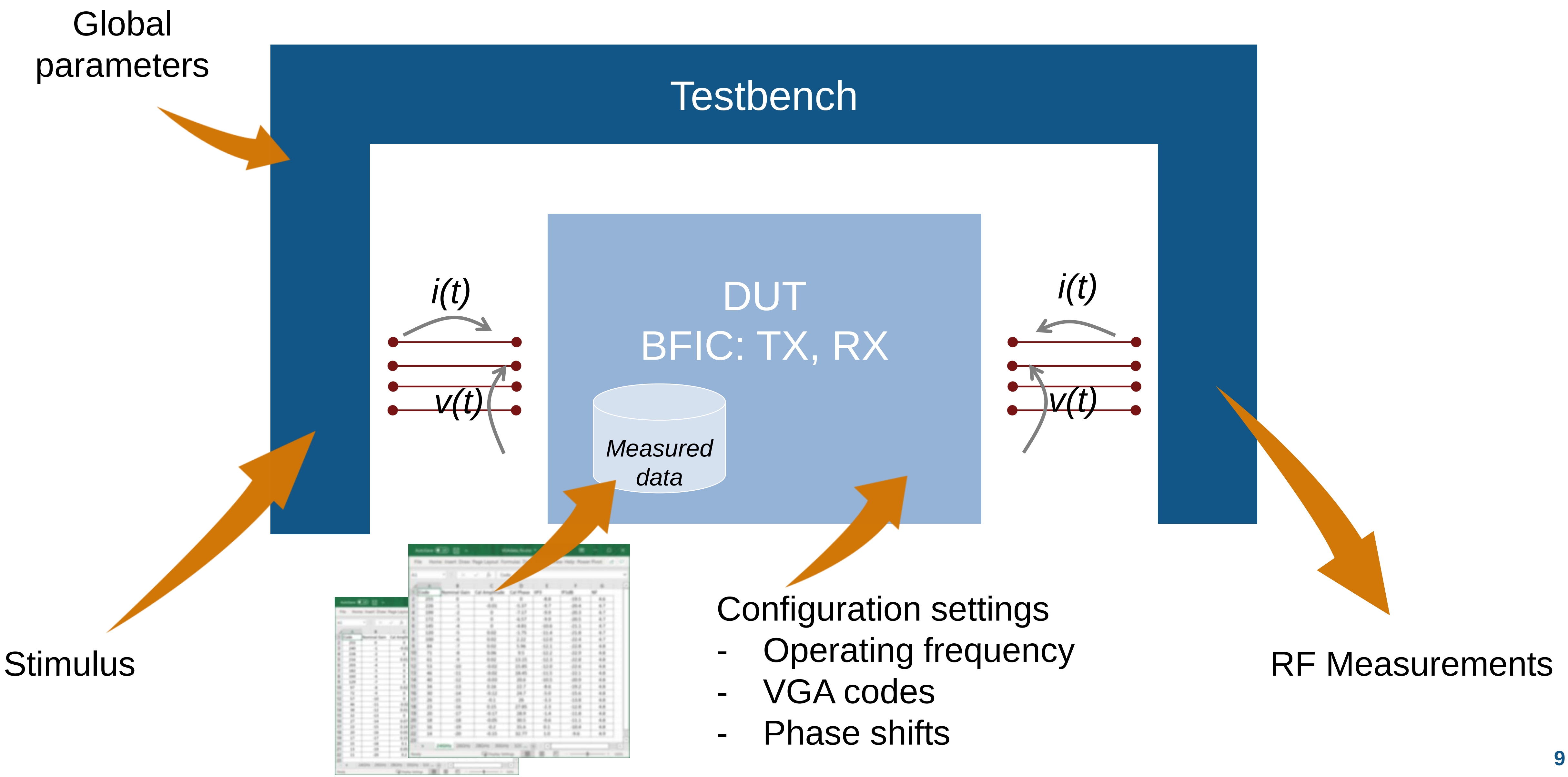
- ✓ Device input and output S-parameters
- ✓ Gain vs. RF Frequency
- ✓ P1dB and IP3 as a function of VGA state and frequency
- ✓ NF as a function of frequency and VGA state
- ✓ Amplitude error vs. phase and gain state
- ✓ Phase error vs. phase and gain state

User enters/calculates the following parameters:

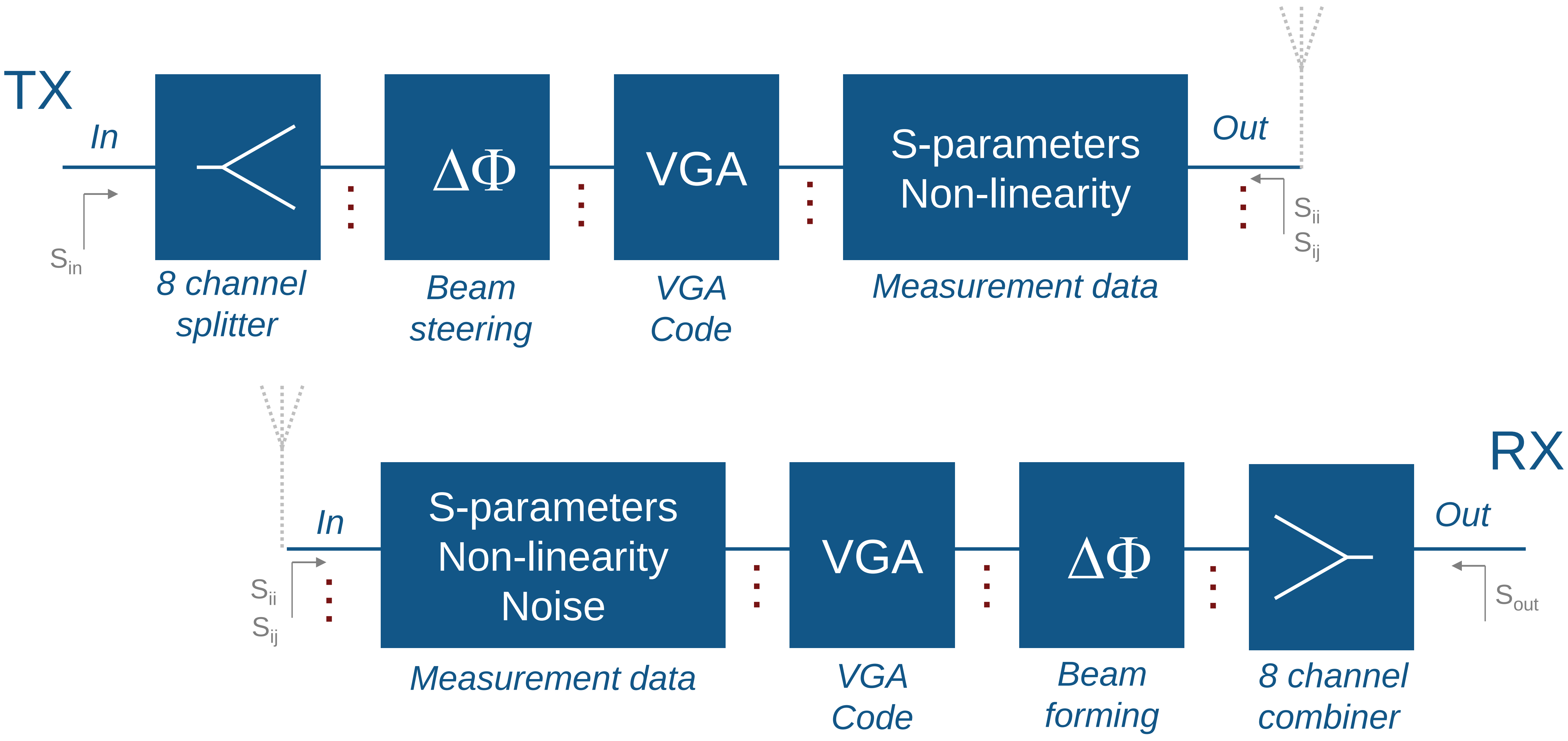
Freq CF | VGA Gain/ch | Phase/ch



Overall Modeling Guidelines

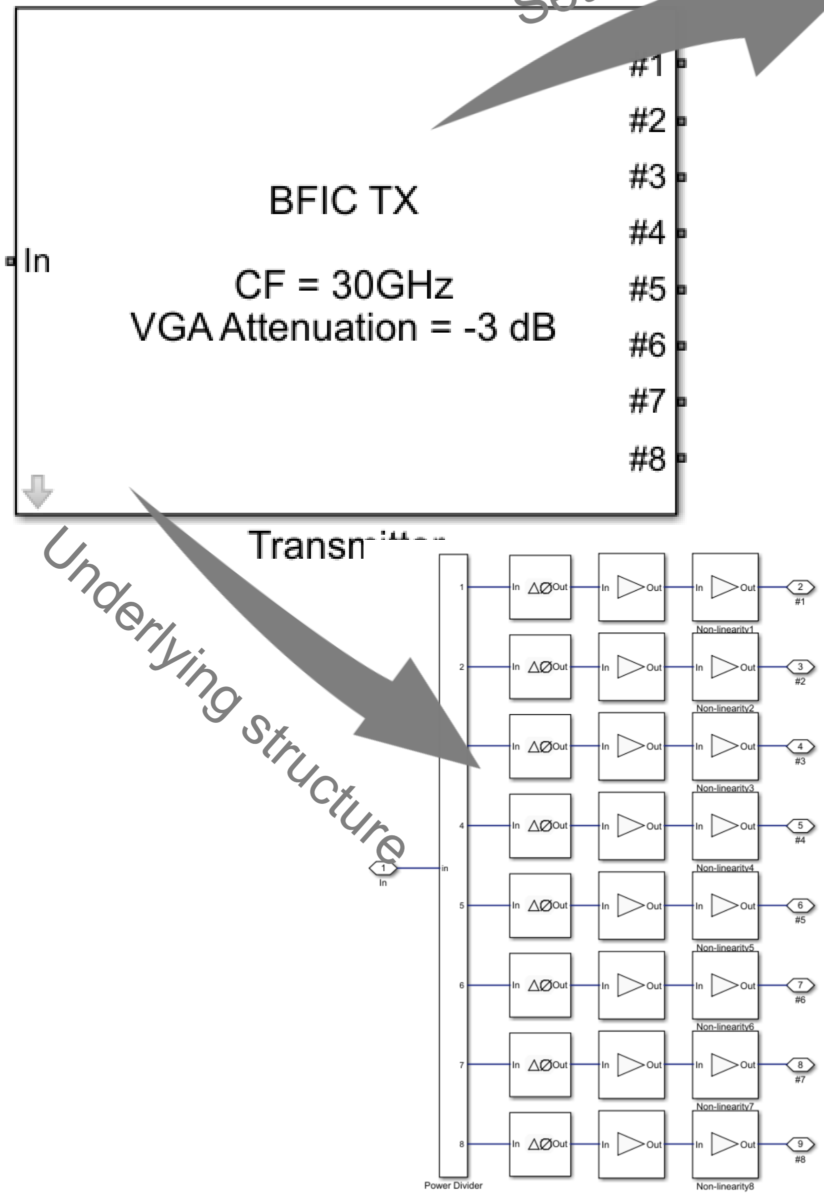


Structure of the BFIC Models

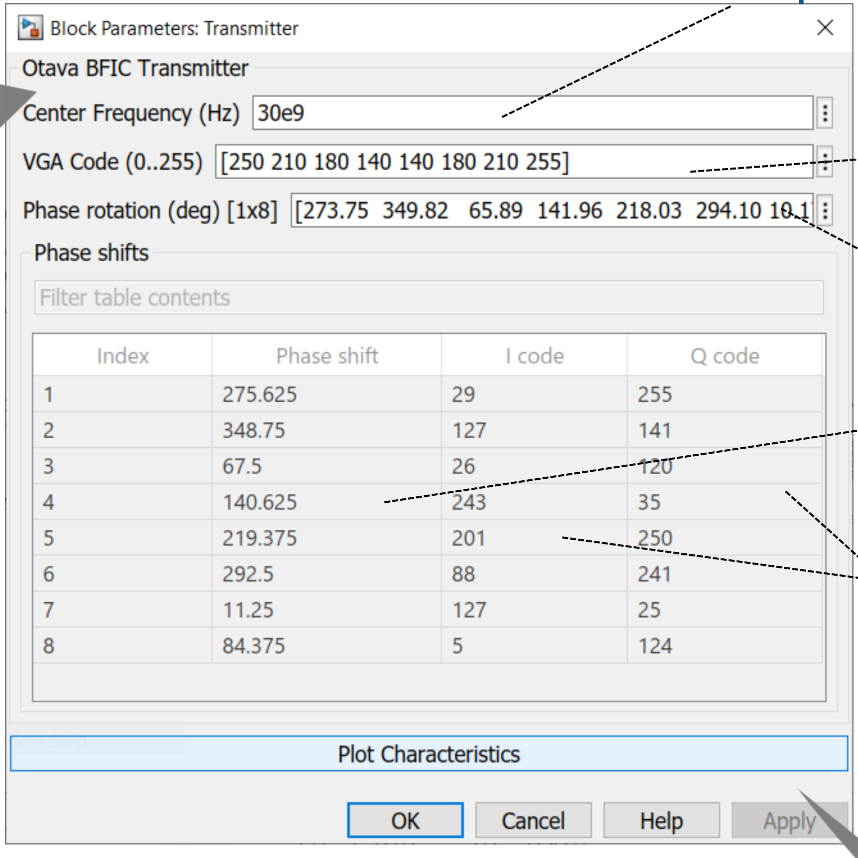


TX Model in Practice

Settings



Underlying structure


Block Parameters: Transmitter

Otava BFIC Transmitter

Center Frequency (Hz) 30e9

VGA Code (0..255) [250 210 180 140 140 180 210 255]

Phase rotation (deg) [1x8] [273.75 349.82 65.89 141.96 218.03 294.10 10.1

Phase shifts

Filter table contents

Index	Phase shift	I code	Q code
1	275.625	29	255
2	348.75	127	141
3	67.5	26	120
4	140.625	243	35
5	219.375	201	250
6	292.5	88	241
7	11.25	127	25
8	84.375	5	124

Plot Characteristics

OK Cancel Help Apply

Operating frequency (24-40GHz)

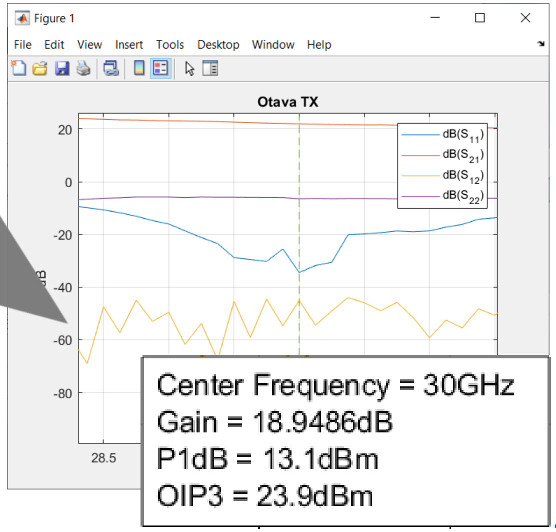
VGA codes (tapers)

Phase shifts

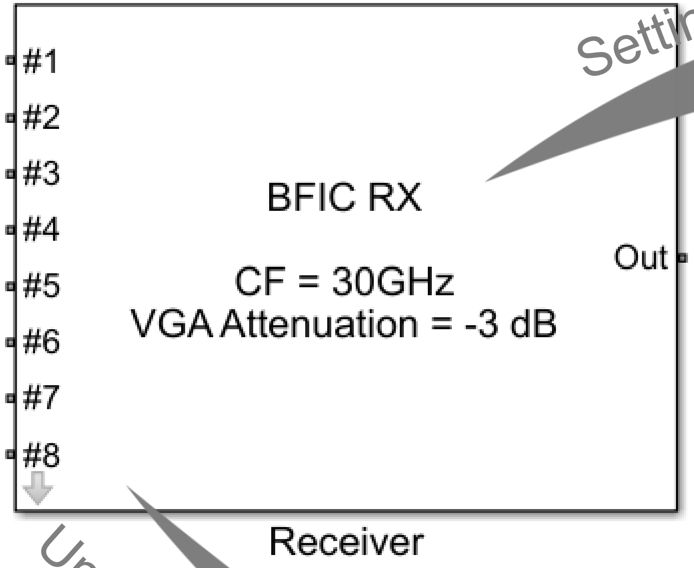
Applied quantized phase shifts

Applied I/Q codes

Nominal specs

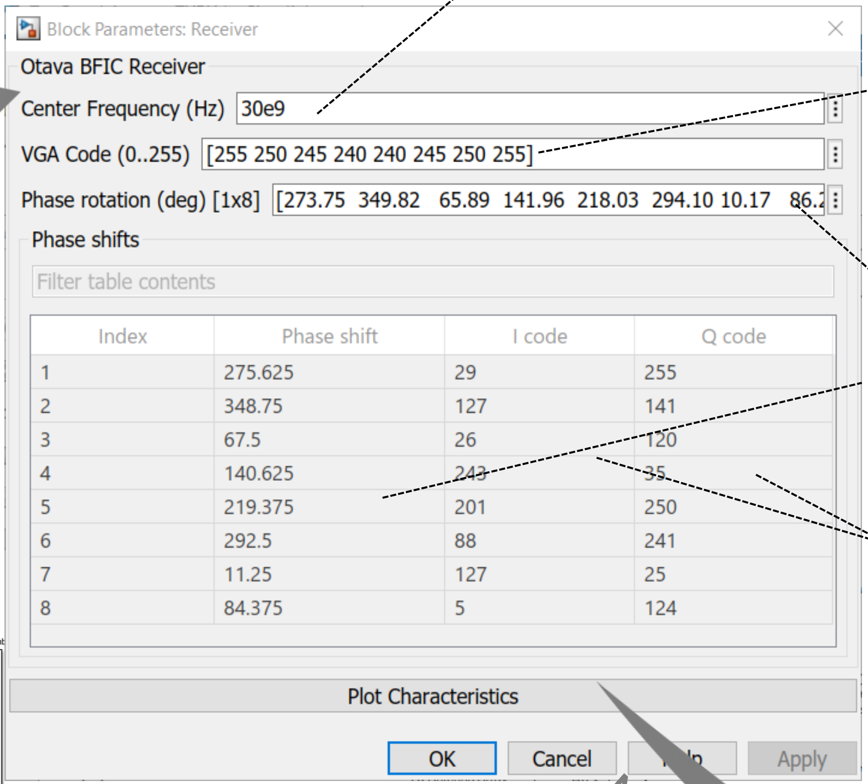


RX Model in Practice



Settings

Underlying structure



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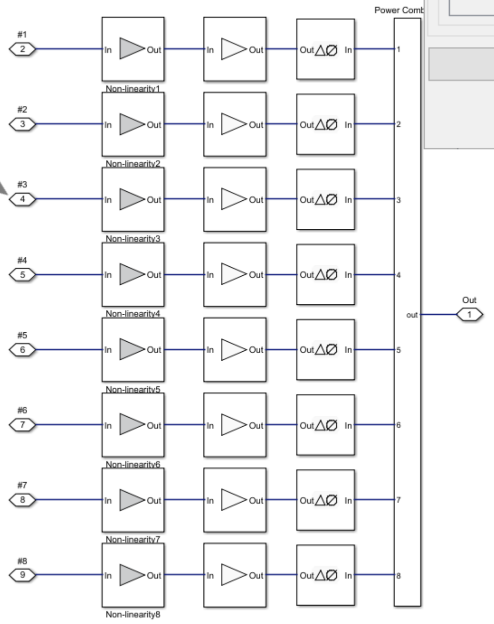
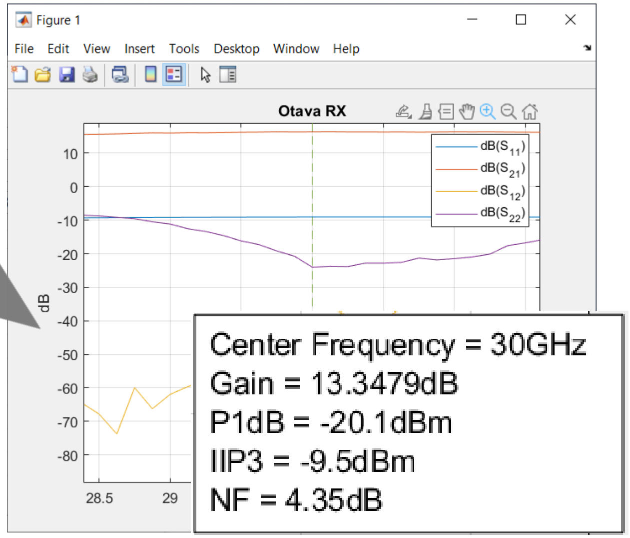
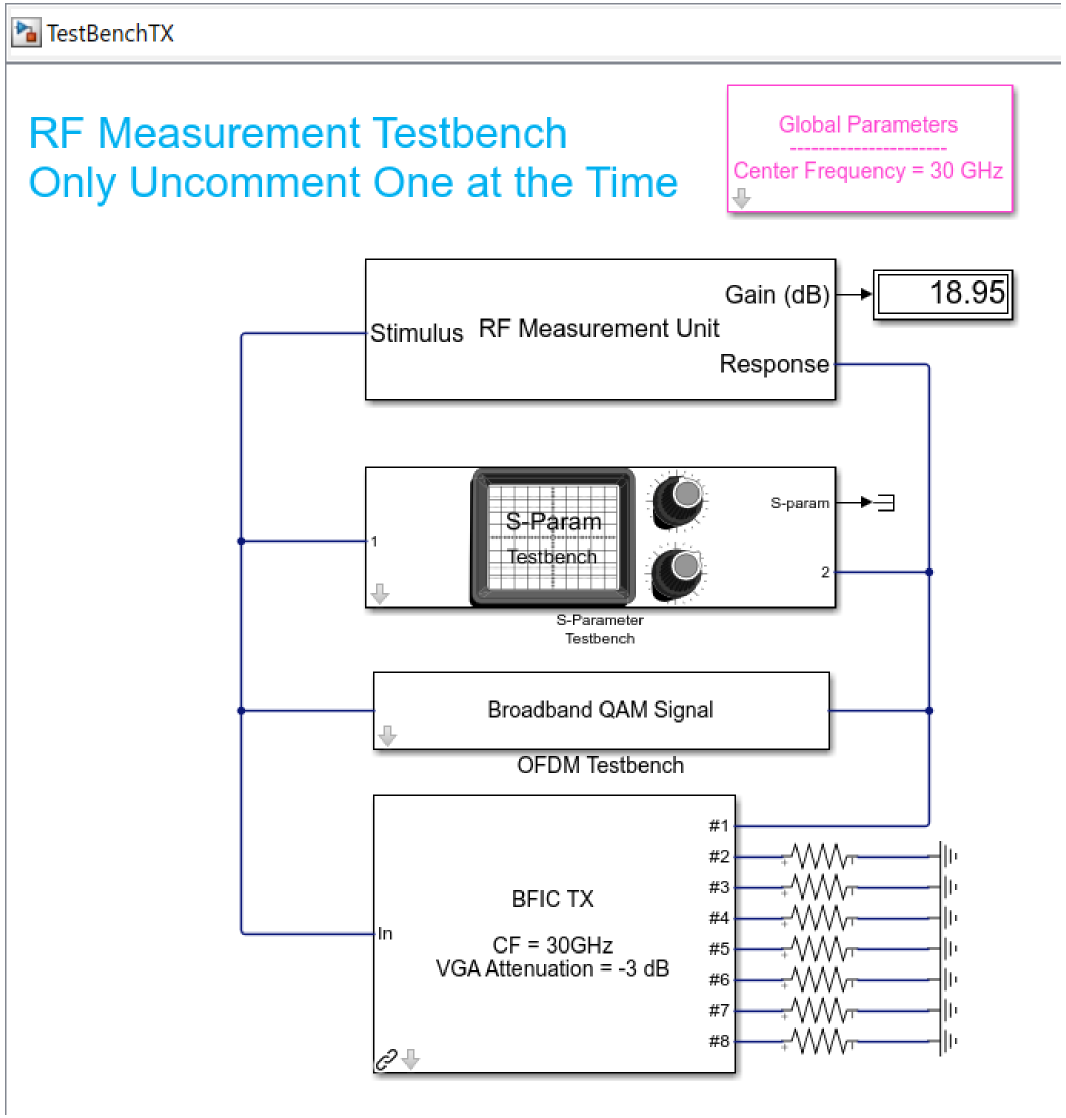


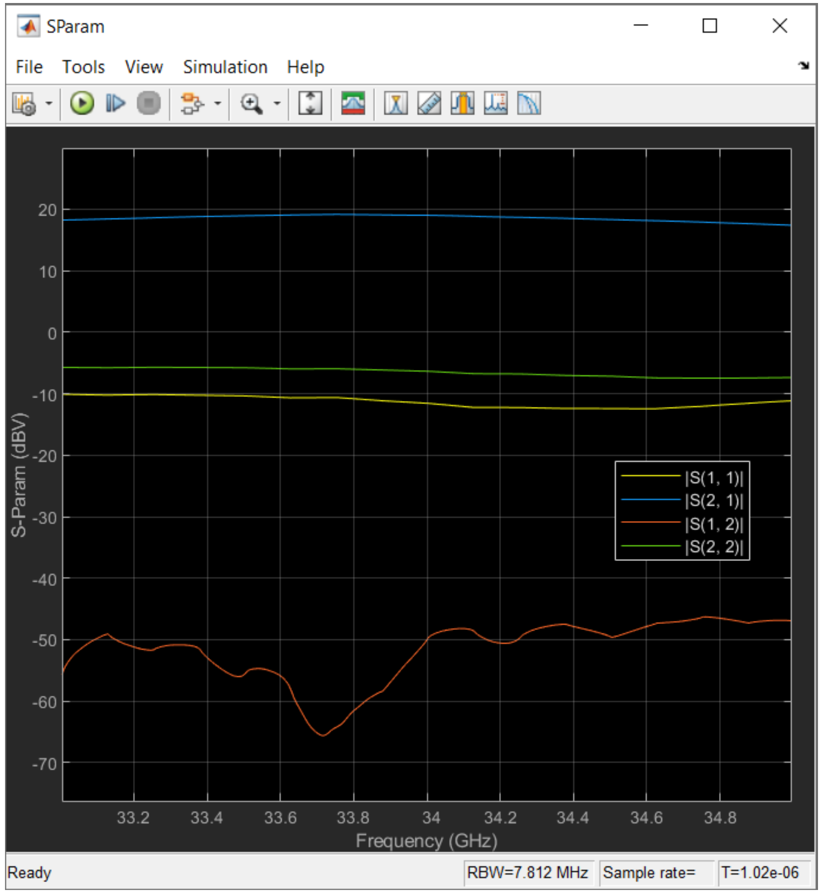
Nominal specs



Simulating RF Performance



From S-parameter simulation



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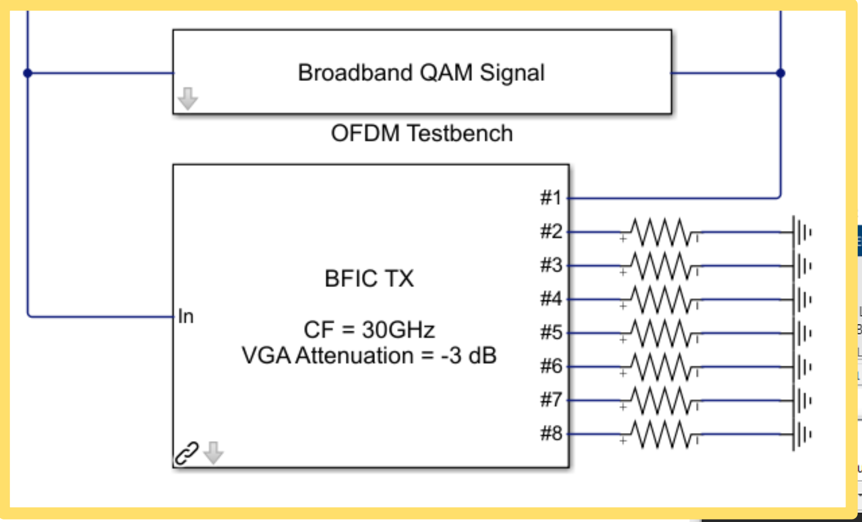
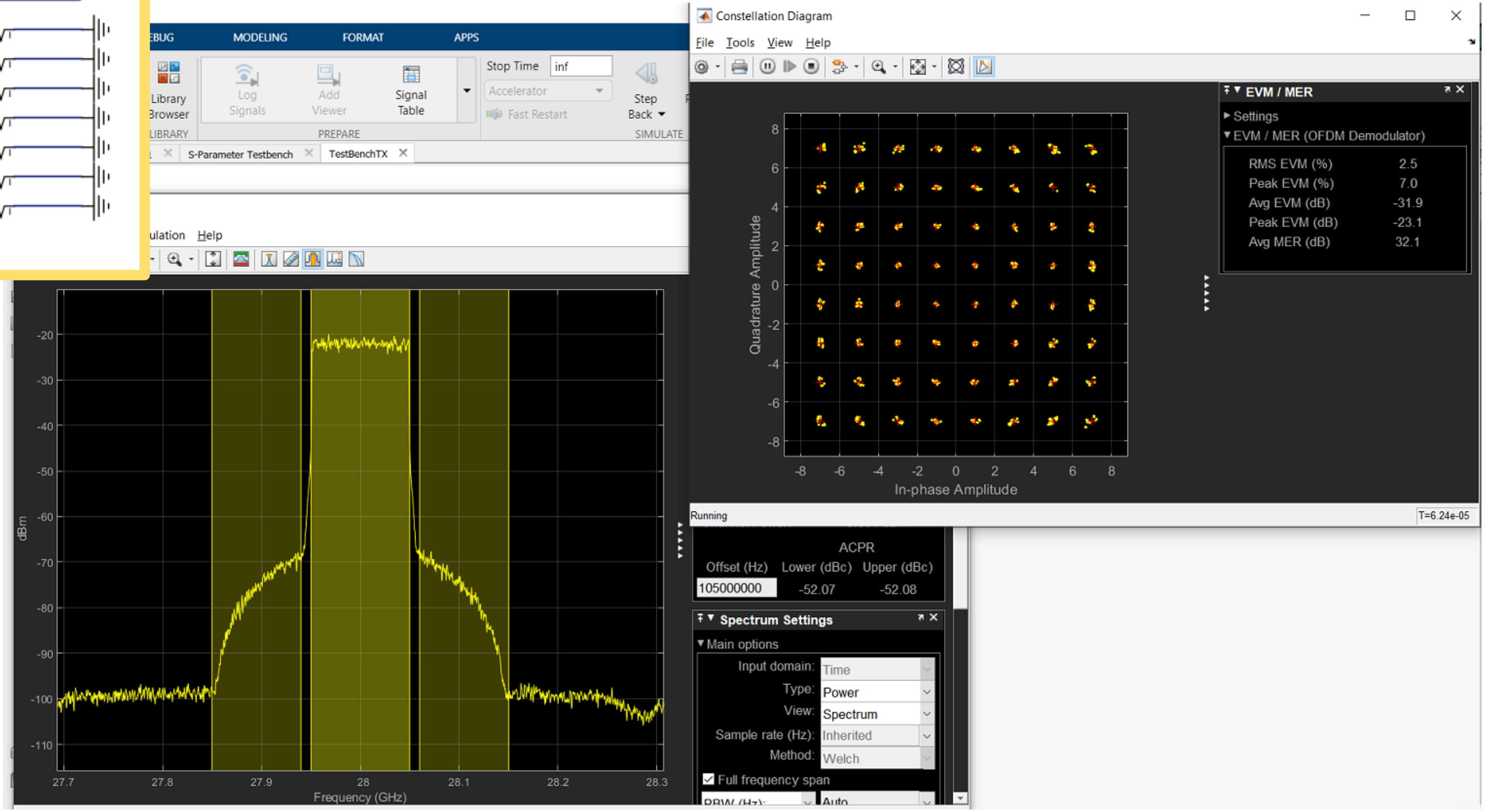
Transmitter Signal Integrity Modeling



100MHz OFDM ACLR

100MHz OFDM EVM



Extract key transmitter specs such as ACLR, noise floor, and EVM

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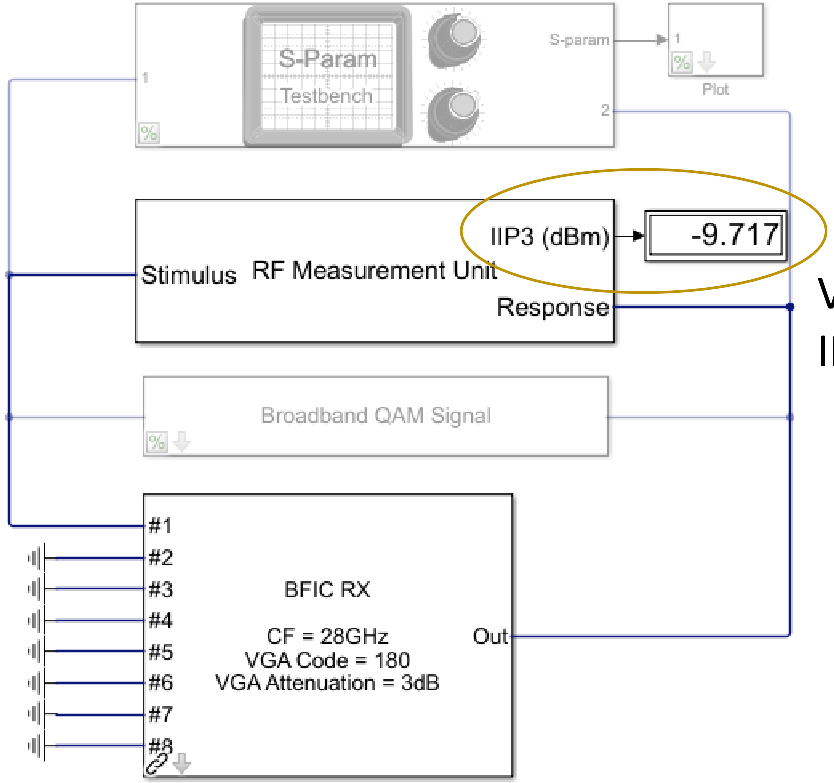
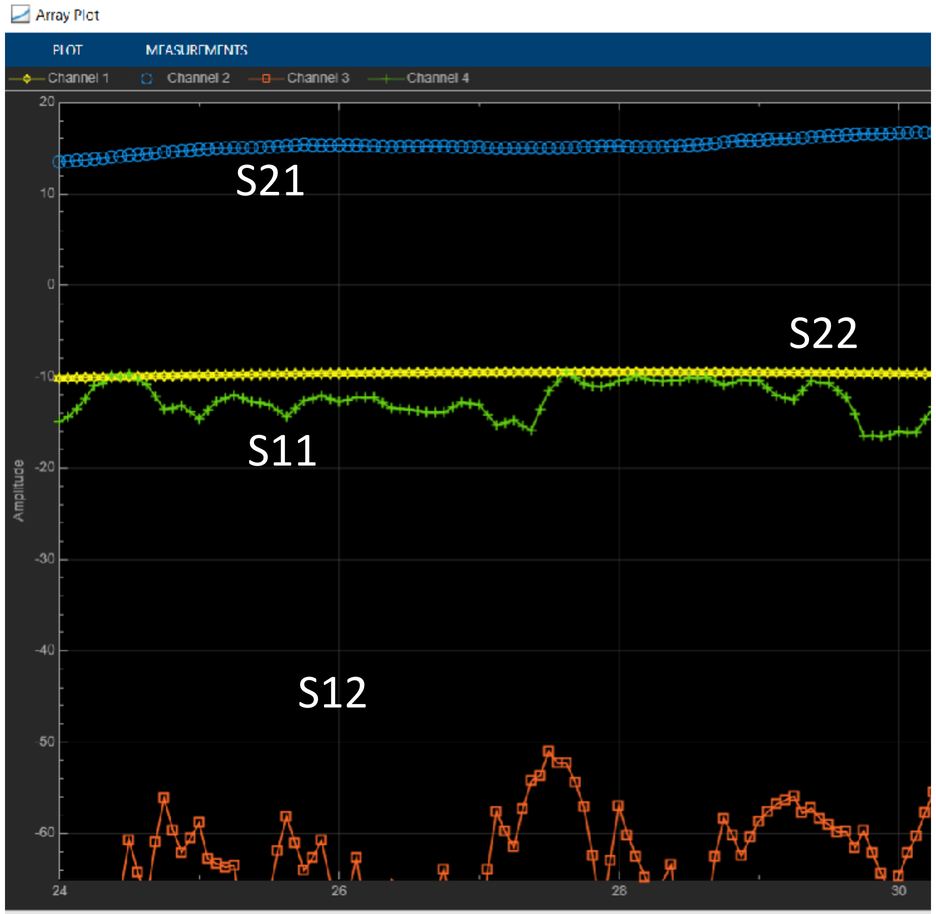
Beamformer Receiver Model: Performance Verification

RF Measurement Testbench
Only Uncomment One at the Time



Vs. Measured
IP3 at -9.7dBm

Single Channel S-parameter simulation results



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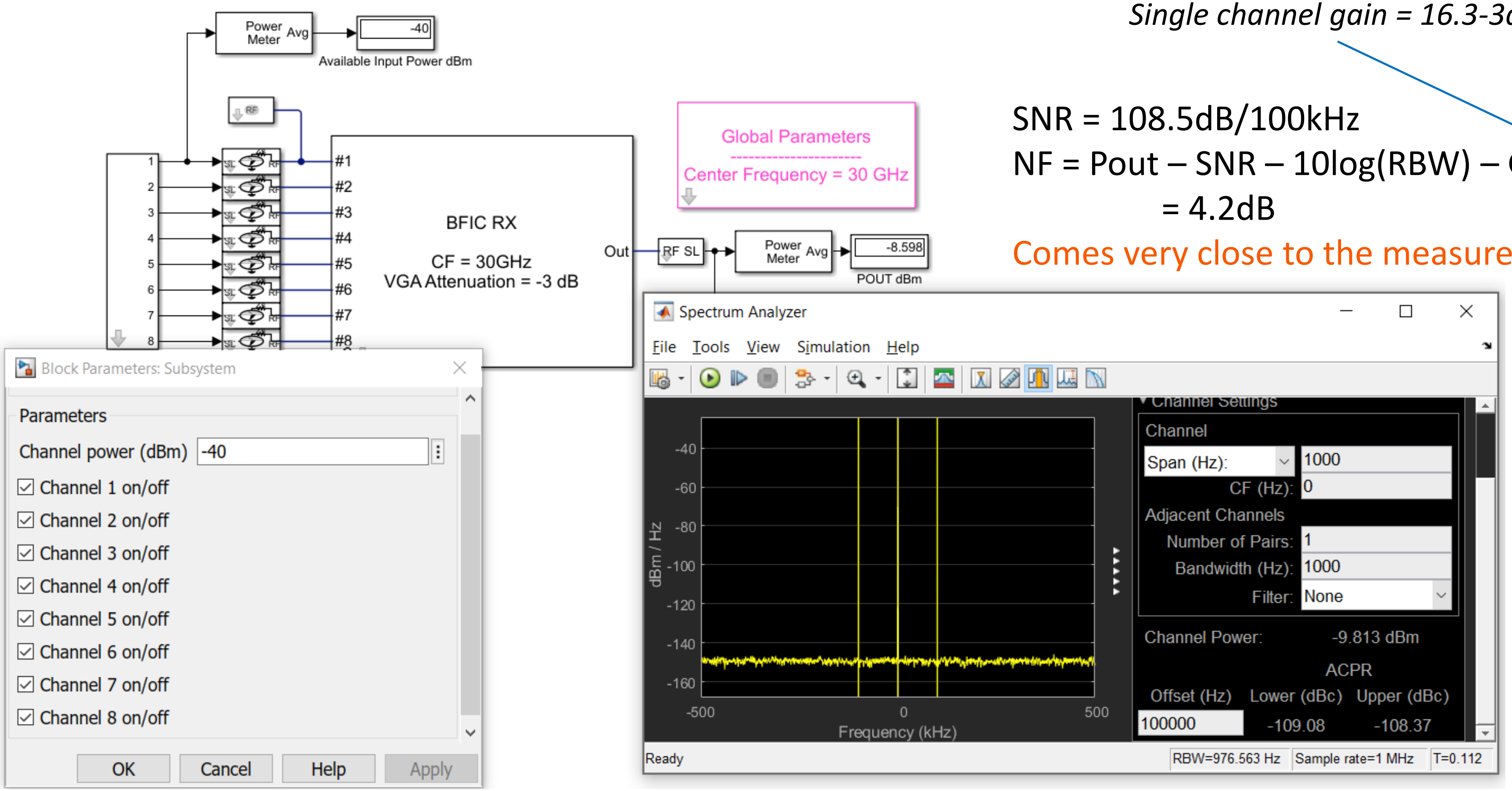
Beamformer Receiver Model: Check N:1 Gain and SNR as a Function of Active Channels



Single channel gain = 16.3-3dB

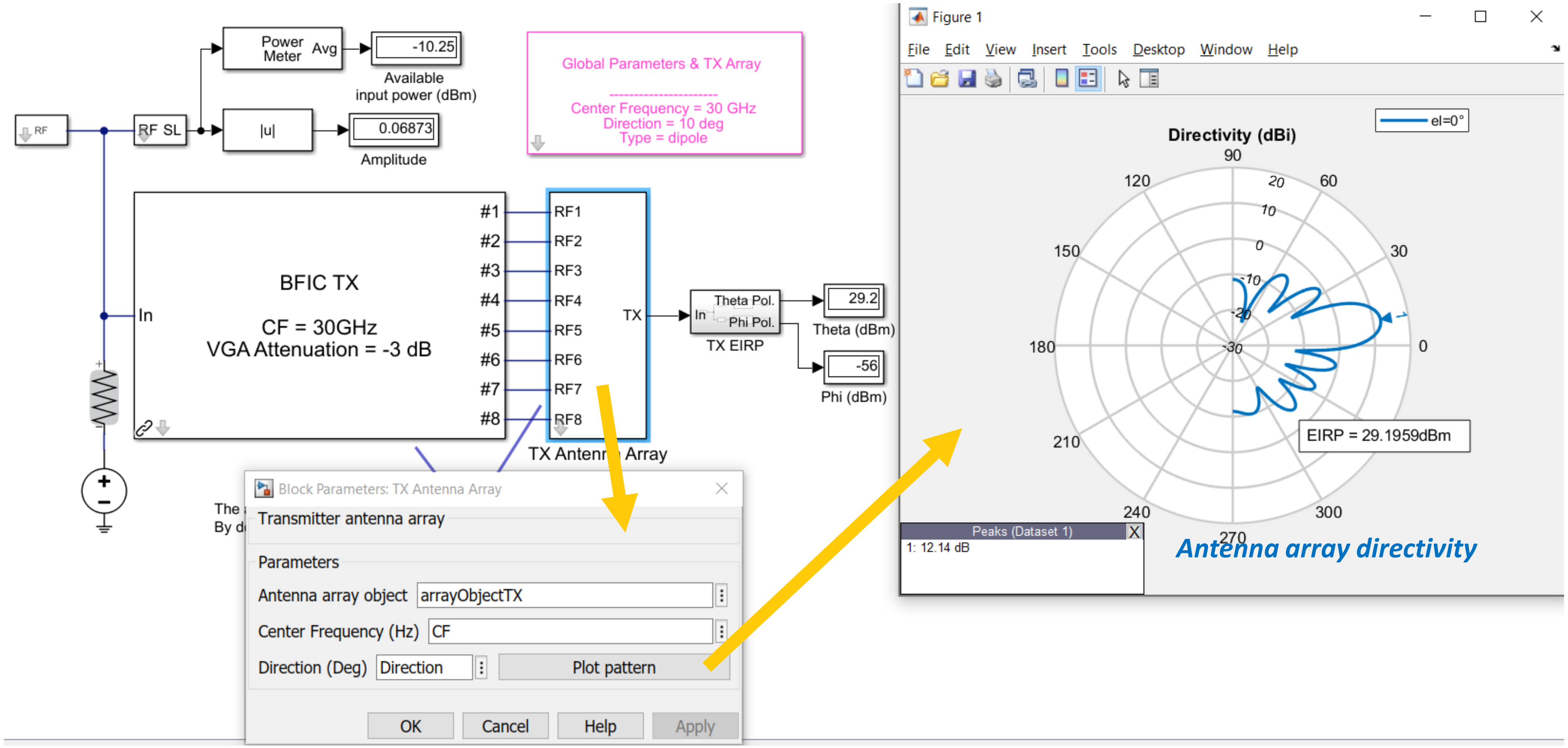
SNR = 108.5dB/100kHz

NF = Pout – SNR – 10log(RBW) – Gain – 10*Log(8) - Nth

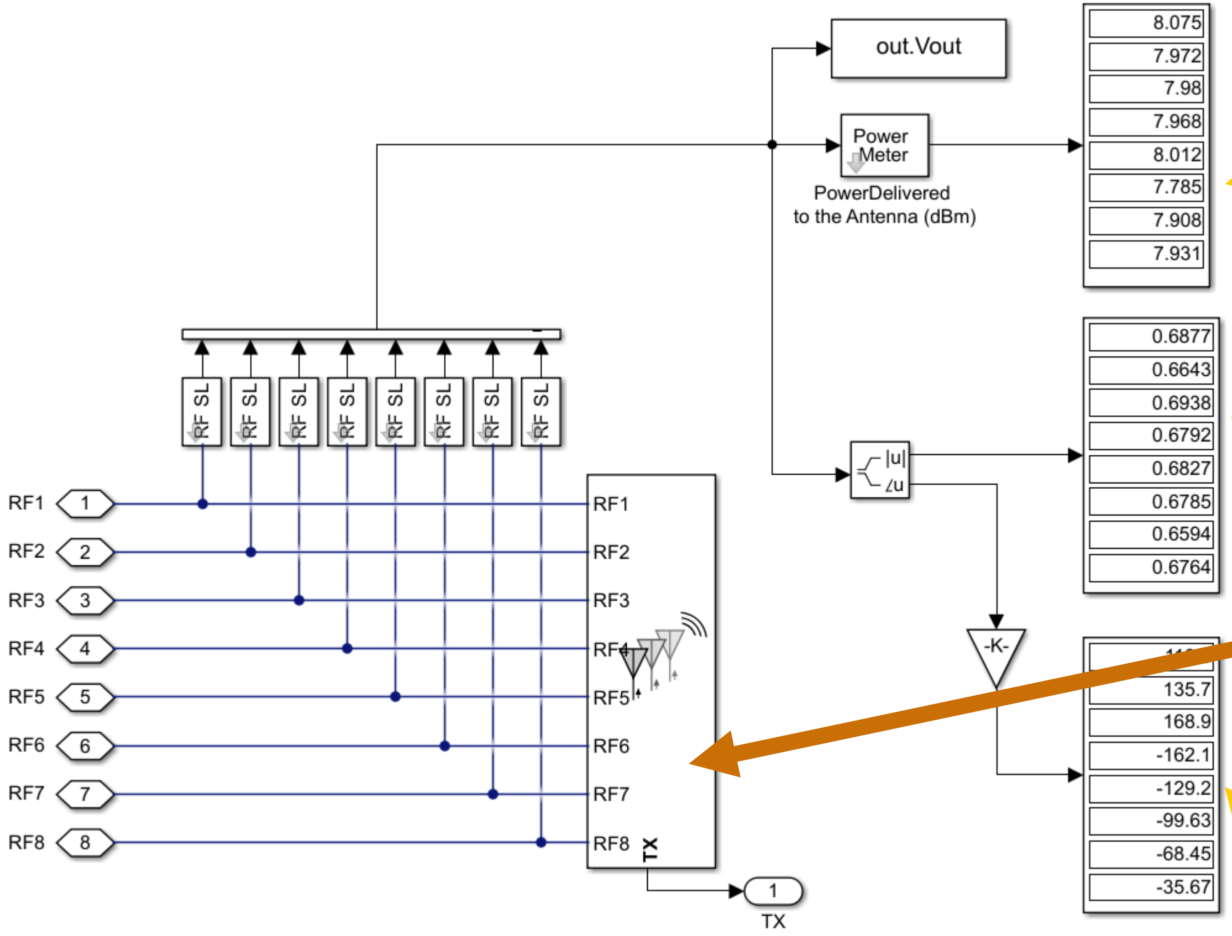
= 4.2dB

Comes very close to the measured value of 4.4dB!

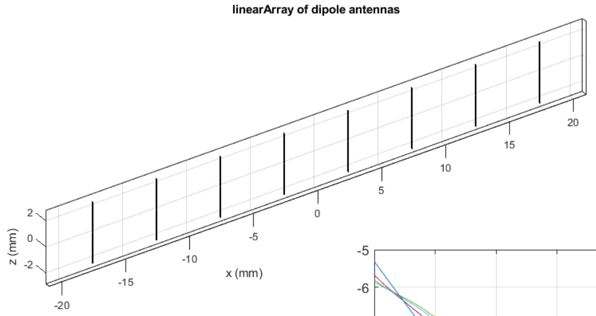
Now Attaching an Antenna Array Model



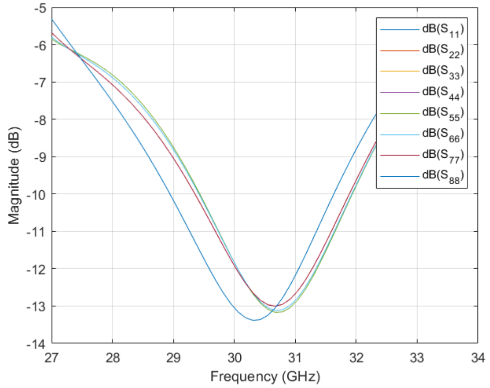
8-channel Antenna Array Model Details



BFIC output power level and linear amplitude levels for BFIC model loaded with dipole ULA with its S-parameters



Array Object



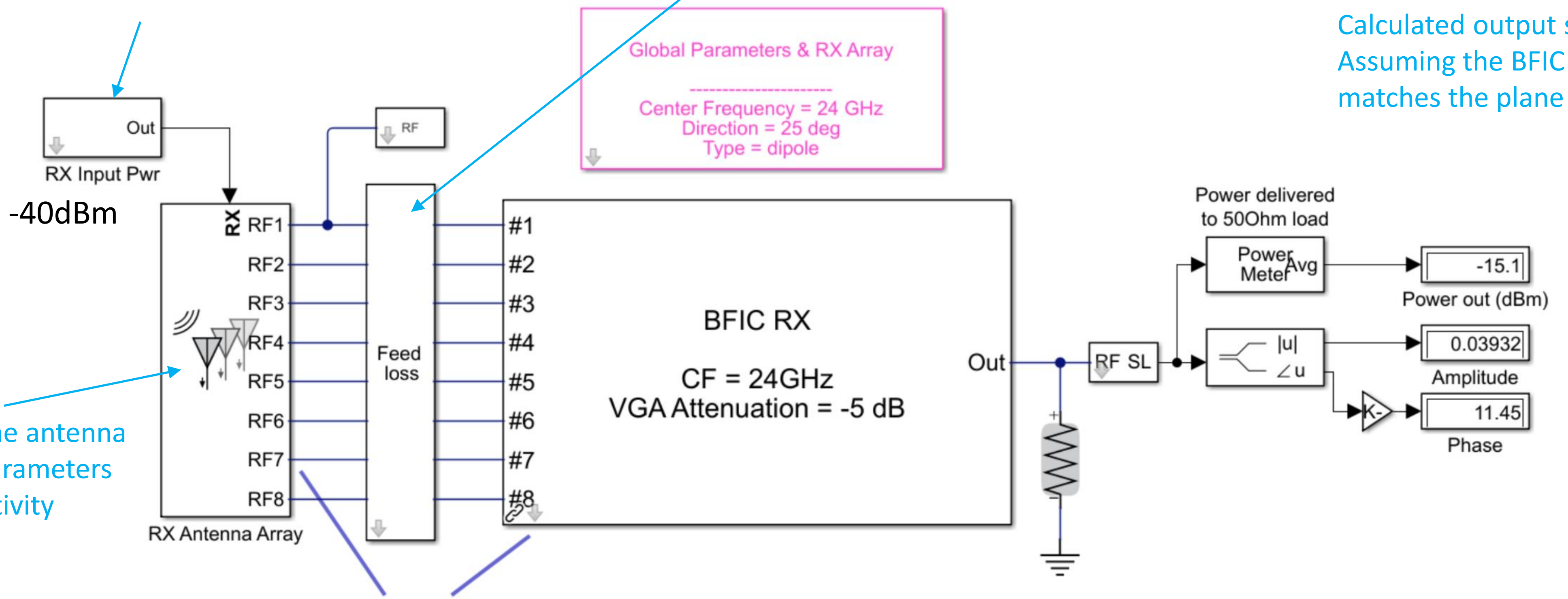
Phase weights for given steering angle

Beamformer Receiver Model: Phased Array Analysis with Dipole or Patch Antenna ULA

Generates feed current at the antenna Elements from far-field plane wave excitation at the specified direction angle

Programmable feed Loss to the RX BFIC

Calculated output signal level Assuming the BFIC steering angle matches the plane wave direction



Models the antenna array S-parameters and directivity

The antenna array is designed to resonate at CF (dipoles impedance ~70Ohm)
By default the direction of arrival and beamforming angle are the same

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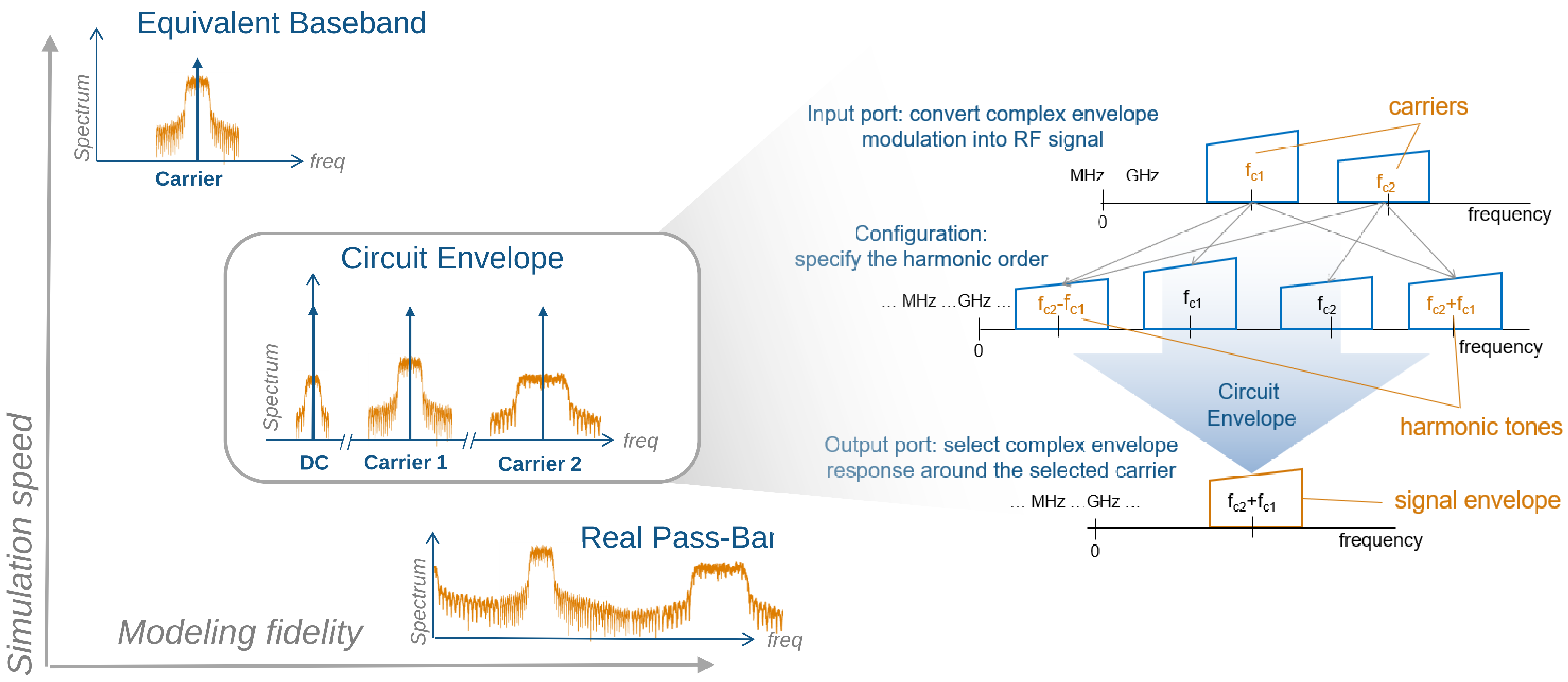
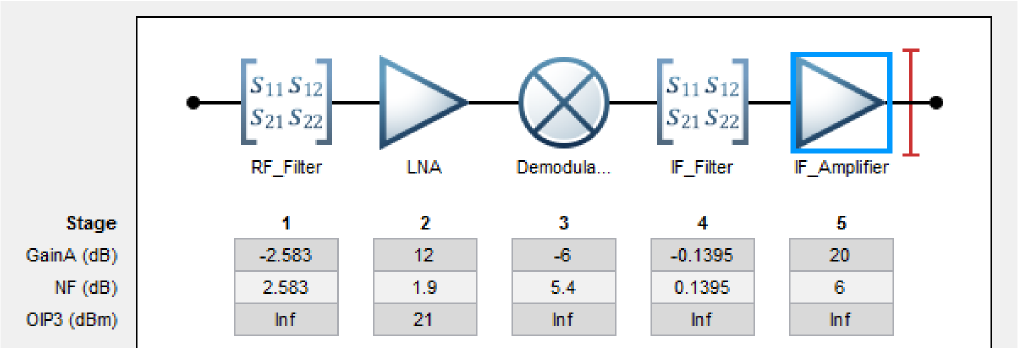
RF System Simulation with RF Blockset

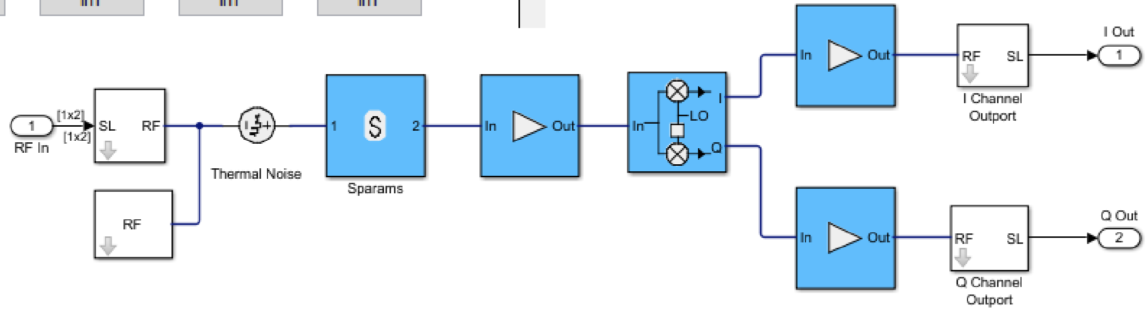


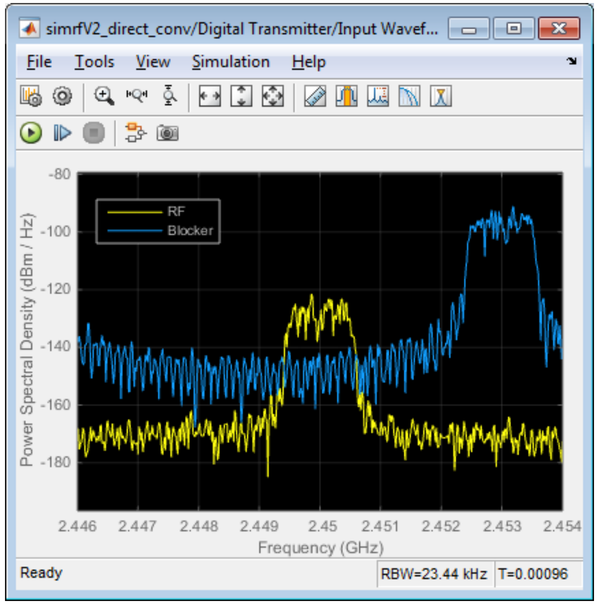
Trade Off Fidelity and Speed with System-Level RF Models

- Design the architecture and define the specs of the RF components
- Integrate RF front ends with adaptive algorithms such as DPD, AGC, beamforming
- Test and debug the implementation of the transceiver before going in the lab
- Use models and measured data to gain insights in your design
- Provide a model of the RF transceiver to your colleagues and customers

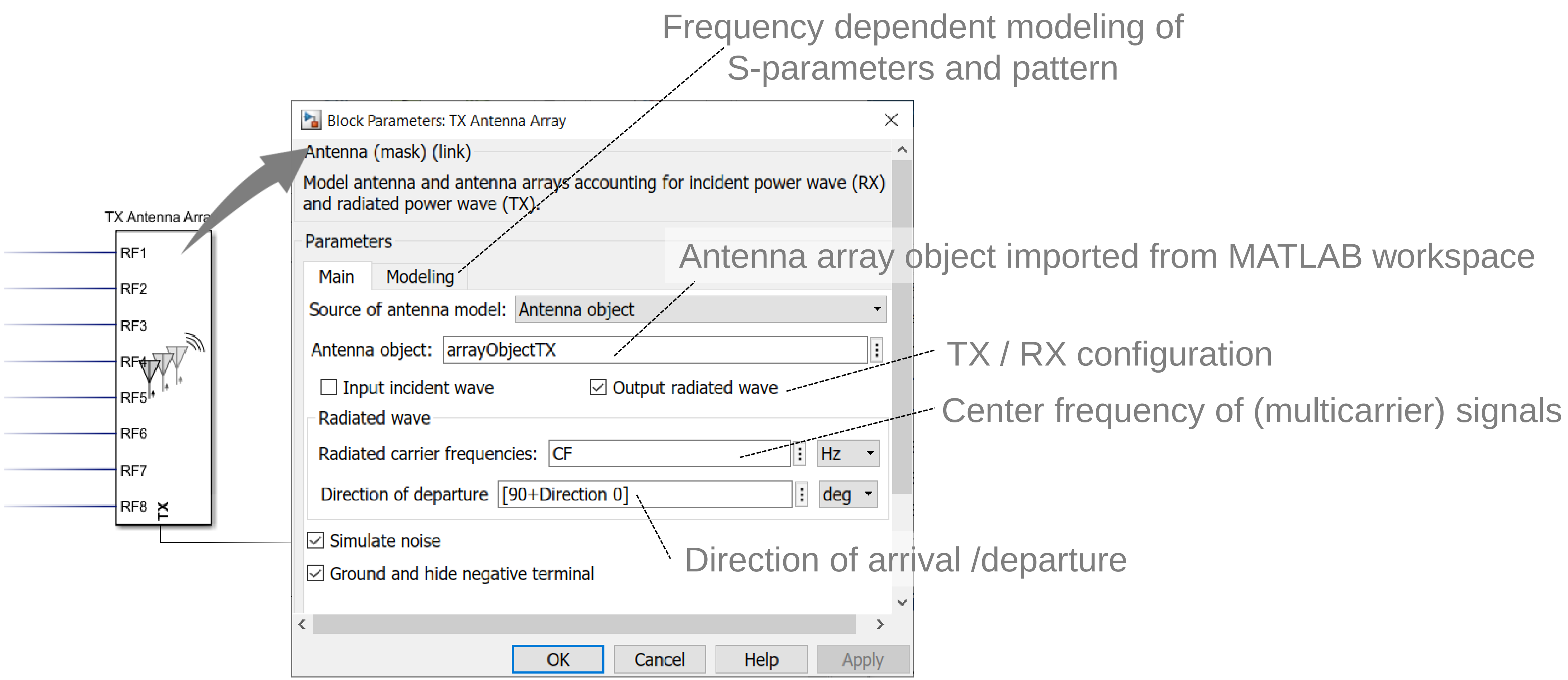


Stage	1	2	3	4	5
GainA (dB)	-2.583	12	-6	-0.1395	20
NF (dB)	2.583	1.9	5.4	0.1395	6
OIP3 (dBm)	Inf	21	Inf	Inf	Inf

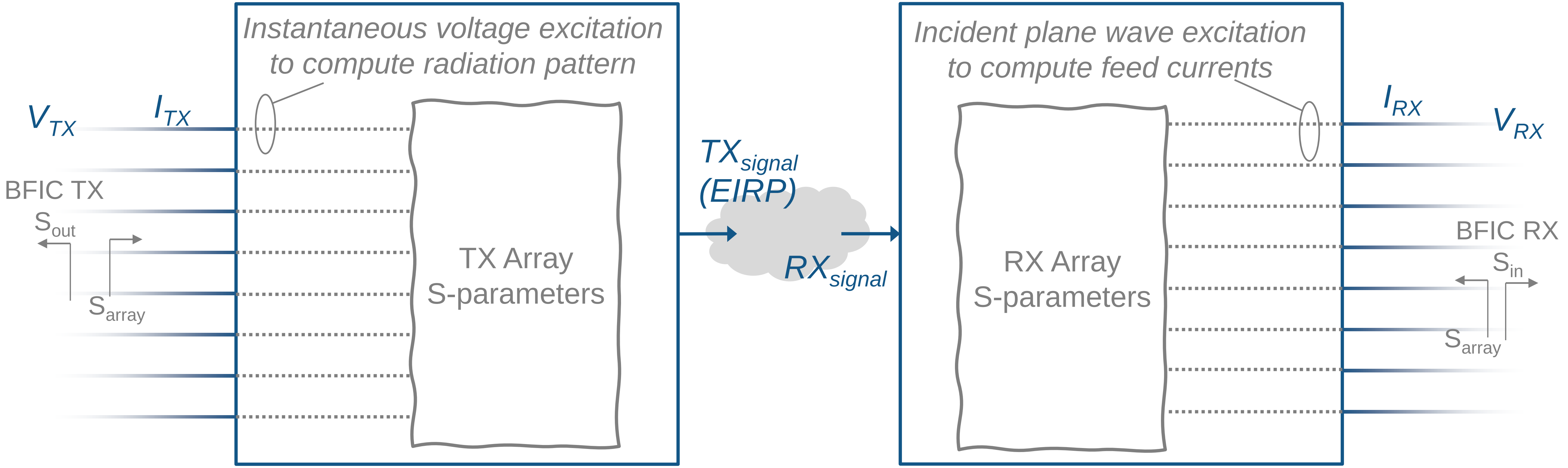




Antenna Array Modeling for RF System Simulation

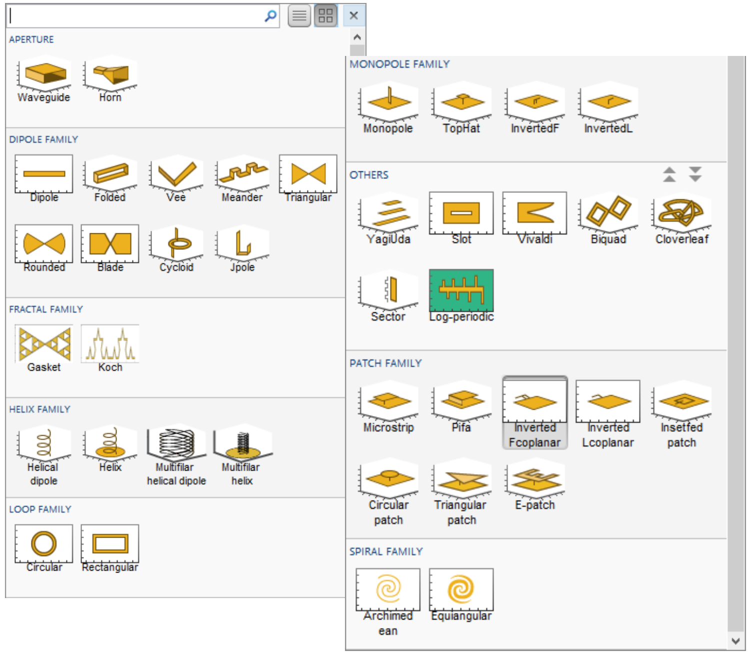


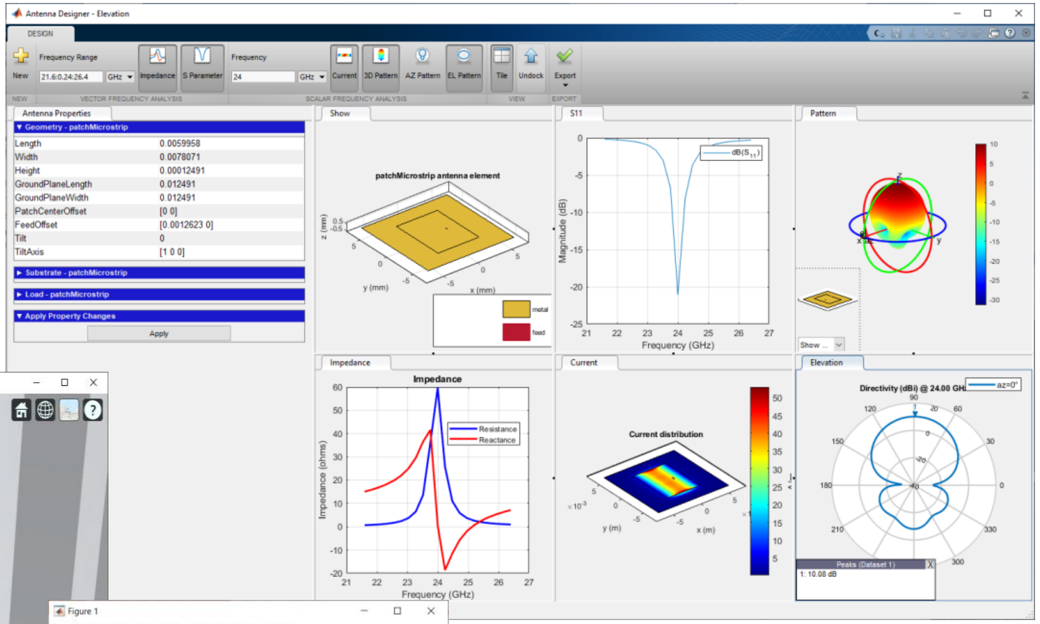
Behind the Scenes: Antenna Array Modeling for Simulation

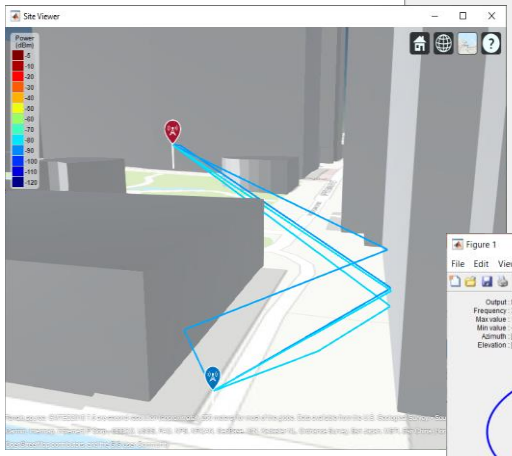


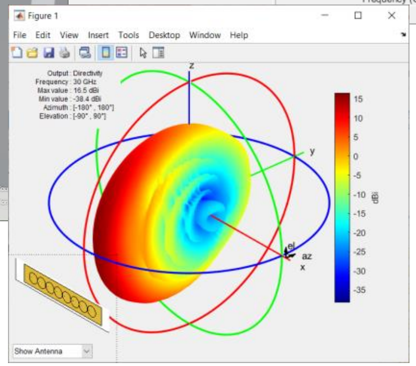
Design, Analyze, and Visualize Antennas

- Get started with antenna and array catalog and apps
- Perform full-wave EM simulation (Method of Moments)
- Improve the performance using surrogate optimization
- Design and fabricate PCBs with Gerber file generation
- Analyze the effects of installation on large platforms
- Include RF propagation effects



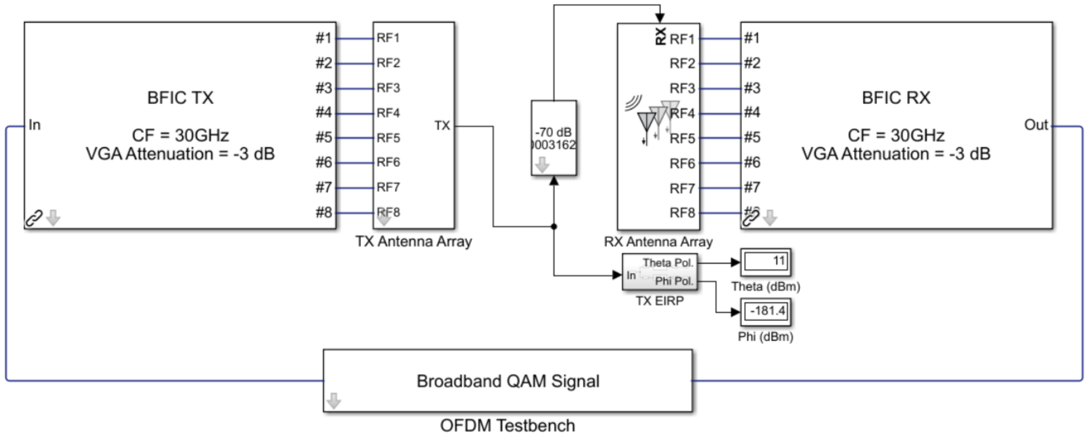


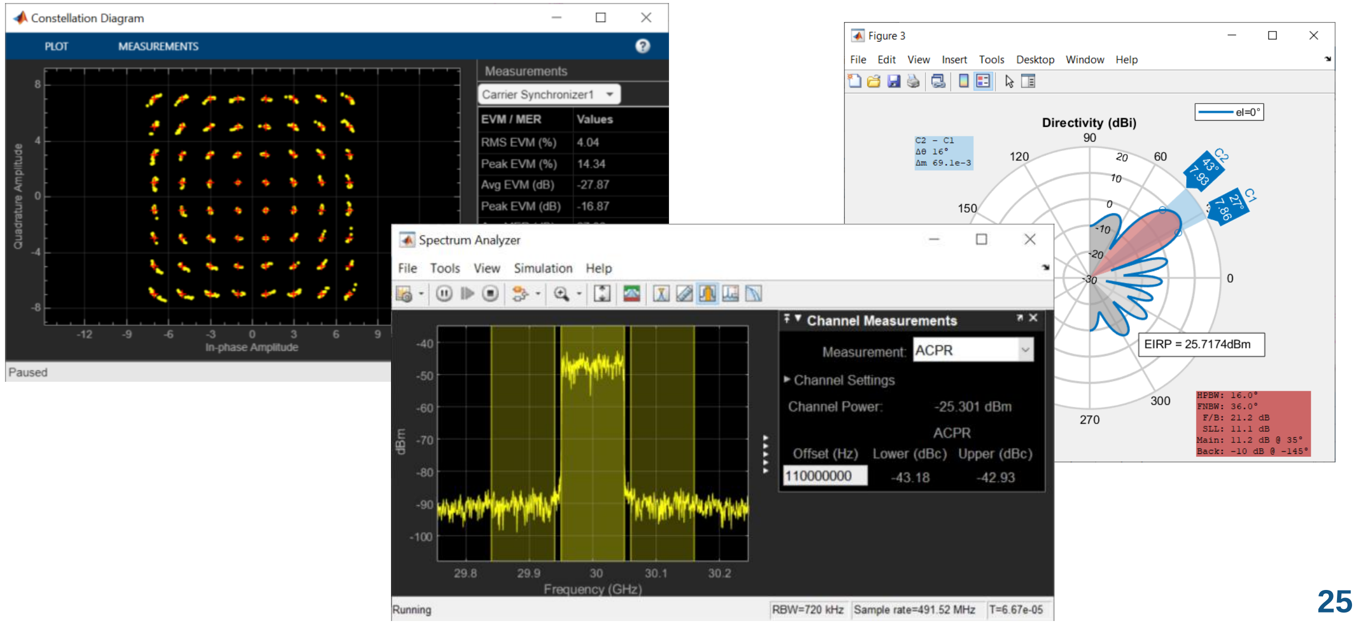




Summary

- BFIC models based on actual measurements and reproducing lab-results
- Testbenches for performance verification: gain, IP3, NF, S-parameters
- Integration with antenna arrays for beamforming applications
  - Full-wave EM analysis to compute impedance, pattern, polarization
- End-to-end simulation for system-level integration
  - Circuit envelope multi-carrier RF simulation for high-frequency and broadband applications





Practical Use Beyond These Example Testbenches

- **Build 2D array, combining multiple BFICs**
  - Combine the BFIC models to build a NxM phased array system

- **Ability to insert a custom antenna model**
  - It is possible to replace the current antenna object with a custom antenna design, from its S-parameter matrix and using it element’s directivity pattern

- **Complete the whole signal chain with the BFIC model as front-end circuit**
  - Attach a transceiver model for the up and down conversion to baseband
  - Build a TX-to-RX system to extract link budget and signal quality at the target receiver

For Follow-Up and Contact Information

- For model inquiries, please email Otava at hello@otavainc.com
- Or fill out a request form at https://www.otavainc.com/products/otbf103

- Learn more about RF Blockset and Antenna Toolbox:
  - https://www.mathworks.com/products/rf-blockset.html
  - https://www.mathworks.com/products/antenna.html