# IEEE IMS 2022 RF BOOT CAMP

# RFMW Application Focus

Bryan Goldstein



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# Abstract

This session will follow the development of a microwave Transmit/Receive system, from concept to production. We will show how the system-level performance and environmental requirements drive the electrical and mechanical design specifications, packaging approach and materials selection. We will demonstrate modeling/simulation approaches from the device to the system level for both electrical and mechanical aspects and we will describe bread-boarding strategies to affirm simulation models and to minimize risk. Lastly, we will demonstrate production test strategies and methodologies to guarantee performance compliance of the deliverable product.


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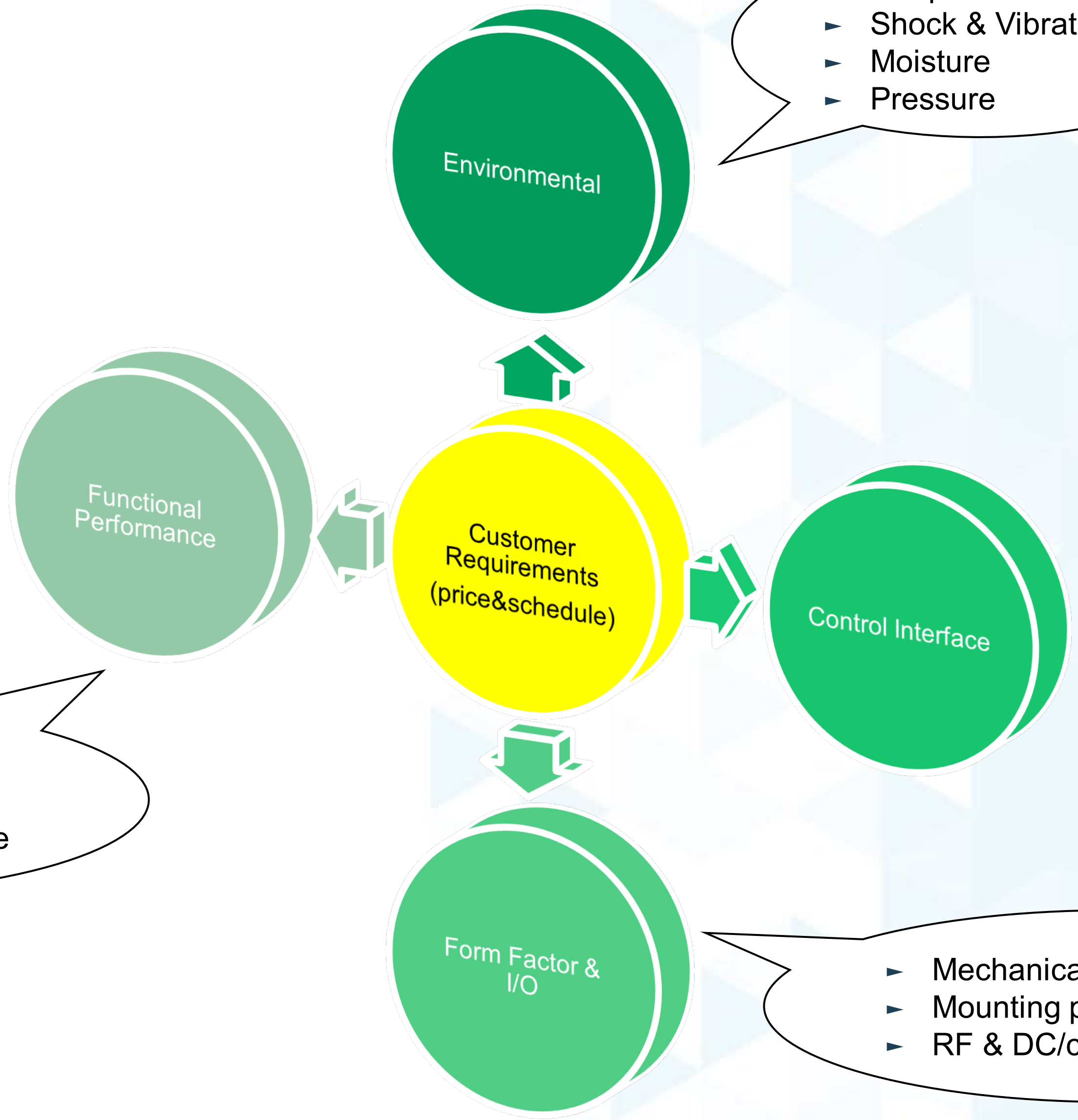
# Start With Product Requirements!




- Temperature
- Shock & Vibration
- Moisture
- Pressure

- Customer defined control protocol
- i.e. I2C, SPI, ENET

- RF requirements often drive…
- Digital, Power, and Software

- Mechanical outline: LxWxH
- Mounting provisions
- RF & DC/control connectors

# The Development Journey from Idea to Product

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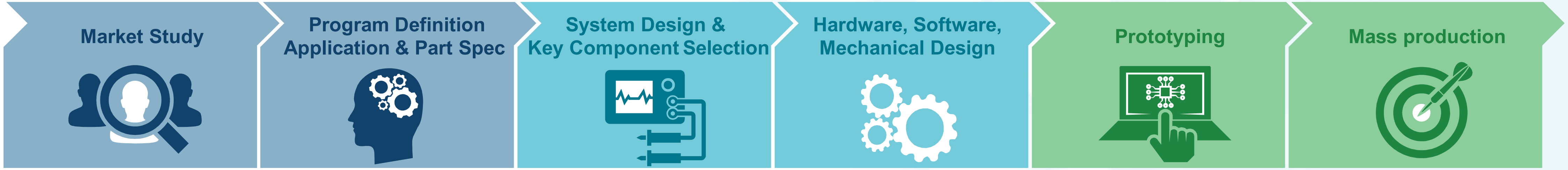


**Prioritizing Needs**

- Collecting market input
- Reviewing competition
- High-level system specs

**Concept Phase**

- Defining architecture and partitioning
- Sub-system specifications
    - HW/SW &data/control paths
- List of critical system components
- Market survey of possible solution

**Proposal**

- Part evaluation to meet spec & cost
- Finalizing specifications (HW/SW)
- Make critical system component choices

**Solution Development**

- System/board/firmware/software
- Problem and issue mitigation

**Validation**

- Engineering samples
- Software deliverables
- Debugging
- Field trials
- Market feedback

**Implementation**

- Qualification and production start
- After action review including suppliers


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# How ADI can Assist with your Product Development Journey

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Market Study → Program Definition Application & Part Spec → System Design & Key Component Selection → Hardware, Software, Mechanical Design → Prototyping → Mass production

**Prioritizing Needs** → **Concept Phase** → **Proposal** → **Solution Development** → **Validation** → **Implementation**

**Prioritizing Needs**
- Understand your needs
- Educate (talks, webinars)
- Collateral (datasheets)

**Concept Phase**
- Understand requirements
- Recommend (or initiate new) solution
- Provide Reference Designs

**Proposal**
- Early samples and Evaluation Tools
- Simulation models

**Solution Development**
- Development tools / drivers
- Problem and issue mitigation
- Provide data, access to ADI team
- Create new SW features

**Validation**
- Pre-release samples
- Test development
- Evaluation data
- Qualification data

**Implementation**
- Lifetime product support with clear contacts
- Cost improvement roadmap
- Prompt FA and transparent communication
- Inventory management


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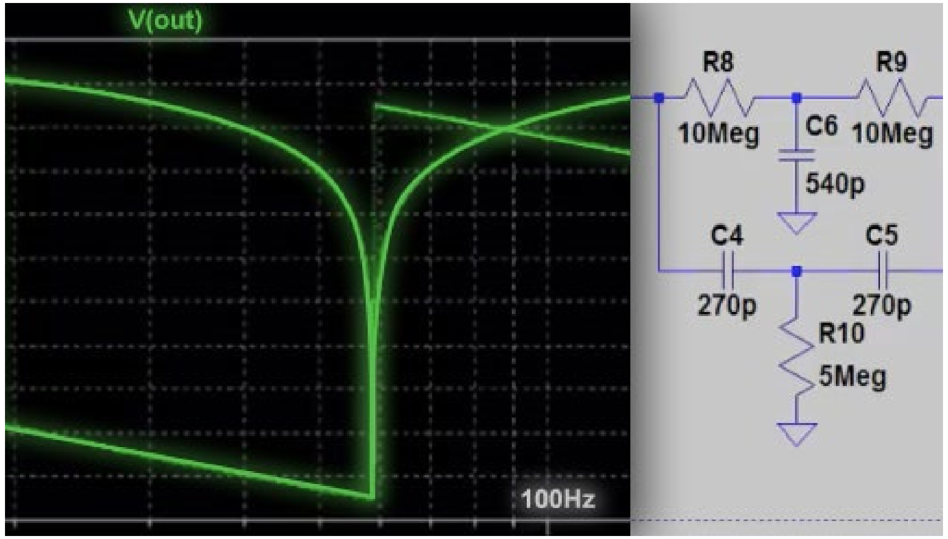
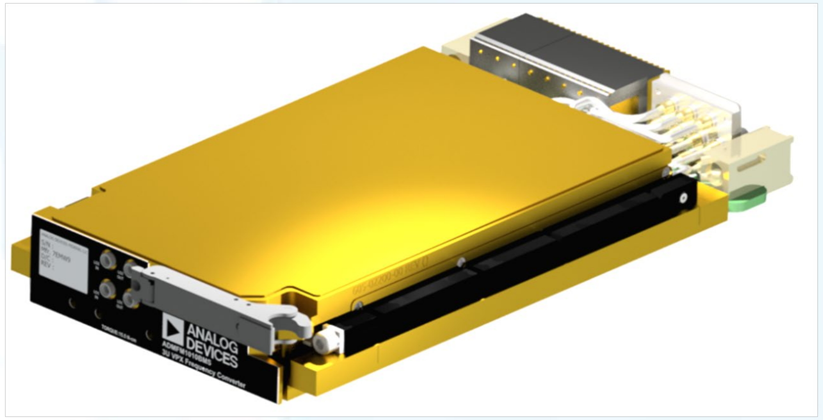
# An Important Decision – Design vs. Buy



- Ground Up Design
- Complete Design Freedom
- Simulation, Circuit Design, Fabrication, Assembly, Debug, Mechanical Design, Qualification

- Off the shelf Module
- Qualified Design & Performance Ready to Go
- Take it Leave Functionality
- Form Factor Restrictions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# Electrical Design - From Architecture to Block Diagram to Schematic to Layout

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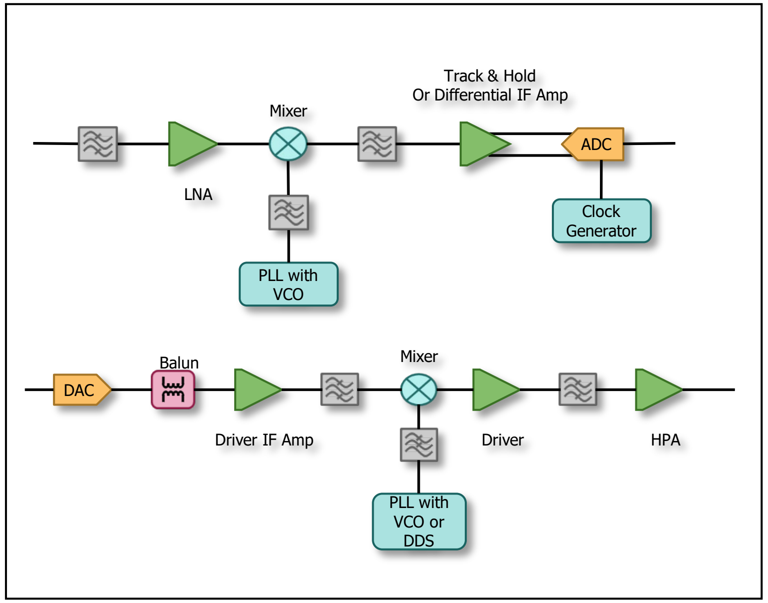
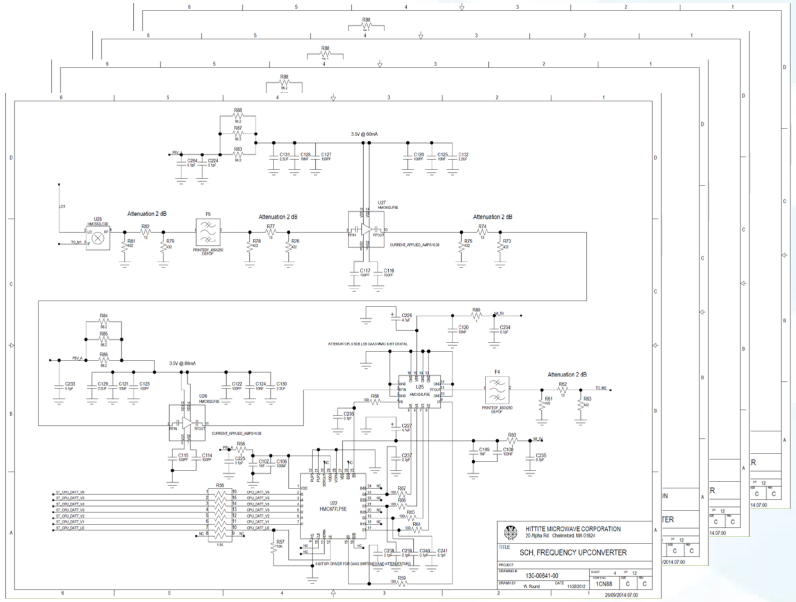
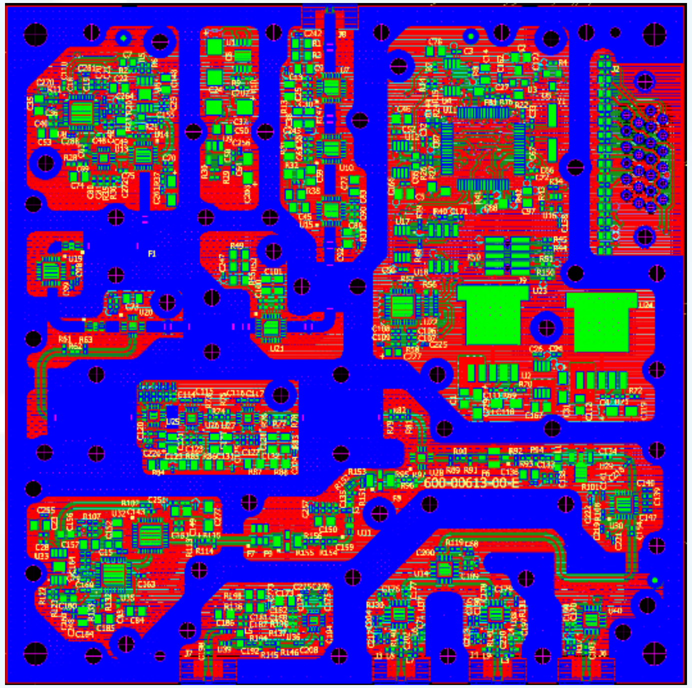



Parts List/BOM (55)

Export | Reports | Configuration: [Base] | Create/Modify

| Item | Part Number | Qty | UOM | Refdes | Find | Description | Rev |
|---|---|---|---|---|---|---|---|
| 1 | 120-00146-00 | 0 | REF | | | AD, HMC7053 FREQUENCY UPCONVERTER | K |
| 2 | 165-00734-00 | 0 | REF | | | ATP, HMC7053 FREQUENCY UPCONVERTER | G |
| 3 | 130-00641-00 | 0 | REF | | | SCH, FREQUENCY UPCONVERTER | C |
| 4 | 155-00302-00 | 0 | REF | | | PC, HMC7053 FREQUENCY UPCONVERTER | K |
| 5 | 605-00409-00 | 1 | EA | | | MCH, BASEPLATE, FREQUENCY UPCONVERTER, HMC7053 | C |
| 6 | 090-01723-00 | 1 | EA | | | LM COVER ASSY UPCONVERTER HMC7053 | B |
| 7 | 090-01080-00 | 1 | EA | | | LM, PWA, FREQUENCY UPCONVERTER | E |
| 8 | 165-00736-00 | 0 | REF | | | PRO, HMC7053, TEST AND TUNE PROCEDURE | B |
| 9 | 195-00344-17 | 1 | EA | F1 | | FILTERS 30GHZ 10 MIL ALUMINA LO2 BPF NOM | B |
| 10 | 195-00344-11 | 2 | EA | F2-F3 | | FILTERS 30GHZ, 10 MIL ALUMINA, BW3 NOM | B |
| 11 | 195-00342-02 | 2 | EA | F4-F5 | | 8GHZ HAIRPIN BPF, 15 MIL ALUMINA, BW1 NOM | A |
| 12 | 480-HMC652-00 | 7 | EA | P1-P3,P5,P7-P9 | | Wideband Fixed Attenuator, DC - 50GHz, 2dB | 1 |
| 13 | 105058-004 | 1 | A/R | | | GOLD RIBBON, 3.0X0.5 MIL | 1 |
| 16 | 610-00325-00 | 13 | EA | | | SCR SHC SK 2-56 .188L SS PV MS LP | |
| 17 | 610-00328-00 | 2 | EA | | | SCR SHC SK 2-56 .375L SS PV MS LP | |
| 18 | 610-00036-00 | 19 | EA | | | WSH FLT #2 .089 .149 .016 SS PV NS DFARS | 3 |
| 19 | 610-00384-00 | 44 | EA | | | SCR SCR F82 CR 2-56 .438L SS PV MS LP | |
| 20 | 620-00123-00 | 2 | EA | | | SCD, EPOXY PREFORM, F2-F3, .240 X .100, HMC7053 | B |
| 21 | 620-00124-00 | 2 | EA | | | SCD, EPOXY PREFORM, F4-F5, .440 X .240, HMC7053 | B |
| 23 | 107503-004 | 1 | A/R | | | EPOXY, ELEC COND, ABLEBOND 84-1LMIT1, MIL-STD-883, METHOD 5011 CERTIFIED | 1 |
| 24 | 620-00001-00 | 1 | A/R | | | RTV, MIL-A-46146, DOW CORNING 3145 GRAY | 2 |
| 25 | 620-00002-00 | 1 | A/R | | | PRIMER, CLEAR, DOW CORNING 1200 OS | 1 |
| 26 | 605-02641-00 | 0 | REF | | | MCH, COVER, PRESSBD UPCONVERTER HMC7053 | 2 |
| 27 | 620-00129-00 | 1 | EA | | | SCD, EPOXY PREFORM, F1, .270 X .100, HMC7053 | B |



Block Diagram → Schematic & BOM → Layout

# Developing a Software Strategy

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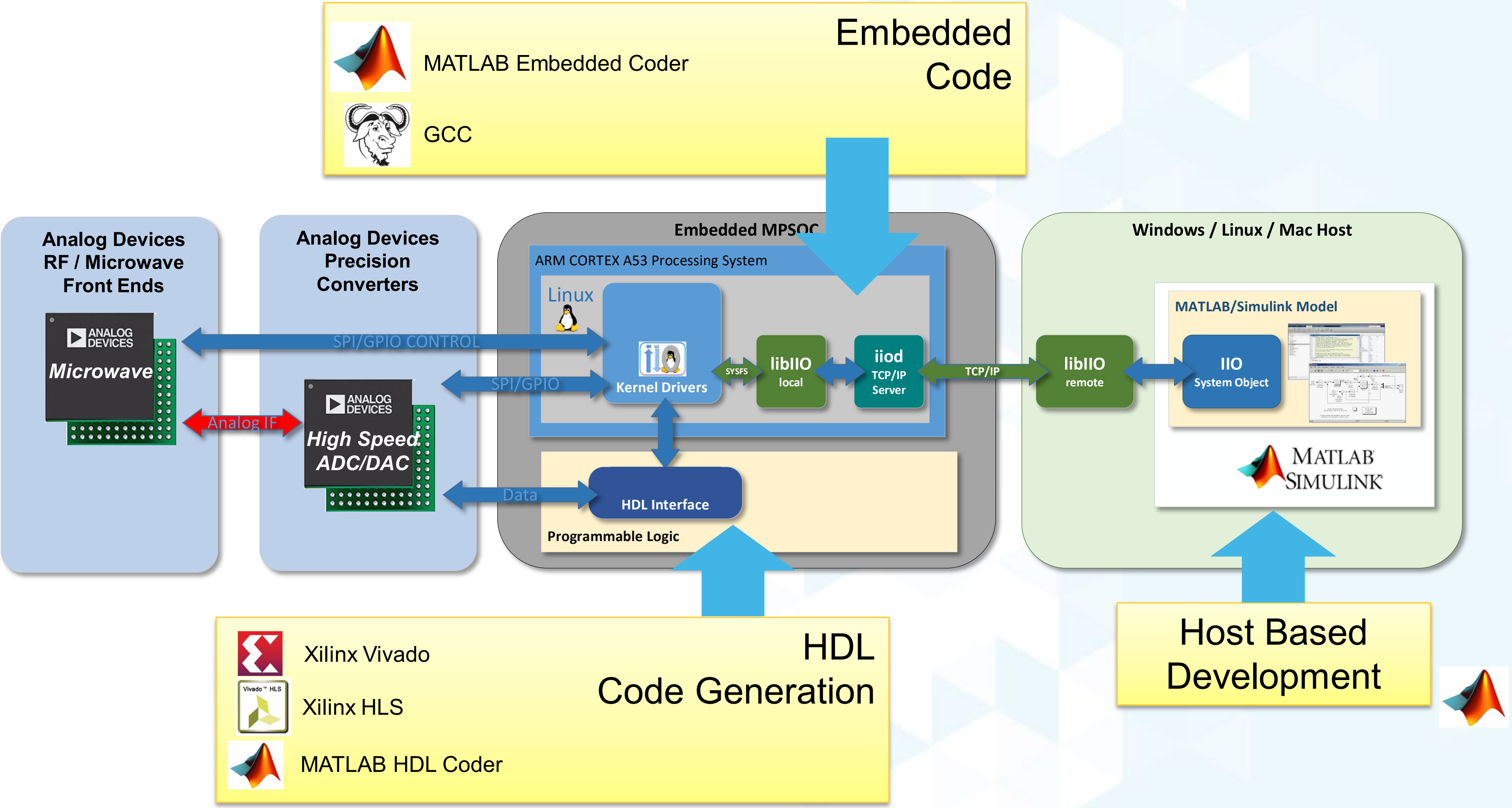



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# Simulation


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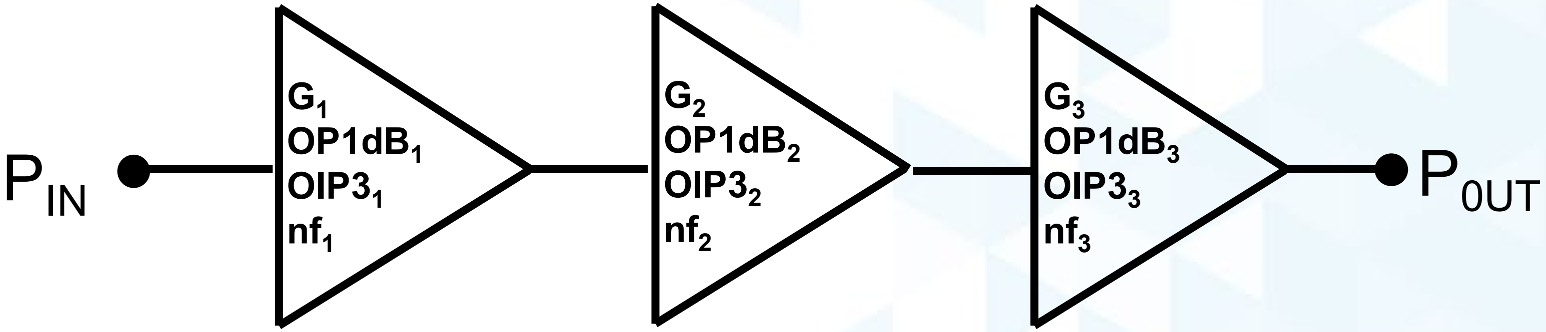
# Four Equations to Rule Them All!

(a universal set of equations that applies to every component in the signal chain)



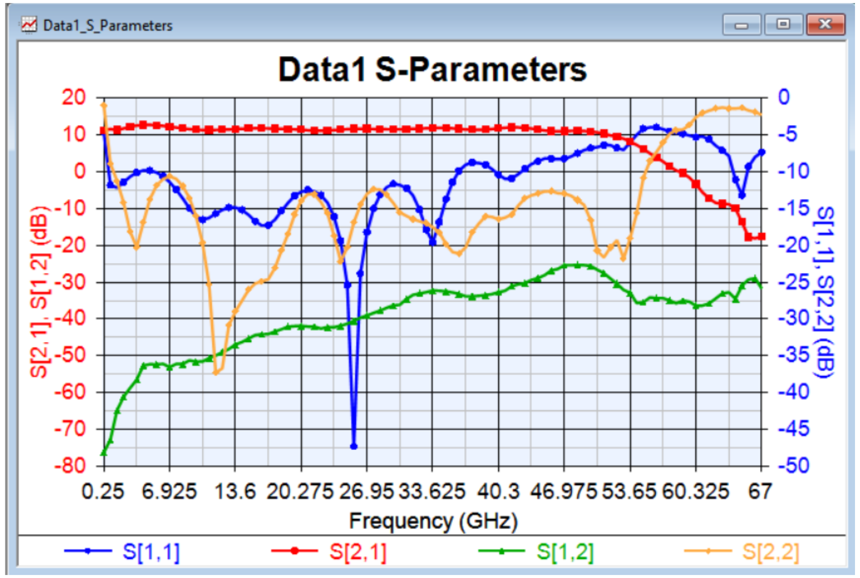

$$G = G1 \times G2 \times G3$$

$$\frac{1}{\mathrm{OIP3}} = \frac{1}{(\mathrm{OIP3}_1 \times \mathrm{G2} \times \mathrm{G3})} + \frac{1}{(\mathrm{OIP3}_2 \times \mathrm{G3})} + \frac{1}{(\mathrm{OIP3}_3)}$$

$$\frac{1}{\mathrm{OP1dB}} = \frac{1}{(\mathrm{OP1dB}_1 \times \mathrm{G2} \times \mathrm{G3})} + \frac{1}{(\mathrm{OP1dB}_2 \times \mathrm{G3})} + \frac{1}{(\mathrm{OP1dB}_3)}$$

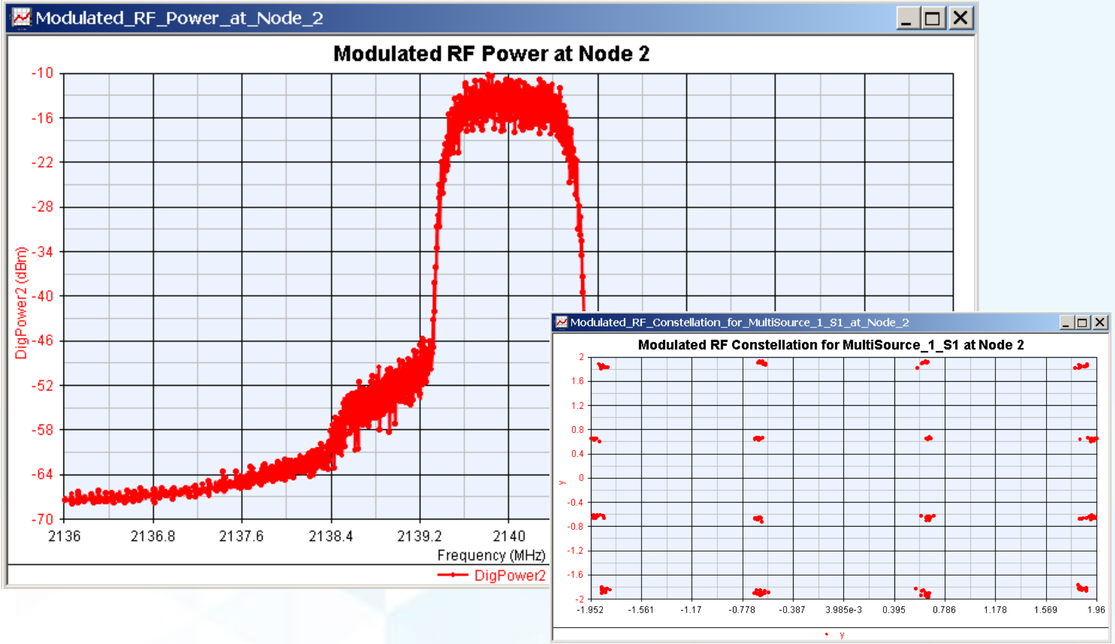
$$\mathrm{nf} = \mathrm{nf}_1 + \frac{\mathrm{nf}_2 - 1}{(G1)} + \frac{\mathrm{nf}_3 - 1}{(G1 \times G2)}$$

# Linear vs. Non-Linear Simulation




```
! Analog Devices
! AD8354 RF Gain Block
! These data are intended to be used for performance analysis of the AD8354.
! These data represent the typical performance of the AD8354.  No performance guarantees are expressed or implied by
! these data.
! "All magnitudes are expressed in decibels, all angles are expressed in degrees, frequency expressed in Hz."
! VPOS = 2.7 V
#       HZ      S       DB      R       50
!
!Freq          S11Mag        S11Angle      S21Mag        S21Angle      S12Mag        S12Angle      S22Mag        S22Angle
50000000       -23.87698712  147.7256851   16.59355889   41.63798537   -33.22036621  44.46158355   -4.568674786  135.8691532
99500000       -31.77469785  87.54310022   18.31725182   20.2535882    -31.48121677  24.47200564   -8.932488918  109.4881559
149000000      -31.8172713   68.42492935   18.84712798   9.252110754   -31.04363911  15.36743729   -12.43311688  95.74935668
198500000      -33.65493611  62.80619473   19.1203411    1.687599301   -30.88855212  10.38882606   -15.27832937  86.27556992
248000000      -27.75595284  33.64638359   19.30414098   -4.358865627  -30.66866418  6.956094946   -17.63684947  79.64427076
297500000      -34.08989266  18.32029828   19.4817902    -9.94402412   -30.13764797  0.498063021   -19.20428978  70.90158408
347000000      -26.54331425  44.81458446   19.46760586   -15.31887698  -31.52045761  -5.123001925  -21.85788815  58.61725984
```

- S-Parameters




| !TEST CONDITIONS: Vd = 5.0V; Id = 104mA; Temperature = 25degC | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Freq | Gain | Noise Figu | OP1dB | RISO | OIP3 | S11m | S11a | S22m | S22a |
| (MHz) | (dB) | (dB) | (dBm) | (dB) | (dBm) | (dB20) | (deg) | (dB20) | (deg) |
| 400 | 17.6 | 4.4 | 25.4 | -32.5 | 42 | -1.4 | 179.5 | -3.5 | 176.1 |
| 450 | 18.4 | 4.4 | 25.4 | -32.2 | 42 | -1.4 | 176.9 | -3.6 | 175.7 |
| 500 | 18.5 | 4.4 | 25.4 | -32 | 42 | -1.4 | 174.6 | -3.7 | 175.3 |
| 550 | 17.8 | 4.4 | 25.4 | -31.8 | 42 | -1.4 | 172.7 | -3.9 | 175 |
| 600 | 17.5 | 4.4 | 25.4 | -31.7 | 42 | -1.5 | 170.9 | -4 | 174.9 |
| 650 | 17.5 | 4.4 | 25.4 | -31.5 | 42 | -1.6 | 169.3 | -4.1 | 174.7 |
| 700 | 17.2 | 4.4 | 25.4 | -31.4 | 42 | -1.6 | 167.9 | -4.2 | 174.7 |
| 750 | 17.2 | 4.4 | 25.4 | -31.3 | 42 | -1.7 | 166.4 | -4.3 | 174.8 |
| 800 | 16.9 | 4.4 | 25.4 | -31.1 | 42 | -1.8 | 165 | -4.4 | 174.9 |
| 820 | 16.9 | 4.4 | 25.4 | -31.1 | 43 | -1.9 | 164.5 | -4.5 | 175 |

- Sys-Parameters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# RF Simulation Tools and Device Libraries

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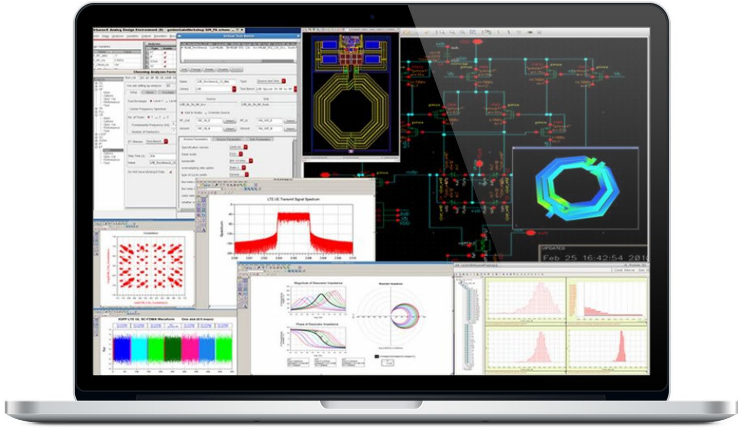
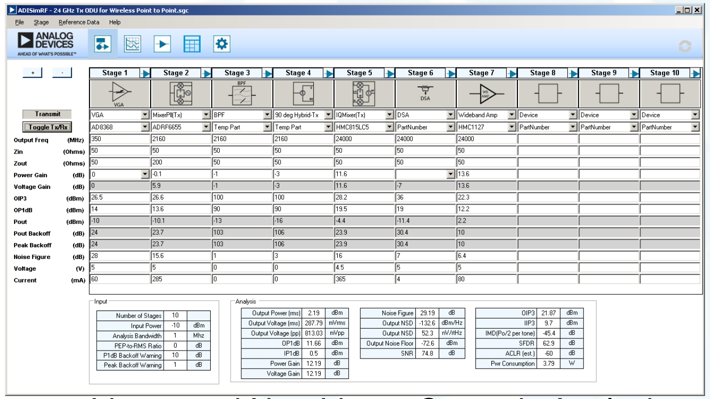
## Keysight ADS, Genesys and SystemVue



Circuit and System Simulation

Large ADI Library of Non-Linear Models

## ADIsimRF



Linear and Non-Linear Cascade Analysis

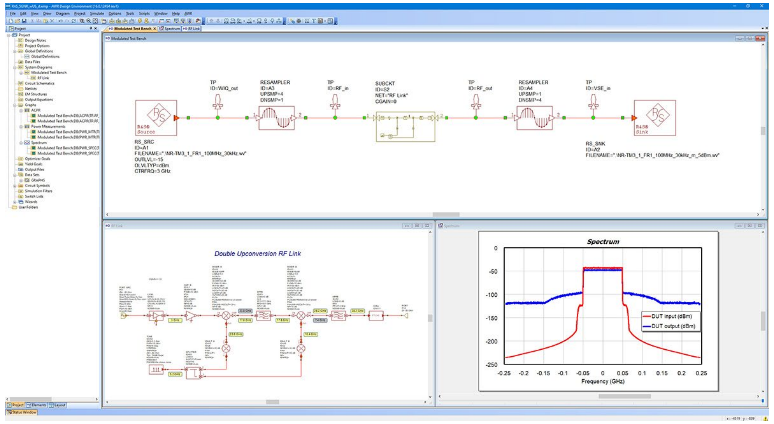
Large Library of Device Models

## ADIsimPLL

PLL Phase Noise and Lock Time

Device Models for all ADI PLLs & VCOs

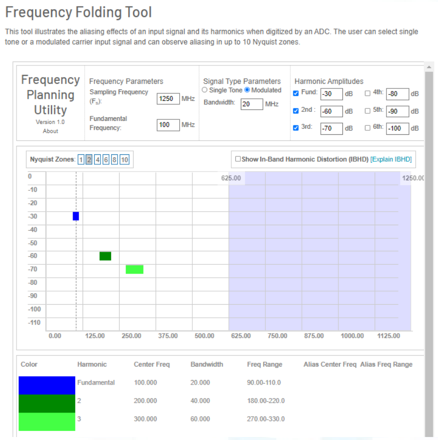
## Cadence VSS



System Simulator

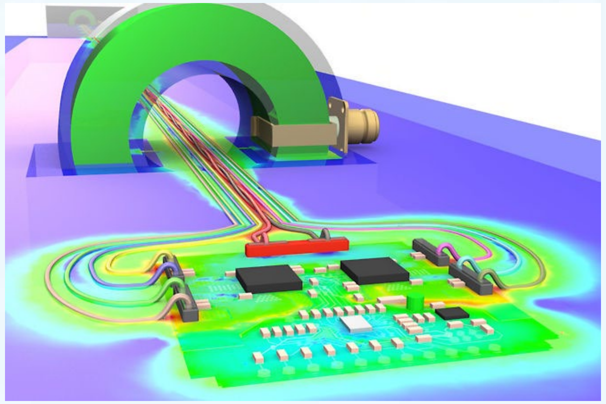
Large ADI Library of Non-Linear Models

## ADI Frequency Folding Tool




Nyquist Zone Frequency Planning

## Anysys HFSS



3D High Frequency Simulation Software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# Keysight RFPro Simulation of Stingray Radar Front-End

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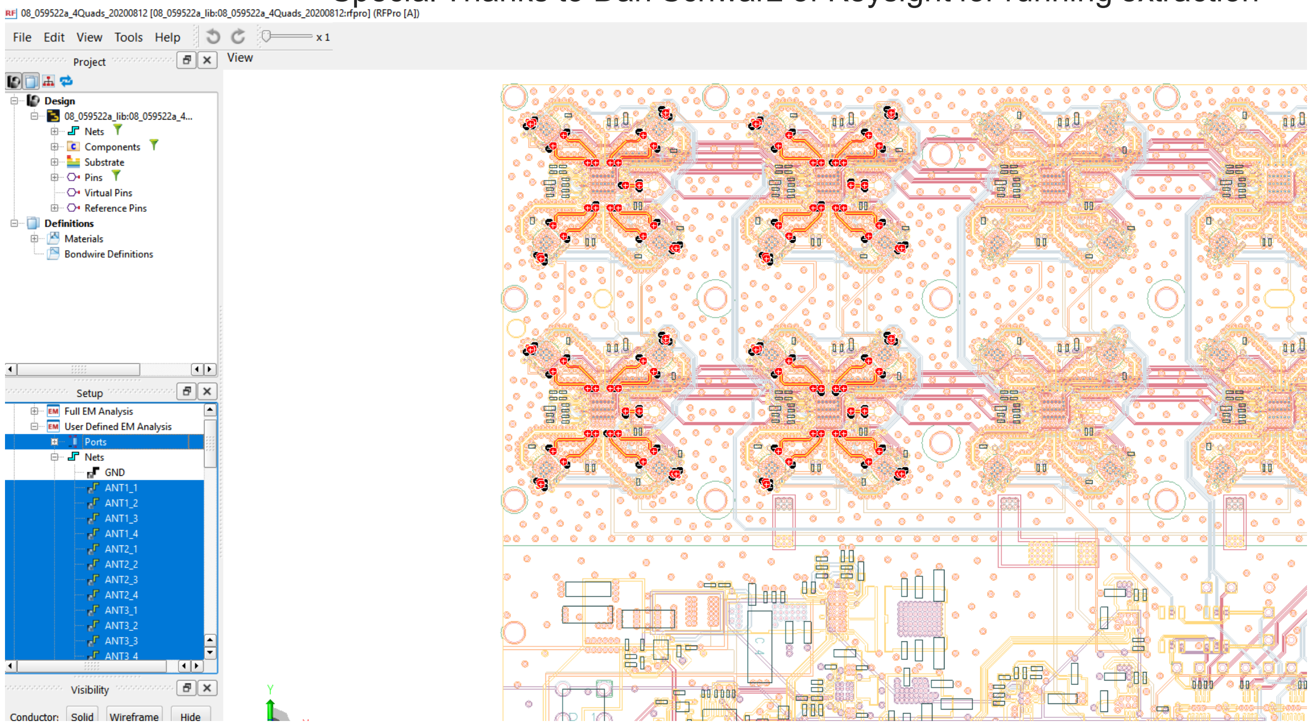
104 ports!  Using new Mesh Domain Optimization and 2nd generation meshing technology design simulates in about 7 hours rather than days.

Special Thanks to Dan Schwarz of Keysight for running extraction




Simulated Rx1 Response

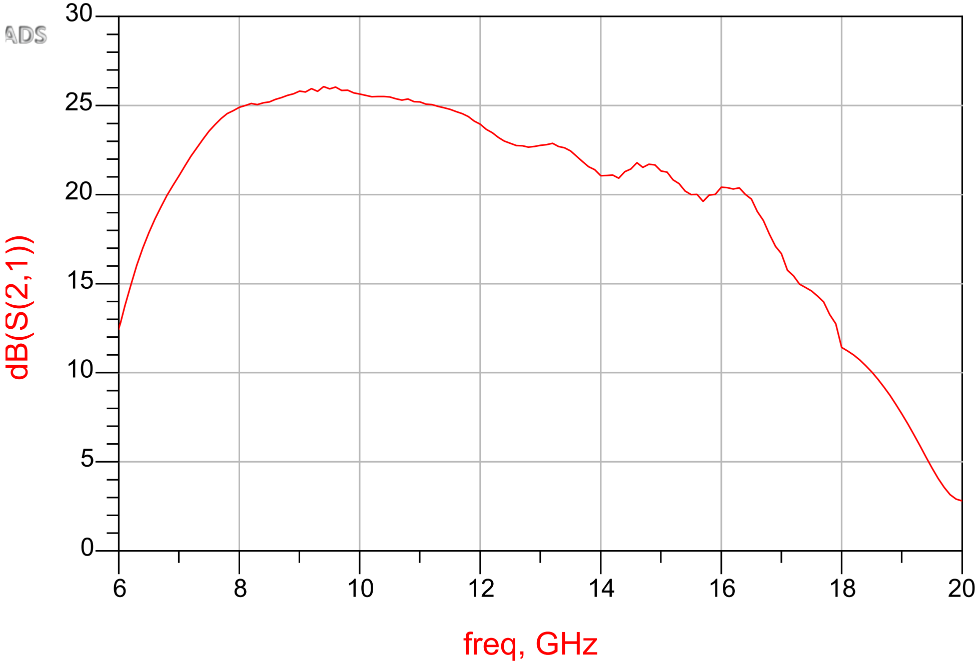



**Table of max gain and phase imbalance of critical Stingray traces at 10GHz**

| RFIO | TX | RX | Ant |
|---|---|---|---|
| 0.04dB/2° | 0.02dB/1.5° | 0.015dB/<1° | 0.06dB/8° |

After extracting parasitics of the PCB, we can recombine with circuit models to predict the frequency response

# Mechanical Design

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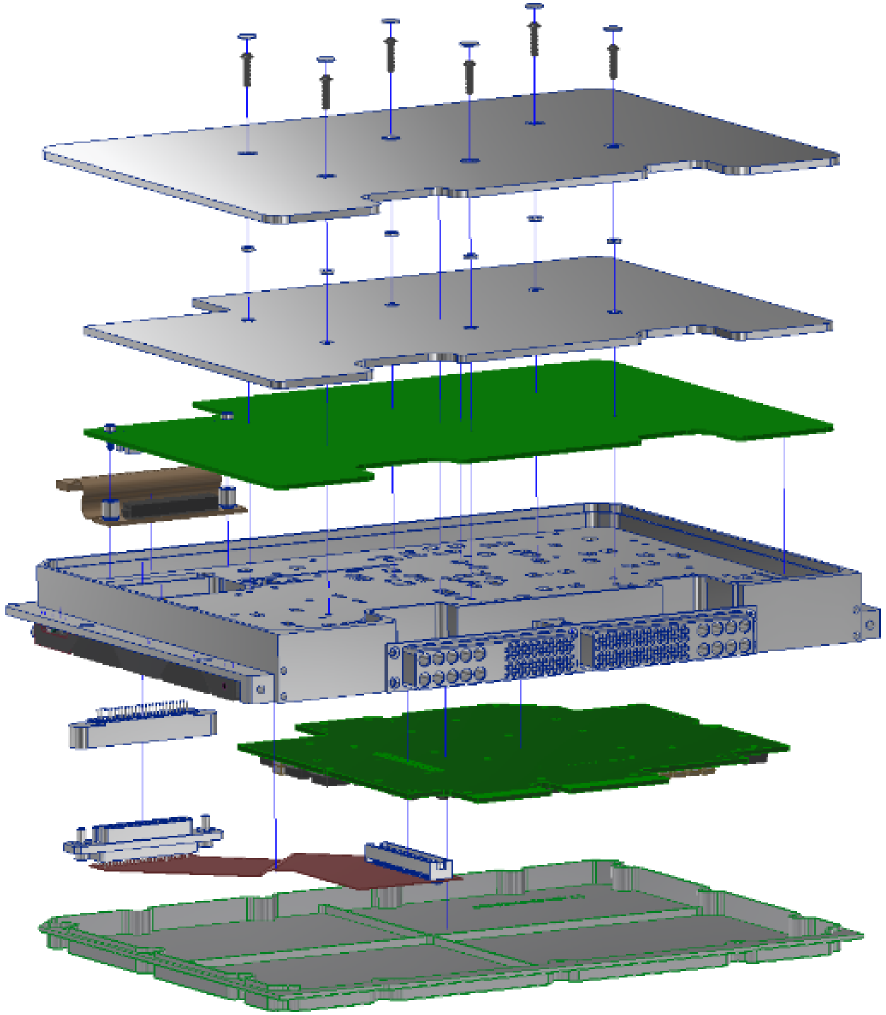

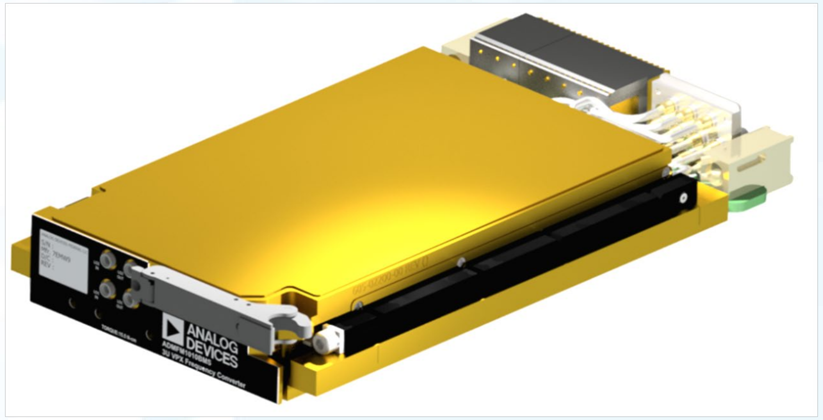



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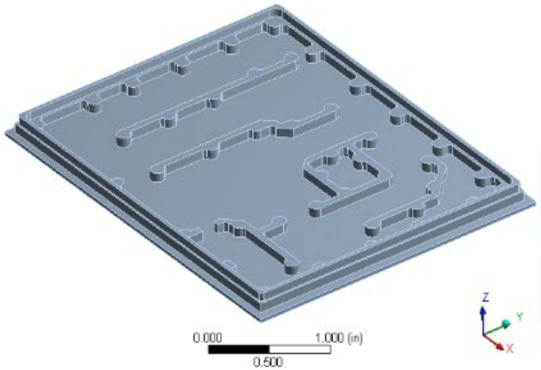
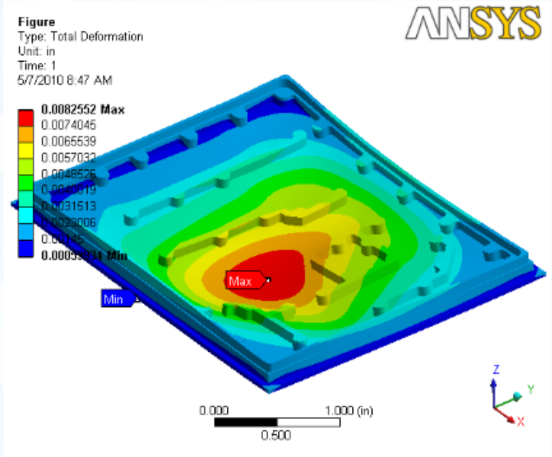
# Thermal and Structural Analysis

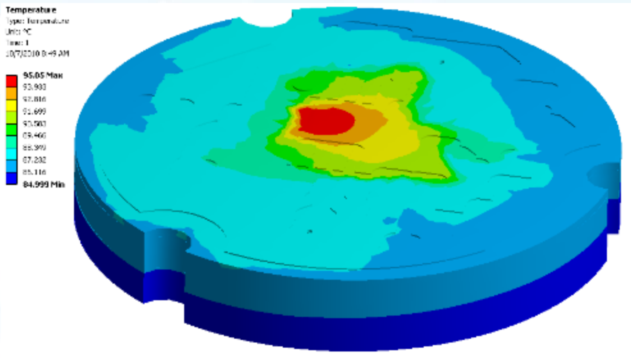


Structural Analysis - Housing

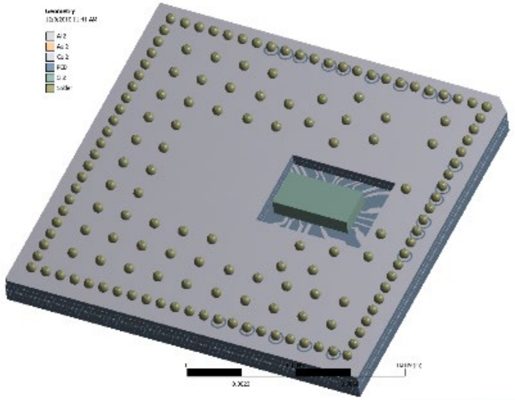


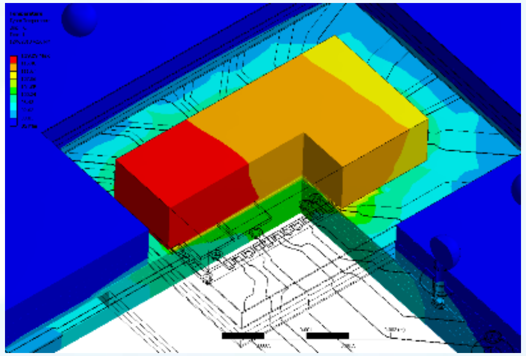




Thermal Analysis – Board Level

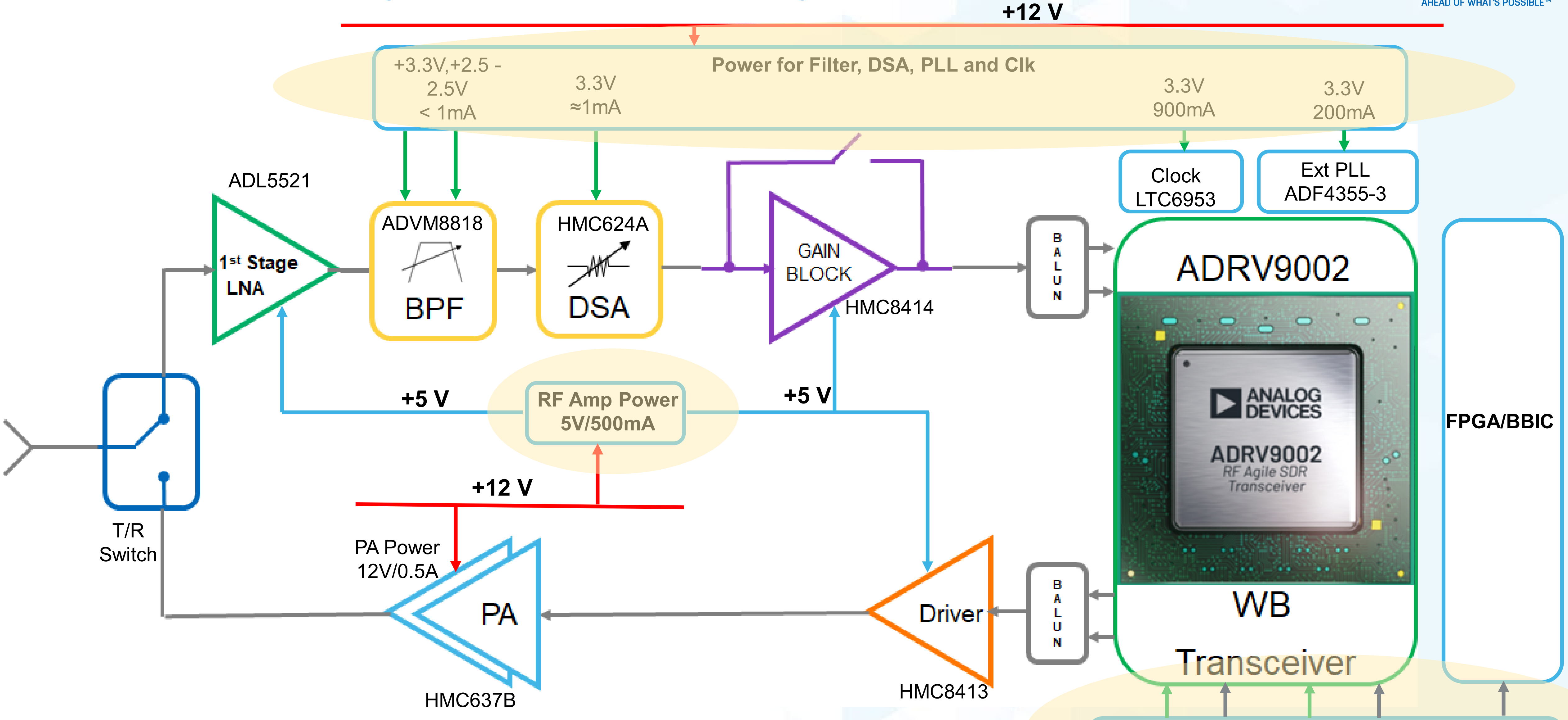



Thermal Analysis - BGA





# Power Management Planning





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# Power Management Design & Simulation Tools

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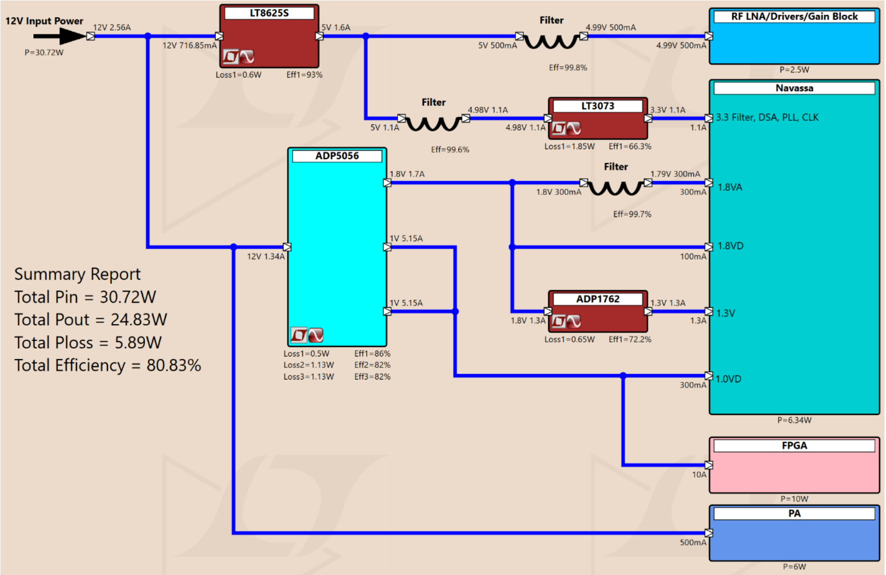


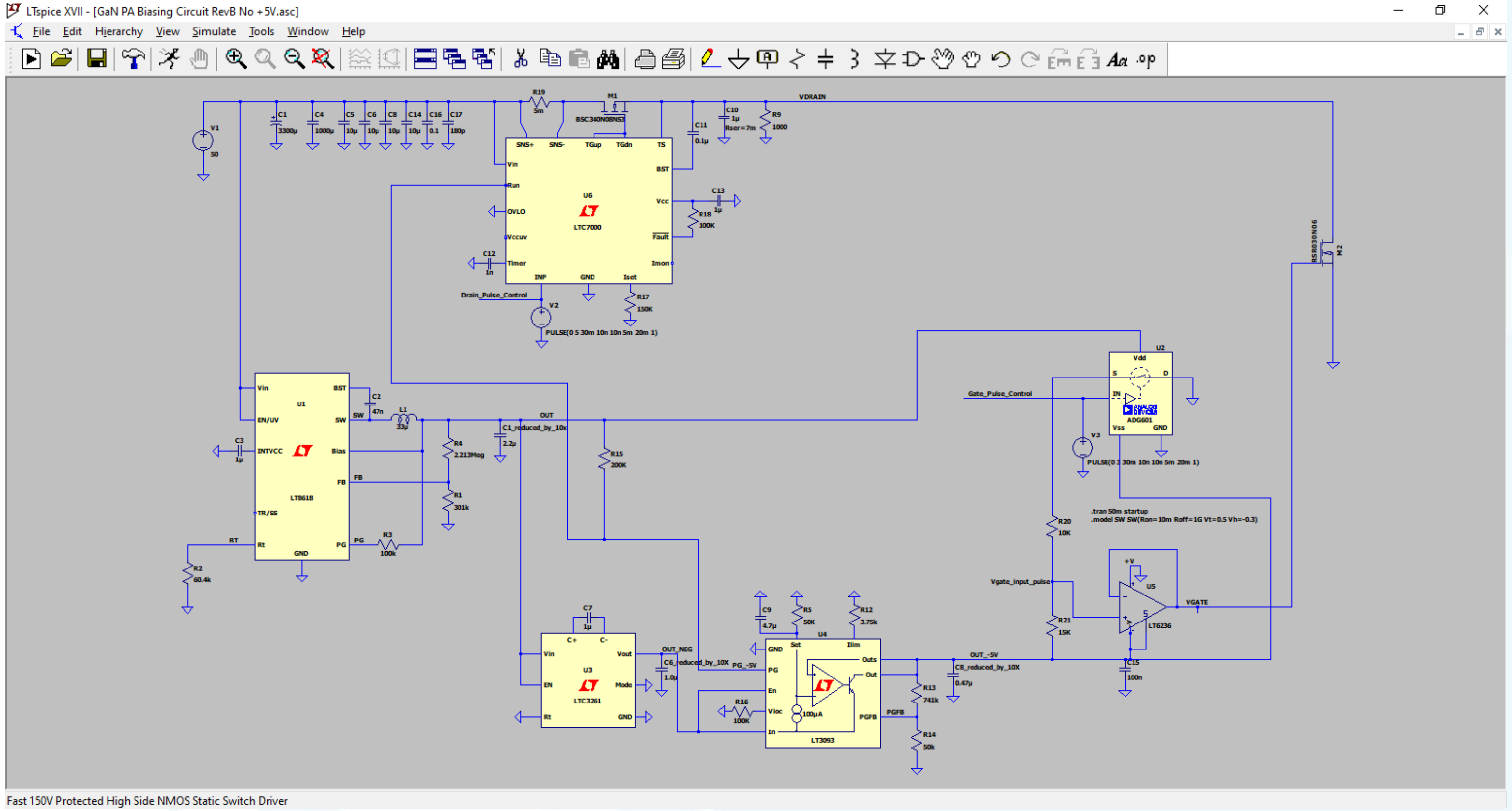


LT Power Planner

Power Management Planning

LTSpice

Power Management Simulation



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# Prototyping


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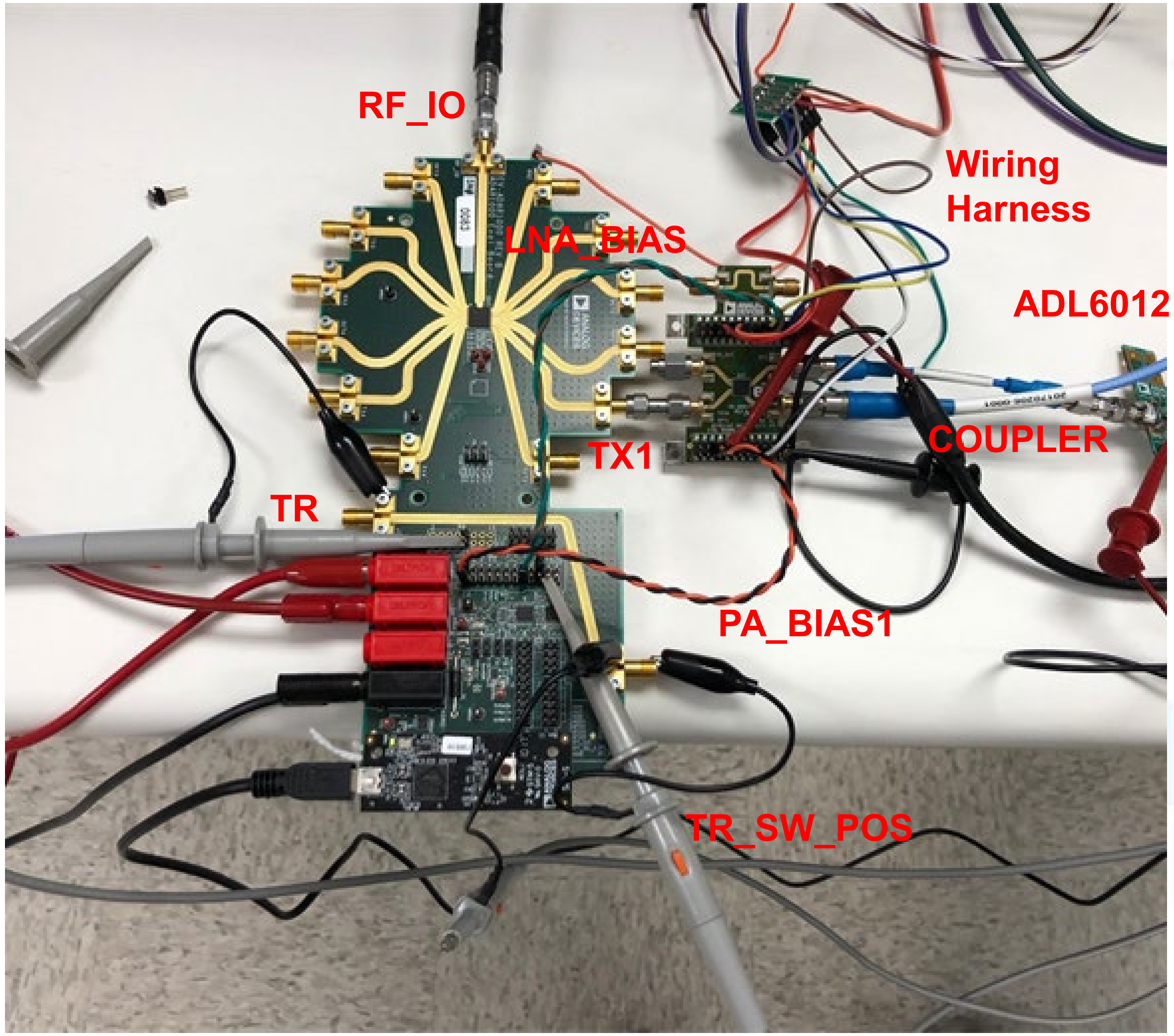
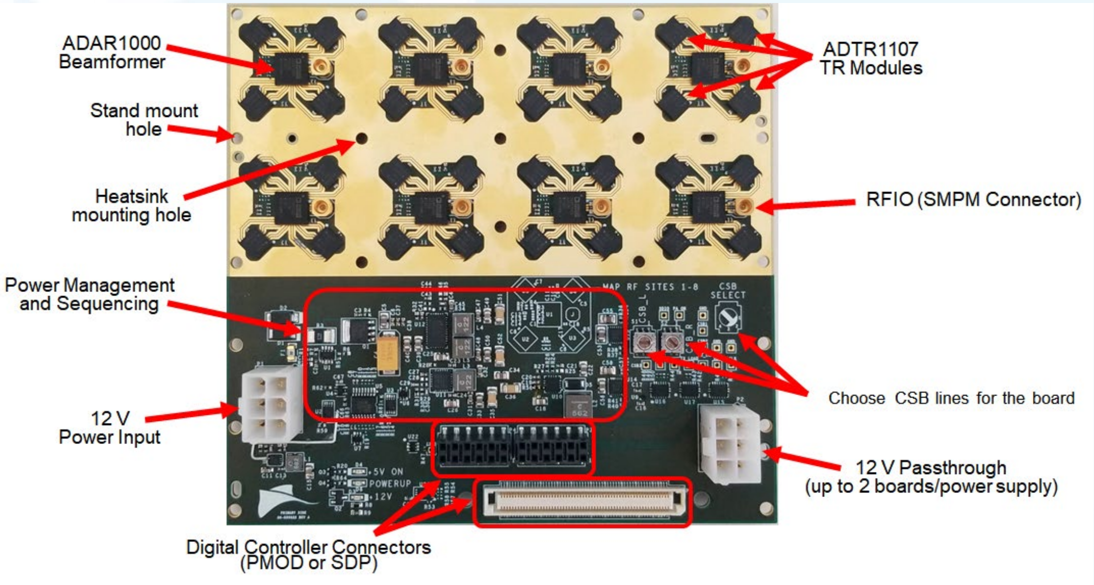
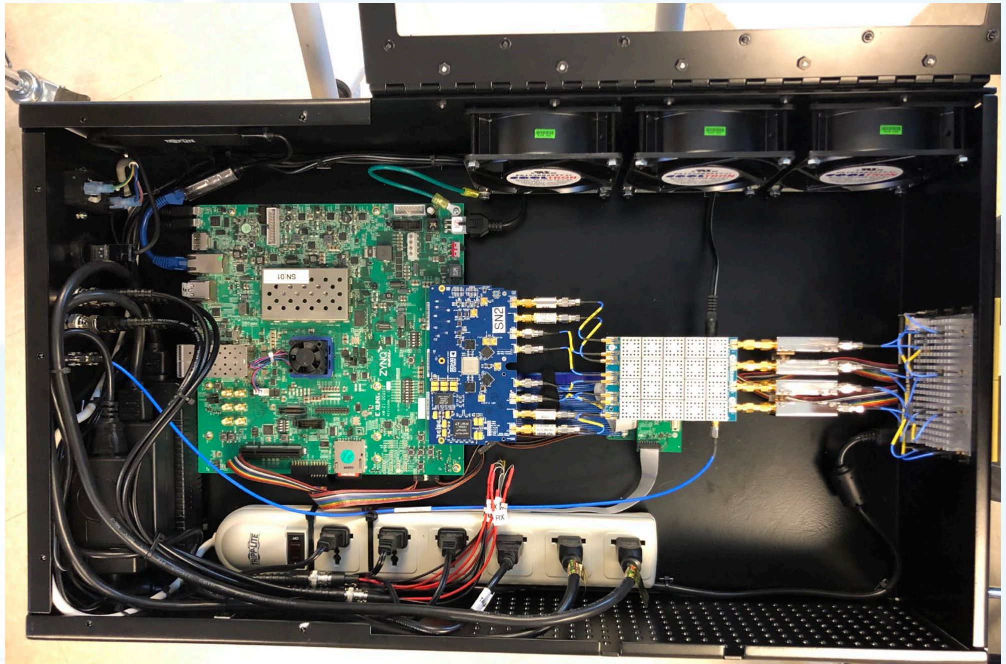
# Evaluation Boards vs. Development Kits

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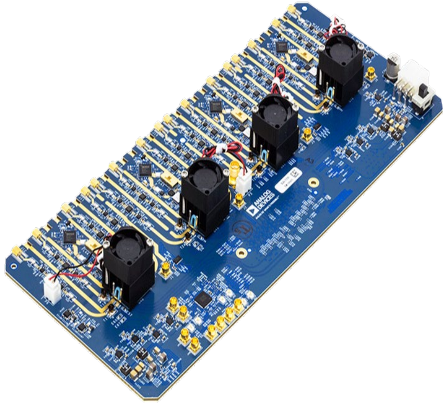
# ADI Development Kits

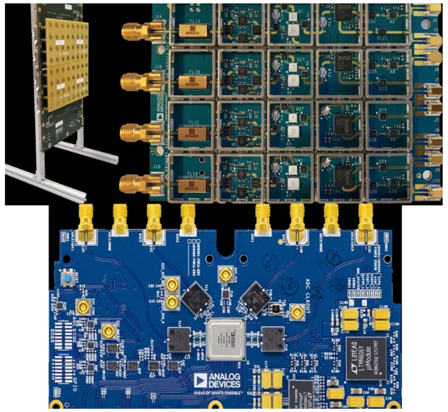
Available | In Development

## Quad MXFE



- L-/S-/C-Band Digital Beamforming
  - Direct Sampling to 5.8 GHz
- Applications
  - Radar
  - Electronic Warfare
- 16R16T FDD
- Focus ICs: AD9081, ADF4371, HMC7043
- Key System Level Demonstration:
  - Channel Sync + Calibration
  - RF + ADC/DAC + Power + Clocking Ref Design
  - FPGA HDL, Matlab GUI

## X-Band Radar

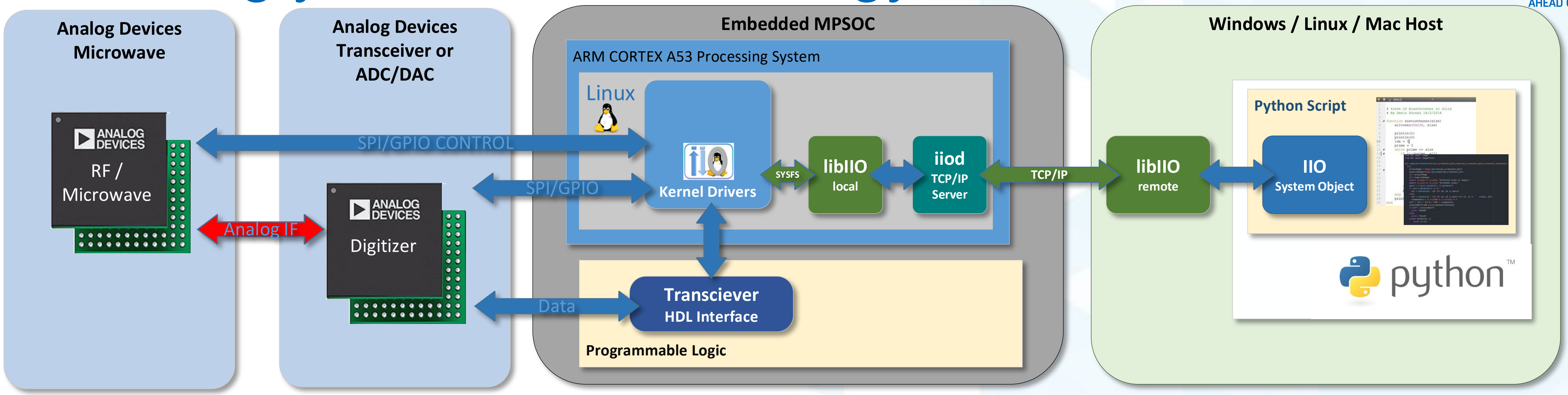


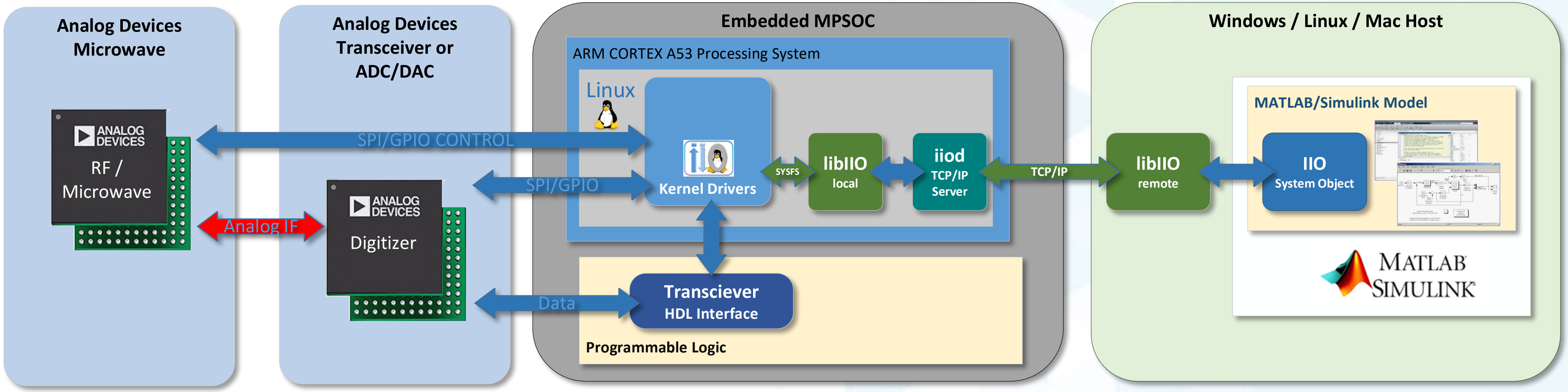
- X-band Hybrid Beamforming
  - 8-12 GHz
  - Up-/Down-Conversion X-to-C Band
  - Digitizing IC Provides Rx to Bits & Tx Synthesis
- Applications
  - Phased Array Radar
- 32 Element TDD
- Focus ICs: ADAR1000, ADTR1107, AD9081, HMC773, ADF4371
- Key System Level Demonstration:
  - Lattice Spacing Layout
  - Full Chain Performance/Control
  - Analog : Digital Ratio Tradeoffs
  - Array Calibration

## Adalm Pluto


- **Portable self-contained RF learning module**
- **Uses Analog Devices AD9363-- Highly Integrated RF Agile Transceiver and Xilinx® Zynq Z-7010 FPGA**
- **RF coverage from 325 MHz to 3.8 GHz**
- **Up to 20 MHz of instantaneous bandwidth**
- **Flexible rate, 12-bit ADC and DAC**
- **One transmitter and one receiver, half or full duplex**
- **MATLAB®, Simulink® support**
- **GNU Radio sink and source blocks**
- **libiio, a C, C++, C#, and Python API**
- **USB 2.0 Powered Interface with Micro-USB 2.0 connector**

# Implementing your software Strategy




Python or MATLAB – you pick (ADI supports both!)



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# Environmental and Shock

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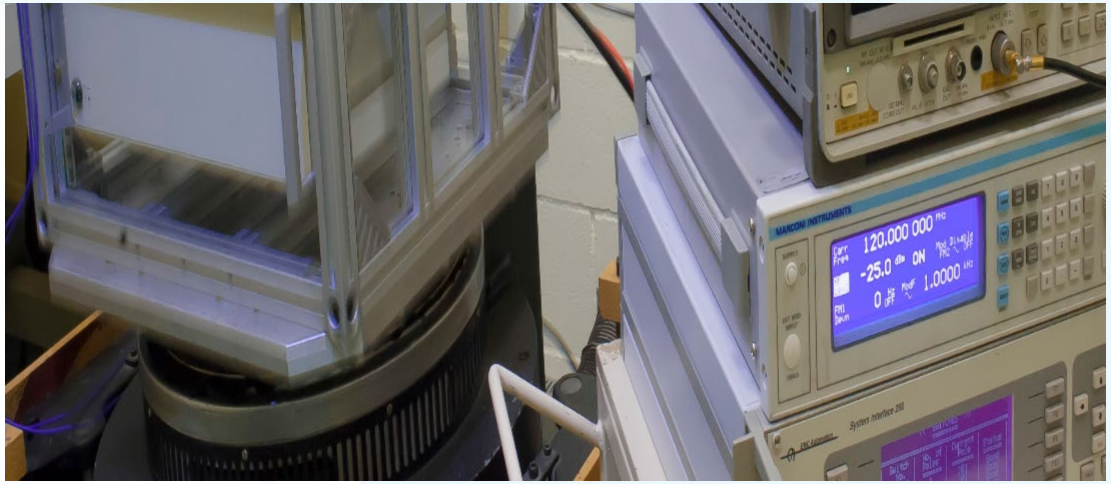
Temperature and Humidity




Shock and Vibration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# Summary

- RF circuit design is a multi-disciplinary effort
  - Systems Engineering
  - Electrical, Mechanical and Thermal Simulation
  - Electrical and Mechanical Design
  - Debug
- Evaluation boards, development kits and simulation tools make the journey easier
- While ADI is traditionally an IC company, we have the expertise to help you in every step of your product development journey


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# IEEE IMS 2022 RF BOOT CAMP

# RFMW Application Focus

Bryan Goldstein



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# Test Questions

- Sys-Parameter Models can be used to
  - Perform Electromagnetic (EM) Simulation
  - *Perform Linear and Non Linear Simulation (e.g. gain, return loss, noise, distortion)*
  - Perform Linear Simulation (gain, return loss, reverse isolation
- When calculating cascaded noise figure, the calculation tends to be dominated by
  - *The noise figure of first element in the signal chain*
  - The noise figure of last element in the signal chain
  - No specific element, each element's noise figure contributes equally
  - None of the above


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