



**AVNET**<sup>®</sup>

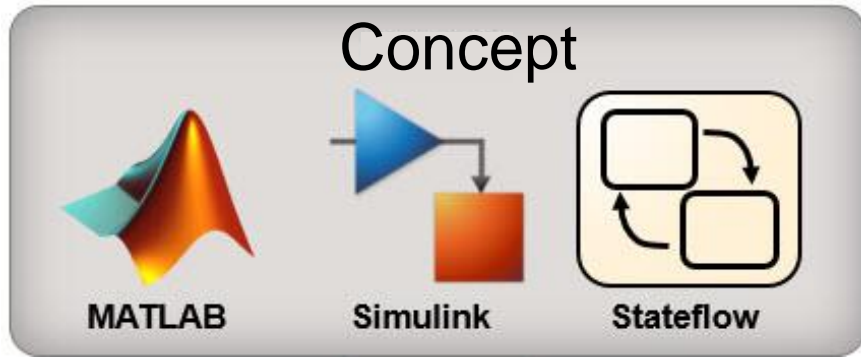
## Secure, Automated, Internet-based mmWave Testing with Xilinx RFSoc

*Fabrício Dourado, Rohde & Schwarz*   *Luc F. Langlois, Avnet*



**MATLAB EXPO**

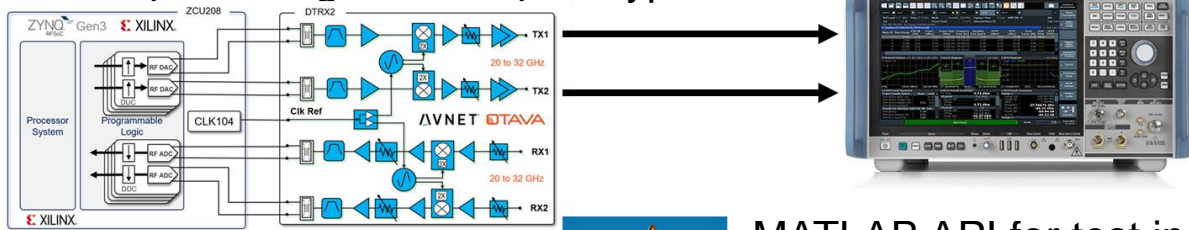
# Technology Design Cycles are Expanding



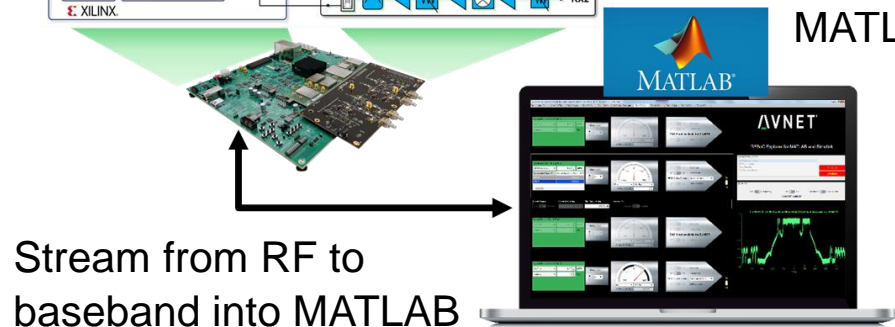
2+ years

# Xilinx RFSoc Design Cycle

Develop from algorithm to prototype



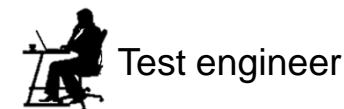
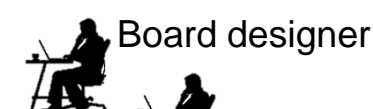
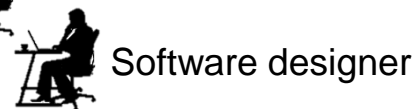
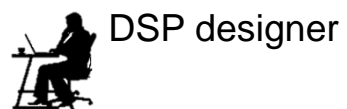
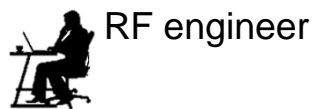
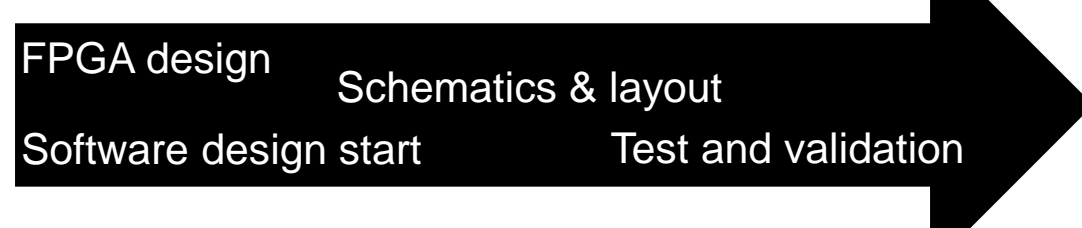
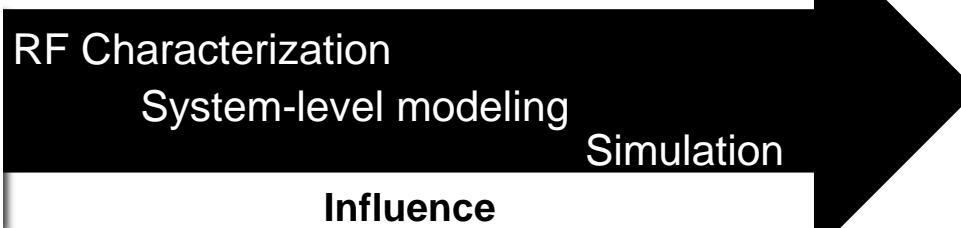
MATLAB API for test instrument automation



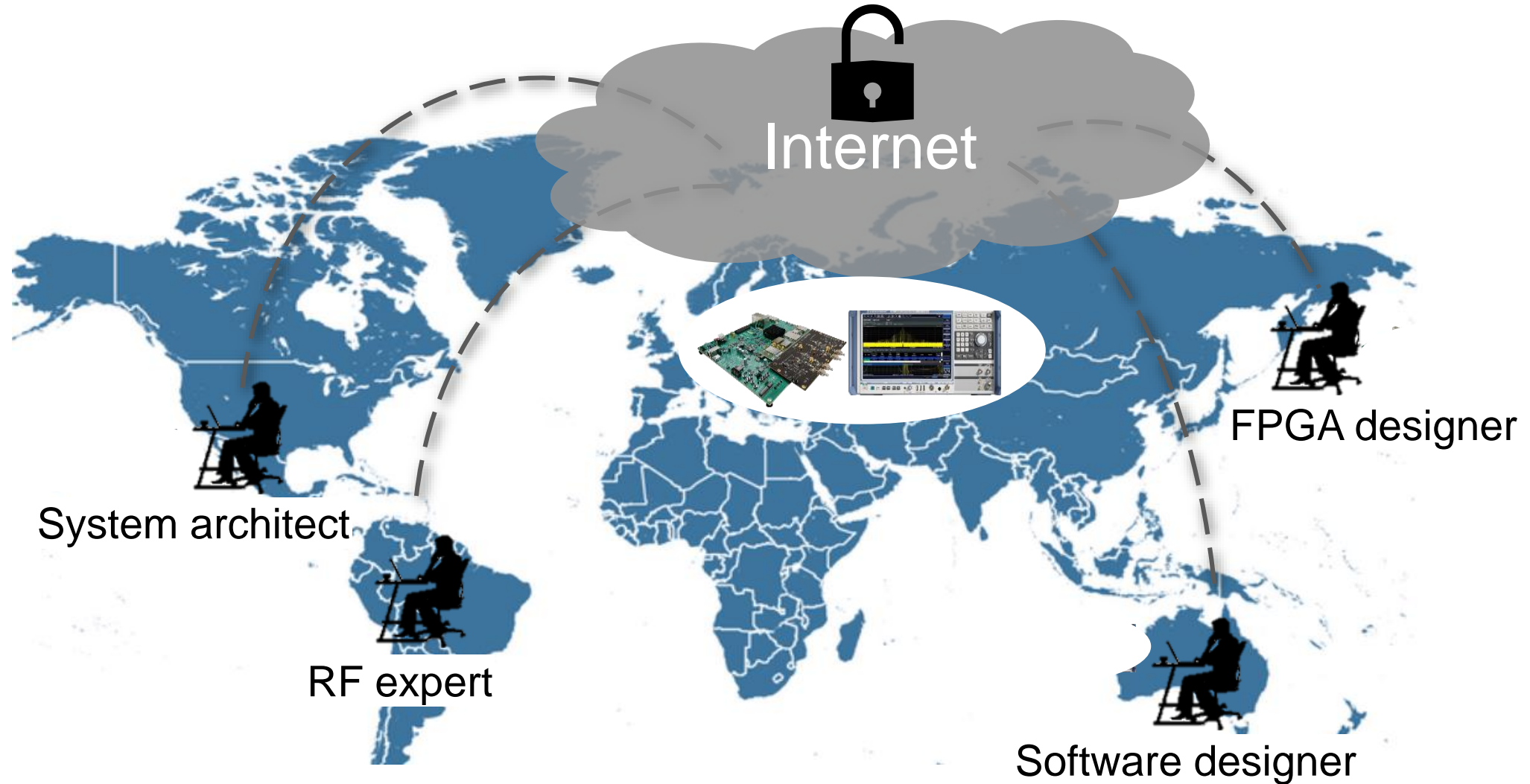
Stream from RF to baseband into MATLAB

Proof of Concept

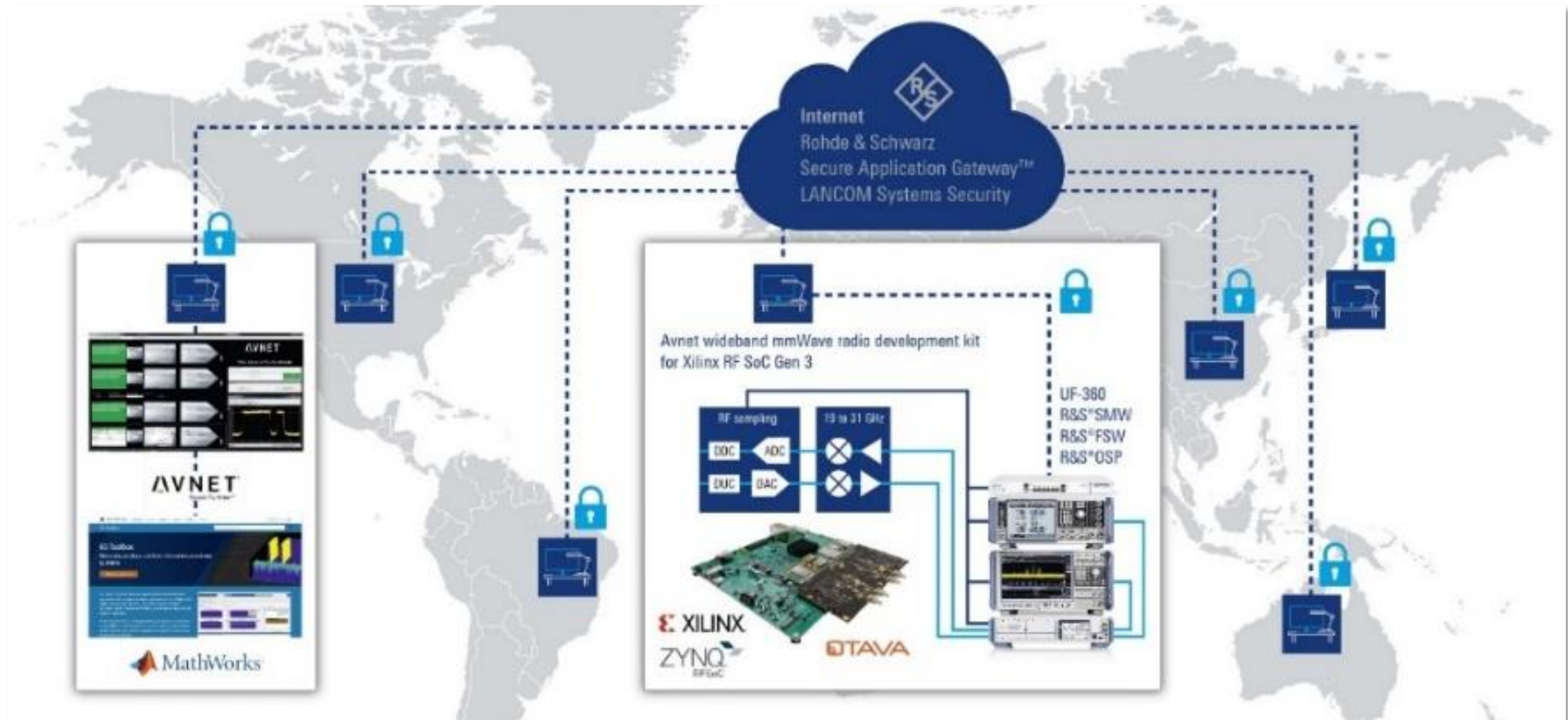
Product Design



# Distributed Design Teams

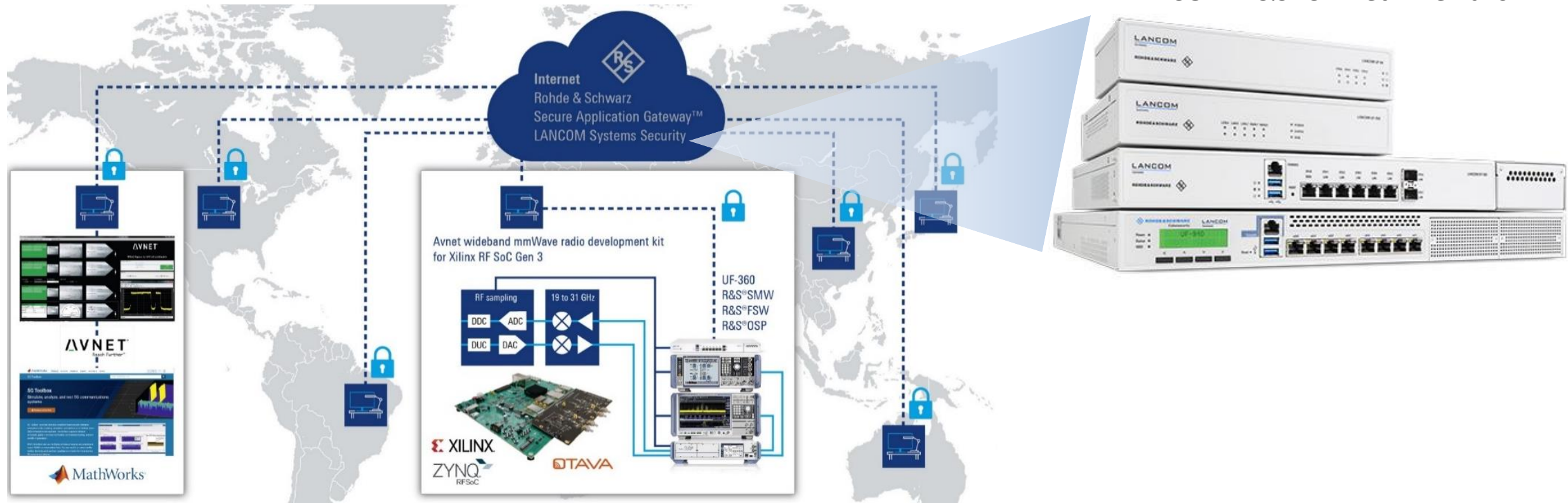


# Secure, Automated, Internet-based mmWave Testing with Xilinx RFSoC



# Rohde & Schwarz Secure Application Gateway

## Network security by design



- Connectivity to test instruments through MATLAB-based RFSoc Explorer
- State-of-the-art security and Unified Threat Management

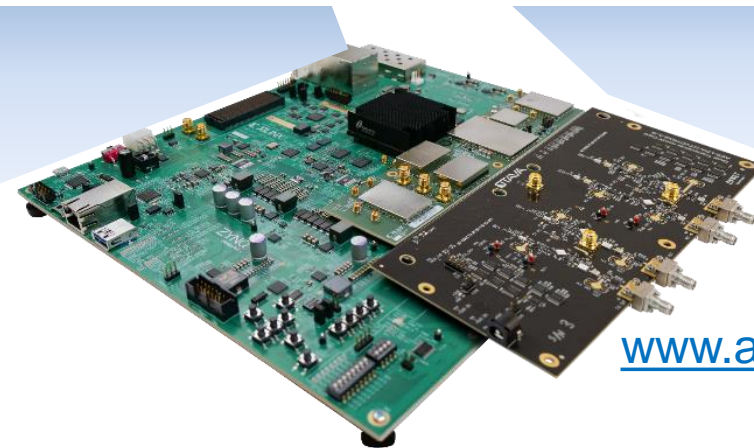
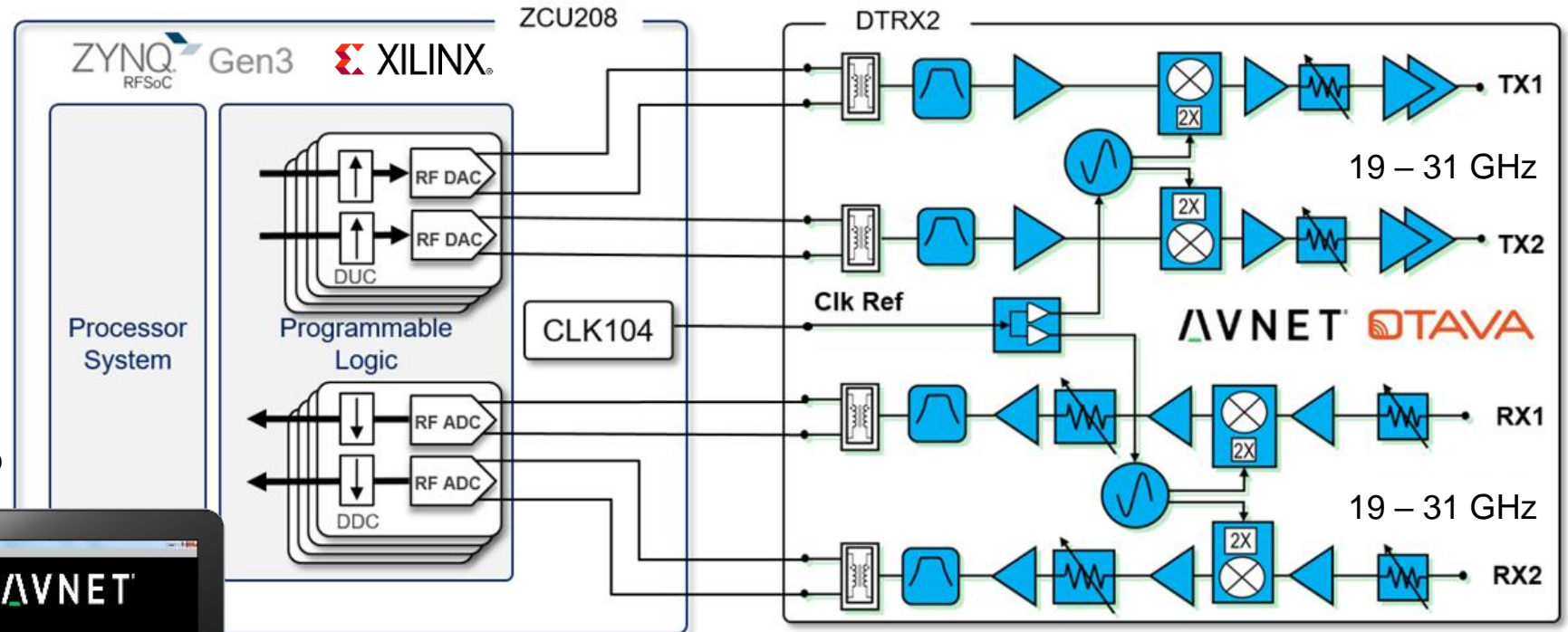
# Avnet mmWave Radio Kit for AMD/Xilinx Zynq® UltraScale+™ RFSoc

Requires:

- MATLAB
- Communications Toolbox
- DSP System Toolbox
- Fixed-Point Designer
- Signal Processing Toolbox



Avnet RFSoc Explorer®

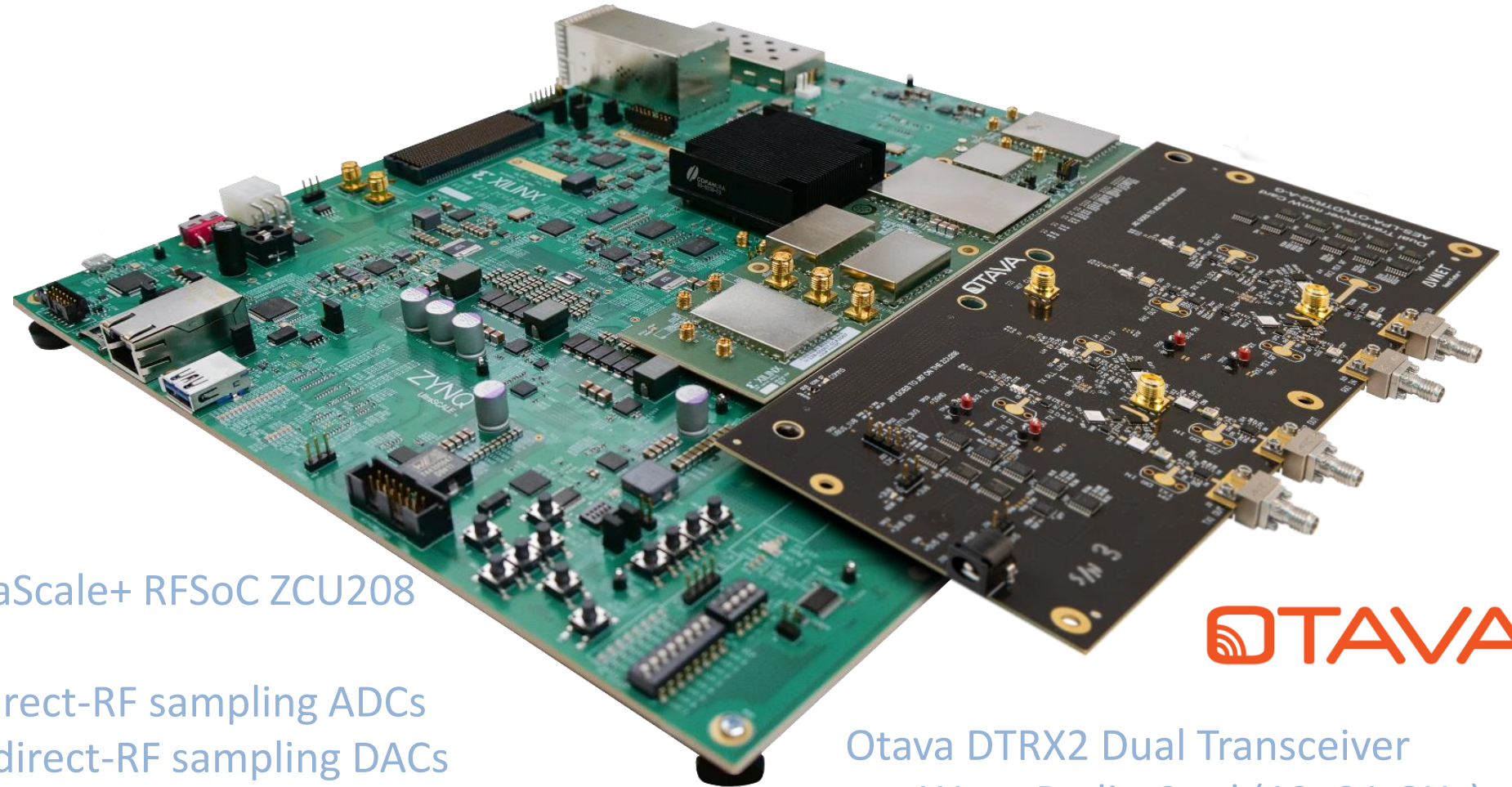


DTRX2 Dual Transceiver  
mmWave Radio Card

[www.avnet.com/rfsoc-mmw](http://www.avnet.com/rfsoc-mmw)

# Radio under Test

# Avnet Wideband mmWave Radio Development Kit for Xilinx RFSoc Gen-3



AMD/Xilinx Zynq UltraScale+ RFSoc ZCU208  
Evaluation Kit  
8 x 14-bit, 5.0 GSPS direct-RF sampling ADCs  
8 x 14-bit, 9.85 GSPS direct-RF sampling DACs  
6 GHz analog bandwidth

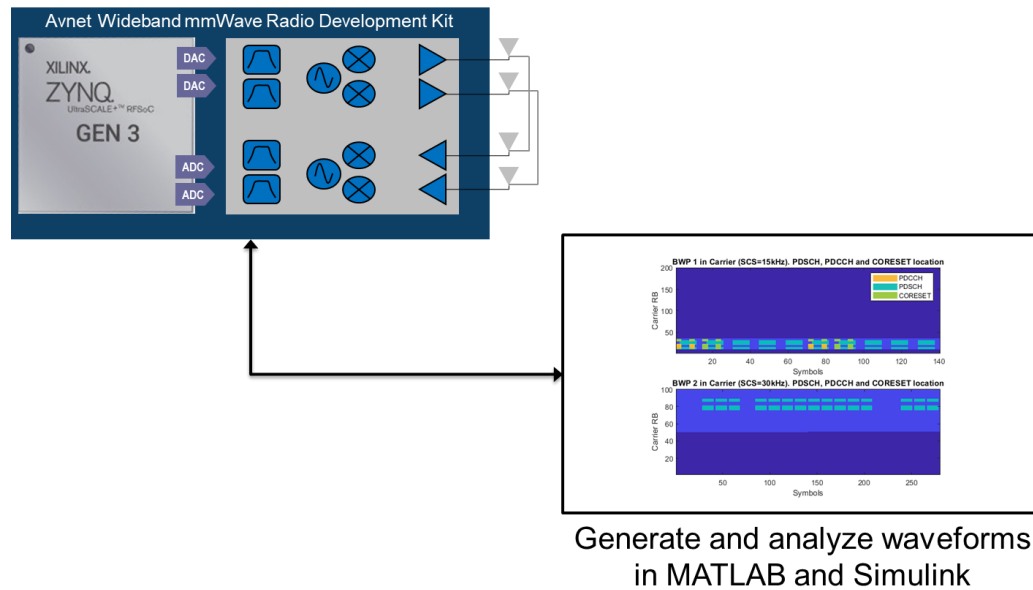
Otava DTRX2 Dual Transceiver  
mmWave Radio Card (19–31 GHz)



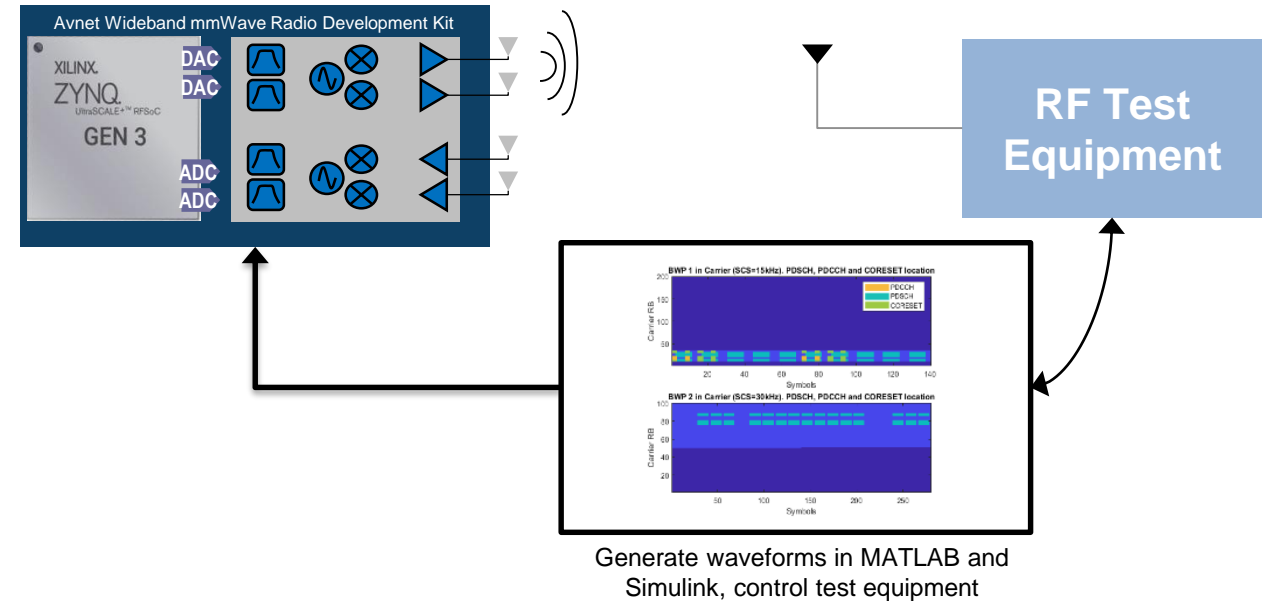


# Traditional Test & Measurement

## Hardware Evaluation in loopback testing

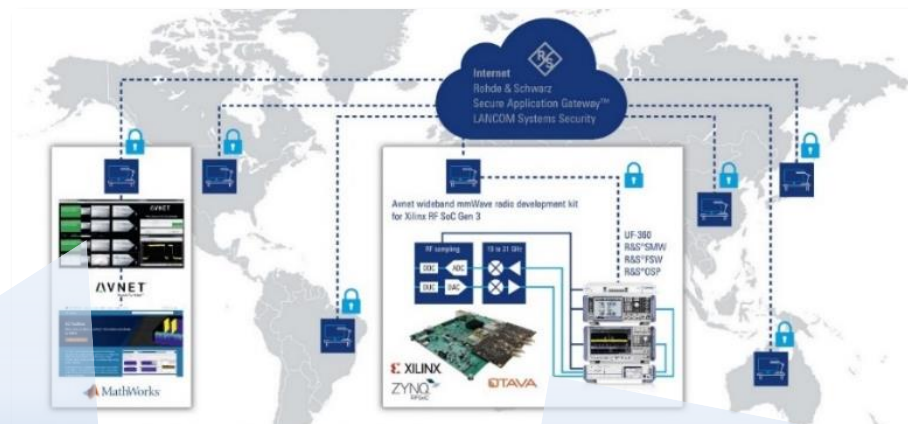


## Over-the-air Testing



- Lacking closed-loop instrument control / MATLAB integration

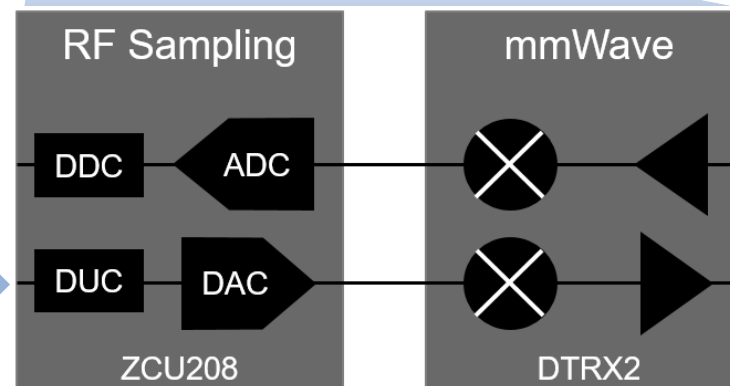
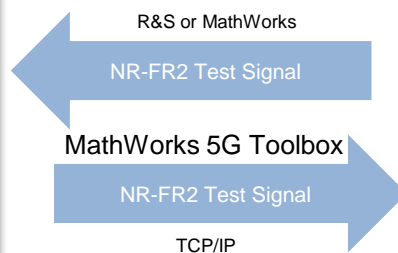
# Our Reference Design Testing



Avnet mmWave Radio Development Kit for Xilinx RFSoc Gen-3

**R&S VSE**  
Vector Signal Explorer

**MATLAB**  
Avnet RFSoc Explorer®



**R&S SMW200A High End**  
Vector Signal Generator

**R&S FSW High End**  
Signal and Spectrum Analyzer

Control

VISA

**ROHDE & SCHWARZ**  
Make ideas real



Future Lab – A ONE Rohde & Schwarz Project

# SECURE APPLICATION GATEWAY



Services  
T&M Device Handling



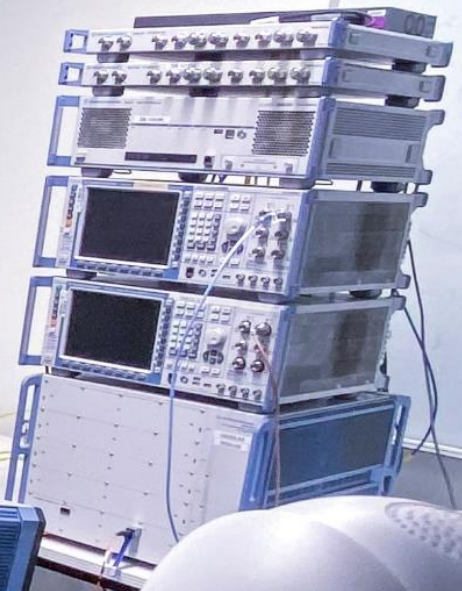
Applications  
Edge Computing Platform

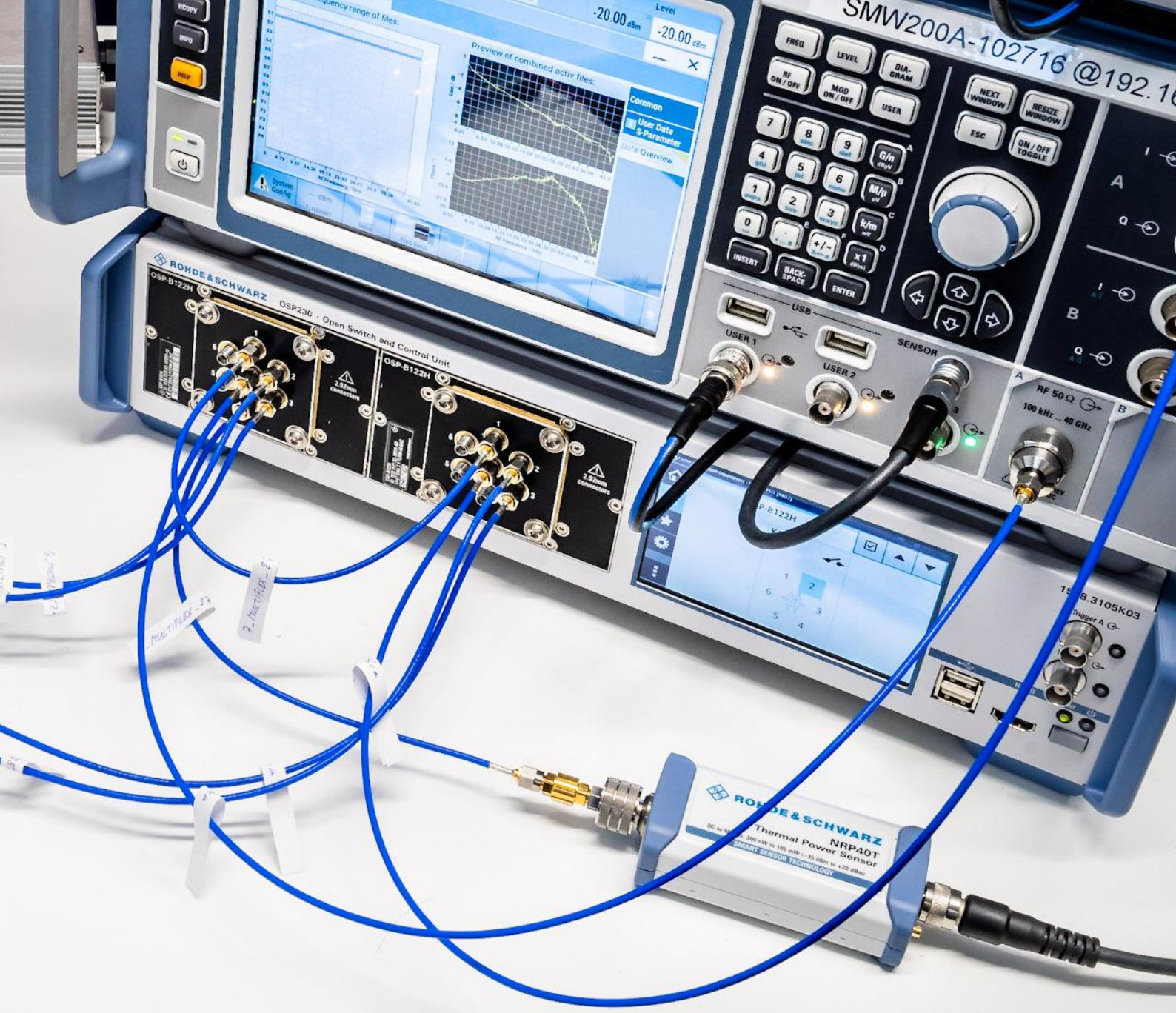
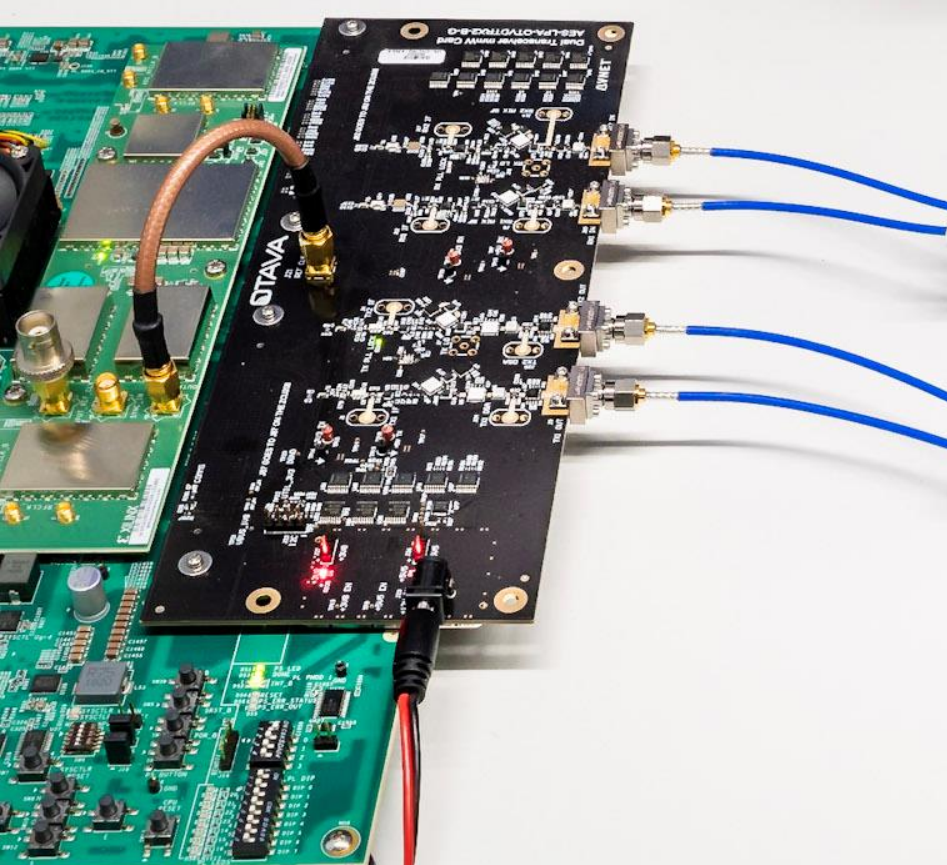


Connectivity  
AI-based Inspection

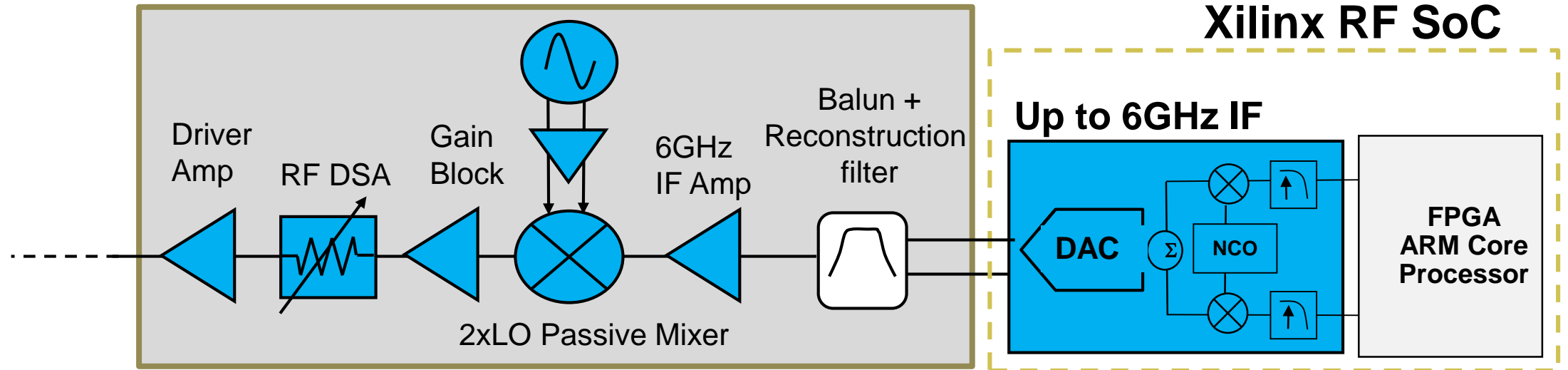


Security  
Next-Generation Firewall

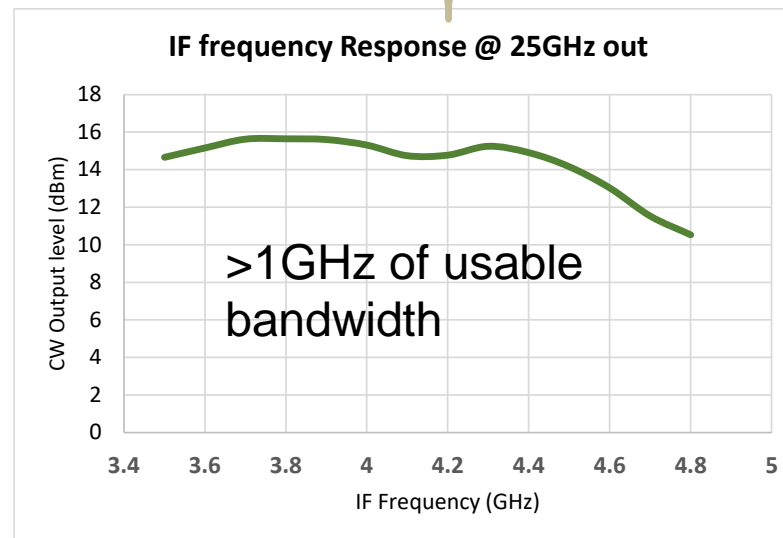




# The RF-sampling Tx Signal Chain

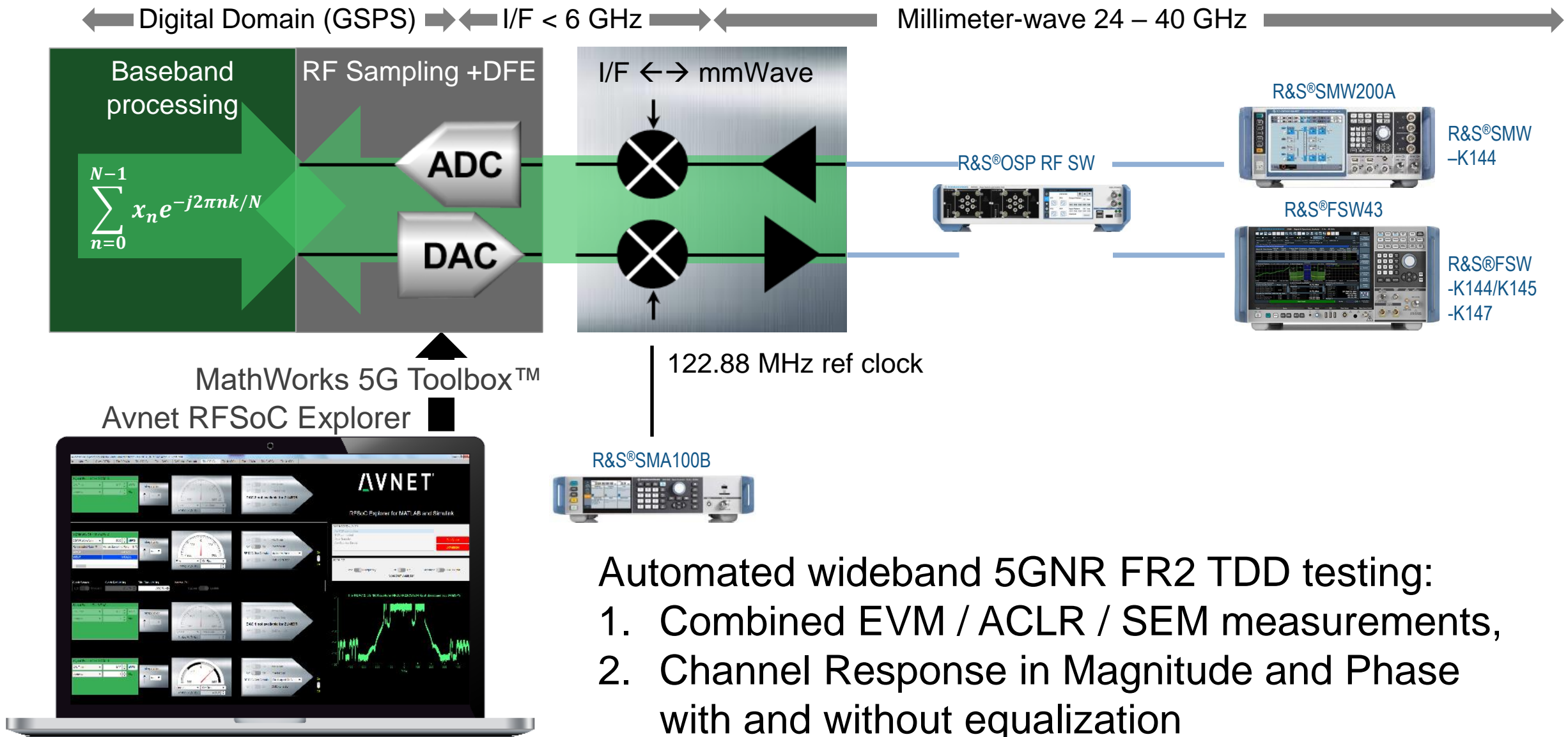


*How to achieve best wideband RF performance?*



Focus on optimizing wideband 5G NR performance for the whole signal chain

# Demo: Automated Test Sequencing with User MATLAB Functions





Combined Measurement

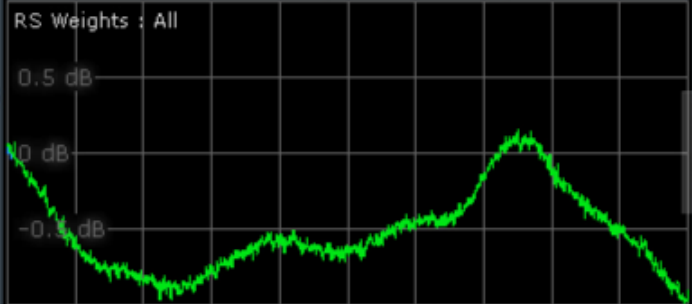
MultiView Sp...um Spe...m2 SGNREVM ACLR AC...EM Dis...ion

Ref Level 2.27 dBm Freq 27.9 GHz Mode Downlink, 400 MHz Capture Time 20.0 ms BWP/SS All SGL  
Att 12 dB Event Count 5 of 5 Selected Meas ID 1 I/Q RAM  
TRG:EXT2 FRCORR YIG Bypass EVM/ACLR/SEM

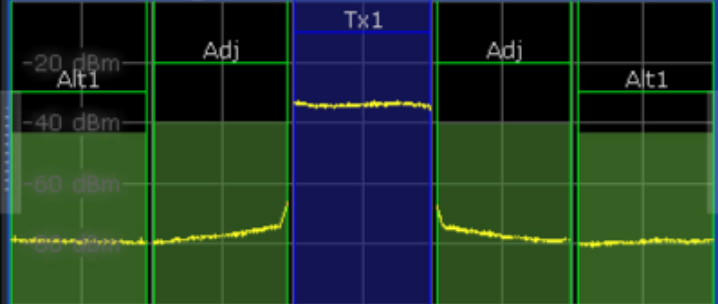
1 Combined EVM/ACLR/SEM Result

| Meas ID | Time Stamp | EVM All [%] | Power [dBm] | Frame Start Offset | Frequency Error [Hz] | Sampling Error [ppm] | OSTP [dBm] | RSTP [dBm] | Crest Factor [dB] | Sync State | ACLR PASS/ |
|---------|------------|-------------|-------------|--------------------|----------------------|----------------------|------------|------------|-------------------|------------|------------|
| 1       | 0.00s      | 2.66        | 1.86        | 2.174 ms           | -25 186.48           | -0.36                | 1.86       | -32.85     | 9.86              | PASS       |            |
| 2       | 7.82s      | 2.57        | 1.86        | 2.177 ms           | -25 195.05           | -0.36                | 1.86       | -32.86     | 9.98              | PASS       |            |
| 3       | 16.23s     | 2.65        | 1.85        | 9.680 ms           | -25 195.64           | -0.36                | 1.85       | -32.86     | 9.84              | PASS       |            |
| 4       | 24.27s     | 2.65        | 1.86        | 9.683 ms           | -25 193.13           | -0.36                | 1.86       | -32.87     | 9.79              | PASS       |            |
| 5       | 32.38s     | 2.64        | 1.86        | 9.686 ms           | -25 199.25           | -0.35                | 1.86       | -32.86     | 9.81              | PASS       |            |

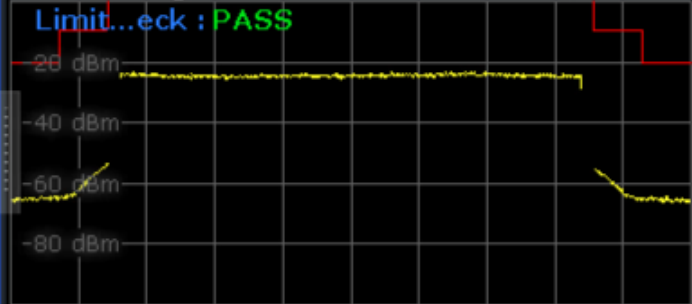
2 Channel Flatnes



3 ACLR Diagram



4 SEM Diagram



5 EVM Result Summary

| Frame Results Select...                  | Mean | Limit |
|------------------------------------------|------|-------|
| EVM PDSCH QPSK (%)                       |      | 18.50 |
| EVM PDSCH 16QAM (%)                      |      | 13.50 |
| EVM PDSCH 64QAM (%)                      | 2.57 | 9.00  |
| EVM PDSCH 256QAM (...)                   |      | 4.50  |
| Results for Selection BWP/SS All, Sub... |      |       |
| EVM All (%)                              | 2.55 |       |
| EVM Phys Channel (%)                     | 2.57 |       |
| EVM Phys Signal (%)                      | 2.06 |       |

6 ACLR Result Summary

|                   |                   |
|-------------------|-------------------|
| Tx Total          | <b>1.86 dBm</b>   |
| Channel Tx1 (Ref) |                   |
| Bandwidth         | 380.160 MHz       |
| Offset            |                   |
| Power             | <b>1.86 dBm</b>   |
| Channel Adj       |                   |
| Bandwidth         | 380.160 MHz       |
| Offset            | 400.000 MHz       |
| Lower Abs         | <b>-39.97 dBm</b> |

7 SEM Result Summary

|           |                     |
|-----------|---------------------|
| Range 1   |                     |
| Range Low | -280.000 MHz        |
| Range Up  | -240.500 MHz        |
| RBW       | 1.000 MHz           |
| Frequency | <b>27.65885 GHz</b> |
| Power Abs | <b>-63.91 dBm</b>   |
| Power Rel | <b>-65.78 dB</b>    |
| ΔLimit    | <b>-43.91 dB</b>    |
| Range 2   |                     |

- Signal Description
- Radio Frame Config
- Restore Settings
- Trigger/Signal Capture
- Parameter Estimation/Tracking
- Demod
- Evaluation Range
- Result Settings
- Display Config
- Overview



Combined Measurement

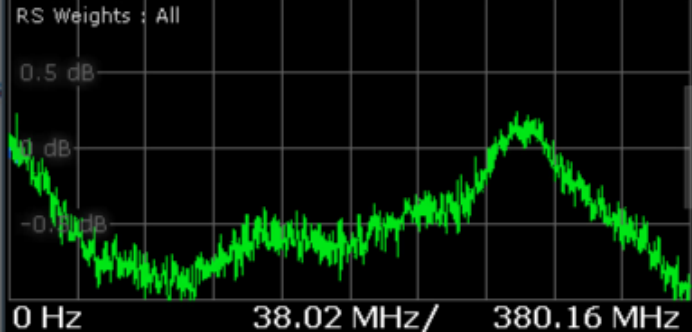
MultiView Sp...um X Spe..m2 X 5GNREVM \* X ACLR X AC..EM X Dis..ion X

Ref Level 2.20 dBm Freq 27.9 GHz Mode Downlink, 400 MHz Capture Time 3.5 ms BWP/SS All SGL  
Att 12 dB Event Count 5 of 5 Selected Meas ID 1 I/Q RAM  
TRG:EXT2 FRCORR YIG Bypass EVM/ACLR/SEM

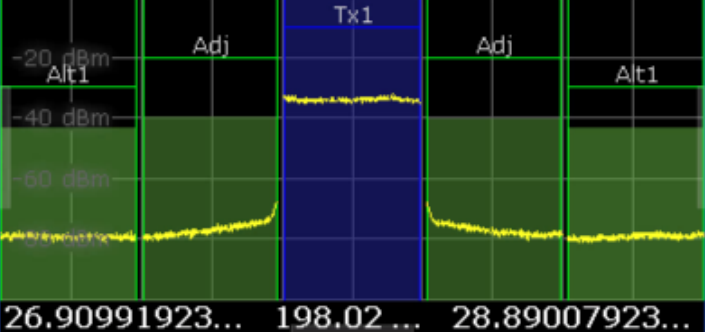
1 Combined EVM/ACLR/SEM Result TableConfig

| Meas ID | Time Stamp | EVM All [%] | Power [dBm] | Frame Start Offset | Frequency Error [Hz] | Sampling Error [ppm] | OSTP [dBm] | RSTP [dBm] | Crest Factor [dB] | Sync State | ACLR PASS/ |
|---------|------------|-------------|-------------|--------------------|----------------------|----------------------|------------|------------|-------------------|------------|------------|
| 1       | 0.00s      | 2.77        | 1.88        | 2.196 ms           | -25 179.82           | -0.36                | 1.86       | -32.88     | 9.49              | PASS       |            |
| 2       | 5.55s      | 2.70        | 1.88        | 2.198 ms           | -25 181.33           | -0.36                | 1.85       | -32.87     | 9.51              | PASS       |            |
| 3       | 11.01s     | 2.52        | 1.88        | 2.200 ms           | -25 200.58           | -0.35                | 1.86       | -32.87     | 9.57              | PASS       |            |
| 4       | 16.41s     | 2.56        | 1.88        | 2.202 ms           | -25 181.81           | -0.36                | 1.86       | -32.87     | 9.71              | PASS       |            |
| 5       | 22.00s     | 2.88        | 1.89        | 2.204 ms           | -25 199.80           | -0.36                | 1.86       | -32.87     | 9.83              | PASS       |            |

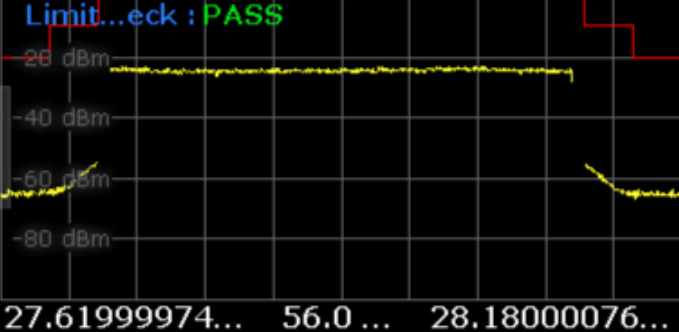
2 Channel Flatness 1 AP 1000 2 AP 2000



3 ACLR Diagram 1 Clrw



4 SEM Diagram 1 Clrw



5 EVM Result Summary

| Frame Results Select...                  | Mean | Limit |
|------------------------------------------|------|-------|
| EVM PDSCH QPSK (%)                       |      | 18.50 |
| EVM PDSCH 16QAM (%)                      |      | 13.50 |
| EVM PDSCH 64QAM (%)                      | 2.80 | 9.00  |
| EVM PDSCH 256QAM (...)                   |      | 4.50  |
| Results for Selection BWP/SS All, Sub... |      |       |
| EVM All (%)                              | 2.77 |       |
| EVM Phys Channel (%)                     | 2.79 |       |
| EVM Phys Signal (%)                      | 2.28 |       |

6 ACLR Result Summary

|                   |             |
|-------------------|-------------|
| Tx Total          | 1.88 dBm    |
| Channel Tx1 (Ref) |             |
| Bandwidth         | 380.160 MHz |
| Offset            |             |
| Power             | 1.88 dBm    |
| Channel Adj       |             |
| Bandwidth         | 380.160 MHz |
| Offset            | 400.000 MHz |
| Lower Abs         | -40.04 dBm  |

7 SEM Result Summary

|           |               |
|-----------|---------------|
| Range 1   |               |
| Range Low | -280.000 MHz  |
| Range Up  | -240.500 MHz  |
| RBW       | 1.000 MHz     |
| Frequency | 27.655 94 GHz |
| Power Abs | -63.58 dBm    |
| Power Rel | -65.46 dB     |
| ΔLimit    | -43.58 dB     |
| Range 2   |               |

Signal Description

Radio Frame Config

Restore Settings

Trigger/Signal Capture

Parameter Estimation/Tracking

Demod

Evaluation Range

Result Settings

Display Config

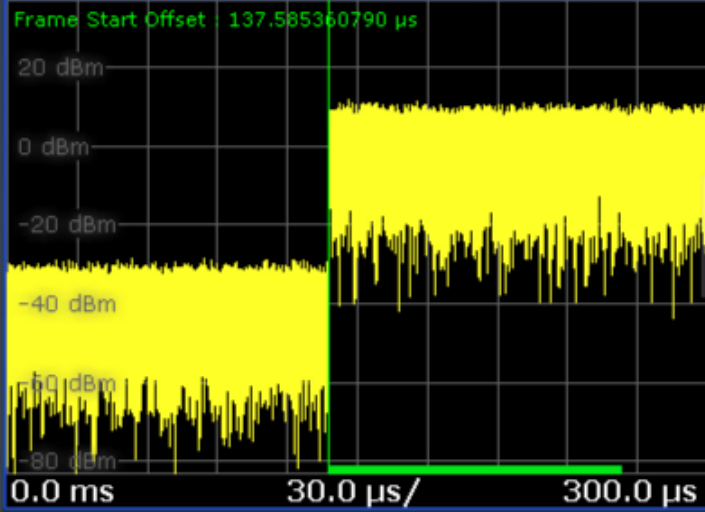
Overview



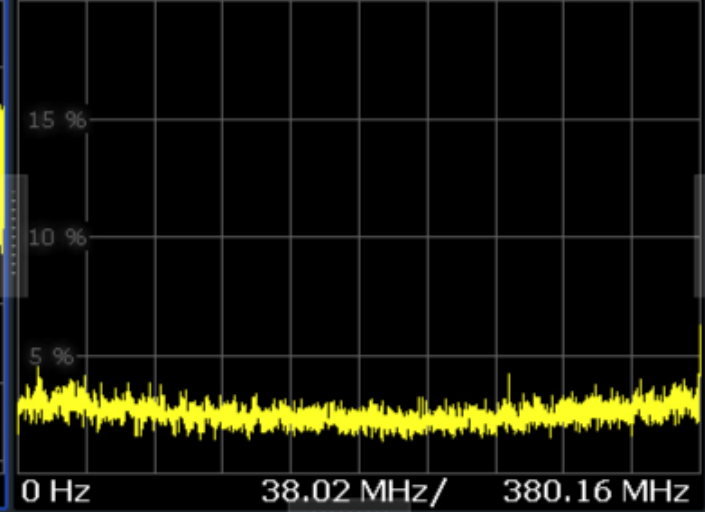
Ref Level 7.00 dBm Freq 27.9 GHz Mode Downlink, 400 MHz Capture Time 300.0  $\mu$ s BWP/SS All  
 Att 17 dB Frame Count 1 of 1(1) Frame 1 Auto Demod Once

TRG:TIM FRCORR YIG Bypass

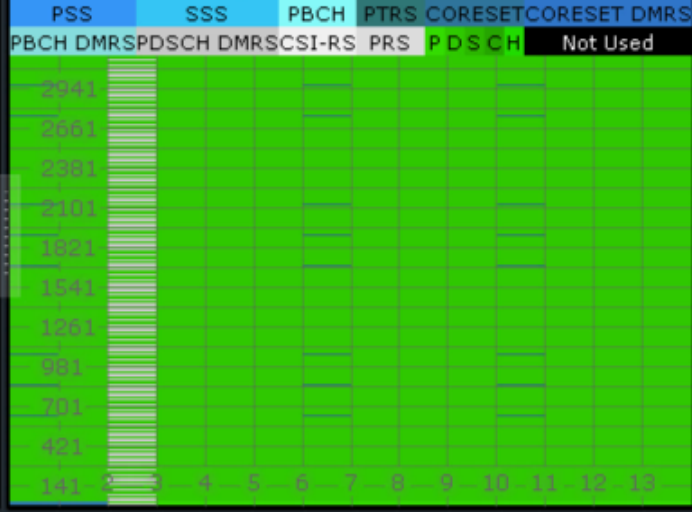
1 Capture Buffer I/Q Export 1 Clrw



3 EVM vs Carrier 1 Avg 2 Min 3 Max



4 Alloc ID vs Symbol X Carrier



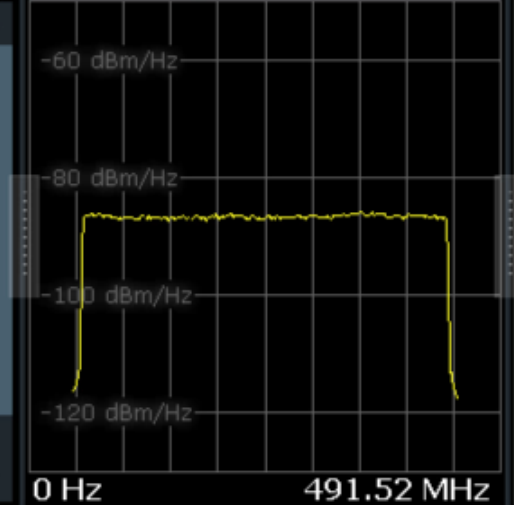
2 Result Summary Selected Frame Frame Averaged

| Frame Results Averaged | Mean | Limit | Max  | Min  |
|------------------------|------|-------|------|------|
| EVM PDSCH QPSK (%)     |      | 18.50 |      |      |
| EVM PDSCH 16QAM (%)    |      | 13.50 |      |      |
| EVM PDSCH 64QAM (%)    | 2.61 | 9.00  | 2.61 | 2.61 |
| EVM PDSCH 256QAM (%)   |      | 4.50  |      |      |

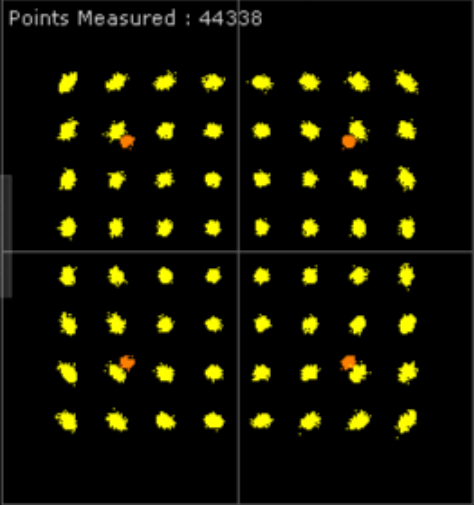
Results for Selection BWP/SS All, Subframe All, Slot All

|                          |        |  |        |        |
|--------------------------|--------|--|--------|--------|
| EVM All (%)              | 2.58   |  | 2.58   | 2.58   |
| EVM Phys Channel (%)     | 2.60   |  | 2.60   | 2.60   |
| EVM Phys Signal (%)      | 2.04   |  | 2.04   | 2.04   |
| Sampling Error (ppm)     | -0.36  |  | -0.36  | -0.36  |
| I/Q Offset (dB)          | -56.50 |  | -56.50 | -56.50 |
| I/Q Gain Imbalance (dB)  | -      |  | -      | -      |
| I/Q Quadrature Error (°) | -      |  | -      | -      |
| OSTP (dBm)               | 1.88   |  |        |        |

5 Power Spectrum 1 Clrw



6 Constellation Diagram Points Measured : 44338



Signal Description

Radio Frame Config

Trigger/Signal Capture

Parameter Estimation/Tracking

Demod

Evaluation Range

Result Settings

Display Config

Overview

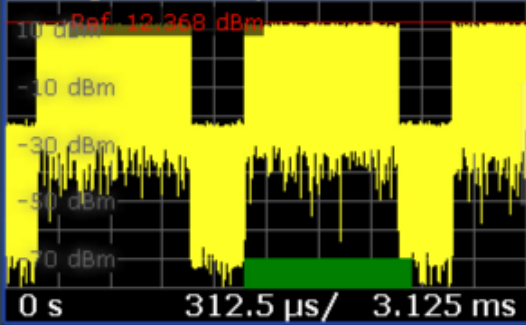


Amplifier

MultiView Sp..um x Spe..m2 x 5GNREVM x ACLR x AC..EM x Dis..ion x

Ref Level 12.37 dBm Capture Time 3.125 ms TTS 1.430041 ms  
Att 22 dB Freq 27.9 GHz Meas BW 491.52 MHz SRate 614.4 MHz  
TRG:TIM FRCORR YIG Bypass EQUALIZER

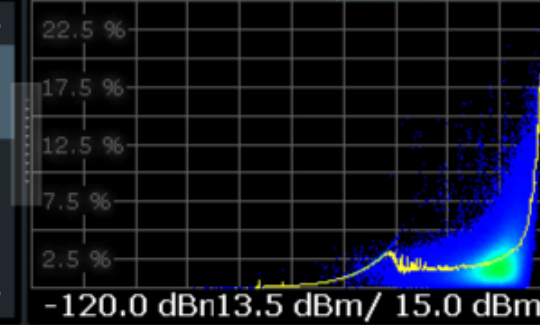
1 Magnitude Captur... ● 1Clrw



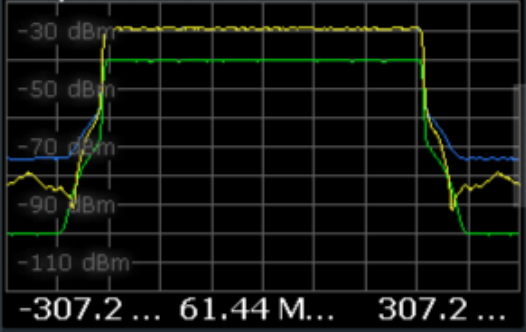
2 Result Summary

| Modulation Accuracy | Min   | Current    | Max    | Unit |
|---------------------|-------|------------|--------|------|
| Raw EVM             | 0.002 | 2.665      | 22.509 | %    |
| Raw Model EVM       | 0.001 | 2.540      | 19.753 | %    |
| Frequency Error     | ---   | -25183.... | ---    | Hz   |
| Power               | Min   | Current    | Max    | Unit |
| Power In            | ---   | -9.04      | 1.61   | dBm  |

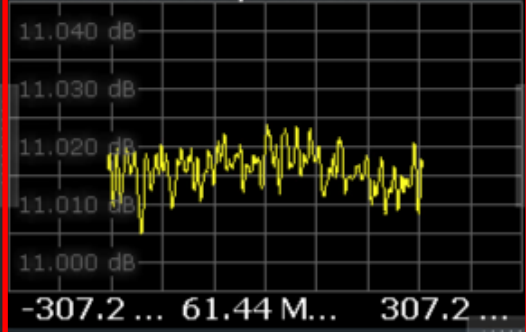
3 EVM \ ● 1Av Clr low 2C...



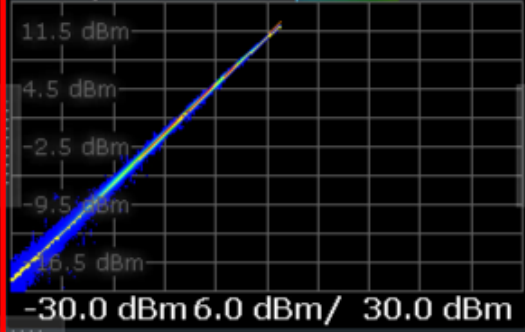
4 Spectrum FFT ● 1Clrw



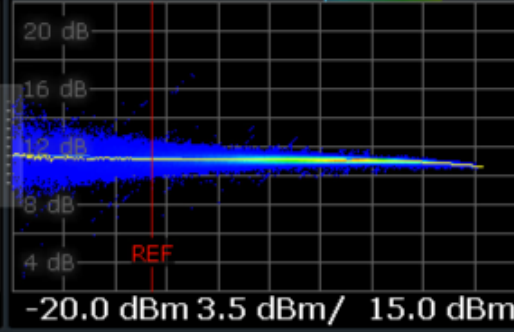
5 Channel Response... ● 1Clrw



6 AM/... ● 1Av Clr low 3Clrw



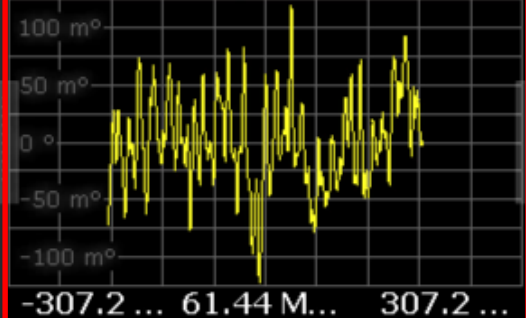
7 Gain ( ● 1Av Clr low 3...



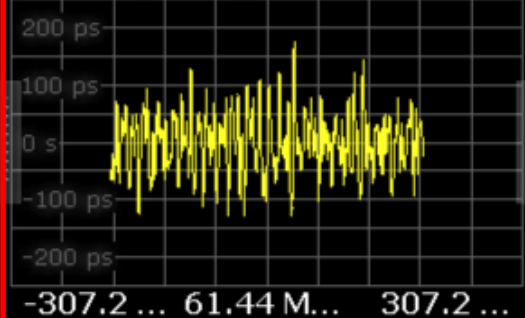
8 ACLR - RBW: 4.9152 MHz

| Channel Band... | Offset              |
|-----------------|---------------------|
| Tx1 (R...       | 380.01...           |
| Tx Total        |                     |
| Channel Band... | Offset              |
| Adj             | 380.01... 400.00... |

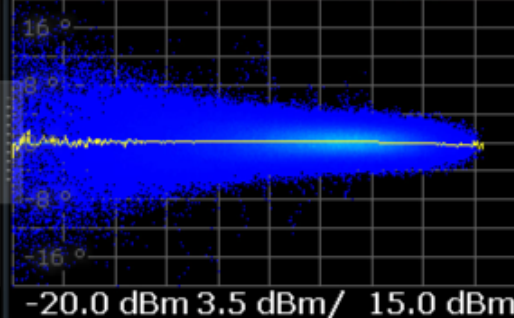
9 Channel Respons... ● 1Clrw



10 Group Delay ● 1Clrw



11 Phase ● 1Av Clr low 3...



- Reference Signal
- Input/Output
- Data Acquisition
- Sync/Error Est/Comp
- Meas Settings
- Update DPD Tables on Generator
- Apply DPD On  Off
- Result Config
- Display Config
- Overview

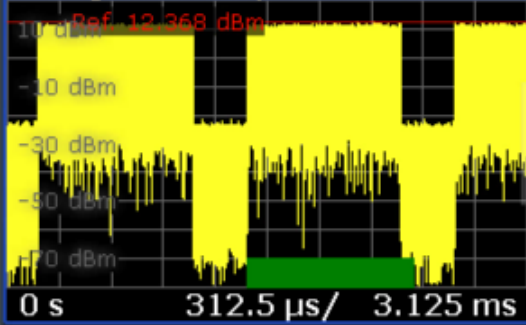


Amplifier

MultiView Sp..um x Spe..m2 x 5GNREVM x ACLR x AC..EM x Dis..ion x

Ref Level 12.37 dBm Capture Time 3.125 ms TTS 1.437831 ms  
Att 22 dB Freq 27.9 GHz Meas BW 491.52 MHz SRate 614.4 MHz  
TRG:TIM FRCORR YIG Bypass

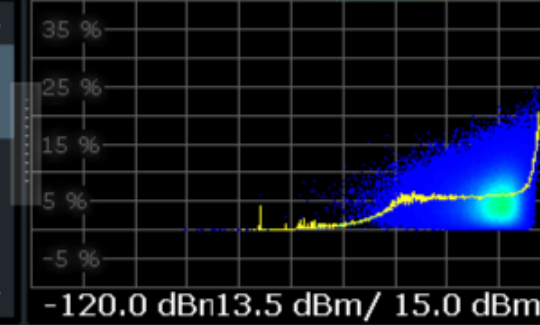
1 Magnitude Captur... ● 1Clrw



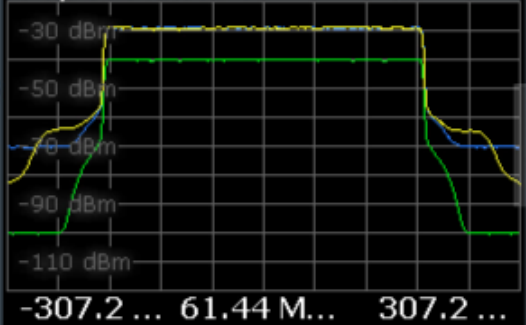
2 Result Summary

| Modulation Accuracy | Min   | Current    | Max    | Unit |
|---------------------|-------|------------|--------|------|
| Raw EVM             | 0.008 | 5.958      | 24.826 | %    |
| Raw Model EVM       | 0.003 | 5.913      | 22.912 | %    |
| Frequency Error     | ---   | -25182.... | ---    | Hz   |
| Power               | Min   | Current    | Max    | Unit |
| Power In            | ---   | -9.04      | 1.61   | dBm  |

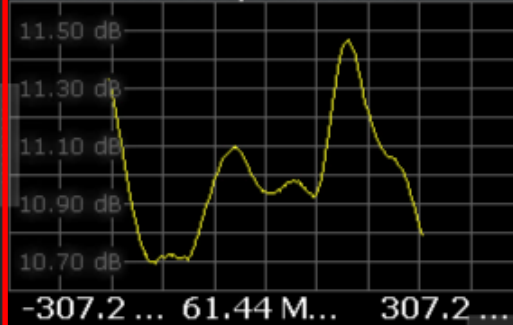
3 EVM \ ● 1Av Clr low 2C...



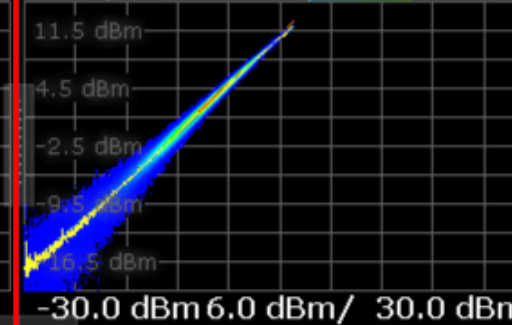
4 Spectrum FFT ● 1Clrw



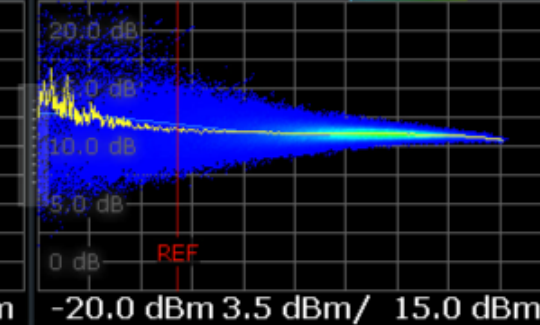
5 Channel Response... ● 1Clrw



6 AM/... ● 1Av Clr low 3Clrw



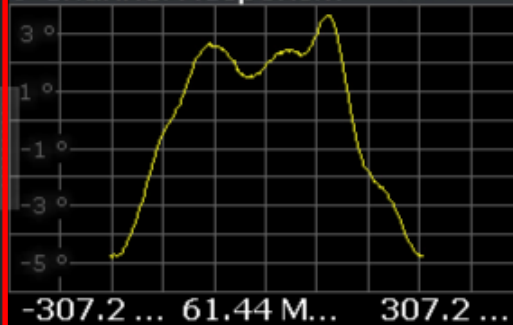
7 Gain ( ● 1Av Clr low 3...



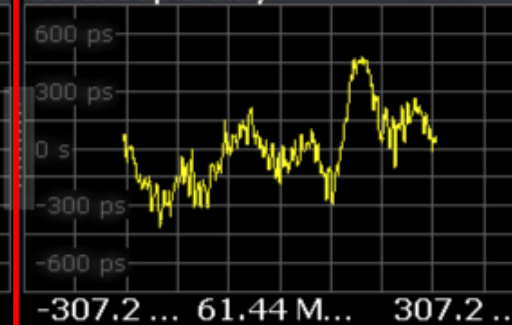
8 ACLR - RBW: 4.9152 MHz

| Channel Band... | Offset              |
|-----------------|---------------------|
| Tx1 (R...       | 380.01...           |
| Tx Total        |                     |
| Channel Band... | Offset              |
| Adj             | 380.01... 400.00... |

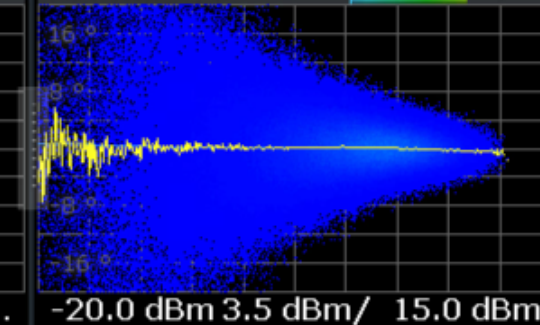
9 Channel Respons... ● 1Clrw



10 Group Delay ● 1Clrw

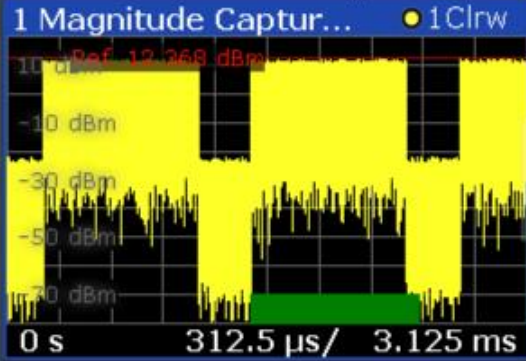


11 Phas... ● 1Av Clr low 3...



- Reference Signal
- Input/Output
- Data Acquisition
- Sync/Error Est/Comp
- Meas Settings
- Update DPD Tables on Generator
- Apply DPD On Off
- Result Config
- Display Config
- Overview

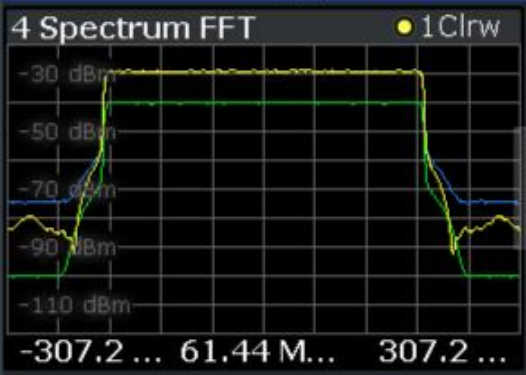
Ref Level 12.37 dBm Capture Time 3.125 ms TTS 1.469883 ms  
 Att 22 dB Freq 27.9 GHz Meas BW 491.52 MHz SRate 614.4 MHz  
 TRG:TIM FRCORR YIG Bypass EQUALIZER



2 Result Summary

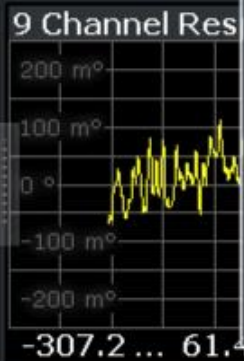
| Modulation Accuracy | Min | Current | Max | Unit |
|---------------------|-----|---------|-----|------|
| Raw EVM             |     |         |     |      |
| Raw Model EVM       |     |         |     |      |
| Frequency Error     |     |         |     |      |
| Power               |     |         |     |      |
| Power In            |     |         |     |      |

3 EVM 22.5 % 1Av Cln low 2C...



8 ACLR - RBW: 4.9152 MHz

| Channel   | Band...   | Offset    |
|-----------|-----------|-----------|
| Tx1 (R... | 380.01... | 0         |
| Tx Total  |           | 0         |
| Channel   | Band...   | Offset    |
| Adj       | 380.01... | 400.00... |



### Synchronization/Error Est/Comp

Sync and Eval Range Error Est/Compensation Equalizer

Equalizer Filter Length (Samples) for Training:

Train Equalizer Filter on Current I/Q Data

Load Equalizer Filter... Save Equalizer...

Current Equalizer Filter

Equalizer Filter Source: Generated by FSW-K18  
 Date Modified: 11.04.2022 18:11:46  
 Equalizer Filter Length: 100

Apply Equalizer Filter



### Save Equalizer

Drive: (C:) SYSTEM Path: \_K18\_Equalizer (C:/R\_S/instr/user/\_K18\_Eq

| Files              | Size |
|--------------------|------|
| ..                 |      |
| EqualizerCoeff.csv | 2 kB |

File Name: EqualizerCoeff.csv

File Type: **.csv** .fres

File Explorer Save

MultiView Sp..um

Ref Level 12.37 dBm

Att 22 dB

TRG:TIM FRCORR YIG Bypa

1 Magnitude Captur...

0 s 312.5 μs/ 3

4 Spectrum FFT

-307.2 ... 61.44 M...

8 ACLR - RBW: 4.9152 M

|                 |                 |
|-----------------|-----------------|
| Channel Band... | Offs            |
| Tx1 (R...       | 380.01...       |
| Tx Total        |                 |
| Channel Band... | Offs            |
| Adj             | 380.01... 400.0 |

Amplifier

Reference Signal

Input/Output

Data Position

Equalizer

1Av Cln low 2C...

Equalizer...

Off

Meas settings

Update DPD Tables on Generator

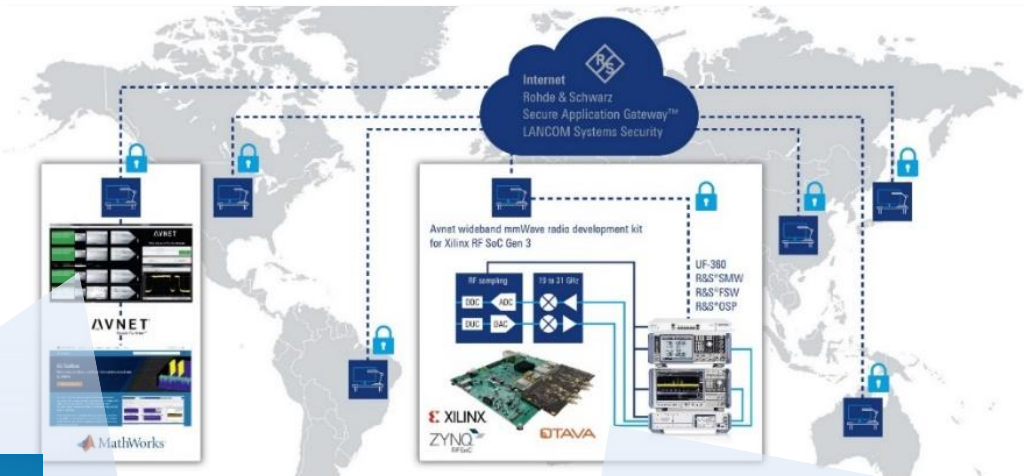
Apply DPD On Off

Result Config

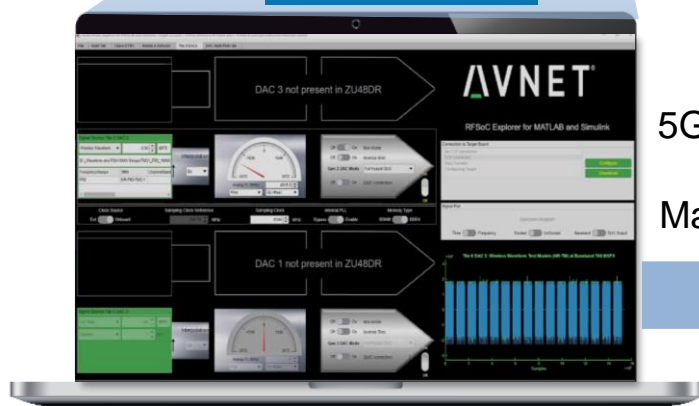
Display Config

Overview

# Instrument-assisted pre-equalizer in Xilinx RFSoc Gen-3

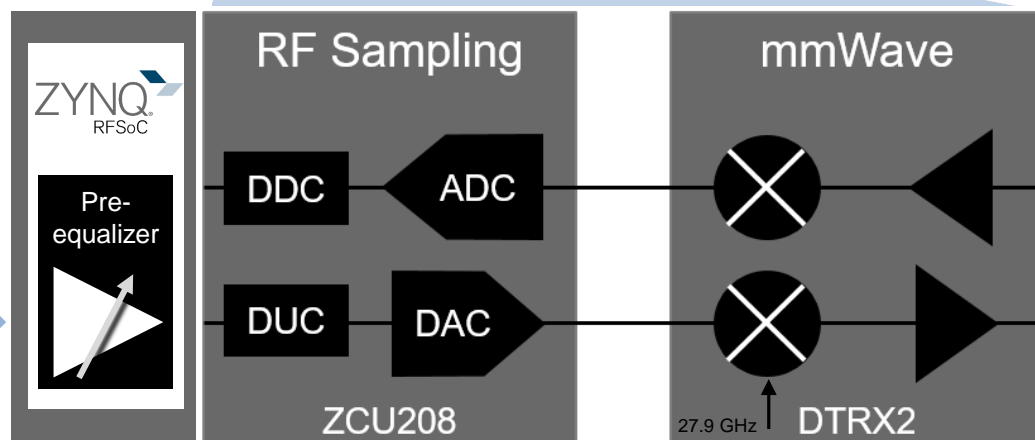


Avnet RFSoc Explorer<sup>®</sup> for MATLAB



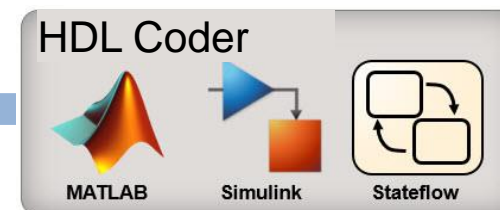
5G ToolBox from MathWorks

Avnet mmWave Radio Development Kit for Xilinx RFSoc Gen-3



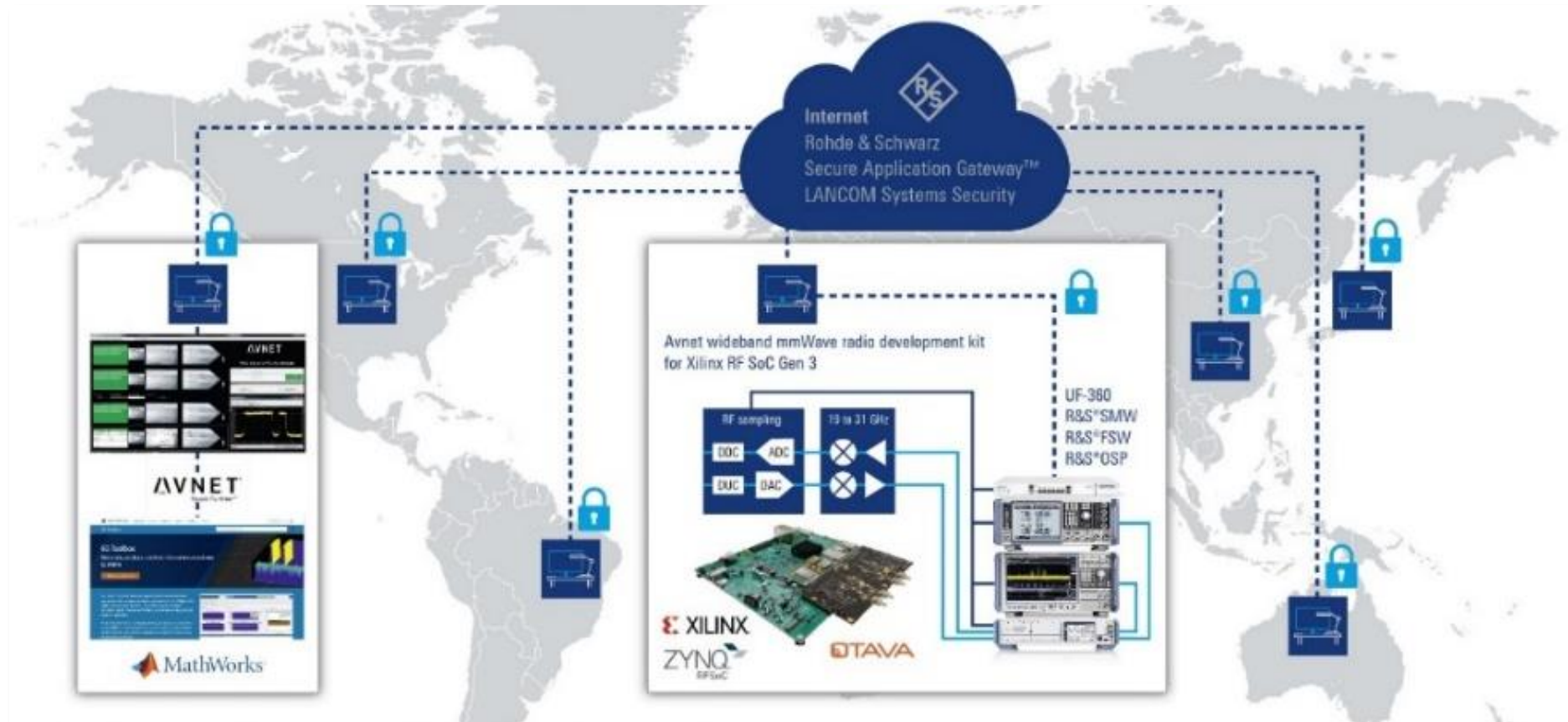
R&S FSW High End Signal and Spectrum Analyzer

Synthesizable HDL  
Avnet



VISA  
Channel response  
Rohde & Schwarz

# Rohde & Schwarz Secure Applications Gateway



- Join engineers from Avnet, Otava and Rohde & Schwarz for guided tour of automated remote testing
- Experience 'virtual hands-on' access as though the test equipment were on your desk
- Register for the Avnet workshop at: [www.avnet.me/mmw-workshop](http://www.avnet.me/mmw-workshop)

## Conclusion

- mmWave RF systems require secure, robust test automation
- Avnet RFSOC Explorer enables AMD/Xilinx RFSoc within MATLAB with Rohde & Schwarz MATLAB support for 'instrument in-the-loop' standard compliance testing
- Rohde & Schwarz Secure Application Gateway™ platform enables worldwide collaborative remote access in real-time with state-of-the-art data security



# MATLAB EXPO

Thank you



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