Optimizing Terminal Connectivity: Advanced RF Testing Strategies for Satellite User Stations

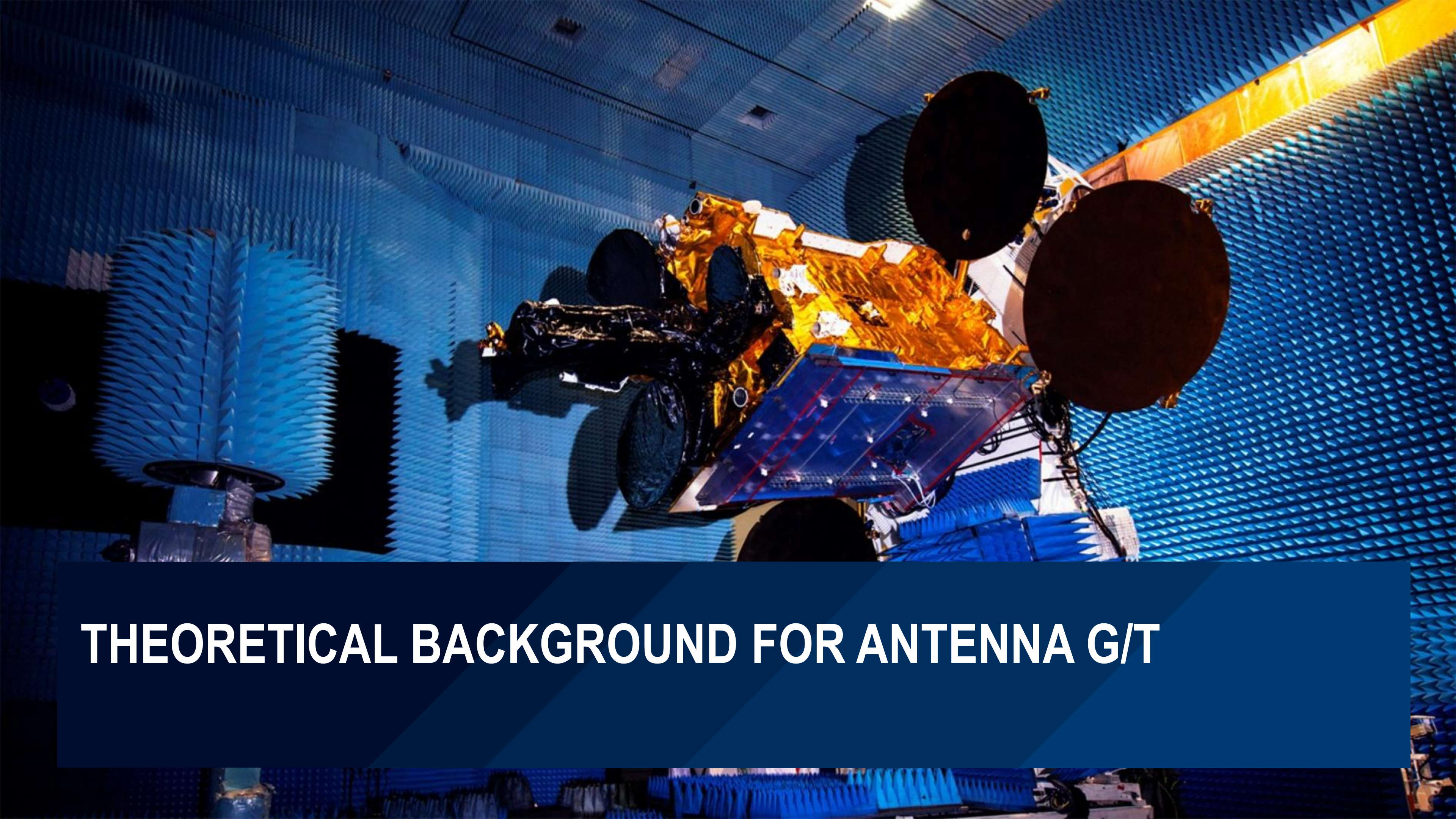
Arsene Chen
Senior Application Engineer Manager

ROHDE&SCHWARZ

Make ideas real

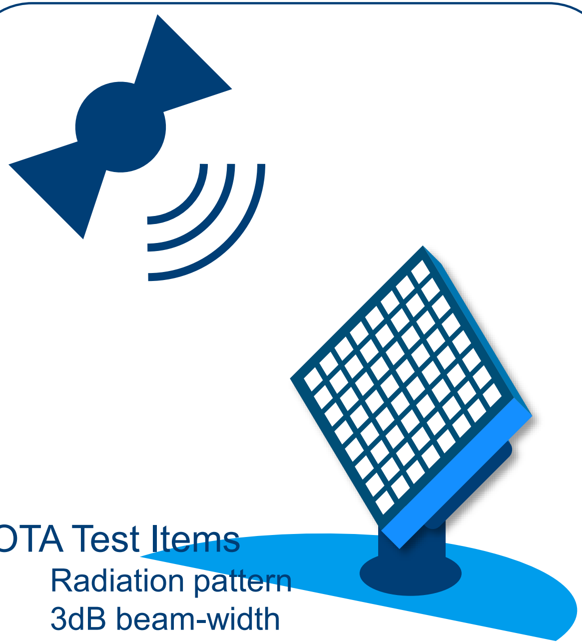
OUTLINE

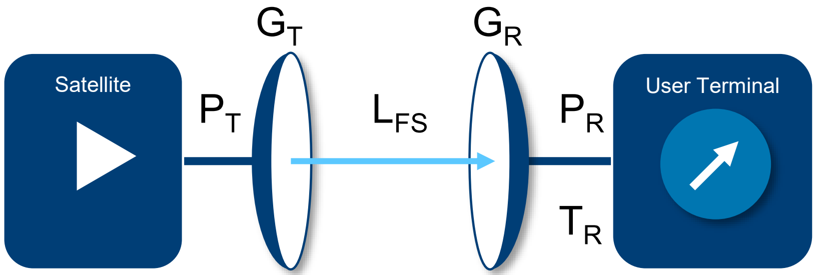
- ► G/T Recap
- ► Advanced RF Testing Strategies for UT
- ► Summary



THEORETICAL BACKGROUND FOR ANTENNA G/T

LINK BUDGET AND CARRIER-TO-NOISE RATIO CALCULATION





OTA Test Items
- Radiation pattern
- 3dB beam-width
- Beam accuracy
- G/T (mostly concerned for Satellite)
- EIRP…

Effective isotropic radiated power: $EIRP_T = P_T G_T$

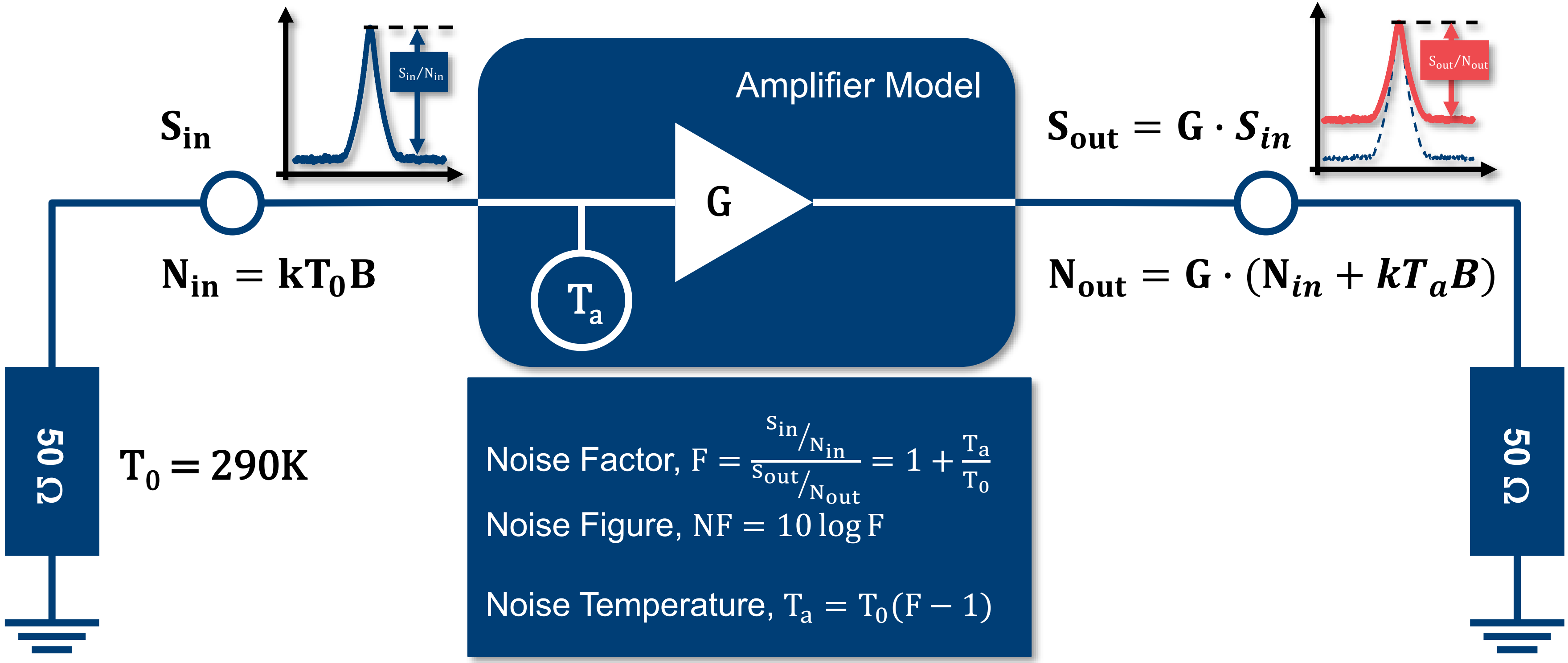
Received carrier power: $P_R = \frac{P_T G_T G_R}{L_{FS}}$

Carrier-to-noise ratio: $\left(\frac{C}{N}\right)_{UT} = \frac{P_R}{N} = \frac{P_T G_T G_R}{L_{FS} k T_R B} = (EIRP_T)\left(\frac{1}{L_{FS}}\right)\left(\frac{G_R}{T_R}\right)\left(\frac{1}{k}\right)$

$$\left(\frac{C}{N}\right)_{UT} = (EIRP_T)\left(\frac{1}{L_{FS}}\right)\left(\frac{G_R}{T_R}\right)\left(\frac{1}{k}\right)$$

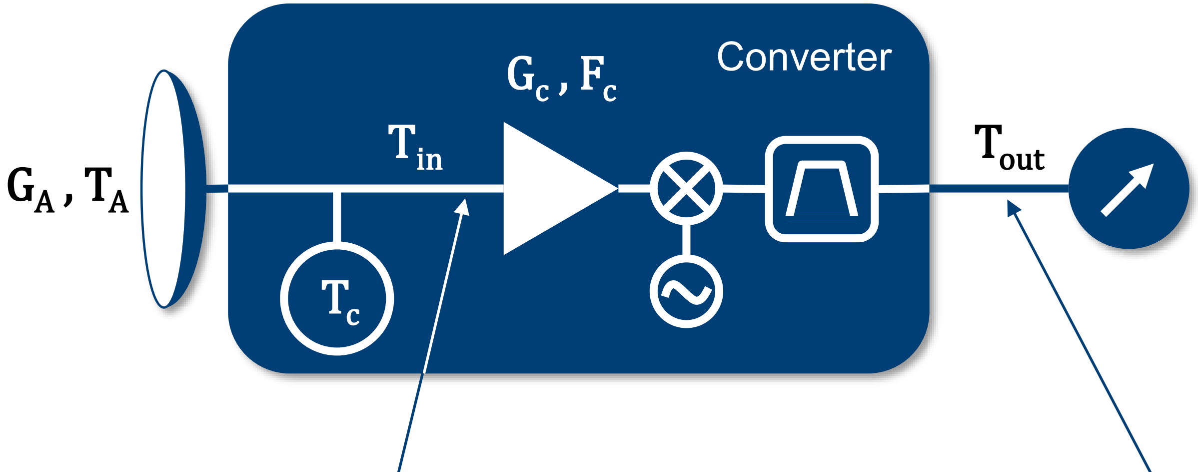
Transmitter — Channel — Receiver — Constant

NOISE TEMPERATURE OF AN AMPLIFIER MODEL



The noise temperature T_a of the amplifier model is defined at its input side

RECEIVING SYSTEM NOISE TEMPERATURE



G_A: Antenna gain
T_A: Antenna noise temperature
G_c: Converter gain
T_c: Converter noise temperature
F_c: Converter noise factor
T_{in}: system noise temperature at input
T_{out}: system noise temperature at output

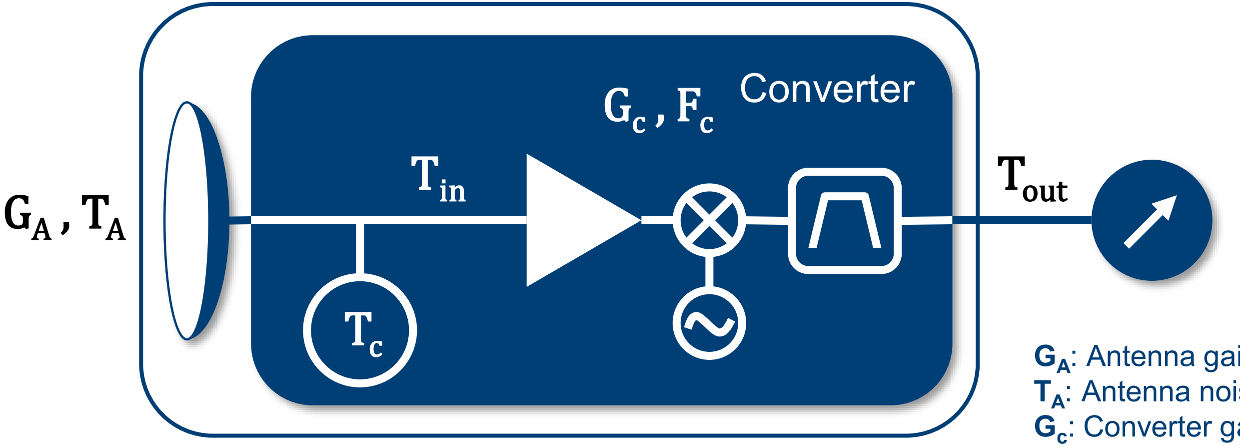
$$T_{in} = T_A + T_c$$

noise temperature at input

$$T_{out} = G_c T_A + G_c T_0 (F_c - 1)$$

noise temperature at output

ANTENNA G/T PERFORMANCE



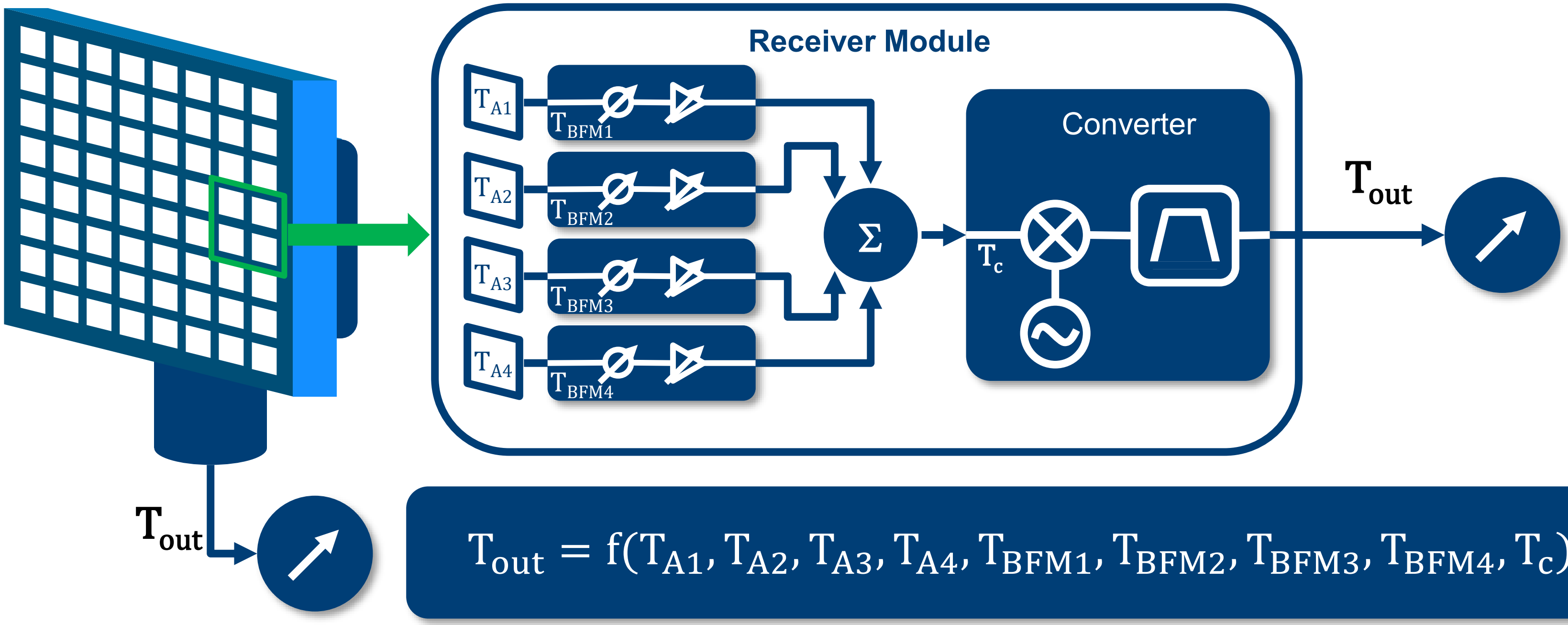
- G_A: Antenna gain
- T_A: Antenna noise temperature
- G_c: Converter gain
- T_c: Converter noise temperature
- F_c: Converter noise factor
- T_{in}: system noise temperature at input
- T_{out}: system noise temperature at output
- G_R: Antenna receiver module gain
- T_R: Antenna receiver noise temperature

For an antenna receiver module:

$$\frac{G}{T} = \frac{G_A}{T_{in}} = \frac{G_A}{T_A + T_c} = \frac{G_A G_c}{G_c T_A + G_c T_0 (F_c - 1)} = \frac{G_A G_c}{T_{out}} = \frac{G_R}{T_R}$$

The converter (amplifier) gain does not affect G/T.
Instead, it contributes to overall noise in antenna receiver module G/T.

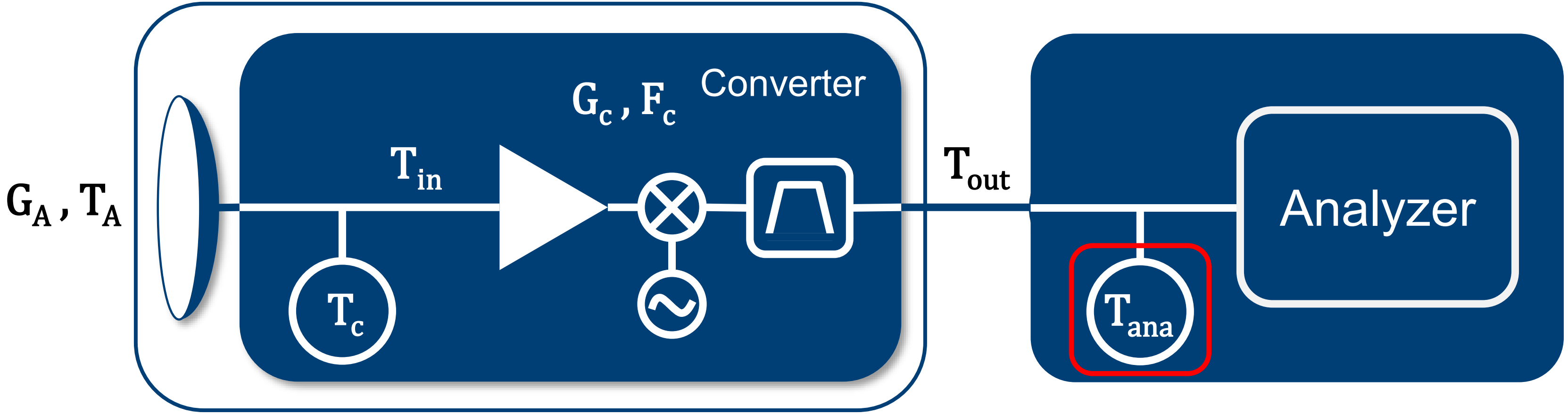
PHASE ARRAY ANTENNA NOISE TEMPERATURE



$$T_{out} = f(T_{A1}, T_{A2}, T_{A3}, T_{A4}, T_{BFM1}, T_{BFM2}, T_{BFM3}, T_{BFM4}, T_c)$$

Hardly to access T_{in} in a highly integrated system

G/T CALCULATE WITH GENERAL INSTRUMENTS



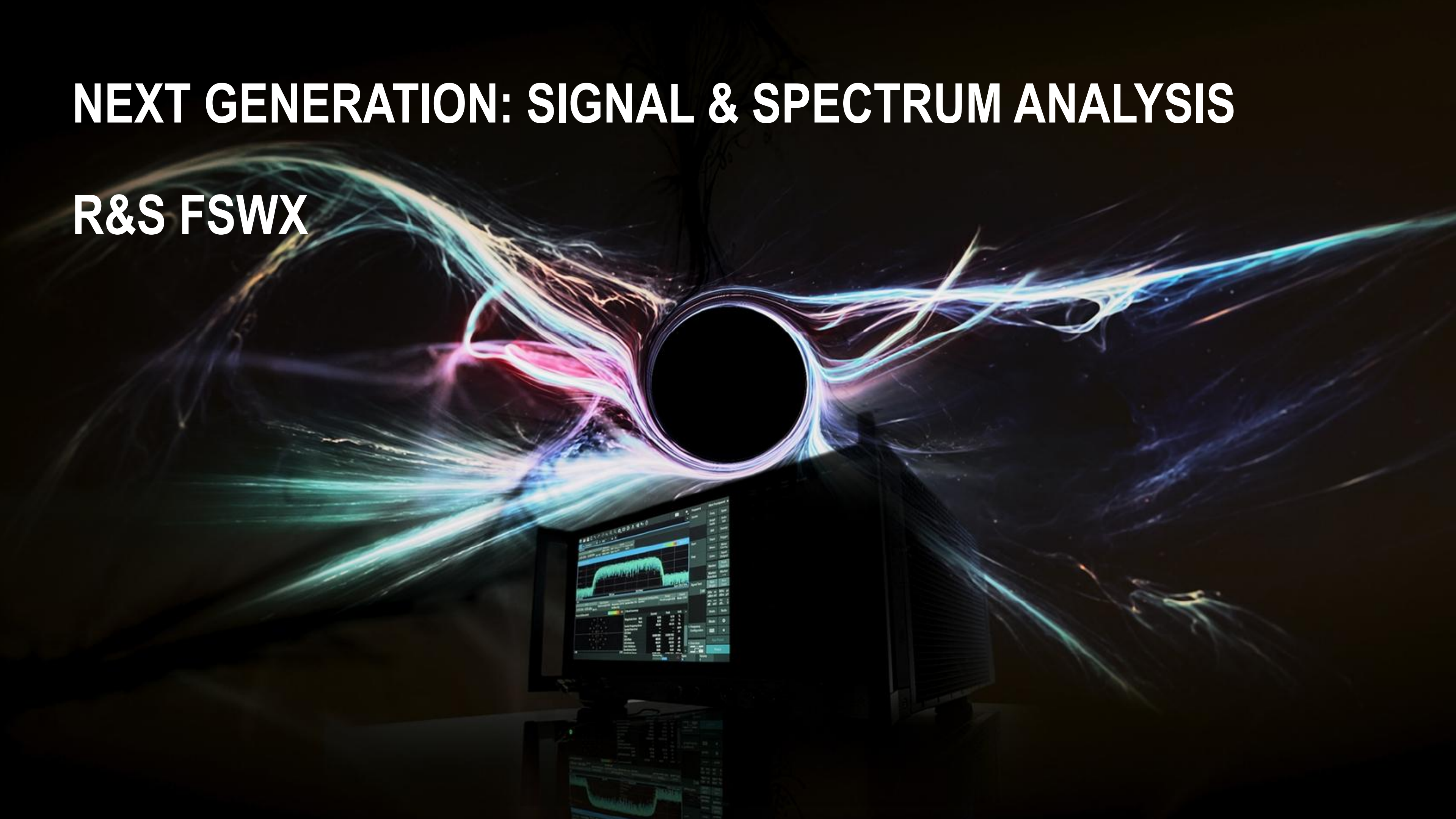
$$\frac{G_r}{(T_{out} + T_{ana})} = \frac{G_r}{\frac{ND}{k}} = \frac{G_r}{ND} \cdot k = \mathrm{Gain(dB)} - \mathrm{NoiseDensity\_meas}\left(\frac{\mathrm{dBm}}{\mathrm{Hz}}\right) + k\left(\frac{\mathrm{dBm}}{\mathrm{K} \cdot \mathrm{Hz}}\right)$$

Analyzer's Noise Figure, or T_{ana}, also plays a role in the noise density measurement result
Lower noise floor (DANL) or noise figure of analyzer is required to test G/T of high-performance UT

ADVANCED RF TESTING STRATEGIES FOR SATELLITE USER TERMINALS

NEXT GENERATION: SIGNAL & SPECTRUM ANALYSIS

R&S FSWX



FSWX – MEASURE THE IMPOSSIBLE

MULTIPLE INPUT CHANNELS

- First signal analyzer with multiple phase coherent channels

ENTIRE NEW MULTI-PATH INTERNAL ARCHITECTURE

- Cross correlation (high dynamic range for noise, phase noise and EVM measurements)
- Extended spurious free dynamic range

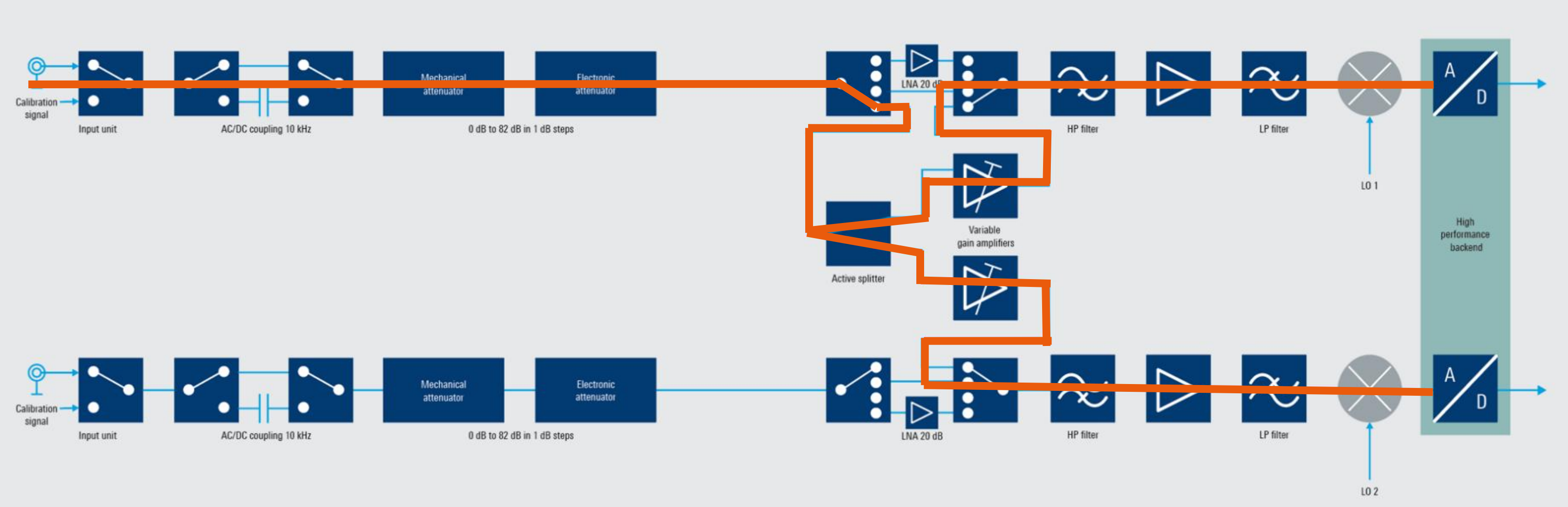
FREQUENCY > 100 GHz

- Unique instrument covering frequencies higher than 100 GHz as one box solution with pre-selection

ANALYSIS BANDWIDTH UP TO 8 GHz

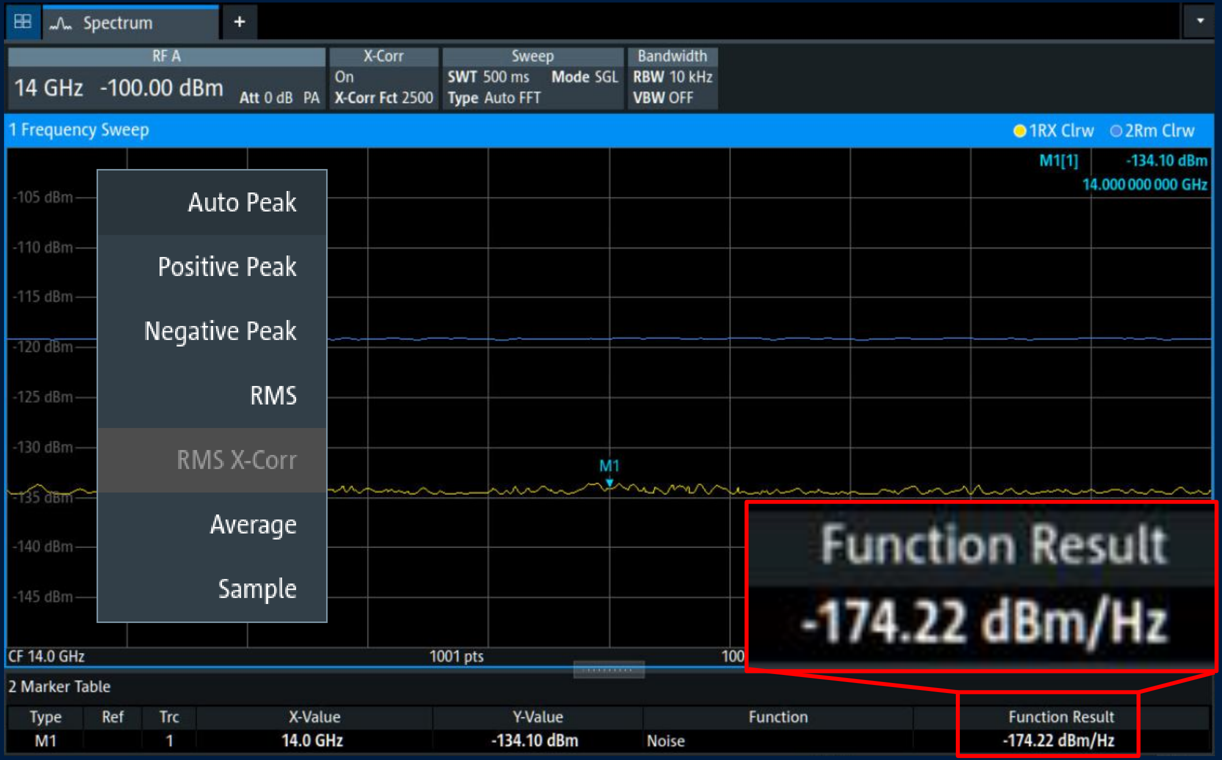
- Widest bandwidth on the market

ONE RF INPUT
HIGH PERFORMANCE CROSS-CORRELATION BACKEND



- Same LO Frequency
- Splitter/ switch
- Additional local oscillator
- High performance digital backend / enhanced signal processing

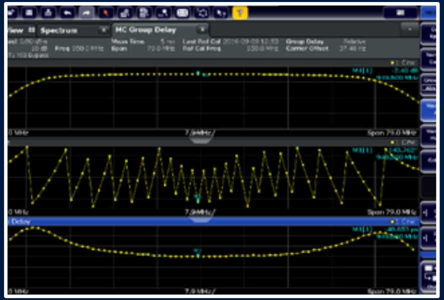
FSWX CROSS-CORRELATION – REACH THE LIMIT



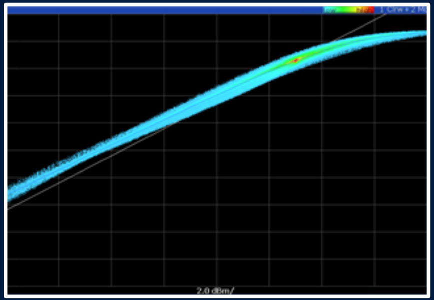
DANL reaches to thermal noise floor in room temperature (-174 dBm/Hz)

- Highest possible measurement sensitivity
- True DUT noise temperature performance is measured by ND

CROSS-CORRELATION BENEFITS FOR
SATELLITE MEASUREMENT APPLICATIONS



Group Delay

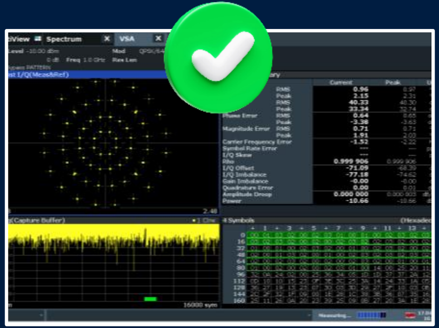


Gain Transfer / DPD

Noise Power Ratio

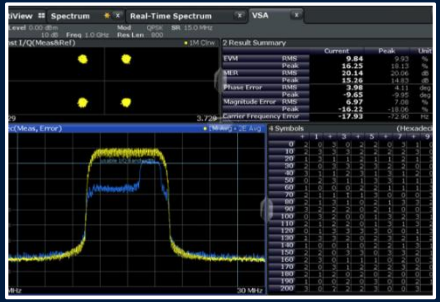
Spurious

Phase Noise



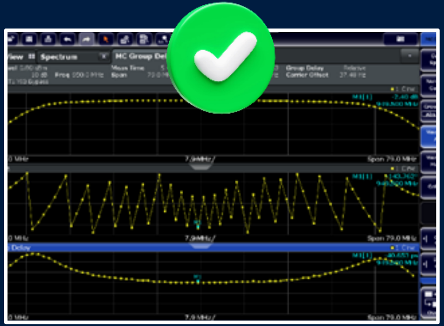
S2/S2X - Wideband

Bit Error Rate

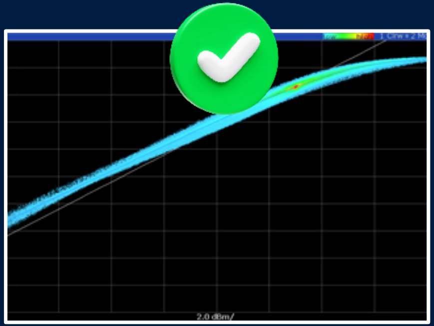


Interference

NEW TWO-PORT ARCHITECTURE BENEFITS FOR
SATELLITE MEASUREMENT APPLICATIONS



Group Delay



Gain Transfer / DPD

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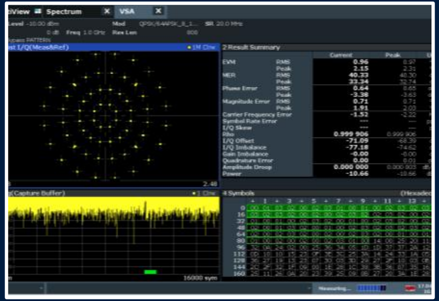

S2/S2X - Wideband

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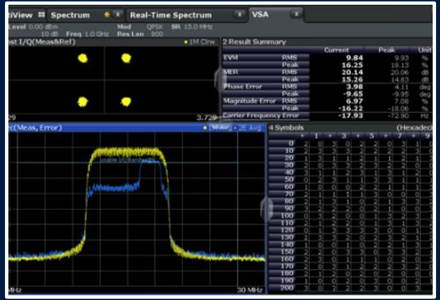
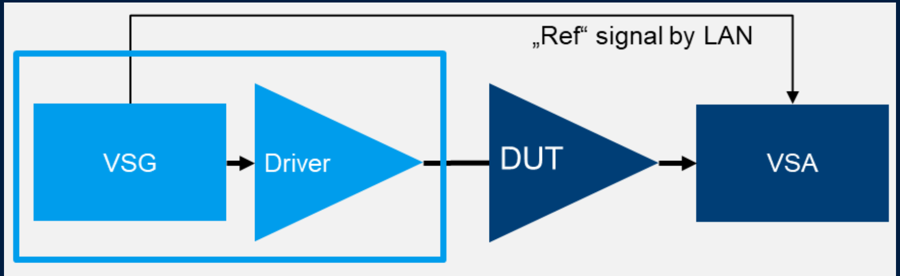


Interference

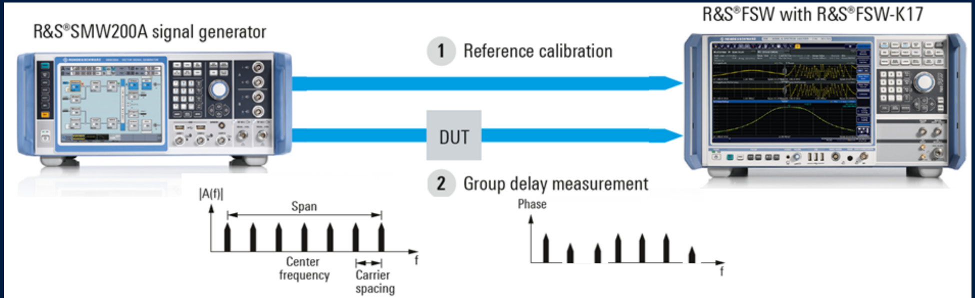
LEGACY GAIN TRANSFER, DPD, AND GROUP DELAY MEASUREMENTS

► Gain transfer / DPD



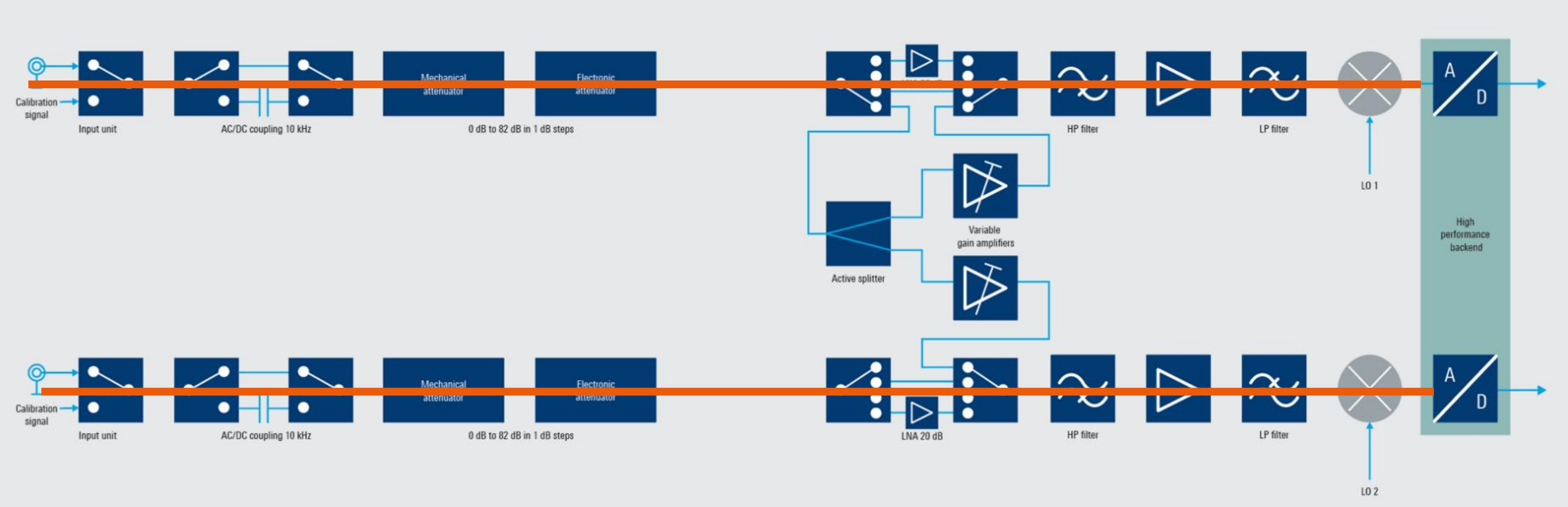
► Typical measurements include AM/AM, gain compression, AM/PM, EVM, distortion, ACLR
► Captures RF signal and compare measured and reference signal
  – Reference signal is an ideal waveform from VSG and transferred by LAN
  – SG/driver amplifier non-linearity didn’t consider

► Group Delay



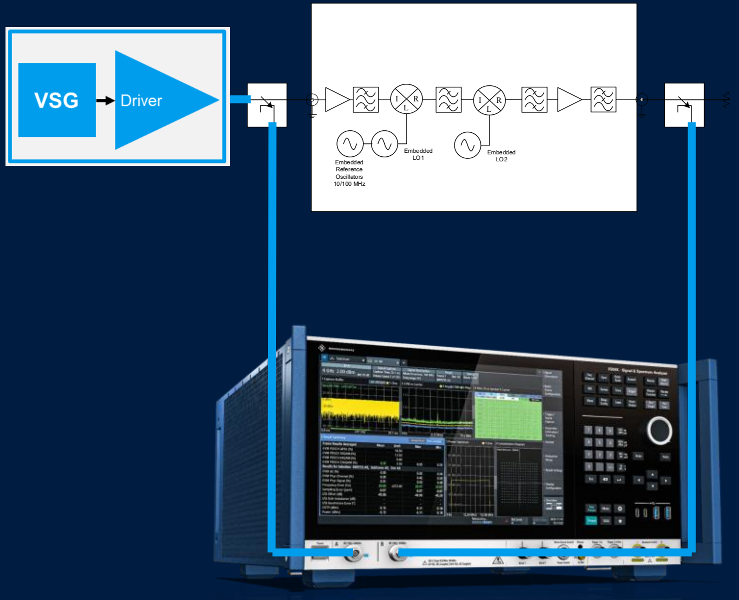
► Multicarrier-CW based group delay measurement, measures phase shift for each pair of consecutive carriers
► Reference calibration needed
► Supports frequency converting devices, absolute & relative group delay, no reference mixer required

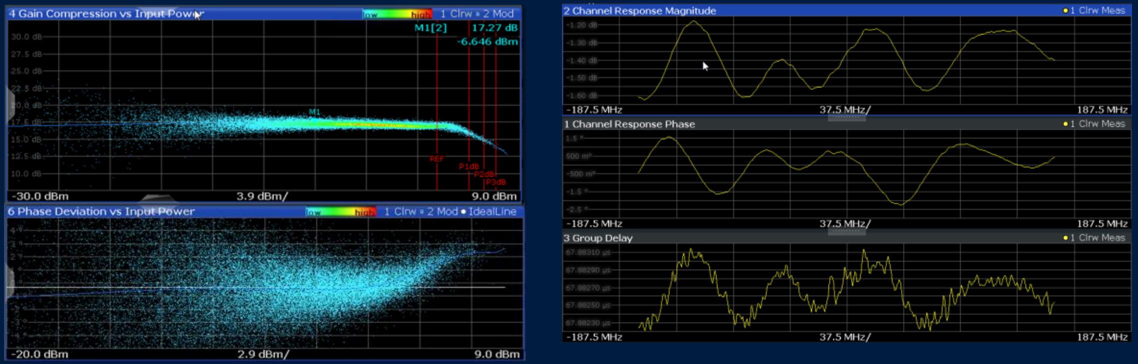
TWO RF INPUT
HIGH PERFORMANCE CROSS-CORRELATION BACKEND



- Additional RF input channel
- Additional local oscillator
- High performance digital backend / enhanced signal processing

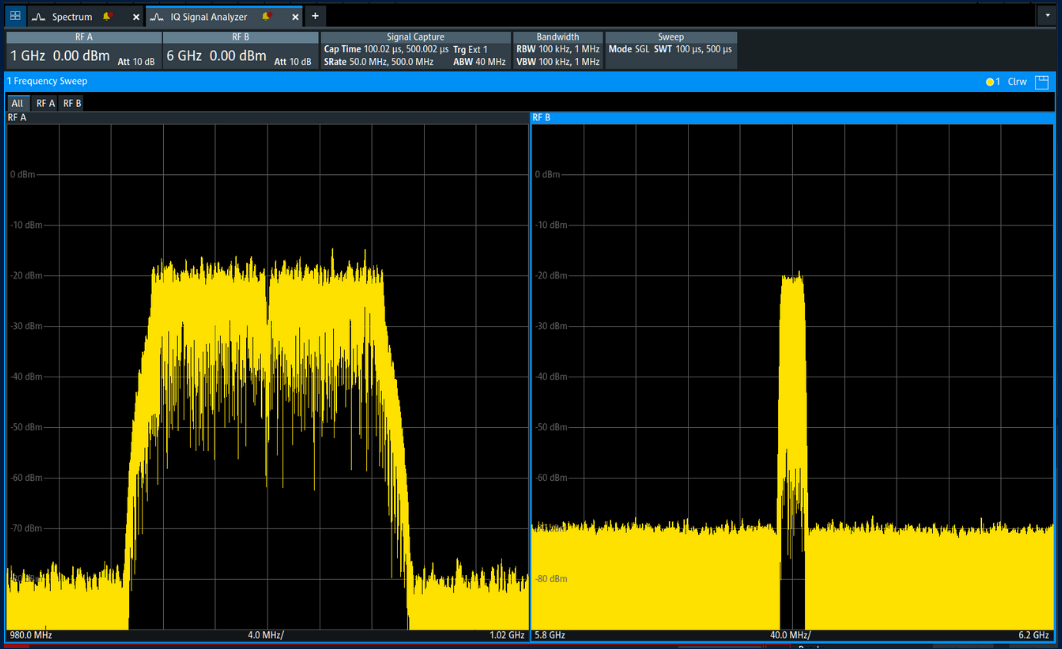
APPLICATION USE CASE
TRUE GAIN TRANSFER AND GROUP DELAY OF WIDEBAND SIGNALS





- ▶ Characterize DUT's true performance using modulated signals
- ▶ Dual channel measurement reduces uncertainty significantly
  - – Compare DUT input (IF or RF) to DUT output (RF or IF)
  - – Removed uncertainty of generator and driver amp RF stage
  - – Improved handling of non-linearity
- ▶ How much group delay/distortion is added by the DUT
- ▶ DUT is a Satellite User Terminal, Payload, or RF Component

FSWX IQ SPECTRUM ANALYZER
FOR MULTI-BAND, MULTI-BEAM, AND MULTI-ORBIT SOLUTION

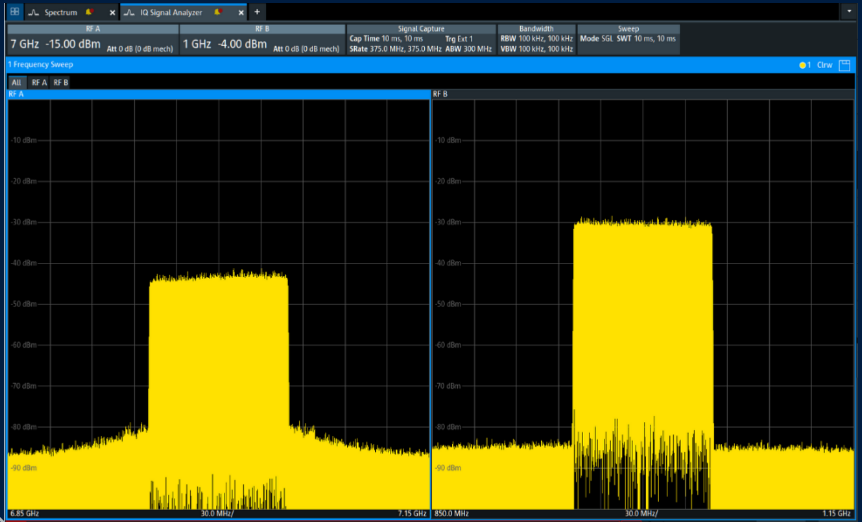


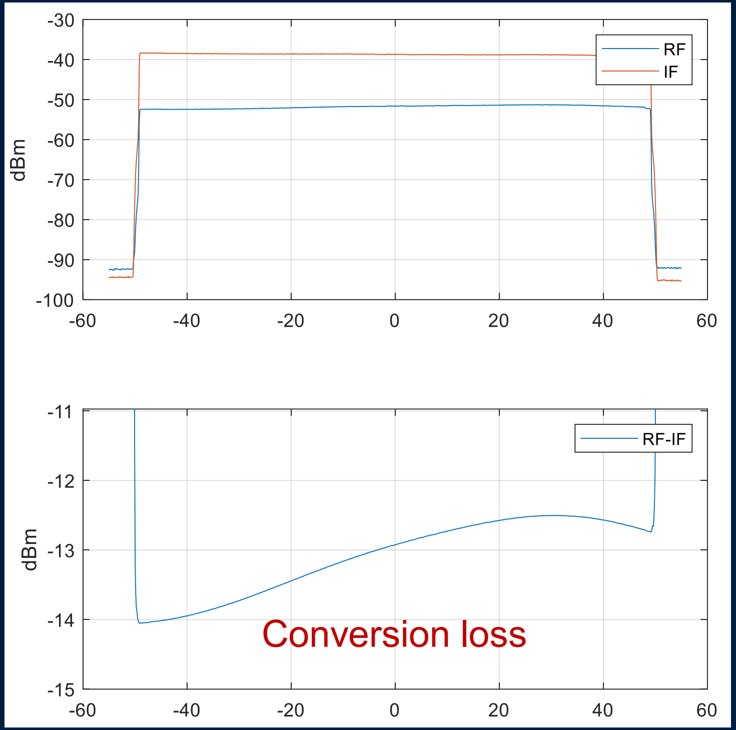
- IQ SPectrum Analyzer has **native support of multiple RF Inputs**
- Individual settings on both inputs:
  - Center frequency
  - Preamp, attenuation, reference level
  - Span, RBW, sweep time
  - …
- Power trigger on one RF Input can be used to start both measurements

IQ SPECTRUM ANALYZER
FOR MULTI-BAND, MULTI-BEAM, AND MULTI-ORBIT SOLUTION

Transfer function of a mixer

– Up-conversion mixer
– IF: 1GHz => RF B
– RF: 7GHz => RF A

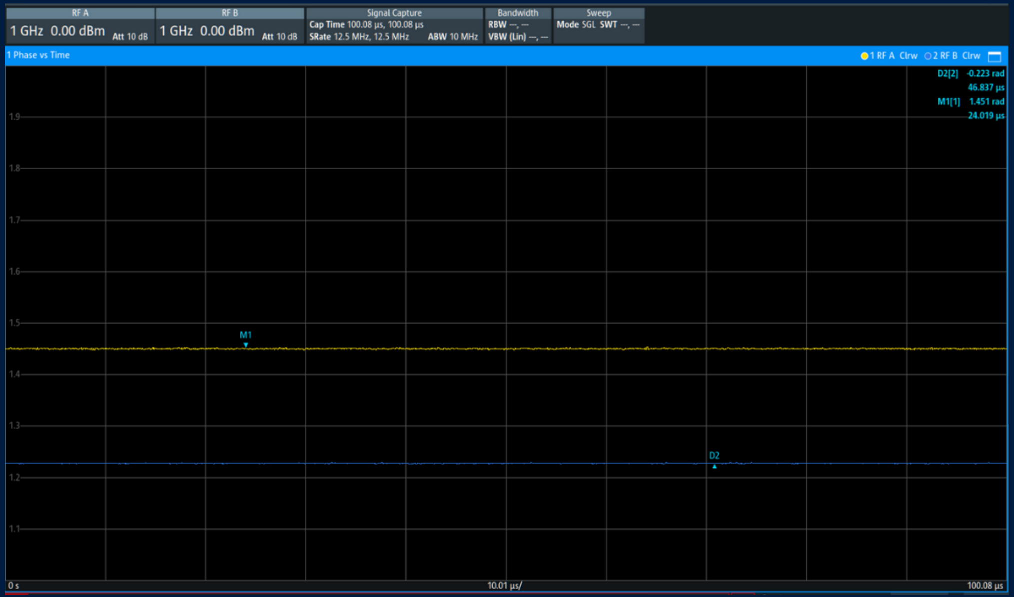


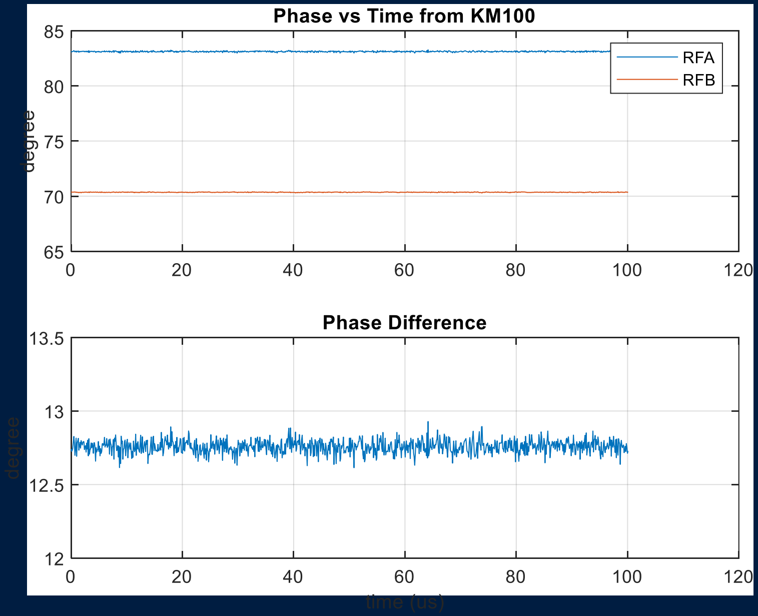


IQ SPECTRUM ANALYZER – PHASE VS. TIME
FOR BEAMFORMER AND PHASED ARRAY CALIBRATION

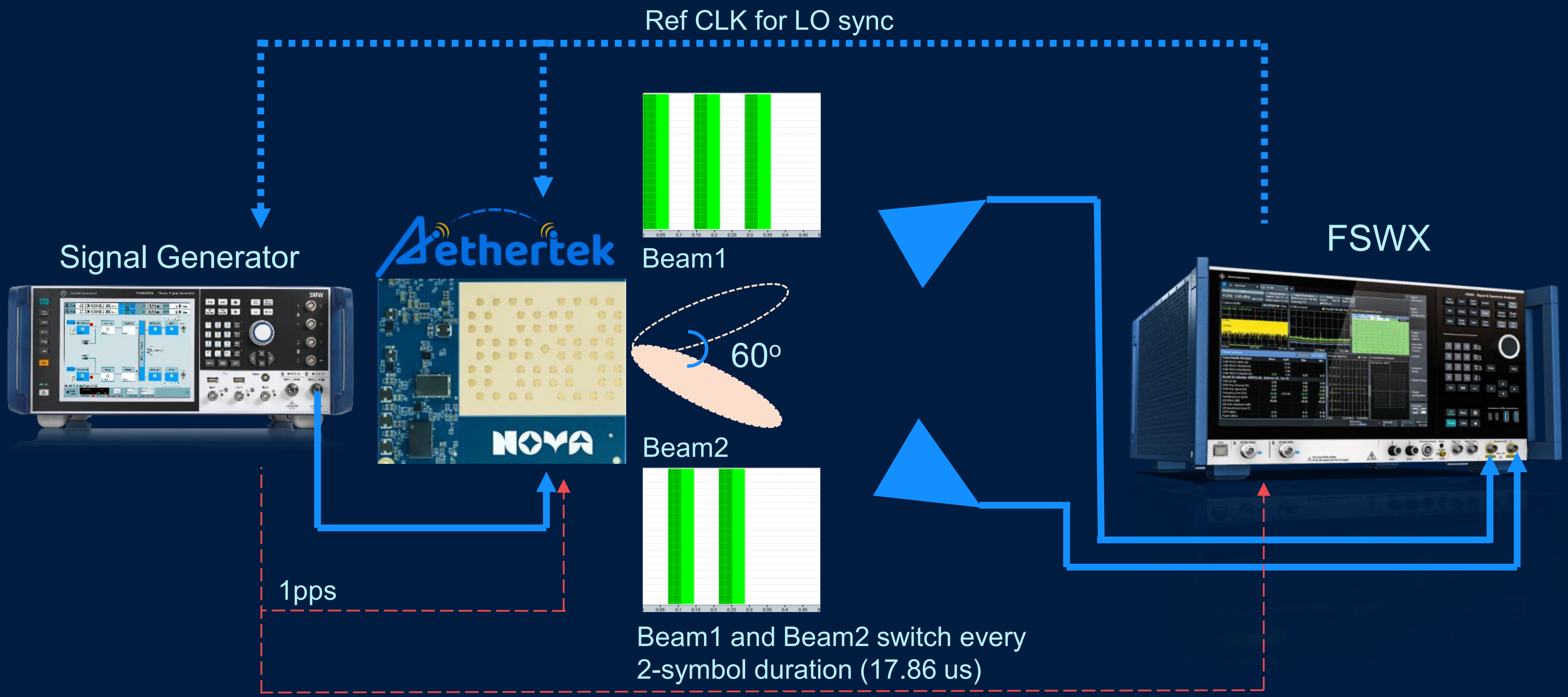
Phase difference of two ports – CW as stimulus

Phase vs. Time of 2 RF inputs



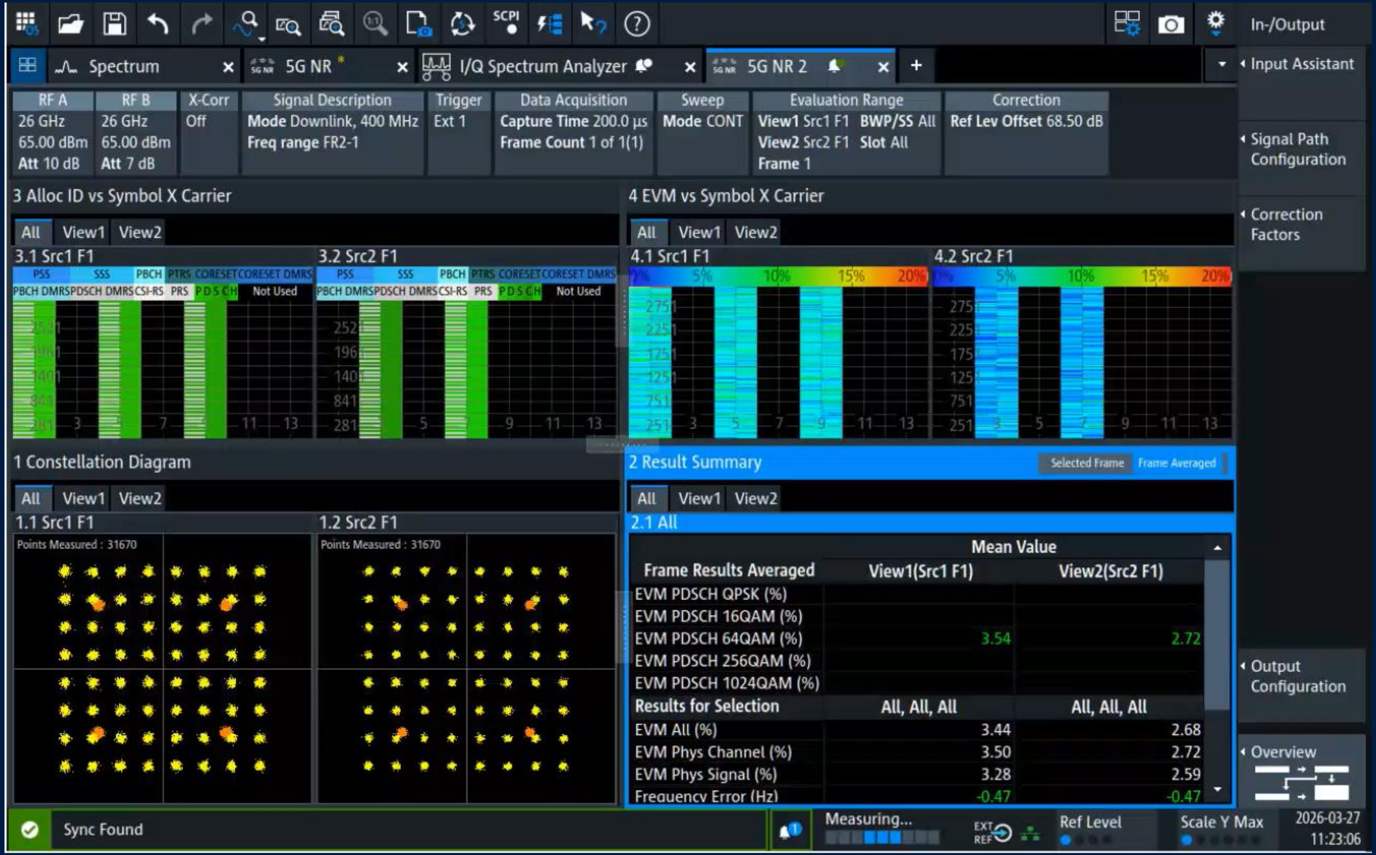


BEAM SWITCHING MEASUREMENT WITH FSWX



Beam1 and Beam2 switch every
2-symbol duration (17.86 us)

BEAM SWITCHING MEASUREMENT WITH FSWX



SUMMARY

- To achieve good **carrier-to-noise ratio** for high loss satellite communication, the design of antenna receiver module with good **G/T** is important.

- Advanced RF Test strategies are introduced.
  - The **cross-correlation** could improve the analyzer sensitivity and improve the test accuracy of G/T, spectral, and demodulation measurements.
  - A **two-port** measurement setup increases the efficiency and accuracy of amplifier, group delay, and multi-band / multi-beam test scenarios

THANK YOU FOR YOUR ATTENTION