PHASE ARRAY ANTENNA G/T MEASUREMENT

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Make ideas real

COMPANY RESTRICTED

OUTLINES

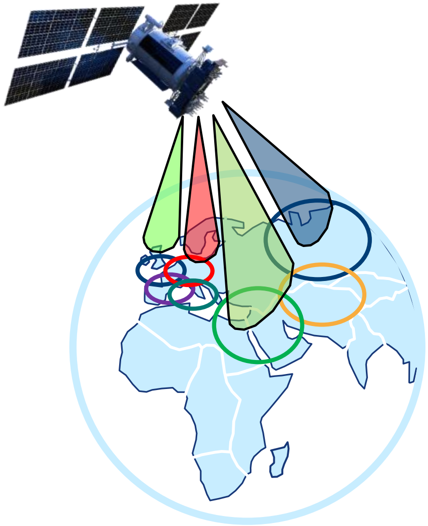
- Overview of Satellite Communication Antenna
- Theoretical Background for Antenna G/T
- G/T Test Method
  - Y-Factor Method Using Modified Noise Source
  - Cold Source Method for Noise Power Density
- Practical G/T Testing
- Wrap up

OVERVIEW OF SATELLITE COMMUNICATION ANTENNA

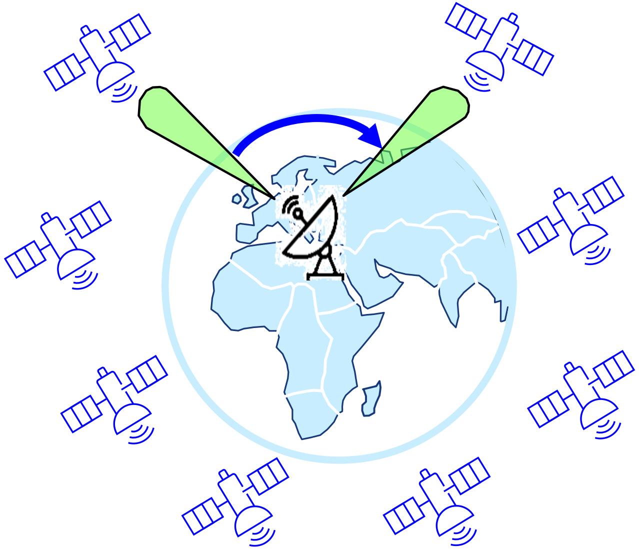
ANTENNA REQUIREMENTS FOR FUTURE SATCOM SYSTEMS

Flexible and reconfigurable beamforming: Active antennas are key to achieve these targets.

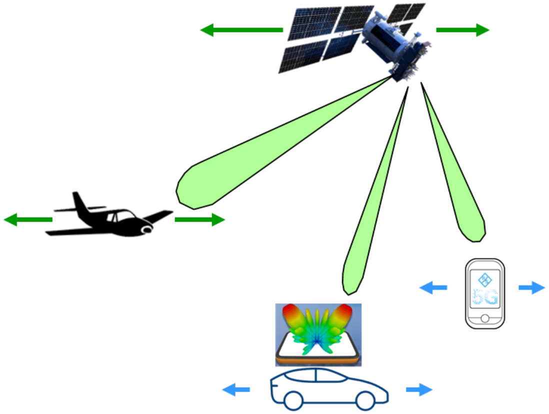
HTS and VHTS



Mega-constellations



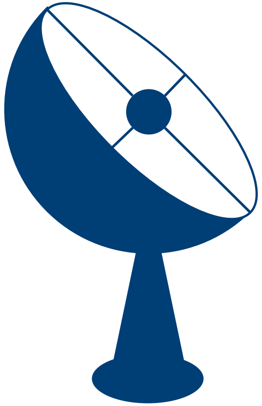
Non-terrestrial NWs in terrestrial mobile NWs



AESA, PESA, AND PARABOLIC DISH ANTENNA

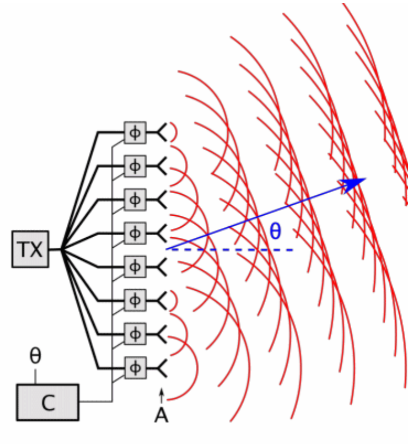
Parabolic Dish Antenna
Mechanical controlled antenna

- High gain
- High power



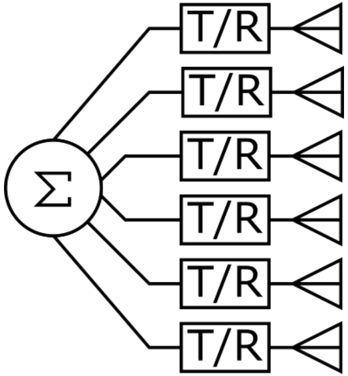
PESA
passive electrically scanned array

- Quick beam steering
- Precise targeted



AESA
Active electrically scanned array

- Longer range
- Able to detect small target
- Resistance to jamming



THEORETICAL BACKGROUND FOR ANTENNA G/T

NOISE TEMPERATURE, NOISE POWER, AND NOISE POWER DENSITY

$$N = kTB$$

N: Noise Power (J)

k: Boltzmann constant (1.38×10^{-23} J/K)

T: Kelvin's temperature (K)
room temperature T_0 = 290 K

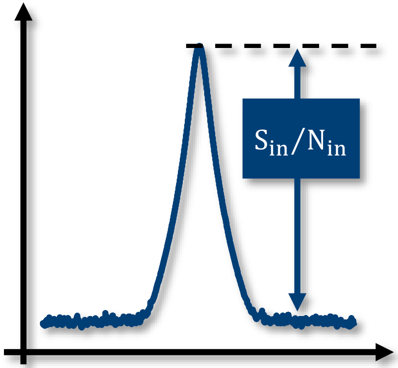
B: Receiver Bandwidth (Hz)

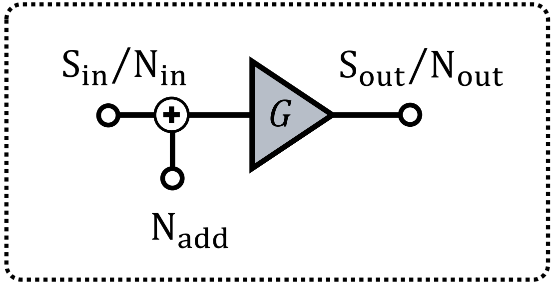
NPD (Noise Power Density) at room temperature = N/B = kT_0

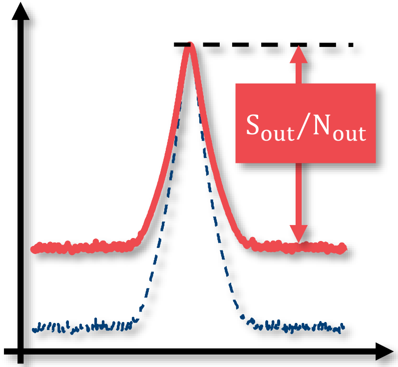
$$= 4 \times 10^{-12}\, W/Hz = -204\, dBW/Hz = \mathbf{-174\, dBm/Hz}$$

DEGRADATION OF SIGNAL-TO-NOISE RATIO

General Definition: The noise factor, F of a network is the ratio of the signal-to-noise power ratio at the input of a network to the signal-to-noise ratio at the output. (Linear Term)



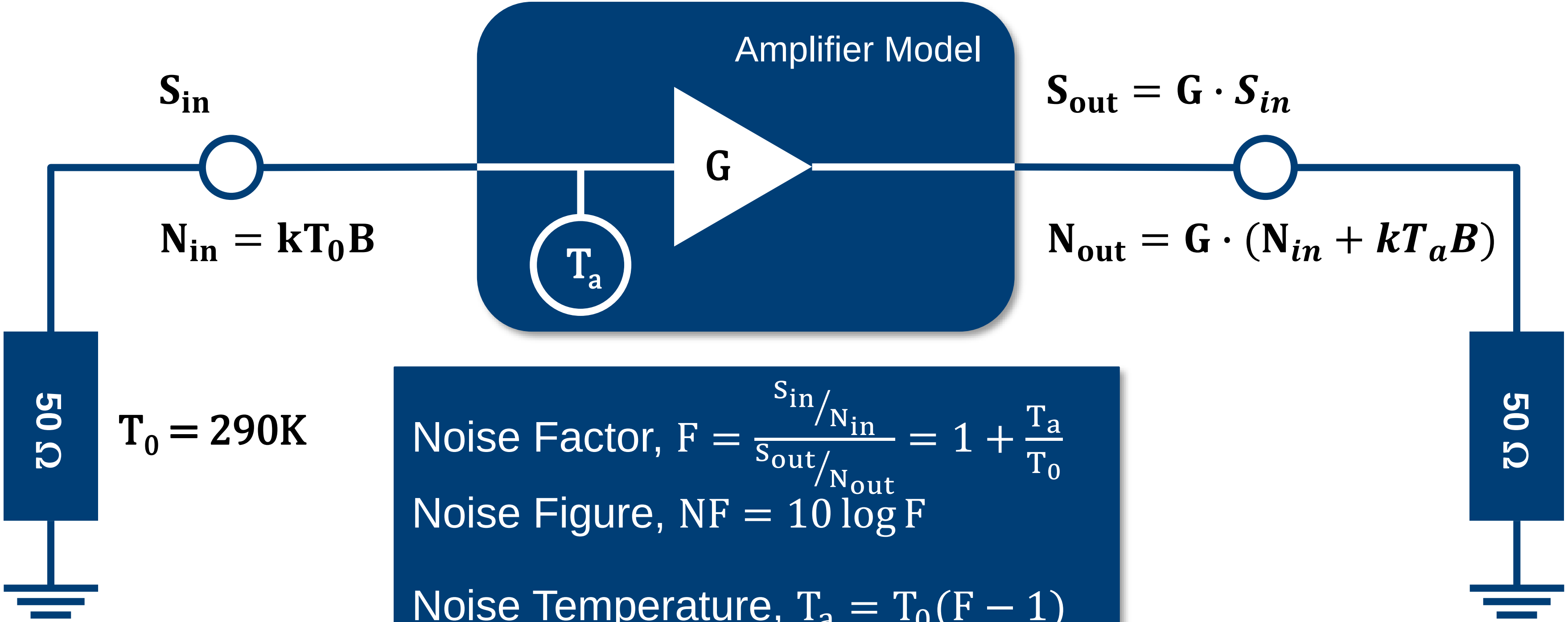




Noise factor:
(linear value)

$$F_{noise} = \frac{S_{in} \cdot N_{out}}{S_{out} \cdot N_{in}}$$

AMPLIFIER NOISE MODEL

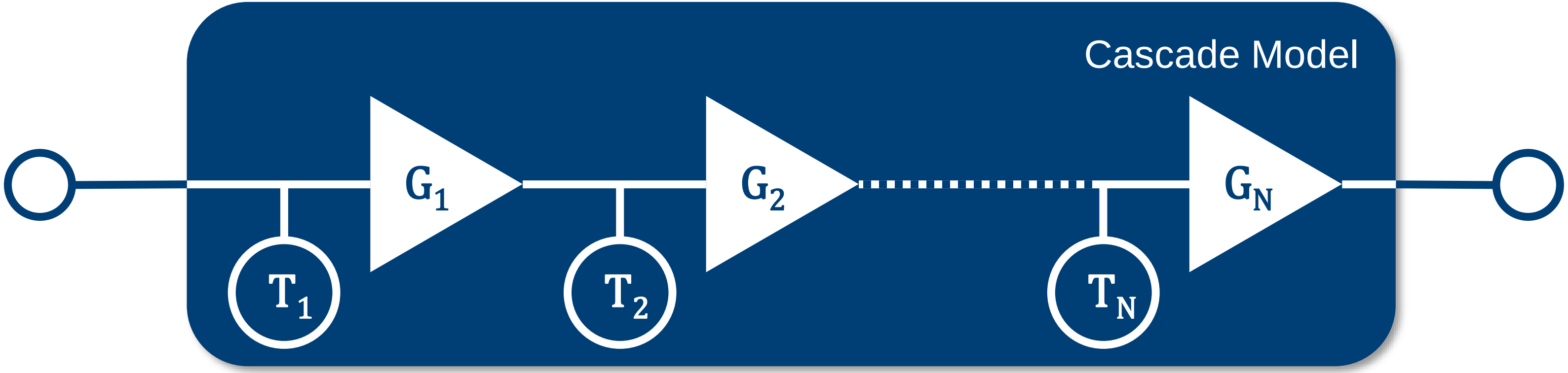


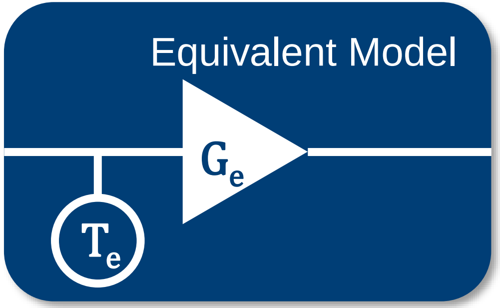
Noise Factor, $F = \frac{S_{in}/N_{in}}{S_{out}/N_{out}} = 1 + \frac{T_a}{T_0}$

Noise Figure, $NF = 10 \log F$

Noise Temperature, $T_a = T_0(F - 1)$

CASCADED NOISE

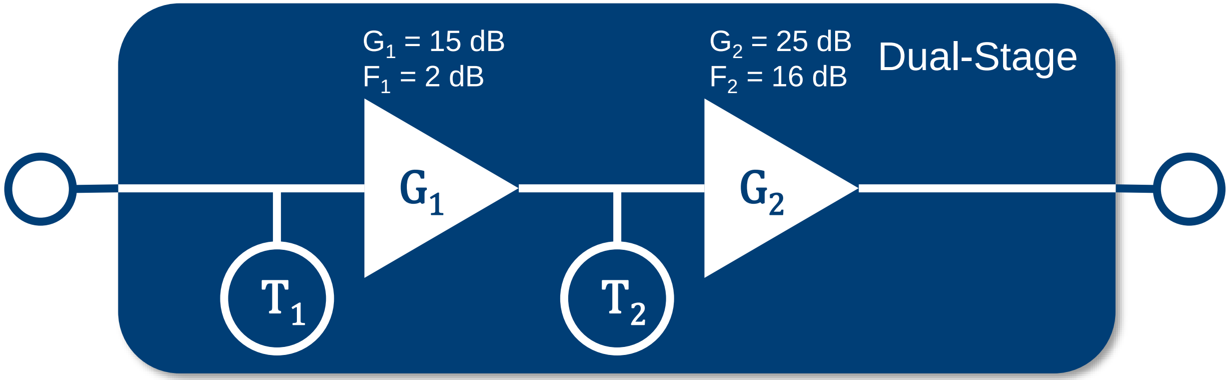




Noise Temperature, $T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \cdots + \frac{T_N}{G_1 G_2 \ldots G_{N-1}}$

Noise Factor, $F_e = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots + \frac{F_N - 1}{G_1 G_2 \ldots G_{N-1}}$

CASCADED NOISE CALCULATION



$$F_e = F_1 + \frac{F_2 - 1}{G_1} = 1.585 + \frac{39.81 - 1}{31.62} \sim 2.812$$

Effective gain, $G_e = G_1 \times G_2 = 15\,dB + 25\,dB$

Effective noise figure, $NF_e = 10 \cdot \log(F_e) = 10 \cdot \log(2.812)$

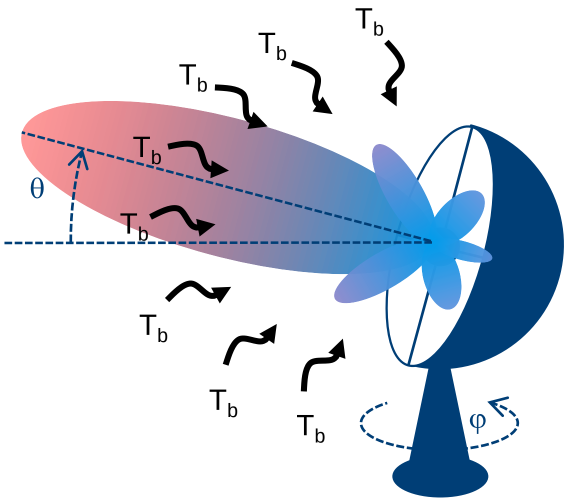
Effective noise temperature, $T_e = T_0(F_e - 1) = 290 \cdot (2.812 - 1)$

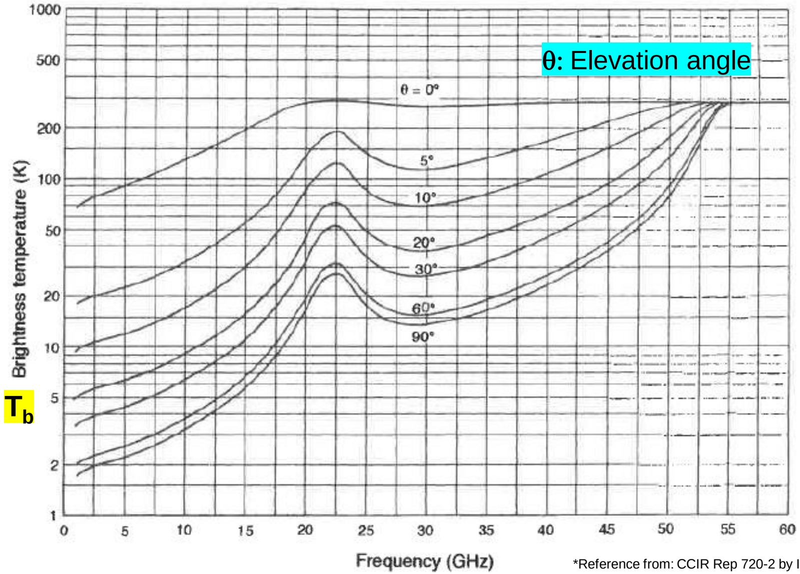
$G_e = 40$ dB

$NF_e \sim 4.49$ dB

$T_e \sim 525.54$ K

PASSIVE ANTENNA NOISE TEMPERATURE

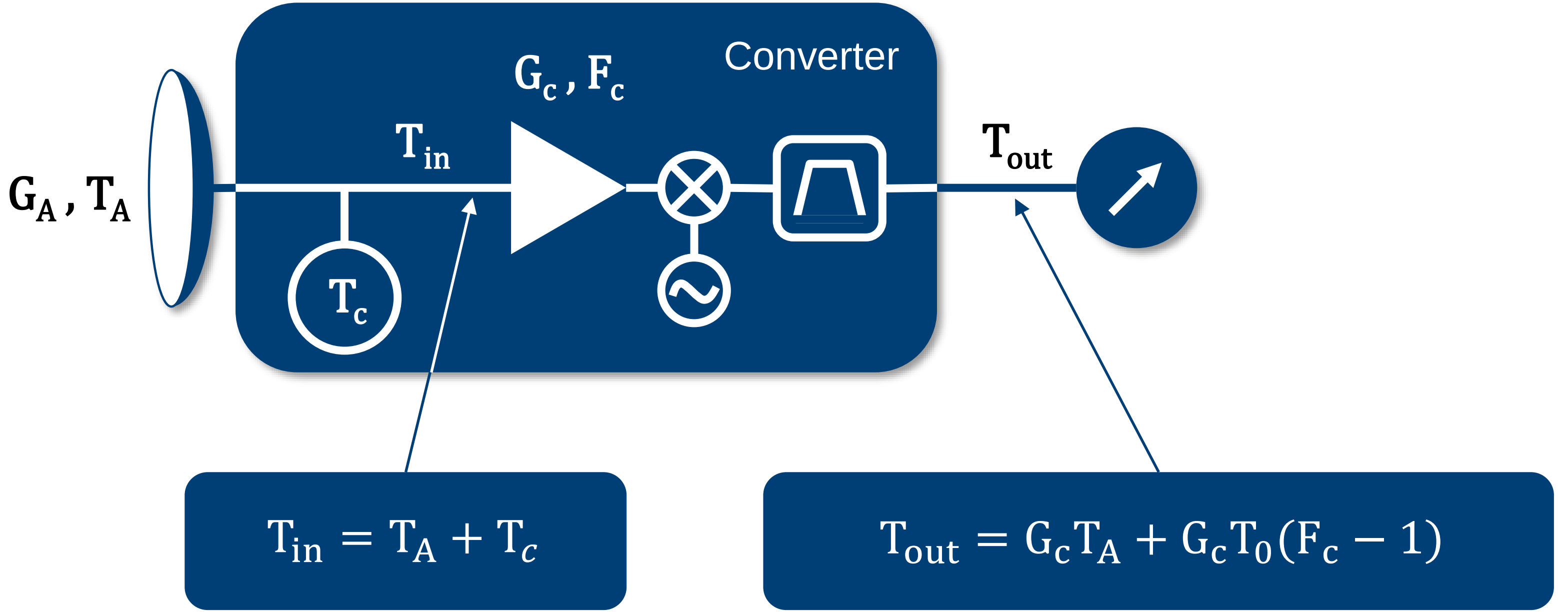




*Reference from: CCIR Rep 720-2 by ITU

$$T_{Antenna} = \frac{1}{4\pi} \iint T_b(\theta, \varphi) G(\theta, \varphi) \sin\theta \, d\theta d\varphi$$

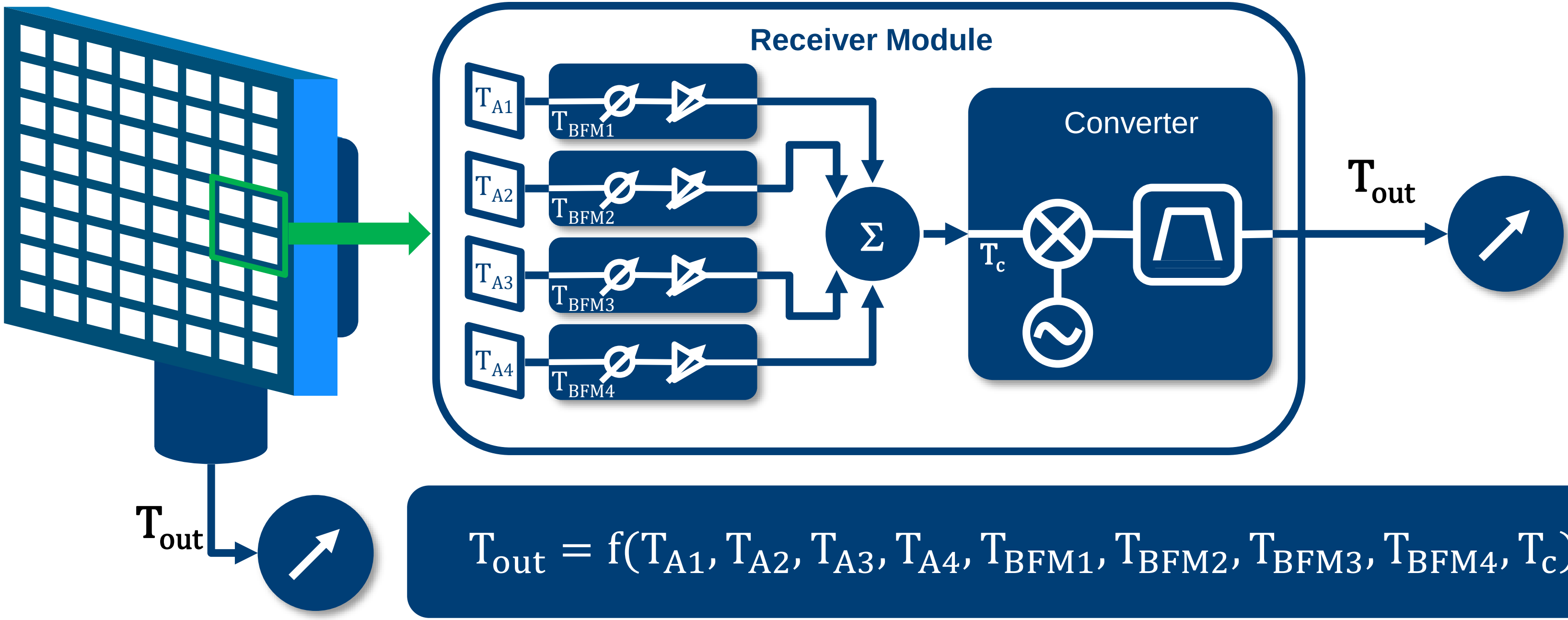
RECEIVING SYSTEM NOISE TEMPERATURE



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

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

PHASE ARRAY ANTENNA NOISE TEMPERATURE

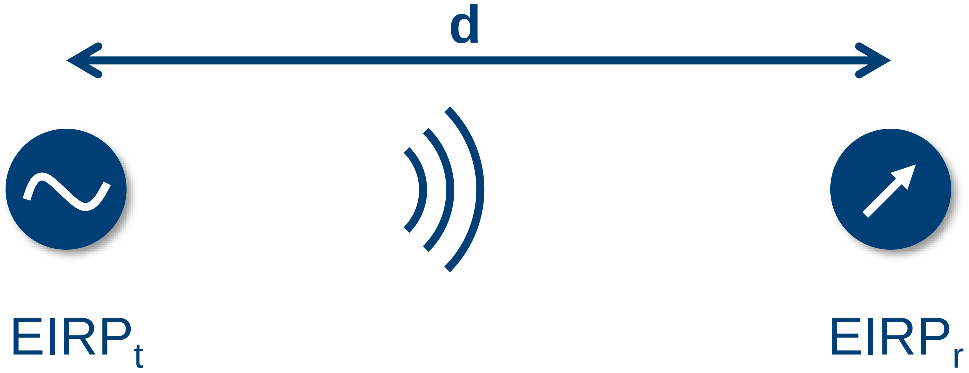


$$T_{out} = f(T_{A1}, T_{A2}, T_{A3}, T_{A4}, T_{BFM1}, T_{BFM2}, T_{BFM3}, T_{BFM4}, T_c)$$

Not possible to access T_{in} in a highly integrated system

FRIIS EQUATION

EIRP: Effective isotropic radiated power
d: Electro-magnetic wave propagation distance
λ: Operating wavelength

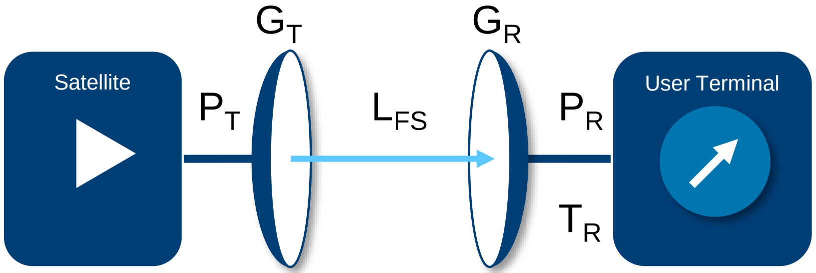


Free space loss: $L_{FS} = \frac{EIRP_r}{EIRP_t} = (\frac{4\pi d}{\lambda})^2$

Signal transmitted from space to earth with
Distance: 1000 km
Operating frequency: 10 GHz
Calculate the free space loss L_{FS}

$$L_{FS} = (\frac{4\pi d}{\lambda})^2 = (\frac{4\pi df}{c})^2 = (\frac{4\pi \times 1000km \times 10GHz}{3 \times 10^8\ m/s})^2 \sim 172.45\ dB$$

LINK BUDGET AND CARRIER-TO-NOISE RATIO CALCULATION



Effective isotropic radiated power: $EIRP_T = P_T G_T$

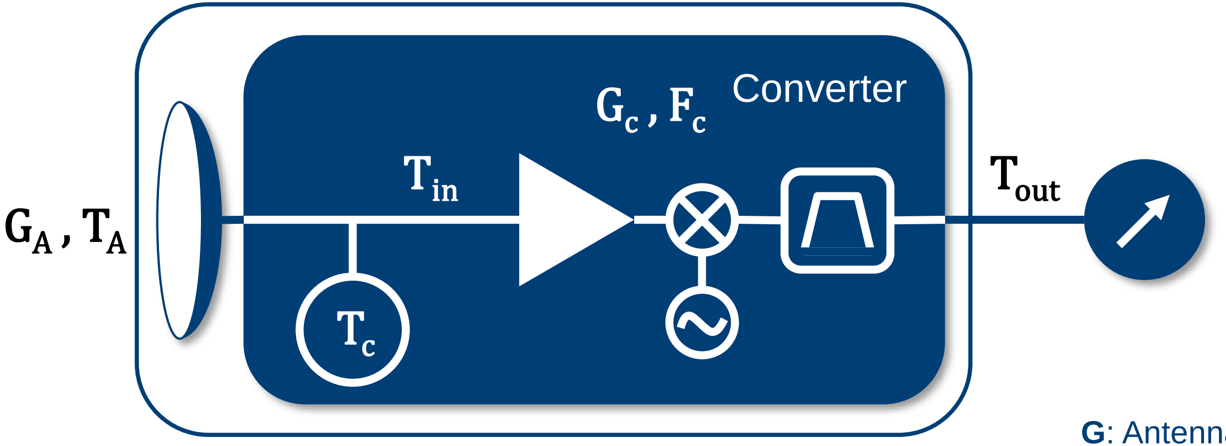
Received carrier power: $P_R = \frac{P_T G_T G_R}{L_{FS}}$

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

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

- $(EIRP_T)$ → Transmitter
- $\left(\frac{1}{L_{FS}}\right)$ → Channel
- $\left(\frac{G_R}{T_R}\right)$ → Receiver
- $\left(\frac{1}{k}\right)$ → Constant

ANTENNA G/T PERFORMANCE



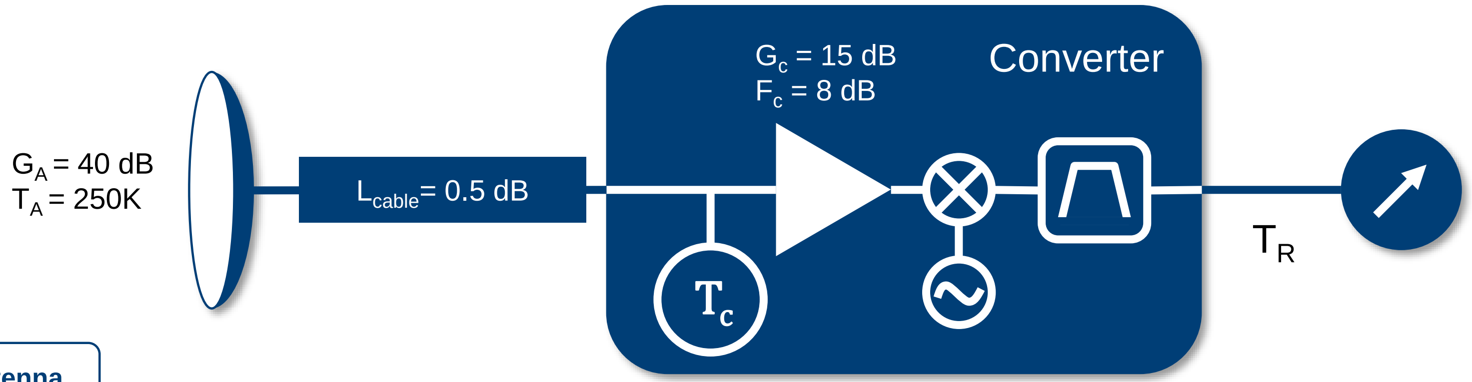
G: Antenna gain
T: System noise temperature

For a 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 influence G/T instead contributes noise in antenna G/T.

ANTENNA G/T CALCULATION



Pure dish antenna

$$\frac{G}{T} = G_A - 10 \times \log T_A = 40\ \text{dB} - 10 \times \log 250 = \mathbf{16.02\ dB/K}$$

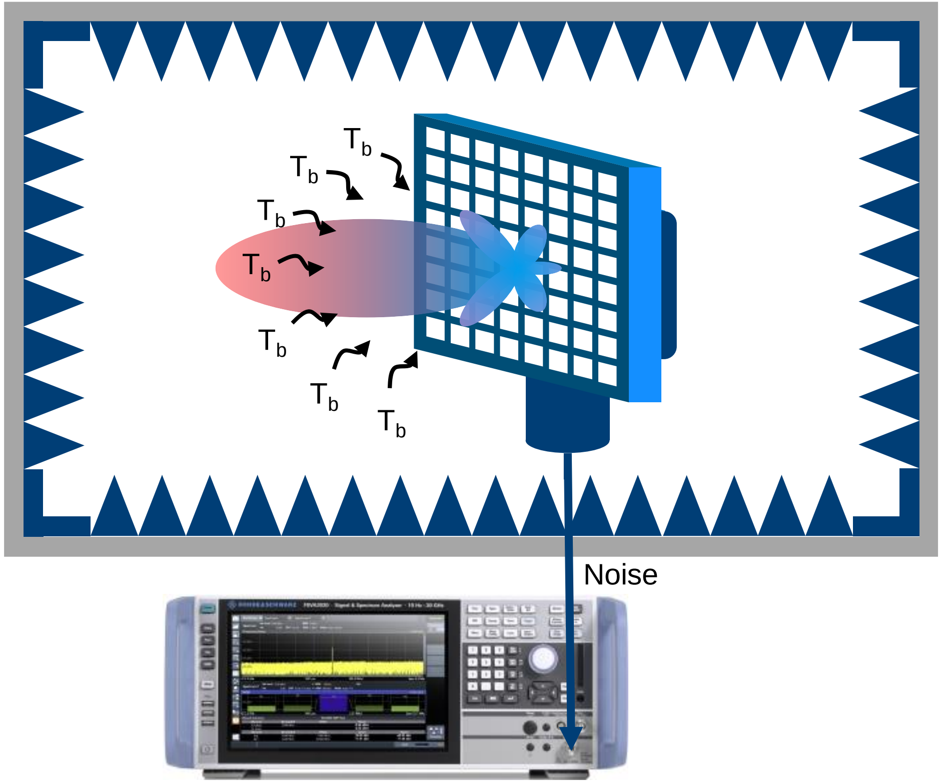
Antenna receiver module (Antenna + converter)

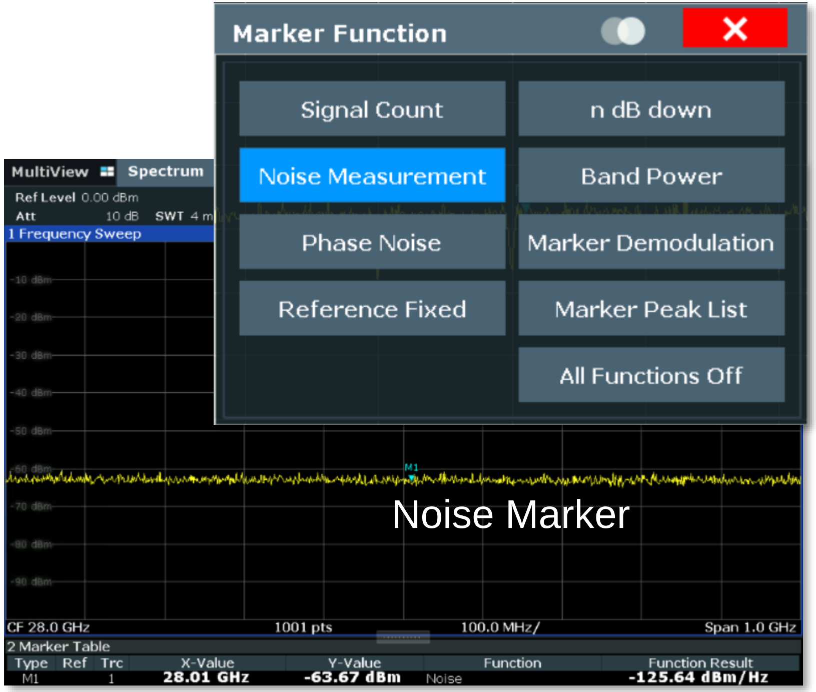
$$\frac{G}{T} = G_A - 10 \times \log[(T_A + T_{cable} + T_c L_{cable})] = G_A - 10 \times \log[(T_A + T_0(L_{cable} - 1) + T_0(F_c - 1)L_{cable})]$$

$$= 40\ \text{dB} - 10 \times \log\left[10^{\frac{15}{10}}(250 + 290 \times \left(10^{\frac{0.5}{10}} - 1\right) + 290 \times \left(10^{\frac{8}{10}} - 1\right) \times 10^{\frac{0.5}{10}}\right] = \mathbf{6.96\ dB/K}$$

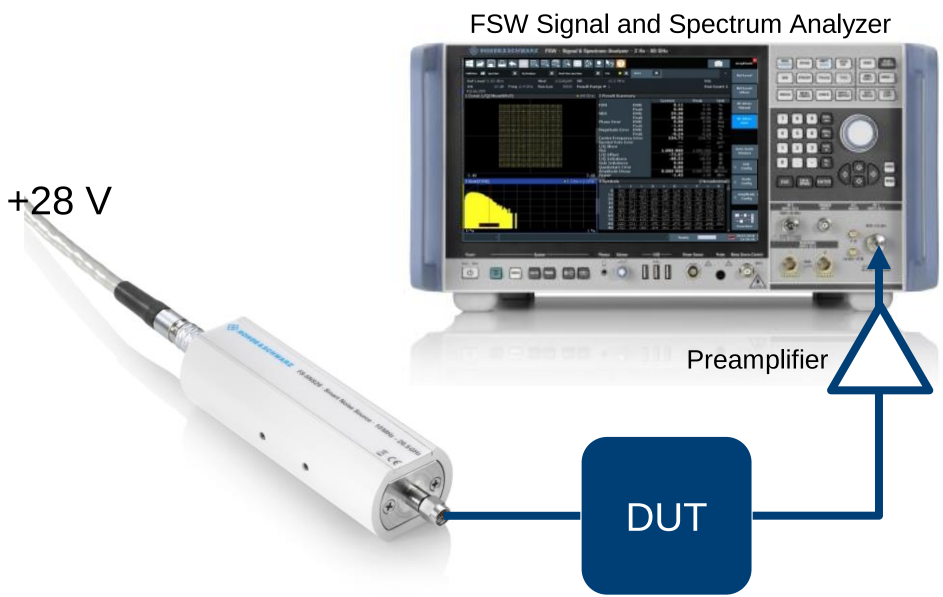
G/T TEST METHOD

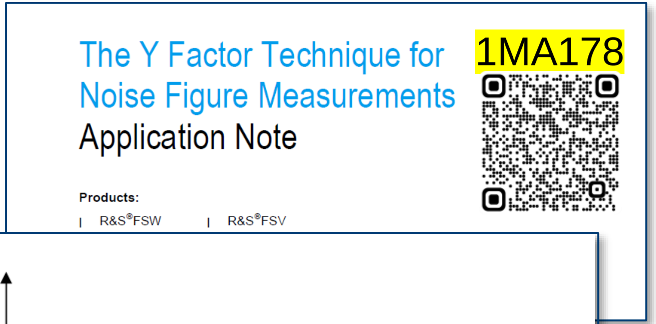
NOISE POWER DENSITY IN SPECTRUM ANALYZER

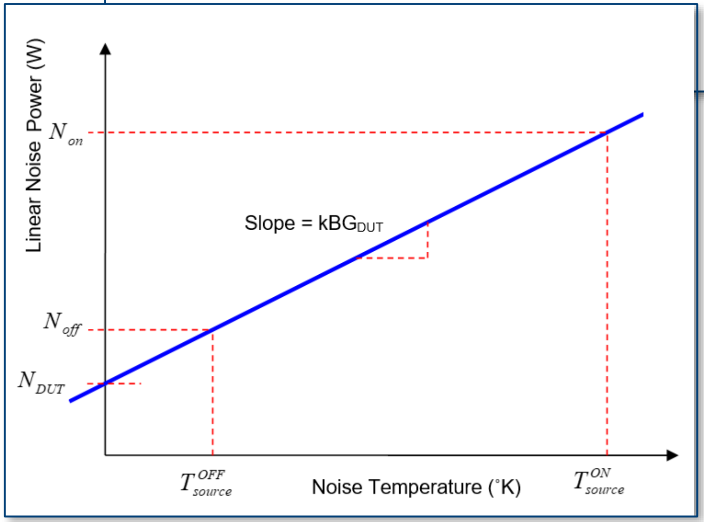




Y-FACTOR METHOD FOR SPECTRUM ANALYZER

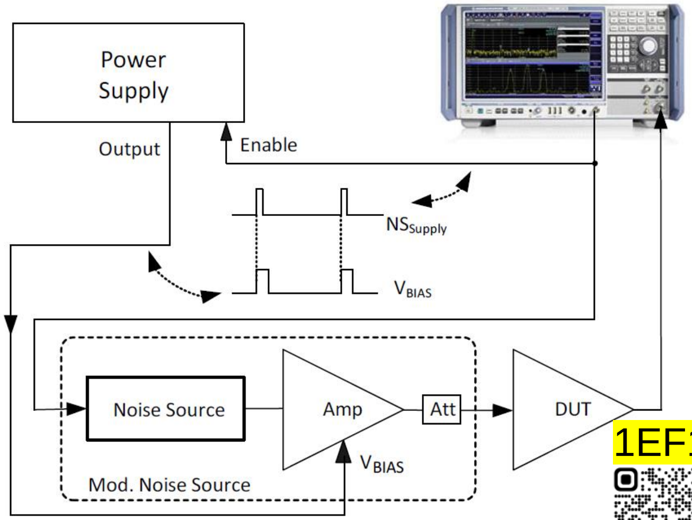






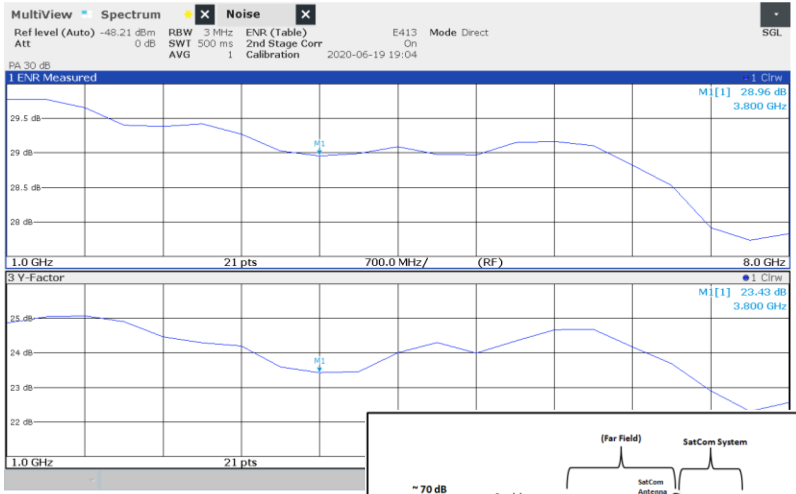
MEASUREMENTS WITH VERY HIGH NOISE FIGURE

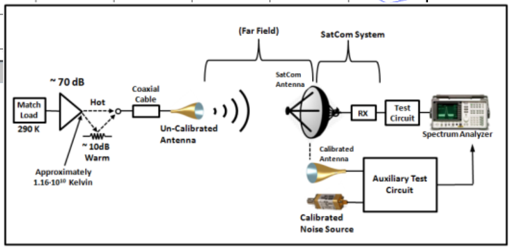
ENR measurement of a modified noise source is needed for very high noise figure testing



1EF110

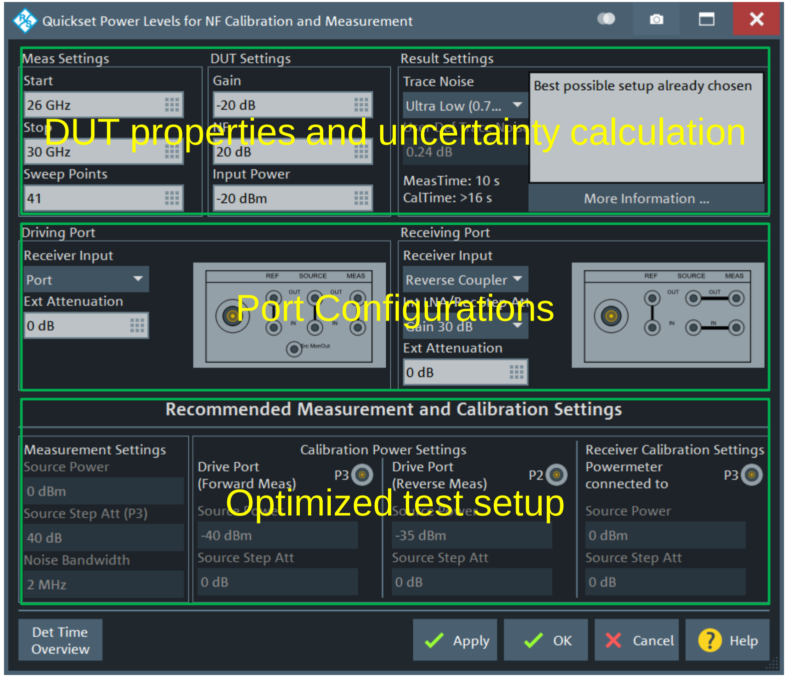
*reference: Kay-Uwe Sander, “Measurements on Devices with Very High Noise Figure”, Rohde&Schwarz appl.note, 1EF110

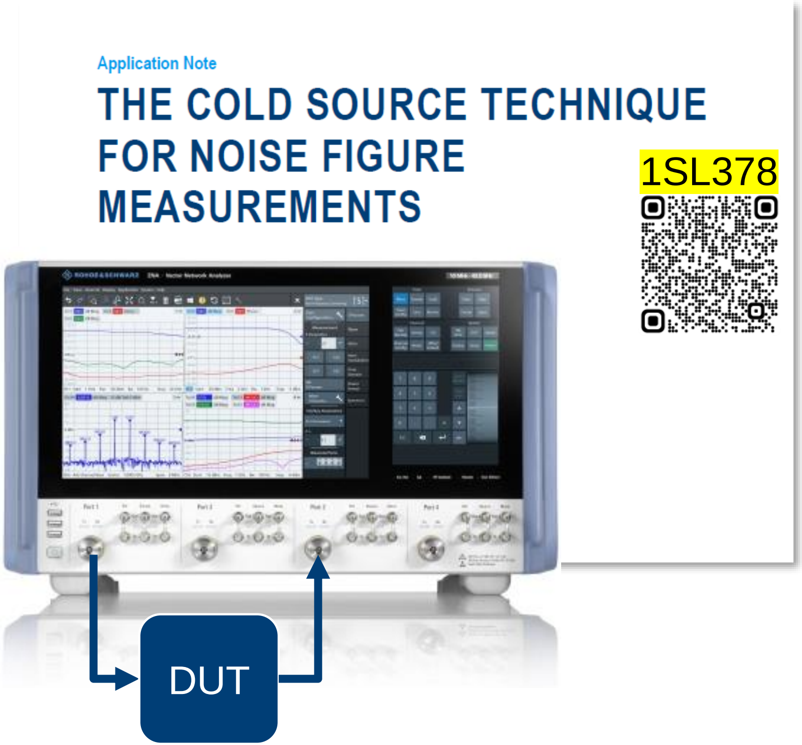




*reference: Roy C. Monzello, “Eliminate Celestial Noise Sources in Your SatCom G/T Measurements”,

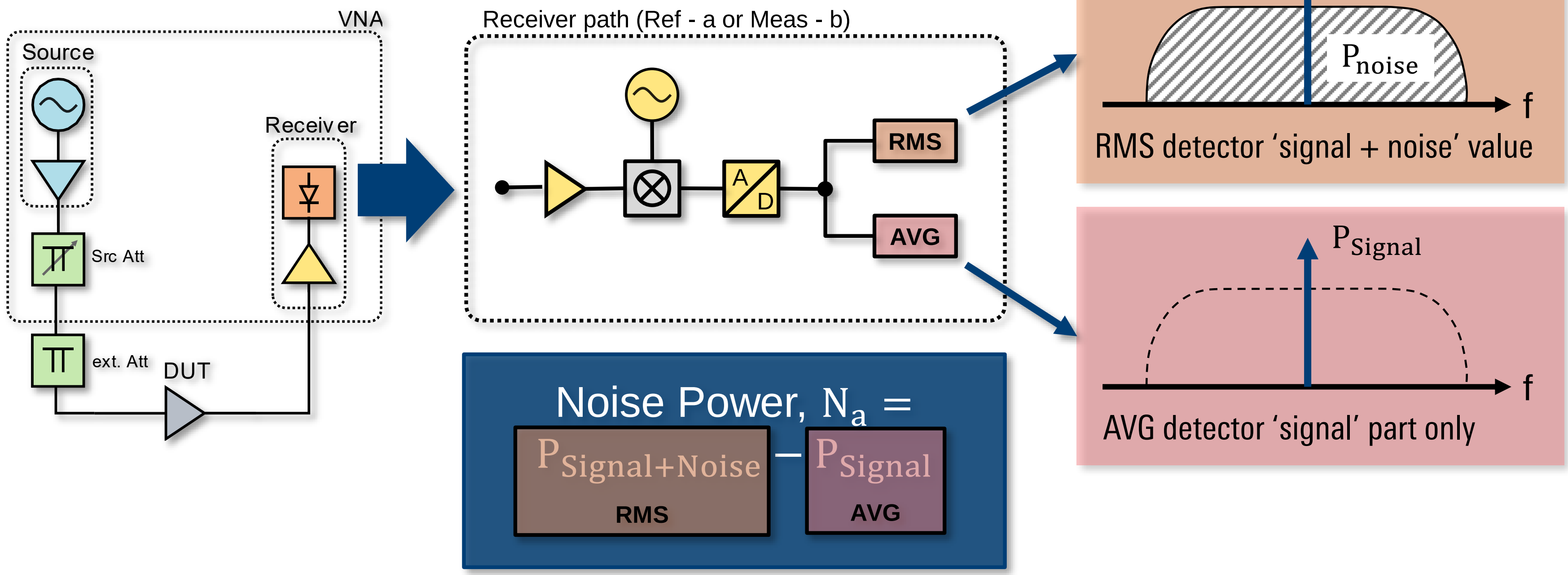
COLD SOURCE METHOD FOR G/T TESTING





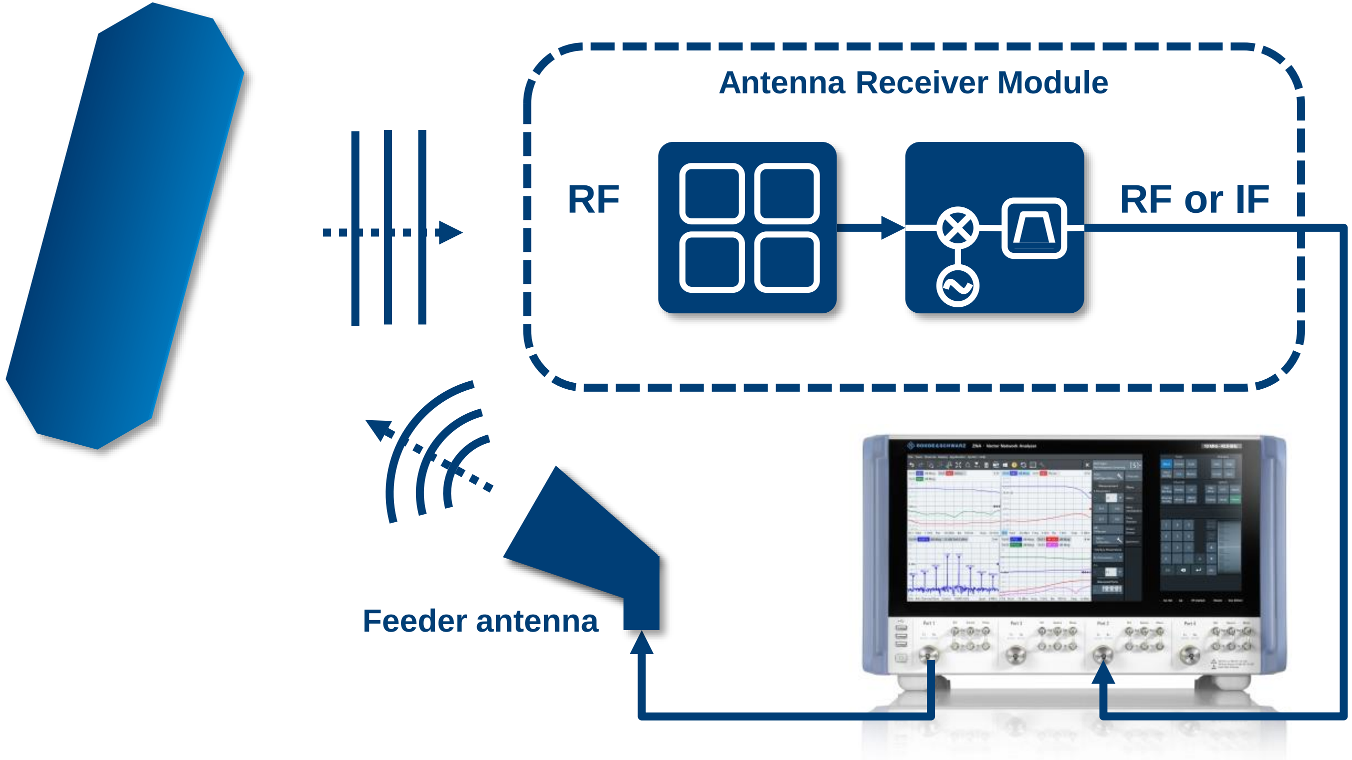
NOISE FIGURE MEASUREMENTS WITH R&S ZNA

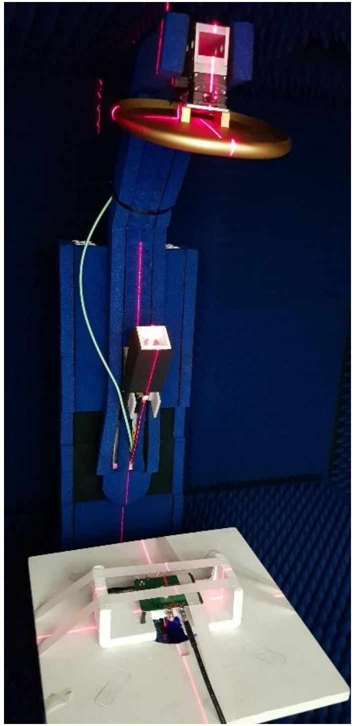
- The ZNA noise figure software samples and processes the signal in two different parallel detectors:



PRACTICAL G/T TESTING

G/T TESTING SETUP IN A CATR CHAMBER

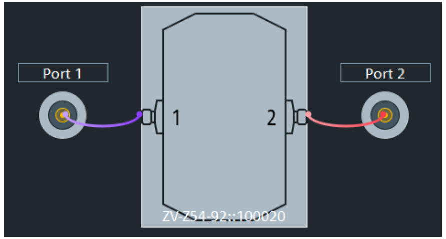




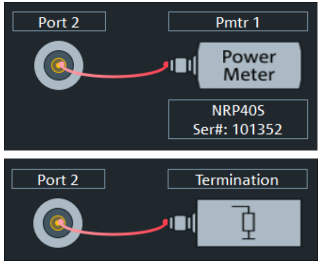
Measured in BWant MW6

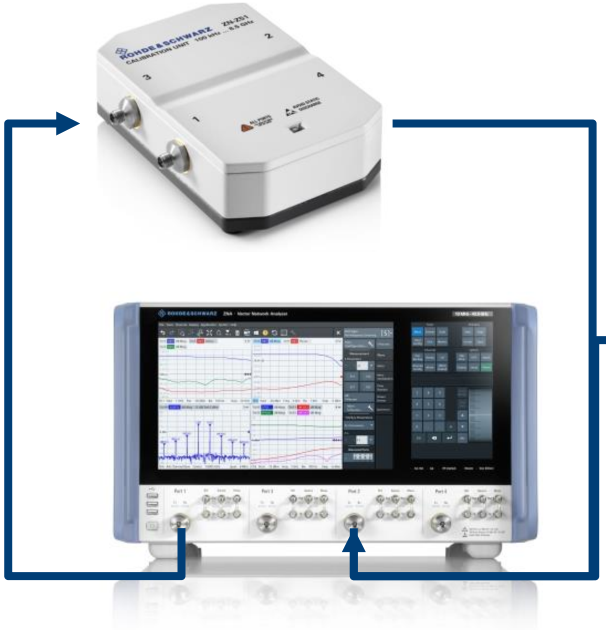
CALIBRATIE ZNA FOR G/T TESTING

Step 1



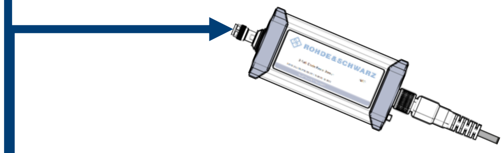
Step 2





Calibrate step 1

1. Mismatch error
2. Power ratio

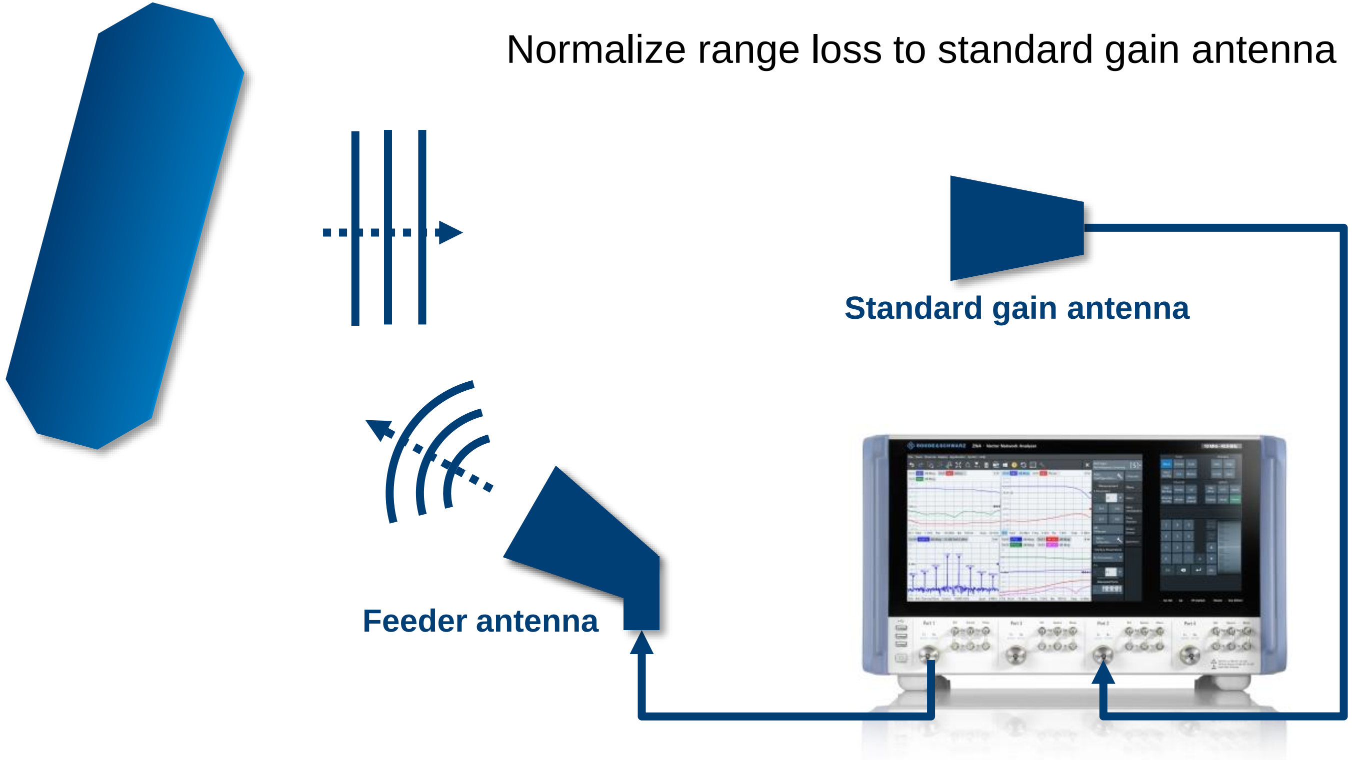


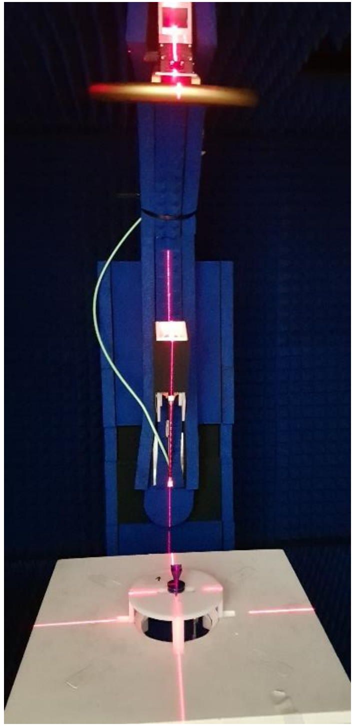
Calibrate step 2

1. Absolute power
2. Receiver port NF

G/T TESTING CALIBRATION IN A CATR CHAMBER

Normalize range loss to standard gain antenna



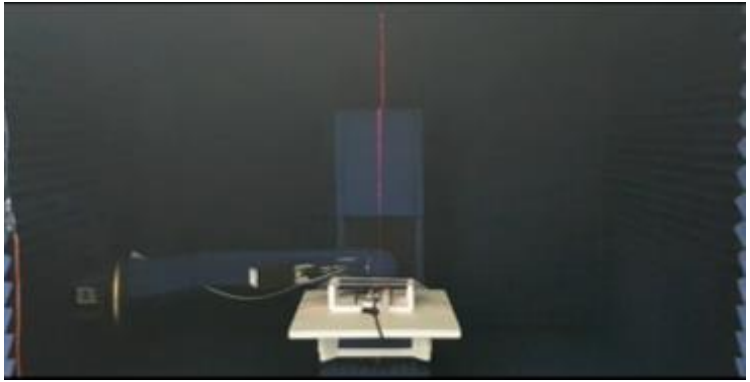


Measured in BWant MW6

G/T TESTING IN A CATR CHAMBER

ZNA screen

DUT measurement video

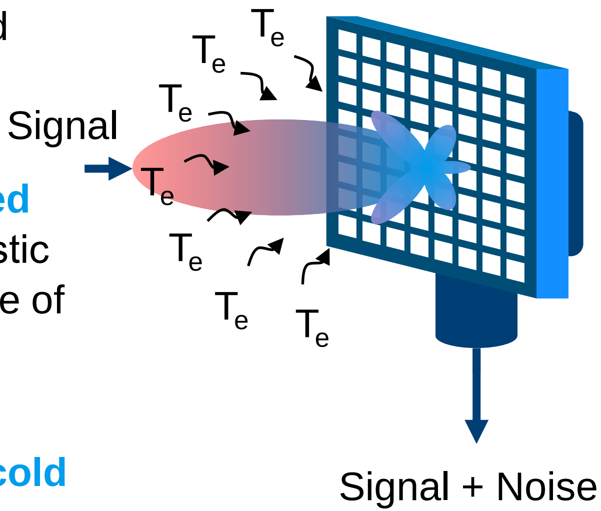


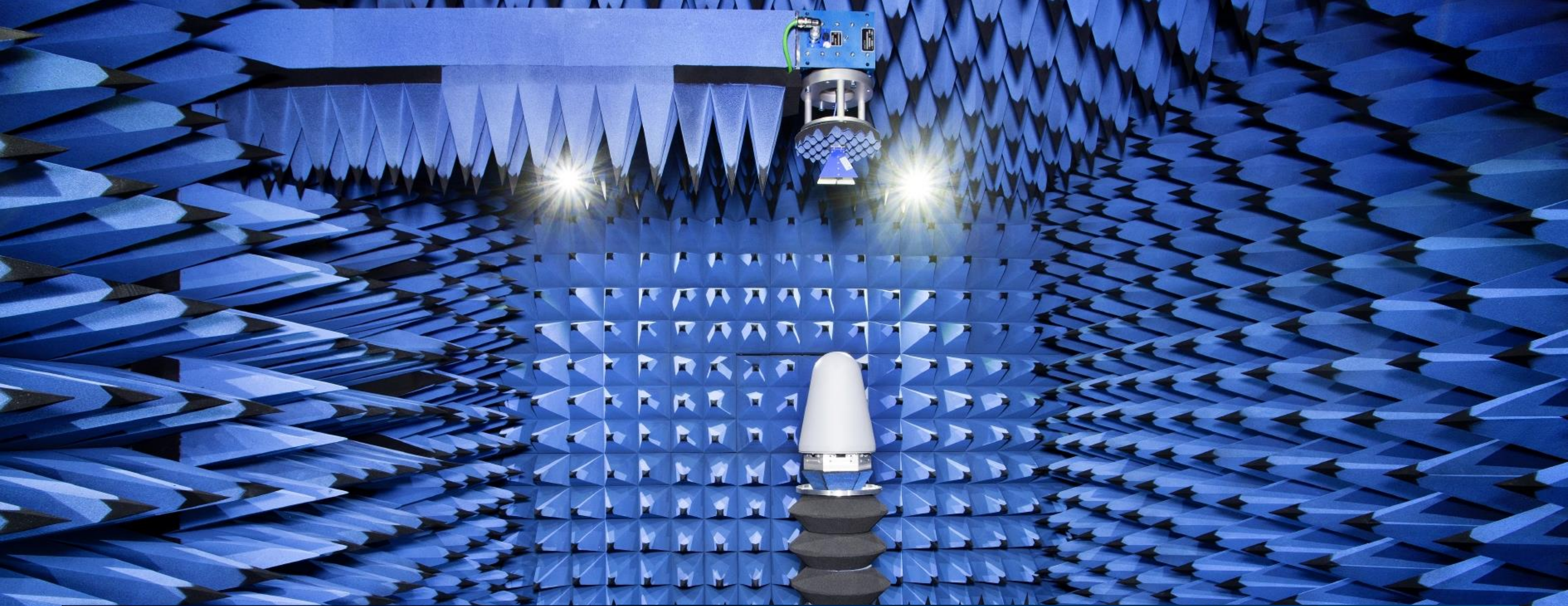
Measured in BWant MW6

WRAP UP

WRAP UP

- In order to achieve good **signal-to-noise ratio** for high loss satellite communication, the design of antenna receiver module with good G/T is important.
- Modern active array antenna receiver module is **highly integrated** with amplifiers, phase shifters, and even converters. It's not realistic to measure every single stage NF. G/T describes the performance of antenna receiver module.
- **Y-factor** method with **modified ENR** for spectrum analyzer and **cold source method** for vector network analyzer are proposed.
- In this presentation slides, measurement of antenna receiver module G/T with cold source method in an anechoic chamber is shown.





THANKS FOR YOUR ATTENTION