

# TESTING 6G SUB-THZ COMMUNICATION

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**ROHDE & SCHWARZ**

Make ideas real



# FROM 5G TO 6G

## FIRST, SOME OBSERVATIONS...

- ▶ Odd numbered G's were almost exclusively for business, even-numbered G's for consumers
  - 1G: Connection for business people
  - 2G: Commercialization of cellular communication
  - 3G: Internet access/email for business customers
  - 4G: Internet, video streaming, social media for everyone
  - 5G: eMBB, yes, but the focus is on market verticals (automotive, IIoT)
  - 6G: Metaverse, digital twin, holographic communication, etc.
- ▶ Another observable trend: we tend to change the physical layer from an odd to an even G
  - 1G to 2G: analog → digital (CDMA/TDMA/FDMA)
  - 3G to 4G: CDMA/TDMA/FDMA → OFDM
  - 5G to 6G: OFDMA → ??? (e.g. AI-native air interface)

# IF 6G IS FOR THE CONSUMER, WHAT DO WE NEED? A NEW TYPE OF DEVICE!?

*“A hologram display over a mobile device (one micrometer pixel size on a 6.7-inch display, i.e., 11.1 Gigapixel) form-factor requires at least 0.58 Tbps.”*

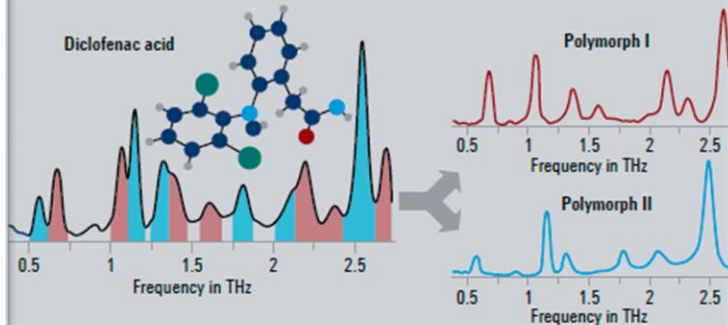
Source: [Samsung 6G White Paper](#)



# 6G USE CASES SPAN A PLETHORA OF APPLICATIONS COMMUNICATIONS, SPECTROSCOPY, IMAGING AND...

## Spectroscopy

- ▶ Material analysis
- ▶ Analysis of the terahertz spectra from diclofenac acid can distinguish between the two chief forms of the drug



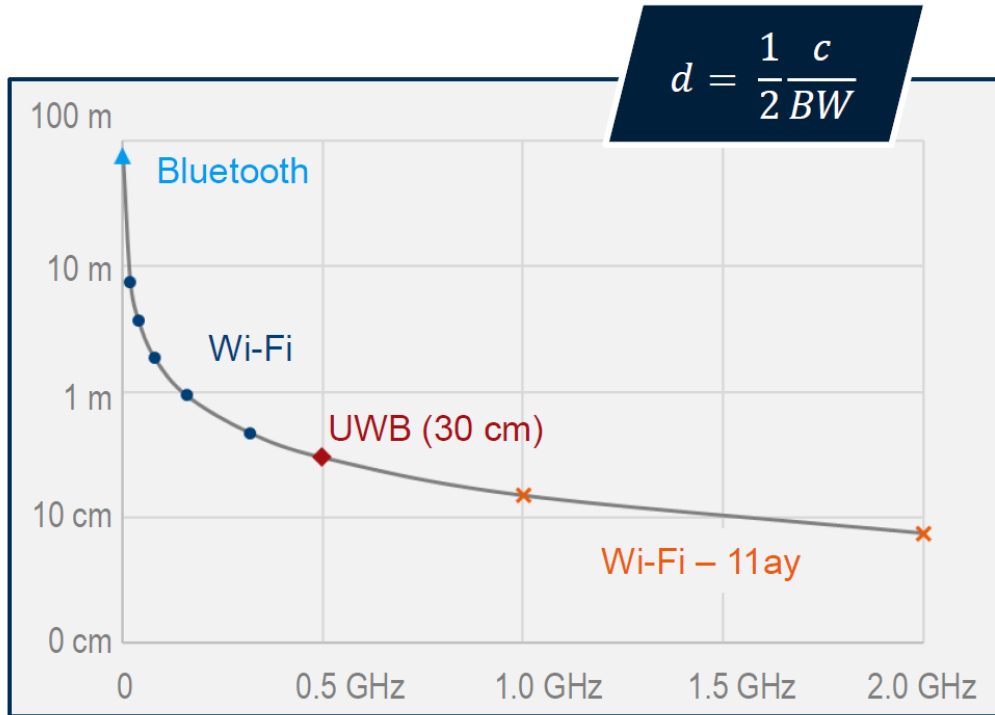
## Imaging

- ▶ Nondestructive imaging (with R&S®QPS100 security scanner)
- ▶ Production line (final assembly test)





# THE DEPENDENCY OF BANDWIDTH AND RESOLUTION

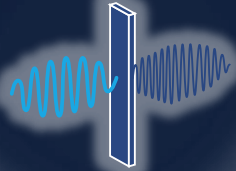


BW [MHz]	Resolution [m]
100	1.5
500	0.30
1000	0.15
5000	0.030
10000	0.015

► Note that there are many techniques to improve resolution accuracy, e.g. averaging

# HOW DO WE ENABLE ALL OF THIS? WITH AN ORCHESTRA OF 5G TECHNOLOGY COMPONENTS

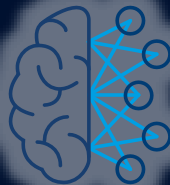
THz communication  
& "FR3"



Joint communication  
& sensing



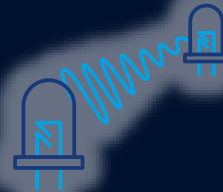
Artificial Intelligence  
and Machine Learning



Reconfigurable  
Intelligent Surfaces



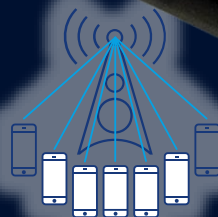
Photonics, Visible  
Light Communication



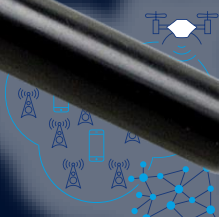
Multiple access,  
new waveforms,  
channel coding



Ultra-massive  
MIMO



New network topologies,  
distributed computing



Full-duplex  
communication



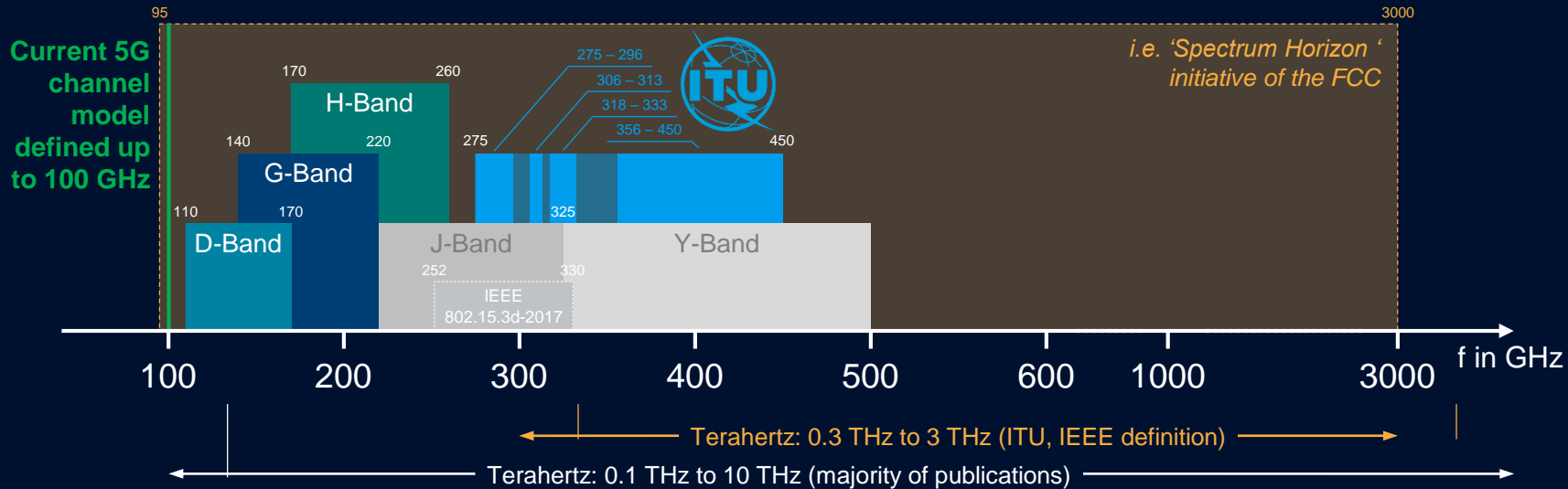
Security &  
Trustworthiness



*A high-level overview on  
all these research areas  
is provided in one of our  
[#THINKSIX](#) video.  
Don't miss it!*



# 6G WILL TAKE ADVANTAGE OF FR1 AND FR2 THz WILL BE ANOTHER FREQUENCY LAYER





# BUT AGAIN, 6G SPECTRUM IS MORE THAN THz

## A LOT OF INDUSTRY PLAYERS DISCUSS “FR3” SPECTRUM



(drawing not to scale)

- 6.1.6 Potential Spectrum bands for study
  - 6.1.6.1 UHF Band
    - 6.1.6.1.1 1300-1350 MHz
    - 6.1.6.1.2 1780-1850 MHz
  - 6.1.6.2 Lower-cmW spectrum
    - 6.1.6.2.1 3100-3450 MHz
    - 6.1.6.2.2 3980-4180 MHz (TBD)
    - 6.1.6.2.3 4400-4940 MHz
    - 6.1.6.2.4 7125-8500 MHz
  - 6.1.6.3 Upper-cmW spectrum
    - 6.1.6.3.1 10-10.5 GHz
    - 6.1.6.3.2 10.7-12.2 GHz
    - 6.1.6.3.3 12.2 – 12.7 GHz
    - 6.1.6.3.4 12.7-13.75 GHz
    - 6.1.6.3.5 13.75-15 GHz
    - 6.1.6.3.6 25.25-27.5 (TBD)
  - 6.1.6.4 EHF Band
    - 6.1.6.4.1 37.0-37.6 GHz
    - 6.1.6.4.2 42-43.5 (TBD)
    - 6.1.6.4.3 92-114.25 GHz (W-band) and 122.25-174.8 GHz (D-band):

Source:  NEXT G ALLIANCE  
Spectrum Working Group

# (SUB)-THZ RESEARCH EXAMPLES

The 6G SENTINEL (Six-G Enablers: Flexible Networks, THz Technology and Integration, Non-Terrestrial Networks, SidElink and Localization) project



Artificial Intelligence aided D-band network for 5G long term evolution



**6G-TERAKOM:**  
Key components for THz communication for intelligent 6G networks



# FCC GRANTS QUALCOMM AND SAMSUNG D-BAND FREQUENCY LICENSES IN THE US

## Samsung

The South Korean company's license started in **December 2021 and will last until January 2024**. Samsung will test a 6G wireless communication system prototype comprising a phased array transmitter and receiver to emulate a cellular base station and mobile device.

The FCC has granted authorization for works in the range between **133-148 GHz**, and the experiments will take place in **Plano, Texas, within a 500 metres radius**. "The end-to-end test is to verify the feasibility of long-range cellular communication in the sub-Terahertz spectrum, in terms of coverage, throughput, latency, beam steering capability," the company said in its application.

According to Samsung's filing, the key innovations in this test would be the **high-performance phased array using Indium Phosphide (InP)**, a compound inorganic semiconductor; adaptive beamforming at Terahertz carrier frequencies; and full digital beamforming to support multi-beam communication systems.

## Qualcomm

Qualcomm's license started in **January 2022 and will expire in February 2024**. The company explained to the FCC that "the experimental license would allow Qualcomm to develop new wireless communications systems technologies for the operating range of **132.5-147.5 GHz in San Diego, California.**"

According to the company, the experiments will include prototype transmitters and receivers. "Higher power transmitters will be fixed and located indoors and outdoors. Mobile devices will operate within the coverage range of the transmitter. **Transmission BW [bandwidth] is comprised of four subcarriers at 2.5 GHz each using OFDM [Orthogonal Frequency-Division Multiplexing]** modulation. Fixed site transmitters will use beam-steering antenna arrays," Qualcomm details in one document supporting its application.

Source: <https://www.6gworld.com/exclusives/qualcomm-samsung-and-the-us-battle-for-beyond-5g/> (March 2022)

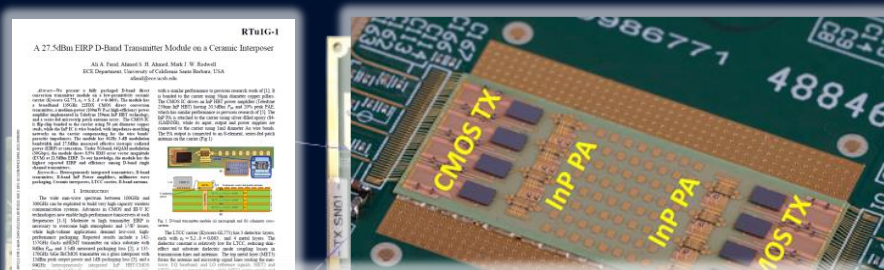


# THE INDUSTRY IS ACTIVELY WORKING ON THz, SO DO WE!

## Samsung Electronics and University of California Santa Barbara Demonstrate 6G Terahertz Wireless Communication Prototype

Korea on June 16, 2021

Audio   Share  



RTu1G-1

A 27.5dBm EIRP D-Band Transmitter Module on a Ceramic Interposer

Ali A. Farid, Ahmed S. H. Ahmed, Mark J. W. Rodwell  
ECE Department, University of California Santa Barbara, USA  
afarid@ece.ucsb.edu



- CMOS-based D-Band (110 to 170 GHz) RFIC with 128 antenna element array
- 2 GHz signal bandwidth with MIMO 2x2
- 12 Gbps @ 30 m, 2.3 Gbps @ 120 m

<https://news.samsung.com/global/samsung-electronics-and-university-of-california-santa-barbara-demonstrate-6g-terahertz-wireless-communication-prototype> [June 2021]



# R&S SUPPORTS CHANNEL SOUNDING MEASUREMENTS

- ▶ Fraunhofer IAF InGaAs mHEMT technology: extremely low-noise and broadband applications at room temperature
- ▶ Signal generation TX and analysis RX at 275 to 325 GHz operating frequency
- ▶ Signals can be arbitrary modulated for transmission experiments with beyond 5G candidate waveforms for THz communication or for channel propagation measurements



„THz Channel Sounding: Design and Validation of a High Performance Channel Sounder at 300 GHz“ (IEEE WCNC2020) <https://ieeexplore.ieee.org/document/9124887>



Rohde & Schwarz

**Sub-THz Channel Measurements at 158 GHz and 300 GHz in a Street Canyon Environment**

Wilhelm Keuvsen<sup>1</sup>, Alper Schuitze<sup>1</sup>, Michael Peter<sup>1</sup>, Tam Eichler<sup>2</sup>  
<sup>1</sup>Technische Universität Berlin, Berlin, Germany, [wilhelm.keuvsen@tu-berlin.de](mailto:wilhelm.keuvsen@tu-berlin.de)  
<sup>2</sup>Fraunhofer Heinrich Heine Institute, Berlin, Germany  
<sup>3</sup>Rohde & Schwarz, Munich, Germany

**I. INTRODUCTION**

This paper presents first results of a channel measurement campaign performed in an urban canyon (UC) street canyon scenario at 158 GHz and 300 GHz. The measurements are part of a larger research activity aiming for a better understanding of the millimeter and sub-millimeter (sub-THz and THz) mobile radio channel in extension to prior work [1]. The frequencies were chosen with respect to ongoing discussions for the sixth generation of mobile networks (6G). The presented results address fundamental questions with respect to the processing of measurement data and give some insight into typical properties of the radio channel at these frequencies.

**II. CHANNEL SOUNDER SETUP**

The measurements were captured using an instrumented time-domain channel sounder equipped with D-Band (110 GHz to 170 GHz) and H-Band (220 GHz to 330 GHz) front-ends. The setup consists of a static transmitter and a mobile receiver. The transmitter comprises a broad-band vector signal generator, that generates an IP signal from a digital baseband sequence, as well as a single-sideband upconverter with a distinct LO source, that mixes the signal into the RF domain. The receiver consists of a step-rate variable downconverter with a distinct LO source that amplifies the antenna signal and mixes it into an IF domain, and a signal analyzer that samples the IF signal and stores it as IQ samples. At each measurement point, the receiver was rotated by 360 degrees in 24 uniform steps, resulting in a directional sampling of the propagation channel in the azimuth plane with a resolution of 15 degrees. For each angle approached, 150 sequence snapshots were taken and used for averaging to increase the instantaneous dynamic range. For both bands, the receiver was equipped with standard gain horn antennas with a gain of 20 dBi. Transmitter and receiver are synchronized with two submillimeter-band reference clocks and trigger units, enabling coherent measurements and the determination of the absolute time of flight. The fundamental channel sounder parameters are the carrier frequencies of 158 GHz and 300 GHz, a measurement bandwidth of 2 GHz, and the use of a complex correlation sequence with a duration of 100  $\mu$ s. Further information about the setup and performed measurements at 300 GHz can be found in [2], [3].

**III. MEASUREMENT SCENARIO AND PROCEDURE**

The measurements took place on company premises in Munich, Germany, well representing a UC street canyon scenario as shown in Fig. 1. The 25.5 m wide street canyon is bounded by two buildings with a height of approx. 20 m. The transmitter was located in the middle of the street at a height of 1.5 m. The receiver, which exhibited the same antenna height, was moved to multiple positions along the middle of the street up to a maximum distance of 170 m. Most of the measurements were made in line-of-sight condition.

**IV. MEASUREMENT EVALUATION AND RESULTS**

In order to get calibrated channel impulse responses (CIRs), the accumulated IQ samples are passed through several processing steps, which include resampling, filtering, estimation and compensation of common phase drift, coherent averaging and correlation with pre-recorded back-to-back calibration data. Fig. 2 shows measurement results for both carrier frequencies at a distance of 30 m. Both figures illustrate the CIR measured in the direction of the LOS path as a line plot and the pseudo-conductivity CIR including all directions as an area plot. The leading part of the CIR is additionally depicted with an expanded delay axis.

One can see the first peaks at 0.1  $\mu$ s, which corresponds to a distance of 30 m. The noise floor at 158 GHz can

**Observations on the Angular Statistics of the Indoor Sub-THz Radio Channel at 158 GHz**

Alper Schuitze<sup>1</sup>, Wilhelm Keuvsen<sup>2</sup>, Michael Peter<sup>1</sup>,  
<sup>1</sup>Fraunhofer Heinrich Heine Institute, Berlin, Germany  
<sup>2</sup>Technische Universität Berlin, Berlin, Germany  
<sup>3</sup>Rohde & Schwarz, Munich, Germany

**I. INTRODUCTION**

Previous research related to 5G millimeter-wave systems has shown that adapted narrow-beam antennas have a major impact on the radio channel—the “effective channel” consisting of transmit antenna, propagation channel and receive antenna [1]. Recent discussions on the sixth generation of mobile networks (6G) have further increased the importance of such studies and accurate modeling approaches for the sub-THz and THz frequency range. Based on channel measurements, this paper investigates the impact of multipath propagation at 158 GHz in a shopping mall scenario and the directional channel gain (normalised received power) that a system with beamforming functionality would observe by exploiting the receiver directions with the strongest reflection paths.

**II. CHANNEL SOUNDER SETUP**

The instrumented time-domain channel sounder makes use of D-band front ends acting as up-llows-converters from an intermediate frequency (IF) stage and mixers operating at a carrier frequency of 158 GHz with a measurement bandwidth of 2 GHz. The complex sounding sequence, which has a duration of 100  $\mu$ s, is provided on the IF by a wideband vector signal generator. At the receiver side, a minimum of signal periods are sampled in the IF domain using a signal analyzer. A rotation table enables angle-resolved measurements by turning the sounder in the azimuth plane. The channel sounder was equipped with a standard gain horn antenna with a gain of 20 dBi. The channel sounder setup, including the evaluation of another indoor measurement campaign are discussed in [2] in more detail.

**III. MEASUREMENT SCENARIO AND PROCEDURE**

The measurement’s venue was a company building’s atrium that well represents a shopping mall scenario. The room size is 13 m x 20 m with a ceiling height of 21 m. Continuous glass fronts and a steel floor characterize the room’s procurement. The transmitter was placed centrally at the beginning of the

**IV. MEASUREMENT EVALUATION AND RESULTS**

In the first evaluation step, the received sounding sequences were subjected to a phase compensation, coherent averaging, and correlation with a pre-recorded back-to-back calibration, resulting in one channel impulse response (CIR) per measurement position and direction (see Fig. 2).

In the second step, a discrete path estimation in the angular delay domain was performed by means of a local peak search [2], leading to complex path coefficients being discretized into cyclic angular bins with 1° width and delay bins with 0.5 ns width. The estimation was performed with respect to a fixed threshold of  $-130$  dB, which is significantly higher than the noise floor coverage (Fig. 2). The sum of path gains in one direction yields the directional channel gain, whereas the sum over all directions yields the omnidirectional channel gain. In this paper, we are more interested in the underlying directional statistics, thus we apply a normalization to the omnidirectional channel gain in the sequel.

Fig. 3 shows estimated directional channel gains and path gains per angular bin for position P3 in terms of a rose plot.

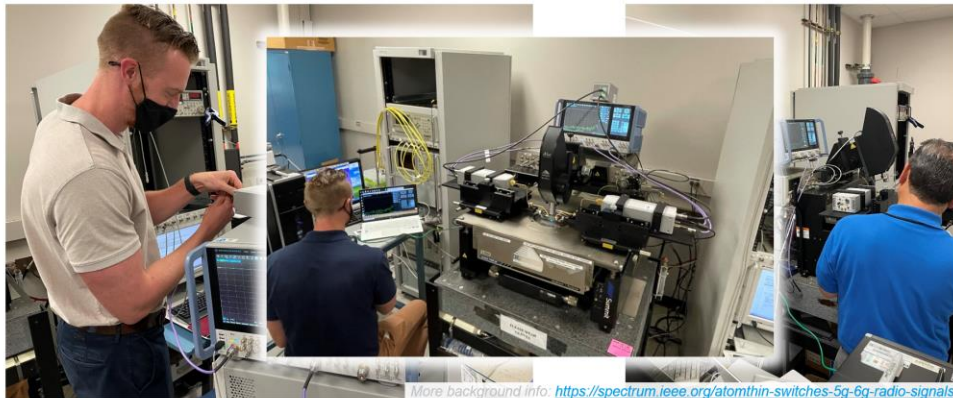
<https://arxiv.org/abs/2203.04404>  
(March 2022)

<https://arxiv.org/pdf/2203.04397.pdf>  
(March 2022)

# COLLABORATION WITH ACADEMIA ON mmWAVE AND THz TESTING RF SWITCHES @ D-BAND W/ R&S®ZNA43 & R&S®ZC170

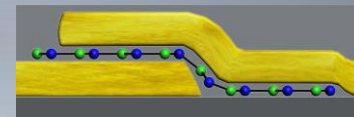
## COLLABORATION WITH UNIVERSITY OF TEXAS IN AUSTIN

MEASURE RF SWITCHES WITH R&S®ZNA43 AND R&S® ZC170



More background info: <https://spectrum.ieee.org/atomthin-switches-5g-6g-radio-signals>

Non-volatile memristor-like switch from 2D hexagonal boron nitride



An atom-thin layer of hexagonal boron nitride sandwiched between gold electrodes acts as a switch to route 5G and possibly higher frequencies <https://spectrum.ieee.org/atomthin-switches-5g-6g-radio-signals>

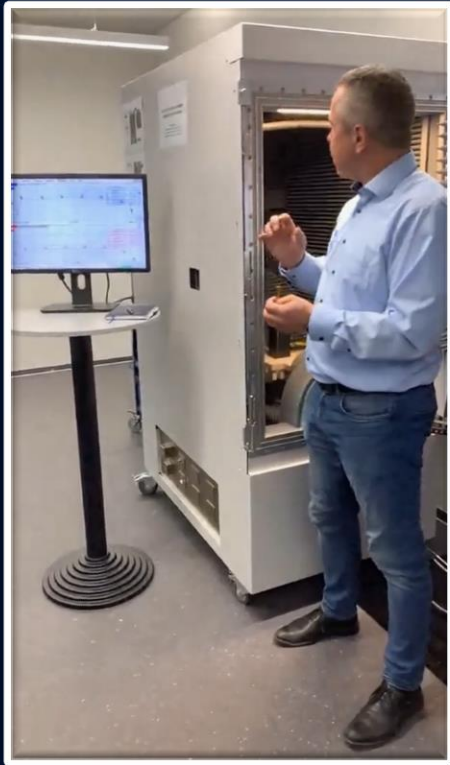
Munich / 13-Jan-2022

Rohde & Schwarz and FormFactor support the University of Texas at Austin in research on improved RF switches for 5G and 6G

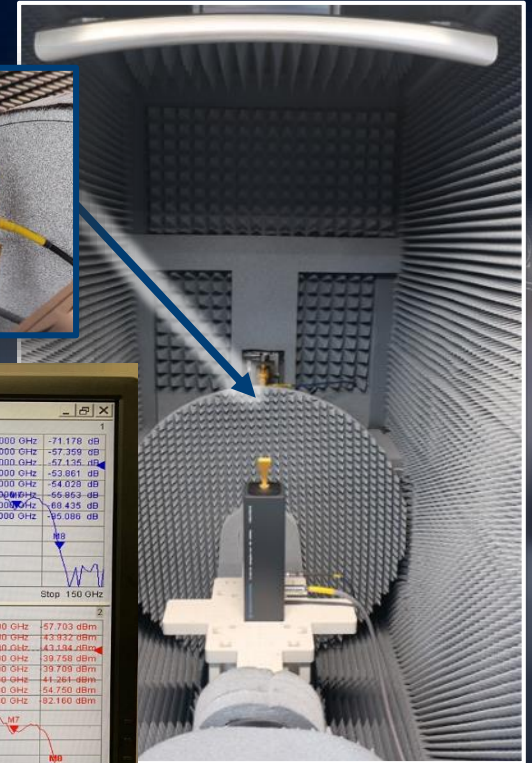
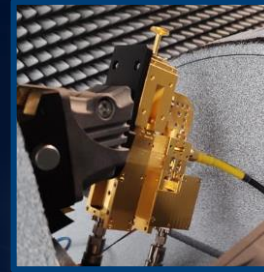
The University of Texas at Austin, Rohde & Schwarz and FormFactor have collaborated to characterize a new technology for RF switches that improves battery life performance and supports higher bandwidths and switching speeds.



# SIMULTANEOUSLY WE TAKE THE NEXT STEP TOWARDS FULL OTA TEST SOLUTIONS FOR D-BAND



Initial realization:  
90 to 140 GHz  
– full D-band  
support under  
development



# ONE OF THE OFTEN RAISED QUESTION

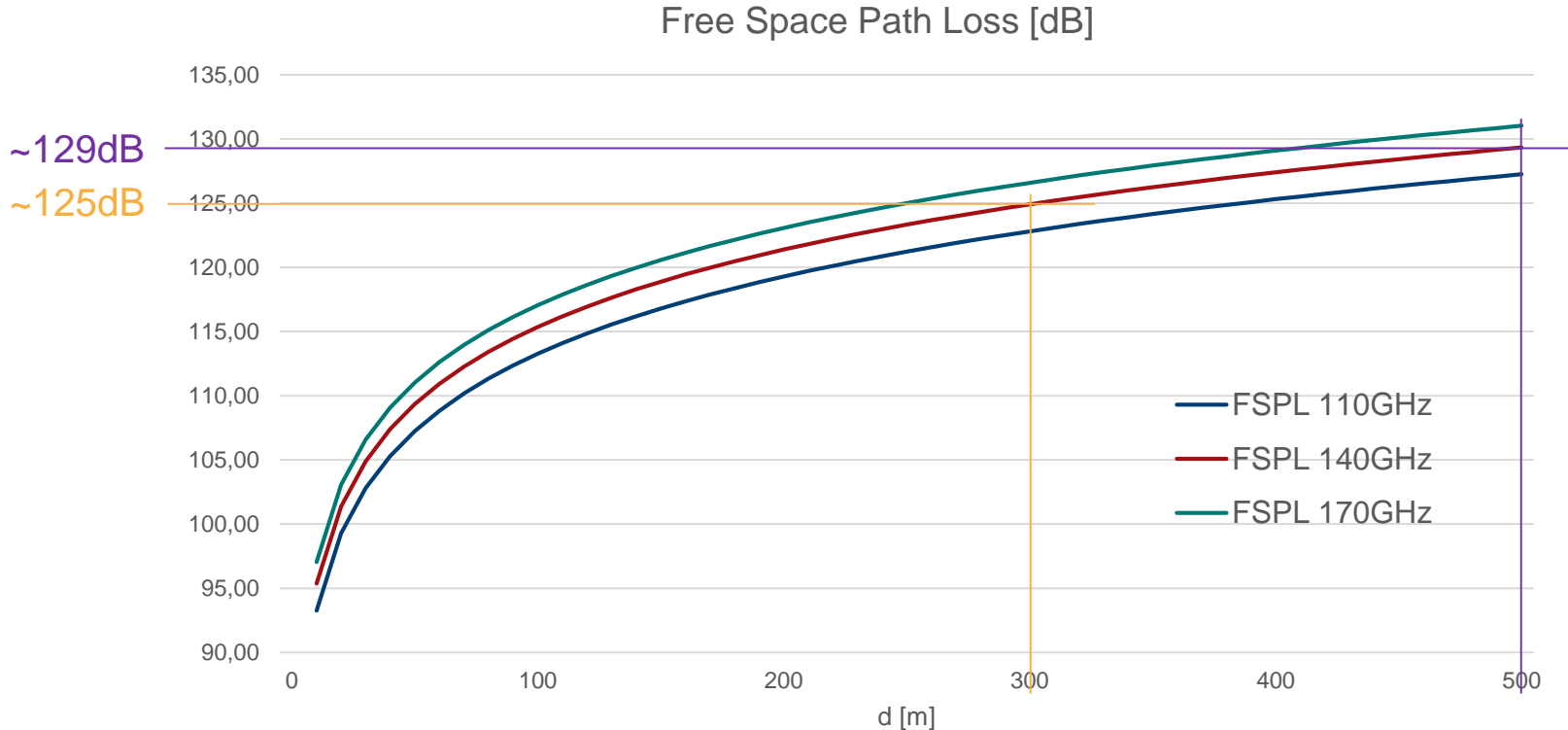


Can we ever realize significant cell sizes at D-Band frequencies?



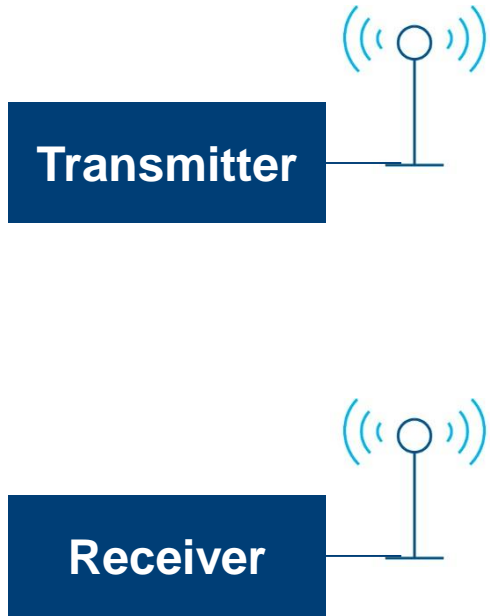
# D-BAND BASICS

## FREE SPACE PATH LOSS



# D-BAND LINK BUDGET

## A VERY BASIC EXAMPLE



$$\text{Path loss} = \text{TX power} - \text{RX sensitivity}$$

### TX power

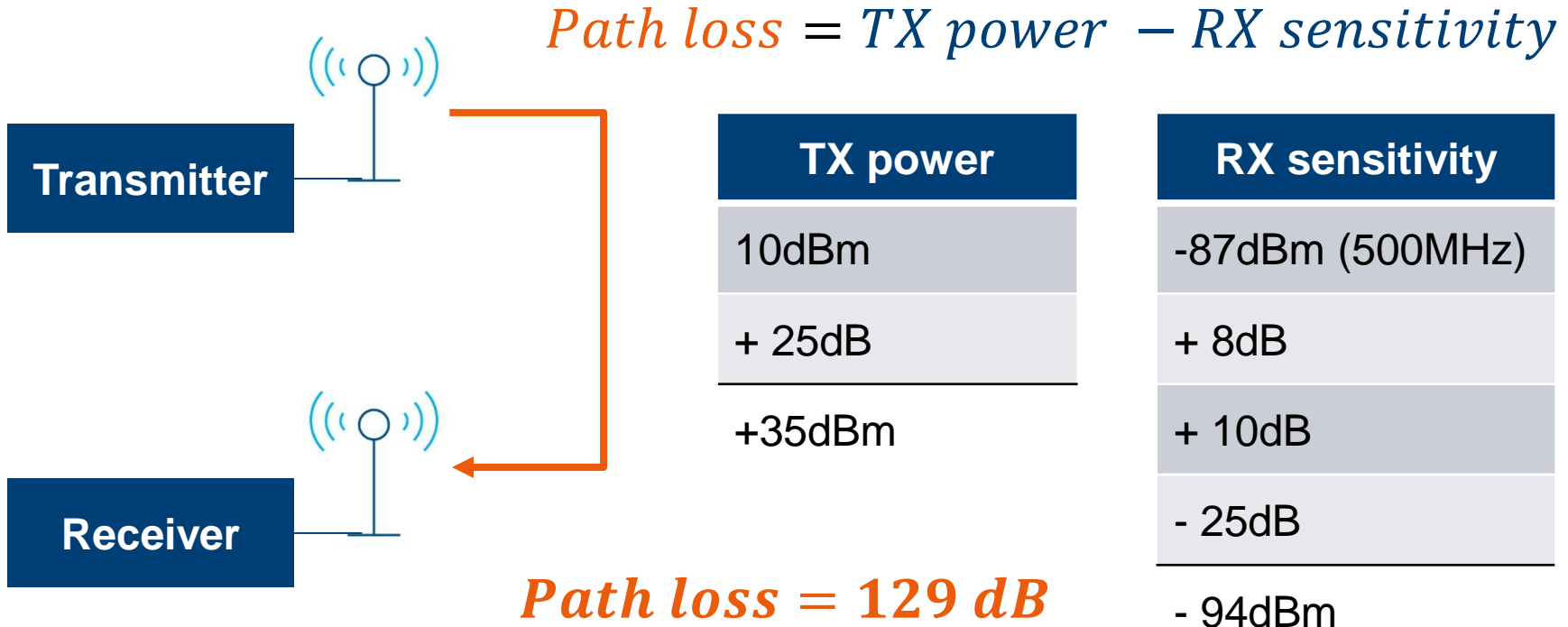
Device power  
+ TX ant gain

### RX sensitivity

Noise (BW)  
+ Noise figure  
+ Required SNR  
- RX ant gain

# D-BAND LINK BUDGET

## A VERY BASIC EXAMPLE



# ANOTHER OFTEN RAISED QUESTION

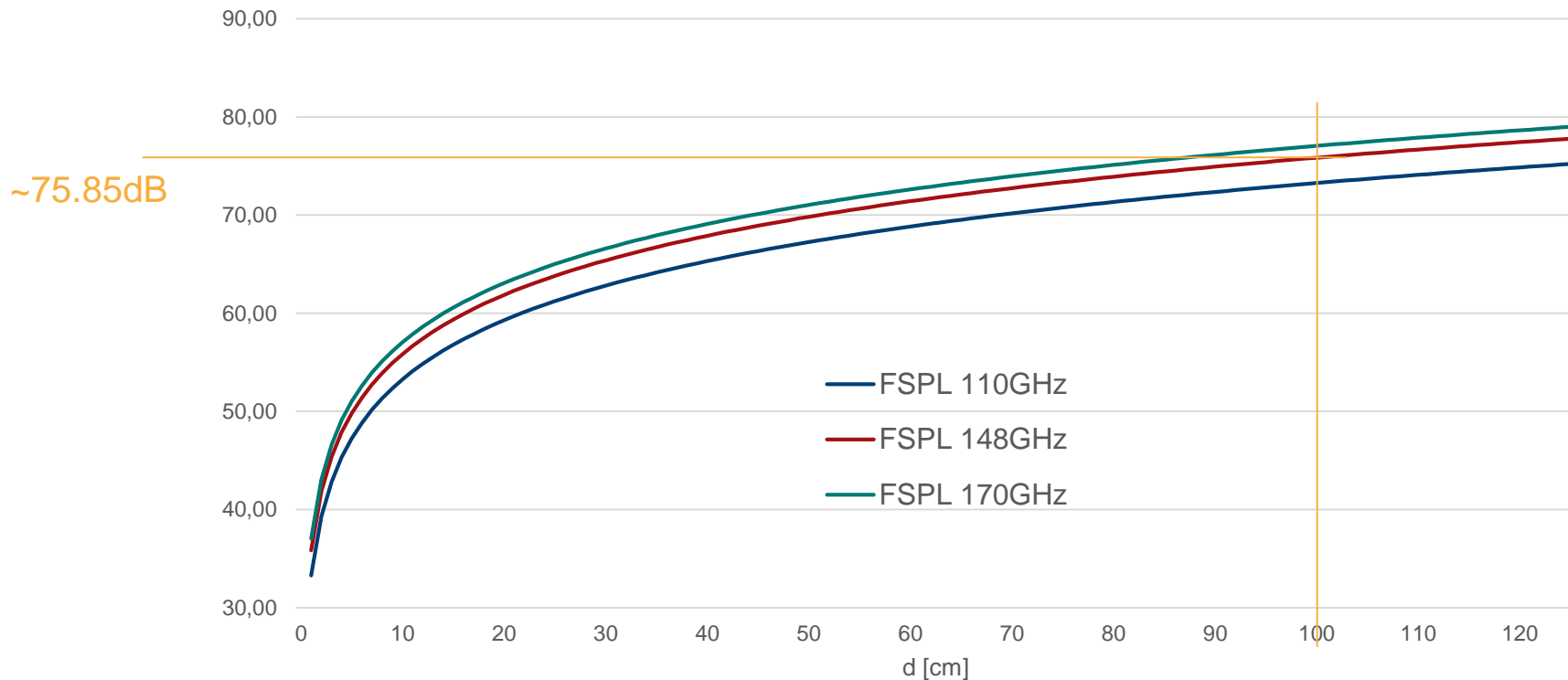


Can we at all transmit  
through material?

# D-BAND BASICS

## FREE SPACE PATH LOSS

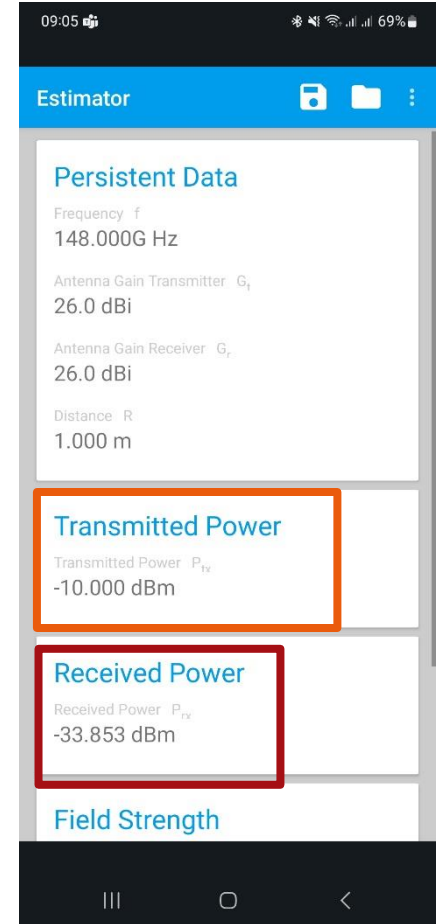
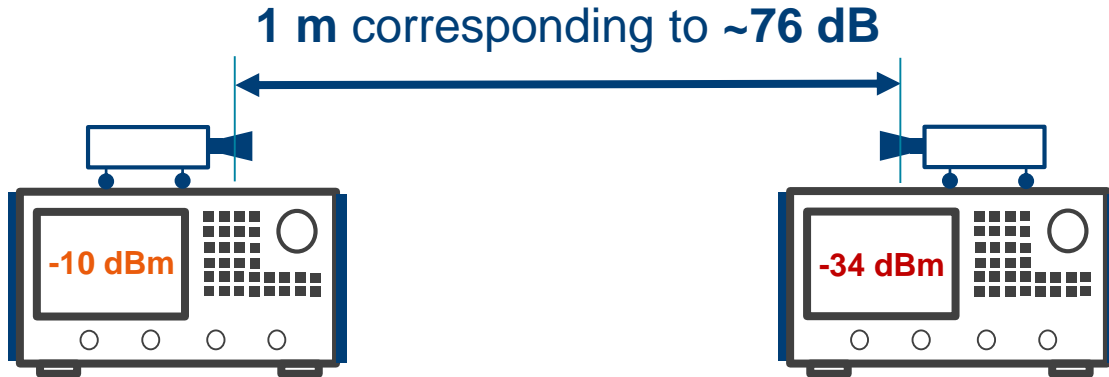
Free Space Path Loss [dB]



# CALCULATIONS

## TODAYS DEMO SETUP

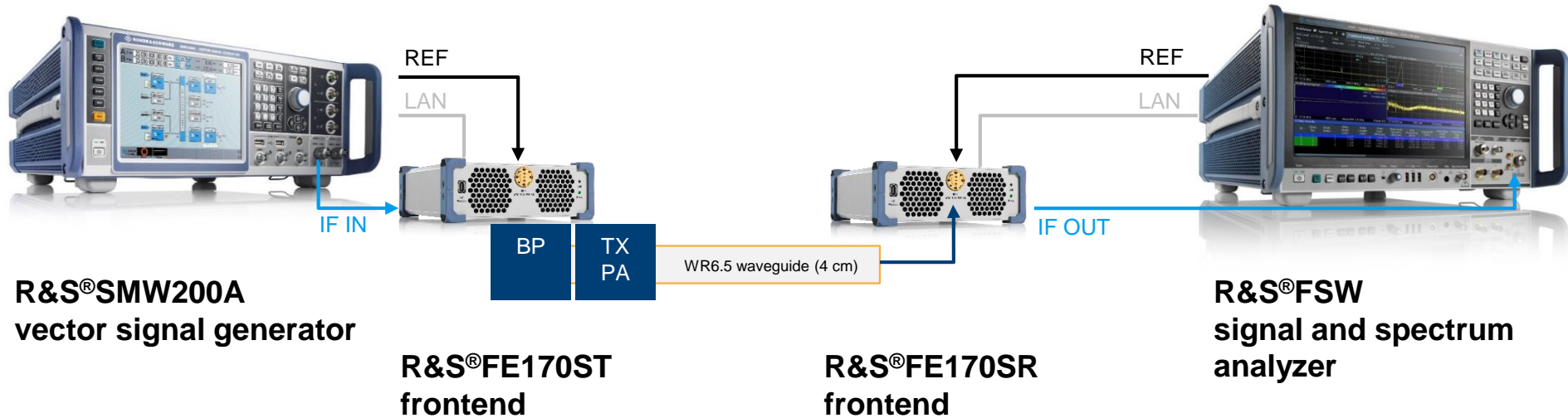
- ▶ Part 1: simple LOS case
- ▶ Part 2: impact from various materials
- ▶ Part 3: reflection NLOS case



# DEMO

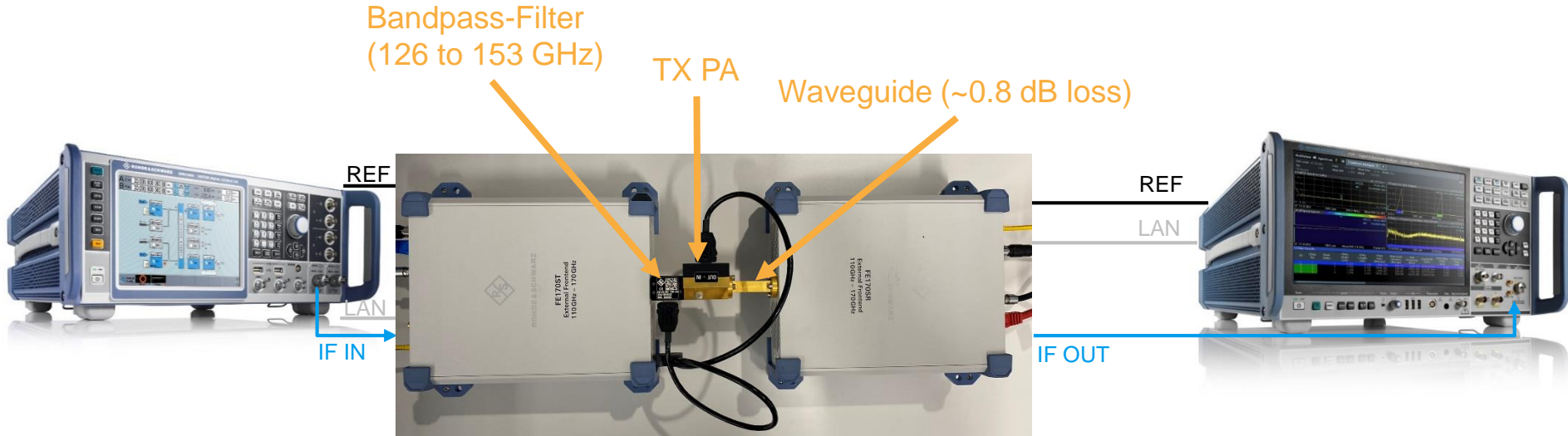


# TEST SETUP





# SETUP



# SETUP

**A** Freq: 148.000 000 000 GHz RF Off Int Ref Mod Off PEP: -10.00 dBm Level: -10.00 dBm

**B** Freq: 1.000 000 000 000 GHz RF Off Int Ref Mod Off PEP: -30.00 dBm Level: -30.00 dBm

IP: 10.102.189.49

System Config VNC 0: Power A 5G NR A

MultiView Spectrum IQ Analyzer 5G NR

Ref Level: -15.00 dBm ExtFe: Att 20 dB SAN: Att 10 dB Freq 148.0 GHz Meas Time 31.281 μs SRate 4.0 GHz

Inp: ExtFe EVM Optimized IFCorr YIG Bypass Rec Length 125 125 RBW 3.74 MHz

**1 Spectrum** M1[1] -76.54 dBm #0 148.000 000 000 GHz

CF 148.0 GHz 1001 pts 400.0 MHz/ Span 4.0 GHz

2 Marker Table

Wnd	Type	Ref	Trc	X-Value	Y-Value	Function	Function Result
1	M1		1	148.0 GHz	-76.54 dBm	Band Power/1.75 GHz	-49.39 dBm

Measuring... 2022-12-13 13:20:43



# CONCLUSION

- ▶ Academia and key industry players are exploring the boundaries and many research projects started looking into the next generation of wireless communication, aka 6G.
- ▶ One – out of multiple – research items investigate D-band spectrum as potential band offering wider bandwidth and therefore enabling new or enhanced use cases.
- ▶ Testing D-band components requires easy to use instruments, which provide stable and accurate measurement results as calibration is key in the sub-THz frequency range.



Find out more

[www.rohde-schwarz.com/wireless/6G](http://www.rohde-schwarz.com/wireless/6G)

**ROHDE & SCHWARZ**

Make ideas real

