Webinar series: 5G Device Testing Journey

CHALLENGES TO 5G MMWAVE COMPONENT CHARACTERIZATION

Kuek CY
Regional Application for Test and Measurement

ROHDE&SCHWARZ

Make ideas real

- 15th June – Production test strategies and smart solutions
- 8th June – Making lab testing more realistic with R&S®CM360
- 1st June – ONE tool for automated device testing
- 25th May – Simplifying 5G mobile device testing
- 11th May – Challenges to 5G mmWave component characterization
- 4th May – Validation of digital design of next gen devices

5G DEVICE TESTING JOURNEY

Webinar Series

AGENDA

- Motivation for mmwave in 5G
- OTA testing becomes the default case
  - Beamforming
  - Near field, Far field, Quiet zone
  - Black box / White box approach
  - DFF, IFF, CATR
- Impacts on UE RF frontend
  - Antenna
  - Power Amplifiers
  - Envelope tracking, DPD
- R&S Solutions
- Demo and Q&A

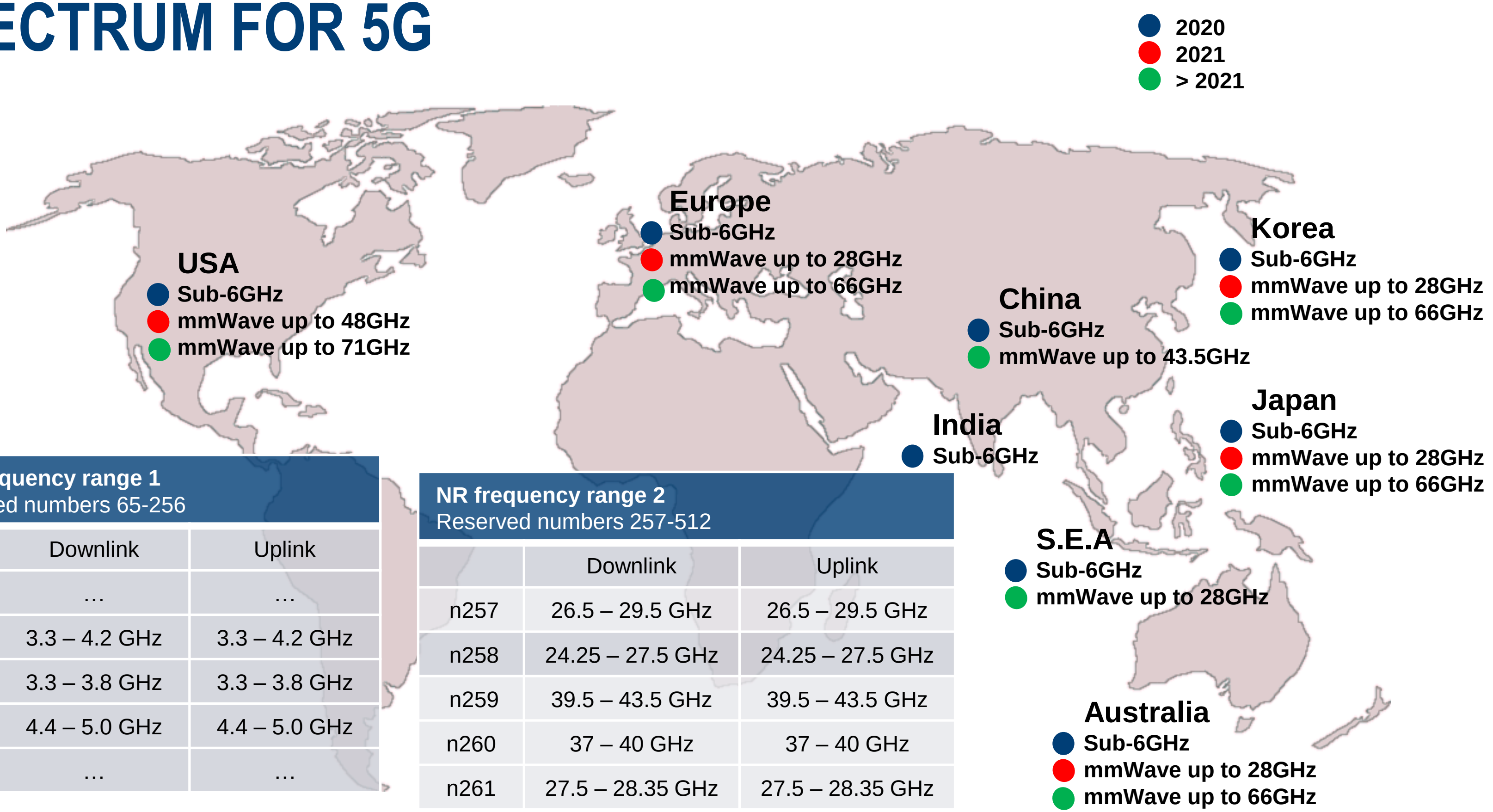
NEED FOR 5G MMWAVE

- Outdoor Entertainment
- Virtual reality experience
- Smart manufacturing
- Connected vehicles
- Smart surveillance

⋮

High Gigabytes Data Rates | Lower Latency | Higher Capacity

SPECTRUM FOR 5G



NR frequency range 1
reserved numbers 65-256

	Downlink	Uplink
…	…	…
n77	3.3 – 4.2 GHz	3.3 – 4.2 GHz
n78	3.3 – 3.8 GHz	3.3 – 3.8 GHz
n79	4.4 – 5.0 GHz	4.4 – 5.0 GHz
…	…	…

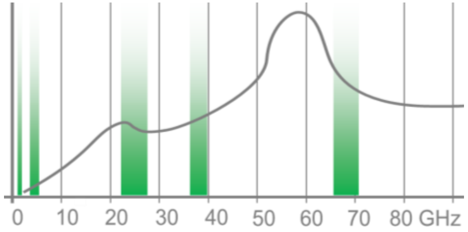
NR frequency range 2
Reserved numbers 257-512

	Downlink	Uplink
n257	26.5 – 29.5 GHz	26.5 – 29.5 GHz
n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz
n259	39.5 – 43.5 GHz	39.5 – 43.5 GHz
n260	37 – 40 GHz	37 – 40 GHz
n261	27.5 – 28.35 GHz	27.5 – 28.35 GHz

5G NEW RADIO (NR) AIR INTERFACE PARAMETERS

Parameter	FR1 (410 MHz – 7.125 GHz)	FR2 (24.25 – 52.6 GHz)
Carrier aggregation	Up to 16 carriers	
Bandwidth per carrier	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100 MHz	50, 100, 200, 400 MHz
Subcarrier spacing	15, 30, 60 kHz	60, 120, 240 (not for data) kHz
Max. number of subcarriers	3300 (FFT4096 mandatory)	
Modulation scheme	QPSK, 16QAM, 64QAM, 256QAM; Uplink also supports π/2-BPSK (only DFT-s-OFDM)	
Radio frame length	10 ms	
Subframe duration	1 ms (alignment at symbol boundaries every 1 ms)	
MIMO scheme	Max. 2 codewords mapped to max 8 layers in downlink and to max 4 layers in uplink	
Duplex mode	TDD, FDD	TDD
Access scheme	Downlink: CP-OFDM; Uplink: CP-OFDM, DFT-s-OFDM (network controlled)	

CHALLENGES FOR 5G MMWAVE



High path loss

Susceptible to interference

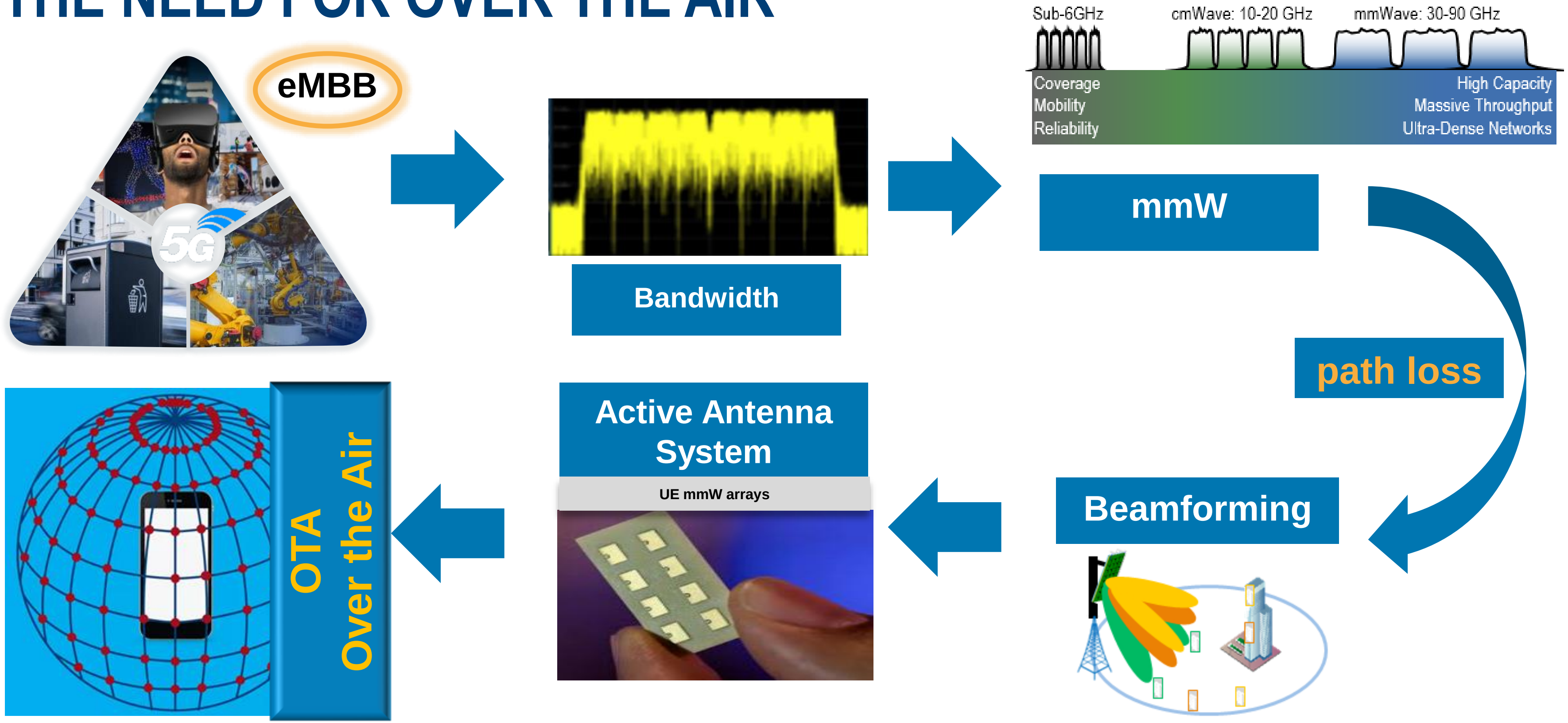
High energy consumption

Short range

Indoor penetration difficulties

OTA TESTING BECOMES THE DEFAULT CASE

THE NEED FOR OVER THE AIR



OVERCOMING PATH LOSS ISSUES

Higher frequencies = higher attenuation
Higher frequencies = smaller antennas

γ = path loss exponent

Friis equation

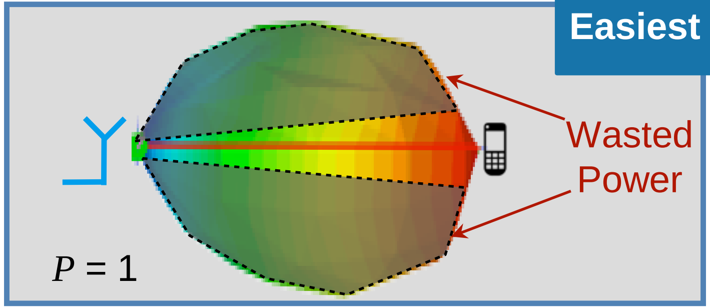
$$\frac{P_{Rx}}{P_{Tx}} = G_{antenna}\left(\frac{c}{4\pi f d}\right)^{\gamma}$$

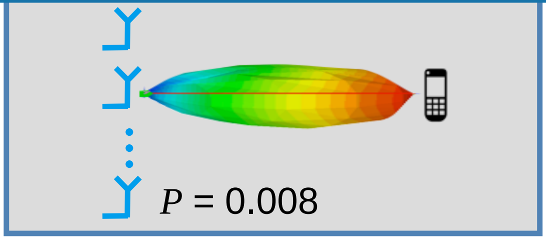
PathLoss 28 GHz	γ = 2 Free Space	γ = 1.6 to 1.8 Indoor LOS	γ = 2.7 to 3.5 Urban Area
1 m	- 61,4 dB	- 52 dB (k=1,7)	-92,1 dB (k = 3)
10 m	- 81,4 dB	-69 dB	-122,1 dB
100 m	- 101,4 dB	-86 dB	- 151,1 dB
1000 m	- 121,4 dB	-103 dB	- 181,1 dB

BEAMFORMING TECHNIQUE

► Antenna systems with a high number of antenna elements, which can be individually controlled in phase and amplitude, enable high antenna gains and beam steering.

Easiest way to improve energy efficiency: more antennas

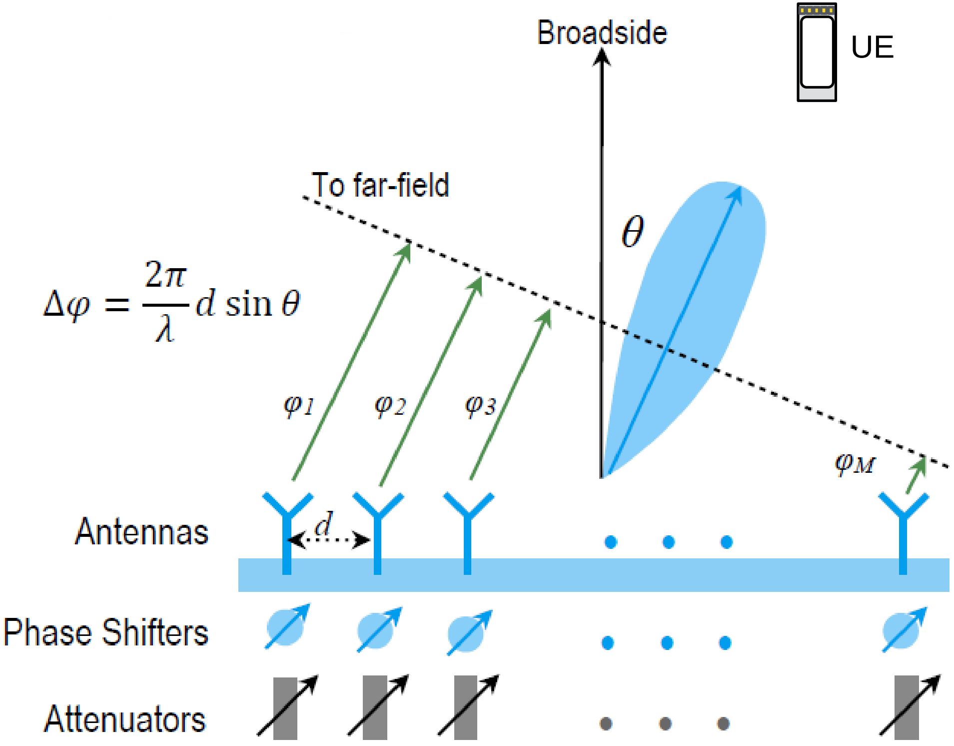




Number of Antennas = 1	
Number of transmit antennas (M_t)	1
Normalized output power of antennas	$P_{ant} = \frac{1}{M_t} = 1$
Normalized output power of base station	$P_{total} = \sum_{i=1}^{M_t} P_{ant}{}^{i} = 1$

Number of UEs: 1 **120 antennas per UE**
120
$P_{ant} = \frac{1}{M_t{}^2}$
$P_{total} = \sum_{i=1}^{M_t} P_{ant}{}^{i} = 0.008$

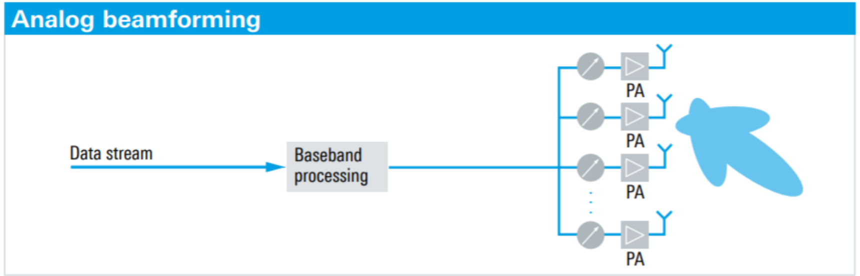
BEAMFORMING TECHNIQUE

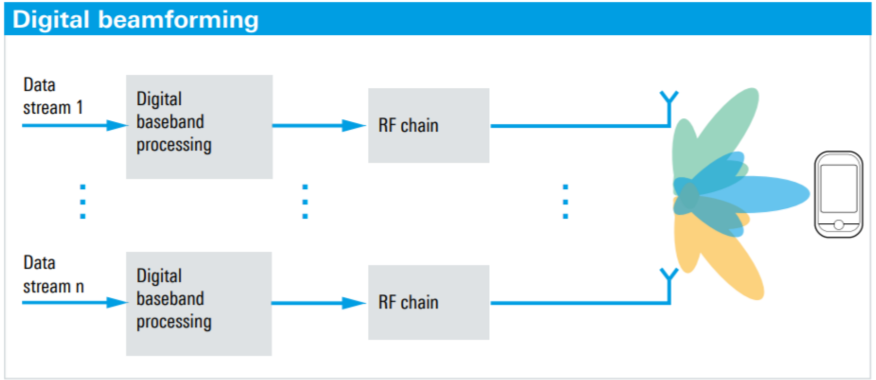


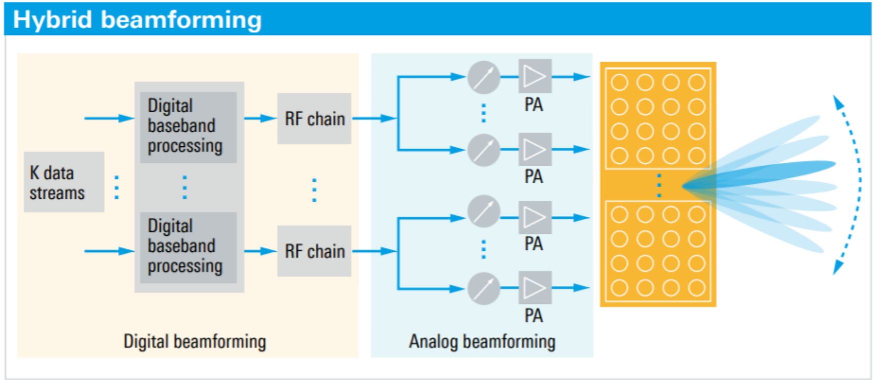
Main beam direction steerable with phase shifters

phase shifters
Weighting by phase

BEAMFORMING TECHNIQUE

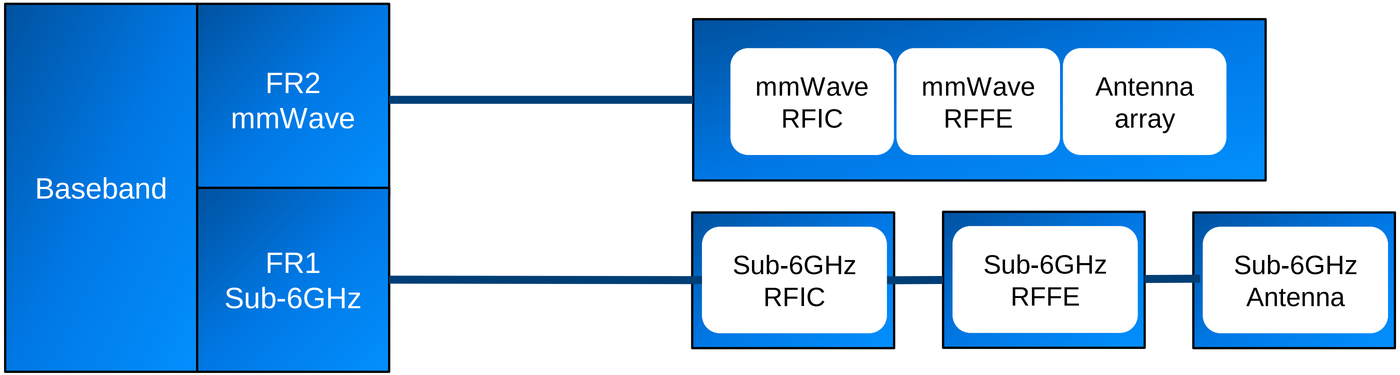






USER EQUIPMENT (UE) RF FRONTEND

- ► Support Beamforming with phase array antenna implementation
- ► High Integration for RF frontend



IMPACTS ON UE RF FRONTEND

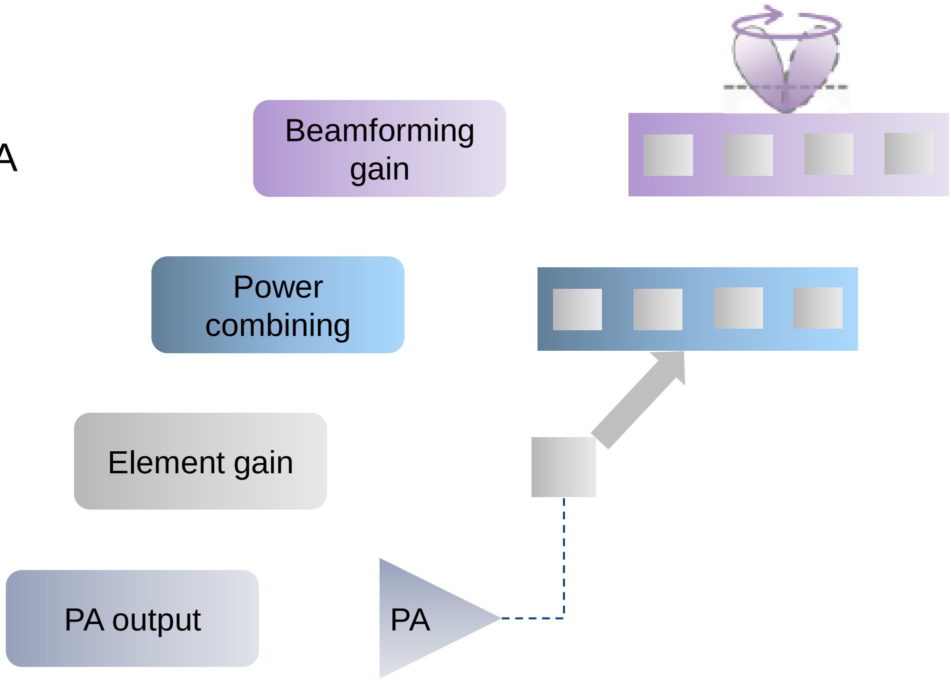
CHARACTERIZING RF FRONTEND CHALLENGES

- Over the air testing
  - Beam direction
  - Elimination of RF connectors
  - Far field measurement – large chamber required

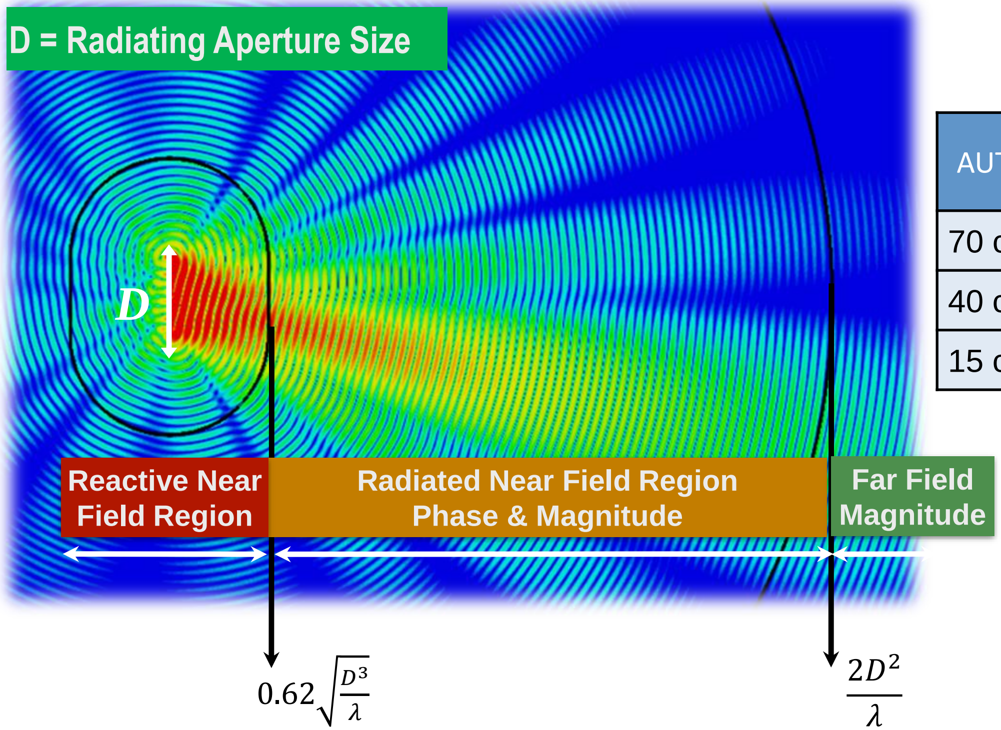
- Device Calibration and Measurement
  - Ensure correct beam phase and amplitude
  - Any phase difference has a significant influence on beamforming accuracy
  - Characterization of array antenna using modulated signal

CHARACTERIZING RF FRONTEND CHALLENGES

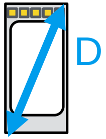
- Power amplifier efficiency
  - To achieve desired EIRP
  - Increasing array elements, increasing PA
  - Maintaining power efficiency with many beamforming PA channels



OTA MEASUREMENT



AUT size (D)	FF distance at 3.5 GHz	FF distance at 28 GHz
70 cm	11.4 m	91.2 m
40 cm	3.74 m	29.9 m
15 cm	0.53 m	4.2 m

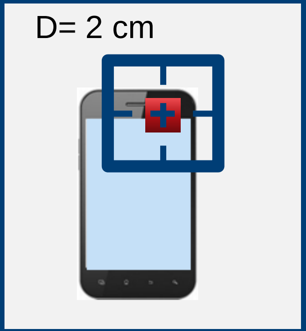


OTA MEASUREMENT

White box

- Size and position of the antenna known
- This size can be taken as D
- White box testing - device is a “white box” for the user since position of the antenna is known
- Example @ 30GHz
  - λ = 1cm
  - D= 2cm
  - Far field distance: 8cm

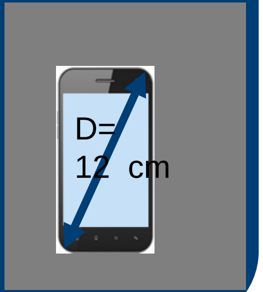
$$\frac{2D^2}{\lambda}$$



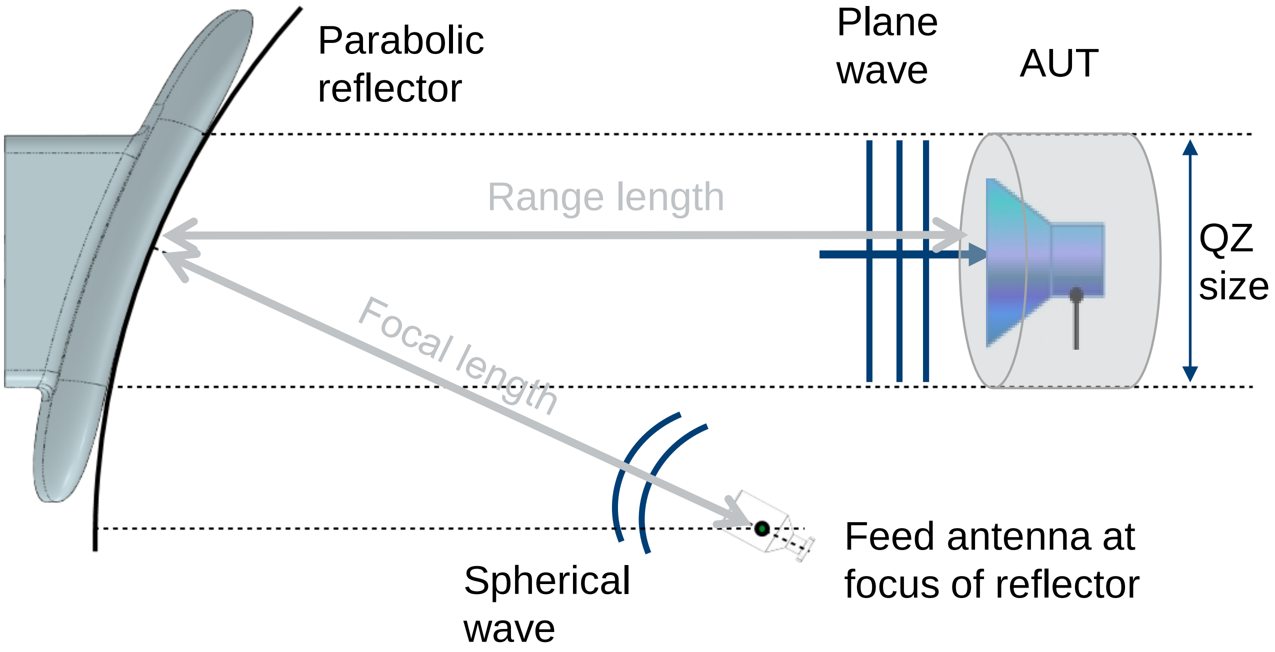
Black box

- Size and/or position of the antenna is unknown
- Entire DUT maximum distance to be considered as D
- Black box testing - device is a “black box” for the user
- Example @ 30GHz
  - λ = 1cm
  - D= 12cm
  - Far field distance: 2.9 m

$$\frac{2D^2}{\lambda}$$



CATR BASIC THEORY OF OPERATION

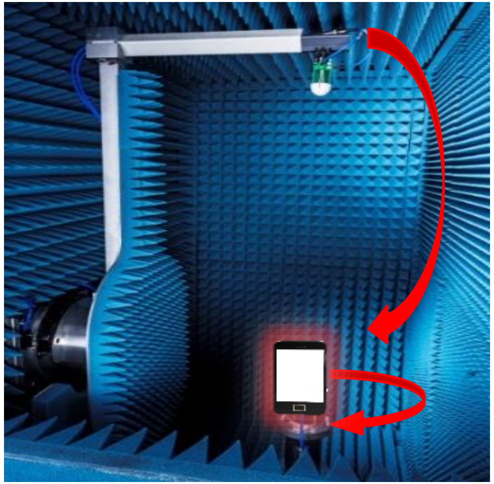


QZ size depends on
- Size of reflector
- Feed antenna properties
- Focal length

No direct relation between chamber size and QZ size

OTA MEASUREMENT

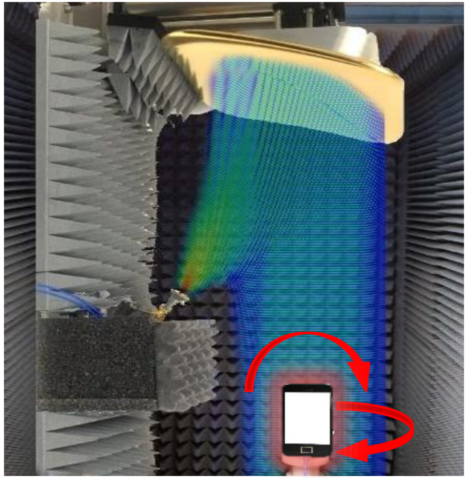
DFF solution for Whitebox & extreme temperature testing



Azimuth
+/- 180°

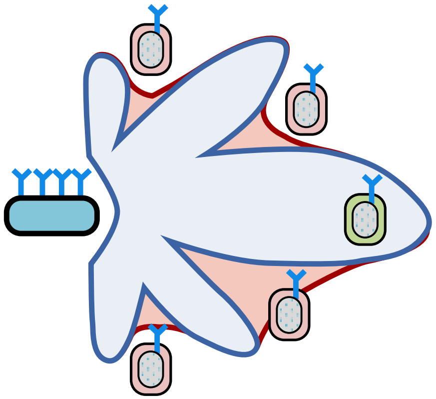
✓ Both systems fit in ATS form factor

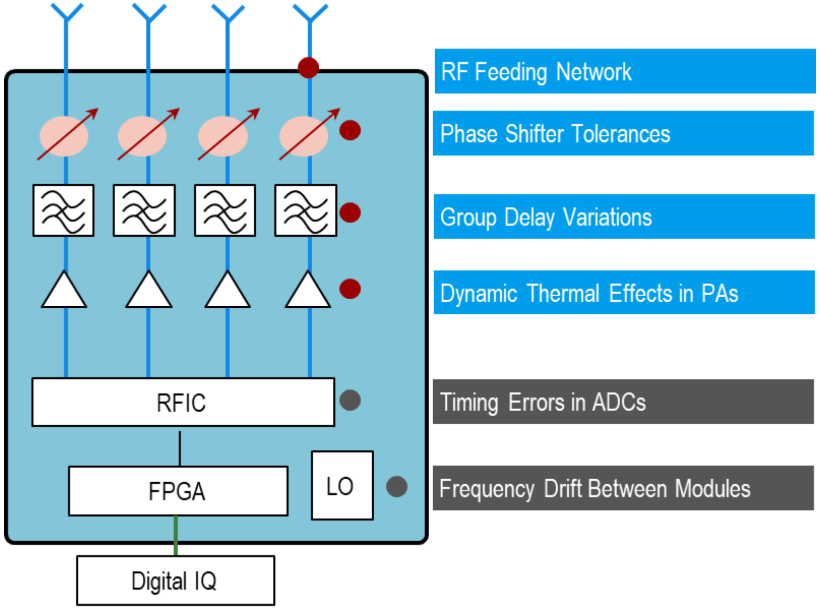
IFF solution for Blackbox & standard temperature testing



CHARACTERIZING BEAMFORMING COMPONENTS

- Beamforming accuracy dependent on phase, amplitude and timing differences of array elements

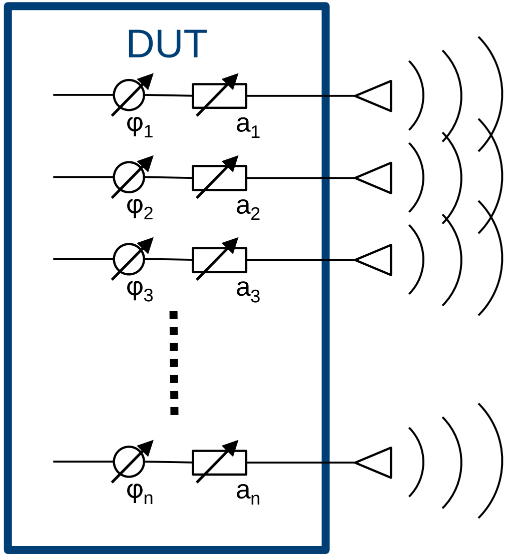




ARRAY ANTENNA CALIBRATION

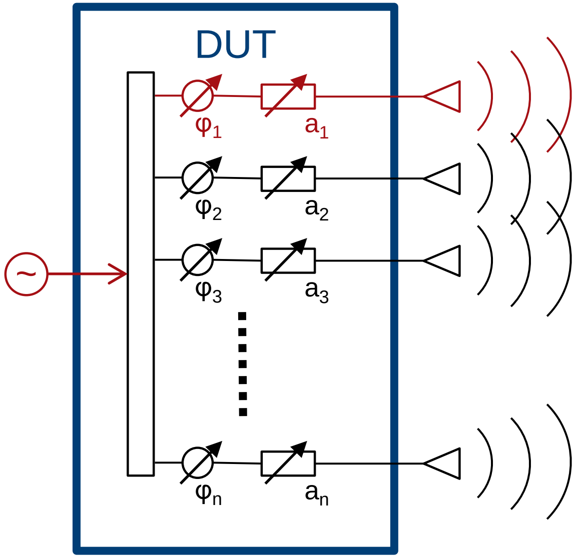
- Phase array antenna calibration
  - To correct for relative amplitude and phase offsets

- Main challenges
  - Over the air measurement
  - No phase coherent between array antenna and receiver
  - Various calibration methods



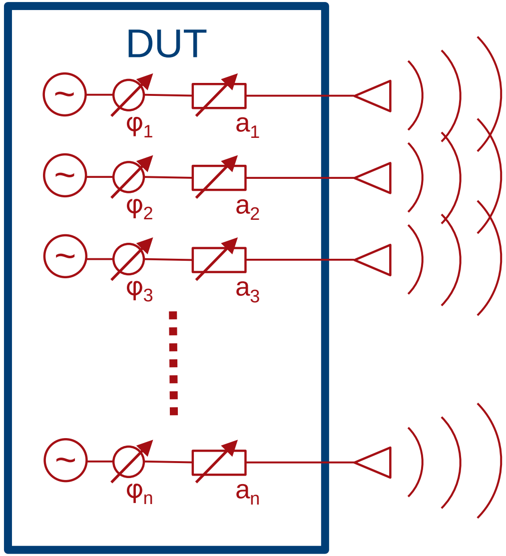
ARRAY ANTENNA CALIBRATION METHOD

- Direct Measurement
- Measure **attenuation and phase** over time
  - Switch through all elements sequenctially,
  - Straight forward approach
  - Get absolute information for each element
- No phase coherent required
  - Correction of common frequency error
- Test instrument
  - Signal generator and signal analyzer
  - Vector network analyzer
  - Communication tester



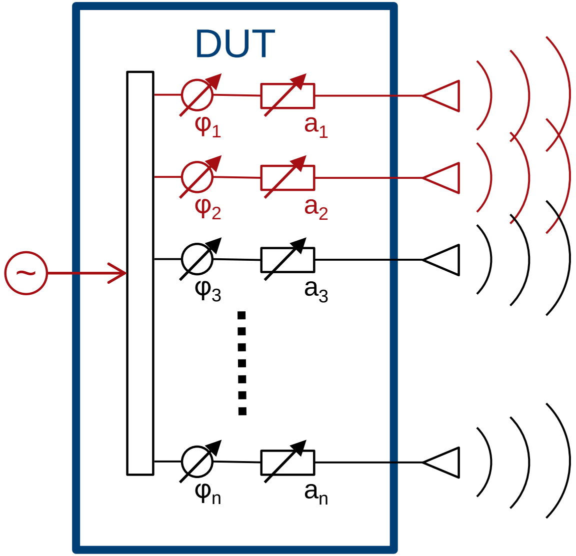
ARRAY ANTENNA CALIBRATION METHOD

- Direct Measurement
- Parallel calibration
  - Use FDMA or CDMA based methodology
  - DUT with multiple processing units
- Retrieve all signals with single receiver
  - Use DSP to discriminate signal sources
- Requires capability to play different signal per element
- Requires transmission of different signal per element



ARRAY ANTENNA CALIBRATION METHOD

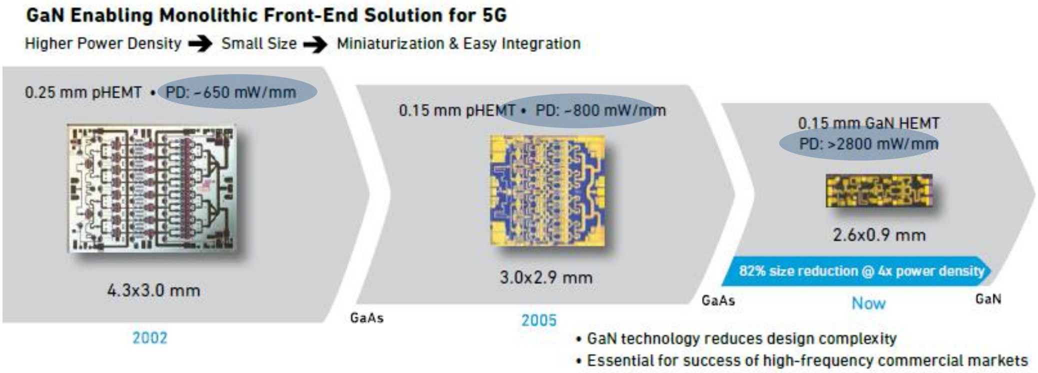
- In-direct Measurement
- Measure **RX power** for two active elements
  - Two active elements
  - Change relative phase between elements
  - Get relative mag/phase setting per element
- Requires possibility to stimulate 2 elements at a time
- No phase coherent required
- Test instruments
  - Signal generator and signal analyzer



POWER AMPLIFIER (PA) TECHNOLOGY

Latest technology: GaN

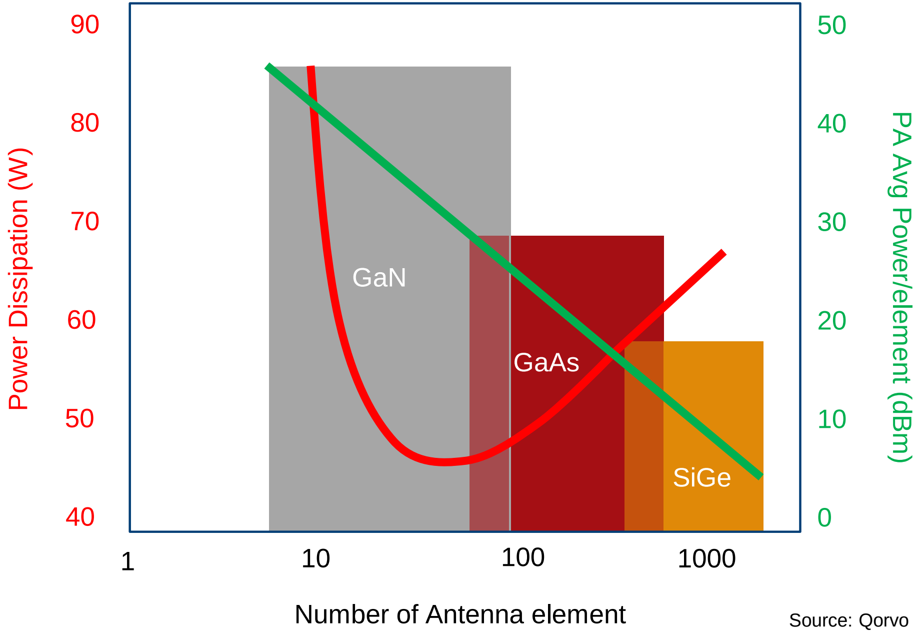
- ► Power density: 8 times of GaAs
- ► Efficiency: 40 to 70 % up to GaAs
- ► Manufacturing cost: 2-3 times of GaAs for the start, but will go down significantly
- ► Higher integration possible thanks smaller package and higher power density
- ► Excellent suited for wideband applications and higher frequencies



EFFECTS OF ANTENNA ARRAY ON PA POWER

- Battle of Technologies
- GaN vs GaAs vs SiGe

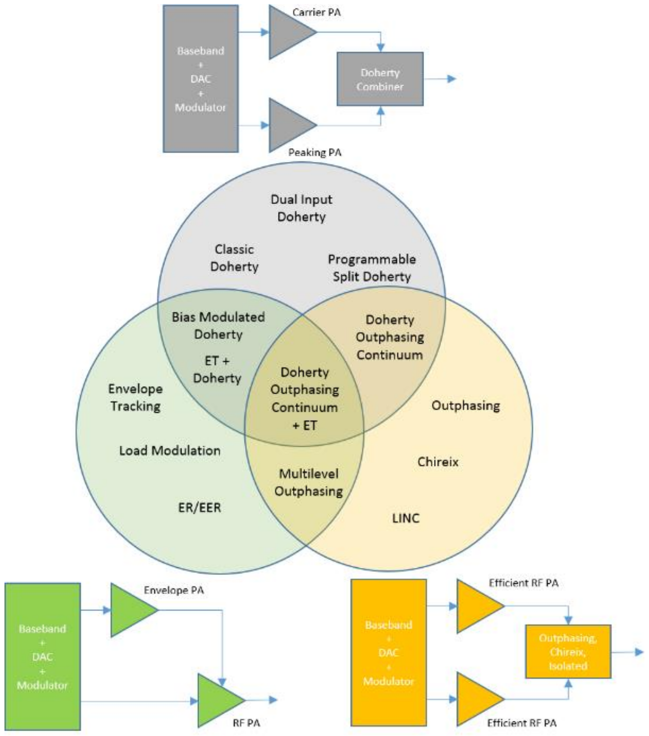
Beamforming system at 28 GHz with 60dBm EIRP



Source: Qorvo

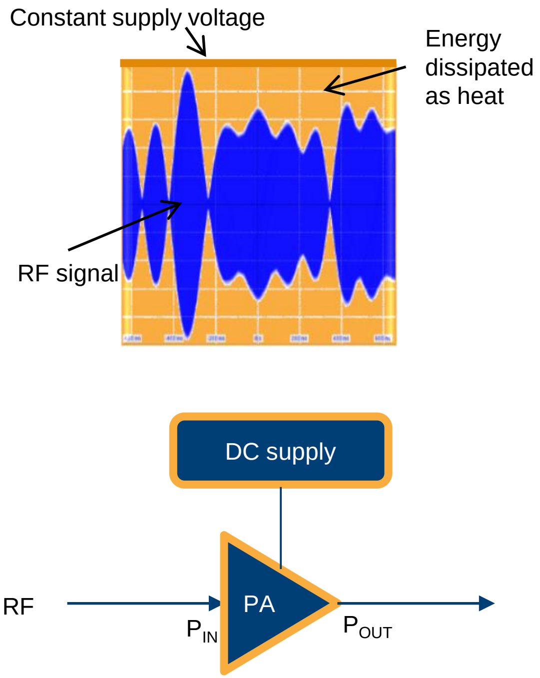
EFFICIENCY AND LINEARITY ENHANCEMENTS FOR RF FRONTENDS

- Predictive Post-Correction methods for classic RFFE
- Construct the signal from 2 (or more) efficiently generated components.
- Three known basic types, plus their hybrids:
  - Envelope = Multiplication
  - Outphasing = Summation
  - Doherty = Reference
- Digital Pre-Distortion (DPD) method

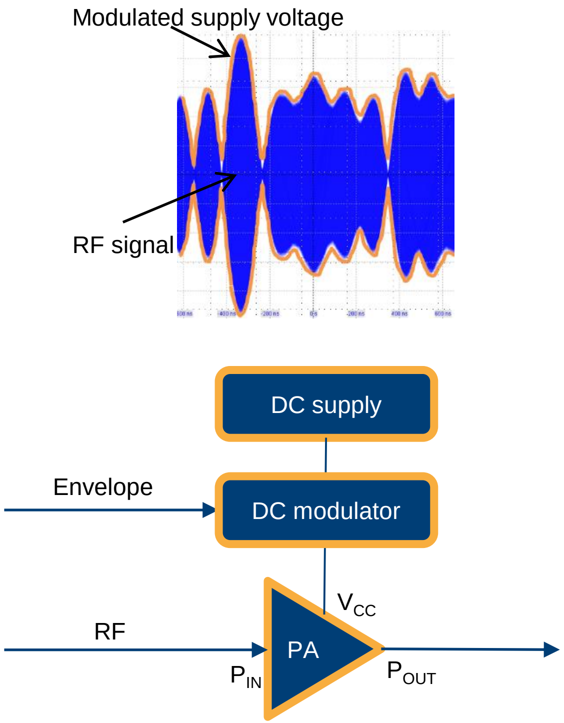


ENVELOPE TRACKING

Constant DC supply

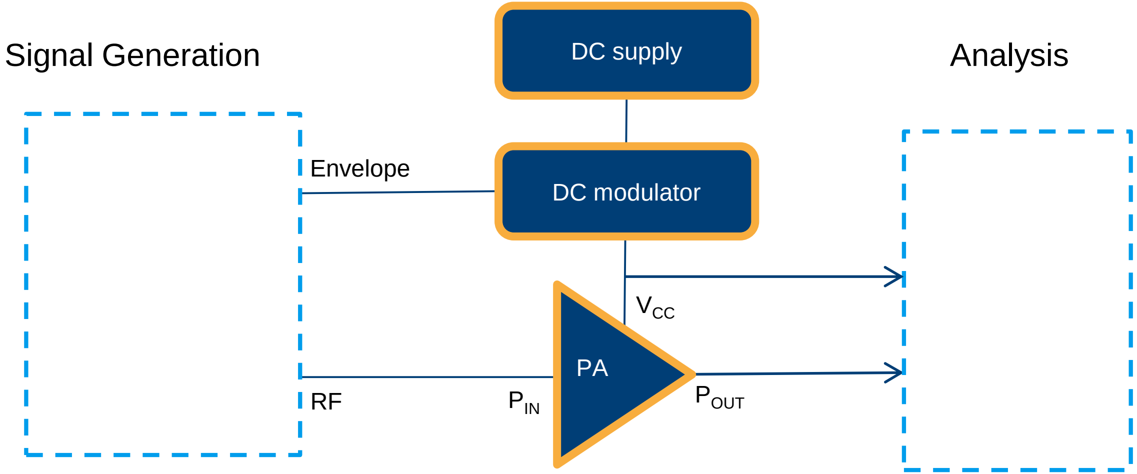


Modulated DC supply

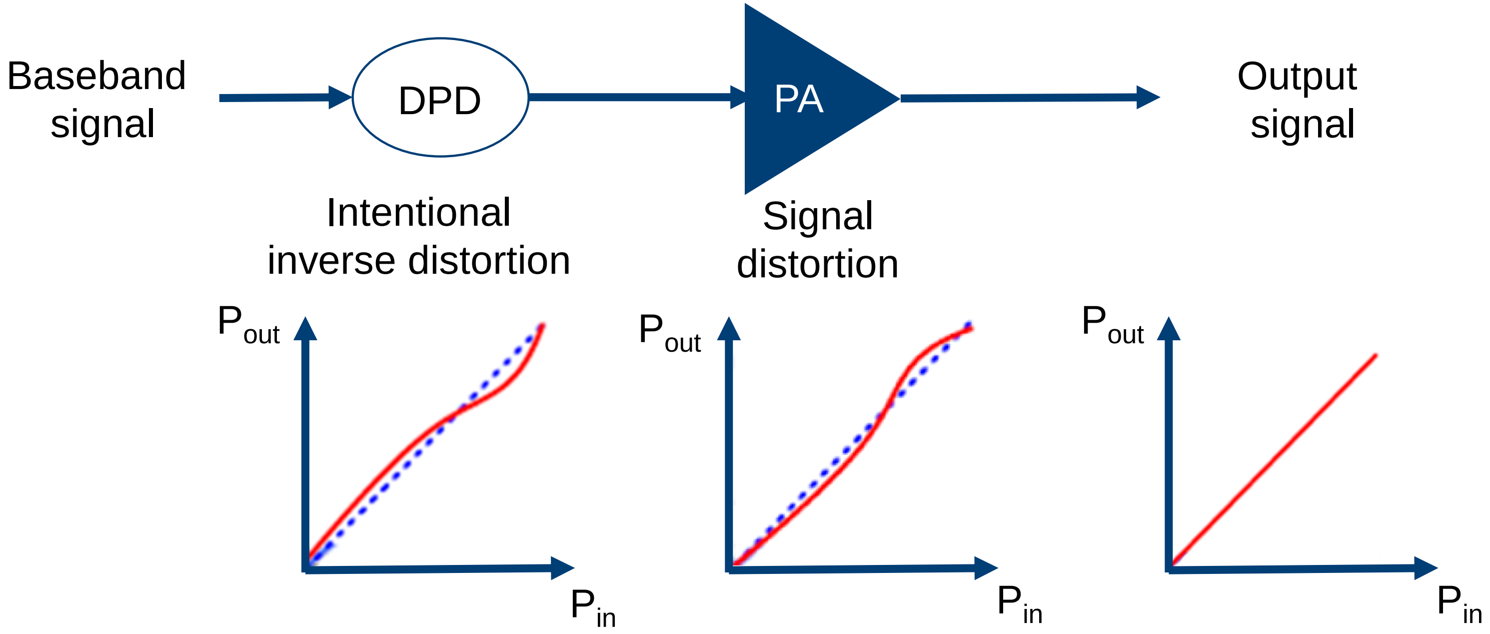


ENVELOPE TRACKING TEST CHALLENGES

- Precise synchronization
- Real time adjustment
- Distortion measurement

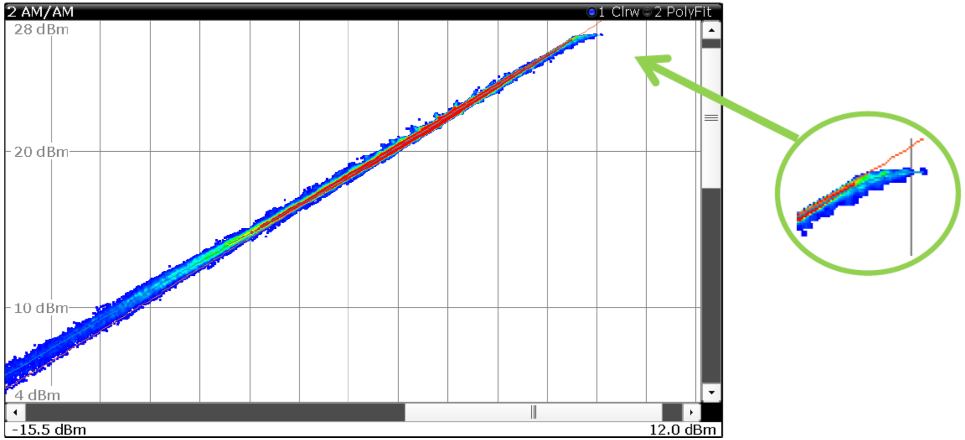


DIGITAL PRE-DISTORTION (DPD)

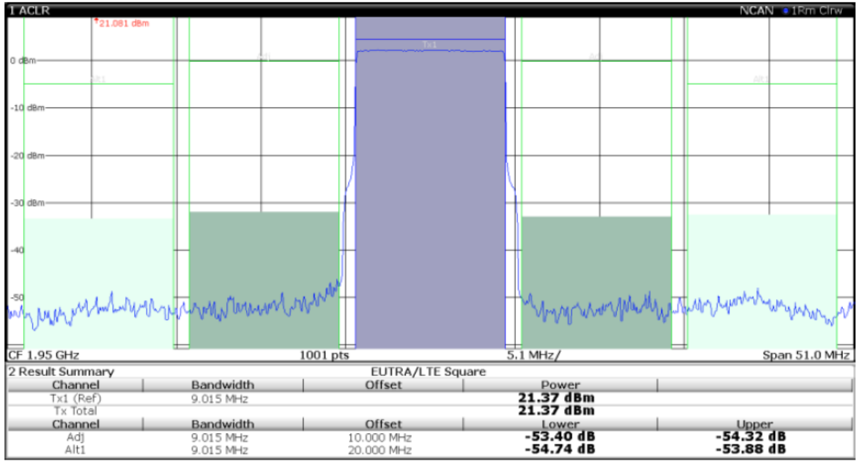


DIGITAL PRE-DISTORTION (DPD) TEST CHALLENGES

With DPD



With DPD

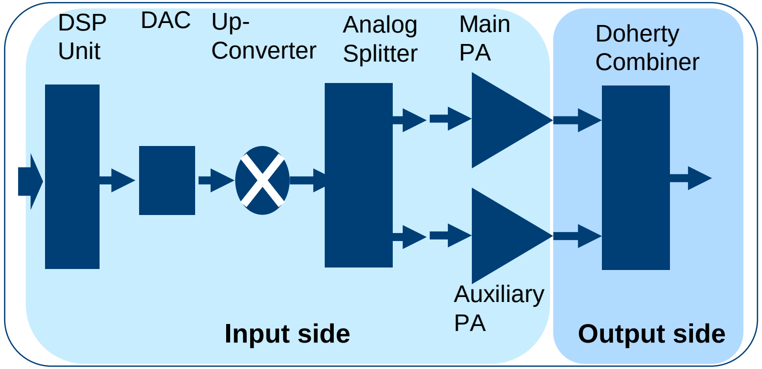


- mmWave Signal with high bandwidth
- Varying DPD modeling
- Memory based DPD

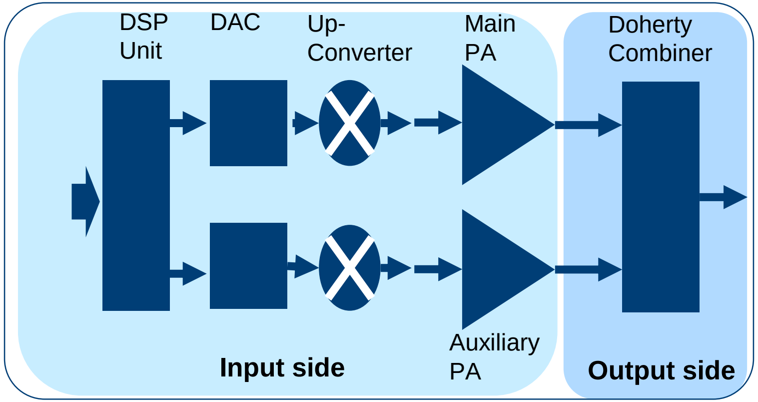
DOHERTY AMPLIFIERS

- Efficiency enhancement method
- Two (or more) amplifiers that interact through a special combining network
- Test Challenges
  - Performance driven by difference between the main and auxiliary curves.
  - Misalignment of signals arriving at the output
  - Amplitude and phase matching through the two paths

Classic Doherty Amplifier



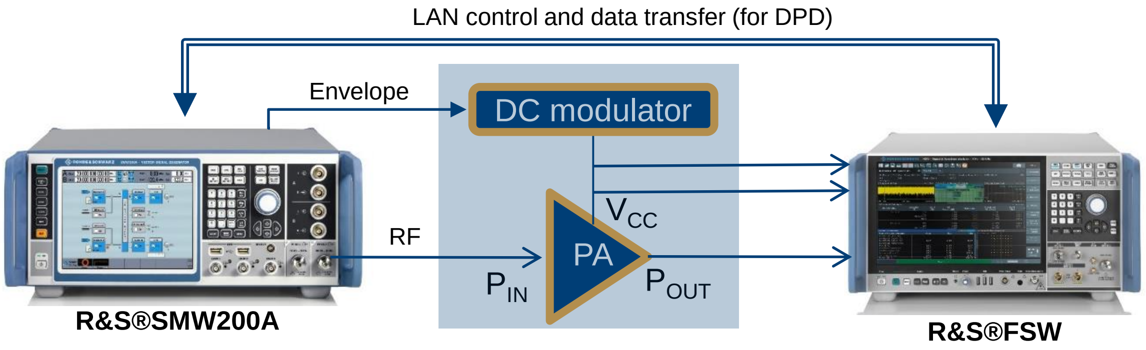
Dual-input Doherty Amplifier



R&S SOLUTIONS

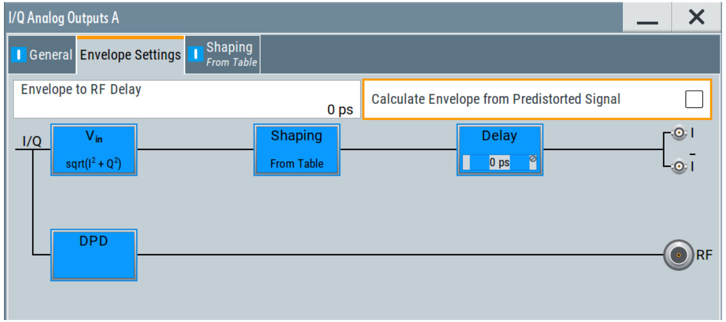
R&S SOLUTION FOR ENVELOPE TRACKING

- RF signal
- Envelope signal
- Power sweeps



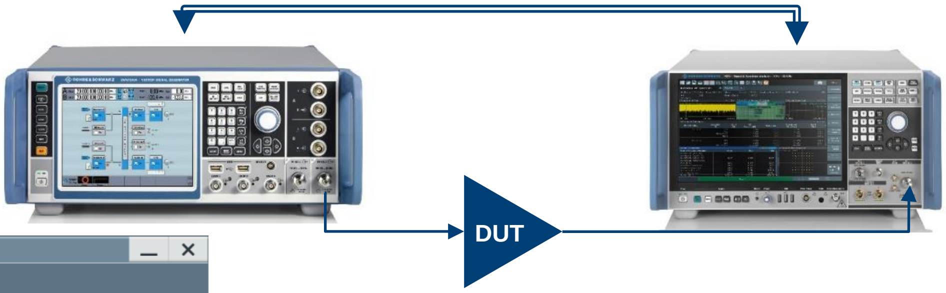
- RF analysis
- Voltage / current analysis
- Distortion analysis

R&S®SMW-K540 Envelope Tracking

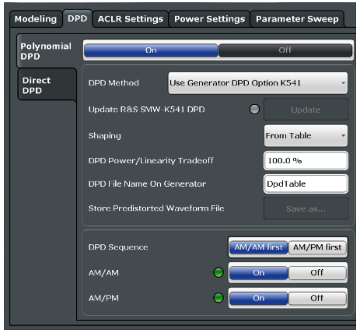


- Envelope to RF delay adjustment
- 1 GHz envelope bandwidth
- Realtime envelope calculation and shaping (K540) or user-defined envelope signal (dual ARB)
- Differential or single-ended analog I/Q OUT

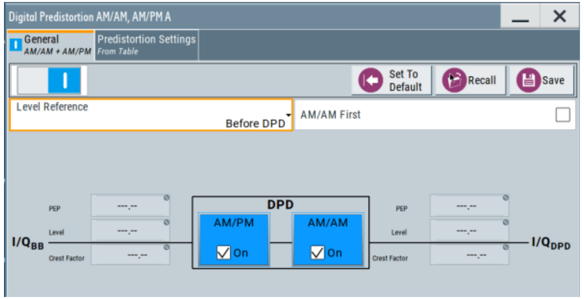
R&S SOLUTION FOR DIGITAL PRE-DISTORTION



R&S®FSW-K18/ -K18D



R&S®SMW-K541

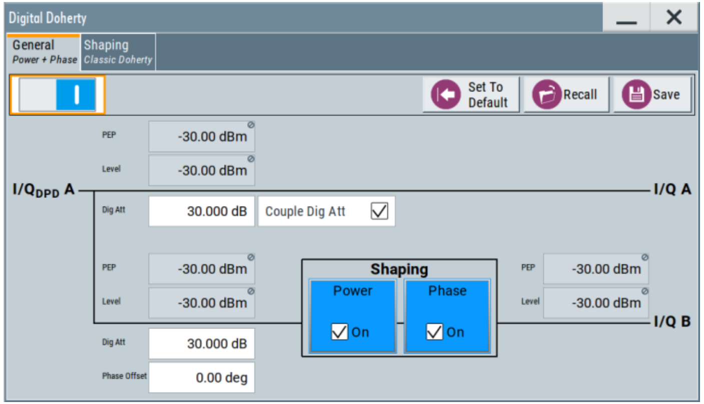


- Realtime amplitude and phase offset on every I/Q sample
- Polynomial shaping, manual DPD Table
- Automatic DPD Table transfer from FSW-K18

- Realtime configuration and control of SMW
- Many reference waveform options: from generator, customized, user-generated
- (Ideal) Memory DPD with upper performance bound characterization (FSW-K18D)
- Extraction of pre-distorted waveform

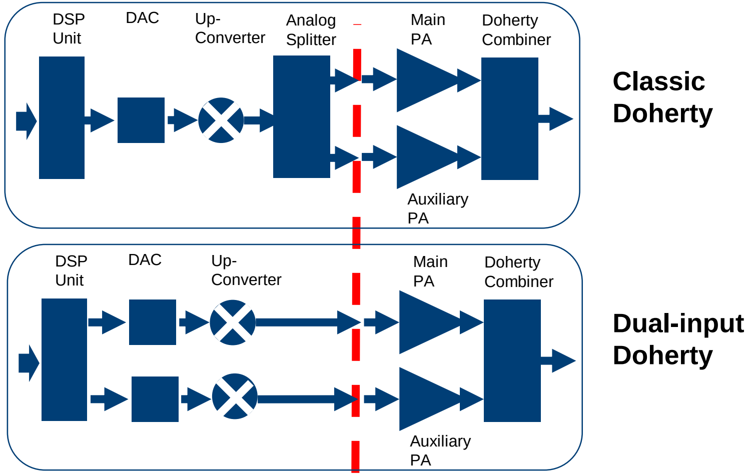
R&S SOLUTION FOR DOHERTY

R&S®SMW-K546 Doherty

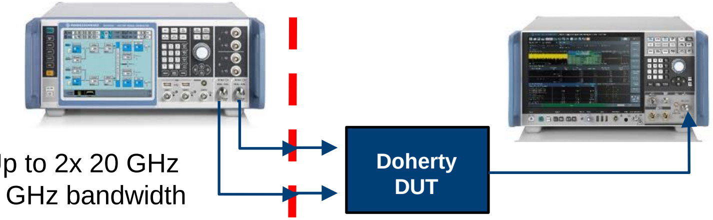


- Couple two RF paths with precise power, phase and timing alignment
- Power split and input-power dependent phase delta in real time
- Realtime shaping and DPD

Simplified Block Diagram



Hardware Test Setup

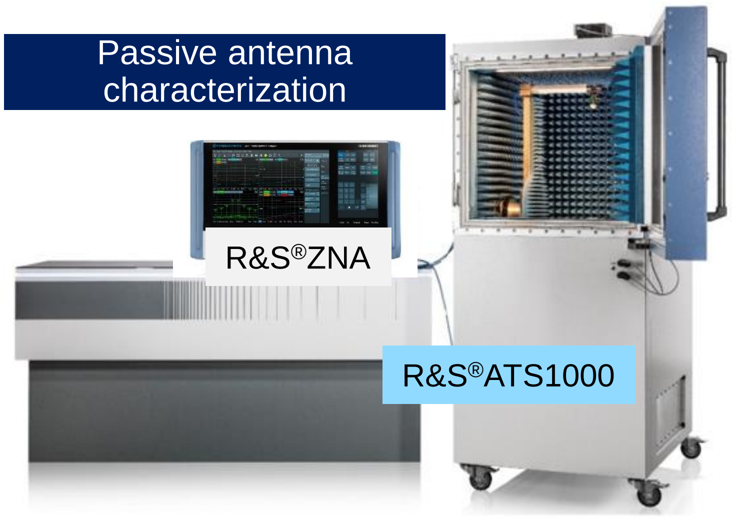


- Up to 2x 20 GHz
- 2 GHz bandwidth

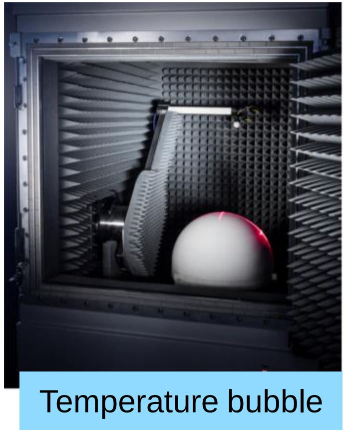
Unprecedented insight into sensitivities and performance tradeoffs to help choose the best input split design

R&S SOLUTION FOR ANTENNA TESTING

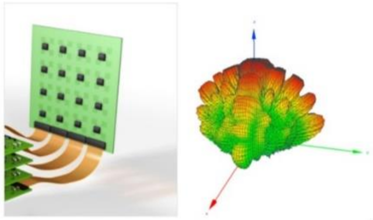
Passive antenna characterization



Active antenna characterization



Extreme temperature test
Radiation patterns of miniaturized **antennas** can be influenced by temperature, so thermal diagnosis is gaining traction, especially in AiP. The R&S®ATS1000 can be retrofitted with a temperature testing option to perform fast and precise 3D thermal measurements from –20 °C to +85 °C.



R&S SOLUTION FOR ANTENNA TESTING

	ATS1000	ATS800B	ATS800R	ATS1800C
				
Dim. (WxDxH)	0.85 x 1.5 x 2	1.2 x 0.6 x 0.8	0.8 x 1 x 2.1	0.9 x 1.5 x 2.1
Application	R&D, antenna measurements	Benchtop R&D, academic, research institutes	R&D, pre-conformance (RF, PQA)	Conformance (RF, RRM), R&D
Approach	White box DFF/NF	Black box CATR	Black box CATR	Black box CATR
Freq. range	18-87 GHz	18-50 GHz	18-50GHz	6-87 GHz
Quiet zone	Ø 4 cm	Ø 20 cm	Ø 20 cm	Ø 30 cm
Positioner	3D conical cut	2D positioner(opt.)	3D Az over El (opt.)	3D Az over El
Shielding	>50dB	-	>40dB	100dB
Extreme Temp.	3D	no	1D	3D

KEY LEARNINGS

- ► Beamforming changes the world for RF frontends
- ► Much higher integration on all fronts needed and will come
- ► OTA become the go to method for testing in mmWave
- ► R&S is the right partner for 5G RF component and frontend tests
  - Multiple chamber solution for OTA measurement
  - Antenna measurement based on CW and modulated signal
  - Improvement of Amplifier efficiency using Envelope Tracking, Digital Pre-Distortion and Doherty architecture