ANTENNA IN PACKAGE: FROM CONDUCTED TO OTA AND THE REQUIREMENT TO MAINTAIN CALIBRATED POWER MEASUREMENTS

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ROHDE & SCHWARZ
Make ideas real
INDUSTRY TREND

Platform trends

► 5G pushes to beamforming
► Satellite payloads and ground stations for LEO systems
► EW systems starting for jamming and ESM
► Radars used phased arrays since the 60’s
WHY BEAMFORMING WITH PHASED ARRAY?

Number of Antennas = 1

- Number of BS Transmit Antennas: 1
- Normalized Output Power of Antennas: $P_{\text{ant}} = \frac{1}{M_1} = 1$
- Normalized Output Power of Base Station: $P_{\text{total}} = \sum_{i=1}^{M} P_{\text{ant}}^i = 1$

Number of UEs: 1

120 antennas per UE

- Normalized Output Power of Antennas: $P_{\text{ant}} = \frac{1}{M_2}$
- Normalized Output Power of Base Station: $P_{\text{total}} = \sum_{i=1}^{M} P_{\text{ant}}^i = 0.008$


Easiest way to improve energy efficiency: more antennas
5G - FREQUENCY RANGES

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Range covered in Rel.15</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR1</td>
<td>450 MHz – 6000 MHz</td>
</tr>
<tr>
<td>FR2</td>
<td>24250 MHz – 52600 MHz</td>
</tr>
</tbody>
</table>

FR1: Evolution from LTE
FR2: All different
- Higher complexity in device development
- Measurement challenges
- New testing approaches

Separate specs for FR1 and FR2

NEW: extension to 7.125 GHz
RAN #82 December 2018
30DB MORE FREE SPACE PATHLOSS IN MMWAVE

Chambers

Small cells

Pathloss in dB vs. distance

~30dB

Pathloss in dB vs. distance

~30dB

5,00 15,00 25,00 35,00 45,00 55,00 65,00 75,00 85,00
0.1m 0.4m 0.7m 1.0m 1.3m 1.6m 1.9m 2.2m 2.5m 2.8m 3.1m 3.4m 3.7m 4.0m 4.3m 4.6m 4.9m

850MHz 2,4GHz 3,5GHz
28GHz 39GHz 52,6GHz
PHASED ARRAYS TODAY

► Now planar using much higher integration
SOLUTIONS FOR AMPLIFIER TEST

Goals
- Check compliance with design targets
- Optimize design
- Shorten design cycle

Test considerations
- No compromises
- Maximum flexibility
- Right tools
- Speed

Selected instruments for modulated measurements
- Single RF up to 44 GHz
- Dual RF up to 20 GHz
- 2 GHz RF BW
- DPD, ET, Doherty suites

- Up to 85 (90) GHz
- 8 GHz internal analysis BW
- 60 dBC SF dynamic range
- PA measurement suites

- 4 channels, 384 W total
- Up to 32V /10A per channel
- DUT protection
- Fully programmable

Excellent performance out of the box for modulated tests during R&D and design validation
TEST OF INTEGRATED AMPLIFIERS

► 1 by 1 is always possible with SMW200A and FSW

► Parallel test of 4 paths: SMW200 + 4 channel RTP + VSE
MULTICHANNEL RF ANALYSIS
ANALYSIS SW IN COMBINATION WITH OSCILLOSCOPE

RF Signal → Direct Sampling → Sampled RF Signal → Digital Down-conversion → IQ Data → Analysis

- R&S VSE-K144
  - Single Channel
  - Comprehensive measurements of 5G signals

- R&S VSE-K146
  - Multichannel
  - Phase-coherent Acquisition

K11

Down-conversion and Down-sampling
NEXT STEPS

► Integration of antenna in package
► Mainly driven by 5G, 60 GHz and automotive radar
► Antenna on chip is possible for higher frequencies, 100 GHz and above

► How to test these devices?
3D gain patterns of mmWave UE antenna

- Phased arrays do not allow connection through cables
- Many antennas – many connectors
- Cable influences antenna characteristics
- Antenna becomes system relevant functionality with beamforming etc.

Antenna couples to all surrounding objects
Conductive measurements introduce large error
R&S TEST SOLUTIONS FOR BEAMFORMING COMPONENTS

Component Characterization

Functional test and calibration of RFIC / beamformer IC

R&S®ZNBT40

Understanding phase relationship on frequency translating devices thanks to phase-coherent and phase-repeatable sources without having to use a reference mixer

Flexible modulated test solution

Flexible modulated test solution

R&S®SMW200A–K144

R&S®FSW85

R&S®FSW-K144/K145

- 40 GHz signal generation
- 90 GHz signal analysis
- 2 GHz bandwidth support
(FSW: 5 GHz with RTO2064 and B5000)

OTA solutions

OTA solutions

R&S®AMS32

R&S®ATS1xxx

R&S®ATS800B

R&S®ATS800R

R&S®CMQ
TESTING OF ACTIVE ANTENNAS
OTA BEAMFORMING MEASUREMENTS

- Antenna gain
- Array antenna gain
  10 LOG N + single antenna gain

- EIRP
  Effective Isotropic Radiated Power
  = Pt * Gt
- Array EIRP = Pe + Ge + 20 LOG N
WHAT AND WHERE IS THE FAR-FIELD? HOW TO REDUCE IT?

$D = \text{Radiating Aperture Size}$

CATR (compact antenna test range)

- Waves reflected and transformed to have far field characteristics using hardware
- Far field conditions achieved in much smaller chamber size
- Typically bigger quiet zone

$D = \sqrt[3]{\frac{0.62}{\lambda}}$

$\frac{2D^2}{\lambda}$
**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
  - $\lambda = 1$ cm
  - $D = 2$ cm
  - Far field distance: 8 cm

**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
  - $\lambda = 1$ cm
  - $D = 12$ cm
  - Far field distance: 2.9 m
**Comparision of DFF & IFF**

- All common antenna properties are defined in far field region
- No special post processing required when measuring at far field
- Typically has a smaller quiet zone
- Whitebox approach
- R&S DFF solutions: ATS1000 & WPTC

- Achieve far field condition in much smaller test range using the parabolic CATR reflector
- Reflector surface roughness is critical (even small bumps will distort reflected RF waves)
- Quiet zone size depends on reflector size
- Blackbox approach
- R&S CATR IFF solutions: ATS800B, ATS800R, ATS1500C, ATS1800C
DFF solution (QZ: 5x5cm) & extreme temperature testing

Elevation arm 0-168°

Azimuth +/- 180°

Both systems fit in ATS form factor

IFF solution (QZ: 30x30cm) & standard temperature testing

Azimuth & Theta +/- 180°
ANTENNA MEASUREMENTS USING CONTINUOUS WAVE OR MODULATED SIGNALS

Measuring with Continuous Wave
- Done during early stages of R&D
- Useful as fast check of parameters
- System components: OTA chamber, ZVA, AMS32
- Measurements: directivity, gain, realized gain, efficiency, beamwidth, EIRP, TRP, 2D/3D patterns, phase measurements

Measuring with Modulated Signals
- Done during advanced stages of development, especially useful for debugging devices
- Improves final type approval rate
- System components: OTA chamber, FSW, SMW, AMS32
- Measurements: EVM, ACLR, SEM, directivity, gain, realized gain, efficiency, beamwidth, EIRP, TRP, channel power, 2D/3D beamforming patterns
OTA CHARACTERIZATION OF PHASED ARRAY ANTENNA AND ANTENNA IN A PACKAGE (AIP)

AiP miniaturizes & increases antenna elements to improve performance & efficiency

Testing, optimization and validation has to be done OTA when RF components are fully integrated into a self-contained module

ATS1000 OTA test system provides the ideal environment for testing the radiation characteristics of AiP modules

ATS1000 works together with VNA or VSG and VSA for both passive and active antenna testing

ATS1000

日夜
ATS800B
BENCHTOP CATR TEST SETUP

Key Features & Benefits
- Frequency range: 20 GHz to 50 GHz
- Ø 20 cm quiet zone
- Easy setup
- Reflector surface roughness < 1µm
- Optional 2D turntable available

Customer Target Group & Applications
- Customers: basic antenna R&D, educational institutions
- Applications: quick antenna characterization, suitable for big DUT as big as a laptop (40 cm x 40 cm)
Key Features & Benefits
- Frequency range: 20 GHz to 50 GHz
- Ø 20 cm quiet zone
- Small footprint of 0.8 m²
- Reflector surface roughness < 1µm
- 14HE space for instruments: CMX, ZVA, etc

Customer Target Group & Applications
- Customers: chipset and mobile phone manufacturers’ R&D teams
- Applications: quick antenna characterization, suitable for big DUT as big as a laptop (40 cm x 40 cm), passive & active antenna measurements
OTA CALIBRATED POWER MEASUREMENTS

► Sounds at first like a contradiction, but easily achieved
  - RF Frontend need power cal
  - Calibrated OTA receiver needed
OTA POWER MEASUREMENT SOLUTION
FACTORY CALIBRATED SYSTEM

► Traditional setup
  - System **calibration required** to compensate
    - Frequency dependent antenna gain
    - Cable loss
    - Mismatch (high contributor to meas. uncertainty)

► Benefits of the NRPM OTA solution
  - Fully calibrated measurement system
    - **Compensated antenna gain**
    - No RF cables → no RF losses
    - No adapters → no mismatch

RF in over the air
Analog measurement signal
No system calibration required
NRPM BENEFITS
FLEXIBLE SCALABILITY

- From single antenna module to 3D beamforming applications
- Unlimited number of NRPM-A90 or NRPM-A90D antenna modules can be remote controlled
NRPM BENEFITS
LARGE DYNAMIC RANGE

► Traditional solution
  - <50 GHz: power sensors with **diode detectors** are available (-70 dBm to +23 dBm)
  - >50 GHz: **thermal power sensors** with limited dynamic range (-35 dBm to +20 dBm)

► Benefits of the NRPM OTA solution
  - -76 dBm to -19 dBm
  - Diode detector for entire frequency range
  - No RF cable loss
  - Fast measurements at low power levels
## OTA Test Solution

### OTA Solution Overview

<table>
<thead>
<tr>
<th></th>
<th>WPTC</th>
<th>ATS1000</th>
<th>ATS800B</th>
<th>ATS800R</th>
<th>ATS1800C</th>
<th>CMQ200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dim. (WxDxH)</td>
<td>5.2 x 4.3 x 4.1 (L)</td>
<td>0.85 x 1.5 x 2</td>
<td>1.2 x 0.6 x 0.8</td>
<td>0.8 x 1 x 2.1</td>
<td>0.9 x 1.5 x 2.1</td>
<td>0.45 x 0.7 x 0.6</td>
</tr>
<tr>
<td>Application</td>
<td>R&amp;D, antenna measurements, CTIA</td>
<td>R&amp;D, antenna measurements</td>
<td>Benchtop R&amp;D, academic, research institutes</td>
<td>R&amp;D, pre-conformance (RF, PQA)</td>
<td>Conformance (RF, RRM), R&amp;D</td>
<td>R&amp;D, production, 5G FR2 device/components</td>
</tr>
<tr>
<td>Approach</td>
<td>White box DFF/NF</td>
<td>White box DFF/NF</td>
<td>Black box CATR</td>
<td>Black box CATR</td>
<td>Black box CATR</td>
<td>DFF FR2</td>
</tr>
<tr>
<td>Freq. range</td>
<td>0.4-90 GHz</td>
<td>18-87 GHz</td>
<td>20-50 GHz</td>
<td>20-50GHz</td>
<td>6-87 GHz</td>
<td>20-75 GHz</td>
</tr>
<tr>
<td>Quiet zone</td>
<td>Ø 10 cm</td>
<td>Ø 7 cm</td>
<td>20 cm</td>
<td>20 cm</td>
<td>30 cm</td>
<td>2 cm</td>
</tr>
<tr>
<td>Positioner</td>
<td>3D conical cut</td>
<td>3D conical cut</td>
<td>2D positioner(opt.)</td>
<td>In development</td>
<td>3D great circle cut</td>
<td>n.a.</td>
</tr>
<tr>
<td>Extreme Temp.</td>
<td>no</td>
<td>3D</td>
<td>no</td>
<td>In devp</td>
<td>In devp</td>
<td>no</td>
</tr>
</tbody>
</table>
SUMMARY

► Beamforming changes the world for RF frontends
► COTS development pushed by 5G, radar and satcom will benefit
► Much higher integration on all fronts needed and will come

► R&S is the right partner for 5G RF component and front end tests
  – from material characterization and filter test with VNA
  – to modulated amplifier tests with 5G signals incl. DPD