Over-the-Air testing of Active Antenna System Base Stations in Compact Antenna Test Range

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Abstract— The definition of suitable test methods for Over the Air (OTA) measurements of non-connectorized devices is an ongoing process in several standardization committees. Among the different possibilities, the Compact Antenna Test Range (CATR) is a well-established technology that can be adapted to OTA measurement application with relatively low development efforts and therefore short deployment time. The main advantages of the use of a CATR for OTA testing is the direct measurement of Far-Field parameters, and the very wide frequency bandwith, allowing sub6GHz and mm-Wave testing.

In this paper, we will summarize the performance and the testing capabilities of a short focal-length, corner-fed CATR design, providing a 1.5 m x 1.5 m cylindrical Quiet Zone, operating from 1.7 GHz to 40 GHz and upgradeable to 110 GHz, allowing OTA measurements of Active Antenna System (AAS) Base Stations (BS), installed at Ericsson premises in Sweden.

***Index Terms*—CATR, 5G, OTA, antenna, measurement.**

I. Introduction

Typical measurement scenarios in 5G mobile communication require Over the Air (OTA) testing of non-connectorized devices.

The transceiver of Base Stations (BS) is located as close as possible to the radiating elements, in order to optimize energy efficiency, thus forming an Active Antenna System (AAS). Typically, the conventional RF test ports used to access the antenna as a passive device are not available, due to the high level of integration of the radio unit. The Device Under Test (DUT) is controlled through data instructions to provide Uplink/Downlink digital streams.

Common OTA parameters to be measured are: Equivalent Isotropic Radiated Power (EIRP), Error Vector Magnitude (EVM), Equivalent Isotropic Sensitivity (EIS), In-band blocking (IBB), Adjacent Channel Selectivity (ACS). By definition, such parameters are related to the Far-Field (FF) radiation characteristics of the Antenna Under Test (AUT), and a distance of 30 meters or more between the AUT and the probe would be necessary in order to make a direct FF measurement at sub-6 GHz band.

Methods to perform OTA testing at Near-Field (NF) distance are a more attractive solution, as the antenna measurement system can fit in an indoor, anechoic and shielded facility. A Compact Antenna Test Range, by means of the optical collimation properties of a parabolic reflector, converts the spherical wave-front produced by the feed antenna into a plane-wave at the AUT, thus providing an analog NF to FF transformation.

Compared to a direct FF range, the quality of the plane-wave in the Quiet Zone of a CATR is typically higher, with respect to amplitude and phase variations. Moreover, because of the collimation properties of the parabolic reflector, the energy flux is constant along the Quiet Zone and therefore power (or gain) measurements do not depend on the location of the AUT with respect to the down-range. In other words, there is no path loss between the reflector and the AUT. The only path loss is between the feed and the reflector and since this distance is fixed, this path loss can be easily calibrated.

The system is configured such that the RF port at the feed horn is available to the user as access point for calibration and OTA testing. For calibration purpose, a modular bi-directional RF system is supplied, covering up to 40 GHz and upgradeable to 110 GHz with the use of mm-Wave heads.

The Quiet Zone is a cylindrical volume of 1.5 m diameter and 1.5 m length, achieved with a short focal-length, corner-fed CATR design. Dual-polarized, wideband feeds allow to drastically reduce the set-up time and the measurement time, with respect to conventional narrow-band feeds.

Finally, the range is equipped with a special DUT positioner that allows Elevation/Azimuth scan by holding the AAS-BS antenna horizontally. The positioner can be also configured as Roll/Azimuth, which is more convenient for mm-wave planar antennas.

II. CATR System Design

A. CATR geometry design

The system is a corner-fed, short focal length design, providing a cylindrical Quiet Zone of 1.5 m diameter and 1.5 m length, that exhibits excellent co-pol and good cross-pol performance. Frequency requirement is from 1.7 GHz to 40 GHz with upgrade capability to 110 GHz.

The chamber size is 9.5 m x 5.6 m x 5.2 m, which is very compact considering the quiet zone size. This was achieved thanks to the corner-fed geometry, and short focal length design.

Compared to a floor fed geometry, the height of the chamber is reduced by a factor 1.4 with a corner-fed geometry. Moreover, the length of the chamber is also shorter, due to the fact that the feed and the antenna positioner system are not in line with each other, therefore the antenna positioner system can be pushed closer to the reflector.

A relatively large offset angle reduces reflections and diffraction by the plane wave hitting the feed system and reduces mechanical interaction with the antenna positioner. A corner-fed geometry also minimizes direct feed leakage in both Az & El main cuts, which was relevant for the use of the Az/El measurements allowed by the antenna positioner.

Another interesting advantage of corner-fed geometry is the ease of access to the feed station for feed interchange, as well as the proximity to the instrumentation which allows shorter RF path and improved dynamic range.

The 2m x 2m reflector body is milled by one solid piece of aluminum, with a surface finishing of ±0.05mm peak-to-peak. According to the lowest frequency operation and the size of the Quiet Zone, the edge of the reflector was equipped with serrations of 0.9 m, with a shaped profile, see Fig. 1. This led to a total reflector size of 3.8 m x 3.8 m.

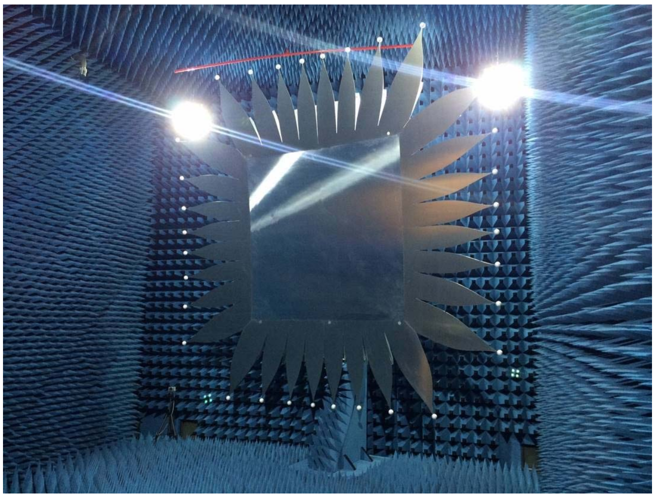

Fig. 1. Serrated-edge reflector

A new generation of high-performance octave bandwidth dual polarized low gain feeds was designed to deal with the shorter focal length, in order to keep the amplitude taper below 1 dB. These feeds have excellent cross-pol, so that the cross-pol in the QZ was driven by the reflector geometry (typically better than -30 dB in the central 1.0 m diameter, and worst case -27 dB at the outer edge of the cylindrical quiet zone.

The system is equipped with a bi-directional RF system dedicated to passive antenna measurements, which is mainly utilized for path loss calibration. The system is controlled by the MVG antenna measurement software MiDAS.

B. *Octave dual-polarized feeds*

The short focal length design of the CATR described in this paper requires feeds with low gain characteristics. A new series of low-gain dual-polarized corrugated horns have been specifically conceived to ensure quiet zone (QZ) performance over the full frequency range of the measurement system, from L- up to Ka-band. These feeds, referenced as LGF-11 series, exhibit a stable rotationally symmetric radiation pattern, matching the reflector illumination requirements and ensuring an amplitude taper in the quiet zone (QZ) below 1dB. The corresponding directivity levels at primary pattern level are between 10-12dBi, with very low cross-polarization within the reflector field-of-view.

These feeds, shown in Fig. 2, are typically composed of the ortho-mode-junction (OMJ) feeding two orthogonal polarizations to the common waveguide, the radiating aperture, and the absorber provisions minimizing the scattering from the mounting fixture and the positioner. In addition, all feeds are equipped with highly accurate mechanical interfaces, containing an integrated spirit level as a polarization reference.

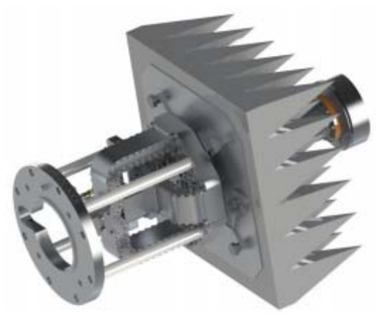

Fig. 2. Octave band dual polarized CATR feed

Dual polarization high-precision performance is obtained over a wide operational bandwidth by two different OMJ design approaches, both taking advantage of a balanced feeding scheme.

Below 4 GHz, feeding of the OMJ is done by precision 3dB/180° hybrid couplers based on a coaxial technology [1] and [2]. Above 4 GHz, a proprietary OMJ design in ridge waveguide has been used [3].

The main advantage of the presented feeds is the frequency coverage of each individual feed exceeding the full-octave bandwidth. Measurement time efficiency can also be further improved using pin diode RF switches [4]. This allows the measurement of both complex components (H and V) radiated by the antenna under test (AUT) within the same acquisition scan.

C. *Antenna Measurement Positioner*

This system is equipped with a special DUT positioner type, which is specifically designed to allow dual use: for linear array type antennas, such as the AAS-BS sub-6 GHz and for planar or aperture antennas in the mm-Wave bands.

A circular dielectric mast is mounted horizontally between two short linear slides, connected to a roll positioner on one side and to a passive rotary stage on the other side. The linear slides allow to adjust the antenna phase center to coincide with the horizontal rotational axis. The pole mount brackets of the AAS-BS can be used to fasten the antenna to the positioner, without the need of dedicated test fixtures.

The model tower is mounted on top of an Azimuth positioner allowing +/- 200 deg rotation. The horizontal and vertical rotational axis in this configuration have their intersection in the origin of an Elevation over Azimuth spherical reference system [4].

This configuration (Fig. 3) allows performing a full-spherical pattern scan of an AAS-BS, with accurate measurement of the backward hemisphere due to the fact that the antenna mast is of low-permittivity dielectric material.

The positioner can be converted into a standard Roll/Azimuth positioner, by removing the column opposite to the motor, and rotating the Azimuth axis by 90 deg so that the upper positioner can face the reflector and operate as the Roll axis. The platform is also equipped with a linear slide, allowing to adjust the antenna phase center to coincide with the rotational axis.

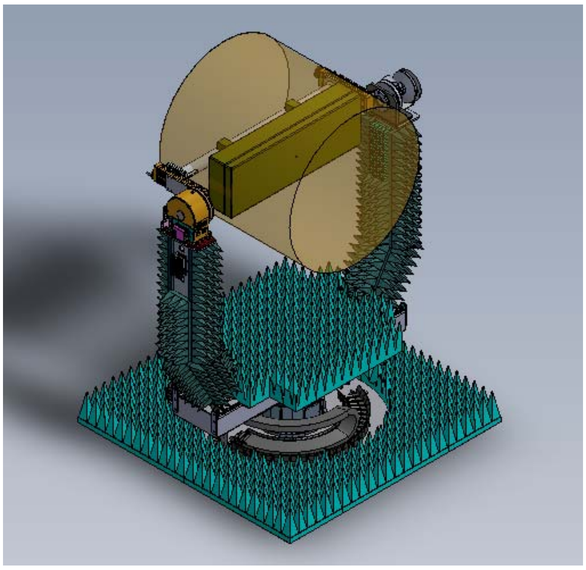

Fig. 3. El/Az positioner for AAS-BS – The Quiet Zone volume is represented by the light yellow cylinder

D. Quiet Zone performance

The electric field produced by the reflector system in the Quiet Zone has been measured with a probe mounted on a linear scanner, and the results are used to validate co-polar and cross-polar performance of the CATR system.

The probing was performed in the horizontal and vertical cuts, at three positions in the down-range, at several frequencies from 1.7 GHz to 40 GHz.

The results are equal or better than the specifications, with less than ±0.5 dB co-polar amplitude variations, phase variations within ±5 deg, and cross-polarization better than -30 dB in the central 1.0 m diameter, and worst case -27 dB at the outer edge of the cylindrical quiet zone.

The following plots show the measured co- and cross-polarization performance in the horizontal cut at the QZ center down range position, for three representative frequencies.

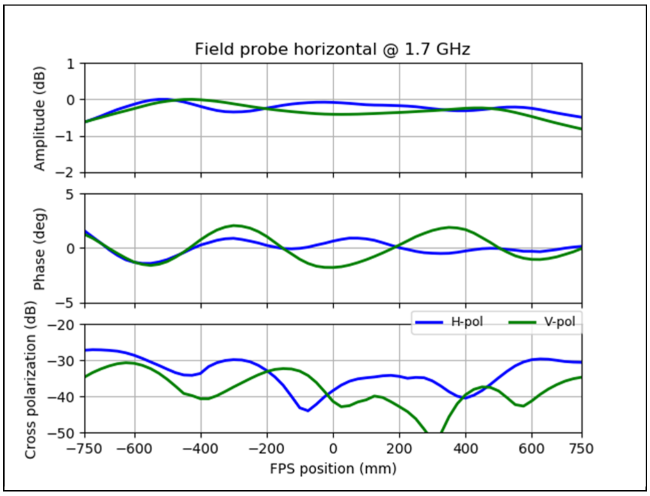

Fig. 4. Quiet Zone performance at 1.7 GHz

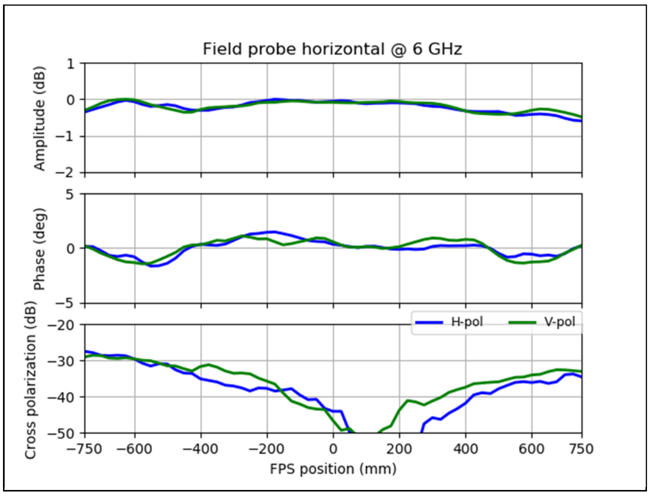

Fig. 5. Quiet Zone performance at 6 GHz

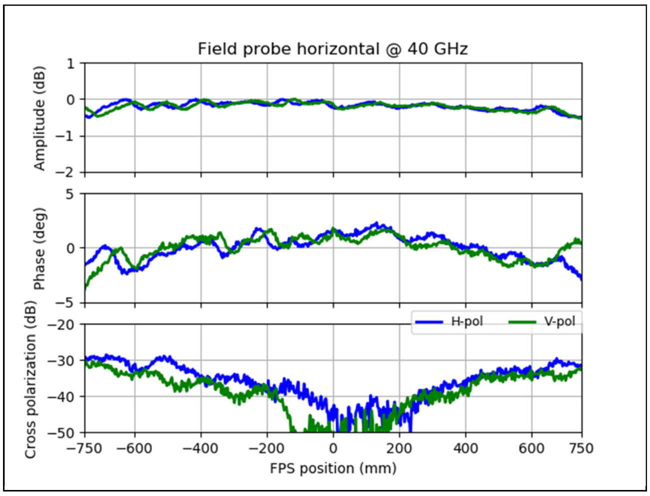

Fig. 6. Quiet Zone performance at 40 GHz

III. Over-the-Air Conformance Testing Requirements

A. CATR system for OTA measurements

The Compact Antenna Test Range can be seen as a simple transducer, a test box that converts the radio signal into an electrical signal and vice versa (Fig. 7). Any instrumentation such as power meter, spectrum analyzer and RF signal generator can be connected to the test box, through the RF port located at the CATR feed horn.

Due to the low free-space path loss, the CATR can be used as a passive transducer and therefore it can be seen a purely linear channel.

Moreover, the CATR operates as a spatial filter: due to the optical properties of the parabolic reflector, only one direction of propagation is collimated to the feed and therefore transduced.

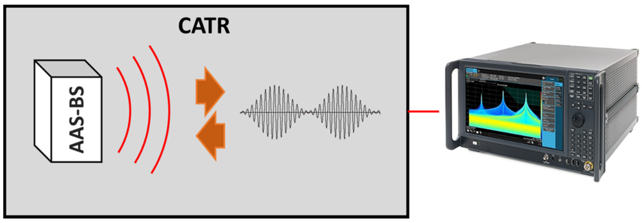

Fig. 7. CATR as a Test Box

The measurement of Downlink parameters requires the feed horn to receive the signal radiated by the AAS-BS and convey it to the measurement instrumentation, for instance a Power Meter or a Spectrum Analyzer.

The Uplink communication is established by using the feed horn as a transmitter. Typical measurement instruments used in this mode are Signal Generator and Radio Communication Tester.

In both type of tests, a proprietary software is used to control the AAS-BS and analyze the performance in Downlink and Uplink.

B. 3GPP OTA conformance testing requirements

OTA conformance testing is split in two groups: OTA TX type of measurements (Downlink) and OTA RX type of measurements (Uplink). Similarly, these are split in directional and TRP based requirements.

Table 1 lists the OTA conformance testing requirements as standardized by 3GPP and included in 3GPP TR 37.843 v 15.0.0 [7]:

For TX directional requirements, testing using the narrowest "declared" beam-width (in a single point or multiple point in the main beam) is sufficient for demonstrating conformance, except for the case of EVM (Error Vector Magnitude) in which testing shall be performed in all the 3GPP [7] conformance directions of the OTA coverage. This is not the case for TRP based requirements where the full 3D EIRP beam pattern shall be sampled in order to properly compute TRP by integrating the measured EIRP:

$$TRP = \frac{1}{4\pi} \int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} EIRP(\theta,\phi)\ \sin\theta\, d\theta d\phi$$

where θ is defined in the range [0;π] while ϕ is defined in the range [0;2π].

The fact that discrete samples of EIRP are measured at different locations (θ,ϕ), a TRP integration error shall be considered when evaluating the accuracy of a TRP measurements. Fast OTA technique which would imply either the use of coarse measurement grids or measurement of few patterns. Some techniques are well-documented in [7].

TABLE I. OTA CONFORMANCE TESTING REQUIREMENTS

AAS BS - LTE/NR FR1	Requirement
OTA TX type of measurements	
Radiated Transmit Power - EIRP	Directional
Base Station Output Power	TRP based
Output Power Dynamics	Directional
Transmitt ON/OFF	Co -location Directional
EVM	Directional
Frequency Error	Directional
Time Alignment Error	Directional
Occupied Bandwidth	Directional
ACLR	TRP based
Operating Band Unwanted Emission (OBUE)	TRP based
Spectrum Emission Mask	TRP based
Spurious Emission (in-band)	TRP based
Spurious Emission (out of band)	TRP based
TX spurious Emission	Co-location Directional
TXiMD (TX Intermodulation Distortion)	Co-location - TRP based
OTA RX type of measurements	
Sensitivity	Directional
REFerence SENSitivity	Directional
Dynamic Range	Directional
Adjacent Channel Selectivity	Directional
In band blocking	Directional
Out of band blocking	Directional
RxiMD (Rx Intermodulation Distortion)	Directional

C. OTA Path Loss Calibration

In order to measure the OTA performance of the radio unit, it is necessary to accurately characterize the over-the-air path between the AUT and the measurement instrumentation.

The path loss calibration is performed in two steps and the data are acquired using the software MiDAS.

The first step is a conducted measurement of the system losses, by means of a low-loss coaxial cable, sufficiently long to cover the distance between the feed horn and the AUT. The losses of such cable are known from a separate calibration. The user will connect the first end of the long coaxial cable to the feed side of the RF system (A in Fig. 8), connect the second end to the AUT port (B in Fig. 8) and make a reference amplitude measurement over a frequency sweep.

Next step a calibrated SGH is connected to the AUT port (B in Fig. 8), the second end of the long cable is connected to the instrumentation interface (C in Fig. 8), and the amplitude coming through the compact range reflector system is measured. The delta between these two measurements, compensated for the SGH gain, is the path loss of the setup. A signal amplitude from an AAS measured with a signal analyzer at the instrumentation interface can now be referenced to an EIRP, and vice versa for EIS.

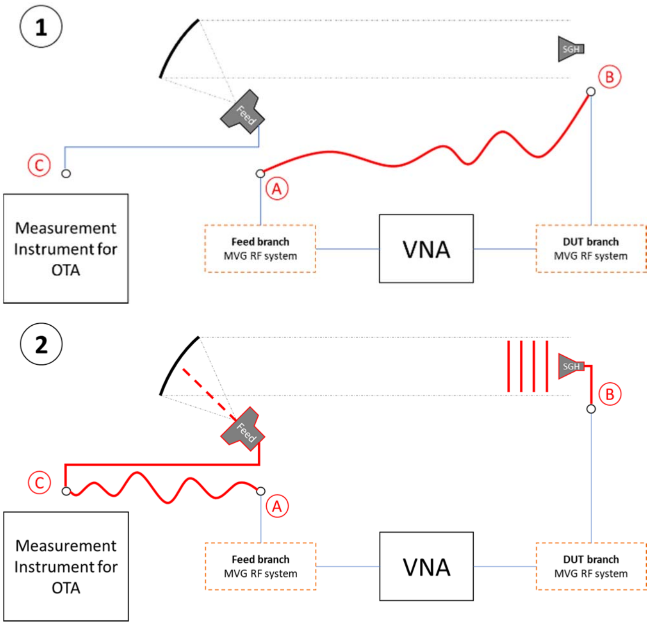

Fig. 8. OTA path loss calibration procedure – the path measured in each calibration step is in red color

D. Test example: EIRP

Once CATR has been designed, installed and calibrated, the OTA system setup can be seen as a black box to where any instrumentation such as power meter, spectrum analyzer and RF signal generator can be connected. In Fig. 9 the system setup is shown for the EIRP type of measurement.

The test procedure consists of:

1. AAS BS is placed in the setup and configured by using proprietary SW interface to transmit a modulated signal in the most directive beam
2. AAS BS beam is aligned with the feed antenna which acts as measurement antenna when CATR is configured in RX mode. Measure the mean power of the modulated signal arriving at the RF connector of the instrumentation – power meter in our case
3. Calculate the EIRP by applying the path loss calibration to the measured mean power, where $EIRP = P_{meas} + L_{A \rightarrow B}$
4. Repeat step 2, and 3 for both polarization so that $EIRP = EIRP_{p1} + EIRP_{p2}$

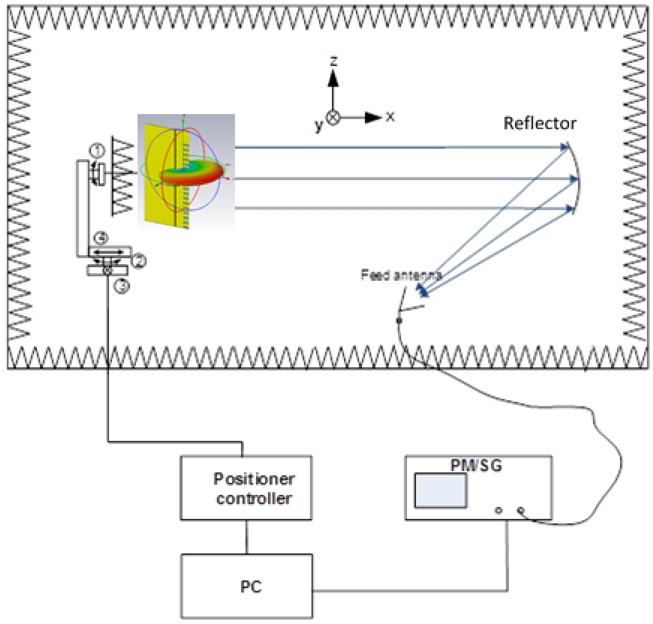

Fig. 9. Typical CATR set up for EIRP measurements

IV. Conclusions

A Compact Antenna Test Range system has been designed for OTA testing of 5G AAS-BS devices at both sub6GHz and mm-Wave frequencies. OTA test capabilities and path-loss calibration procedures have been defined, based on the 3GPP requirement. The performance of the Quiet Zone has been validated with the field probing technique and show an excellent behavior in both Horizontal and Vertical polarizations over the whole operational frequency band, from 1.7 GHz to 40 GHz.

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