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Trends in Development of Test and Certification Laboratories for Antenna Systems Used as Part of 5G NR Telecommunication System Equipment

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Abstract. **An analysis of international organizations involved in measuring the radiation characteristics of antenna systems in their near radiation zone is presented. Out of the great variety of such organizations we selected only those that specialize in testing of antenna system parameters for base stations and terminals that meet 5G NR telecommunication system standards. We have reviewed standards adopted by these testing laboratories and their cutting-edge samples of the testing systems. We have also analyzed the level of development of Russian specialized testing laboratories that perform testing and certification of 5G NR mobile network equipment. We have reviewed their equipment and capabilities for testing the parameters antenna systems being part of 5G NR telecommunication systems.**

Keywords: **near-field testing, measurements of antenna radiation patterns, certification of antennas, near-filed scanner.**

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Contents

1. INTRODUCTION

Development of modern wireless communication systems and equipment is totally dependent on enhancement and upgrade of applicable antennas. Antennas act not only as so called wave field generators in transitional sense, i.e. as devices radiating and receiving radio waves, but also as devices that form a radio channel with a help of their polarization, spatial and frequency selectivity. Application of such antennas in modern wireless communication systems increased usefulness of these systems to the customers.

Use of acoustic chambers for measurement of the external characteristics of smart antennas having complex radiation field control algorithms often causes difficulties in ensuring the measuring distance in the far-field radiation area of such antennas. Due to this fact as well as following 3GPP TR 37.94 recommendations [1], measurements of antenna characteristics in open air are performed in the near-field radiation area

of these antenna systems. The methodology of such measurements is well advanced and includes:

- the collimator method, which involves the use of a compact antenna test range (CATR), which includes a collimating installation [2] that forms almost flat wavefronts at a very short distance (typically 10–20 m); to achieve this, a two-mirror [3] or three-mirror focusing system [4] is often used;
- measurement in the near field (NF) using a scanner where a sensor located next to the antenna under test (AUT) moves over the scanning surface, which can be:
  – flat allowing for planar-rectangular scanning [5], planar-spiral scanning [6] or bipolar scanning [7];
  – cylindrical [8];
  – spherical [9].

To date, for all types of scanning there have been developed techniques that help reduce the amount of required NF data as well as measurement time [10,11].

Modern laboratories involved in testing and certification of smart antenna systems for 5G base stations and user terminals operate using both theoretically elaborated methodologies for performing NF measurements and documentation detailing the scope and procedure for performing such NF measurements.

Proper metrological equipment for 5G communication systems offered by these laboratories is a strategically important element in establishing a market segment of specialized telecommunications equipment in the face of increasing competition and dominance of large telecommunications corporations.

Therefore, we find it particularly relevant to perform an analysis of both the experience of leading international testing laboratories, including those involved in NF-based measurements of smart antenna systems and the degree of participation of domestic testing laboratories in this area.

2. GLOBAL ORGANIZATIONS PERFORMING MEASUREMENT OF SMART ANTENNA SYSTEM CHARACTERISTICS

The world's leading organizations involved in measuring the characteristics of antenna systems, including smart antennas for the new generation telecommunication systems are listed in **Table 1** with data obtained mostly from the Global Certification Forum (GCF) [12].

7Layers [13] is a GCF recognized testing organization (GSF RTO) that performs testing of wireless networks for Internet of Things and smart devices with a built-in wireless connection:

Table 1

World's leading organizations performing measurements of antenna characteristics for 5G telecommunication systems

№	Name of company	Location, country
1	7 Layers [13]	Ratingen, Germany; Irvine, USA; Beijing, P.R. China
2	Absolute Validation [14]	Farnborough, Great Britain
3	Bureau Veritas [15]	Taoyuan, Taiwan; Suwon, Korea
4	CETECOM [16]	Essen, Germany; Anyang, Korea; Milpitas, USA; San Diego, California, USA
5	CTTL (China Telecommunications Technology Laboratory) [17]	Beijing, P.R. China
6	Testing and certification DEKRA [18]	Malaga, Spain; New Taipei, Taiwan; Herndon, Virginia, USA
7	Intel Mobile Communications [19]	United States of America
8	Intertek [20]	Lexington, USA; Taipei, Taiwan
9	KTL (Korea Testing Laboratory) [21]	Soul, Korea
10	PCTEST Engineering Laboratory Inc. [22]	Columbia, Maryland, USA; San Jose, California, USA
11	Qualcomm [23]	San Diego, California, USA
12	SGS Wireless [24]	New Taipei, Taiwan; Gunpo, Korea; San Diego, California, USA
13	Shanghai Tejet Communications Technology [25]	Shanghai, P.R. China
14	Sporton International Inc. [26]	Taoyuan County, Taiwan
15	TEOCO. Laboratories AIRCOM [27]	USA
16	Verkotan [28]	Oulu, Finland

- certification: Wi-Fi Alliance, GCF, Cybersecurity CTIA IoT, AT&T, Vodafone, Telekom, Verizon.
- technologies: 3G, 4G, 5G, A-GPS, WLAN, Bluetooth.
- the OTA testing (Over-The-Air) encompasses the entire signal path and involves measuring of the external characteristics of the antenna. Among other things, antenna performance is affected by various product requirements, area of application, frame size, materials, bandwidth, frequencies, etc. OTA tests are carried out at all stages of a product's life cycle such as research and development, approval or certification.

Bureau Veritas [15] company conducts Mobile OTA Performance measurements of radiation patterns as defined by CTIA (Cellular Telephone Industries Association) for wireless devices to verify their three-dimensional "Radiated RF Power" and "Receiver Performance". The testing is divided into two main parts: TRP (Total Radiated Power) and TIS (Total Isotopic Sensitivity).

MIMO OTA performance testing focuses on testing the downlink throughput of wireless devices in various channel environments.

List of offered measurements:

- mobile equipment for 2G/2.5G/3G/3.5G/4G /5G networks;
- ultra-wideband equipment;
- Zigbee, Z-Wave, LoRa, Sigfox;
- systems of broadband power lines;
- femtocells, base stations;
- Wi-Fi equipment (IEEE 802.11*a*/*b*/*g*/*n*/*ac*/*ax* WLAN);
- Bluetooth equipment;
- RFID;
- SRD (Short Range Device);
- wireless equipment with frequencies up to 60 GHz;
- wireless charging;
- automotive sensors with frequencies up to 77 GHz;
- mmWave equipment.

CETECOM [16] deals with OTA performance and reliability testing of wireless devices, their antennas and other components.

OTA acoustic chamber in Silicon Valley features 5G FR1 and FR2 mm wave; carrier aggregation, including combinations with 5CA and NR; CAT M1; NB IoT; WiFi; bluetooth; MIMO; GSM/UMTS/LTE frequencies.

OTA chamber in Germany is capable of the following:

- specific antenna testing: radar beam details, e.g. for 79 GHz radar devices;
- support for the frequency range up to 500 GHz;
- active 3D tests with base station simulators for mobile phones;
- passive antenna testing (e.g., matching, efficiency, 3D radiation pattern, circular polarization);
- CTIA test plan for SISO OTA Performance v3.9 certification.

CETECOM manufactures and sells WTS-80 wireless test system (**Fig. 1**), which can optimize the spurious emissions of your device, as well as measure characteristics of antennas.

WTS-80 wireless test system can be used for a wide range of tests with frequencies ranging from 300 MHz to 13 GHz. Designed and manufactured in Germany, it is equipped with a patented technology: six broadband circular polarized antennas. They allow measuring the

Fig. 1. *WTS-80 wireless testing system.*

six main directions of radiation without moving the device, which greatly simplifies the testing process.

The 75 cm wide shielded box is quite narrow. This makes it possible to conveniently set up the WTS-80 wireless test system in a desired testing environment. Additionally, connection to a filtered 230V power supply ensures maximum compatibility.

Upon request, it is possible to supply a system with an RF switching relay. This makes it possible to use, for example, a high-pass filter and a special preamplifier for GSM and LTE measurements. Additional software adaptation is also available which ensures maximum scalability to suite various testing requirements.

CETECOM was one of the first laboratories in the world to ba able to test the OTA performance of products using 5CA, the highest five band combination. LTE carrier aggregation allows operators to simultaneously use multiple channels of sub-6 GHz spectrum to transmit data between base stations and a 5G mobile device. Up to five component carriers can be combined to carry an aggregated bandwidth of up to 100 MHz. Two aggregated component carriers are called 2CA, three component carriers are called 3CA, and so on.

In August 2020, the CETECOM test laboratory in Essen (Germany) became the first laboratory in Europe accredited for testing 5G devices. Thus, the German accreditation body (DAkkS) confirmed that the laboratory was officially authorized to carry out 5G tests on telecommunications devices. CETECOM laboratories are accredited to the following standards:

- 5GS; User equipment (UE) compliance specification. Part 1: General Test Environment (ETSI TS 138 508-1 V15.4.0 (2019-07));
- 5GS; User Equipment (UE) conformance specification. Part 2: Proforma Generic Implementation Conformity Statement (ICS) (ETSI TS 138 508-2 V15.4.0 (2019-07));
- 5GS; Specific user equipment (UE) conformance testing functions (ETSI TS 138 509 V15.4.0 (2019-07));
- NR; User Equipment (UE) conformance specification. Radio transmission and reception; Part 1: 1.92-5.0 GHz Autonomous Operation (ETSI TS 138 521-1 V15.3.0 (2019-07));
- NR; User Equipment (UE) conformance specification. Radio transmission and reception; Part 2: Autonomous Operation in Band 2, 26.5-28.35 GHz (ETSI TS 138 521-2 V15.3.0 (2019-07))
- NR; User Equipment (UE) conformance specification. Radio transmission and reception; Part 3: Interoperability in Band 1 and Band 2 with other radios (ETSI TS 138 521-3 V15.3.0 (2019-07));
- NR; User Equipment (UE) conformance specification. Radio transmission and reception; Part 4: Performance Requirements (ETSI TS 138 521-4 V15.1.0 (2019-07));
- NR; User Equipment (UE) conformance specification. Radio Transmission, Radio Reception and Radio Resource Management Test Case Applicability (ETSI TS 138 522 V15.3.0 (2019-07));
- 5GS; User Equipment (UE) conformance specification. Part 1: Protocol (ETSI TS 138 523-1 V15.4.0 (2019-07));
- 5GS; User Equipment (UE) conformance specification. Part 2: Protocol Test Case Applicability (ETSI TS 138 523-2 V15.4.0 (2019-07))
- 5GS; User Equipment (UE) conformance specification. Part 3: Protocol test suites (ETSI TS 138 523-3 V15.5.0 (2019-10));
- NR; User Equipment (UE) conformance specification; Radio Resource Management (RRM) (ETSI TS 138 533 V15.1.0 (2019-07)).

- CETECOM laboratories also perform tests in accordance with FCC standards:
- FCC PART 22, 24 and 27 for GSM/ WCDMA/LTE devices;
- FCC PART 15.247 for Bluetooth/WLAN 802.11 b/g/n (2.4 GHz);
- FCC PART 15.407 for WLAN 802.11 a/n/ ac (5 GHz);
- FCC PART 15.245 (902-928 MHz band, ISM bands);
- FCC PART 15.225 for RFID (13.56 MHz);
- FCC PART 25 for satellite communications devices;
- DFS tests for equipment operating in the 5.25-5.35 GHz and 5.47-5.725 GHz bands. (FCC PART 15 Subpart E);
- SAR tests in accordance with FCC requirements.

China Telecommunications Technology Laboratory CTTL [17] owns the Taier laboratory with vast experience and advanced equipment in the field of international and domestic antenna certification testing. The Beijing laboratory has 5 fully equipped acoustic chambers, 2 reverberation rooms and 1 small mobile complete acoustic chamber. It also has several full sets for OTA and positioning testing including 5 sets for full coverage OTA testing, 3 sets for MIMO-OTA testing (covering all solutions), 3 sets of A-GPS OTA positioning systems, 2 sets for A-GNSS radio performance testing, 2 sets of Beidou test systems, 2 sets of WLAN OTA test systems, etc. The scope of testing and certification includes full-featured terminals or system equipment, including GSM / GPRS / EDGE, CDMA 1X, cdma2000 (EVDO), WCDMA, TD- SCDMA, LTE and WLAN 802.11abgn etc. It has a large test field in Baoding.

US based Intel Mobile Communications participates in more than 300 standards groups worldwide and holds leading positions in various work groups such as ITU-R, 3GPP and IEEE, etc. Intel corporation offers its own researches, benchmarks, and insights to fulfill the potential of 5G [19].

Korean Test Lab (KTL) [21] conducts suitability tests (RF, OTA, RSE, Audio, (U)SIM/ SAT, MMS, NFC, etc.). Tests are performed for mobile communication devices that support GSM/WCDMA/LTE, etc. in accordance with the required 3GPP standards from GCF (Europe) and PTCRB (North America). Tested are portable devices and mobile communication devices (smart device, USB key, module, etc.), devices with GSM, WCDMA, LTE support (trial band contact).

Domestic and international certifications and validation tests are carried out for various wireless devices.

PCTEST Engineering Laboratory Inc. [22] conducts certification testing for compliance with industry, carrier and/or CTIA/PTCRB/ GCF standards.

Available testing services include:

- CTIA wireless performance test plan;
- CTIA test plan for 2×2 downlink MIMO and over-the-air transmission diversity;
- CTIA/Wi-Fi Alliance test plan to evaluate RF performance of mobile converged Wi-Fi devices;
- Test plans for specific operators;
- Engineering assessment.

For MIMO an acoustic chamber is used with multiple probes and channel emulators to simulate a realistic spatial propagation environment, and multi-antenna devices are tested over the air by estimating the downlink Signal-to-Interference Ratio (SIR) required to achieve various throughput rates. The results are averaged over several azimuth orientations to evaluate the spatial multiplexing performance of the device at multiple user positions.

Qualcomm Corporation [23] has been working on major advancements in the mobile industry from 2G to 5G.

Development of new paradigms for 5G spectrum sharing.

Extensive mobile testing and innovation in the millimeter wave range.

In collaboration with Ericsson and a group of leading mobile network operators including AT&T, NTT DOCOMO, Orange, SK Telecom, Sprint, Telstra, T-Mobile US, Verizon and Vodafone, Qualcomm Corporation announced a multi-vendor interoperable connection compatible with Non- Standalone (NSA) 5G New Radio (NR) 3GPP global standard.

In November 2020, DISH Network Corporation and Qualcomm Technologies, Inc. announced their collaboration aimed at testing open and virtualized 5G RAN solutions containing new Qualcomm® 5G RAN platforms.

Qualcomm has developed a fully integrated extended range mmWave antenna module designed for 5G fixed wireless access equipment at the customer's premises.

SGS Wireless [24] is a major inspection, verification, testing and certification company for mobile phones, tablets, IoT/M2M devices, telematics devices, chips and modules covering 2G/3G/4G/5G, a member of the 5G Automotive Association (5GAA) .

With centers of excellence for its wireless business in North America, Asia and Europe, SGS has an extensive portfolio of certifications and accreditation. This includes ISO 17025 accredited labs worldwide offering testing services for cellular (2G/3G/4G/5G), IoT, V2X and LPWA technologies, in addition to GCF, PTCRB, CTIA, Bluetooth SIG, Wi-Fi Fi Alliance, NFC, WPC, USB and Global Platform.

Shanghai Taijie Communication [25] uses ETS solution in its OTA testing labs to fully comply with CTIA OTA testing requirements, including: GSM/CDMA/WCDMA/TDSCDMA/LTE (including FDD/TDD and 2CC/3CC, etc.) , WIFI/AGPS/AGLONASS etc. Testing includes the following:

- CTIA OTA Test Plan;
- CWG RF Test Plan;
- GSM/CDMA/WCDMA/TDSCDMA/LTE-FDD/TDD/2CA/3CA/Wi-Fi.

Taijie Communication has a 3m full/half acoustic chamber, conduction/emission test lab, immunity test lab, etc., covering all major EMC standards.

Sporton International Corporation [26] has the following experience in the field of antenna equipment testing [29]:

- in 2010, the Korean laboratory was qualified by CTIA / WiFi Alliance WiFI OTA;
- accredited by LTE PTCRB in 2011;
- in 2012 laboratories in Shenzhen and South Korea received LTE PTCRB accreditation;
- in 2014, the third MIMO OTA laboratory was established;
- received AT&T MIMO OTA and AT&T Wearable OTA testing qualification in 2014;
- the fourth MIMO OTA laboratory was created in 2015;
- Qualified as China Mobile OTA performance test in 2015.

Another well-known company is TEOCO (USA) [27], whose structural subdivision is AIRCOM, a 5G expert center that provides a full range of testing services both in the laboratory and in the field. AIRCOM Lab is fully accredited by AT&T, T-Mobile and Verizon.

AIRCOM's state-of-the-art test platforms, tools and systems cover FR1 and FR2 test areas for both standalone and non-standard 5G devices. The lab provides a full range of life-cycle testing for IoT modules, modems, and wearables, with the ability to certify protocols, radio frequencies, data performance, and market key performance indicators.

Technological partnerships with industry leaders such as Spirent, Qualcomm, L&T Technical Services, and Wireless Metrics makes it possible to perform OTA testing, certification, and offer support for 5G product development, R&D test services, and 5G tools and training.

In 2014, AIRCOM expanded its laboratory's testing capabilities by acquiring additional testing systems from Rohde&Schwarz. Combined

with Rohde&Schwarz's extensive compliance and test case support for operators, the R&S TS-LBS Location Services (LBS) and R&S CMW-PQA performance test systems enable TEOCO to support new industry and operator test requirements for next generation wireless technologies including carrier aggregation, IMS, VoLTE, RCS, E911 over IMS, LTE A-GNSS, LTE OTDOA and LTE eCID.

Another company worth mentioning is Verkotan [28], which is an ISO 17025 and ISO 9001 accredited test laboratory with over 20 years of experience in developing advanced wireless performance testing systems, implementing new test methods, and providing numerous test results for 3GPP. The lab provides a wide range of flexible SAR, OTA and custom testing services for wireless device manufacturers.

5G NR Active Antenna Test Service (AA TaaS) for Base Station (gNB) provides FR1 active antenna test service in accordance with 3GPP TS38.141-2, radiated transmit power 6.2 and OTA sensitivity 7.2 for base stations and ancillary equipment.

The laboratory has two independent test methods to measure the EIRP radiated transmit power (3GPP 38.141-2 6.2) and EIS OTA sensitivity (3GPP 38.141-2 7.2). These two test methods are based on the near and far field active antenna testing and offer a plane wave synthesis active antenna test service using the R&S PWC. By providing active antenna testing services, the laboratory supports customers during product development and type approval.

Test Method #1. Verkotan's unique service for active antenna testing in near field (NF) and far field (FF) is available across the entire FR1 frequency range with a help of proper wide bandwidth horn antenna setup. The testing frequency from NF to FF is from 600 MHz to 6 GHz. It is scaled to suite different gNB sizes and has a configurable fine positioning system. Testing is conducted within the scope of accreditation for 3GPP TS38.141-2, 6.2 EIRP and 7.2 EIS.

Test Method #2: The Verkotan Active Plane Wave Synthesis Antenna test service using the R&S PWC is available for the 2.3 to 3.8 GHz frequency bands covering the most important FR1 5G bands. There is a customized precision positioning system, and it is possible to test gNB sizes of up to one meter. Test services are performed within the scope of accreditation for 38.141-2, 6.2 EIRP and 7.2 EIS.

Verkotan offers all the necessary OTA testing and analysis services tailored to the client's needs. It helps to fully meet the OTA requirements declared by the wireless provider. OTA testing measures the radiated RF characteristics of a device. This is one of the most difficult aspects in the development of wireless devices.

The lab's testing capabilities cover the testing of a wide range of radio systems. TRP and TIS (Total Isotopic Sensitivity) can be measured according to the industry standards. Their state-of-the-art labs support testing of up to 5G. Here is the list of radio systems supported by Verkotan Laboratories: 5G Bands, GSM Bands, UMTS Bands, LTE Bands, LTE CAT NB1, LTE CAT M1, CDMA bands, TD-SCDMA Bands, Gps, Passive Antenna Testing, Glonass, Beidou, FM radio, WiFi, Bluetooth.

The laboratory offers preliminary measurements for MIMO OTA compliance in accordance with the latest CTIA specifications.

MIMO OTA Testing measures changes in data throughput and signal strength of a device as it moves further away from the nearest base station. The high accuracy of MIMO OTA measurements during the R&D phase of the product helps to avoid very extensive product modification costs in the final stage of the product development.

There is also the possibility for MIMO OTA measurements for devices that support MIMO 4x2 and MIMO 4x4.

Verkotan has one accredited high quality acoustic chamber for OTA testing and antennas for SISO and MIMO testing purposes.

Acoustic chamber can be used for 3GPP and SISO measurements and preliminary MIMO measurements. In this chamber it is possible to create a radio environment according to the needs of the client and test the device in a repeatable and reliable way. The camera is also being used to develop 5G test system solutions and can be used for GNSS, WLAN and IoT testing.

Overall dimensions: 6×5.8×2.2 m. MIMO frequency range: 600 MHz to 6 GHz.

Verkotan has introduced a 6-axis industrial robot with digital motion modes. The robot allows measuring 3D antenna patterns of radio modules of 5G base stations and terminals. The testing frequency of FR1 and FR2 is from 400 MHz to 53 GHz. Testing is performed in an acoustic chamber using direct field conversion techniques in the far field and from near to far.

Antenna parameters evaluated include the following:

- gain;
- beam width;
- the angle between two azimuth peaks of the antenna pattern;
- cross-polarization decoupling;
- beam tilt accuracy;
- protective action coefficient;
- suppression of the first upper side lobe;
- efficiency.

Antenna Measurement Services include:

- measurement of antenna patterns (3D and 2D patterns);
- measurement of antenna efficiency;
- absolute gain measurement;
- measurement of VSWR and antenna matching;
- measuring the correlation of MIMO antennas (ECC, Envelope Correlation Coefficient);
- measurement of antenna polarization (linear, right-hand circular, left-hand circular and others);
- antenna beam-forming measurement.

To test 5G MIMO base stations in the FR1 band, Verkotan uses the R&S PWC200 plane wave converter.

3. RUSSIAN TESTING LABORATORIES ACCREDITED FOR MEASURING CHARACTERISTICS OF SMART ANTENNA SYSTEMS

The Russian company LLC "Testing Technical Center of Microdevices" [30] is accredited to test domestic and foreign electronic components in accordance with the requirements of GOST ISO / IEC 17025-2009 and ES RD 005-2016 (accreditation certificate No. C 01.061.0071-2019). The company has its own acoustic shielded chamber ETS-Lindgren AMS-8500.

The Russian PJSC "Radiophysics" [31] offers testing of antenna devices, including Active Phased Antenna Arrays (APAA) and reflector antennas ranging from 1 GHz to 110 GHz. Measurements in a large-scale Acoustic Chamber (AC) are carried out both in the far zone and in the intermediate zone (Fresnel zone), as well as in the near zone (planar scanning) with subsequent processing of the results.

PJSC "Radiophysics" scope of work includes the following:

- adjustment and calibration of APAA;
- measurements of amplitude and phase radiation patterns of antennas of various types, including APAA;
- measurements of polarization characteristics of antennas;
- gain measurements;
- measurement of the effective isotropically radiated power (EIRP) of active antennas;
- measurement of angular accuracy and other parameters of APAA during scanning;
- testing of APAA components for noise immunity and electromagnetic compatibility (see section on EMC);
- diagnostics of failures of APAA elements;
- measurements of back-scatter characteristics of complex radio systems.

The enterprise has made seven ACs, including an AC with linear dimensions of 80×32×24 m. All ACs are shielded and equipped with filters for incoming power and communication cables. Shielding is made according to class II GOST

R 50414 and is at least 60 dB in the range from 30 MHz to 40 GHz. ACs are equipped with automated measuring benches fitted with equipment from such manufacturers as Agilent (Keysight) Technologies, Rohde & Schwarz, National Instruments, SATIMO, ORBIT-FR, MI-Technologies, Frankonia. Automated measuring stands are equipped with three-coordinate rotary devices with a load capacity of up to 2000 kg with an accuracy of positioning the measured products to the order of 1 angular minute.

Large-aperture phased arrays having extensive overall dimensions and weight, are tested in AC in the near field using an automated measuring and computing complex based on a planar T-scanner with a working area of 9×6 m (**Fig. 2**).

PJSC "Radiophysics" has developed a method for measuring antenna characteristics in the intermediate zone (Fresnel zone). It has a certificate for the corresponding specialized software for measuring the characteristics of antennas in the Fresnel zone.

PJSC Radiophysics has experience in calibrating multi-element antennas (up to several thousand channels). Phased antenna arrays (PAA) and APAA are calibrated both by a remote signal source and by using a T-scanner through measuring the signal in the near field. It has an experience in developing built-in calibration and control systems, as well as "in the field" calibration for portable and stationary phased arrays. There is specialized software for calibration of PAA and APAA.

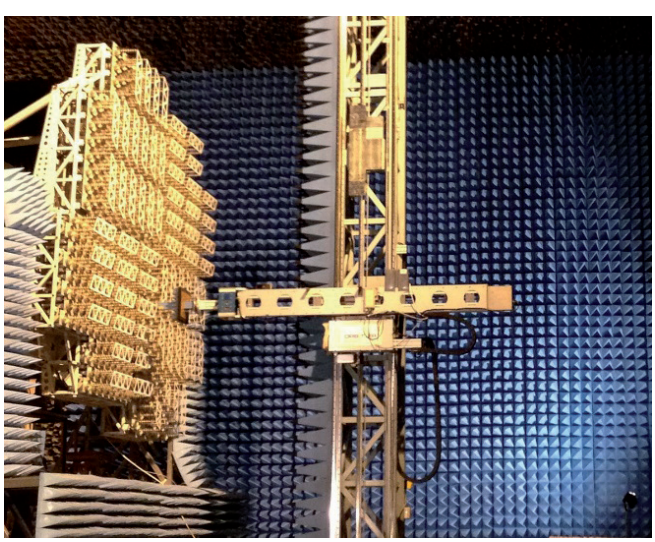

Fig. 2. *T-scanner with working area of 9×6 m.*

The enterprise has various test bench size to calibrate a variety of PAA (including large ones) in multiple modes. In this case, there are usually no specific additional requirements for the PAA design. PAA is calibrated "as is". In this case, there is no need to turn on and off the power to the channels of the antenna array. It is possible to start measurements without dismantling the antenna and transferring it to another test bench. This enables flexible tuning and debugging of the PAA.

The Research Department of Metrology of Radio Engineering and Electromagnetic Measurements (NIO-1), a structural subdivision of the FGKP VNIIFTRI [32], has developed a hardware and software system for testing antenna arrays in the near field (MIMO, active, digital, hybrid) that are part of 5G communication systems.

Distinctive features of the hardware-software package are:

- possibility of measuring volumetric directivity characteristics and energy characteristics of non-reciprocal (active) antennas;
- possibility of measurements on regular broadband signals with digital modulation, having a bandwidth of up to 1 GHz;
- flexible specialized software adaptable to various test objects;
- measurements are conducted in compliance with the conditions of the far zone and free space (anechoic coefficient less than minus 50 dB);
- reliability of measurements based on the use of reference class equipment.
- Parameters of the AC FSUE "VNIIFTRI":
- frequency range: 0.5 to 50 GHz;
- analysis bandwidth: up to 1 GHz;
- maximum track length: 24 m;
- EIRP measurement error: ±1 dB;
- anechoic coefficient: no more than –20 dB.

The following is measured during the tests: volumetric amplitude radiation patterns, equivalent isotropically radiated power, spectral characteristics of the generated signals, equipment noise immunity parameters, including resistance to radio interference with complex types of signals simulating the operation of a radar.

A distinct feature of the measurements is the absence of radio frequency interfaces in the tested products. In addition, modern systems typically operate using pulsed and modulated broadband signals. In the case of 5G communication systems, a pulse may be impregnated with useful information that can vary from pulse to pulse. Since the receiving device used for measurements is not connected to the signal source in the MIMO array, the current parameters of the signals remain unknown, and the recorded signals themselves do not have a reference value. These specifics were taken into account during the development of the FSUE VNIIFTRI measuring complex, which during 2018 was used to test antenna arrays manufactured by Nokia, Huawei, Ericsson, made using MIMO technology.

4. CONCLUSION

Reviewed were some well-known international and Russian testing laboratories accredited to perform measurements of smart antenna systems a brief description of their experience was presented.

A number of laboratories carry out measurements not only in the near field or in the Fresnel zone with subsequent processing of the results, which is justified in terms of the cost of such chambers, but also in large acoustic chambers in the far field.

Field measurements make it possible to trace the entire signal path and characteristics of the antenna, which are affected by various product requirements, applications, famesize, materials, bandwidth, frequencies, etc. OTA tests are conducted at all stages of the product life cycle: research and development, type approval or certification.

MIMO antenna tests are performed using acoustic chambers with multiple probes and channel emulators to simulate a realistic spatial propagation environment, while multi-antenna devices are tested over the air by evaluating the downlink SIR required to achieve different throughputs.

Some labs conduct their own test research (e.g. Intel Mobile Communications, Intel, Qualcomm, etc.). Many laboratories participate in various work groups like ITU-R, 3GPP and IEEE, and also join forces to test open and virtualized 5G RAN solutions.

Today, the world's leading telecommunications organizations have all necessary metrological equipment for development and production of equipment for base stations and terminals of 5G NR mobile communication systems, which include various smart antennas with high performance technical characteristics and relatively complex operational algorithms.

Over the past ten years in Russia a number of specialized measuring organizations have been actively involved in the field tests of 5G NR smart antenna performance. Cooperation has been strengthening between Russian testing laboratories and standardization organizations as well as manufacturers of antenna equipment for modern communication systems.

It is important to note that Russian test and measurement laboratories have accumulated a vast scientific and technical potential that allows them to develop, test and manufacture telecommunications equipment of any technical complexity, including those for 5G/6G NR systems.

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