5G Spectrum:
How Proper Testing Maximizes ROI

White paper

Overview

The 5G rollout significantly changes the radio access network (RAN) to accommodate the expanding use cases. Among the most important technologies integrated into RAN designs are network slicing and mobile edge computing. Both are necessary to help 5G meet key performance indicators (KPIs) and expanding applications.

The importance of these technologies cannot be understated, however, the currency of 5G is spectrum. Mobile operators spent more than $2.7 billion in the first phase of 5G spectrum auctions for the 28 GHz band, according to the Federal Communications Commission (FCC).1 Subsequent auctions are expected to be as financially impactful. The result is that spectrum is now a major—and still growing—portion of providers' investments, as well as their balance sheets.

The increased need for spectrum is necessitated by the exploding demand for data. 5G goes beyond traditional consumer mobile demands and extends to new industries, from mobile healthcare and industrial automation to smart cities and autonomous verticals. To fit all these verticals, 5G networks must have a new level of flexibility and agility. Technologies such as network slicing, however, can only be as flexible and efficient as a mobile operator's spectrum assets allow.

For these reasons, it is imperative that spectrum is properly managed and monitored, from network deployment to operation and maintenance. Given the technologies used in 5G and the mission critical nature of many applications, testing becomes paramount. While many tests are similar to LTE – only with new more stringent specifications – new analysis is also required to ensure network operation. Understanding the use cases and evolving RAN, as well as implementing the necessary test processes due to these factors, will help 5G networks perform to specification.

Key Elements of 5G

By now, everyone involved in 5G services is familiar with the three main use cases - Enhanced mobile broadband (eMMB), Ultra-reliable and low latency communications (URLLC), and Massive machine-type communications (MTC). Figure 1 is a breakout of all 5G use cases.

With peak download speeds of at least 20 Gbps and a reliable 100 Mbps user experience data rate in urban areas, eMMB will support consumers' growing appetite for video as well as virtual reality (VR) and augmented reality (AR). URLLC, with 1 ms latency and very high availability, reliability and security, supports mission critical applications, such as autonomous vehicles and mobile healthcare. To support the estimated 5.8 billion IoT endpoints expected by 2020[3], there is MTC.

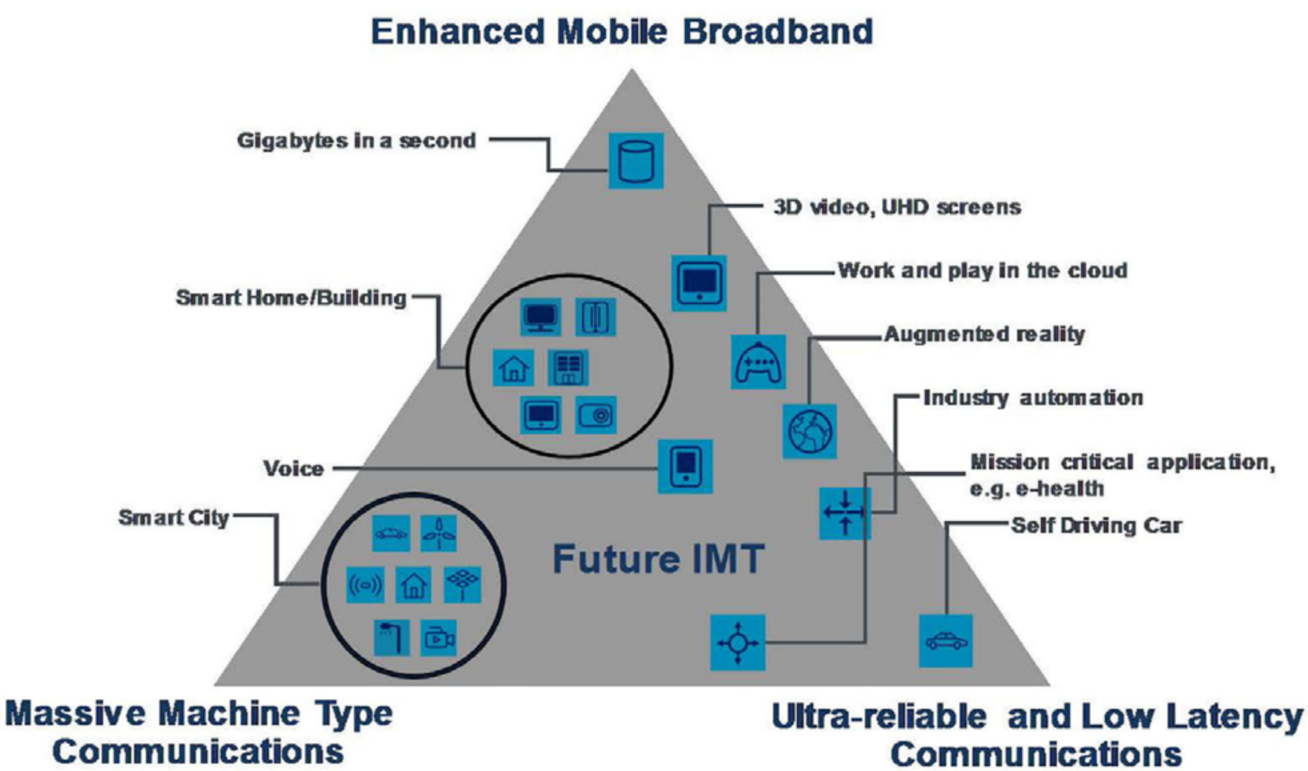


Figure 1: *5G use cases (courtesy of ITU-T).*

5G presents three key performance improvements compared to 4G LTE to meet the demands of these use cases:

Low Latency – 5G is designed to significantly reduce latency; a 10X decrease in end-to-end latency is specified but it may be higher. The average latency on a 4G network is approximately 50 ms, while latency as low as 1 ms may be achieved with 5G.

High-speed – It is generally agreed that 5G will be as much as 50x faster than 4G. Of course, there are variables such as the specific operator network and the number of users accessing the network at the particular time that will affect real-world numbers. Table 1 shows the difference between 4G, 4G LTE-Advanced (LTE-A) and 5G when it comes to speed.

Wireless Network Speeds

	4G	4G LTE-A	5G
Max. speed	150 Mbps	300 Mbps – 1 Gbps	1-10 Gbps
Avg. speed	10 Mbps	15-50 Mbps	=/> 50 Mbps

Table 1: *Wireless Network Speeds.*

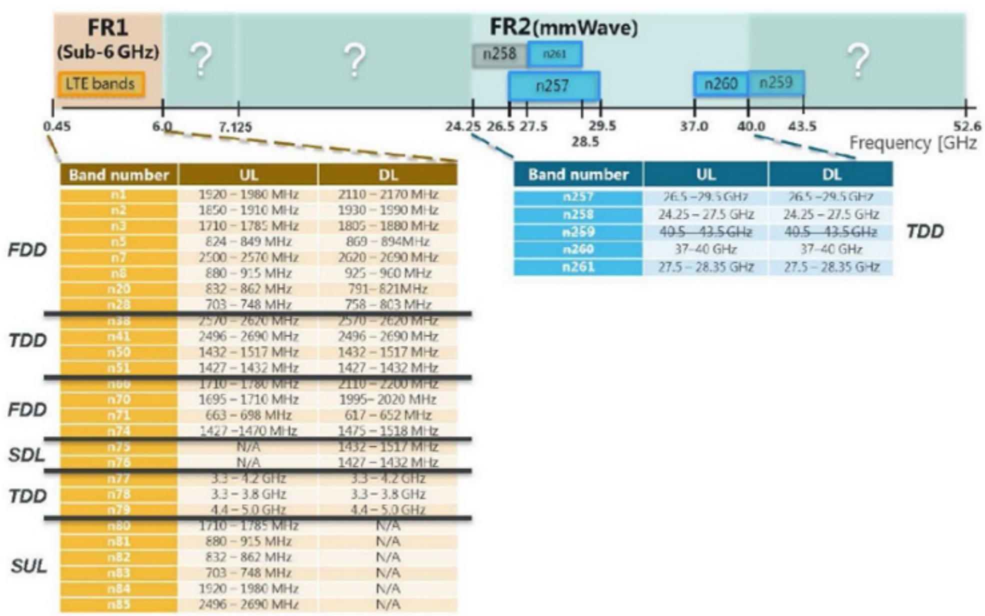
Multiple Simultaneous Connections – 5G is expected to have significantly more traffic capacity and network efficiency. Most estimates target it as a 100x increase compared to 4G. That is necessary to accommodate the aforementioned billions of IoT devices, in addition to traditional wireless and emerging mission critical applications.

To address these opportunities, a wide range of radio frequencies from sub-1 GHz to 100 GHz including licensed, unlicensed, and shared spectrum, will be utilized in 5G. Several factors, however, need to be taken into consideration before any spectrum strategy can be put in place.

How 5G Changes Spectrum Analysis

5G needs a significant amount of spectrum to accommodate all the use cases. 5G New Radio (NR) will introduce flexible spectrum usage with scalable numerology, Time Division Duplex (TDD), massive MIMO and beam forming. All come with significant challenges in the field for RF engineers validating, testing and optimizing the 5G network, creating new requirements for spectrum analysis.

5G frequency is segmented into frequency range 1 (FR1) and frequency range 2 (FR2). FR1 is currently from 450 MHz to 6 GHz (although there are discussions to expand both ends of the FR1 definition); basically overlapping and extending 4G LTE. FR2 operates at the higher millimeter wave (mmWave) frequencies, with the first release supporting up to 52.6 GHz. Figure 2 provides a breakout of the two segments.



	Band number	UL	DL
FDD	n1	1920 – 1980 MHz	2110 – 2170 MHz
	n2	1850 – 1910 MHz	1930 – 1990 MHz
	n3	1710 – 1785 MHz	1805 – 1880 MHz
	n5	824 – 849 MHz	869 – 894MHz
	n7	2500 – 2570 MHz	2620 – 2690 MHz
	n8	880 – 915 MHz	925 – 960 MHz
	n20	832 – 862 MHz	791– 821MHz
	n28	703 – 748 MHz	758 – 803 MHz
TDD	n38	2570 – 2620 MHz	2570 – 2620 MHz
	n41	2496 – 2690 MHz	2496 – 2690 MHz
	n50	1432 – 1517 MHz	1432 – 1517 MHz
	n51	1427 – 1432 MHz	1427 – 1432 MHz
FDD	n66	1710 – 1780 MHz	2110 – 2200 MHz
	n70	1695 – 1710 MHz	1995– 2020 MHz
	n71	663 – 698 MHz	617 – 652 MHz
	n74	1427 –1470 MHz	1475 – 1518 MHz
SDL	n75	N/A	1432 – 1517 MHz
	n76	N/A	1427 – 1432 MHz
TDD	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
SUL	n80	1710 – 1785 MHz	N/A
	n81	880 – 915 MHz	N/A
	n82	832 – 862 MHz	N/A
	n83	703 – 748 MHz	N/A
	n84	1920 – 1980 MHz	N/A
	n85	2496 – 2690 MHz	N/A

Band number	UL	DL	
n257	26.5 – 29.5 GHz	26.5 – 29.5 GHz	TDD
n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz	
n259	~~40.5 – 43.5 GHz~~	~~40.5 – 43.5 GHz~~	
n260	37–40 GHz	37–40 GHz	
n261	27.5 – 28.35 GHz	27.5 – 28.35 GHz	

Figure 2: *FR1 and FR2 ranges*

FR1 has had a new addition – C-band – in 2021 that will significantly impact how 5G networks operate, as well as how they will have to be tested. C-band sits between 3.4 GHz and 4.2 GHz and has three bands – n77, n78, and n79 – that will be used in 5G. C-band is particularly appealing in 5G because it offers a nice balance of coverage and high throughput.

The higher frequencies for 5G enable higher data transmission through wider channels than legacy LTE signals. 5G NR supports channel sizes from 50 MHz to 400 MHz in bands above 24 GHz (as well as from 5 MHz to 100 MHz for bands below 6 GHz). As noted earlier, latency will be significantly reduced, as well, dropping from 25 ms – 40 ms to as low as 1 ms. Data speeds are expected to range from 100 Mbps on lower frequencies to up to 10 Gbps on the higher bands.

Challenges of TDD

Higher frequency and spectrum crowding due to expanding use cases are only two of the considerations when testing 5G. Another is TDD, which will be used prominently in cellular networks for the first time with 5G NR. In fact, a report from Ericsson predicts TDD-based spectrum will eventually comprise as much as 80% of total 5G network capacity.

Because TDD transmits using the same channel at different times, interference becomes a dicey predicament. For example, higher power transmissions from base stations on one network can interfere with base stations on nearby networks receiving signals from lower power UE.

Due to TDD, highly accurate time synchronization is necessary throughout the network. GPS – the standard process in LTE – is no longer practical to prevent sync loss. TDD spectrum such as Citizens Broadband Radio Service (CBRS) and mmWave, require much tighter time and phase synchronization to prevent interference between the uplink (UL) and downlink (DL).

C-band, which is currently being deployed, utilizes TDD transmission. As a result, interference will be a key factor when deploying C-band. On-going spectrum analysis and monitoring are required to identify interference during the transition from TDD UL and DL frames. That is particularly important with C-band, as the spectrum has to be cleared because it was used by different entities from the federal government to satellite services.

Another critical factor for proper C-band deployment due to its use of TDD technology is timing and synchronization to eliminate crosstalk. Key measurements for C-band are time error (TE) and absolute TE. The time difference between two points or clocks is TE. Absolute TE is the time difference between a device and Primary Reference Time Clocks (PRTC). It is measured using PreciseTimeBasic (PTB) and must be 1.1 us maximum to comply with ITU-T.

Need for OTA Testing

Scalable numerology, massive MIMO and beamforming are other 5G factors that will impact testing. Beamforming (figure 3) is used to help massive MIMO arrays make more efficient use of the spectrum by allowing multiple transmissions to occur simultaneously. At higher FR2 (mmWave) frequencies, beamforming also creates a stronger signal by concentrating the transmit power in a certain direction, as well as the sensitivity of the receiver, reducing interference from other devices. Due to these factors, tests need to be performed “in the beam” which means over-the-air (OTA).

Figure 3: *Example of 5G beamforming.*

Another reason for OTA testing is 5G requires associated adaptive antenna system (AAS) technologies, so the respective radio and antenna performance can't be split. The result is that testing each antenna, which was possible on 4G LTE and other legacy wireless technologies, is a thing of the past.

Framing & Structure

The complexity of 5G NR signals is evident by the frame structure used. Signals must support TDD and FDD transmissions, as well as operate in licensed and unlicensed spectrum. Very low latency, fast hybrid automatic repeat request (HARQ) acknowledgements, coexistence with LTE, and transmissions of variable lengths, such as short durations for URLLC and long durations associated with eMBB, must be supported, as well.

To meet the myriad of factors, the frame structure adheres to three key design principles:

1. **Self-contained transmissions.**
   Data in a slot and in a beam are decoded separately without relying on other slots and beams.

2. **Transmissions confined in time and frequency.**
   By keeping transmissions together, new transmission types can be integrated with legacy transmissions more easily.

3. **Avoid static and/or strict timing relations**
   across slots and across different transmission directions.

Figure 4 shows the 5G slot structure. A frame in 5G NR consists of 10 subframes, each with a duration of 1 ms. This design is similar to LTE. Each subframe consists of 2μ slots that can have either 14 (normal CP) or 12 (extended CP) OFDM symbols. Normal CP is always used with subcarrier spacing, while normal and extended CP types are supported by 60 kHz spacing.

μ	SCS (2^{μ} x 15 kHz)	Symbol Time	Nominal CP (4.7 μs/2^{μ})
0	15 kHz	66.7 μs	4.7 μs
1	30 kHz	33.3 μs	2.4 μs
2	60 kHz	16.6 μs	1.2 μs
3	120 kHz	8.3 μs	.6 μs
4	240 kHz	4.2 μs	.3 μs

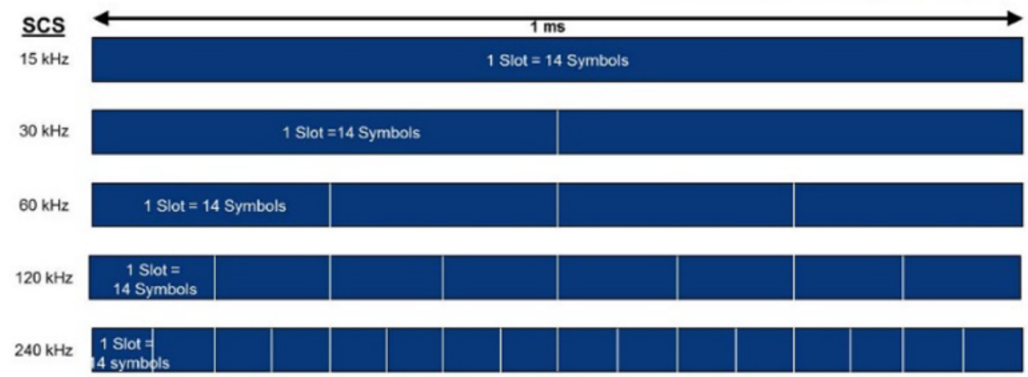


Figure 4: *Slot structure in 5G.*

Flexible numerology enables multiple frequencies and scheduling of diverse services to be transmitted and received via signals consisting of data channels and sync signal blocks. A single SS block spans 4 OFDM symbols on time axis and 240 subcarriers on frequency axis. SS blocks carry PSS (Primary Synchronization Signal), SSS (Secondary Synchronization Signal) and PBCH with DMRS. The SS blocks are grouped into the first 5 ms of the SS burst, with the maximum number of SS blocks in single burst dependent on frequency. The SSB contains vital data about the cell ID and position, as well as enabling measurements of the transmitter quality.

Sub-carrier spacing enables scalable slot duration, so more can operate in less time, helping to achieve 5G's high speed. To support low-latency, mission-critical applications, a mini-slot that has a shorter duration and can start at any time without waiting for the initiation of a slot boundary is utilized.

Measurements Create Greater ROI

Accurate and thorough testing of all these elements during installation of 5G networks will help create a greater return on investment (ROI) on those spectrum purchases. Better spectrum clearing will avoid future performance issues that can cost thousands of dollars to identify and fix. The cost of sending technicians to revisit tower sites and troubleshoot is expensive, so eliminating interference when the towers are installed will save money over the life of the network. It also prevents lost revenue caused by customer churn due to poor network performance.

Field test analyzers must be pushed higher than ever with respect to capturing bandwidth to accommodate the wider signals. Real-time spectrum analysis is also key for capturing and analyzing the frame structures of the 5G signals to understand their configuration and timing, as well as helping locate the SSB within the 5G waveform.

With LTE RF testing, field technicians typically attach an omni-directional antenna to a spectrum analyzer and monitor OTA data traffic from the radio. That is no longer an option with 5G, as the radios are not always transmitting data. Data beams are only formed if a UE is pulling data from the base station.

These factors alter the way 5G must be tested in the field, where technicians need to visit a site, identify the radios and acquire basic data on the signals. Implementing OTA test methods to test MIMO beam steering and beamforming technologies used in 5G NR is the best approach.

Measurements to ensure the beam strength and quality of 5G transmissions are listed in table 2. We will focus on a few of the key measurements.

Beam Strength & Quality

Adjacent Channel Leakage Ratio (ACLR)	Modulation Quality
Cell/Sector ID	Occupied Bandwidth (OBW)
Equivalent Isotropic Radiated Power (EIRP)	Spurious Noise
Frequency Error	Synchronization Signal Blocks (SSB)
	Time Offset

Table 2: *5G Beam Strength and Quality Measurements*

EIRP – The total power that would have to be transmitted by a base station with an isotropic antenna that would result in the same power measured at a fixed point from a base station using direction or beamforming antennas. Since Total Radiated Power (TRP) cannot be measured on the beamformed signals, this measurement allows the amount of power being radiated from the radio in a specific beam to be traced. EIRP tests measure the power emitting from a beamforming signal to ensure it is within FCC guidelines. Maximum EIRP DL for the 28 GHz band is 78 dBm, therefore, the test solution must be able to measure this specification.

SSB - The maximum number of SSB beams per cell is between 4 and 64, depending on the frequency range. SSB beams are static, or semi-static, and always point in the same direction. They form a grid of beams covering the entire cell area. Different SSB beams of a cell are transmitted at separate times. Therefore, there is no intra-cell interference among the SSB beams and scanning receivers should be able to detect extremely weak SSB beams, even in the presence of a dominant, strong beam from the same cell.

Figure 6 indicates of the challenges associated with 5G signal testing due to SSB and beamforming. The display shows a 5G antenna transmitting SSB beams into a 120-degree sector. The signal is divided into eight separate sectors with each beam pointing in a different direction.

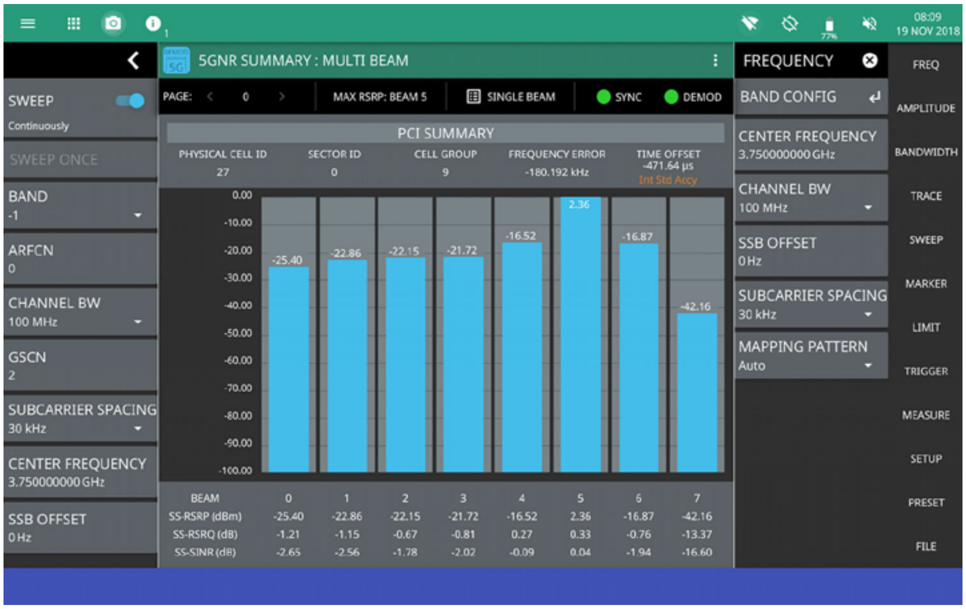


Figure 6: *Display of 5G beamforming measurement.*

To conduct this measurement, advanced sync signal analysis is required to decode the information in each beam. A spectrum analyzer must have the capability to conduct accurate isotropic radiation measurements so field technicians can travel across the sector and have the power levels move from sector to sector to understand and track beam coverage.

OBW - The occupied bandwidth for each 5G NR carrier wave must be smaller than the base station channel bandwidth. OBW is a necessary 5G spectrum measurement to ensure transmitting products meet specifications.

ACLR – Another spectral measurement to ensure transmissions, ACLR is the ratio of the filtered mean power centered on the assigned channel frequency to the filtered mean power centered on an adjacent channel frequency.

Time Offset – This measurement is necessary to indicate the difference between the beginning of the time capture and the start of the measurement interval. For example, when time offset is 5 ms and the search time trace starts at -8.3 ms, the beginning of the measurement interval is located at -3.3 ms within the search time trace. In this case, time offset will show the offset between the frame trigger and the actual start of the frame.

Interference Testing

Because 5G signals are more directional than their LTE counterparts, signal hunting is increasingly important to eliminate interference that will cause networks to fall below established KPIs. Table 3 shows typical causes of interference.

Interference
Fast Transient Signals
Hidden Signals
Border Issues
Subcarrier Analysis
Physical Obstructions

Table 3: *Potential causes of 5G signal interference.*

In these scenarios, a real-time spectrum analyzer with 100 MHz bandwidth provides distinct advantages. It allows technicians to analyze wider signals in real-time speeds to track persistent and intermittent interferers.

Spurious signals are of particular concern with 5G NR signals operating in the sub-6 GHz frequencies. While it is essential for existing spectrum requirements, testing spurious signals will be of even greater importance in the near term. For these measurements, the field instrument should have a strong TOI spec of +20 dBm to ensure the instrument front end is not overdriven, as well as displayed average noise level (DANL) of -164 dBm to display weak signals.

Test Solutions for 5G

Given the new test requirements for 5G and signal complexity, a new generation of test solutions is necessary when deploying, installing, and maintaining the networks now being rolled out. Anritsu provides the solutions that meet the field requirements.

Field Master Pro™ MS2090A - With continuous frequency coverage from 9 kHz to 54 GHz, the MS2090A meets the challenges of 5G test. Its high performance makes spectrum clearing, radio alignment, harmonic measurements, distortion measurements, and coverage mapping more accurate than previously possible. For modulation measurements on digital systems, 100 MHz modulation bandwidth coupled with best-in-class phase noise performance maximizes measurement accuracy and 0.5 dB typical amplitude accuracy provides confidence when testing transmitter power and spurious.

Field Master Pro™ **MS2090A**

OTA measurements are supported by standing in front of the 5G NR and AAS, ideally in the far field, and using a wave guide horn or broadband antenna to make measurements on the beams formed. It can make a full range of RF measurements by decoding the SSBs and displaying values of RSRP, channel power, and EVM of each beam.

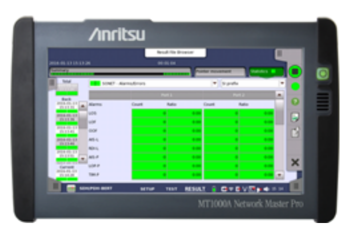
Spectrum Master™ handheld spectrum analyzers – With frequencies ranging from 9 kHz to 43 GHz, the Spectrum Master is ideal for spectrum clearing and monitoring, interference hunting and mitigation, and general purpose measurements on transmitting devices. Its low phase noise, wide RBW range down to 1 Hz, and wide dynamic range make it well suited to locate hidden interferers within 5G networks, including intermittent signals.

Spectrum Master™

Site Master™ cable and antenna analyzers – With the integration of C-band into the 5G network mix, line sweeps become an important measurement. Trusted and field-proven, Site Master is the de facto industry standard for the installation, maintenance, and troubleshooting of cable and communication systems. Its measurement capabilities include precision return loss/VSWR, cable loss, and distance-to-fault.

Site Master™

Network Master™ Pro Tester – The all-in-one design of the Network Master Pro supports 5G base-station interface eCPRI/ RoE throughput and delay measurements, as well as high-accuracy time synchronization tests. Adding the 100G Transport Module enables eCPRI/RoE, and precision latency and time synchronization measurements.



NetworkMaster™ Pro

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[3] Ericsson Mobility Report - IoT connections outlook

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• United States
Anritsu Company
450 Century Pkwy, Suite 109,
Allen, TX, 75013 U.S.A.
Toll Free: 1-800-267-4878
Phone: +1-972-644-1777
Fax: +1-972-671-1877

• Canada
Anritsu Electronics Ltd.
700 Silver Seven Road, Suite 120,
Kanata, Ontario K2V 1C3, Canada
Phone: +1-613-591-2003
Fax: +1-613-591-1006

• Brazil
Anritsu Electrônica Ltda.
Praça Amadeu Amaral, 27 - 1 Andar
01327-010 - Bela Vista - Sao Paulo - SP - Brazil
Phone: +55-11-3283-2511
Fax: +55-11-3288-6940

• Mexico
Anritsu Company, S.A. de C.V.
Av. Ejército Nacional No. 579 Piso 9, Col. Granada
11520 México, D.F., México
Phone: +52-55-1101-2370
Fax: +52-55-5254-3147

• United Kingdom
Anritsu EMEA Ltd.
200 Capability Green, Luton, Bedfordshire LU1 3LU, U.K.
Phone: +44-1582-433280
Fax: +44-1582-731303

• France
Anritsu S.A.
12 avenue du Québec, Batiment Iris 1-Silic 612,
91140 Villebon-sur-Yvette, France
Phone: +33-1-60-92-15-50
Fax: +33-1-64-46-10-65

• Germany
Anritsu GmbH
Nemetschek Haus, Konrad-Zuse-Platz 1
81829 München, Germany
Phone: +49-89-442308-0
Fax: +49-89-442308-55

• Italy
Anritsu S.r.l.
Via Elio Vittorini 129, 00144 Roma Italy
Phone: +39-06-509-9711
Fax: +39-06-502-2425

• Sweden
Anritsu AB
Kistagången 20B, 164 40 KISTA, Sweden
Phone: +46-8-534-707-00
Fax: +46-8-534-707-30

• Finland
Anritsu AB
Teknobulevardi 3-5, FI-01530 VANTAA, Finland
Phone: +358-20-741-8100
Fax: +358-20-741-8111

• Denmark
Anritsu A/S
Kay Fiskers Plads 9, 2300 Copenhagen S, Denmark
Phone: +45-7211-2200
Fax: +45-7211-2210

• Russia
Anritsu EMEA Ltd.
Representation Office in Russia
Tverskaya str. 16/2, bld. 1, 7th floor.
Moscow, 125009, Russia
Phone: +7-495-363-1694
Fax: +7-495-935-8962

• Spain
Anritsu EMEA Ltd.
Representation Office in Spain
Edificio Cuzco IV, Po. de la Castellana, 141, Pta. 5
28046, Madrid, Spain
Phone: +34-915-726-761
Fax: +34-915-726-621

• United Arab Emirates
Anritsu EMEA Ltd.
Dubai Liaison Office
P O Box 500413 - Dubai Internet City
Al Thuraya Building, Tower 1, Suite 701, 7th floor
Dubai, United Arab Emirates
Phone: +971-4-3670352
Fax: +971-4-3688460

• India
Anritsu India Pvt Ltd.
2nd & 3rd Floor, #837/1, Binnamangla 1st Stage,
Indiranagar, 100ft Road, Bangalore - 560038, India
Phone: +91-80-4058-1300
Fax: +91-80-4058-1301

• Singapore
Anritsu Pte. Ltd.
11 Chang Charn Road, #04-01, Shriro House
Singapore 159640
Phone: +65-6282-2400
Fax: +65-6282-2533

• P. R. China (Shanghai)
Anritsu (China) Co., Ltd.
27th Floor, Tower A,
New Caohejing International Business Center
No. 391 Gui Ping Road Shanghai, Xu Hui Di District,
Shanghai 200233, P.R. China
Phone: +86-21-6237-0898
Fax: +86-21-6237-0899

• P. R. China (Hong Kong)
Anritsu Company Ltd.
Unit 1006-7, 10/F., Greenfield Tower, Concordia Plaza,
No. 1 Science Museum Road, Tsim Sha Tsui East,
Kowloon, Hong Kong, P. R. China
Phone: +852-2301-4980
Fax: +852-2301-3545

• Japan
Anritsu Corporation
8-5, Tamura-cho, Atsugi-shi,
Kanagawa, 243-0016 Japan
Phone: +81-46-296-6509
Fax: +81-46-225-8359

• Korea
Anritsu Corporation, Ltd.
5FL, 235 Pangyoyeok-ro, Bundang-gu, Seongnam-si,
Gyeonggi-do, 13494 Korea
Phone: +82-31-696-7750
Fax: +82-31-696-7751

• Australia
Anritsu Pty Ltd.
Unit 20, 21-35 Ricketts Road,
Mount Waverley, Victoria 3149, Australia
Phone: +61-3-9558-8177
Fax: +61-3-9558-8255

• Taiwan
Anritsu Company Inc.
7F, No. 316, Sec. 1, Neihu Rd., Taipei 114, Taiwan
Phone: +886-2-8751-1816
Fax: +886-2-8751-1817

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