NewSpace terminal testing challenges and considerations

White paper

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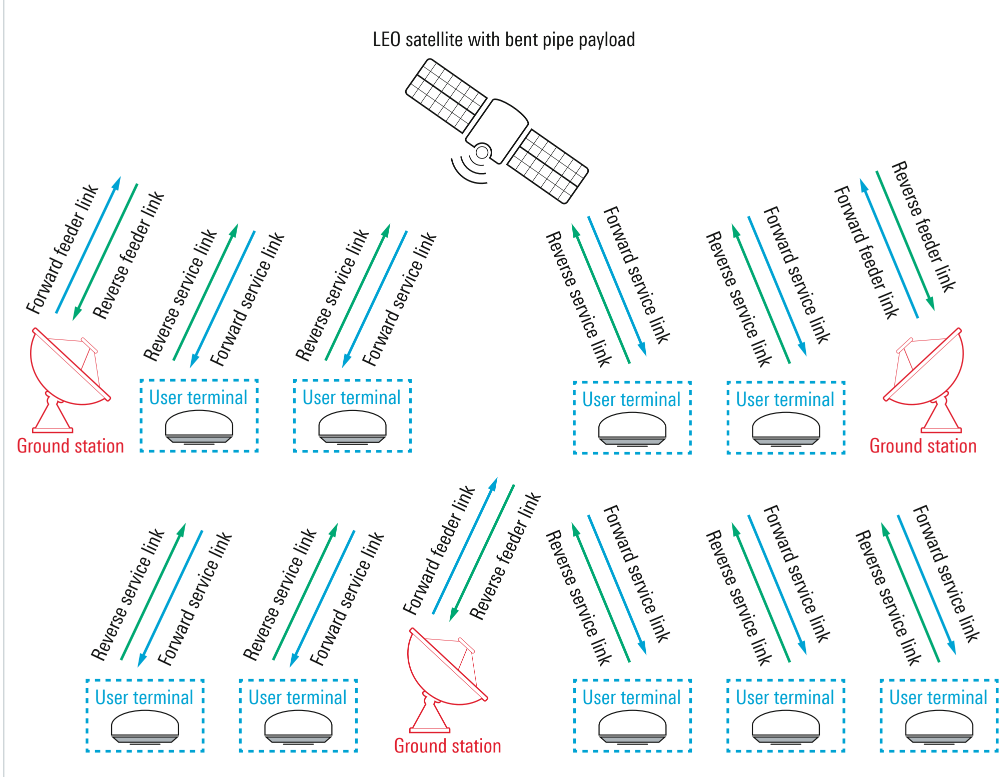
Table of contents

NewSpace user terminals introduce testing challenges

Today's satellite communication systems combine features from legacy cellular networks and emerging wireless technologies. New constellations are under development that attempt to provide ubiquitous mobility and internet networks via satellites, ground stations and user terminals (Figure 1). Each link in the supply chain presents unique challenges for R&D, production and deployment for both the components and system development.

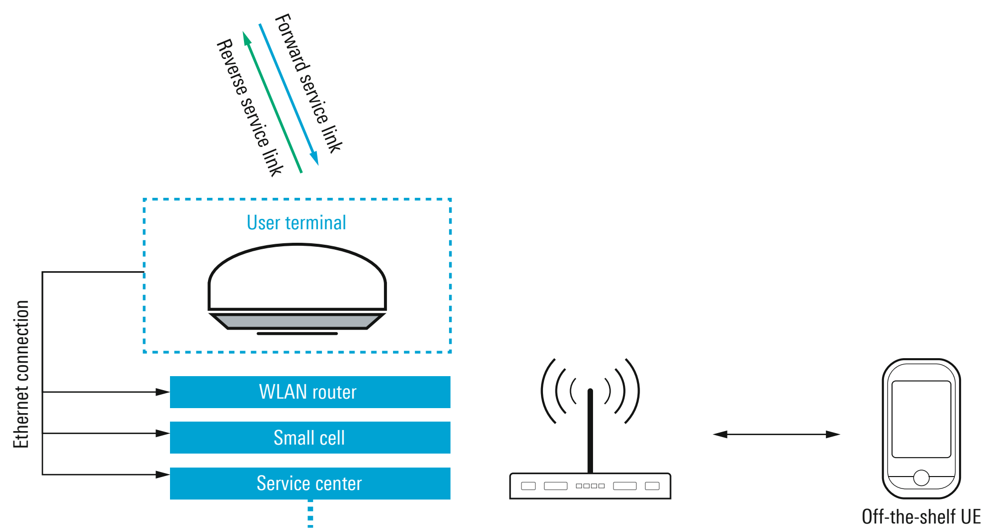
Figure 1: NewSpace constellations



NewSpace constellations promote ubiquitous mobility and internet connections via satellites, ground stations and user terminals.

LEO constellations introduce a challenging set of requirements for user terminal test engineers, when compared to legacy GEO VSAT terminals. For example, Iridium mobile phones deployed a compact circular polarization antenna that communicated directly with the satellite. NewSpace networks, on the other hand, deploy user terminals as agnostic interfaces between the satellite and the end-user communication device (Figure 2). These networks typically deploy fixed antenna user terminal designs which employ a parabolic or phased-array terminal solution that mounts to a fixed position or even on maritime or aero vehicles. These CPE-like devices then typically communicate via a commercial interface, such as Ethernet, to a commercial, off-the-shelf device, such as a server, base station or Wi-Fi router. The user terminal acts as a transparent relay to a preferred commercial user device.

Figure 2: NewSpace user terminals



NewSpace user terminals act as an agnostic communications interface between the satellite and wide variety of commercial user equipment (UE).

NewSpace networks and terminal vendors need to thoroughly test wireless communication systems and components to ensure uninterrupted operation and high quality of service. Additionally, manufacturers need to reduce test time in order to keep user terminal costs at a practical level. These challenges demand test and measurement solutions that provide high measurement performance and repeatability. Rohde & Schwarz offers innovative NewSpace measurement solutions to support successful design, integration and testing of user terminals, ground stations and satellite payloads.

This white paper focuses primarily on the challenges ground terminals (user terminals and gateway terminals) present to design verification testing and manufacturing. Conducted and radiated test solutions are also discussed.

Testing challenges

RF verification versus modem verification

LEO user terminals require significantly greater complexity compared with point-to-point GEO VSAT terminals. Historically VSAT terminal testing focused mainly on static RF performance, ensuring that frequencies and power level tolerances fall within defined limits. While fading exists in both systems, high-rate Doppler issues that invoke complex handovers are inherent in the LEO constellations and require greater sophistication in design, integration and test.

NewSpace applications require increased complexity in the radio resource management (RRM) system, which demands increasingly complex user terminals designs compared to legacy VSAT terminals. These solutions are more dynamic, with some constellation scenarios requiring several handovers per minute. This creates scheduling issues not typically experienced in legacy VSAT modems. Protocol stacks in LEO NewSpace systems require greater complexity. Consequently, user terminals resemble complex terrestrial mobile phones with perhaps even more stringent requirements on the radio resource management relating to handovers and scheduling.

This engineering challenge represents why VSAT engineers may be unfamiliar with the nuances of evaluating the RRM performance of LEO terminal modems in design verification and manufacturing (Table 1). Legacy terrestrial mobile measurement techniques can offer assistance in translating these test needs into LEO terminal test requirements.

Table 1: RF verification versus modem verification considerations

RF verification	Modem verification
▪ Non-signaling testing requirements ▪ Parametric tests ▪ EVM ▪ In-orbit testing ▪ Production Go/NoGo testing	▪ Handovers ▪ Power control ▪ Data end-to-end throughput characterization ▪ Antenna pattern characterization after deployment ▪ Radio resource management

Network emulation test systems

Modems running commercial firmware implement dynamic algorithms that respond in real time when terminals measure network power, provide measurement reporting and respond to system scheduling. This dynamic behavior prevents controlled RF parametric testing. Consequently, test engineers are unable to parametrically characterize modems and RF systems under these conditions. In an ideal world, a test engineer could set the modem state machine to any condition and execute measurements in that fixed condition.

Legacy terrestrial mobility engineering teams benefit from "callboxes", which are network emulator test systems that control a mobile phone state machine, and subsequently make RF parametric measurements on a mobile phone in a controlled state, such as fixed power or frequency. Callboxes require a significant development NRE, which is typically offset by the large scale commercial ecosystem of mobile networks, mobile phone manufacturers and mobile chipset vendors (LTE, WCDMA, etc.). This is not an option for NewSpace constellations that implement custom air interfaces which do not scale economically like large mobile networks. So, how can NewSpace engineers realize the same features of a callbox, given the cost constraints?

NewSpace engineers can utilize one the following network emulation implementations:

- Golden radio
- Software defined radio (SDR)

Golden radio

Golden radios are not new to test engineering. System and test engineering teams utilize golden radios frequently in all wireless applications. However, in order to accommodate complex NewSpace RRM and even basic RF performance requirements, early system design considerations are mandatory for down-the-line test benefits. For example, a commercial ground terminal communicating to a user terminal behaves in a dynamic fashion which is not conducive to static RF testing. In other words, commercial firmware and algorithm features typically prevent "interrupts" to the state machine flow, which is required for making accurate RF measurements. This prevents engineers from accurately identifying the conditions which cause measurement failures. In contrast, if a modified golden radio included software instructions which interrupt the terminal under test, causing it to "freeze" its power, frequency and other RF and modem conditions, then the test system can parametrically step through a variety of possible conditions which could identify a failure.

This leads to the concept of "early design consideration". Changing firmware and possibly hardware algorithms to behave in a non-commercial way, is a non-trivial engineering exercise to say the least. In fact, for most network modems, like gateway modems, for example, once the design reaches commercialization, the possibility of retroactively modifying the functionality becomes small, and the cost soars. In order to avoid this, system engineers should accommodate test algorithms in the golden device very early in the design process. Additionally, system engineering should account for user terminal considerations. Some examples could include loopback tests for receiver performance testing, single ended receiver measurement techniques and very fast test sweep modes that accommodate very fast and efficient testing.

Software defined radio (SDR)

Software defined radios provide an alternate approach to golden radio testing. Instead of modifying a golden radio, an SDR might better address the test solution, depending on the scenario. In an example case where different vendors contract for gateway terminals and user terminals, perhaps the cost of modifying the gateway terminal into a golden radio is cost or technically prohibitive. An SDR allows for a scaled down set of stack features that only need to accommodate the test requirements. In other words, the entire protocol stack, which would normally reside in a golden radio, is not required in this implementation. Only a minimum suite of protocol features need implementing, depending on the test requirements.

Cost probably influences more than any other factor in deciding which approach to use. If early system engineering accommodates the "early design considerations" for testing, then the golden radio approach will be most cost effective. However, if early system engineering is unable to accommodate early design considerations, then a more complex cost benefit analysis is required. Rohde & Schwarz can provide on-site support anywhere in the design phase and encourages NewSpace constellations to consider these requirements prior to actual design and integration. Experience shows millions or even tens of millions of dollars can be saved by implementing these early design considerations. Conversely, failure to adequately test and verify these complex modem and RF features, prior to commercialization, can lead to system delay or even data throughput reduction, which leads to crippling opportunity cost at even higher financial loss.

It should be noted that golden radio and SDR test systems both require complementary test equipment, such as vector signal analyzers, spectrum analyzers and signal generators, to fully characterize the RF performance of the terminal under test. They all work together to simulate a real network in order to stress the terminal in real world conditions.

The following is a practical example of a measurement requiring a network emulator test system. A user terminal registration procedure is a dynamic real time signaling process only applicable in a full network environment. Most two-way communication registration processes utilize something usually referred to as a random access channel (RACH) – like that observed in mobile phone RACH procedures. Basically, when the user terminal turns on or attempts to establish a new network connection, the terminal incrementally transmits short bursts of information, which at some point is captured and acknowledged by the network with an acknowledge message in the reverse direction. A static test system without any network response could only test a limited set of scenarios. However, a dynamic network emulator with test friendly software interrupts, coupled with test equipment, fully characterizes a network's ability to respond appropriately under a wide variety of parametric conditions, and allows greater flexibility for troubleshooting and failure reproduction.

Over-the-air (OTA) testing

Wireless enabled devices must pass a variety of industry certifications prior to commercialization. These certifications include regulatory and compliance testing such as EMC, conformance testing such as protocol, RF, RRM or LBS, as well as performance testing that is measured over-the-air (OTA). Generally, conformance testing is performed at the conducted port(s) of the device under test (DUT) and is based on pass/fail tests.

Traditionally the mobile phone industry uses conducted measurements, but for satellite user terminals with beamforming and tracking antennas, over the air RF measurements supplant conducted methods. The wireless industry is still debating how best to accomplish this for satellite user terminals and next generation 5G mobile phones. Traditional antenna test facilities can be used, but they are very expensive, usually exceeding one million dollars for each device commercialization. Many near field and quasi near field chamber concepts are under investigation. With no industry wide winning test method so far, Rohde & Schwarz is actively working with customers to define a proper OTA test philosophy. The OTA testing solutions section discusses this in more detail.

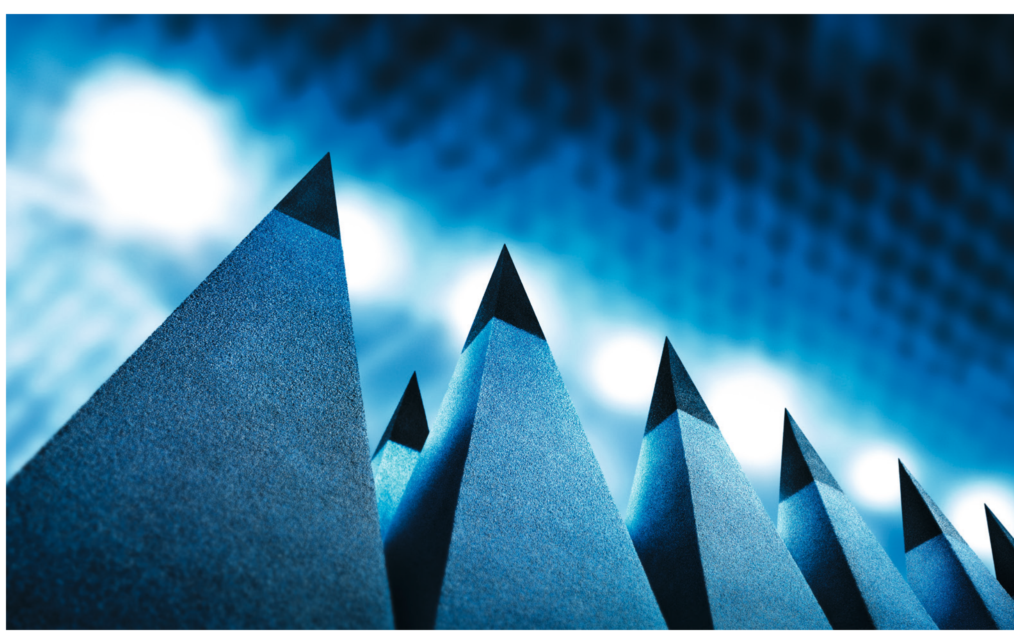


Figure 3: With complex antenna designs, like phased-array systems, over-the-air (OTA) test systems are increasingly important.

RF calibration and fast RF verification added to production

The added complexity of modem testing also impacts production testing. While initial manufacturing volumes might not exceed hundreds or even thousands of units, networks anticipate full production volumes with yields in the millions of units. Manufacturers require advanced strategies for reducing cost through efficient test methods.

RF calibration, or tuning and alignment for RF frontend modules, is common to both mobile phone and user terminal manufacturing. Terminals must compensate for non-linearities in power amplifiers during the manufacturing process. Basically, this requires frequency and power measurements, sometimes using CW signals, and other times using calibrated modulated wideband signals. Swept power and frequency measurement techniques, coupled with advanced measurement algorithms remove the non-linearities, sufficient to allow terminals to pass RF measurement specifications. High-volume, low-cost terminals require these compensations as lower cost components increase non-linearities compared to legacy, more expensive terminals, with higher performance power amplifiers.

In addition to RF calibration, all devices require basic RF and modem verification in manufacturing. Similar to calibration, fast test methods utilizing pre-programmed sweep methods significantly reduce overall test time by reducing legacy iterative and repetitive setup production processes, with the terminal under test and the test equipment.

Just as early design considerations are critical for network emulation test methods, production calibration and verification test also require early consideration. The most important step concerns the chipsets and modem in the terminal radio. By implementing fast test modes in the system engineering design, chipset and modem designers can engineer these features early with technical ease and minimal cost. Additionally, engineers can design limited layer 1 receiver measurements which could allow receiver testing in production without using an expensive and complex network emulator. In this case, a pre-determined waveform through a Rohde&Schwarz signal generator is sufficient. Waiting until just prior to manufacturing to consider these features is typically too late to take advantage of these cost saving features. Chipset and modem firmware may not allow modification after commercial firmware development. However, implementing these features early can reduce test times in manufacturing for both calibration and verification by several orders of magnitude. Rohde&Schwarz can provide a detailed on-site technical consultation regarding the requirements early in the design cycle.

Ground station considerations

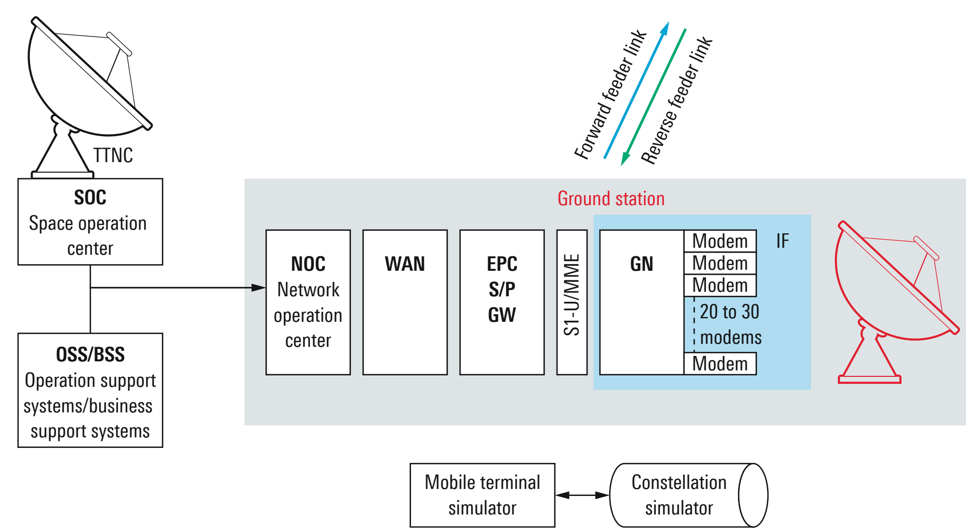
Different NewSpace design approaches impact ground station functionality. Networks based on digital regenerative payloads implement much of the radio resource management on board the satellite. For bent pipe systems, the radio resource management controls reside in the ground station, which direct the user terminals regarding IP scheduling and radio control.

From a testing perspective, the ground stations require similar testing to the user terminals. The need for RF calibration and modem verification are similar, although the cost and test methodologies could differ depending on cost and complexity. Fewer ground stations exist in a network, significantly reducing handover burdens. However, the larger data throughput and combining of multiple return link signals adds significant complexity to the bandwidth and data handling. With the lower volume and higher responsibility, ground station modems and RF systems require longer test times, typically.

Some of the key components in the ground stations require extra considerations during testing. Antenna size is obviously dramatically larger. Gateways and TT&C terminals may use 10-meter dishes or large phased arrays. Over-the-air (OTA) testing solutions most likely require large indoor or outdoor test ranges and chambers. Small OTA chambers are not relevant for large ground antenna testing. Ground station power amplifiers require additional high power and wide bandwidth, compared to user terminal power amplifiers.

Ideally, engineers thoroughly test the terminal radios prior to satellite launch. In addition to the single satellite network emulation tools already discussed, LEO constellations especially require constellation simulators. Constellation simulators marry multiple network terminals with fading and ephemeris emulation models so the terminal under test can prove its functionality in a real world environment. This scenario most closely resembles a functional, multi-satellite dynamic constellation. While the single network emulator generally proves individual terminal modem and RF functionality, the constellation simulator adds increased complexity to the test models that most closely resemble actual working network conditions. Static GEO systems did not require such complex systems for verification. However, complex RRM intensive systems, such as LEO NewSpace constellations, require a constellation simulator to reduce the tremendous risk of failure that is extremely difficult to troubleshoot with orbiting satellites.

Figure 4: Ground station terminals testing



While gateway terminals, TTCN terminals and user terminals require similar RF and modem verification, ground station terminals require more rigorous testing.

Testing solutions

The testing of NewSpace user terminals and ground stations require rigorous performance design verification and manufacturing testing compared to legacy terminals. Introducing Radio Resource Management test methodologies, common in the mobile phone industry, creates a more complex verification and conformance testing requirement.

For example, in LTE, the 3GPP standard 36.101 for mobile phones and 36.104 for ground stations, can provide templates for NewSpace performance requirements. Rohde & Schwarz already offer complete solutions for the 36.101 and 36.104 standards. Engineers familiar with these mobile industry standards will be able to quickly integrate best practices in developing next generation platforms.

This section discusses both conducted and radiated testing solutions. As components continue to integrate into smaller and cheaper packaging, the frequencies and test ports become a limiting factor. Traditionally manufacturers test terminals at the IF, RF and antenna stages. In some cases, especially in satellite ecosystems, no conducted contact points exist for testing at the IF or even RF stages.

Conducted testing

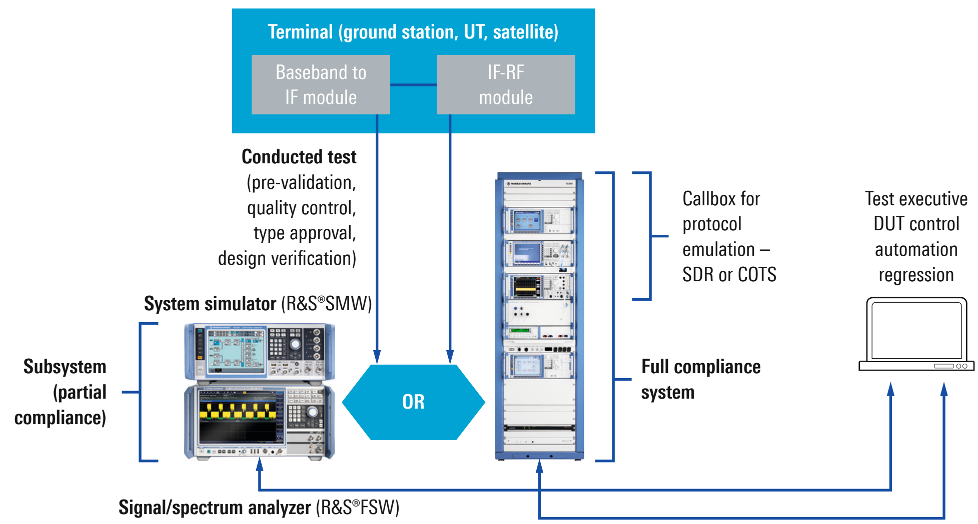
Today, most mobile phone type-approval systems utilize conducted test strategies. Depending on the component or subsystem, these conducted test connections exist at either the IF or RF link. Conducted testing allows for simple and effective troubleshooting and isolating any performance problems. It also more easily allows design engineers to characterize both the early stage pre-compliance performance, as well as final performance verification.

Depending on the specific test need, engineers verify terminals with either a scaled pre-compliance or full compliance test solution (Figure 5). A pre-compliance test solution offers a lower cost test system which provides a reduced degree of verification. It can perform a smaller number of tests at lower cost and is more suited for benchtop troubleshooting and pre-verification. The smaller system is also well suited for production test.

The full rack system on the right represents a full compliance or type approval system, capable of a more advanced set of measurements for evaluating the terminal performance. Full type approval systems typically require higher layer stack functionality, thus requiring the network emulators discussed previously.

Type approval or pre-compliance systems without complex network emulators are possible, providing at least a subset of the overall test requirement. However, in order to realize this, engineers must implement features described in the production test section regarding the layer 1 receiver test features and probably various power setting modes. Rohde & Schwarz can consult regarding features that make this possible. Again, these features require early design consideration very early in system engineering.

Figure 5: Conducted measurements



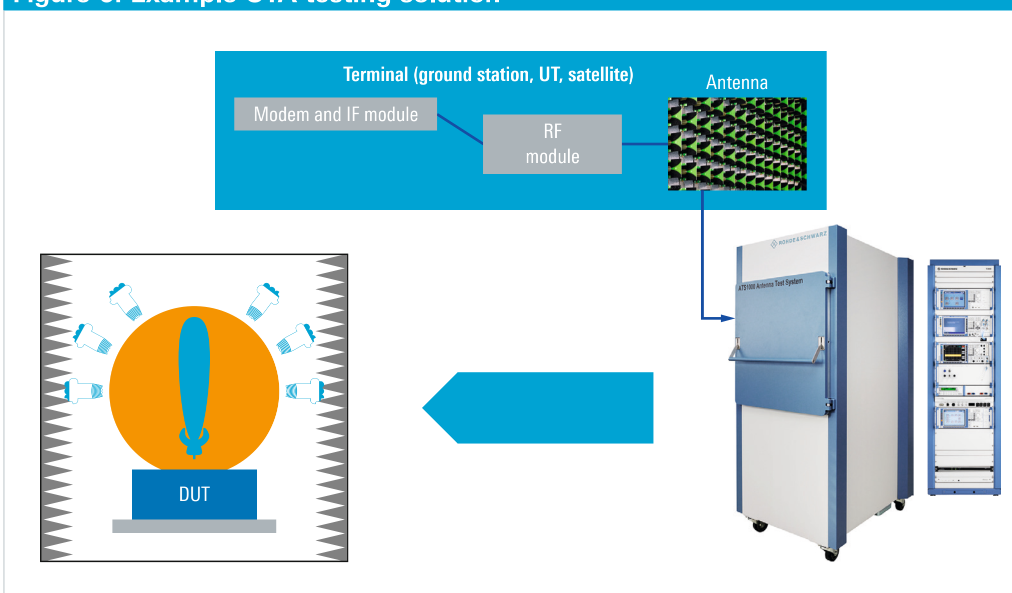
Conducted measurements are possible either the IF or RF stages for pre-validation, quality control, type approval and design verification.

OTA testing solutions

Rohde & Schwarz provides system solutions for the majority of wireless-enabled device certification tests. OTA test systems analyze and optimize the radiated device performance and provide a controlled physical environment to validate terminal radiated performance with industry, operator and internal company requirements. OTA systems verify the antenna patterns and the wireless system performance of the transmitter and receiver chain, such as TRP and TIS/TRS respectively. These measurements follow test plans and detailed test and setup procedures published by industry organizations such as CTIA and 3GPP. Rohde & Schwarz provides chamber and range solutions for all frequencies and device sizes and architectures.

Complex beamforming, phased array antennas or multi-element passive antennas, operating at high frequencies and wide signal bandwidths, introduce new complexities which the industry is currently trying to understand better. Advanced techniques such as near field to far field transformations are increasingly important for reducing cost. Rohde & Schwarz leads in the area of signal transformations for characterizing antenna patterns and performance. A Rohde & Schwarz applications team can provide on-site consultation regarding best practices for all antenna designs, and provides complete turnkey solutions for chambers and ranges, in addition to the test instrumentation.

Figure 6: Example OTA testing solution



Network emulation for physical layer

Absent a full ground station emulator (like a conventional callbox) or the network emulation methods discussed earlier, the R&S®SMW200A signal generator provides network emulation of the physical layer signal conditions (Figure 7). This enables layer 1 receiver testing via BER/PER/BLER measurements. The process of establishing receiver sensitivity testing in the absence of a closed link full protocol system requires the modem to be designed with test modes to operate in such a manner. This process is already common in commercial mobile LTE handsets for both integration and production. This allows for custom payloads to facilitate rapid signal/waveform development for many conditions.

Rohde & Schwarz implements custom air interface physical layer standards into both signal generators and analyzers. This accommodates more advanced open loop testing for single ended receiver performance. The generator also allows engineers to inject a custom MAC sequence in the waveform payload. This enables limited receiver synchronization verification in the absence of a full network emulator.

Rohde & Schwarz applications engineers can advise steps to implement custom air interfaces in the Rohde & Schwarz waveform generator tools.

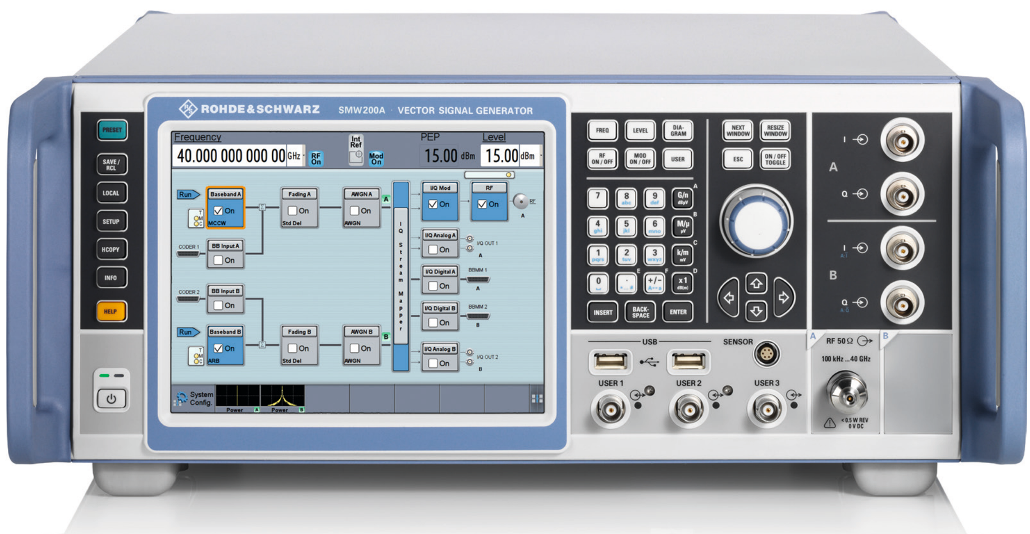


Figure 7: The R&S®SMW200A signal generator provides network emulation of the physical layer signal conditions.

Terminal transmitter analysis

The R&S®FSW provides signal and spectrum analysis capability for terminal transmitter testing. Many NewSpace air interface signals work with existing legacy measurement personalities, such as LTE and DVB-S2X. These are easily modified to include updated air interface changes. The R&S®FSW locks to specific air interface signals to allow for more exact filter and frequency measurements, which allows for tighter EVM, ACLR and other modulation quality measurements.

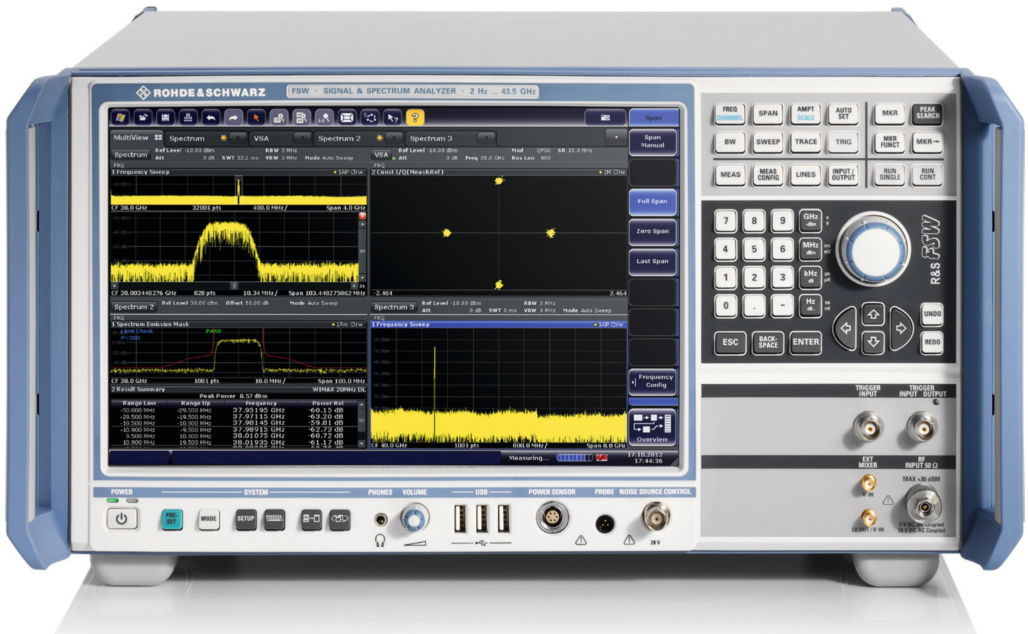


Figure 8. The R&S®FSW enables dedicated transmitter physical layer analysis.

Summary

NewSpace constellations introduce new challenges for test engineers when compared to legacy VSAT terminals. Satellite engineers need to thoroughly test RF sub-systems and components to ensure uninterrupted operation with a high quality of service. On the other hand, engineers need to reduce test time and cost while the total number of beams and links is increasing. These challenges require test solutions that provide high measurement performance and repeatability. Rohde & Schwarz offers innovative NewSpace measurement solutions to help users successfully design, develop and test user terminals, ground stations and satellite payloads.

Rohde&Schwarz

The Rohde&Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, monitoring and network testing. Founded more than 80 years ago, the independent company which is headquartered in Munich, Germany, has an extensive sales and service network with locations in more than 70 countries.

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