A test guide for small-satellite constellations and NewSpace applications

Rajan Bedi - January 28, 2019

As launch costs continue to fall, almost 17,000 small satellites will be built over the next decade to deliver the next generation of space-based applications.

NewSpace companies around the world are planning large constellations to provide global, low-latency internet coverage, Earth-observation analytics, and satellite-based IoT for asset management. Manufacturers of military spacecraft are developing LEO cube, mini and micro-satellites to deliver more affordable defence-related services. Universities and research institutes now routinely offer students the ability to design and launch small satellites. In addition to aspiring commercial operators, developing countries are seeking low-cost access to space for national capacity building, the desire to become self-sufficient for data collection, and to address local societal needs such as environmental monitoring, climate change, disaster management, deforestation, geospatial imaging to locate sub-surface natural resources such as oil and gas, understanding agriculture yields for food sustainability, plant physiology, crop science, plant speciation, and geological formations.

The key challenge for manufacturers of small satellites is to design, test, and deliver low-cost spacecraft to meet operators' price-points, aggressive time-to-market schedules, and/or the demands of investors for quick financial return. Consequently, OEMs typically baseline less expensive, short lead-time COTS components and to allow them to remain competitive, they are looking for an affordable test solution to confirm functionality efficiently.

When developing small-satellite electronics, testing occurs throughout all stages of spacecraft development: from characterising the performance of COTS analogue parts, digital logic, RF circuits, and antennas during the initial system architecture, to verifying the functionality of hardware demonstrators and validating proof-of-concepts at the prototyping (EM) phase. This is followed by measuring the performance of complete payload sub-systems and then entire spacecraft validation in a representative environment using thermal-vacuum chambers during the qualification (EQM) stage. Prior to lift-off, final integration checks are typically performed at the launch site and throughout operation, regular in-orbit checks of the transmission links are made to monitor and confirm quality of service (QoS).

Small-satellite OEMs are motivated by cost and are looking for an affordable test solution which will allow them to verify performance efficiently. Depending on the level of reliability required, the cost to test, as well as mission duration, manufacturers may skip some of the measurement stages listed above. Many aspiring NewSpace companies simply cannot afford traditional, dedicated racks full of expensive, sophisticated instruments.

As the speed and performance of payloads continue to improve, OEMs are increasingly concerned at
being able to correctly verify performance and dynamic range without being polluted by phase noise, spurs, or interference generated within the test and measurement equipment. Small-satellite manufacturers need to meet operators' price-points and time-to-market schedules, and want to be able to automatically replay and re-use the manual tests developed during the EM phase throughout qualification and production. A single channel of an analogue and digital transponder are illustrated below.

**Figure 1** Analogue, bent-pipe transponder

**Figure 2** Digital satellite transponder

Based on mission and functional needs, small satellites require low-cost, light-weight, mechanically and thermally-robust antennae for tracking, telemetry, command, and payload links. A key concern for spacecraft manufacturers is how to reliably characterise their emission and susceptibility performance as most OEMs do not have dedicated antenna testing facilities. To address this need, Rohde & Schwarz offers a mobile anechoic chamber, the **ATS1000**, allowing near and far-field testing from 18 to 87 GHz with > 50 dB of shielding across this frequency range. Its compact form allows it to be used throughout all stages of spacecraft development from initial EM verification to production. The accompanying **ATSCAL** software enables over-the-air calibration and measurement of total-radiated power (TRP), equivalent isotropic radiated power (EIRP), total isotropic sensitivity (TIS), effective isotropic sensitivity (EIS), error vector magnitude (EVM), as well as real-time visualisation of horizontal and vertical polarization.
For bent-pipe transponders, a key challenge for OEMs is to find an economical test solution to characterise individual analogue parts and the complete payload during the EM project phase. Traditionally, many separate instruments are needed to characterise different components, which increases cost and bench space.

I previously described how to test RF-frequency converters and mixers and in this post, I wish to focus on affordable and efficient measurements using representative carriers. To characterise analogue components and bent-pipe payloads, Rohde & Schwarz’s ZVL combines a two-port, bi-directional VNA with spectrum analyser and power-meter options in a single, compact instrument. The VNA has a specified frequency response from 9 kHz to 13.6 GHz, a dynamic range of 123 dB (typical) and an output power ranging from −60 to +10 dBm (typical).

Modern satellite transponders often have to receive and process weak carriers and a key issue for OEMs is how to accurately measure low-amplitude signals. The ZVL’s spectrum analyser has a displayed average noise level (DANL) of < −140 dBm and < −156 dBm with a pre-amplifier at 1 GHz. DANL refers to the level of the instrument noise floor given a particular bandwidth and represents the best-case sensitivity of an analyser when measuring small signals. Any input below
this level cannot be detected. To allow real-time analyses of frequency and level, a spectrogram option can be added to monitor QoS.

To allow nano, mini, and micro-satellites to deliver the required performance to operators as part of a physically smaller payload, the noise generated by individual components as well as the complete transponder must be minimised. An option can be added to the ZVL to enable noise-figure and gain measurements to characterise the amplifiers, the mixer, and the entire payload. Harmonics, intermodulation distortion, and adjacent channel power ratio (ACPR) at the receiver and transmitter can also be tested.

Once the functionality of the bent-pipe transponder has been verified, small-satellite manufacturers require characterising their performance using representative signals. An analogue demodulation option can be added to the ZVL allowing analyses of AM, FM, and PM carriers. This also allows for the in-orbit verification of transmission links.

To assist with spacecraft testing at the launch site, distance-to-fault (DTF) and time-domain analyses options can be added to the ZVL to detect faulty cables and connectors. The instrument displays discontinuities, reflection factors, and impedance versus delay and length.

For digital transponders, a key concern for OEMs is to find an economical approach to characterise individual parts as well as the complete payload during the EM project phase. Rohde & Schwarz's ZNL combines a two-port, bi-directional VNA with spectrum analyser, demodulation and power-meter options to provide a single, compact test solution. The VNA has a specified frequency range from 5 kHz to 6 GHz, a dynamic range >130 dB (typical) and an output power ranging from −40 to +3 dBm (typical).

Digitally-modulated, single carriers can be directly demodulated with up to 40 MHz of analysis bandwidth. The ZNL receives and digitises the signal which is then analysed using the Vector Signal Explorer software, which can be installed on the VNA or an external PC. Real-time spectrogram, DTF, and time-domain analyses options can also be added to the instrument.

For digital demodulation, Vector Signal Explorer software can be installed on a PC for full signal-analysis capability including the measurement of bit-error rate (BER) and EVM.
The ZVL and ZNL are portable instruments weighing less than 7 kg that can also be powered using a 12 VDC supply or internal battery. This all-in-one test solution can easily be used throughout all stages of spacecraft development from the initial validation of prototyping hardware in the lab, to qualification and production testing, checks at the launch site, followed by in-orbit verification of satellite transmission links. To assist with practical measurements, both are extremely compact requiring minimal work bench space compared to having dedicated instruments as illustrated below.

Once the performance of the payload hardware has been successfully verified and qualified, testing of the flight-grade (FM) production electronics can be automated to allow OEMs to meet time-to-market needs, while at the same time, providing a fast and repeatable test solution. All functions provided by the ZVL and ZNL can be controlled remotely using GPIB and LAN interfaces supporting scripting languages such as Matlab, Python, and CVI.

After launch, both the ZVL and ZNL can be used for ground station, terminal, and in-orbit verification to measure the quality of downlink carriers from satellites, the received uplink or the regenerated signal inside the transponder by comparing with known references.

For in-orbit verification of satellite links and ground stations, the key challenges are to ensure that carriers arrive with sufficient power to maintain QoS and that frequency components experience the same delay to preserve their relative phases. The conventional approach to measuring long-distance group delay and phase linearity uses RF cables whose lengths result in losses degrading SNR as well as introducing phase errors.
A concern for operators is unintentional or deliberate interference which degrades the QoS of a satellite link or in the worst case, puts it out of operation. Ground stations can direct an uplink to the wrong satellite, saturating a transponder.

LEO satellites are particularly fast moving which can introduce Doppler shifts in the range of hundreds of kilohertz relative to the ground station tracking them. The cost to perform tests is also a major concern, i.e. the time a channel is out-of-service for post-launch maintenance rather than generating revenue.

![In-orbit satellite link verification and OneWeb illustration](image)

*Figure 8* In-orbit satellite link verification and OneWeb illustration

Until next month, the first person to tell me how a time-domain DTF test can detect an open circuit in a faulty cable will win a [Courses for Rocket Scientists](https://www.coursesforrocketscientists.com) World Tour t-shirt. Congratulations to Jean from France, the first to answer the riddle from my previous post.

**Rajan Bedi** is the CEO and founder of [Spacechips](https://spacechips.com), which provides on-board processing products, design consultancy in space electronics, training, technical-marketing, and business-intelligence services. Spacechips is currently helping satellite OEMs and operators architect test solutions.
Spacechips will be teaching three-day courses on space electronics in San Jose, CA this January, Beijing, China in February, Bremen, Germany this March, Los Angeles, CA in April, Colorado Springs, CO this May, and Harwell, UK in June. Email us for further information. We will also be offering a course on satellite payload testing in 2019!

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