Advanced Testing Solutions for Small Satellite Applications

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Small Satellites Offer New Opportunities

Putting satellites into space has always been an extreme engineering challenge. This has historically made it the preserve of national governments and large organisations. Traditional satellite manufacturers with the scale and resources to meet these challenges still dominate the market but there is a new breed of satellite systems opening up new possibilities for non-mission critical applications. These possibilities are open to all and can include augmenting larger commercial applications, facilitating educational activities and enabling low-cost research projects.

A number of developments are transforming the economics of small satellite production and launch, reducing the cost of access to space and making satellite use feasible for a wide range of new applications. For example, CubeSats, which were initially conceived in 1999, have moved out of the university research domain and into the commercial arena. The reference CubeSat design, based on a 10cm cube, has been facilitated by the ongoing miniaturization of the on-board electronics. The CubeSat's low mass, (less than 1.33Kg), significantly reduces launch costs and enables them to share a launch vehicle with larger satellites.

The CubeSat falls under the Nanosatellite classification (1kg to 10kg); a subset of the Small satellite classification which covers any satellite with a mass of less than 500 Kg. This includes seven mass classifications ranging from Minisatellites (100kg to 500kg) to Zeptosatellites (0.1g to 1g). According to the online database of nano satellites, nanosats.eu, more than 1800 CubeSats and nanosats have been launched since the technology was first deployed, as shown in Figure 1.

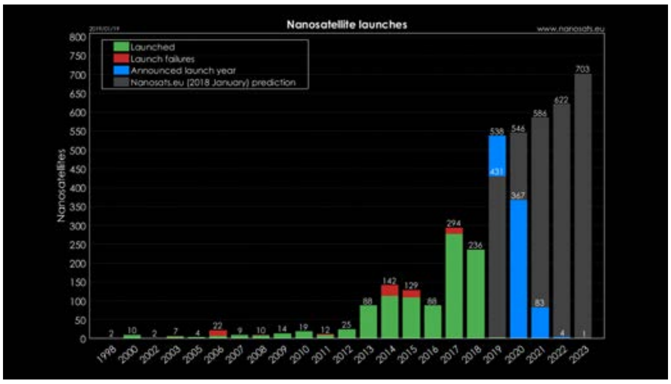

Figure 1: Launched, planned and predicted nanosatellites as of January 2019

Although beginning to be deployed in deep-space exploration, mainly as adjuncts to traditional, large satellites, small satellites are typically used in low-earth orbit (LEO) for applications such as scientific experiments, remote sensing applications and tele-communications. The explosive growth of the IoT is perhaps the single biggest driver of the trend towards small satellite use, with the world's hunger for connectivity and bandwidth attracting investors' cash into the space industry. Two organisations in particular are driving this transformation, with SpaceX driving down launch costs, developing re-usable rockets, Figure 2, and OneWeb changing the economics of satellite production and deployment. SpaceX's aggressive market positioning has seen it emerge as an industry front-runner, disrupting a formerly mature market and generating fierce competition with existing players such as Europe's Arianespace and US launch services provider, United Launch Alliance.

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Small Satellites Offer New Opportunities

The growing popularity of small satellites, particularly nanosat (wet mass between 1 and 10 kg) and picosat (wet mass between 0.1 and 1 kg), is opening multiple opportunities for developers to quickly and cheaply implement satellite projects for a variety of applications, such as remote sensing and measurement and scientific experiments.

The characteristics of small satellite missions enable the relaxation of many of the design and testing principles of traditional satellites, but pre-launch and integration testing is still essential, particularly for the satellite transmission functionality. Testing at satellite frequencies is however complex and requires expensive equipment and, for many developers, it does not make sense to purchase such equipment, given the infrequency of its use when balanced against the purchase price and impact on the overall project budget.

Flexible sourcing options such as those offered by Electro Rent, a global market leader in electronic test equipment, offer cost-effective ways of acquiring leading edge test and measurement equipment without the need for capital investment.

This paper examines the changing dynamics of the satellite market and the implications and opportunities for developers of small satellite applications.

SpaceX's Falcon 9 re-usable rocket

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Designing for Harsh Environments

Space is an extremely harsh environment which poses multiple threats to satellite components. During launch, forces generated from acceleration, plus shocks and vibrations experienced when rocket stages separate, can dislodge components and connectors. Once in orbit the satellite will experience extreme high and low temperatures, must operate in an ultra-low vacuum and will be exposed to electromagnetic interference and energetic radiation. To mitigate risk in these conditions traditional satellite design employs techniques such as use of hardened, mil-spec components, in-built redundancy and extensive and thorough testing processes.

Many of these techniques however are not practical for small satellite projects, due to physical space and power-budget constraints. Also, the low-cost and short implementation cycles demanded by many small satellite applications do not accommodate the same levels of extensive testing.

Table 1 shows how satellite missions can be characterised by risk tolerance and this analysis highlights a number of factors which influence the design specifications for small satellites, including:

- Most small satellite missions are in low earth orbit where the environment is not as harsh as deep space
- Most missions also have short lifetimes, often measured in days or weeks, reducing the cumulative effect of exposure to the conditions in space
- Many small satellite applications employ constellations of multiple satellites where failure of one or more individual satellites does not compromise the overall success of the mission
- Relatively low launch and satellite production costs make it more feasible to replace a failed satellite

Risk Tolerance		Very Low	Low	High	Very High
Mission Characteristics	Mission Criticality	National Security	Operational Primary Science	Experimental Technical Demos	Tech Demos Teaching Systems
	Mission Life - LEO	5+ years	3 – 5 years	Months	Days- weeks
	Mission Life – Deep Space	10+ years	5+ years	Months	Days
	Single satellite	Operational Mission	Data gathering	Experiment	Tech demo
	Constellation (>10) Satellites	Common mode failures ruled out	High unit cost	Multiple spare vehicles	Re-launch readily available
	Flight development time	>5 years	High unit cost	Multiple spare vehicles	<12 months

Table 1: Satellite Mission Risk Profile Analysis

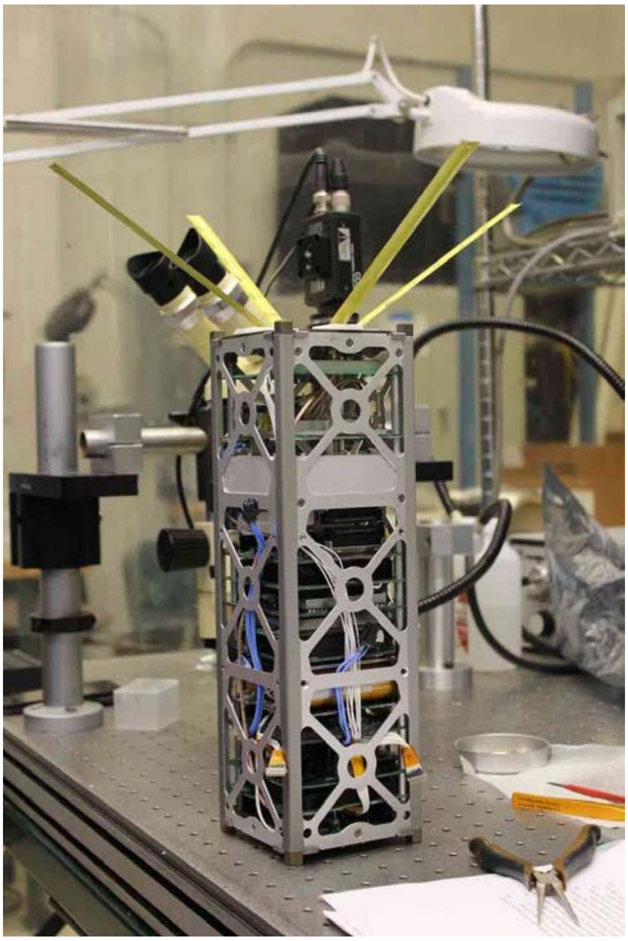
Designing for Harsh Environments

These factors make it possible to relax the design specifications for small satellite missions, enabling the use of non-space, commercial off-the-shelf (COTS) components. This is one of the major reasons why small satellite designs can be implemented quickly and cost-effectively and has enabled the development of many standardized functional modules such as power systems, communication systems, etc.

The original instantiation of the nanosat class is the CubeSat, an open source architecture based on the 1U size, (10cm × 10cm × 10cm) cube but available in sizes ranging from 1U to 3U (Figure 3). Permissible materials for a CubeSat structure are aluminium alloys: 7075, 6061, 5005 and 5052, which must be anodized to prevent cold welding. CubeSat components can be classified into six major subsystems: structure, communication, power, attitude determination and control, command and data handling, and the payload.

CubeSat itself is a specification as opposed to a piece of off-the-shelf hardware so the small satellite developer has the option of either building everything themselves, following the open-source CubeSat specification or purchasing a pre-built kit from organisations such as Pumpkin or Interorbital Systems, (IOS). A pre-built kit provides all of the core components of the CubeSat, including, an antenna, a radio transceiver for up-linking commands or downloading data, a computer-on-a-chip such as an Arduino or a Basic-X24, a power system, usually solar cells, along with a battery and a power bus, plus a variety of sensors. The kits will also allow for the inclusion of the developer's application or experiment and are designed to offer a platform for in-orbit experiments.

IOS also offers the TubeSat PicoSat Kit (Figure 4), an alternative to the CubeSat with 75% of the mass but similar volume as a CubeSat. A 1U CubeSat kit from Pumpkin Inc starts at $7,500, whilst the TubeSat kit price for academic applications is $8,000, which includes launch costs, offered by IOS.



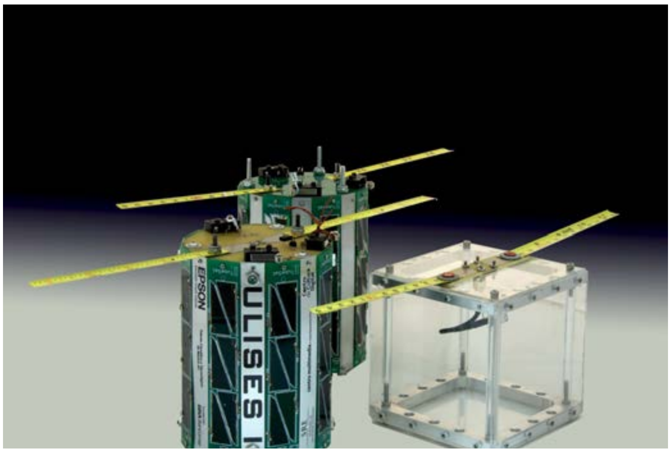
Testing for Space

Although small satellites are inexpensive when compared to traditional satellite systems, appropriate testing is still vital to ensure that the pre-launch development effort and investment is not wasted and that the satellite performs the tasks for which it was designed. By buying a kit such as those discussed above, developers are gaining access to a satellite system whose core functions have been pre-tested, enabling design, development and test effort to focus on the functionality of the application itself, as well as integration testing of the final, assembled satellite. Key elements of the satellite to be tested include:

- Solar panels
- Antennas
- Batteries
- Electrical checks
- Centre of gravity and mass measurements
- Fuel cells
- Data transmission systems

With forecasts predicting the launch of large numbers of LEO satellites, there will be a significant increase in the numbers of satellite uplink and downlink stations, driving the need for advanced transmission techniques, involving ever higher frequencies and complex modulation and spread-spectrum techniques. Satellite transmission systems must be capable of achieving high data throughputs at millimetre wave frequencies, with high signal fidelity and the ability to reject RF interference from other satellite systems.

Small-satellite developers must balance the imperative to thoroughly test the satellite's RF communication systems against the need to carefully manage test time and costs. A wide range of high performance test and measurement equipment, including analogue and vector signal generators, spectrum analysers, oscilloscopes, network analysers and more is available on today's market to support the testing of the entire RF channel, from ground station to ground station, as well as inter-module communication within the satellite itself. The next section examines the benefits offered by the comprehensive Electro Rent portfolio of test equipment and solutions.



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Test Equipment Solutions

A number of integration and operational tests are required to fully characterise and validate the performance of satellite RF systems, as summarised in table below.

Test	Description	Instrumentation
Amplifier Linearity and gain transfer	Satellite transponders or components such as power amplifiers and frequency converters are characterised by measurements such as gain compression, AM/AM, AM/PM and distortion NPR/ACLR	Signal Generator with Signal Analyser
Group Delay	The quality of a transmission path in satellite communications, is characterised by phase distortions, determined using group delay measurements	Signal Generator with Signal Analyser
Noise Power Ratio	An important standard RF payload test. NPR testing involves the simulation of a Gaussian noise-like distribution of a multi-channel communications payload and NPR measurements are taken to test the linearity of the transponder	Signal Generator with Signal/spectrum analyser
Signal Quality	The quality of satellite links during integration as well as in-orbit operation are verified using Modulation accuracy and bit error rate (BER) measurements	Signal Generator with Signal/spectrum analyser
Spurious Emissions	Searching for spurious emissions with spectrum analysers is an essential measurement when designing, verifying and manufacturing RF and microwave devices	Spectrum analyser
Digital Interface Testing	The data communications between different systems and components within a satellite is crucial for a mission and must be ensured under all conditions	Oscilloscope
Power Supply testing	Provision of sufficient power to the electrical subsystem, minimising power drain from the batteries, ensuring battery efficient charging	Specialised Power Supplies

Table 2: Small Satellite Test Requirements

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Test Equipment Solutions

Keysight DSAV204A Infiniium S-Series Oscilloscopes

Whether you have to debug your latest design or verify compliance, it is critical that your oscilloscope displays a true representation of your signal. This requires world-class signal integrity. Infiniium S-Series oscilloscopes were designed with this in mind. The S-Series provides superior time base, front-end, and ADC technology blocks. This gives you a platform with up to 16 bits of resolution, low noise, low jitter, and high ENOB — giving you visibility into the true performance of your device.

Rohde & Schwarz FSW

The R&S FSW offers a suite of dedicated measurement applications for the most important measurements, including noise power ration and group delay. It is also capable of demodulating the satellite RF signals of multiple standards, such as DVB-S2X and OneWeb. As the unit is scalable, with a wide analysis bandwidth of up to 2GHz internally, it can meet the new demands for wider signal bandwidths

Keysight N9020B Signal Analyser

The N9020B MXA is a flexible signal analyser with a frequency range of 10 Hz up to 50 GHz and up to 160 MHz analysis bandwidth. It offers hardware-accelerated power measurements, rapid display updates, marker peak searches, fast sweeps and helps capture elusive or transient signals with full-band real-time spectrum analysis. This allows you quickly adapt to the evolving test requirements of wireless devices and shortens test times allowing for faster development cycles.

Anritsu MS2090A

This portable Spectrum Analyser delivers the highest levels of RF performance available in a handheld, with excellent displayed average noise level (DANL) of -164dBm, as well as 100MHz Analysis bandwidth. This allows for in-depth interference hunting, allowing you to accurately search out rogue signals and aid in the clearance of spectrum ahead of new deployments.

Test Equipment Solutions

Keysight N5225B Network Analyser

In R&D, the Keysight PNA family provides a high level of measurement integrity, allowing you to translate a deeper understanding into better designs. As satellite production increases, the drive to lower the cost and increase the reliability of components becomes paramount, using the more accurate tools in the design process lowers costs later in the production cycle.

Rohde & Schwarz SMBV100B Signal Generator

The state of the art SMBV100B from Rohde & Schwarz sets new performance standards in its class. It can be equipped with a multitude of GNSS options, turning the instrument into a reliable, highly featured GNSS simulator. This allows its users to simulate realistic, complex GNSS scenarios, which are easily repeatable and can be run under controlled conditions.

Spirent Testcentre Security Testing Software

As the threats from cyberattacks grow more dangerous with today's connected infrastructure, properly stress testing networks and ensuring data security is more important than ever. The Spirent Testcentre and Avalanche software packages allow execution of extensive testing for secure network communication, vulnerability assessment, attack generation, and user authentication including: IPSec, HTTPS/TLS (including TLSv1.3), 802.1x, Network Access Control (NAC), RADIUS and custom user imported traffic over TLS.

Keysight E4360A Power Supplies

These modular power supplies are designed to accurately simulate the I-V curve of the solar panel arrays used on Satellites under various environmental conditions, including eclipse, spin, rotation, age and temperature. These devices are small and high power, making them ideal for the limited space in today's modern satellite labs.

Summary

Test and measurement instruments capable of operating at the frequencies employed by satellite communications systems and with the required sensitivities are complex systems and represent a significant investment for the small-satellite developer.

With a constantly refreshed inventory, Electro Rent has over $1 billion invested in its test equipment portfolio, which is managed by a team of 350 specialists in over 150 countries. This exceptional level of support is backed by range of flexible sourcing options.

Electro Rent's rental solutions offer flexibility without the high costs of ownership and equipment maintenance. Rental gives next-day access to a range of equipment from top manufacturers including Anritsu, EXFO, Fluke, Keysight Technologies, Rohde & Schwarz, Tektronix, Viavi and over 300 more. Equipment is available to rent from periods as short as one week, or for as long as it is needed. This flexibility is designed to reduce the inherent risk associated with projects, such as delays in the design phase or unforeseeable problems in the field. With lifetime support for its entire portfolio, manufacturers and designers have access to equipment long after it may have stopped being supplied to the main market.

For scenarios where purchase of a piece of equipment is essential a variety of lease and rent-to-buy options can spread the acquisition costs over time and avoid the need for large capital expenditures.

Developments in the space industry including reduced launch costs and the availability of nano and pico-satellites using COTS components are making space more affordable for a wide spectrum of applications, including scientific experiments, remote monitoring and sensing, telecommunications and many more. This will augment rather than replace the role of traditional larger satellite systems, making space more accessible to existing manufacturers while opening it up to new entrants for whom the cost, complexity and development time would otherwise preclude access.

Pre-fabricated kits such as Pumpkin's CubeSat range and the IOS TubeSat simplify the implementation of small satellites, enabling the developer to focus on the specifics of the application and shortening the development timescales and costs. The integrated small satellite still requires extensive testing before launch however and satellite testing requires advanced and expensive test equipment. Where the cost of buying essential test equipment is prohibitive in relation to the cost and duration of the project, especially for short or rapidly evolving projects, equipment rental is an ideal solution.

Electro Rent's extensive portfolio of industry-leading solutions, the ability to offer independent expert advice, and a range of flexible sourcing options enable the small satellite developer to minimise capital expenditure whilst reducing risk.

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