Space Diversification Requires Space-grade & New Space RF Component Strategies

Abstract

The space near Earth, and even deep space, is no longer the domain of large and sophisticated Satellites, Space Stations, and Exploration Vessels owned by governments, militaries, and the rare commercial-satellite concern. Over the past several years, there's been a growing interest and investment in satellite and space systems that offer services to consumer and commercial business that are driven by fast-paced and budget-minded practices. These New Space organizations are developing businesses aimed at commercializing space, from communications satellites all the way to civilian-space travel. This new approach to space also requires a different approach to space technology, specifically radio frequency (RF) components and devices, which are already constrained by the unforgiving environment beyond Earth's atmosphere. Using mass-production methods that tip the economy-of-scale in their favor, these New Space companies are providing a growing opportunity for traditional high-reliability space technology for mission-critical applications, along with a new breed of cost-effective and compact components and devices for space.

Introduction

In previous years, space has been dominated by a few countries' government/military and a handful of multinational commercial efforts. Now, lower cost launch vehicle prices have given rise to a growing trend of additional countries, businesses, and even research institutes investing and developing space systems [1]. An enabling factor of this trend is a departure from the medium-to-large satellite approach and a focus on small satellites (Smallsats) and micro-satellite constellations, or mega-satellite constellations. These smaller satellites and payloads benefit from mass produced technologies and common platforms, saving both component and device costs, as well as engineering, development, and testing expenses.

However, with many of these systems, especially launch vehicles and mission-critical payloads, the high-reliability and performance capabilities of RF components, devices, and assemblies that are developed for traditional space applications still are necessary. Withstanding the harsh environment of space while providing next-generation bandwidth, noise figure, amplification, and multi-function capabilities still requires high performance RF and microwave design and hardware. This is why a blend of tactics is required to meet New Space technology objectives alongside the still large and growing traditional military/industrial space sector. This article aims to educate readers on the requirements of both traditional space and New Space applications for RF technology.

Furthermore, this article discusses RF components, devices, and assemblies used in space applications and the qualifications and certifications used with space-grade technologies.

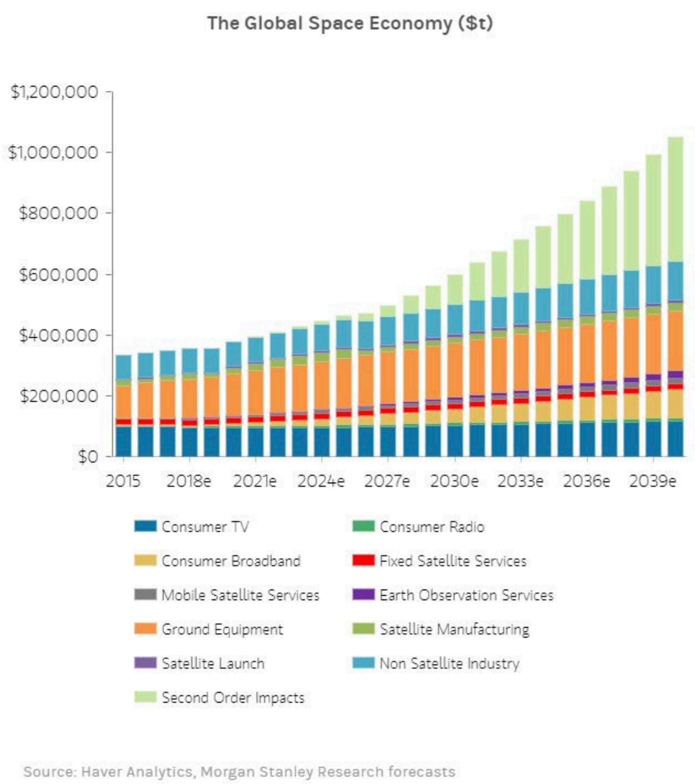


Figure 1 - The Global Space Economy

Terrestrial Versus Space Environments

Terrestrial environments are harsh. They contain high amounts of solar radiation, high winds, rain, corrosive chemicals, and erosive agents but these factors tend to pale in comparison to the environmental threats faced in deep space and the space around Earth. The main factors of concern for space and spaceflight systems include various forms of radiation, impacts from space debris and space objects, as well as a diverse range of gravitation and other phenomena associated with the hard vacuum of space. Space-grade components and systems need not only to survive in this environment meet performance expectations while facing a myriad of interference and noise generators.

There are many sources and types of space radiation that can be destructive, such as high-energy cosmic rays that directly penetrate and damage electronics and insulation materials, as well as high energy particles that can induce charge to build up on a metallic surface that leads to anomalous static discharges. Energetic particles, such as high-energy protons/electronics, and even heavy ions, can be emitted by solar events, while cosmic radiation can lead to interference and even damage of space electronics. There also are regions near Earth's orbit, such as the Van Allen Radiation Belts, that can directly damage or interfere with the performance of space systems passing through these areas.

Vacuum itself is a danger to space technology for various reasons. The absence of air pressure (and a dielectric atmosphere) can lead to some materials emitting gases (out-gassing) that can stay suspended or settle on other materials, causing reactions or obstructions of optical components. Other destructive material interactions and behavior also occur in a space environment, such as cold welding, multipaction, and other material degradation phenomena.

Moreover, in vacuum, the only form of heat dissipation is radiative, which may be less effective at dissipating heat from electronics susceptible to degraded performance from thermal fluctuations. Alongside this, space systems face temperatures ranging from several Kelvin (outer space baseline temperature 2.7 K) to hundreds of degrees Celsius, as well as temperature fluctuations that are much more rapid than in terrestrial environments.

The Traditional Space Sector

The long-standing military/industrial space sector is a large industry built around the concept of high-reliability (Hi-Rel) and long-term operation of highly sophisticated and capable space systems. This approach has safely brought people from the moon and back, and led to a revolution in navigation using GPS satellite constellations and communications with high throughput communication satellites (HTS). The International Space Station (ISS) and it's many scientific missions are powered and enabled by Hi-Rel electronic and mechanical systems that took decades to develop and deploy for this, and other, critical missions. The technologies, especially the essential RF, microwave, and millimeter-wave communications, telemetry, navigation, and sensing systems, were developed in a similar manner. High-cost and optimum-performance components and devices were designed and assembled in world-glass facilities in low-volume and often specialized production systems. Qualification and certification standards and systems are used throughout the supply, design, development, and installation of this technology to ensure reliability, traceability, and reproducibility of every aspect of systems. One of the major drivers for this is the requirement to reproduce and troubleshoot any event in space on the ground with 1:1 parity.

New Space Concepts & Emerging Business

Opportunities moving away from the risk-averse and high-capital expense method of developing space systems, New Space companies and organizations are instead using "up-scaled" industrial, automotive, and commercial aviation components alongside "down-scaled" space-grade components. Part of the justification for this is that these new organizations use production and business models built around space systems that only need to last a few years for adequate return-on-investment (ROI), as opposed to traditional space systems that require 15 years or more to meet ROI expectations. Therefore, these New Space systems are developed and deployed within a fraction of the time and cost of traditional space systems.

This approach is enabling deployment of massive satellite constellations designed to provide global Internet services that may likely become available as a competitor to cellular and broadband services. Other New Space plans include civilian spaceflight activities, spaceplane development, reusable rocket parts, private space station visits, and future plans for manned spaceflight to other planets. Other commercial interests include satellite surveying, satellite imaging services, and the potential for future satellite maintenance and cleanup services.

A key difference with prior space satellite services is that many New Space mega-constellations are being planned for Low-Earth-Orbit (LEO) and Medium-Earth-Orbit (MEO), as opposed to High-Earth-Orbit (HEO) or Geosynchronous Orbit (GEO). Having satellite constellations in closer orbit to Earth presents several benefits, but requires many more satellites to cover a similar area. Moreover, hand-off capabilities are necessary to pass ongoing service from one satellite to the next as they pass overhead every tens of minutes.

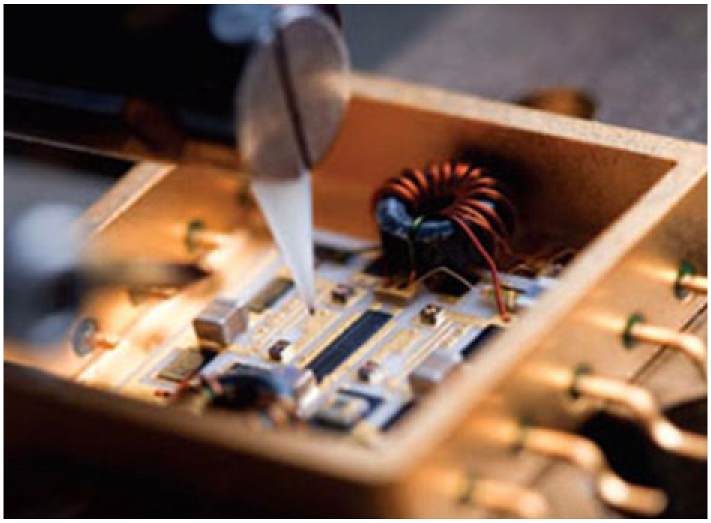
Benefits of LEO Satellites

- Shortens the time of travel of electromagnetic communications signals (tens of milliseconds as opposed to hundreds)
- Reduces potential interference and blocking from lower orbit debris
- Lower propagation loss
- Higher C/N ratio reduces the bulk of receiver equipment
- Lower-priced ground equipment
- Better frequency reuse from tighter spot beams
- Better global coverage, especially for polar regions

For instance, SpaceX launched the first of many batches of Starlink satellites in May 2019. Over the next few years, SpaceX plans on launching nearly 12,000 satellites to provide high-speed communications services around the globe. OneWeb and other companies are planning a mega-constellation aiming to offer “fiber-like” internet services to aviation, oil and gas, nautical, and other client applications that are otherwise lacking in high-speed and reliable communications services in remote locations. Future mega-satellite constellations are being considered a key component of bridging the digital divide with 5G technologies, as well as enabling global Internet of Things (IoT) infrastructure and services [2].

RF Components In Space

Much the same as traditional satellites, New Space satellites also require telemetry capabilities with multiple communication and sensing technologies. There also are new technologies, such as the intersatellite optical communications link proprietary to SpaceX’s Starlink satellites. In the case of New Space, the entire technological payload must fit within a satellite that only is several hundred pounds, compared to traditional satellites that weigh thousands of pounds.



This means that much of the heavy metal components and redundant systems must be forgone for lower cost, more compact, and lighter weight commercial, industrial, and automotive variants that have been “upscaled” to meet with less stringent New Space qualification and certifications [3]. There aren’t any standards for this, and New Space companies often are doing in-house qualification and certification.

However, there are likely some requirements that only RF/microwave components designed for space operation can meet, and New Space applications are likely to continue to leverage “down-scaled” space-grade components produced in higher volumes and at a lower cost by manufacturers that are familiar with designing and producing space-grade components. The “down-scaling” of space-grade components could involve the use of materials that are lower cost and lighter than rugged space materials, such as using certain plastics instead of specialized metal alloys.

RF Frequencies in Space

Early satellites used lower frequency spectrum for communication, but due to the demand for higher throughput services, satellite manufacturers have moved to millimeter-wave frequencies, such as the K and Ka bands. Future plans for terabit per second (Tbps) satellite communication services likely will require a shift toward even higher frequencies, such as the V band. Another benefit of using higher frequencies is that some RF components, such as filters, resonators, oscillators, circulators/isolators, etc. are physically proportional to the size of the operating wavelengths. Hence, using higher-frequency transceiver equipment can save on size and weight of the satellite and communications payloads.

Bands	Minimum Frequency (GHz)	Maximum Frequency (GHz)
HF	0.003	0.03
VHF	0.03	0.3
UHF	0.3	1
L*	**1**	**2**
S*	**2**	**4**
C*	**4**	**8**
X*	**8**	**12**
Ku*	**12**	**18**
K*	**18**	**27**
Ka*	**27**	**40**
V*	**40**	**75**
W	75	110
MM/g	110	300

**frequencies most relevant to current satellite and space technology*

Space Applications For RF Components

Space applications face stiff constraints on performance and reliability for complex systems to function. This is especially true for RF technology, which generally is highly susceptible to environmental influence if not carefully designed and manufactured to mitigate these factors. Moreover, designing RF technology for space requires accounting for more than just the harsh environment, but also radiation and interference in space as well as the physical factors of launch vibration and shock.

The size and weight of some RF component technologies, and additionally the materials used in their construction, may not be viable for space applications. Hence, there are only specific materials, designs, and manufacturing processes that are capable of producing RF technology that will operate in space, let alone be reliable.

As RF technology is essential for virtually all space applications, each major space application presents its own specific constraints and requirements for RF components, devices, and assemblies. New Space applications often are creating their own requirements qualification criteria, and sometimes based on enhanced automotive standards for electronics that will lead to an evolving perspective on space-grade RF technology.

Space Applications & Mission types

- Space Station
- Unmanned Exploration System
- Manned Exploration System
- Space Plane
- Satellites
- Payloads
- Launch Vehicles
- Mega-satellite Constellations

Satellites

Satellite manufacturing is one of the fastest growing areas of the global space sector [Figure 1]. This is in large part due to the growth of the Smallsats and mega-constellation public sector business emergence, but also the growth of a global demand for connectivity, satellite imaging, and navigation services. Furthermore, As more countries and organizations are planning satellite launches for research and other tactical purposes, there is a greater concern over the security of government satellite assets. This concern is leading to a growing interest in enhancing redundancy of satellite-based tactical abilities. All of these roles require a diversity of RF technologies, including sensing and metrology, advanced imaging, radio-navigation, and ultra-reliable communications.

As intercommunication between satellites also grows on new satellites, optical and laser-based transceivers for inter-satellite communications also are becoming prevalent.

Payloads

Never before has there been a greater diversity in satellite and spacecraft payloads. This applies not only to the types of missions these systems are performing but also the technology that supports these missions. Recent payloads are requiring the most advanced and reliable RF technology, as well as massive numbers of "upscaled" industrial and automotive components and assemblies. Moreover, modular payload technology, such as "digital payload" systems also are increasing the feature-set of some payloads, requiring advances in software-defined radio (SDR) and RF Front-end (RFE) technology to account for the very high throughput (VHT) specifications of the latest communication satellites.

Launch Vehicles

Launch vehicles undergo extreme stresses and require sophisticated control and flight systems that ensure a successful launch, flight, payload delivery, and successful return landings. Reliable communication and sensing systems are necessary to achieve these goals, which is why even space-launch vehicles employ a wide array of RF components and equipment. Depending on the type of launch vehicle, it may use RF equipment that can perform all of the necessary aerospace communications and telemetry may be used alongside enhanced communications necessary for manned spaceflight. With the approach of commercial manned spaceflight, complex RF systems that enable launch vehicle communication and operation will likely become increasingly common.

Mega-satellite Constellations

The definition of a satellite has changed from tens to hundreds of million-dollar government/military or aerospace conglomerate asset to a mass-produced competitor to broadband with satellites a fraction of the size and cost of traditional systems. These new mega-satellite constellations are comprised of satellites in LEO and MEO that orbit the Earth in less than an hour. There are substantial benefits to a LEO and MEO for satellite communications, but these satellites and ground systems now need to handle regular hand-offs and account for anomalies that could occur from the less-rigorous qualifications and requirements for these low-cost systems. Hence, the RF technology used in these mega-satellite systems is more integrated with digital technology to enable adaptability, lower costs, and much more rapid development than traditional satellites.

Space Qualifications

Decades of deploying technology in space has led to a rigorous set of standards and requirements for space-grade systems. These standards and requirements extend from performance criteria to material sourcing, manufacturing, and handling of space-grade technology. Though some New Space organizations may eschew the need for traditional space-grade components, these qualifications still are essential for mission-critical space systems and have provided a foundational supply chain and knowledge base for developing space technology. There is now a mix of space-grade (Class K), military-grade (Class H), automotive-grade (AEC-Q), and industrial-grade components being used in new space systems. In some cases "up-screened" military and automotive components are being used in traditional space and New Space applications due to cost and procurement benefits, while space-grade and military-grade technologies also are being "down-screened" for a lower-cost use in New Space applications that may not require the most stringent qualifications and material quality.

RF Technology Typical to Space Applications

Satellites	Payloads	Launch Vehicles	Mega-Satellite Constellations
Low Noise Amplifiers	Low Noise Amplifiers	Low Noise Amplifiers	Low Noise Amplifiers
Microwave Diodes	Filters	Microwave Diodes	Filters
Limiters	Mixers	Limiters	Oscillators
RF Passives	Couplers/Dividers	RF Passives	Microwave Diodes
Optical Transceivers	Oscillators	Filters & Filter-Based Assemblies	Limiters
	Microwave Diodes	Integrated Microwave Assemblies (IMAs)	RF Passives
	Limiters		DC/DC Converters
	RF Passives		Optical Transceivers
	DC/DC Converters		Integrated Microwave Assemblies (IMAs)
	Optical Transceivers		Transmit/Receive Modules
	Integrated Microwave Assemblies (IMAs)		Custom Hybrids
	Transmit/Receive Modules		GPS LNA

The Difference Between Class H and K Certification

(MIL-PRF-38534) A main difference in the cost and availability of space-grade components is the necessity of additional screening qualifications that help mitigate any defective or anomalous components prior to integration in a space platform. This is an essential step in being able to provide absolute traceability and reproducibility of events that may happen in space on Earth. Military-grade components undergo less screening and burn-in procedures, but still require rigorous screening stages for RF components and assemblies (See table "Comparison of Class H and Class K Screening).

It is possible that current and future New Space systems are/ will create their own screening standards for RF components. These companies may also use either automotive or industrial components that can meet their specialized screening qualifications or adapt space-grade and military-grade components to meet the cost and production quantity requirements of new systems.

Either way, there are few organizations in the world that are able to manufacture and qualify space-grade components – to Class K. There are less than 20 Class K certified facilities in the world. This means there are few organizations, engineers, and technicians with the capability of designing, manufacturing, and qualifying space-grade components. This expertise and capability is essential for traditional space applications, but also may be pivotal for New Space organizations seeking to source or develop RF components and assemblies that can reliably operate in space for even a few years.

Comparison of Class H and Class K Screening

MIL-PRF-38534 Test or Inspection Requirements	Screening Level		MIL-STD-883 Method
	Class H	Class K	
Preseal Burn-in	Optional	Optional	1030
Nondestructive Bond Pull	–	100%	2023
Internal Visual	100%	100%	2017
Temperature Cycle	100%	100%	1010
Constant Acceleration	100%	100%	2001
Mechanical Shock	100%	100%	2002
Particle Impact Noise Detection (PIND)	–	100%	2020
Pre Burn-in Electrical	Optional	100%	–
Burn-in	100%	100%	1015
Final Electrical	100%	100%	–
Seal	100%	100%	1014
Radiographic	–	100%	2021
External Visual	100%	100%	2009

Conclusion

These reasons, along with Spectrum Control's expansive range of RF and EMI components and high precision manufacturing services, are why Spectrum Control has been one of the largest non-prime providers of RF/ microwave and microelectronics suppliers to space technology manufactures. Of the less than 20 Class K certified facilities, Spectrum Control operates two such facilities (one in the US and one in the UK) and has provided components and manufacturing services for more than 60 major space programs for more than 60 years. Both traditional space and New Space organizations can benefit from Spectrum Control's capabilities and employee expertise in ongoing and next-generation space programs.

Resources

1. Tech Trends 2019: Space Industry Perspective (Deloitte)
2. ITU News Magazine: Evolving Satellite Communications No. 2, 2019
3. Space Electronics Market by Platform Type, Component Type, Subsystem Type, Product Type, & Region, Trend, Forecast, Competitive Analysis, and Growth Opportunity: 2018-2023
4. The Ins and Outs of Spaceflight Passive Components and Assemblies (Spectrum Control.)
5. SpectrumControl.com/Space

Appendix

RF Components in Space				
Components	**Capabilities**	**Topologies & Technologies**	**Key Features**	**Spectrum Advantage**
Diodes	Broadband performance 1 MHz to 20 GHz	Frequency multiplier	Manufactured in Class H & K facility	Over 40 years of space heritage. Centralized design vault. Up-screening of MIL-STD products ESA-Qualified product listings. Manufactured in H & K class facility. Tested to MIL-STD-883, MIL-PRF-38534, & MIL-STD-202. Space qualified to individual customer specifications. Large portfolio of proven designs.
		Step recovery		
		Ceramic packaged tuning varactor	Tested to MIL-STD-883, MIL-PRF-38534 & MIL-STD-202	
		PIN		
		NIP		
Filters, Diplexers, Multiplexers	Broadband Performance	Lumped element	Custom filter design capability	
		Cavity/combine/ interdigital types		
		Surface Acoustic Wave		
	L, S, C, X, Ku, Ka, Frequencies	Tubular		
		Waveguide		
		Ceramic		
		Suspended sub-strait stripling		
Oscillators & VCSOs	Full octave performance from 25 MHz to 7 GHz	Hermetic Kovar package of 1.0''x1.0''x0.2'' SMT	Ruggedized hybrid construction	
	VSCO Enhanced comms distances for frequencies from 350 MHz to 4 GHz	Chip & wire architecture		
	Low phase noise to -109 dB/Hz at 1 KHz			
	Low Vibration Sensitivity to 2x10-9 per g	SAW Oscillators		
	Operating Temperature range -55 C to +125 C			
Amplifiers	Broadband performance from 1 MHz to 6 GHz	Low noise	Manufactured in Class H & K facility	
	Low Noise to 1 dB	Small signal		
	Output to 1 watt	Hybrid amplifier	Tested to MIL-STD-883, MIL-PRF-38534 & MIL-STD-202	
	Customizable designs.			

RF Components in Space

Components	Capabilities	Topologies & Technologies	Key Features	Spectrum Advantage
Attenuators & Terminations	Broadband performance from DC to 40 GHz	Solderless Assemblies	Largest provided of Hi-Rel attenuators for space applications	Over 40 years of space heritage. Centralized design vault. Up-screening of MIL-STD products ESA-Qualified product listings. Manufactured in H & K class facility. Tested to MIL-STD-883, MIL-PRF-38534, & MIL-STD-202. Space qualified to individual customer specifications. Large portfolio of proven designs.
		Injection molded connectors	Designed to withstand mechanical shock/ vibration and thermal extremes	
		SMA, SMK, & Type N connectors		
Resistors & Attenuators (SMT)	TAN an thick film resistors	Flanged, tabbed, and pill packages	Testing to MIL-PRF-55342 / MIL-DTL-3933	
	TAN an thick film conductors	Surface-mount and wire-bondable chips		
	Tiinned and gold terminal finishes			
Multi-chip Modules & Hybrid Microcircuits	Hermetically sealed designs for harsh environments	PCB	Environmental testing toward IECQ, MIL-STD-810, ect.	
	Operating temperatures to 150/165 C	Thin film		
	Thick film designs with operating temperatures to 225 C	Thick film		
Integrated Microwave Assemblies (IMAs)	Cross-facility synergy enables vertically integrated assemblies	Frequency Converters	Radiation/temperature tolerant and rugged	
		Complex filter assemblies and switched filter banks		
	Multi-disciplined engineering expertise enables integration assemblies, and optimization	Multifunction assemblies	Integration of Spectrum Control components	
		Amplifier based assemblies		
Single & Multifunction Assemblies	Robust designs covering 10 MHz to 50 GHz	TEM cavity/combine coaxial	Custom capability	
		Dielectrically loaded waveguide		
		Lumped element		
		Various filter types		
		SAW technology		

Spectrum Control Space Program Heritage

Deep Space

Orion
Galileo
Cassini
USERS (2 sats)
Selene & Okina
Mars Phoenix
Lunar Reconnaissance Orbiter
Europa
Exomars
OCO
LCROSS
Mars Science Lab
ISS Kibo EF
Mars Curiosity Rover

New Space

GPS-2F/GPS3
Prima O3B
Inmarsat
Intelsat
Sirius Radio
Direct TV
Optus 10
Amazonas 3
Thor 7
MUOS
Hot Bird
MARECS
Olympus
SkyNet
Eutelsat
Koreasat
Various classified programs

Launch and Re-entry

Perseverence
Taurus
IRBM
Minuteman
H-II
Falcon 9

Scientific Missions

SAOCOM
Hershel Plank
AMS-02
Aquarius (SAC-D)
Lisa Pathfinder
Juno
Grail (2 sats)
EnMap
Vegetation
Cassini
Meteosa

Spectrum Control Certifications

- 11 Manufacturing Facilities Certified to ISO 9001:2015
- 7 Certified AS9100D Facilities
- ANSI 20.20 Compliant Facilities
- Department of State ITAR Compliant
- Cleared Facilities & Personnel
- Two MIL-PRF38534 (Class H and K) Facilities
- QPL MIL-PRF-15733 & MIL-PRF28861 (Selected Products)
- Solder/Assembly J-STD-001 Class 3 and IPC-A-610 Class 3
- NEBS Approved (Selected Products)
- RoHS Compliant (Selected Products)
- UKAS Accredited Test House Facility
- DLA Laboratory Suitability Approved for Performing Test in Accordance with: MIL-STD-883 and MIL-STD-202
- ISO17025 Accredited Facility – General Requirements for Testing and Calibration Laboratories