The Ins and Outs of Spaceflight Passive Components and Assemblies

By: Paul Kovacich, Engineering Manager, APITech

RF and microwave components deployed in space flight applications can experience hundreds of degrees of temperature variation, massive amounts of radiation, and can be expected to operate at an elevated level for sometimes decades. The demands of operating in a space environment bring many unique challenges and unforgiving reliability requirements; therefore, designing passive components to meet these rigorous operation criteria necessitates a high level of design expertise, qualifications/certifications, and testing capability.

Advancements in telecommunications technology and an increased demand for connectivity to high speed data services is leading to an increase in space deployments of telecommunications platforms. These platforms offer services ranging from surveillance and military intelligence to GPS and commercial high-speed data for home internet. Many remote industrial services also rely on satellite communications for control and monitoring. However, deploying the sensitive RF/microwave equipment necessary to support these critical data links—hundreds of miles from the surface of the earth—brings in a host of challenges not seen on earth's surface. Though operation on land, air, and sea pose many extreme design challenges for RF/microwave passive components, typically these platforms experience limited terrestrial exposure to temperatures, radiation, g-forces, and pressures. In the bleakness of space, there are much greater extremes and environmental instabilities to contend with. Couple these factors with the inability to provide maintenance service, and these high performing space technologies must operate, reliably, for up to 15 years. The rigorous operational requirements, in turn, demand stringent design and manufacturing practices for space qualified components that must be taken into consideration throughout the design, fabrication, and delivery of space-grade, or space flight, RF passive components and assemblies.

What Is The Big Difference Between Space Environments And Terrestrial Environments?

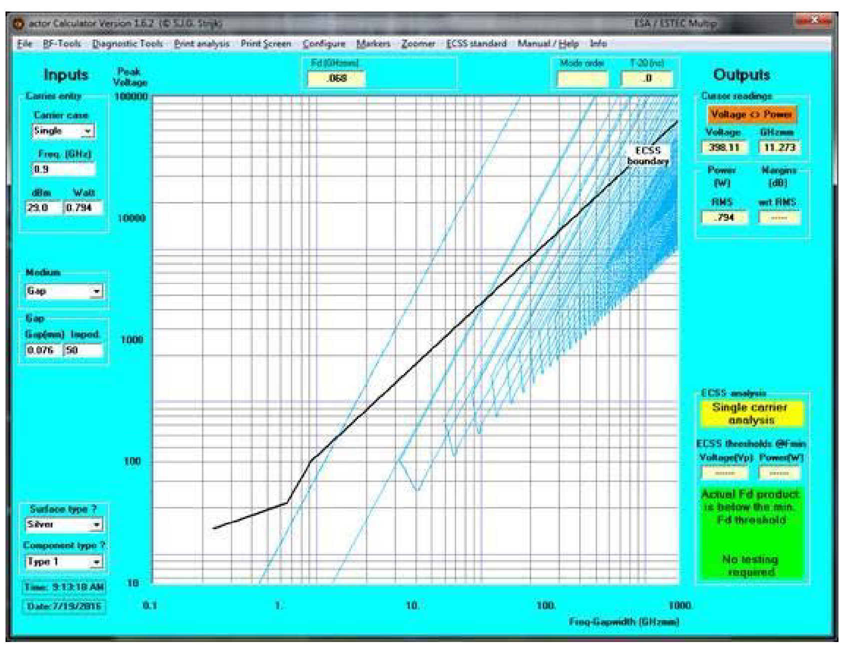
Though many of the electrical and RF performance criteria may be similar between space flight and terrestrial passive RF components and assemblies, there are additional environmental considerations and design requirements based on the physical geometry constraints of the components. For example, the temperature range of operation for space-grade components in the US are required to meet the military required temperature range, -55°C to +125°C. Nevertheless, space qualified components are required to operate in the extremes of these temperature ranges for 15 years without service, and potentially within a hard vacuum.

The vacuum of space is unlike any terrestrial environment, as there is no dielectric atmosphere to insulate between component elements or regulate temperature fluctuations. Specifically for high power and highly sensitive assemblies, the lack of atmosphere may require the component or assumbly to be hermetically sealed. If not, effects such as multipaction and outgassing, can occur. There are strict limits on materials that can be used in space, as outgassing, radiation-based material degradation, and adverse material interactions can lead to catastrophic cascaded failures. Additionally, materials such as cadmium and zinc will disintegrate in low pressures, and other metals, such as tin, will develop metallic whiskers—called dendrites—that could bridge electrical connections and induce component and assembly failures. Also, as there is no surface corrosion in space, when dissimilar and similar metals touch, a metallic welding may occur, a process known as cold welding, and this may change the RF and electrical behavior of metallic contacts. Some insulators will also be reduced to dust when exposed to high cosmic radiation levels. For example, Teflon materials may suffer derated electrical characteristics when exposed to radiation levels above 5 Megarads. Other materials may face the generation of hotspots when exposed to gamma, or other cosmic radiation, and deteriorate. In space structures that also contain optics, for example, an outgassing material or one that creates debris could deposit material or generate a haze that reduces the satellites optical performance. Hence, every material that is used for space qualified devices must be an approved material, or a nonstandard materials part request must be submitted in order to approve and validate the material choice.

Another key difference with space flight hardware, is that the components and assemblies must be completely shielded in a faraday cage. This cage is commonly composed of aluminum for low-weight purposes, and must be of a necessary thickness to withstand radiation specifications delivered by the organization deploying the hardware.

Design Considerations For Space Qualified, Or Space-Grade, RF Passive Components And Assemblies

With these factors in mind, the size, weight, and specific shape of the component and assembly must be kept to the minimal and most efficient format possible. Each kilogram of mass launched into space costs thousands of dollars. Certain passive component topologies and technologies may not be viable for space, as these methods cannot meet the weight or size restrictions. Ultimately, there is no opportunity for tune-ups, service, or maintenance in space, so any component in space must be designed to survive within the harsh environmental parameters for at least 15 years. This includes under high temperature and power conditions for extended periods of time. Moreover, the clever use of components can also lead to reduced circuit complexity and size, which may involve much more detailed design resources invested upfront and may give designers with prior space experience a significant advantage. For instance, as stability is a high priority requirement for space flight components, in order to reduce size and circuit complexity, instead of adding frequency equalizer components, negative and positive coefficient of thermal expansion materials can be used in conjunction to reduce thermal variance in device performance (as you could in a resonator or filter tuning element). As mentioned previously, in a hard vacuum, multipactor breakdown can take place when there aresignificant voltage gradients between conductive elements of a component or assembly, mainly in high power filters. For example, in a resonator cavity of a RF filter stage, the impedance changes within the filter could lead to much higher voltage gradients than the input and output port impedances are specified for. These internal potentials could cause ionization and eventually multipactor breakdown—cascading electrons from one



Highly specialized multipactor predictive tools enable filter and other RF passive component designs that ensure a long life of operation without concern of this breakdown threat.

The Ins and Outs of Spaceflight Passive Components and Assemblies

By: Paul Kovacich, Engineering Manager, APITech

conductive surface to another. As using large gaps may not be an option, certain filter topologies or materials may be unacceptable in space environments. Specialized simulation technology and design experience are required to tackle obscure effects, such as multipactor breakdown.

Furthermore, as the communication links which these devices support must overcome high levels of path loss and interference, the loss of the components must be extremely low. Each watt of power on a satellite or space platform is generated by solar cells, so any lack of efficiency requires additional solar elements and increased size and cost of the overall space structure. Cavity, lumped element, and dielectric resonator filters with elliptic topologies are more common in space flight applications, as the insertion loss, return loss, size, and weight are much lower than other technologies and topologies. The frequency of operation for the filter heavily determines the size of some technologies, for example at 18 GHz, a dielectric resonator element is roughly the size of a pencil eraser, at 1 GHz, a similar performance dielectric resonator is the size of a hockey puck.

What Qualifications And Standards Must Be Met To Be Considered Space Qualified, Or Space-Grade?

In order to qualify a component or device for space applications, an element by element screening and qualification with rigorous process controls is necessary. Each stage of the material supply, manufacture, and assembly must be meticulously documented. In addition to the documentation, there are several industrial and military standards that may apply, depending upon the application. As the process of space qualification is no easy feat, process experience and space heritage is extremely valuable. There are few organizations that can prove several successful deployments and have engineers with experience of space qualification able to design and follow all of the necessary process and documentation steps.

As a result of the stringent space requirements, facilities that produce space-grade devices must meet certain quality management standards, such as AS9100, which is a modified and extended version of ISO-9001 specifically for the aerospace and defense industry. Quality assembly training and standards are also required, namely IPC J-STD-001 with amendment 1 for soldering and electrical assembly for space, and IPC-610 class 3 for soldering electronic assemblies. Military standards, such as MIL-PRF-38534 and MIL-STD-883, dictate many of the screening and quality conformance inspection requirements for testing and screening RF components and assemblies for space applications. These requirements demand a series of physical, environmental, and electrical testing, which is 100% mandatory for space level, or Class K. MIL-STD-883 provides the methods of screening and examination for space level components dictated in MIL-PRF-38534.

Test Or Inspection Requirements For MIL-PRF-38534	Screening Level		MIL-STD-883 Method
	Class H	Class K (Space Level)	
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%	2012
External visual	100%	100%	2009

For military and defense applications and many other space-grade applications, all materials and material suppliers must be listed in the Qualified Products Listing (QPL) or Qualified Manufacturers Listing (QML), or a nonstandard parts or nonstandard materials request must be processed. Each component must also be shipped with all of the documentation describing its complete design, fabrication, and operation. This documentation could amount to several hundreds of pages of detail, down to the precise curing time of adhesives used in a sub-element construction process.

Over and above these requirements, specific customers for space flight parts may require additional levels of documentation, processes or testing. These requirements may be subject to security measures, so often are not available for discussion or detail outside of the requirements. Many times with military and defense clients, there may be little feedback on the use and performance of the qualified part once it leaves the manufacturer, unless there is a failure or problem that arises in the future.

Testing Requirements For High-Reliability Space Qualification

For space applications, and many military and defense applications, the testing requirements for high reliability (Hi Rel) dictate an elevated level of testing and certification of the facilities where the testing is performed. ANSI/ISO/IEC 17025 provides a set of general requirements that are used to indicate the competence for a facility to carry out the necessary tests and calibrations to meet various other standards. Exceeds ISO/IEC 17025 in its inclusion of relevant requirements and is designed to increase the quality assessment system requirements for demanding applications. Some documentation still exists that may reference inspections IAW with MIL-I-45208, which has since been replaced by ISO 9001 certification. Many of the Hi Rel tests necessary to meet space qualification are indicated in MIL-STD-883 and MIL-STD-202, with calibration and inspection criteria provided in resources, such as ANSI/NCSL Z540-1. Configuration management information is also shared in MIL-STD-961. The key features of this process are to ensure complete product qualification, materials traceability, calibration, and testing to all applicable standards with documentation outlining the complete life-cycle of each unit produced. This may include an operator inspection, 3rd party inspection, customer inspection, and government inspection, with photographs of each component or feature that cannot be completely visually inspected. Ultimately, this rigor is designed to be able to completely reproduce on land any scenario encountered in space in order to diagnose and troubleshoot problems that occur when the devices are deployed. For instance, if a material doesn't have absolute traceability, a sample must be sent for destructive chemical testing to ensure its exact chemical makeup.

Considering the deep detail and design strategy necessary to produce space-grade RF components and assemblies, it is understandable why there are few organizations capable of meeting all of the criteria for space qualification. Beyond sheer design capability, every choice down to the material must be made with a complete understanding of the end spaceapplication, which involves a heavy process of elimination even prior to investing design effort. Nevertheless, this level of rigor is necessary to keep highly critical space-based systems operating under extreme vacuum conditions year after year.