

Power Sub-Miniature (PSM) Interface

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ABSTRACT

While the desire to reduce size and weight of the system without sacrificing performance is not new, the current growth drivers in the aerospace industry demand it now more than ever before. The SMA RF connector is widely recognized as the preferred interface in a radio frequency application due to its light weight and small size. However, due to the interface's limitation in power handling, many system and design engineers are forced to switch to the heavier and bulkier TNC connector. The TNC connector provides superior RF power handling performance and is also a space-qualified interface used on many programs; however, it increases the system's overall weight and footprint, resulting in a higher satellite launch cost. To meet the increasing demand of cost and weight sensitive applications in the space-flight market, HUBER+SUHNER introduces the PSM (Power Sub-Miniature) interface, offering power levels equivalent to a standard TNC interface without exceeding the envelope of an SMA connector. The PSM interface will enable customers to maximize connector density and minimize weight to reduce the overall system footprint without sacrificing power handling capability. This paper is a follow up to "Power Sub-Miniature (PSM) Connectors for Space Application" presented during the 1st Space Passive Component Days in 2013. During the 2013 presentation, PSM was introduced through simulation and performance results of the initial prototypes, but since then HUBER+SUHNER has optimized the design to successfully finalize and qualify the interface to both ESCC 3402 and MIL-PRF-39012 specifications to mitigate risk and cost to the space-flight market. In addition, HUBER+SUHNER worked with the joint ESCC-VSC high power RF laboratory in Valencia, Spain to successfully test the power handling, corona, and multipaction performance of the interface, the results of which will be discussed in this paper.

INTRODUCTION

The revenue of the satellite industry and associated services is expected to grow at 15-20% annually and nearly half of the satellites launched will be commercial as there is a high demand for data in the world today [1]. The military satellite operators are also expected to forge a relationship with the commercial satellite providers who are building more satellites and launching constantly. New satellite technologies will be available onboard commercial satellites well before military satellite programs, which could take decades to plan, design, build, and launch satellites [2]. As increasing amount of information is processed through the satellite payloads, satellite manufacturers must design high bandwidth systems and present innovative cost saving solutions to stay competitive or to increase their market share in the industry. The commercialization of technologies to meet the aggressive cost and performance targets is referred to by many as the NewSpace, which is defined as a global sector of relatively new, distinctly commercially minded, aerospace companies and ventures working to independently develop faster, better, and cheaper access to space, spaceflight technologies, and overall space missions [3].

Miniaturization of hardware and increasing payload capability can reduce satellite launch costs, particularly if initiated at the component level. In order to produce more bandwidth, each component must operate at higher frequencies and handle higher input power without sacrificing other features. To support the growth of the satellite industry and assist system engineers to meet the performance objectives of their RF architecture, HUBER+SUHNER introduces the newly designed PSM (Power Sub-Miniature) interface, offering standard TNC (Threaded Neill-Concelman) interface level power handling, but with a small form factor of a SMA (Sub Miniature version A) interface.

As a follow up to "Power Sub-Miniature (PSM) Connectors for Space Applications" presented during the 1st Space Passive Component Days in 2013, this paper will focus on the final design along with the full qualification of the PSM interface.

BACKGROUND

Microwave coaxial connectors, also known as radio frequency (RF) connectors, play an essential role by connecting two units together within the satellite payload. One such widely used RF connector is the SMA. The SMA is often used to provide RF connectivity between boards and microwave components including filters, attenuators, and oscillators. The threaded SMA interface offers excellent electrical connection and desirable physical attributes due to its low weight and small size. However, the SMA interface is limited in terms of RF power handling capability. Space-flight applications with power levels exceeding 10 W are not typically supported by SMA interface, forcing design engineers to switch to a heavier and bulkier TNC interface [4]. This interface is able to withstand higher power levels, but it increases the overall footprint and mass of the satellite payload, leading to a higher cost-to-launch a satellite payload and conflicting the market's needs.

While meeting or exceeding the higher power levels of a standard TNC interface, the PSM interface is designed to not exceed the small envelope of the SMA interface. The standard TNC connector in the context of this paper refers to the interface built to MIL-STD-348 with the material and performance specifications built to MIL-PRF-39012, both of which are common industry standard military specifications for coaxial connectors. There are several other coaxial TNC connectors designed for high power space applications, but they do not comply with MIL-STD-348 or MIL-PRF-39012, and are not considered part of the standard TNC connectors in the context of this paper. HUBER+SUHNER has successfully designed, tested, and space-qualified the PSM interface, the details of which will be presented herein.

In order to understand the design approach and features of the PSM connector, it is important to be familiar with concepts of multipaction breakdown, corona discharge, and thermal breakdown.

Multipaction and Corona Breakdown

In a vacuum environment, charged particles or electrons move freely, without resistance from air molecules, and strike the connector component walls through the inherent gaps within the cable-connector junction or male-female interface of a coaxial line. These electrons, accelerated by the microwave field, collide with the metal boundaries and release secondary accelerated electrons. If the resonant condition between the motion of electrons and the RF signal is maintained and the secondary electrons yield is higher than one when colliding with the walls, an electron cascade is formed [4]. As this cycle keeps repeating over time, this impact is multiplied, leading to a phenomenon known as multipactor (Figure 1). The multipactor, or multipaction discharge, is a resonance type of RF discharge, which can occur under vacuum conditions within microwave devices and could lead to an electrical arc and short the circuit inside a microwave device. It may also cause partial or complete damage to the component over time.

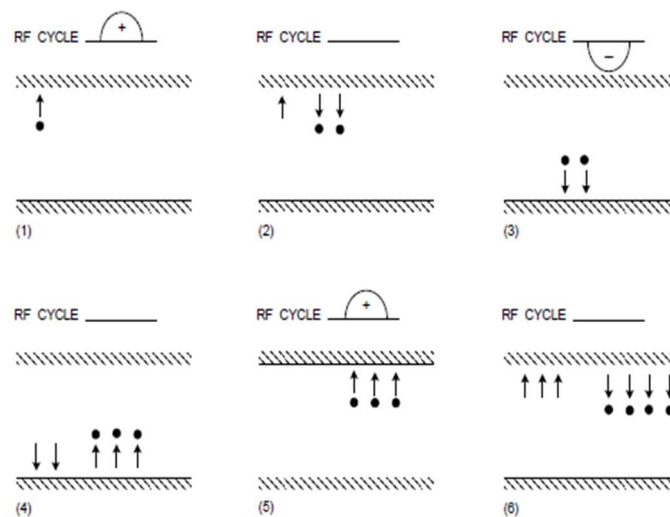


Fig. 1. Illustration of electron collision leading to release of secondary electrons

Corona breakdown, which has a similar effect on a microwave component and can short an electrical circuit, occurs at a higher pressure when the collision of highly energized electrons can ionize air molecules resulting with secondary

electrons. Corona breakdown is produced by a rapid increase in the electron population because of the ionization of gas molecules trapped within gaps inside microwave devices. The ionization of air molecules renders the gas conductive, creating an electron plasma and eventually cutting off the transmission signal. The potential of corona breakdown exists in a vacuum environment as well. The materials which meet low outgassing requirements per ECSS-Q-ST-70-02 and NASA Reference Publication 1124, will still out-gas when exposed to high temperature in a flight application. The source of high temperature could be the environmental condition of the satellite, external heating within the system, or internal heating due to resistive losses. This outgassing, while still within the ECSS and NASA outgassing limits, will lead to partial pressurization in the system and potential corona breakdown if the component is not properly vented.

Applications involving re-entry vehicles, missions exploring other planets, HAPS (High-Altitude Platform Station), or a TTC (Telemetry, Tracking, and Control) system that is switched on during the launch of the satellite to check parameters such as the velocity or the position of the spacecraft [4], will be exposed to atmospheric pressure and also need to mitigate the risk of corona breakdown.

PSM DESIGN FEATURES

Electrons travel from the center conductor outward to the outer conductor within the given electrical field and gain energy as they accelerate on this one-directional path. As the field of direction to induce multipactor is radial and determined by the frequency-distance product, the inherent design of the SMA interface is highly susceptible to multipaction and corona breakdown. The PSM connector utilizes a cone or wedge shaped dielectric, shortening the electron travel path or the arc distance and also reducing the electric field (Figure 2). This inhibits electrons from gaining enough momentum to release secondary electrons upon collision. If the air gap between mating dielectrics is narrow, it will suppress multipaction charge by preventing electron acceleration [5]. Even though it is possible to induce multipaction charge between two dielectrics, the voltage required for such breakdown is very high. Furthermore, use of sharp edges or peaks are minimized within the connector, as they may lead to intense electric fields and ionization rates.

In a coaxial cable assembly, the primary source of breakdown is typically the cable-connector junction due to the gaps within the dielectric. In contrast to SMA, the TNC connector junction uses overlapped dielectrics to minimize these gaps and offers increased multipaction and corona breakdown resistance (Figure 2). The PSM interface also incorporates overlapped dielectric design to minimize the gaps within the cable-connector junction. To ensure no gas or contaminants remain within the component as a result of outgassing, the design also includes vent holes as a standard to allow pumping or depressurization.

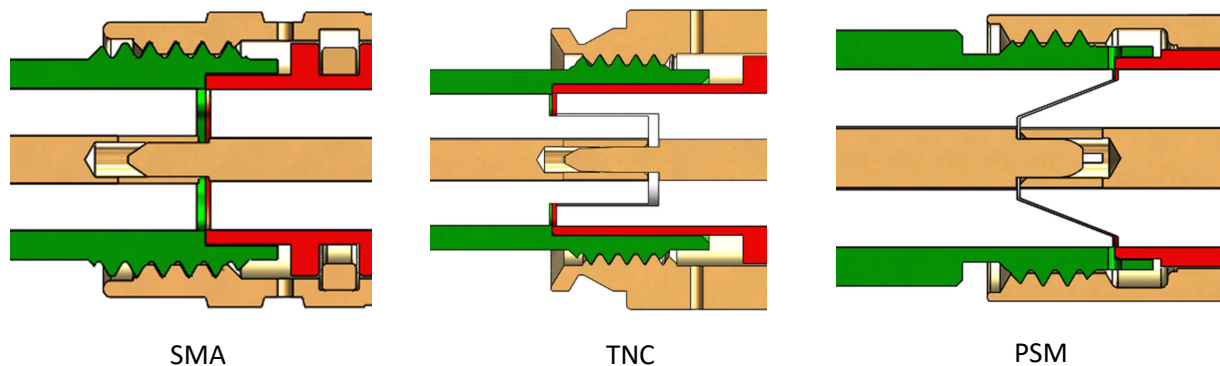


Fig. 2. Coaxial Interface Junctions

CW (continuous wave) power handling is a function of the energy transfer capacity of the coaxial line and ambient environment. The input RF power transmitted along the center conductor of the coaxial line will have a percentage of its magnitude decreased by conductor losses. The highest concentration of dissipated energy is along the center conductor skin. The lower the transmission efficiency of the coaxial line, the greater the magnitude of dissipated energy present. The transmission efficiency of the coaxial line is primarily a function of its attenuation. This energy raises the temperature of the material layers within the coaxial line and it is conducted away from the source [6]. As the energy dissipates from the center conductor, the temperature to which the surrounding materials are exposed to increases. One such critical surrounding material in a cable assembly is solder, which has a lower melting temperature than the melting temperature

of the dielectric or the metal. If the solder is melted, it will weaken the cable-connector junction and breakdown the transmission line. A larger coaxial line size provides lower attenuation, improves transmission energy, and decreases the magnitude of dissipated energy present. By achieving a substantial increase in the radial dimension, the PSM interface is designed for optimized loss in a coaxial line and therefore able to handle higher RF CW power. To accommodate a larger coaxial line size, the dielectric has also been carefully compensated to produce a 50 Ohm coaxial line.

Furthermore, the PSM connector provides better power handling than a standard TNC connector in the frequency range of 15-18 GHz. The standard TNC connector typically has a cutoff frequency around 16 GHz due to the size of its coaxial line. A precision TNC connector with a step-down coaxial line design is required to increase the connector's operating frequency range up to 18.5 GHz. This step-down in the diameter of the coaxial line degrades the CW power handling capability of the precision TNC interface, whereas the PSM uses a uniform coaxial line size to offer linear power handling capacity up to 18 GHz. Some applications use an air loaded TNC, known as ATNC (Air TNC), operating up to 18 GHz; however, the use of an air loaded dielectric compared to an overlapped PTFE (Polytetrafluoroethylene) dielectric is certainly not recommended for high power space applications because there is no overlap in the dielectric.

Additionally, the materials are carefully selected to provide excellent electrical conductivity, high power, temperature resistance, light weight, and low PIM (Passive Intermodulation) characteristics.

Figure 3 represents how installing the PSM connector can reduce the overall size of a system compared to the TNC connector. In addition to the smaller pitch, the PSM connector provides approximately 50% weight savings compared to an equivalent TNC connector.



Fig. 3. PSM pitch vs. TNC pitch

QUALIFICATION AND TESTING

In a space-flight environment, reliability of a product being used on a payload is crucial. The superior technical features and commercial benefits are secondary to heritage and qualification. As stated earlier, the satellite industry is looking for innovative solutions to reduce overall cost. Satellite manufacturers cannot afford to invest in qualification of a new product, nor can they delay the production cycle by waiting for the qualification of a new product to be completed. To mitigate the risk of designing a new product for the next satellite payload, HUBER+SUHNER has successfully completed the qualification of the PSM interface to industry space standards for a coaxial connector – ESCC 3402 and MIL-PRF-39012. A full qualification report can be supplied upon request to HUBER+SUHNER.

Since the PSM interface is designed to replace the heavier and bulkier standard TNC connectors, verification of power handling, multipaction and corona breakdown of the interface through testing is critical. In a joint effort with the European High Power Laboratory in Valencia, Spain (ESA-VSC), HUBER+SUHNER tested the PSM interface for multipaction breakdown, corona discharge, and RF power handling.

Figure 4 shows a basic schematic of the high power test bed utilized by the laboratory to carry out the tests. A total of six (6) DUTs (Devices Under Test) were exposed to various high power tests. Four (4) DUTs (DUT 0, 1, 2, 3) were coaxial cable assemblies using PSM male and female connectors and two (2) were PSM-TNC hermetic feedthroughs (DUT 4, 5). The whole test campaign was carried out in a class 100,000 (ISO 8) clean room along with temperature and humidity controls. Temperatures on the DUTs, applied input and output, and reflected RF power were all monitored. During each test, a continuous monitoring of the return and insertion losses was carried out as well [7].

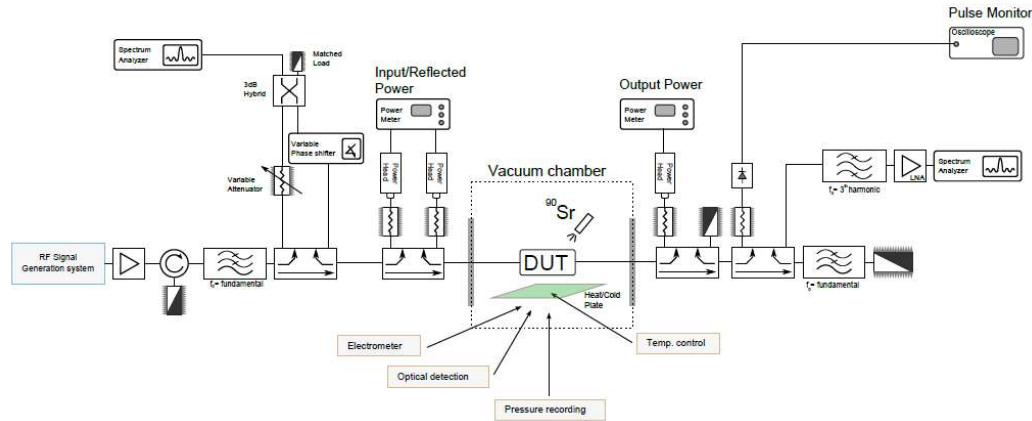


Fig. 4. Example of high power test bed

Detection methods

Forward/reverse power nulling (global)

In this detection system a proportion of the transmitted and the reflected power are coupled into a phase and amplitude-matching network. Once the system is balanced these two signals produce a null, which is very sensitive to amplitude and phase variations within the system. A RF discharge creates an imbalance and a loss of the null [7].

Harmonic detection (global)

This detection method works as a RF breakdown spreads energy over the spectrum, resulting in increased power in the harmonics [8].

Electron avalanche monitoring (local)

This method relies on the ability of a small positively charged probe to attract free electrons generated as a result of a RF breakdown. This method works as follows: an electron probe is placed nearby the critical area; the electrons emitted from the breakdown are collected and converted in DC current by means of a very sensible electron meter [8].

Optical detection (local)

This detection method is based on the principle that once a RF breakdown takes place photons are released along with low energy electrons. This emission can be from the surface of the material or by ionizing the residual gas molecules present within the vacuum system [8].

To initiate a multipactor discharge, one beta emitting radioactive source ^{90}Sr was placed near the DUT to have sufficient free electrons in the test chamber. The test set-up was validated by ESA-VSC laboratory using the same detection methods and test parameters of the PSM high power test to demonstrate discharge-free operation of the test bed up to the maximum RF power at each test frequency and test temperature. A summary of test results from one (1) mated DUT (DUT 0+1) is shown in Table 1.

Table 1. High Power Test Results

Test Type	Frequency	Temp.	RF Power
Multipactor	1 GHz	+22°C	800 W peak
Power Handling (in vacuum)	1 GHz	+60°C	130 W CW
Power Handling (in vacuum)	4 GHz	+60°C	110 W CW
Power Handling (in vacuum)	11.6 GHz	+60°C	100 W CW
Corona	1 GHz	+22°C	100 W peak
Destructive Corona ¹	1 GHz	+22°C	800 W peak (1 mbar)
Destructive Multipactor ²	1 GHz	+22°C	1500 W peak

¹ No breakdown was detected at 800 W peak. The maximum RF power capability of the test bed was 800 W peak for corona detection.

² No breakdown was detected at 1500 W peak. The maximum RF power capability of the test bed was 1500 W peak for multipaction detection.

TECHNICAL SPECIFICATIONS

Table 2. Technical Specifications of PSM connector - Electrical

Specification	Requirements
Impedance	50 Ω
Frequency Range	DC - 18 GHz
Return Loss (Straight connectors)	1 GHz: 36 dB (typical) 4 GHz: 31 dB (typical) 12 GHz: 28 dB (typical) 18 GHz: 26 dB (typical)
Insertion Loss	0.05 dB (typical)
RF Leakage	> 90 dB
Corona threshold ¹	200 W peak
High power handling (in vacuum) ¹	1 GHz: 150 W (CW) 4 GHz: 76 W (CW) 12 GHz: 40 W (CW)
Multipactor threshold ¹ 20 μ s, 2% duty cycle	800 W peak
PIM performance (2 x 20 W)	-168 dBc (3 rd order power at 1900 MHz)
Insulation resistance	> 5000 M Ω
Contact Resistance - Center conductor - Outer conductor	< 2 m Ω < 2 m Ω

¹ The values include appropriate safety margin

Table 3. Technical Specifications of PSM connector – Mechanical and Environmental

Specification	Requirements
Recommended coupling nut torque	≥ 1.5 Nm / 13.3 in lbs
Coupling nut retention force	≥ 250 N / 56.2 lbs
Contact captivation	≥ 27 N / 6.1 lbs
Cable retention force	≥ 100 N / 22.5 lbs
Temperature range	-65°C to +165°C (thermal vacuum test)
Thermal Shock	MIL-STD-202, Method 107 Condition B
Moisture resistance	MIL-STD-202, Method 106
Corrosion	MIL-STD-202, Method 101 Condition B
Sine vibration	MIL-STD-202, Method 204, 28 g peak
Random vibration	MIL-STD-202, Method 214 Condition K-I, 46.3 g
Mechanical Shock	MIL-STD-202, Method 213, 12000 g peak

CONCLUSION

The fully space-qualified PSM interface will significantly reduce the overall footprint of the RF sub-system within the space-craft, while also offering equivalent or greater power handling and breakdown capability than a standard TNC interface. The reduced profile and mass will enable a lower cost-to-launch a satellite, allowing more frequent satellite launches to supply enough bandwidth and meet the demand of data in the future.

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