TDRS MA antenna ESD qualification program

E. Mikkelson, S. Malek, P. Leung, S. Seki, E. Lee and J. Baldauf
Hughes Space & Communications Company, El Segundo, CA

Abstract. A single antenna element from the Multiple Access array on the TDRS H,I,J spacecraft was tested for electrostatic discharge. The element consisted of a copper trace on a Kevlar/Nomex honeycomb sandwich, all beneath a sunshield. The objective was not only to measure the ground current generated by a discharge, but to determine whether a discharge that couples in-band to the RF communications signal could cause either damage to a sensitive low-noise amplifier downstream, or through repetition an increase in the overall bit error rate of the communications channel. Therefore, measurements of the discharge events focused on the RF in-band peak power and the overall discharge rate. The testing used 25 and 90 keV electron beams, with the sample at both room temperature and the minimum on-orbit expected temperature (-80C). Based on the test results, RF limiters were added to ensure extra margin for the ESD protection of the LNAs. Measured discharge rates were not high enough to increase the overall bit error rate.

Introduction

The TDRS H,I,J spacecraft being built by Hughes Space & Communications Company for NASA includes a multiple access (MA) phased array antenna on the nadir panel. Each element of this array consists of a thin copper circuit on a Kevlar/Nomex honeycomb sandwich, all positioned behind a sunshield. Testing was undertaken to determine the effects of electrostatic discharge (ESD) occurring from the MA elements.

The typical ESD concern for materials on the outside of the spacecraft is a “blowoff” discharge. Such a discharge can create large current transients flowing throughout the spacecraft, which can then couple to unit harnesses and cause damage or spurious commands in an electrical unit. Hughes has well-established guidelines and requirements for protecting its units from such an effect, so although the “blowoff” current was one parameter measured during the test, it was not a major concern.

A different concern is that a discharge could couple in-band to the receive MA elements. Can the in-band power levels can be large enough to cause damage to a downstream low-noise amplifier (LNA), or can repeated discharges at lower levels interfere with the communications signal? If the discharge rate is high enough, ESD can be a significant factor in the uncorrected bit error rate (UBER) of the communications link. The characteristics in recent spacecraft of digital transmission, low data rates (such as voice traffic), and low-power uplinks (mobile handheld transmitters) make these effects increasingly important.

Test setup

The testing took place at an electron beam test facility. The facility includes both a 30 keV and 100 keV electron gun. The test sample was bonded to a cold plate, which was isolated from ground by an effective 1Ω resistance, and could be cooled using liquid nitrogen. Another larger plate was positioned behind the cold plate. This “blowoff” plate was used to capture a fraction of the blowoff current from a discharge. The currents flowing from each plate to ground were monitored as two of the test measurements.

The in-band RF power from the element during a discharge was measured using a set of RF equipment, as shown in Figure 1. A narrow bandpass filter was used to replicate the characteristics of the filter used on the TDRS spacecraft. The filtered (in-band) RF was then passed through a limiter, to attenuate the largest pulses. A variable attenuator was used to optimize the dynamic range, by avoiding saturation of any downstream test equipment. A low-noise amplifier (LNA) boosted low-level signals. The signal was then mixed down to 300 MHz, where a logarithmic amplifier produced a voltage proportional to the power of the signal. This voltage was then measured on a digitizing oscilloscope, which was controlled by a personal computer. This setup allowed for real-time measurement of the in-band RF power from a discharge that is generated in the element.

Before the test, a calibration RF signal, at a frequency within the passband of the filter, took the place of the element. This ensured that the oscilloscope reading corresponded to the in-band

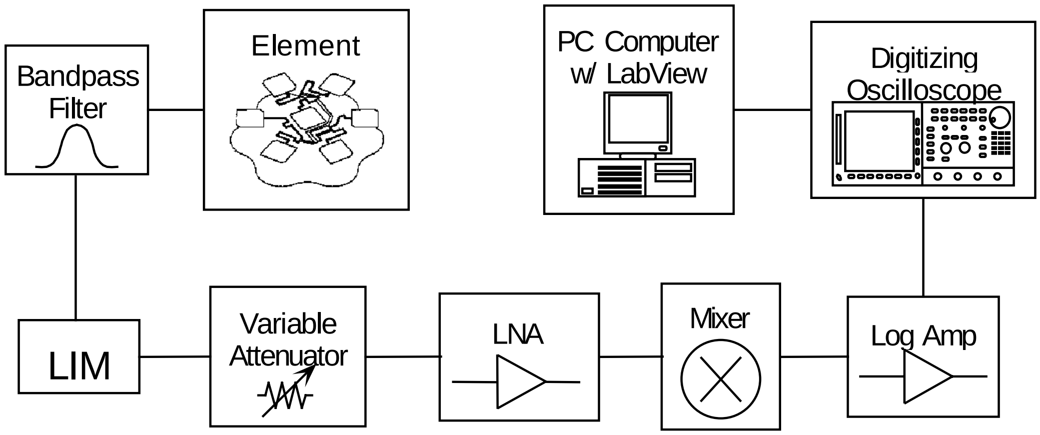


Figure 1. Schematic showing in-band RF measurement chain.

power at the LNA (or limiter, if used) of the spacecraft.

The overall goal of the ESD test was to demonstrate that discharges from the TDRS MA antenna element would not affect the communications signal. This would be accomplished by comparing the measured in-band RF power with LNA damage levels, and measuring discharge rates. Secondary goals were to demonstrate the effectiveness of the limiter and to show ground currents were within design levels.

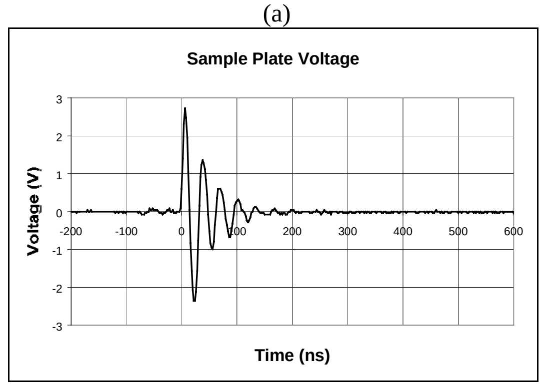
Test conditions

The beam conditions used were 25 keV at 25 pA/cm^2, 90 keV at 10 pA/cm^2, and both beams simultaneously. Low fluxes were used to approximate the flux expected behind the sunshield, which was not included in the test. These test conditions exceed worst-case levels, but were near the low end of what could be reliably measured in the laboratory setup. Because dielectric materials typically become more resistive at cold temperature, testing was done for sample temperatures of both 20C and -80C. The lower temperature closely matches the lowest expected on-orbit temperature for the element.

Test results

Two different types of discharges were collected during the testing, which were termed “blowoff” and “bulk” type discharges. A typical blowoff discharge is shown in Figure 2. The current from the cold plate is initially positive, while the current from the blowoff plate (not shown) is initially negative. This is consistent with electrons leaving the sample during the discharge and collecting on the blowoff plate. The blowoff discharges were typically large, ranging up to 5 amps, and were present under all types of test conditions. A typical bulk discharge is shown in Figure 3. These discharges have currents opposite in polarity from the blowoff discharges, on both the cold plate and the blowoff plate. The bulk discharges are typically small, rarely over 100 mA, but were only present when 90 keV electrons were used, never when only 25 keV electrons were used. It was thus assumed that these discharges occurred at a deeper layer in the antenna element, and consequently

(a)



(b)

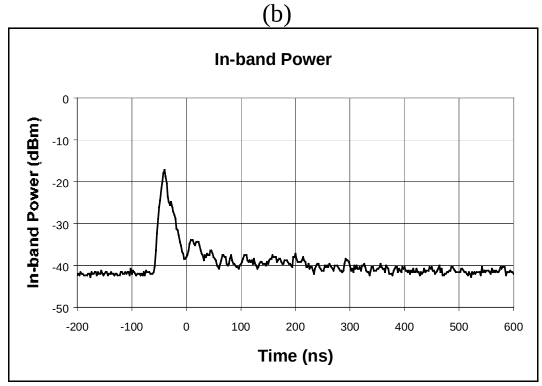


Figure 2. A typical “blowoff” discharge, showing the sample plate current (a) and the in-band RF power (b).

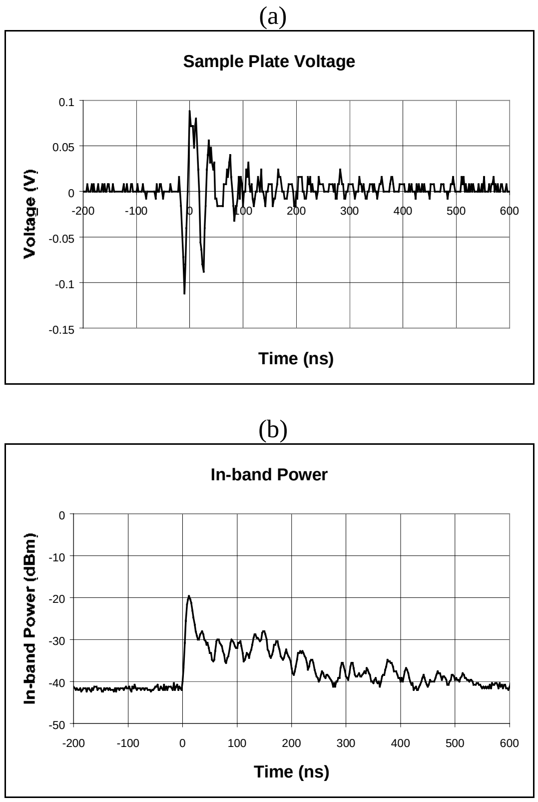


Figure 3. A typical "bulk" discharge, showing the sample plate current (a) and the in-band RF power (b).

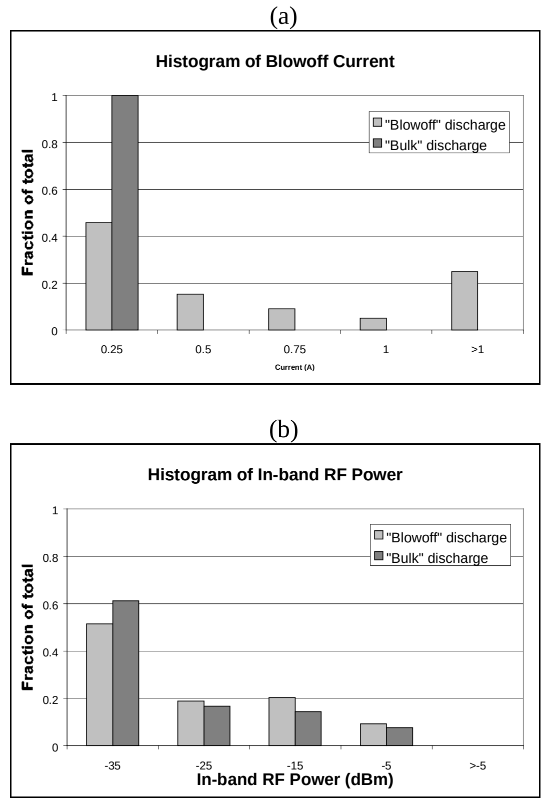


Figure 4. Histograms show a "blowoff" discharge yields a much larger ground current than a "bulk" discharge (a), but is comparable in-band RF power (b).

don't create the avalanche effect necessary for blowoff discharge.

Figure 4 shows the spread in the blowoff current and in-band RF power for each type of discharge. Note that although the distribution of ground currents was very different, there was little difference in the distribution of the in-band power. Although a large contiguous area is necessary for a large ground current, it is not necessary for large in-band RF.

Table 1 shows the results as a function of the test conditions. Over 4000 total discharges were captured. The largest discharge observed during tests with the limiter was at +0 dBm. This is consistent with the design of the limiter, which attenuates signals above +0 dBm. The limiter's effectiveness is further shown by the test without the limiter, which showed a discharge as large as +5 dBm. The limiter thus increases, to over 10 dB, the margin against the LNA damage threshold of +10 dBm (it would take much more than a 10 dB increase *into* the limiter to increase the *output* of the limiter by 10 dB).

Table 1 also shows the discharge rates as a function of the test conditions. Discharge rates were noticeably higher during the 90 keV testing

Table 1. Test results, showing peak in-band RF power and discharge rate for each set of test conditions. The test without the limiter was performed only at T=-180C.

	Peak in-band RF Power (dBm)		Discharge Rate (#/min)	
Test Conditions	T=20C	T=-80C	T=20C	T=-80C
25 keV, 25 pA/cm2	-12	-6	0.0	0.8
90 keV, 10 pA/cm2	-6	-3	5.2	5.4
90 kev, w/o limiter	-----	+5	-----	5.6
dual beam	-13	0	3.5	4.9

compared to the 25 keV testing, which is primarily due to the addition of "bulk" discharges that occur only at the higher energy. A separate analysis showed that these discharge rates do not significantly affect the uncorrected bit error rate.

The ground currents measured did not exceed 10 amps. This is below the design current level for Hughes spacecraft, and thus there is no impact on electronic units due to ground currents from antenna element discharges.

Conclusion

The goal of the ESD test was primarily to demonstrate that discharges from the TDRS MA antenna element would not affect the communications signal. Secondary goals were to demonstrate the effectiveness of the limiter and to show ground currents were within design levels. All of these goals were met with this test.

The in-band RF power from discharges were directly measured. The largest discharge was below the damage level of the spacecraft LNA, and the limiter provided additional margin, to over 10 dB. Even when testing at fluxes that exceed worst-case, discharge rates were not high enough to significantly affect the uncorrected bit error rate of the communications channel. The ground currents measured did not exceed the design level, and thus have no impact on electronic units.

Acknowledgements. The authors thank R. Reynolds for designing and providing hardware for the test setup, and C. Cuevas for discussions on ESD effects on communication systems.

E. Mikkelson, S. Malek, P. Leung, S. Seki, E. Lee and J. Baldauf, Hughes Space and Communications, El Segundo, CA 90245.
(e-mail: Eric.Mikkelson@HSC.com)