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Directional Current Probe Measurements in Multipactor Breakdown

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Current probes (or electron probes) are a simple and yet highly effective diagnostic in detecting multipactor breakdown. The most common geometry for these probes is a piece of semi-rigid cable with a small segment of the center conductor exposed. A small positive bias is applied to the center conductor to collect electrons from the multipactor breakdown. Probes are highly sensitive when set up correctly and within line of sight of the breakdown region – however, they are generally isotropic and are not useful for finely identifying the position of the breakdown.

In this work, a Directional Current Probe (DCP) design is discussed and tested, demonstrating enhanced ability to localize a breakdown region as opposed to standard probes. The DCP consists of a biased collector surrounded by a biased shield, similar to a Faraday cup. By applying a negative bias to this shield, electron collection is limited to the line of sight allowed by the shield opening.

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Abstract

Current probes (or electron probes) are a simple and yet highly effective diagnostic in detecting multipactor breakdown. The most common geometry for these probes is a piece of semi-rigid cable with a small segment of the center conductor exposed. A small positive bias is applied to the center conductor to collect electrons from the multipactor breakdown. Probes are highly sensitive when set up correctly and within line of sight of the breakdown region; however, they are generally isotropic and are not useful for finely identifying the position of the breakdown.

In this work, a directional current probe (DCP) design is discussed and tested, demonstrating enhanced ability to localize a breakdown region as opposed to standard probes. The DCP consists of a biased collector surrounded by a biased shield, similar to a Faraday cup. By applying a negative bias to this shield, electron collection is limited to the line of sight allowed by the shield opening.

Contents

Figures

1. Directional Current Probe Design

1.1 Background and motivation

Current probes (also frequently called electron probes) are what is called a “local” breakdown diagnostic for multipactor testing [1]. These probes use a positive bias on a collecting surface to directly measure current from the RF discharge. All other multipactor diagnostics measure side-effects of the breakdown, such as impact on RF performance (phase null, reflected power detection, and harmonic detection), or photon emission [2].

As they make direct measurements, current probes are regarded as a high sensitivity diagnostic as long as they are properly implemented. This typically requires vent path or other access to the breakdown region. However, current probes collect isotropically, and it can be difficult to use current probes to localize the source of a breakdown. Often when performing testing, being able to localize the source of a breakdown is of key importance, particularly when no breakdown is expected (by either design or modeling).

1.2 Device Geometry

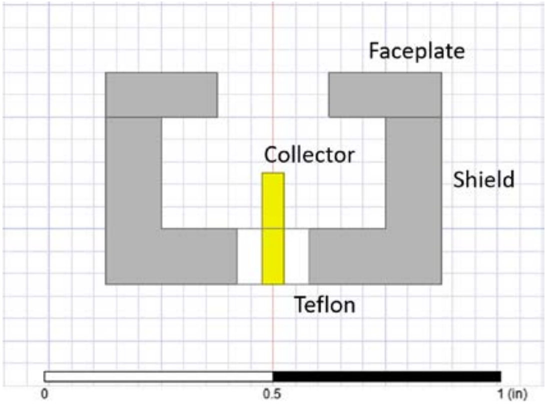

Figure 1. Probe configuration.

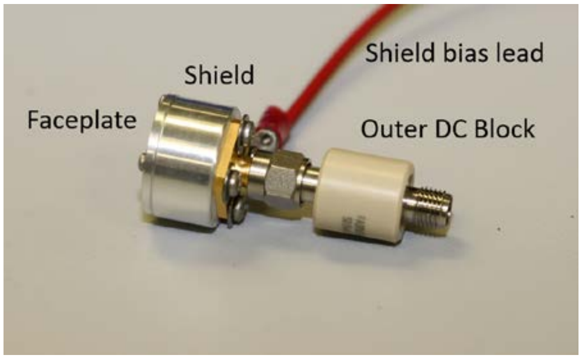

Figure 2. Probe photograph.

Figure 1 depicts the general configuration of the probe. An SMA flange feedthrough serves as the collector. The Teflon insulator of the SMA feedthrough prevents the collector pin from shorting to the outer conductor. The outer conductor shield bolts to the SMA flange, and interchangeable plates can be attached to the shield to effectively limit the field of view of the probe.

The inner collector is biased positively to attract electrons from the multipactor discharge. Both +18 V and +36 V biases were used in this work. The most effective way to apply this bias is simply using 9 V batteries in parallel, usually enclosed within a grounded box. Collector current is measured with a Keithley 6485 picoammeter. The outer shield can be biased either positively or negatively, with a negative bias being essential for performing spatially resolved measurements. The probe is essentially a simple Faraday cup, and the use of interchangeable face plates allows for careful selection of the degree of spatial resolution that is desired. An outer DC block is used to isolate the shield voltage from ground. A photo of the probe is shown in Figure 2.

2. Test Data

2.1 DCP Sensitivity

The effectiveness of the probe both in sensitivity to breakdown and in its capacity to make spatially resolved measurements was assessed using a stripline breakdown device. To assess overall sensitivity to breakdown, the DCP was compared to a control probe. In this test, the control probe was simply the SMA feedthrough with no shield attached.

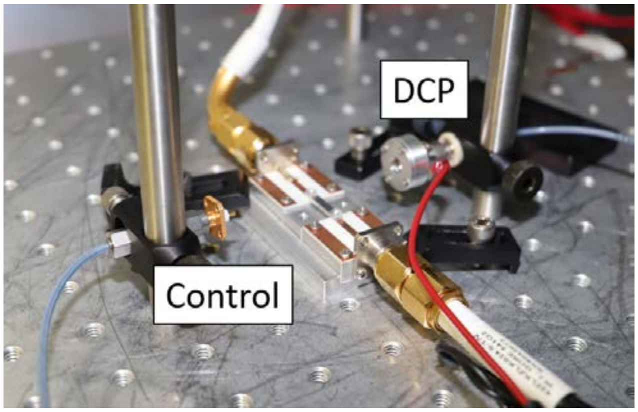

Figure 3. Setup to assess DCP effectiveness.

The probes were placed on opposite sides of the breakdown device, roughly equidistant from the stripline (Figure 3). The same bias was applied to both collectors (either +18 V or +36 V). The collected current on both probes was measured for each breakdown using the analog output voltage of the picoammeters. The ratio of DCP response to control probe response was used to assess the performance of the DCP with shield voltage and faceplate diameter. This corrects for any variation in the electron density of the multipactor breakdown itself.

To initiate breakdown, power was applied to the device in an “instant on” capacity (compared to a traditional breakdown test which ramps test power slowly). This was done to minimize differences in electron density between discharges. A shutdown box [3] was employed to prevent damage to the breakdown device and to minimize device conditioning. The power level was set to 65 W at 1 GHz, which was roughly 1 dB over the breakdown threshold of the device.

Shield voltage was varied from +30 to -30 V for faceplate diameters of 0.125”, 0.375”, and 0.5”. Collector probe bias was set to both +18 V and + 36 V. Results are given in Figure 4 below.

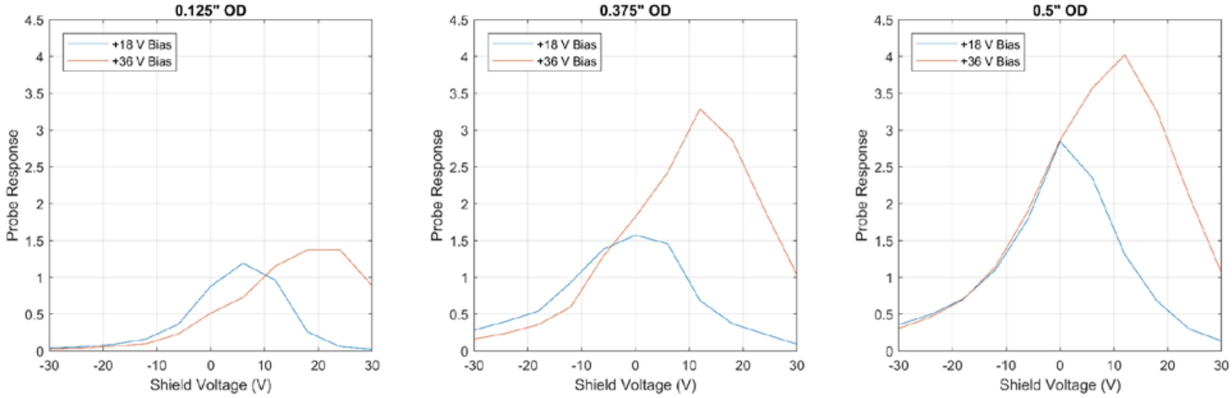

Figure 4. Probe response measured as a ratio of current measured on the DCP to the current measured on the control probe.

Unsurprisingly, probe sensitivity is reduced as faceplate diameter gets smaller and the shield voltage is reduced. A slight positive bias can have an enhancing effect on the probe response, likely because a slight positive bias helps draw current towards the vicinity of the collector, but due to the higher voltage on the collector the majority of current from the discharge still makes its way there. The DCPs can be used this way when probe sensitivity is an issue and spatial resolution is not necessary. Probe sensitivity can frequently be an issue when there is great distance between the device under test and the probe, where breakdown is expected to be internal to a device and the probe must be positioned outside a vent hole, or in magnetic devices where electron confinement prevents electrons from reaching the probe.

2.2 DCP Normal Spatial Resolution

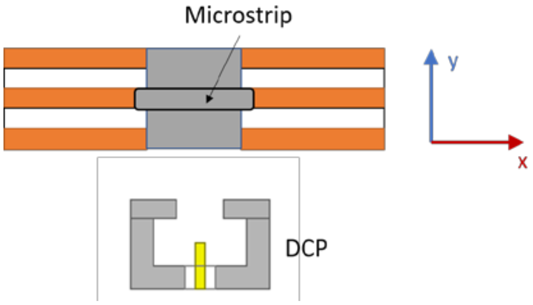

Figure 5. Schematic depicting generalized setup and directions of probe interrogation.

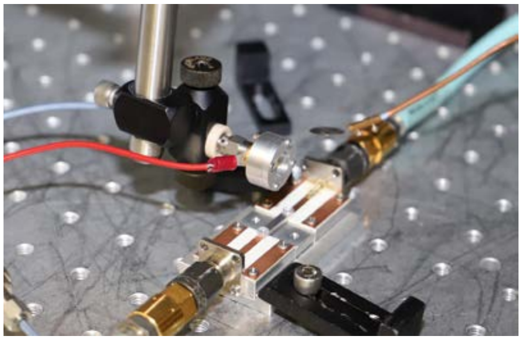

Figure 6. Setup to assess probe response with distance from the breakdown region in the direction across the

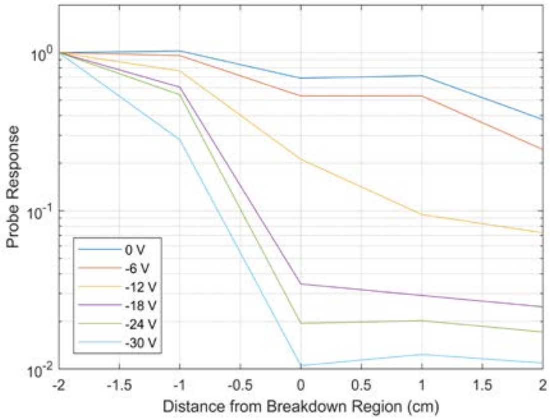

Figure 7. Probe response as a ratio of DCP measured current to center conductor diagnostic measured current.

Next, the spatial resolution of the DCP was evaluated both in the direction along the length of the breakdown device (x) and across the breakdown device (y) (see Figure 5). Due to the orientation of the shield, it is expected that the probe will have optimal shielding in (y) as all field of view of the discharge will be largely blocked by the shield once the probe is beyond the plane of the discharge. To assess this capability, the DCP was attached to a motion arm and translated across the breakdown region perpendicularly (in the y-axis). A photograph of the setup is shown in Figure 6.

Probe response was measured as a ratio of the DCP measured current to the measured current of a center conductor diagnostic [4]. This was needed because it was found the presence of the DCP above the microstrip greatly affected the current measured by a control probe placed within the vicinity of the breakdown region. The probe response versus DCP position is plotted for different shield voltages in Figure 7, normalized to the relative response at y = -2 cm, the measurement with optimal DCP field of view of the breakdown region. The middle of the microstrip in this instance corresponds to y = 0 cm, which is already well shielded even at relatively low voltages. The DCP is highly effective at shielding itself from detecting multipactor events when the body of the shield prevents line of sight to the discharge and a negative bias is applied that is on the order of the collector voltage. The shielding effect is enhanced for narrow faceplate openings and more strongly negative shield voltages, but since both these qualities are known to reduce overall probe sensitivity, DCP characteristics should be optimized for the precise application.

2.3 DCP Lateral Spatial Resolution

Figure 8 depicts a photo of the setup of the lateral probe assessment. A control probe is fixed centered on the breakdown region. The test probe is affixed to a motion stage and current draw is measured along the x-axis. Probe response is plotted in Figure 9 as a ratio of DCP measured current to control probe measured current, normalized to the probes' respective responses at x=0. This plot depicts the effective reduction in probe response as the DCP moves away from the center of the breakdown region. A control (non-shielded) probe was also swept in the x-direction to determine the effect that only the distance from the breakdown region had upon probe response.

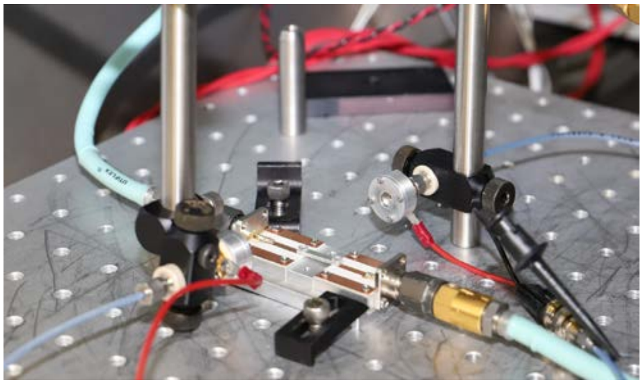

Figure 9. Setup to assess probe response with distance from the breakdown region in the direction parallel to the breakdown device. The DCP (foreground) is attached to a motion stage which allows it to move right to left (the x-axis).

The probe response at x > 2 cm is reduced at all voltages for the smaller faceplate than the larger faceplate, unsurprisingly. The way the probe response is calculated (a normalized ratio of DCP response to control probe response) removes the effect of overall probe sensitivity from the data, so the reduction in response seen is entirely due to the reduction of the field of view due to the smaller faceplate. A smaller faceplate is therefore more effective in resolving the position of the breakdown. Note that for this device, the center of the breakdown region is at x=0, but since the stripline is 12.7 mm long, x=1 cm is effectively still looking at the breakdown directly.

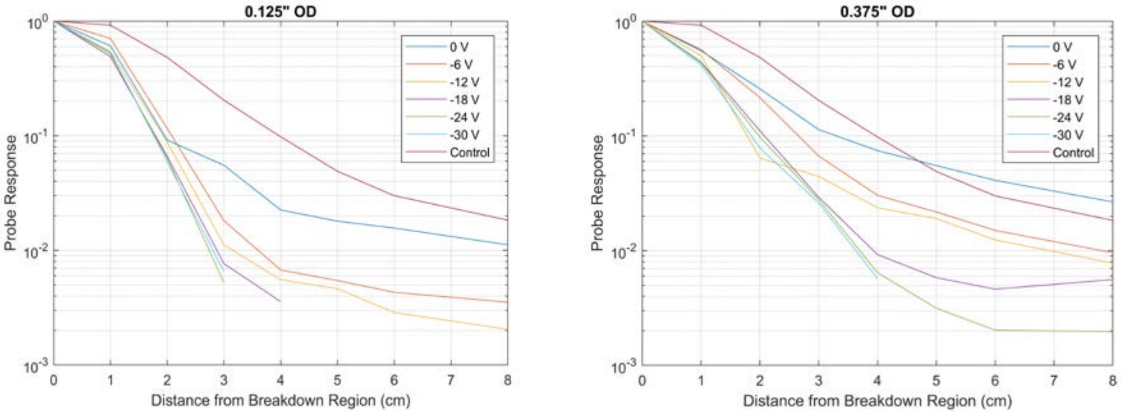

Figure 8. Probe response as a ratio of DCP measured current to control probe measured current, normalized to the probes' respective responses at x = 0 cm. Faceplate diameter is 0.125" (left) and 0.375" (right), and collector bias is fixed at +18 V.

At all voltages there is an immediate reduction in probe response at x = 2 cm and beyond, but in general spatial resolution of the probe response gets better with stronger shield voltage. In practice, it will be wise to select a probe faceplate and shield bias that will adequately resolve the position of the breakdown while maintaining diagnostic sensitivity in order to avoid false results. This means selecting as large a faceplate and as small a shield bias as is sensible (while still maintaining adequate spatial resolution.) Ultimately, this will also depend on the strength of the multipactor event and the distance between the probe position and breakdown region.

For the 0.375” faceplate and no shield bias, the DCP actually has a stronger probe response than the control probe when far away from the breakdown region. This is due to the sensitivity enhancing nature of the shield when unbiased (or at a slight positive bias).

3. Conclusions

Direct electron population measurement of a multipactor discharge is often the most straightforward and unambiguous sign of RF breakdown. This is most commonly done using an exposed wire or plate which has a positive bias applied. While effective, this technique lacks spatial resolution and, while useful for determining whether a breakdown has occurred or not, is not always useful for determining the location of breakdown.

A directional current probe DCP was developed using a biased shield around the probe collector. This technique was demonstrated using a microstrip breakdown device and the relationship between shield voltage, faceplate diameter, and collector bias determined. The probe is most effective in determining the location of a breakdown when it can be positioned so that one potential location is completely obscured by the shield while maintaining field of view of another potential location.

It was also found that these probes can be used to enhance overall probe sensitivity using an open faceplate and a slight positive shield bias. This encourages a broader collection of electrons, and while this technique generally lacks spatial resolution, it may be useful in cases where probe use is otherwise limited or insensitive.

References

[1] “Standard/Handbook for Multipactor Breakdown Prevention in Spacecraft Components,” document ANSI/AIAA S-142-2016, November 2016.

[2] ECSS Secretariat, Space Engineering, Multipaction Design and Test, European Cooperation for Space Standardization, ECSS-E-20-01A, Rev. 1.1 March 2013.

[3] Graves, T.P. et al. Rev. Sci. Inst., 85, 024704 (2014).

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