# Multipactor Thresholds in a Planar Test Cell

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**Abstract:** *A planar test cell was designed and implemented to observe the multipactor effect in waveguide structures. This plug and play device allows for multiple geometries to be machined and easily replaced within the test structure. A direct detection method was used to observe the multipactor effect while the upper and lower thresholds were measured for a 2.1 mm gap at 2.85 GHz. While there is an obvious lower limit to multipactor ( 2 kW), there was no observable upper limit even at powers over 200 kW. This is attributed to the transverse electric field distribution in the dominant $TE_{10}$ mode which is not taken into account in most multipactor theoretical models.*

**Keywords:** multipactor; high power microwaves; electron multiplier tube

## Introduction

Multipactor has been a topic of interest for some time. Recently, interest has been focused on the multipactor phenomena in multiple geometries such as those used in satellite communications. This phenomena can briefly be described as an electron population, typically in vacuum, that moves in sync with an applied RF field. Under such resonance the electrons may impact the walls of their enclosure, normally made of some metal or dielectric, at energies which cause secondary electron emission to occur. Any true secondary electrons are ejected with a much lower energy than their primary electron counterparts and are then subsequently accelerated towards either the same or opposing wall. The utilized experimental setup was specifically designed to investigate the two-sided multipactor mode. It operates at S-Band frequencies (2 – 4 GHz) and incorporates a waveguide structure susceptible to multipactor. A direct electron observation technique is implemented in order to view the multipactor events, and measurements were carried out to find the lower and upper cutoff power of multipactor under pulsed conditions. [1]

## Experimental setup

The experimental setup described herein is composed of three major parts: a high power RF source, a traveling wave resonant ring, and the planar test cell in which multipactor is detected.

A 2.85 GHz magnetron with a nominal pulse width of 4 $\mu$s and maximum output power of 5 MW is incorporated into this experimental setup. This source is used to drive a resonant ring; a passive, high Q structure which can incur powers larger than the RF source provides through constructive interference. Besides providing gain, the resonant ring sensitivity is paramount to the experiment since the multipactor effect can cause easily observable detuning within the high Q structure. Finally, a planar test section was designed and implemented which takes advantage of operating the S-Band structures in the dominant $TE_{10}$ mode. Operation within this mode allows for the manipulation of the waveguide height, in this case a WR-284 waveguide, without affecting the cutoff frequency of the waveguide itself. The final design for the device under test (DUT) incorporates a step-down impedance transformer of specific gap size to not only increase the electric field strength within a certain portion of the DUT, but to also allow for the multipactor effect to occur in a small and observable portion of the ring itself. More information on the resonant ring is found elsewhere. [2]

The DUT is composed of a vacuum sealed, plug and play impedance transformer section (cf. Fig. 1). This setup allows for various impedance transformer geometries to be machined from copper bars which are easily replaceable within the structure. In a separate chamber above the gap in which multipactor is to occur sits an electron multiplier tube (EMT), which is used to directly observe the multipactor event. This direct observation technique allows for the measurement of electron multiplication without the perturbation of the fields within the waveguide structure. [3]

## Experimental results

Measurements were carried out in pulsed conditions in order to determine the lower and upper cutoff in which multipactor would occur within a 2.1 mm gap. A UV source was used to deliver seed electrons into the gap during the rather short pulse duration. Fig. 2 demonstrates a lower multipactor onset occurring at approximately 2.5 kW at 2.85 GHz.

With the lower threshold established, the upper bounds of the multipactor threshold were tested. The multipactor phenomena showed no signs of stopping as the power was increased, and a maximum power of over 200 kW was reached before concluding the experiment. Even with this large amount of power, the EMT detected multipacting events which preceded the detuning of the ring and large loss of power. Fig. 3 demonstrates the multipactor effect taking place at large RF powers. Assuming an incident electron moving normal to the broadside wall, the upper cutoff power to where the surface would yield no true secondaries is calculated to be approximately 90 kW. [4]

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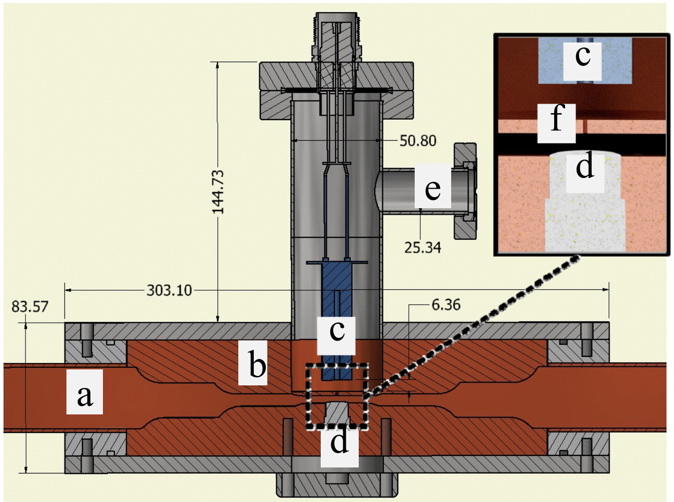


**Fig. 1.** Sectional detail of DUT. a) WR-284 waveguide, b) Impedance transformer plate, c) EMT, d) Replaceable electrode, e) Vacuum port for EMT chamber, f) 1 mm aperture for electron passage. Gaskets are placed around the perimeter of b) and c) in order to provide good vacuum seal. [3]

## Discussion

While the low power threshold of single and two-surface multipactor has been widely discussed, little has been mentioned of the upper cutoff or the range in which multipactor occurs. [5] Due to the peak of the electric field produced within a waveguide in the dominant $TE_{10}$ mode being at the center of the broadside dimension, it would make sense that larger powers would eventually cause electrons within this area to have energies much higher than the secondary crossover point of the material. While this is true, many rudimentary models and calculations of multipactor assume a homogeneous electric field. [1] For a waveguide structure, this is not true since the electric field amplitude is in the form of a half sine when viewed down boresight of the waveguide structure. This means that the electric field decreases as one moves from the center of the waveguide towards one of the two waveguide side walls. It is then reasonable to assume that the theoretical lower power threshold has the appropriate electric field towards the center of the waveguide broadside dimension, but then starts moving towards the walls as the power is increased. Theoretically this would mean that there is always a point along the electric field distribution within the waveguide which meets the criterion for multipactor to occur. Thus, supported by the experimental results, it is the authors' opinion that an upper limit to the multipactor phenomena does not exist in a rectangular waveguide, simply due to the inhomogeneous electric field. In the extreme case of very high fields, of course, the multipactor will transition into vacuum breakdown.

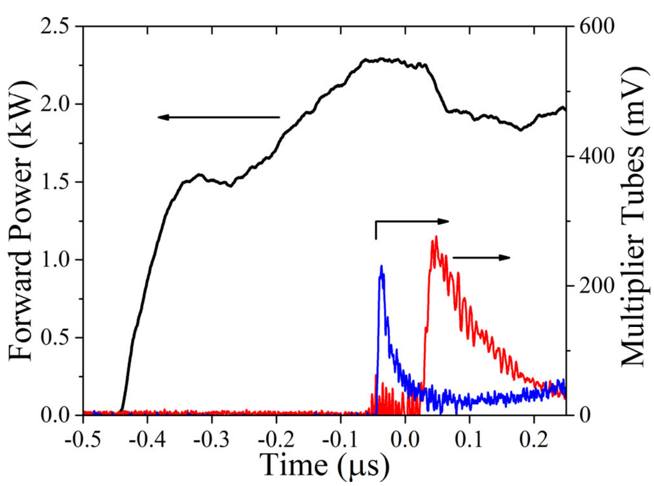


**Fig. 2.** Low power threshold of multipactor at 2.85 GHz. The forward power within the ring shows a peak of approximately 2.5 kW before subsequent detuning. The PMT flash, shown in blue, precedes the multipactor event viewed by the EMT shown by the red curve.

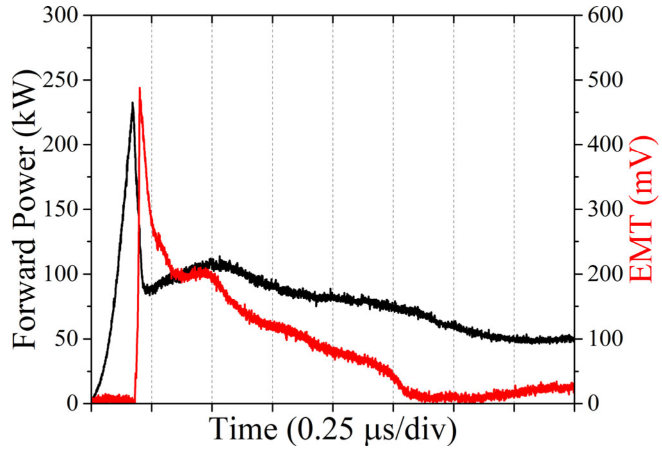


**Fig. 3.** Multipactor occurring at a forward ring power of approximately 230 kW. As the power continued to be raised within the DUT, there was no observable upper limit to the multipactor effect.

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