Multipactor Effects on Signal Quality in Transmission Lines with Impedance Mismatches

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Abstract: *Multipactor is a resonant AC discharge of secondary electrons driven by RF signals and has been a center point of current interest because of its detrimental effects in space satellite communications. Much effort has been placed in mitigating/suppressing or determining the onset of multipactor. However, not much attention has been directed to the effects of multipactor, should it occur, on the quality of the original signal. In this paper, we will look at different types of multipactor (single-surface and two-surface) and how they may affect a signal (single-tone and dual-tone) in planar and coaxial transmission line systems with impedance mismatches. I-Q plots that characterize the multipactor effects will also be presented.*

Keywords: multipactor; signals

Introduction

Multipactor is a nonlinear phenomenon whereby stray electrons, born from any myriad of processes including cosmic rays, become phase-locked to an RF signal and are accelerated by the electromagnetic fields of the signal with sufficient energy until impact with device walls leads to secondary electron emission (SEE). Because the multipactor electrons are resonant with the RF signal, this process may continue, leading to an exponential growth in the electron population. Localized heating, performance degradation, power dissipation, increased system noise, and even damage or complete destruction of the device may result [1]. Thus, it is usually best to mitigate or suppress multipactor in the desired operating parameter regime of a given device.

In recent years, higher demand has been placed on a single satellite to perform the functions of multiple satellites, necessitating complex multi-frequency operation. This inevitably leads to higher RF payload and increased threat of multipactor [2,3]. Consequently, the main concern is signal distortion by multipactor. This concern is addressed here.

Reference [4] has analyzed this problem before, but the examples considered were restricted in scope to perfectly matched coaxial lines. Reference [4] also generalized the approach to include planar transmission lines. Here, we will analyze what happens when impedance mismatches and subsequent end reflections are introduced in the transmission line systems.

Formulation

Transmission Line Model

The transmission line model used here is the same as in [4], and is shown in Fig. 1, where end reflections are allowed at the source and load through their termination impedances Z_S and Z_L, respectively. The general, complex signal is modeled by the voltage source V_S located at z = 0.

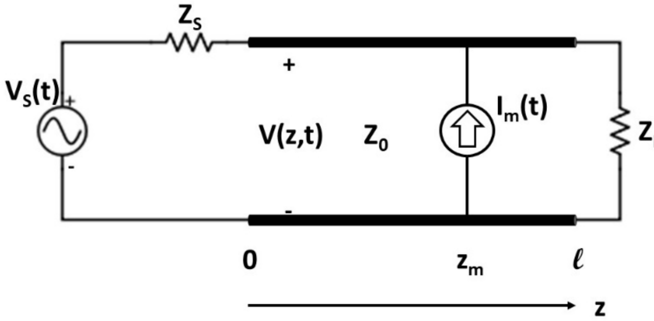

Figure 1. Transmission line model to analyze multipactor effects on signal quality with end reflections.

Localized multipactor is modeled as a current source [5] that is placed at $z = z_m$ along the transmission line. Like in [4], we calculate the contaminated signal downstream at $z = \ell$ due to the presence of the multipactor current I_m, which is model dependent. End reflections arising from impedance mismatches between the load at $z = \ell$, the source at z = 0, and the characteristic impedance of the transmission line itself may affect the stability of the multipactor. In certain regimes, the multipactor may be suppressed, and in others, it may continue to grow. A parameter sweep is done to determine these regions.

Multipactor Electron Current Model

The multipactor current I_m is highly model dependent. For simplicity, we use a 1D coaxial model consisting of a thin annular electron sheet [5], similar to that used by Udiljak et al. [6] and by Sorolla et al. [7]. The force law for this electron sheet reads:

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$$m_e \frac{d^2\rho'}{dt^2} = F(z_m, t) \tag{1}$$

$$F(z_m, t) = \frac{\Lambda_1 \ln\left(\frac{\rho'^2}{ab}\right) - \Lambda_2 \sum_n \left[V_{RF,n} \sin(2\pi f_1 t + \alpha) + \beta V_{RF,n} \sin(2\pi f_2 t + \alpha + \gamma)\right]}{\rho'}, \tag{2}$$

where $\Lambda_1 \equiv \frac{e^2 N_e}{4\pi\epsilon_0 l \ln\left(\frac{b}{a}\right)}$, $\Lambda_2 \equiv \frac{e}{\ln\left(\frac{b}{a}\right)}$, ρ' is the radial position of the electron sheet, a and b are the inner and outer conductor radii respectively, $V_{RF,n}$ is the RF voltage amplitude of the nth reflected wave, and f_1 and f_2 are the frequencies of the first and second tones respectively. α is the multipactor electron launch phase relative to the voltage signal of the first tone, β is the ratio of voltage amplitudes between the second tone and the first, and γ is the relative phase of the second tone to the first. N_e is the number of multipactor electrons present in the sheet, and n refers to the transit of the signal (from source to load or from load to source).

A restriction of this 1D model is that the annular electron sheet is only allowed to move radially and therefore impacts the inner and outer electrodes at normal incidence. When such an impact occurs, the electron-surface interaction and consequent SEE is governed by a modified Vaughan model [8,9], formulated to better capture the low energy impacts and possible reflections of electrons from the surfaces. Attempts will be made here to include azimuthal effects and angular momentum conservation in the model.

Results

We use the same test case in [4], but with $Z_S = 20\ \Omega$ and $Z_L = 100\ \Omega$.

Fig. 2 shows the multipactor electron current induced in the transmission line (proportional to the "error" in the signal) over the time span considered. The effects of this perturbation due to multipactor and end reflections will be presented via the in-phase and quadrature (I-Q) plots of the normalized error vector of the output signal, a sample of which is shown in Fig. 3. Other examples, including multi-tone and digital signals, single-surface multipactor, and planar geometry, will also be presented.

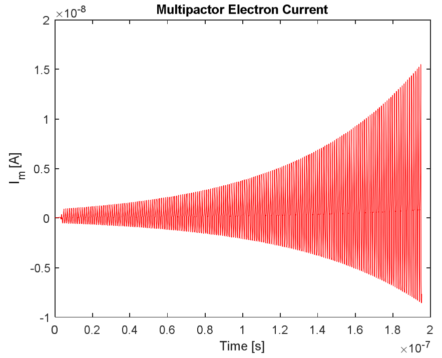

Figure 2. Time evolution of the multipactor electron current.

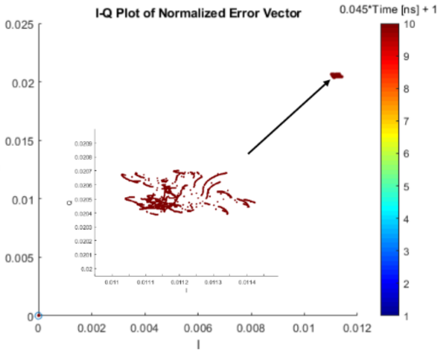

Figure 3. I-Q plot of normalized error vector. The "error" is relatively small and localized.

Acknowledgements

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