Resonance-Related Fluctuations on Experimental Characteristic Impedance Curves for PCB and On-Chip Transmission Lines

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Abstract

It is well known that the fluctuations in experimentally obtained characteristic impedance versus frequency curves are associated with resonances originated by standing waves bouncing back and forth between the transitions at the transmission line terminations. In fact, microwave experimentalists are aware of the difficulty to completely remove the parasitic effect of these transitions, which makes obtaining smooth and physically expected frequency-dependent curves for the characteristic impedance a tough task. Here, we point out for the first time that these curves exhibit additional fluctuations within the microwave range due to standing waves taking place within the transition itself. Experimental demonstration of this fact is carried out by extracting this fundamental parameter from measurements performed on on-chip and printed circuit board (PCB) lines using probe pad adapters and coaxial connectors. This clarifies the conditions under which typical extraction algorithms remain valid.

The fundamental parameters for the representation of the electrical properties of uniform transmission lines (TLs) guiding signals in single mode are the propagation constant (γ) and the characteristic impedance (Z_c) [1]. In this regard, whereas the determination of γ is straightforward solving eigenvalue equations involving measurements of lines varying in length [2], obtaining Z_c is cumbersome [3]. This is because this later parameter is strongly affected by the return loss of the TLs [4]. In fact, even after applying the most advanced de-embedding methods to the measurements, significant fluctuations in the Z_c curves are observed at microwave frequencies determined from experimental data [5]. These fluctuations are associated with the interaction of standing waves with the imperfect terminations of the TLs. Specifically, the fluctuations occur at resonant frequencies where half the wavelength of the signal equals the physical length of the line.

Experiments were performed on three different structures, 1) Transmission lines manufactured using a CMOS process, with lengths l = 1380 μm, 2450 μm, and 4600 μm, over a metal patterned ground shield separated a distance h = 0.8 μm from these. 2) Lines on PCB terminated with probe pad adapters, using a laminate with nominal permittivity and loss tangent of 2.2 and 0.0019, respectively. The lengths of the lines are l = 12.7 mm and 101.6 mm, and present a design $Z_c \approx 51\ \Omega$. 3) Lines on PCB terminated with coaxial connectors designed to present $Z_c \approx 72\ \Omega$ and are terminated with 40-GHz general precision connectors (GPC) with a 2.92 mm interface.

The resonances associated with reflections originated by standing waves in practical transmission line test structures were analysed to determine the corresponding effect on experimentally determined characteristic impedance data. It was concluded that short lines, for instance on chip, are less impacted by this undesired effect when compared to lines on PCB. In fact, the typical line-line algorithm assuming that the transitions are simply modelled using a shunt admittance provides acceptable results up to some tens of gigahertz. Nonetheless, for long lines, such as those on PCB, the fluctuation effect is considerable and is further worsened when using transitions that also exhibit a noticeable distributed nature within the measurement range. This latter effect has been identified for the first time in this paper.

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