A Discussion of Passive Components for Broadband Power Line Communication Coupling Circuits

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***Abstract*— This paper aims to analyze how the characteristics of passive components impact the design of power line communication (PLC) coupling circuits for broadband applications. Based on measurement results from the Impedance Analyzer E4491A, we show that plated through-hole and surface mount device components present distinct behaviors in the higher frequencies. Consequently, we point out that the implementation type of passive components is essential when the design has to result in impedance matching and flat frequency response for minimizing distortions in the coupling process in high frequencies.**

***Keywords*— coupling, broadband, power line communication.**

I. Introduction

The literature shows interesting advances related to the design of power line communication (PLC) coupling circuits [1]. However, literature also shows a lack of discussions about the frequency-dependent characteristics of passive components (i.e., resistor, capacitor, and inductor) when frequency increases, which is very important for designing broadband PLC coupling circuits. In high-frequencies, resistors, inductors, and capacitors are more impacted by parasitic effects [2], which demand more elaborated models to represent them because the electromagnetic wave propagation begins to dominate over Kirchhoff's current and voltage laws [3].

It is well-established that resistors, inductors, and capacitors are often described in terms of nominal values at a particular frequency, quality factor, and self-resonant frequency (SRF). Also, for low frequencies, a resistor is well-represented by a constant resistance R while capacitor and inductor are defined by the reactances ΩL and $1/\Omega C$, respectively. However, as frequency increases, more complex models for these passive components have to be considered for dealing with high-frequency content signals, which are processed by radio frequency (RF), microwave, and broadband PLC devices. Electric circuit models for passive components operating in high-frequencies can be found in [4].

This paper aims to analyze the behavior of the aforementioned passive components in the frequencies between 1 MHz and 3 GHz[1]. Based on measurement results, which were obtained by using a RF impedance analyzer, we point out some limitations and constraints that must be considered for designing broadband PLC coupling circuits when surface mount device (SMD) and plated through-hole (PTH) types of passive components are considered [5]. It affects directly the frequency response, input and output reflection parameters filter of the PLC coupling circuit.

This study was supported in part by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) - finance code 001, CNPq, INERGE, and FAPEMIG.

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[1]The frequency band used by broadband PLC systems is between 1.705 and 100 MHz; however, we show the results up to 3 GHz because it can be useful for more readers.

II. Resistor

The equivalent RF circuit model of a resistor is composed of a resistance R of nominal value and two inductances L for modeling the leads. Also, the parasitic capacitances account for the wire arrangement, which represents a certain charge separation effect modeled by a capacitance C_{A} and interlead capacitance C_{B}, see Fig. 1. Regarding the impedance magnitude, we see that measurement results of the PTH impedance magnitude $|Z|$ of a carbon resistor is equal to its nominal value (i.e., 100 Ω) up to 100 MHz. Thereafter, the impedance magnitude of the PTH resistor increases approximately exponentially with the frequency up to 3 GHz due to leads of the L inductance, in which the skin effect become noticeable. The impedance magnitude of the SMD resistor shows a constant value up to 1 GHz and at the frequency of 1.2 GHz, the inductance L resonates with the capacitance C_{A}, and, as a consequence, it produces a peak of 300 Ω in the impedance magnitude.

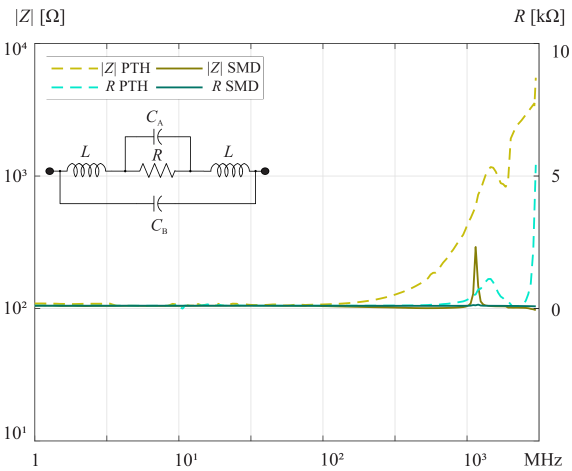

Fig. 1: The impedance magnitude and the resistance value R of PTH and SMD resistors for the 100 Ω value.

The nominal value of R is constant and equal to 100 Ω for the SMD resistor in the frequency band between 1 MHz and 3 GHz. If the PTH resistor is assumed, however, the consequence of the skin effect, stray capacitance, and the inductor leads become dominant, increasing the impedance, which causes the value of R to vary above 800 MHz. As a result, the poor high-frequency performers of PTH resistor become noticeable, i.e, the resistors tend to exhibit increased impedance magnitude . To illustrate it, the nominal values of R are equal to 150 Ω in 1.3 GHz and 5.1 kΩ in 3 GHz, see Fig. 1.

III. Capacitor

The equivalent RF circuit model of a capacitor is shown in Fig. 2, where C is equal to the nominal capacitance value and L is the inductance of the leads and plates. The resistance R_S consists of resistance in lead-in wires, contact surfaces, metalized electrodes, and dielectric losses. The resistance R_P represents the insulation resistance. During current flow, the losses related to R_S and R_P are dissipated by Joule heating. At low frequency, the impedance provided by capacitance is dominant, and the capacitance value is close to the nominal one. At sufficiently high-frequency, the inductance value takes over, and the impedance starts to appear inductive, which is a result of an effect known as SRF. For this capacitor of 56 pF, we see that the frequencies of 180 MHz for the PTH capacitor and 2 GHz for SMD capacitor defines the starts of the inductive behavior of these capacitors. The impedance magnitude of for both capacitors decreases exponentially as the frequency increases up to certain values. This behavior is due to the low values of the capacitor reactance. After the SRF, the impedance magnitude of both capacitors increases due to L inductance leads.

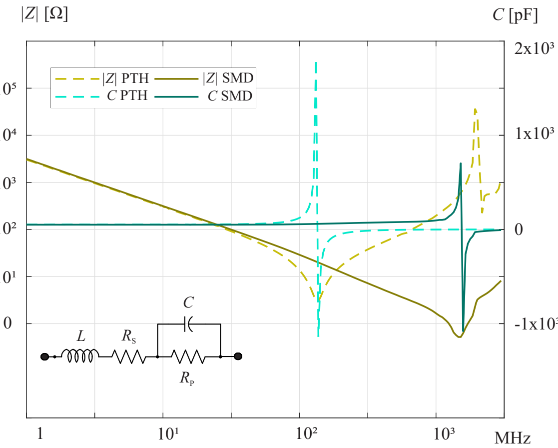

Fig. 2: The impedance magnitude and the capacitance value C of PTH and SMD capacitors for the 56 pF value.

IV. Inductor

Fig. 3 shows the equivalent RF model of an inductor. It is composed of the inductance nominal value equal to L, a heat-dissipation loss modeled by the resistance R_S, and a capacitance C_D that stands for the small parasitic capacitors formed between the windings. It also shows the impedance magnitude of PTH and SMD inductors of inductance equal to 47 μH. Note that impedance magnitude rises somehow exponentially as the frequency increases. It is worth mentioning that C_D and L form a parallel resonance circuit, and, as a consequence, the impedance magnitude shows a V-shape characteristic. The parasitic capacitance C_D in parallel with the inductor results in the SRF, which occurs in 9 MHz for PTH and 30 MHz for the SMD inductor. From Fig. 3, the behavior of the inductance L deviates from the expected behavior of an ideal inductor, and the impedance magnitude increases faster as the frequency approaches the SRF. As the frequency increases, the influence of the parasitic capacitance C_D becomes dominant and the impedance magnitude also decreases. In other words, the inductor's reactance begins to decrease, and the inductor works as a capacitor.

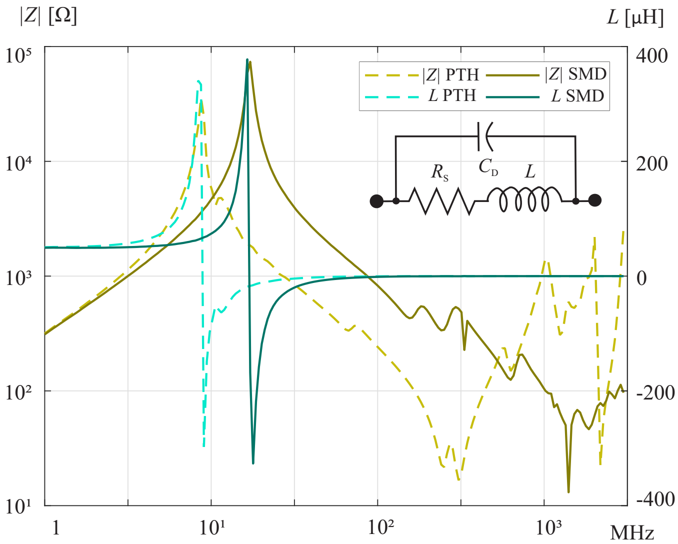

Fig. 3: The impedance magnitude and the inductance value L of PTH and SMD inductors for the 47 μH value.

V. Conclusion

This work has analyzed the behavior of the passive components at high-frequency using an Impedance Analyzer. The attained results have shown that the PTH and SMD implementations of passive components present distinct behaviors when frequency increases. For high-frequencies, the SMD implementation offers the best performance. Also, the knowledge of SRF and the impedance magnitude are crucial for designing effective broadband PLC coupling circuit.

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