semiaxes are, respectively,

$$\begin{cases} a = c \cosh \eta_0 \\ b = c \sinh \eta_0. \end{cases} \tag{7}$$

To determine the magnetic field inside the elliptical conductor, we start from the magnetic vector potential, which has only a z-component, i.e., A_z, here. It satisfies the following differential equations inside and outside of the conductor [3]:

$$\begin{cases} \nabla_{xy}^2 A_z = -\mu J \text{ inside the ellipse } (0 \le \eta \le \eta_0) \\ \nabla_{xy}^2 A_z = 0 \text{ outside the ellipse } (\eta_0 \le \eta < \infty). \end{cases} \tag{8}$$

In addition, the potential and its normal derivative are continuous on the boundary of the elliptical conductor, it remains bounded and unique-valued for $\eta = 0$, and it behaves properly (not faster than $\eta \sim \log|\text{distance}|$) at large distance. In (8), J is the constant current density related to the total current I

$$J = \frac{I}{\pi ab} = \frac{2I}{\pi c^2 \sinh 2\eta_0}. \tag{9}$$

The elliptic cylinder coordinates (6) allow a proper separation of variables to find an analytical solution of (8) for the magnetic vector potential inside and outside the elliptical conductor

$$\begin{cases} A_z = -\frac{\mu J c^2}{8}\left[\cosh 2\eta + \cos 2\varphi - e^{-2\eta_0}\cosh 2\eta \cos 2\varphi\right] \\ \quad (0 \le \eta \le \eta_0) \\ A_z = -\frac{\mu J c^2}{8}\left[\cosh 2\eta_0 + \sinh 2\eta_0 \left(2(\eta - \eta_0) + e^{-2\eta}\cos 2\varphi\right)\right] \\ \quad (\eta_0 \le \eta < \infty). \end{cases} \tag{10}$$

From (10), the expression of the magnetic field is derived, which is inside the elliptical conductor

$$\begin{aligned} \mathbf{H} &= -\frac{1}{\mu}\mathbf{u}_z \times \operatorname{grad} A_z \\ &= \frac{Jc^2}{4}\frac{1}{c\sqrt{\cosh^2\eta - \cos^2\varphi}}\Big[\sin 2\varphi\left(1 - e^{-2\eta_0}\cosh 2\eta\right)\mathbf{u}_\eta \\ &\qquad + \sinh 2\eta\left(1 - e^{-2\eta_0}\cos 2\varphi\right)\mathbf{u}_\varphi\Big]. \end{aligned} \tag{11}$$

The dc internal inductance is then found from the integration of the square of the components of the magnetic field over the complete elliptical cross section

$$\begin{aligned} \frac{L_i}{\ell} &= \frac{\mu}{I^2}\iint_{\text{Ellipse}} |\mathbf{H}|^2 dS = \frac{\mu}{I^2}\int_0^{\eta_0}\int_0^{2\pi} |\mathbf{H}|^2 c^2(\cosh^2\eta - \cos^2\varphi)\, d\eta\, d\varphi \\ &= \frac{\mu}{4\pi}e^{-2\eta_0}\sinh 2\eta_0. \end{aligned} \tag{12}$$

From (7), η_0 can be determined as a function of the semiaxes a and b. When substituted into (12), the final expression (1) is obtained.

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Some Issues on the Characterization of Power-Line Filters and Related Standards

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***Abstract*—This correspondence reviews the literature related to the worst-case behavior of power-line filters (PLFs). It shows that the current standards on PLFs provide test methods that cover worst-case performance.**

***Index Terms*—Conducted emission, conducted interference, input impedance, power-line filter (PLF).**

I. Introduction

A recent paper on the characterization of power-line filters (PLFs) states that "current standards used to characterize PLFs are based on separate phaseless measurements of the attenuation of the common and differential modes using 50-Ω line and load impedances" [1]. In this correspondence, we want to show that this statement does not fully describe the state of the art, and take this opportunity to explore the bibliography related to the worst-case performance of PLFs.

II. Worst-Case Behavior of PLFs

It has been known for a long time that insertion loss measurements of PLFs performed in a 50-Ω measurement system do not characterize the performance of the filter when it is inserted between an actual apparatus and a power network [2], [3]. Consequently, the concept of worst-case insertion loss was introduced, "worst-case" referring to the lowest effectiveness of the PLF in the stopband, when the input impedance and/or the output impedance may take on any value in the half complex plane $\mathrm{Re}(z) > 0$. Measurement techniques were defined for the worst-case insertion loss [2], [4]. Also, it was recognized that high-frequency losses were necessary to obtain an assuredly effective PLF [2], [5]–[8], i.e., a PLF providing a sufficient worst-case insertion loss in the stopband.

The minimum voltage attenuation was also introduced in the 1960's and used for designing PLFs for a minimum worst-case behavior [9]–[13].

Later, several other concepts for taking into account the worst-case behavior of a PLF were introduced: the minimum current attenuation, the mismatch attenuation in the worst case at the input or at the output, the total attenuation in the worst case at the input or at the output, the minimum attenuation, and the input impedance domain of the filter [15]–[18] (these papers may be downloaded from the http://www.eurexcem.com website). It was shown that, for a lossless filter, the input impedance domain is the half complex plane $\mathrm{Re}(z) > 0$, so that the mismatch attenuation in the worst case at the output and the total attenuation in the worst case at the output are equal to 0 dB.

Considering that available measurements of power network impedance [19]–[23] provided some information on the possible differential-mode power network impedances, the concept of worst case in a specified impedance domain was introduced [18], in which the input impedance and/or the output impedance may take on any value in a prescribed frequency-dependent subset of the half complex plane $\mathrm{Re}(z) > 0$.

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We note that it has been shown that lossy multiple section PLFs (partitioned filters) are suitable to obtain good worst-case performances at a low cost [7], [17].

III. Standards on EMC Filters

The old MIL-STD-220 military standard [24] defines methods for the measurement of the insertion loss of PLFs performed in a 50-Ω measurement system. However, it is recognized that the test methods in this standard are intended for quality control, but do not represent conditions that exist in actual circuits or installations [25].

The international standard CISPR 17 [26] describes a similar test method for a 50-Ω or 75-Ω measurement system, and two worst-case methods: a quasi-analytic method in which the minimum voltage attenuation is determined from two measurements, and an approximate method in which the insertion loss is measured in a 0.1-Ω/100-Ω system and in a 100-Ω/0.1-Ω system.

The only standard on PLF listed in the references of [1] is ANSI C63.13-1991 [27], which is a guide intended to provide a basic understanding of the application, evaluation, and safety consideration of PLFs. This document is not a standard used to characterize PLFs.

The IEEE has recently introduced the IEEE Standard 1560-2005 [28], which provides several methods for the measurement of PLFs. In addition to the unavoidable quality assurance test where insertion loss is measured in a 50-Ω system, it provides three test methods for non-50-Ω impedance and an annex on the worst-case behavior of PLFs. This standard also includes a method for S-parameter measurement, which may be used to analytically derive any worst-case parameter, since it is a full characterization of the PLF.

IV. Conclusion

Two major standards on the characterization of PLFs, CISPR 17 and IEEE Standard 1560-2005, describe test methods that are far more elaborate than insertion loss measurements performed in a 50-Ω system. These test methods provide valuable information on the worst-case behavior of a PLF.

It must be recognized that these test methods are not (yet) widespread in data sheets of PLF manufacturers and in filter specifications produced by engineers using PLFs in their electronic designs. One of the cause of this situation is that many EMC tests applicable to an apparatus comprising a PLF use artificial mains networks presenting a fixed arbitrary impedance with respect to a ground plane [29, Sec. 5-1].

CISPR 17 and IEEE Standard 1560-2005 explicitly use the knowledge on the worst-case behavior of PLFs summarized in Section II. However, this knowledge needs to be expanded since many theoretical (analysis and synthesis) and experimental questions remain unanswered.

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