IMPACT OF IMPEDANCE MISMATCH ERRORS ON WIDEBAND TRANSMISSION LOSS MEASUREMENTS OF RECEIVERS

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ABSTRACT

To determine the level of electromagnetic vulnerability (EMV) of a system, one must determine the attenuation of the transmission path from the exterior of the system to the interior upsettable or damageable circuitry. Since many system transmission paths have non-50-ohm characteristic impedances when measured outside their normal operating band, mismatch errors arise in the transmission and return loss measurements when these are obtained using 50-ohm instrumentation. This paper presents a method of determining the amount of transmission loss error that occurs when non-50-ohm instrumentation is used, as well as the impact of this error on the estimates of system susceptibility.

INTRODUCTION

In both electromagnetic interference (EMI) and electromagnetic pulse (EMP) assessment technologies, it is necessary to determine the attenuation of the transmission path from the exterior energy collector to the interior semiconductor component. The radiation power density that will transfer sufficient energy to the component to affect it. The undesired electromagnetic energy is typically coupled to system by an intentional antenna or by unshielded wires, which may act as antennas, and is transferred to interior components such as receiver detectors, wires, which may act as antennas, and is transferred to interior components such as receiver detectors, amplifiers, or mixers, which may be adversely affected by the rf energy. These components are typically semiconductor devices.

The diagram shown in figure 1a represents the three major areas of the system transmission network: the energy collector or "antenna," the transmission path itself, and the critical component that affects the system operation. To determine the exterior radiation power density required to affect the critical system component, we must know the power threshold of the component, PL, at which the damage or upset is induced, the transmission path loss, ap, and the effective aperture (area), Ae, of the energy collector. With these three parameters characterized as a function of the incident radiated frequency, polarization, modulation, and illumination angle, it is possible to calculate the radiation power density required to degrade the system.

Although each of the three parameters is important to characterize the susceptibility threshold of a system, the largest contributor is normally ap, the transmission loss of the path from the antenna output to the component input. The transmission loss is critical because it is a direct measure of the amount of undesired rf that can reach the critical system components and potentially damage or upset them.

This paper presents a method of determining the error that arises due to mismatch with non-50-ohm transmission lines for several different source, path, and load impedances, and assesses the impact of the error on the system susceptibility level.

Figure 1. Block diagram showing (a) typical system transmission path and (b) network analyzer set up to measure transmission loss.

PROBLEM

Ideally, the attenuation of the transmission path from the antenna output to the component input should be measured with instrumentation that has the same impedances as the system interfaces and therefore introduces no mismatch errors in the transmission loss measurement. However, because the undesirable rf energy may in fact be anywhere within a wide band of frequencies, the transmission path attenuation of the system must be measured over that wide bandwidth to characterize its frequency response. The interfaces between the system and the instrumentation are not designed for these frequencies, and so are typically not matched to each other. A typical setup used to measure the transmission loss of a system is shown in figure 1b.

Since network analyzers measure transmission path characteristics with reference to 50 ohms, these characteristics do not change when the transmission path interfaces with other 50-ohm circuits; however, most coupling structures (input ports) tend to be in the 25- to 100-ohm range, semiconductor components (output ports) tend to be in the 5- to 20-ohm range, and the transmission paths (wires and circuit boards) tend to be in the 100- to 200-ohm range. The problem is therefore that the transmission loss measurements of paths normalized to 50 ohms are not directly usable. Despite the problems arising from mismatched characteristic impedances, the typical approach in EMI assessments is to use the attenuation measured with respect to 50 ohms in coupling calculations, with the hope that the errors of mismatching characteristic impedances are not large enough to introduce large errors in the assessment.

Figure 2 shows the transmission loss of a typical radio receiver from the antenna output to the detector input as a function of frequency. Similarly, figure 3 shows the transmission loss of an interconnection cable that goes from the exterior connector of a system to an interior semiconductor component. The transmission losses of both have an uncertainty asso-
Figure 2. Transmission loss for a typical radio receiver out-of-band.

Figure 3. Transmission loss for an interconnection cable as a function of frequency.

Figure 4. Distribution of transmission loss of figure 2 for frequencies above 3.3 GHz.

The forward transmission coefficient $S_{21}$ for a section of lossy TEM transmission line can be derived using ABCD parameters and is given by [ref. 1]

$$S_{21} = \sqrt{\frac{Z_L}{Z_0}} \frac{2}{\eta \cosh \frac{z}{\lambda} + e \sinh \frac{z}{\lambda}}$$

(2)

where

- $Z_L$ = line characteristic impedance,
- $Z_0$ = source impedance,
- $Z_p$ = load impedance,
- $\lambda = \alpha + j\beta$,
- $\alpha$ = attenuation in nepers per unit length,
- $\beta = $ propagation constant ($2\pi/\lambda$),
- $\lambda$ = wavelength on the transmission line,
- $l$ = length of transmission line, and
- $\eta = \frac{1}{2} \left[ 1 + \frac{Z_L}{Z_0} \right] + \epsilon = \frac{1}{2} \left[ \frac{Z_p}{Z_L} + \frac{Z_L}{Z_0} \right]$.

In general, the value of $S_{21}$ oscillates between upper and lower boundary curves as a function of frequency. If the value of $S_{21}$ is needed only at the transmission peaks, equation (2) reduces to

$$S_{21} = \frac{(-1)^n}{\eta \cosh \alpha' l + \epsilon \sinh \alpha' l}$$

(4)

where $n = 0, 1, 2, 3 \ldots$ when the line is $0, \frac{1}{2}, 1, 1-1/2$ wavelengths long. The error is then given by

$$\text{Error(dB)} = 20 \log_{10} \frac{\cosh \alpha' l + \epsilon \sinh \alpha' l}{\eta \cosh \alpha' l + \epsilon \sinh \alpha' l}$$

(5)

The error is the difference in decibels between the measured value of $S_{21}$ and the value of $S_{21}$ in the real system at the peaks of $S_{21}$. The error can also be derived for the minimum transmission peaks.
If the attenuation of the transmission line is sufficiently high, equation (5) reduces to

\[
\text{Error (dB) } = 20 \log_{10} \frac{\sqrt{\frac{Z_0^2 + s_L^2}{50}}}{\frac{Z_0^2 + s_L^2}{Z_0^2 + s_L^2}(Z_0^2 + s_L^2)}
\]

and is a function of the source, line, and load impedances alone.

RESULTS

The transmission loss for a wide range of source impedances, path characteristic impedances, and load impedances was calculated to determine the general performance parameters of the error function. For low path loss there was a periodic fluctuation in the path loss because of the interaction of the mismatches at the ends. For high path loss there was no interaction, and the loss tended to remain constant over the full frequency range of the calculations. For high path loss the system loss could be fully accounted for by the path attenuation and the mismatch losses at each end.

Figure 5 shows the calculated loss of a transmission path 6 in. long and having 0-, 10-, and 20-dB attenuation as it would be measured in a 50-ohm network analyzer. The differences between the curves and the 0-, 10-, and 20-dB attenuations are ascribed to the mismatches to the 50-ohm network analyzer and their interactions. Significantly, when the transmission loss is 20 dB or higher, the fluctuations in transmission loss due to the interactions of the mismatches at the ends are obscured by the loss of the path, and the path loss is dominated by the attenuation of the line and the individual mismatches at the ends of the lines. Therefore, the representation of the path is considerably simplified for those paths having 20 dB or more of loss.

The errors for lines with high attenuation were calculated for the range of parameters expected in systems, giving the errors shown in figure 6. For systems having semiconductor junctions as their damageable/upsettable load (5 to 20 ohms), the error is bracketed by -2 and -10 dB. Two-thirds of the area (± 1 sigma) is between -4 and -8 dB, giving the distribution of -6 ± 2 dB.

The path loss measured in a typical system, given in figures 2 and 3, was 53 ± 5 dB. Solving equation (1) for \( S_{21} \) (system) in decibels gives

\[
S_{21} \text{ (syst) } = S_{21} \text{ (meas) } + \text{Error} \approx (-53 ± 5) + (-6 ± 2)\]

The increase in uncertainty is insignificant and only the average amount of mismatch needs to be added to the attenuation measured. Therefore, for transmission paths with high attenuation, the estimate of the power density required to affect the system is not greatly influenced, since the transmission loss uncertainty is low.

CONCLUSIONS

When system transmission paths are measured on a 50-ohm network analyzer or scalar analyzer, their mismatches contribute to errors in measurements. The uncertainty in these errors is small when the attenuation of the line is higher than 10 dB and insignificant when the attenuation is higher than 20 dB. The error from average mismatch, however, should be factored in, to correct the parameters measured. Most transmission paths that show low losses will be standard characteristic impedances that can be measured with the correct input and output characteristic impedances, producing no additional error from mismatches. Should a low-loss path be a nonstandard characteristic impedance, the only way to characterize it would be to use the full complex parameters measured on the network analyzer for the path and for items connected to each end of the path, and combine them using complex arithmetic.

In summary, for system transmission paths with greater than 20 dB of loss, the uncertainty of the measurement is so small as to have practically no influence on the estimate of power density required to cause system effect.

REFERENCE:

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