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Predictive Modeling of the Effects of Skew and Imbalance on Radiated EMI from Cables

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Abstract—**This paper provides an approach for predicting the effects of skew and imbalance on radiated emission of cables inside a commercial 19-inch rack-based cabinet. Scattering parameters (S-parameters) for two sets of cable assembly are measured with a four-port vector network analyzer (VNA) and converted into mixed mode S-parameters. Time-domain input signals with different slew rates and different amount of skew are transferred into frequency-domain using fast Fourier transform (FFT). The spectra of radiation emission associated with different inputs are then estimated.**

Keywords-radiation prediction; skew; slew rate; scattering parameters; mixed mode scattering parameters; vector network analyzer; frequency spectra

I. INTRODUCTION

Serial links are widely used in modern high-speed digital systems for data transfer rates above 1 Gb/s using differential signaling. The serial links, including differential trace pairs on printed circuit boards (PCBs) and cables between different functional boards or subsystems, are designed to be balanced, and the radiated emissions due to common-mode currents are minimized [1]. However, manufacturing tolerances, non-uniformity and dielectric dispersion of the media used in cables and PCBs, discontinuity of connectors, and imbalance in the differential signal source itself cause some mode conversion from differential-mode to common-mode. The mode conversion will result in electromagnetic radiation, which is frequency dependent.

Radiation prediction for the equipment under test (EUT) can be estimated by multiplying the input spectra with the transform spectra of the EUT. This indicates that the radiated emissions are related not only to the input signal, but also to the transform spectra of the EUT. Since the frequency-domain spectra of an input signal are determined by the input data pattern, amount of skew, and slew rates in the time-domain, it is necessary to deal with both the input spectra and the transform spectra independently so that the radiation can be easily predicted for different input signals. The input spectra for different time-domain signals can be obtained from FFT. The transform spectra for different EUTs are characterized using unbalanced S-parameters, and they can be further represented with mixed mode S-parameters. The radiated emissions for an EUT are predicted when both spectra are known. Formulation derivation and measurement setup for different EUTs are described in Section II. The input signals and their common-mode spectra are described in Section III. The radiated emissions for the two EUTs and different input signals with different amount of skew, different slew rates are predicted in Section IV. Conclusions are summarized in Section V.

II. COMMON-MODE TRANSFER FUNCTION

As for most equipment, high frequency EMI is mainly caused by common-mode currents flowing through connector systems, PCBs and cabling systems. The radiation prediction in this paper is focused on the common-mode transfer function, using the methodology illustrated in Figure 1. To characterize the cable link inside a commercial 19-inch rack-based cabinet so that the radiated emissions can be easily predicted for input signals with various skew and slew rates, a swept frequency approach with a receiving antenna and a three-port VNA measurement setup is used to obtain the mixed-mode S-parameters and therefore the common-mode transfer function.

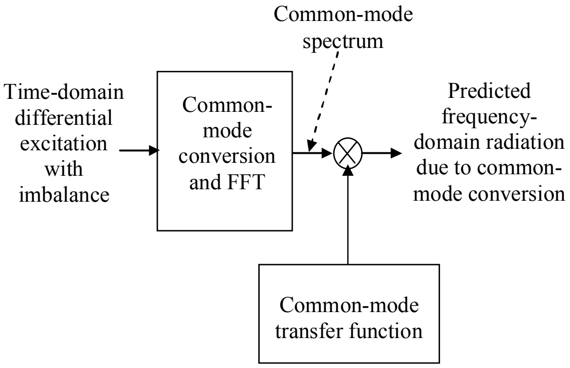

Figure 1. Radiation prediction approach for a system with imbalanced cables

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The schematic of the three-port VNA and antenna measurement setup is shown in Figure 2. The measurements are conducted in an anechoic chamber, as illustrated in Figure 3. The antenna is set at 1 meter height and at a distance of 1.5 meters away from the cable link system and the cabinet. Two types of cables are used for two different sets of measurements so as to compare their radiations. The cable used in the first set of measurements is a high quality cable terminated with a 150 Ω surface mount resistor at one end. The other end of the cable is connected to the connector, which is on a PCB with two differential traces. The PCB is mounted in a computer module inside the cabinet. The terminated end of the cable exits at the bottom of the cabinet. The cable used in the second measurement is a poor quality one with no termination. A view of the actual setup for the three-port mixed-mode S-parameter measurement is shown in Figure 4.

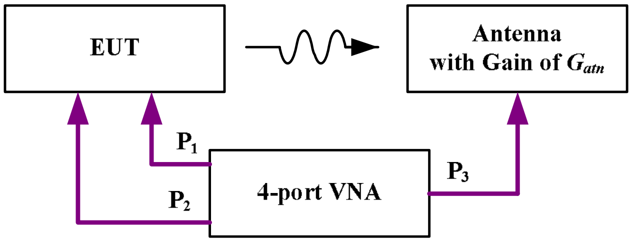

Figure 2. Schematic 3-port measurement setup with an antenna.

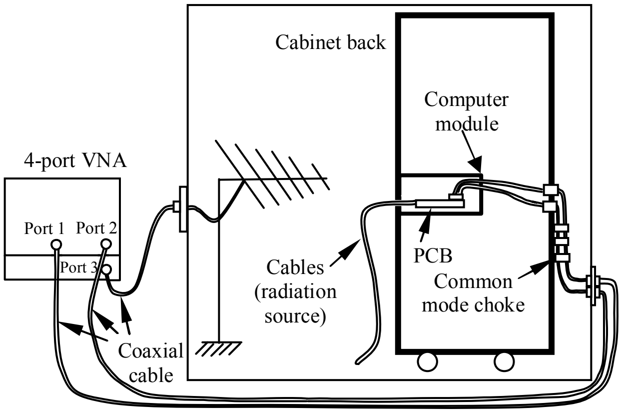

Figure 3. Schematic representation of the three-port mixed-mode S-parameter measurement setup for cables exiting the bottom of the rack.

The measured common-mode transfer function $|S_{21}^{Ac}|$ is shown in Figure 5 over the frequency range of 100 MHz to 2 GHz for the two types of cables. It is observed that the cable link inside a commercial cabinet decides the level of the transfer function. The high quality cable displays a characteristic that strongly suppresses the common-mode conversion, while the poor quality cable tends to radiate larger portion of energy to the surrounding environment. In the measured frequency range, the amplitude of the mixed-mode S–parameter, S_{21}^{Ac}, which measures the ability of the common-mode conversion to antenna port, is about 30 dB lower on the average in the case of high cable link than that for the low quality cable link. Of particular note here are the frequencies of 625 MHz, the fundamental of the clock in a functioning cabinet, and its second harmonic 1250 MHz and the third harmonic 1875 MHz.

Figure 4. Measurement setup

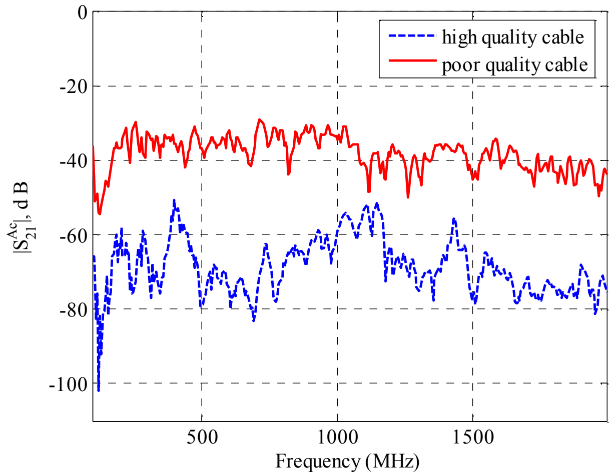

Figure 5. $|S_{21}^{Ac}|$ comparison for two types of cable links.

III COMMON-MODE SPECTRA DUE TO IMBALANCE IN EXCITATION

The clock signal coming out of a functioning commercial 19-inch rack-based cabinet has the standard bit rate 1.25 Gb/sec. There is a nominal differential voltage of 1.6 V p-p.

The nominal rise time and fall time are both 250 ps. Figure 6 shows the standard time-domain pure differential input signals without skew.

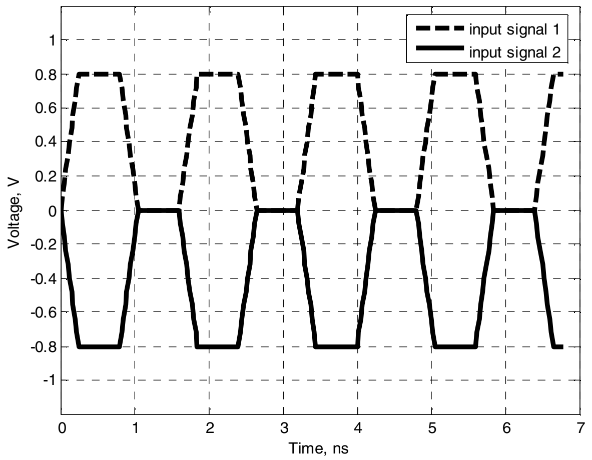

Figure 6. Ideal differential Input signals without skew.

To predict the effects of skew, three different cases are designed for the input differential clock signals. Case I is to observe the delay skew effect. The nominal input signal 1 (Figure 6) is applied at Port 1. A delayed version of input signal 2 (Figure 6) is applied at Port 2. Delays of 50 ps, 100 ps and 150 ps are used. This waveform is shown in the inset of Figure 7. Using FFT, the common mode voltage spectra for these skewed input signals over the frequency range of 100 MHz -2 GHz are generated, and plotted in Figure 7.

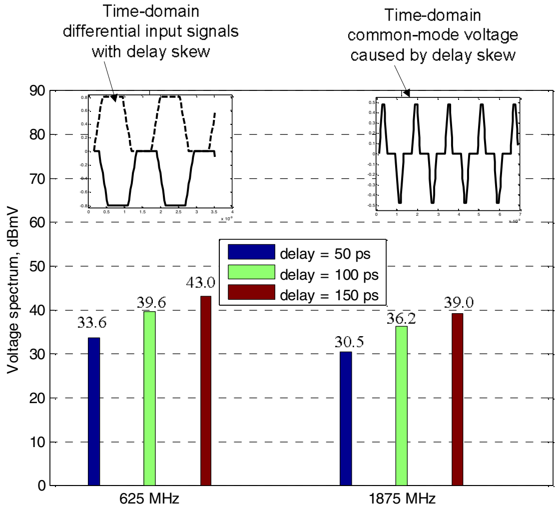

Figure 7. Common-mode voltage spectrum due to delay skew.

Case II compares the effects of slew rate skew. Both input signals no longer have equal rise time and fall time. A slew rate skew of 50/100/150 ps is added to the falling edge of both inputs. The common-mode voltage spectra due to slew rate skew in the input signals is plotted in Figure 8. Comparing with the common-mode voltage spectrum for the delay skew in Figure 7, the common-mode voltage has only nonzero outputs at 1250 MHz, the second harmonic of the fundamental frequency 625 MHz.

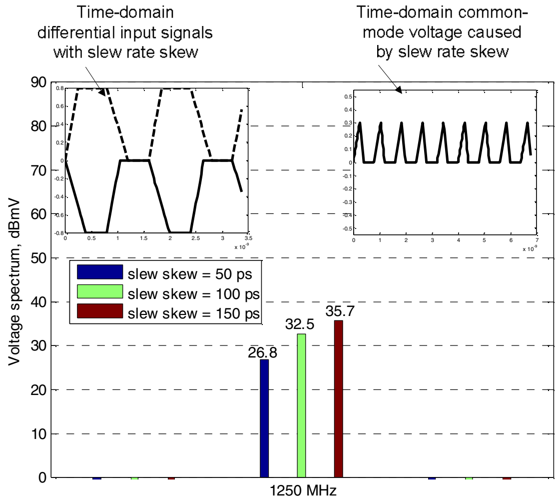

Figure 8. Common-mode voltage spectrum due to slew-rate skew.

Case III investigates the effects of different voltage amplitude between the two input signals. A 1.2V p-p input signal is applied at Port 1. The input signal applied at Port 2 is 0.4V, 0.6V and 0.8V larger than Port 1. Figure 9 shows the common-mode voltage spectra caused by the amplitude differences between the two input signals.

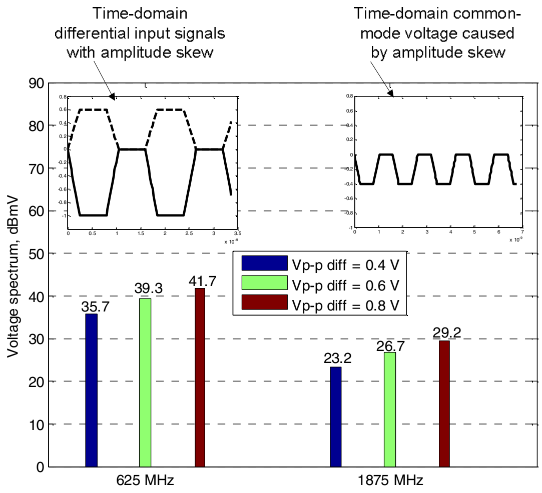

Figure 9. Common-mode voltage spectrum due to amplitude skew.

IV. PREDICTED COMMON-MODE RADIATION DUE TO IMBALANCE

The common-mode radiation effects of the three types of skew introduced to the ideal differential clock signals in the cable links are predicted using the measured mixed–mode S-parameter S_{21}^{Ac} and the calculated voltage spectrum. As the common-mode voltage of the input signals is still purely periodical, the radiation spectra are discontinuous. For the frequency range of 100 MHz - 2 GHz, the nonzero components include the fundamental frequency, the second harmonic and the third harmonic.

Figures 10 - 12 show the predicted radiation for the high quality cable link at the antenna tip. It is easily seen that larger skew causes increased radiation. At the fundamental frequency of 625 MHz, it is observed that the radiation levels caused by the delay skew and the amplitude skew are very close. For the third harmonic 1875 MHz, the delay skew causes stronger radiation effects, as even the smallest delay causes a radiation level that is stronger than that caused by the largest voltage amplitude skew.

Regarding the radiation effects of the slew rate skew, it is noticed that only the second harmonic is excited. The radiation emissions have the amplitudes around the same level with the radiation emissions of the third harmonic in delay skew case.

Figures 13 - 15 show the predicted radiation for the poor quality cable at the antenna tip. The patterns of the radiation emissions are very similar to those of the high quality cable except that the radiation is much stronger for the poor cable. At the fundamental frequency of 625 MHz, the radiation levels are about 30~40 dBμV/m higher than the corresponding radiation emissions in the high quality cable cases. At the third harmonic 1875 MHz, the radiation difference is about 20~30 dBμV/m. Unlike the high quality cable link, in both the delay skew case and the amplitude skew case, the poor quality cable link creates stronger radiation at the fundamental frequency than at the third harmonic. For the slew rate skew case, the radiation emissions at the second harmonic are about the same as the output levels of the third harmonic in the delay skew case.

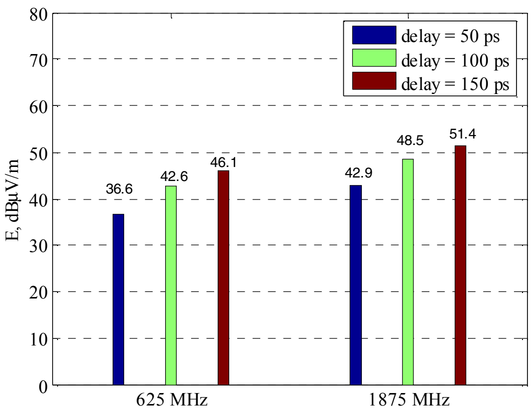

Figure 10. High quality cable EMI from common-mode conversion. Skew type – delay in signal 2.

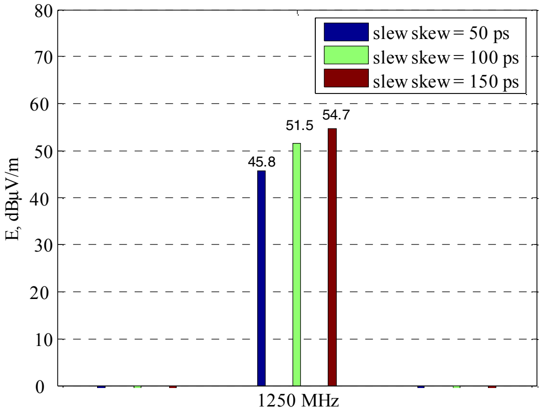

Figure 11. High quality cable EMI from common-mode conversion. Skew type – slew rate at the falling edge of input signals.

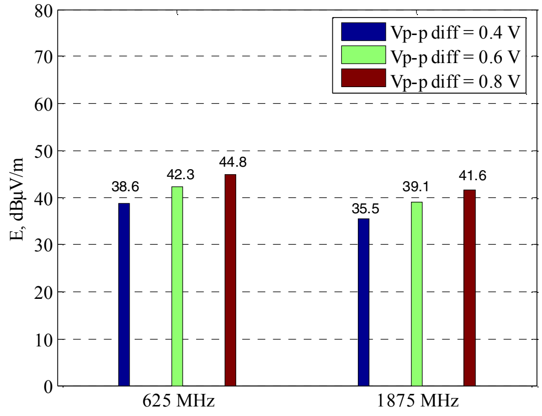

Figure 12. High quality cable EMI from common-mode conversion. Skew type – voltage amplitude difference between input signals.

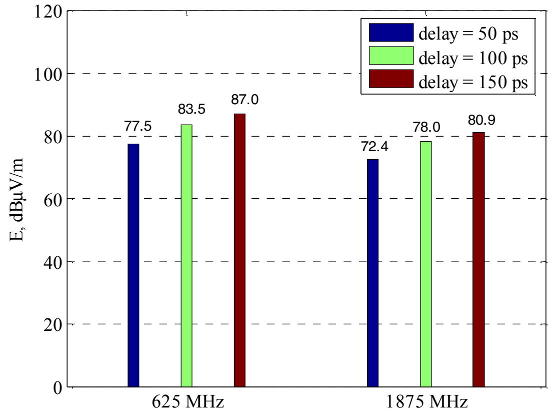

Figure 13. Poor quality cable EMI from common-mode conversion. Skew type –delay in input signal 2.

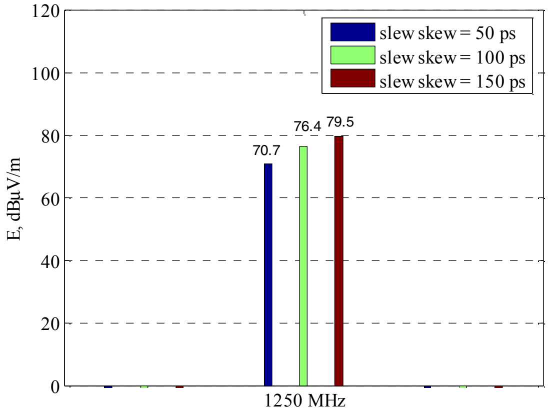

Figure 14. Poor quality cable EMI from common-mode conversion. Skew type – slew rate at the falling edge of input signals.

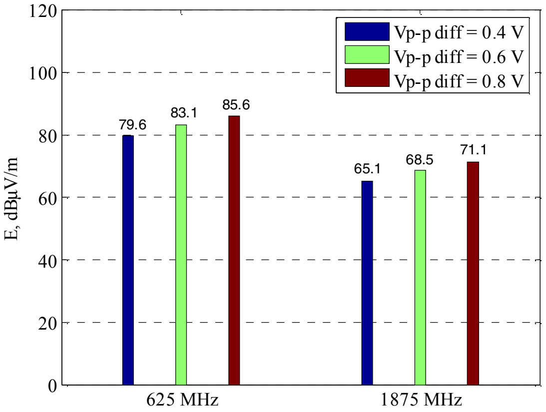

Figure 15. Poor quality cable EMI from common mode conversion. Skew type – voltage amplitude difference between input signals.

V. CONCLUSIONS

Cable link (shielding) quality is an important factor in the radiated EMI from a differential link. Poor quality cable significantly increases radiated EMI, especially at some critical frequencies, the radiated EMI from poor cable can be as much as 40 dBμV/m higher than the radiation from high quality cable. Whatever the skew type, larger skew causes larger radiated emissions, which is true for both the high quality cable link and the poor quality cable link.

Different types of skew affect the radiated emissions both in amplitude and pattern. Among the three types of skew, radiated emissions are most affected by the delay skew. Slew rate skew can excite large radiation on the second harmonic of the fundamental frequency of 625 MHz.

The predictive modeling discussed in this paper provides a practicable and useful method to evaluate the common-mode excited radiation for cable links in large equipment. The input differential signals can be of any pattern, not constricted to the clocks, so that the skew effects on the radiated emissions can be investigated for more extensive frequency response.

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