Attaining Circuit Trace EMC

Performing some simple calculations can help a designer identify sources of likely emissions.

W. DREW PEREGRIM
AMP, Harrisburg, PA

INTRODUCTION

Components of a printed circuit board assembly can produce emissions that create electromagnetic interference (EMI) with other components or devices in their vicinity. In the worst cases, the victim device acts as a receiving antenna and malfunctions. Such detrimental effects, along with government regulations, drive electronic system designers to reduce electronic emissions in their systems.

The most cost-effective area for reducing emissions is in the printed circuit board itself. Producing a circuit board and cable system that has few emissions can enable the manufacturer to purchase lighter, more attractive, and less expensive enclosures, which can save hundreds of dollars per device.

Any piece of metal that is connected to a circuit board is a potential antenna, making it difficult to track down the source of an emission. Performing some simple calculations can help a designer determine the characteristics of likely emissions and provide some clues about the sources of emissions. These calculations yield estimates rather than precise measurements, but their simplicity enables fast and easy calculation as well as efficient problem solving.

SPECTRUM OF A DIGITAL SIGNAL

The voltage over time of a digital signal can be modeled as a trapezoidal waveform (Figure 1). In the radio-frequency domain, the square wave can be analyzed as a series of sine waves that, when added together, form the originating square wave (Figure 2). This series of sine waves, or the digital spectrum of the signal, is not truly continuous, but instead resembles a series of narrowband pulses with peak power in the center of each band. As such, the digital spectrum comprises a series of frequencies. To simplify calculation of the frequency and magnitude of the signal, it is best to assume that the spectrum is continuous and has a magnitude that is proportional to the average of the individual peaks.

The analog spectra of a digital signal transmitted through a circuit board trace to a component acting as an antenna can be approximated by a few simple formulas.

Assume that:

- t = Width of the pulse measured at the top of the pulse (μs)
- t_r = Rise time of the pulse (μs, time from 0 voltage to 90% of peak voltage)
- A = Height of square wave (V)
- F = Frequency (MHz)

The digital spectrum can be broken into three regions, each of which has different amplitude behavior:

- Start Frequency F_S = Digital frequency
- Low Frequency F_L= Segment of the spectrum from the oscillator frequency to $1/(\pi \times t)$
- Medium Frequency F_M = Segment of the spectrum from $1/(\pi \times t)$ to $1/(\pi \times t_r)$
- High Frequency F_H= Segment of the spectrum above $1/(\pi \times t_r)$

Voltage amplitudes of analog components of a digital signal can be determined by these formulas:

Low Frequency:

$$V_S \text{ to } V_L = 126 + 20 \log [A(t + t_r)]$$

Medium Frequency:

$$V_M = V_L - 20 \log [F_M/F_L]$$

High Frequency:

$$V_H = V_M - 40 \log [F_H/F_M]$$

Assuming a 100% efficient loop antenna, these values can be converted to dB μV/m above 1 mV to yield the radiated voltage at specific distances using the following relationship: Reduce the conducted voltage levels V_L, V_M and V_H by 22 dB for the first foot of distance to the measuring antenna, and by 20 times the log of the distance beyond 1 foot, in feet.

These equations produce the graph shown in Figure 3. Because a trace acting like a transmitting antenna with a specific length can be maximized to only one frequency, only one point on the graph is valid per trace length. The efficiency of a trace as an antenna is greatly dependent on the circuit trace lengths. When an uncharacteristically strong signal is being emitted by a system, the designer should suspect that there is a trace with a length that is tuned to or close to the wavelength of that frequency. The measured frequency of a strong emission can indicate the length of the circuit trace causing the emission. Examination of the diagram of the printed circuit board and measuring trace lengths can point to the offending traces. Designers should look for repetitive spikes separated by a specific frequency interval. The lowest frequency at which the repetition starts is usually the frequency associated with a trace length equal to 1/4 or 1/2 the wavelength.

REDUCING CIRCUIT TRACE LENGTH

The most efficient method for reducing an emission is to reduce the length of the circuit trace. Antennas lose efficiency very rapidly as they become shorter than 1/4 wavelength, so reducing a trace to a length much shorter

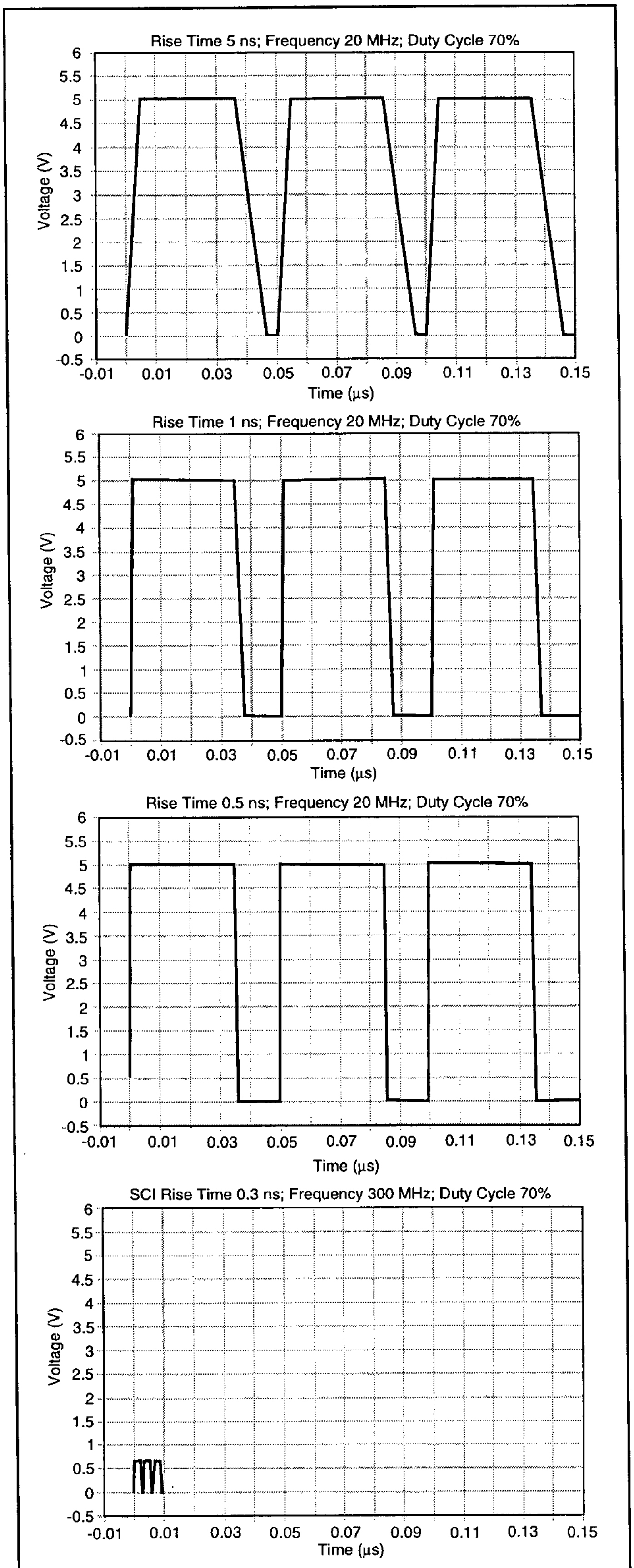

Figure 1. *Square Wave of a Signal.*

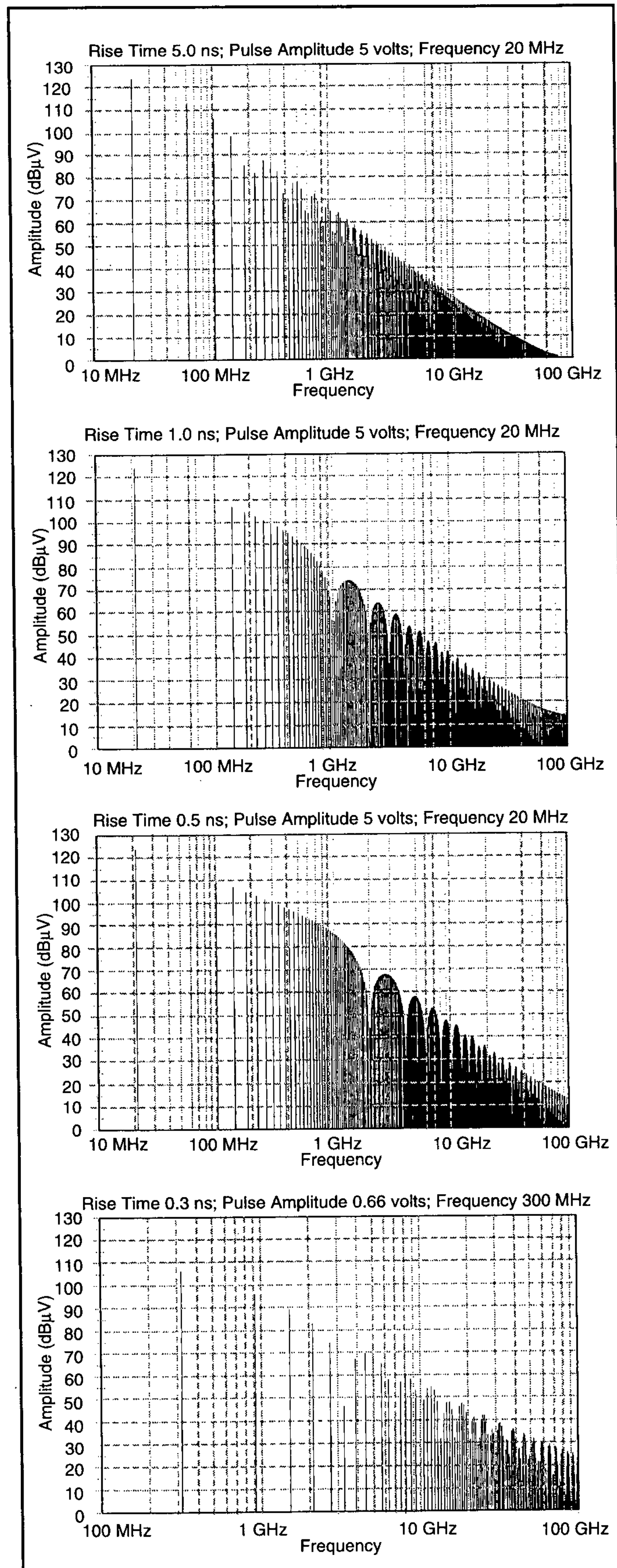

Figure 2. *Spectrum of a Signal.*

than 1/4 wavelength can cause major reductions in radiated emissions. An antenna efficiency chart is shown in Figure 4. If the emissions from an ideal antenna is calculated and compared to lengths of 28 inches, 14 inches, and 7 inches, the emissions are greatly reduced as the trace length is reduced (Figures 5 and 6).

OTHER SOLUTIONS

Image planes and shields further assist in reducing emissions by further attenuating or trapping the signal. In the case of an image plane, a mirror image of the signal is reflected, canceling much of the original emission. Using micro-strip construction for a circuit board places a circuit trace directly above and very near a ground plane. The close proximity of the trace to the ground plane and the large size of the ground plane allow the ground plane to act like an image plane, reflecting a mirror image of the emission, which reduces emissions by about 12 dB. Strip-line construction, which is commonly used for high-speed and clock signals on multilayer circuit boards, sandwiches traces between two ground planes. The dual image planes formed by the two ground planes can reduce emissions by 20 dB or more.

Multilayer circuit boards can further reduce emissions. Four-layer boards can reduce emissions by as much as a factor of ten as compared to a two-layer board by enabling the designer to include a denser routing pattern within the circuit board, saving space and reducing circuit traces.

Surface-mount components, when compared to pin-mount components, provide several benefits in terms of electromagnetic compatibility (EMC):

- There is no lead to act as an antenna.
- There is lower impedance at higher frequencies.
- Designers can place components closer together to further reduce circuit trace length.

Complex integrated circuits that perform the function of multiple standard components can help to decrease the

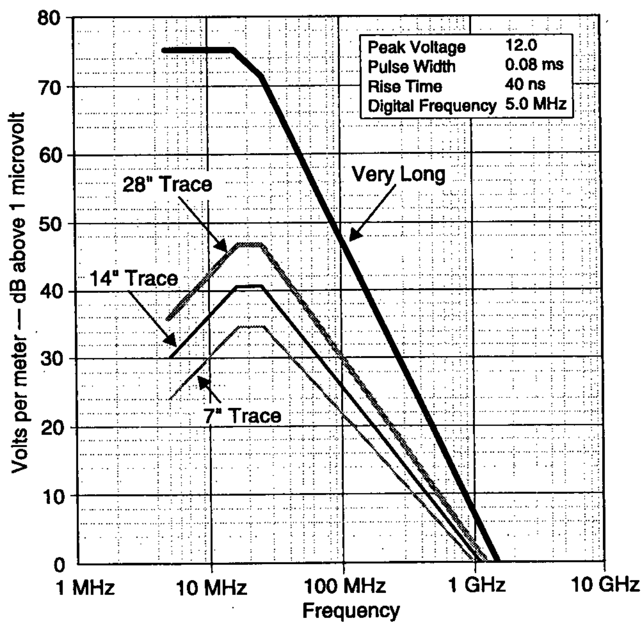

Figure 3. *Signal Strength from Tuned PCB Trace. Calculated Values at 3 m.*

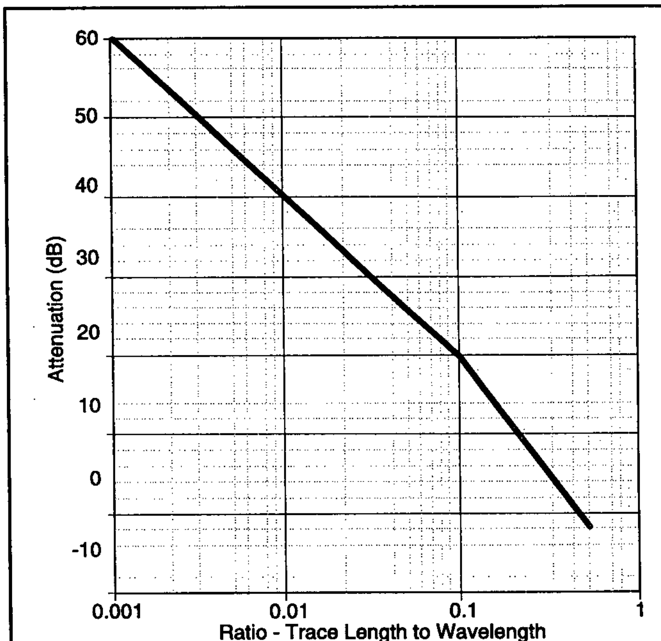

Figure 4. *Antenna Efficiency Chart for Circuit Traces as Antenna.*

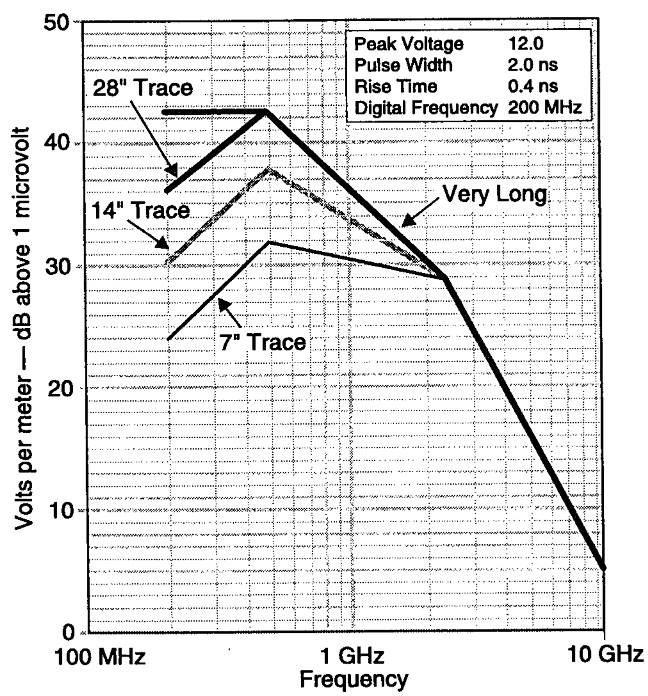

Figure 5. *Signal Strength - Typical Path Lengths. Calculated Values at 3 m.*

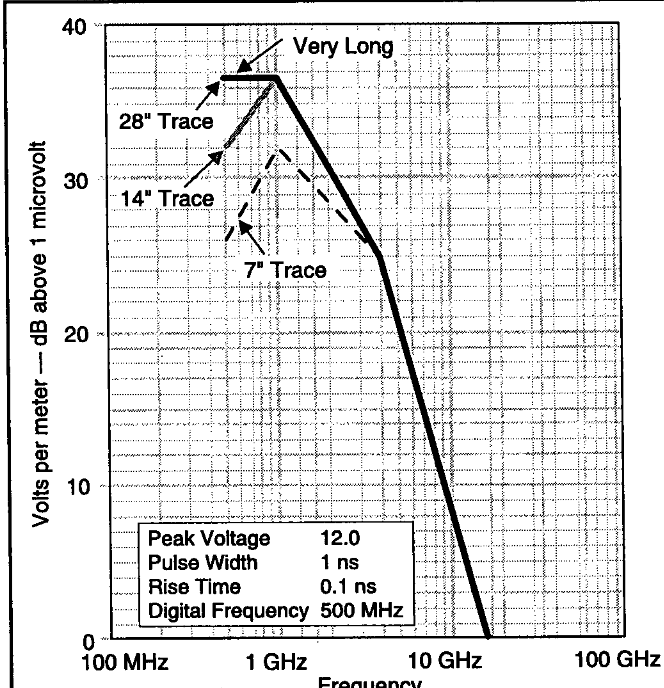

Figure 6*. Signal Strength — Typical Path Lengths. Calculated Values at 3 m.*

size of the printed circuit board. In addition, denser connectors allow shorter distances between daughtercards, a shorter motherboard, and shorter traces.

CONCLUSION

When a source of emissions is found, solutions are usually intuitive. Deciding how to reduce EMI depends on the source and the costs of the options. Implementation of the solution should be monitored to ensure that it does not cause problems in other areas of the design, such as increased impedance or crosstalk.

W. DREW PEREGRIM *is a member of the circuits and design technical staff of AMP, where he specializes in electromagnetic compatibility and circuit design (717) 564-0100.*