UltraCAD Design, Inc.

DESIGN NOTE

SQUARE WAVES, PULSE RISE TIMES and FREQUENCIES

A Service Bureau once told one of our customers it wasn't necessary to worry about "good design practices" because their frequencies were low enough not to be an issue. If your Service Bureau tells you that, run (don't walk) to the nearest exit! The issue is not frequency --- it's wave shape and rise time. A 5 volt peak-to-peak 10 MHz clock line, for example, has many harmonics, one of which is a 450mv 110 MHz signal! Another is a 225mv 220 MHz signal (there are many others). A pulse with a one nsec rise time has a strong 300 MHz frequency component. It may not be obvious that these high frequency components are there. But we've seen many unfortunate situations where companies ignored them and then couldn't understand why their boards were so noisy and why they were having so much trouble with FCC compliance.

This application note discusses some basic relationships between wave shapes, rise times, and frequency harmonics, why it is critically important to design you boards with them in mind, and some design criteria for handling them.

Square Waves

A square wave can be thought of as a combination of a series of sinusoidal waveforms that are odd-numbered harmonics of the square wave fundamental. They are related in frequency and magnitude by the following relationship:

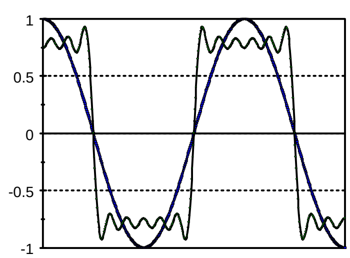

Figure 1

$$\cos(\omega t) - \cos(3\omega t)/3 + \cos(5\omega t)/5 - \cos(7\omega t)/7 + \ldots \text{ (etc)}$$

Thus the 5th harmonic is one-fifth the magnitude of the fundamental, etc. Figure 1 illustrates a square wave signal and a composite of the fundamental and first few sinusoidal harmonics that make it up. Figure 2 shows the relative magnitudes of the square wave signal and its 11th harmonic. From this it can be seen that a relatively low frequency clock signal can have some very high, strong, harmonics that need to be dealt with.

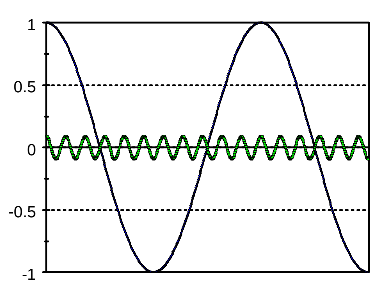

Figure 2

Rise Times

Figure 3 illustrates a common logic pulse transition from a low level to a high level. We don't often think that the rise time of such a pulse (defined here as the time to transition from 10% to 90% of the total magnitude) can cause special problems. But the rise time follows almost exactly the rising edge of a sinusoidal waveform. When we superimpose such a waveform on the pulse (Figure 4, note expanded horizontal scale), it becomes visually clear that this is so.

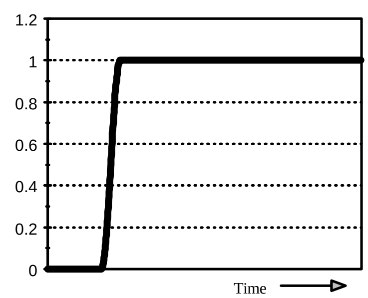

Figure 3

The rise time turns out to be almost exactly 30% of the period of the sinusoidal waveform. From this it follows that a pulse with a 1 nsec rise time might generate a brief 300 MHz transient of the same peak-to-peak amplitude.

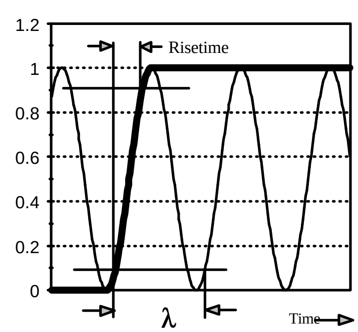

Figure 4

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Effects:

Seemingly low frequency signals can generate powerful harmonics that are surprisingly high in frequency. Most ICs that are designed to work with such waveforms can handle them (there are a few exceptions, unfortunately.) And in fact we often go to some extent to preserve and increase them (in an attempt to keep "clean" waveforms! It is ironic that "clean" waveforms generate "dirty" noise problems!) So one of our design problems is how to get the signal from one IC to the next without radiating these harmonics ... first to other signal lines we want to protect, and secondly to FCC compliance measuring devices outside our system!

Since radiated energy is a function of power, and power is a linear function of voltage but a square function of current, these are even more important considerations for current controlled logic (i.e. ECL) circuits.

Some Simple Design Criteria:

At *UltraCAD* we routinely design to control these harmonics. We have numerous techniques for controlling them; some of these techniques are proprietary, and some are so exotic they are rarely needed. In this note we will describe some that are so fundamental that every designer you use should know and follow them. (If your designer doesn't use them or can't explain why he/she uses them, we'd suggest you get another designer.)

Radiating Points:

Dead End Stubs: **NEVER, EVER** allow a stub trace to exist without a terminating point. Such a stub trace is an antenna and its uncontrolled impedance can cause signal reflections whose results will be absolutely unpredictable (but those results will **NEVER** be positive!)

Right angle turns and "T's": A trace that extends in a straight line is relatively clean. One that extends straight and then turns 180 degrees back on itself looks just like an antenna (like those on a tall building!) A line that makes a right angle turn begins to look like, and have the characteristics of, an antenna. It's admittedly not a real good antenna. But the point is that we don't even want poor antennas on the board! If you probe a board with an EMI detector, the strongest radiating points will almost invariably be at 90 degree corners and "T"s. A board should **NEVER** have signal lines that turn more than 45 degrees ... **ALL** trace corners should be mitered.

REMEMBER: Antennas work both ways. If a stub or a corner emits well, it also ***receives*** well. So these are the points where noise can be injected **INTO** the board, also.

Signal Return Paths:

Each signal has a return path. So an interesting question for each trace is, "Where is its return path?" The higher the frequency (including the higher order harmonics) the closer the return path will be to the signal trace. So it is wise to make provision for it!

The best provision is a ground plane directly under the signal. Studies have shown that if there is a ground plane under the trace, for very high frequencies, the return signal is DIRECTLY under trace. Note the implication ... anything that breaks the continuity of the ground plane under the trace will cause the return signal to deviate around the interruption. It will return under the trace as soon as possible. The path the return signal takes could look just like an antenna! Thus, an otherwise seemingly careful design, one that seems to take everything into consideration, might inadvertantly inject an antenna affect just where you would LEAST expect it ... on the ground plane itself!

The next best provision is sometimes called a guard band ... a parallel trace immediately beside the signal that is tied to the ground plane. Care should be taken to make it as nearly as possible the same length. Different designers like to tie the plane to ground differently. Some tie it only at each end, some "stitch" it to ground along the trace. A few will tie it to ground at only one end ... a practice we recommend against since it defeats the purpose of providing a return signal path.

Note that if you make no provision for the return path, the signal will return by SOME path anyway. If it is uncontrolled, you have no idea where it is going, how it is radiating, and what other signals it is interfering or combining with.

The whole subject of noise radiation and protection has a high component of "Black Magic" associated with it. As in all things, experience helps! We can't (and wouldn't) guarantee that if we design a board there will be absolutely no problems with noise and FCC compliance. But on the other hand, our customers have fewer problems in these areas than people who don't use our services. We believe the reason for that is that NO ONE routinely follows the rigid, very high design standards we do in designing every one of our customers' boards. That is why our repeat customers think of us as the "best in the business".