Application Notes

ScanEM-C CTK015 Probes and Signal Integrity AN103

Problem

High-speed digital circuits often behave more like analog circuits. Instead of usual “0s” and “1s” the electrical signals exhibit such artifacts as ringing, overshoots, undershoots, ground bounce and a plethora of other non-digital characteristics. The reason for such behavior is that at high frequencies parameters like distributed capacitance and inductance of traces, mismatched impedances, etc. – things that are normally considered a worry of an RF Engineer – are becoming harsh reality for a Digital Engineer. If a clock in a system is unhurried by today’s standards 27MHz, just keep in mind that radio remote-controlled cars use this frequency for their RF communication. 49MHz is a carrier frequency for a typical cordless telephone and walkie-talkies and so on. More and more high-speed digital systems invade frequency ranges previously occupied by RF transmission.

However, the high-speed clock frequency by itself is often a secondary problem to the less-obvious corollary of much shorter rise and fall times provided by the ICs. 1.5nS-rise and fall times are not unusual occurrences on today’s PCB assemblies. However glamorous in the digital world, 1.5nS transition creates spectrum of signals extending to 1GHz and beyond. Suddenly, a Digital Designer finds himself immersed deep into the RF and Microwave enemy territory. What used to be a benign copper trace is now a mysterious transmission line; a previously friendly ground plane is now a battleground of unseen currents; and the entire board is suddenly a combination of self-resonances that are eager to take any fast transient and generate unfriendly vibes. All these intrusions alter the waveform of the originally intended square-wave signal to often-unrecognizable squiggle. The end result is a non-working circuit, or, at the best, a circuit with problems.

This application note is not intended to be a signal integrity tutorial – there are plenty of books and articles on the subject. Here we are concerned only with the ability to see the true waveform of “contaminated” signals. If signal distortions cannot be seen, the problem may not be recognized and subsequently left not corrected. Flying blind usually results in prolonged and helpless troubleshooting effort where the unseen problem could be corrected only serendipitously.

Conventional Method

A tool for observing signal waveform is an oscilloscope with its probe. At low frequencies your regular oscilloscope probe served you well. It showed you the actual shape of the signal and its magnitude. Would it be true at high frequencies?

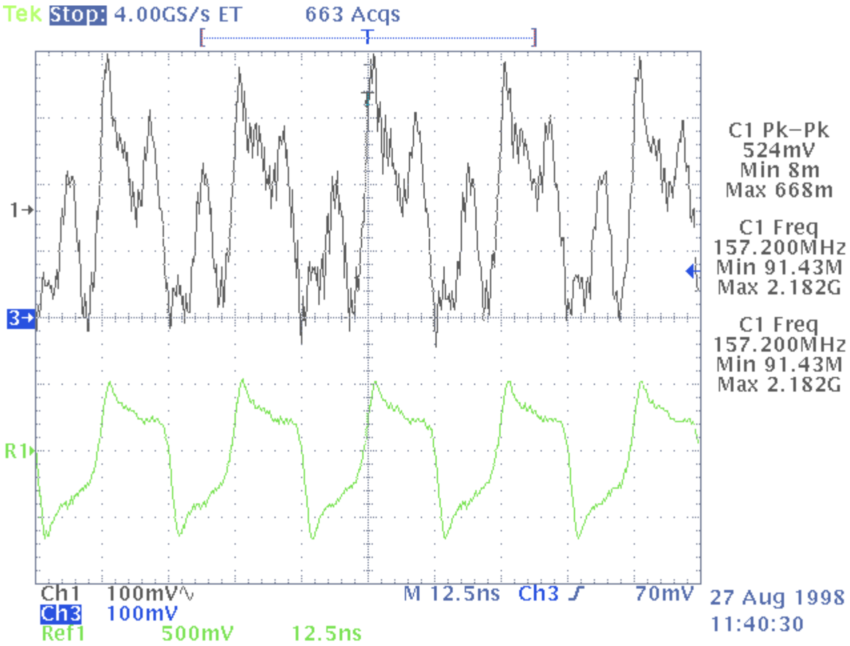
Did it ever happen to you or to your colleague that connecting a scope probe to a malfunctioning circuit suddenly made it work (until removed)? A scope probe has finite resistance and capacitance that load the measured signal. Better probes have higher resistance and lower capacitance. But even the best of the best are not flawless – they still come into the contact with the measured signal and alter the very signal they are supposed to observe. The typical features of the signal that conventional probes easily miss are overshoots and undershoots, ringing and peaks and valleys that are caused by resonances in the traces.

New Solution

Every electrical signal generates electromagnetic field. This field can be picked up by a sensitive instrument, amplified and displayed on the oscilloscope – all without contact with the circuit and without affecting measured signal in any way.

As non-contact instruments, ScanEM-C probes do not affect the measured circuit and can reveal signal integrity problems that even the most sophisticated conventional probes miss.

The screen snapshot to the right shows 40MHz signal on a poorly designed board as measured with the 1.5GHz FET probe and the ScanEM-EC probe. Needless to say, the ScanEM-C trace is on the top. (This test used one of the newest 500MHz oscilloscopes.)



As you can see, not only the conventional FET 1.5GHz probe completely missed high frequency ringing, but also it loaded the poorly balanced trace and made certain peaks “disappear.”

High frequency ringing caused by trace self-resonance results in excessive electromagnetic emission at frequencies that are not correlated with the clock frequency and therefore hard to locate and correct without proper tools. As evident from the bottom trace, such ringing will simply not be found even with the best of conventional probes.

Large peaks and valleys that are also caused by poor balancing of the traces can easily reach dangerous levels and generate false triggering since magnitudes of these artifacts are comparable with the legitimate logic levels. The evidence of it is in front of you. As seen on the screen snapshot, the oscilloscope misinterpreted ~40MHz signal for a higher-frequency signal (157.2MHz) precisely because such artifacts confused it. Less-sophisticated logic circuit could be even more prone to confusion and malfunction. The FET probe loaded the same signal (bottom trace) to the degree where these peaks and valleys disappeared, but only for the duration of the measurements. After the probe is removed, these artifacts will resume haunting the circuit.

Specifics of ScanEM Applications for Signal Integrity Analysis

Which ScanEM Probe to Use?

ScanEM-EC probe being an electrical field probe shows the voltage on the traces, while magnetic-field ScanEM-HC probe displays AC current in the traces and ground planes.

Use ScanEM-EC probe to monitor voltage where a regular probe would be used.

ScanEM-HC probe used with the oscilloscope allows observation of AC currents up to 1GHz in traces and ground planes without disturbing the circuit in any way.

High-Frequency Current Monitoring

The importance of monitoring high-frequency currents in the circuits was downplayed in the conventional literature for simple reason that there was no instrument available for that. However, high-frequency current artifacts can be just as harmful to the operation of the circuit.

Example: Inductive Coupling Between the Traces

It is very common on high-density boards to see traces run close to each other. This can easily cause inductive coupling at high frequencies – these traces behave simply like windings of an RF transformer with air core. The higher the frequency, the better the coupling. If the circuit is not properly designed from the signal integrity point of view, the current from the adjacent trace may inject seemingly legitimate signal into the trace in question and cause malfunction that would be next to impossible to detect without proper tools. Often, even if the induced signals by themselves do not reach legitimate logic levels, they reduce noise tolerance of the circuit making it vulnerable to other influences. Conventional tools cannot show the currents in the traces and as the result the hunting game is conducted in the dark. ScanEM-HC probe will be able to identify the most probable offenders by showing on the regular oscilloscope the waveform and relative strength of the currents in the traces. Once the high-current traces carrying high-frequency (that includes transients, etc.) signals are found, it is possible to increase the values of serial resistors, spread the traces apart or to include ground traces between adjacent traces and thus reduce parasitic inductive coupling between traces.

Example: Ground Bounce

To simplify it, the ground bounce is generated by parasitic voltage at the ground pin(s) of an IC due to high impedance in the ground connection between the IC and the ground of the circuit. Often being considered during the IC design, it is no less important in board design as well. Too long of a trace between the ground pins of an IC and the board ground can exhibit high-enough inductance to create high-frequency voltage at the ground pins that could be sufficient for misinterpreting logic levels. ScanEM-HC probe will allow to evaluate the current going through the ground path and to verify improvements made by shortening and straightening the traces, including bypass capacitors between "ground and ground," etc.

Example: Ground Plane Optimization

A good ground plane is essential for proper operation of a high-speed circuit. Poorly done ground plane results in excessive emission and malfunction of the circuit. Breaks in the ground plane due to physical outline of the board, need to conduct traces, etc. can create unnecessary loops and parasitic inductance. ScanEM-HC probe can easily show not only currents in the ground plane but also their direction (direction of the magnetic field corresponds to the direction of the current that caused it). Once the currents and their properties in the ground plane are observed, it is easy to make proper decisions to optimize the shape of the ground plane. Don't forget the metal stand-offs between the boards that provide ground connectivity between the boards as well. ScanEM-HC can also show currents in the metal enclosures.

Can ScanEM-C Probes Eliminate the Need for Conventional Probes?

Absolutely not. ScanEM-C probes are not substitutes for a regular scope probe, but rather an addition to the standard probe set for those customers for whom EMC and signal integrity issues are important.

ScanEM-C probes are AC probes and will ignore DC signals. ScanEM probes are designed for applications at higher frequencies (1MHz and above). In addition, since ScanEM-C probes' output depends on how close the probe's tip is to the measured trace, one should use regular scope probe for absolute value signal measurements. However, ScanEM-C probes do not come in contact with the signal and are practically not limited in their bandwidth. ScanEM-C probes will not miss the slightest transient or the subtle ringing on would-be square-wave signal making it valuable addition for engineers and technicians concerned with signal integrity and EMC issues. Conventional probes are still needed for DC, low frequency and absolute value signal measurements.

Limitations

ScanEM-C probes are liable to pick up the emission generated not only by the trace or pin in question, but also by adjacent pins and traces. Bringing tip of ScanEM-C close to the trace or the pin helps to localize the measurements. Still, a judgement is required when analyzing the signals on the screen. Typically, 15 minutes of experimenting with ScanEM probes on your own will give you a good idea of how to utilize it in the best way.

ScanEM-C probes measure electromagnetic fields, not electric signals. The waveform of the electromagnetic field can differ from the signal shape. Usually, there is an emphasis on high-frequency content (this is why you may want to use ScanEM-C probes). DC and low-frequency signals are ignored.

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