An Investigation into the Performance of the IEC 1000-4-4 Capacitive Clamp

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Abstract

The IEC 1000-4-4 Electrical Fast Transient test, like ESD, is a severe pulsed EMI immunity test. Data presented shows that the test may be too severe and contains repeatability problems that causes excessive cost to be added to designs. In addition, a common mistake in application of the test is shown to double the stress on the equipment being tested.

Background of IEC 1000-4-4

The IEC 1000-4-4 test applies a conducted impulse waveform to conductors connected to the **e**quipment **u**nder **t**est, EUT. The purpose is to simulate stress due to sparking at contacts on the AC power mains. Performance of this test on equipment to be sold in the European Community is required. Equipment must pass a prescribed set of conditions concerning its operation at given level of stress.[1]

The nature of the noise is similar to that produced by ESD except the frequency components of the waveform are not as high (a few hundred MHz) and the waveform is actually a train of events repeated at several kHz to 100 kHz. The high frequency energy is coupled directly on to EUT power connections and through a device called a capacitive clamp to the I/O signal wires such as telephone or **l**ocal **a**rea **n**etwork ,LAN, connections.

The stress produced on I/O signal leads is extreme and designs must generally include extra cost to pass the test. A problem arises in that the coupling mode of the capacitive clamp is, as its name implies, capacitive whereas the dominant coupling mode between cables in a trough is inductive. In addition, the capacitive clamp injects more noise into I/O cables than lab data presented in this paper shows is realistic. Add these problems to sources of non-repeatability presented in the data of this paper, and design engineers face quite a dilemma.

Test Metholodogy

An investigation was made into the capacitive clamp used in the Electrical Fast Transient/Burst test, IEC 1000-4-4, in order to characterize existing clamps and ultimately to compare them with several new designs under consideration by TC77B.

The test was made by putting a 1.5 meter length of Category 5 **u**nshielded **t**wisted **p**air, UTP, cable in the existing capacitive clamp. All of the conductors were connected together and to a 150 ohm termination to ground on one side of the clamp. The current through the termination or the voltage across it was measured under several conditions with a Hewlett Packard 54542a digitizing oscilloscope. These conditions included three terminations on the far end of the UTP on the opposite side of the capacitive clamp: open circuit, shorted to the ground plane, and terminated with 150 ohms to the ground plane.

Since a capacitively couple signal looks like a current injected onto a conductor and an inductively coupled signal looks like a series voltage in the conductor, the three terminations can listed above can help determine whether the coupling mode is primarily capacitive, inductive, or a combination of the two.

For some of the proposed designs that have comparable amounts of both inductive and capacitive coupling, it is possible that the amount of interference received in the 150 ohm termination will depend on which direction the clamp is installed on the cable. In one direction, the inductive and capacitive signals may add and in the other direction they may partially or completely (under special conditions) cancel each other.

Tests Performed

Measurements were made on three manufacturer's generators and clamps. For the purposes of this paper the equipment will be referred to as manufacturer A, B, or C.. These results were then compared to actual EFT coupled from power lines in a worst case laboratory setup.

All measurements were made with the generator set at 500 V output.

For tests on manufacturer A, a pair of oppositely positioned Fischer Custom Communications F-33-1 current probes with a 5 ohm transfer impedance were placed around the fixed 150 ohm common mode termination of the UTP. The output of one of the probes and the sum of the two was displayed on the scope screen. The sum should be zero if the probes are responding only to current, a concern in situations where high voltages are used. Thus the sum represents the error in the data in the displayed probe's output. This is called a null experiment.[2]

In the Manufacturer B and Manufacturer C tests, a tap was placed at 50 ohms above ground on the 150 ohm fixed termination and this signal was fed to the 50 ohm input of the oscilloscope though a 20X high voltage attenuator. The null experiment to check data validity was done by shorting the input to the scope cable while the EFT was being applied to the clamp. This checks unwanted leakage of the EFT into the cable and scope and confirms that the connectors and cable shield were working properly.

Before each measurement was made, a DC resistance test to ground from the UTP was made to insure all connections were good.

Results

Figure 1 shows current through the 150 ohm fixed termination for the Manufacturer A clamp at 1 amp per division (probe transfer impedance was 5 ohms yielding the vertical scale of 5 volts/division). The far end of the UTP was open circuited. The AC coupled nature of the current probe leads to the dip below ground on the waveform in Figure 1.

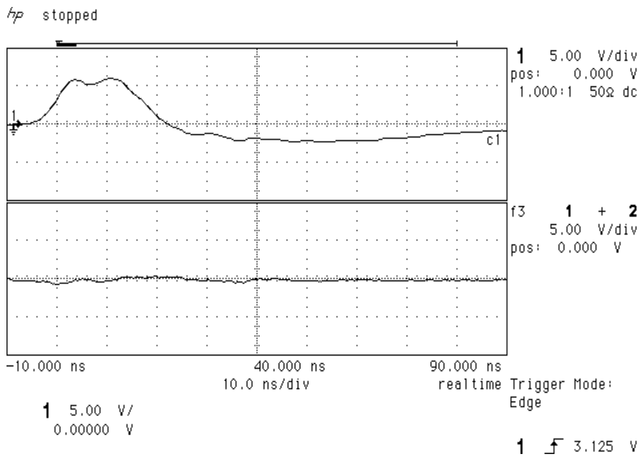

Figure 1. Manufacturer A,
Termination Current, Far End Open

An interesting effect happens if the clamp is reversed from the direction called for in IEC 1000-4-4. The standard specifies that the clamp should be fed from the end closest to the EUT. This leads to the double hump in the waveform in Figure 1. It is caused by the wavefront of the EFT signal entering the clamp and its reflection from the unterminated end of the clamp. The reflection passes the end of the clamp closest to the EUT about 8 ns later on its way back to the EFT generator.

If the clamp is reversed, the incident and reflected wavefronts overlap and reach nearly double the peak amplitude as shown in Figure 1a. This effect significantly increases the di/dt and current stresses on the EUT.

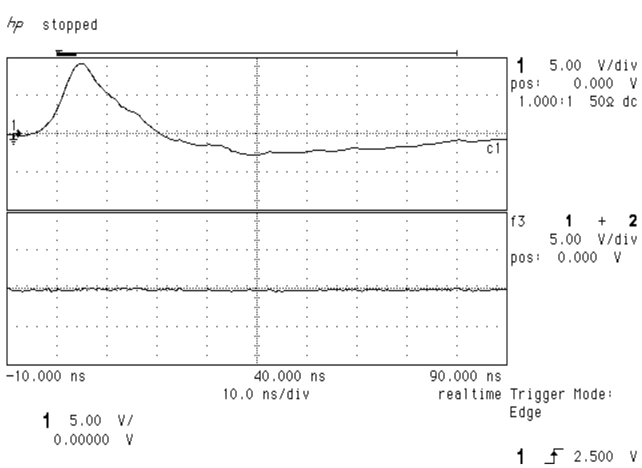

Figure 1a. Manufacturer A,
Termination Current, Far End Open
Clamp Reversed on Cable

Figures 2 and 3 show the result for a short to ground and 150 ohms to ground respectively at the other end of the UTP. The clamp is installed as specified in IEC 1000-4-4. Compare Figures 2 and 3 to Figure 1.

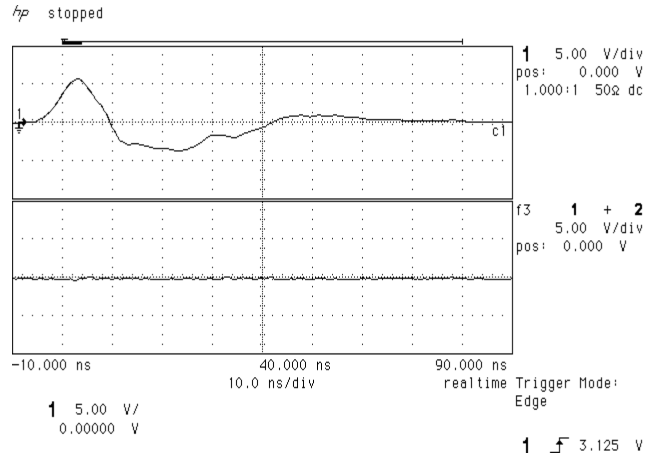

Figure 2. Manufacturer A,
Termination Current, Far End Shorted

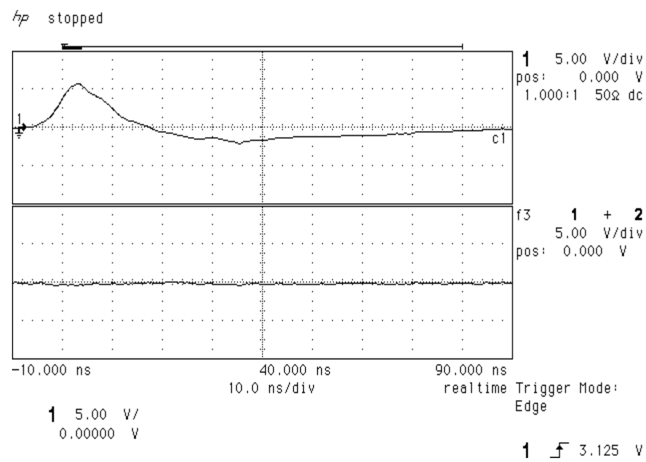

Figure 3. Manufacturer A,
Termination Current, Far End 150 ohms

Note that the peak value of current, about one ampere, was the same in all cases. This represents about 150 volts peak across the termination.

Figure 4 shows the same test as in Figure 1 for the Manufacturer B generator and clamp. The peak voltage is about 250 volts.

Figure 5 and 6, respectively, show the 150 ohm and shorted to ground cased for the Manufacturer B equipment. In each case for manufacturer B, there was over 200 volts across the 150 ohm fixed termination, significantly more than for the Manufacturer A generator and clamp. Worst case current probe calibration can only explain less than half the difference observed.

Figures 7, 8, and 9 show the fixed termination voltages for the open, short, and 150 ohm far end terminations of the UTP, respectively, for the generator and clamp from manufacturer C.

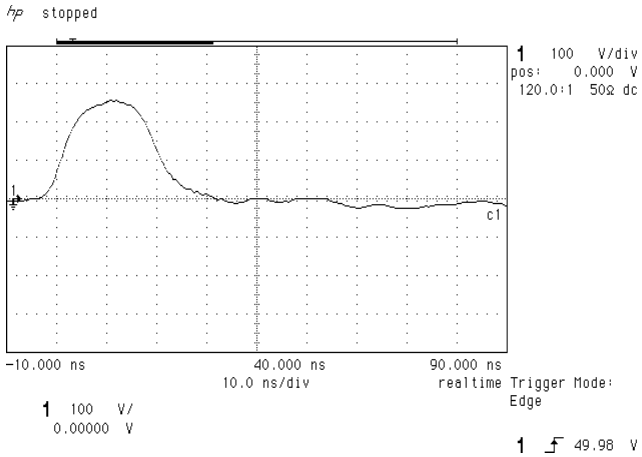

Figure 4. Manufacturer B,
Termination Voltage, Far End Open

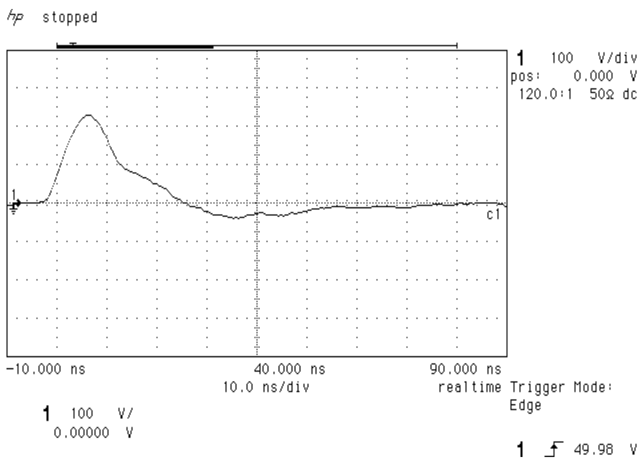

Figure 5. Manufacturer B,
Termination Voltage, Far End 150 Ohms

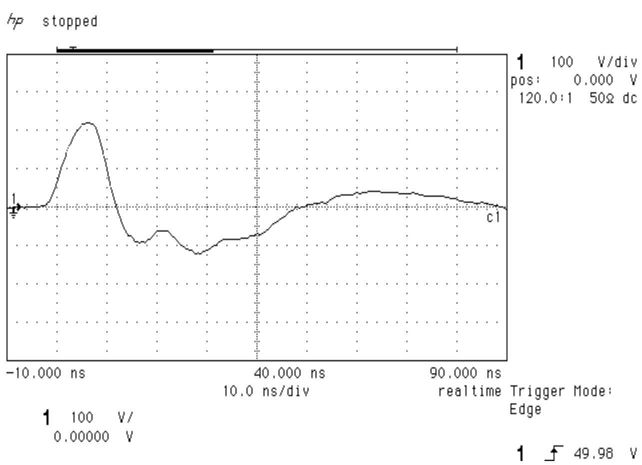

Figure 6. Manufacturer B,
Termination Voltage, Far End Shorted

For manufacturer C, the peak termination voltages ranged from 220 volts to 170 volts for the three terminations.

A test was set up with 150 ohm mode common mode terminations on a 25 meter length of Category 5 UTP running parallel and close to power conductors for about 15 meters. The power cable was arranged to produce worst case coupling. First 500 volt EFT was launched on the power cable using the generator of manufacturer A and the result measured on the UTP termination. Figure 10 shows resultant waveform in one of the UTP terminations at a scale of 200 milliamps per division.

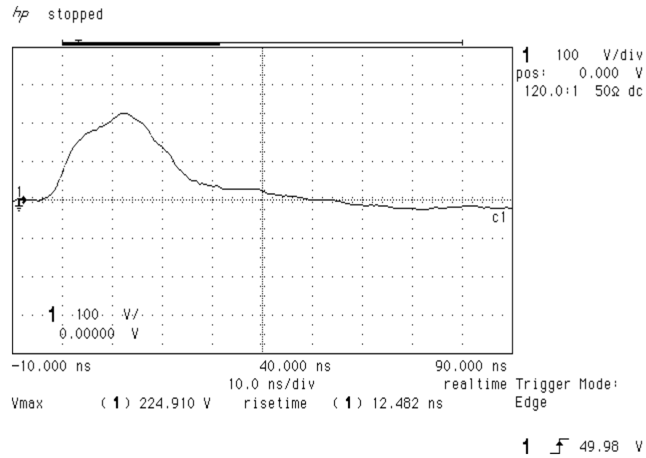

Figure 7. Manufacturer C,
Termination Voltage, Far End Open

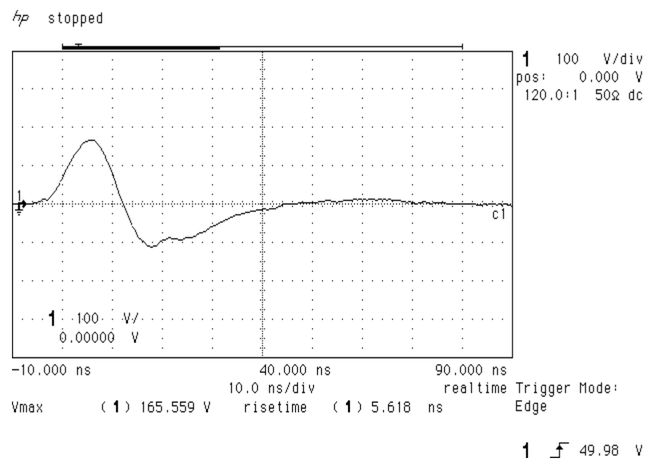

Figure 8. Manufacturer C,
Termination Voltage, Far End Short

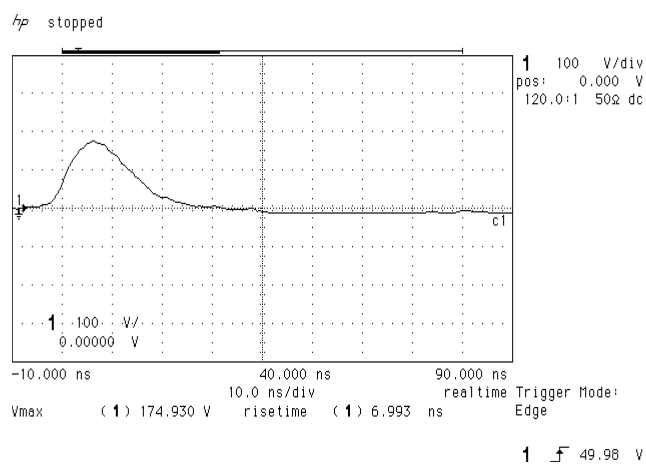

Figure 9. Manufacturer C,
Termination Voltage, Far End 150 Ohms

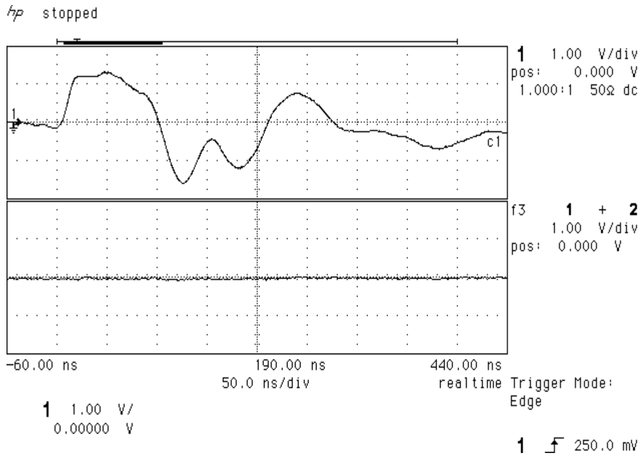

Figure 10. Manufacturer C,
Termination Current, 15 Meters of Cable

The amplitude was **<u>much</u>** less than the interference generated by the clamps investigated above. The peak current in the termination was only about 250 milliamps instead of about 1 ampere generated by the capacitive clamps.

The EFT generator was then replaced by a pencil sharpener whose motor generated significant amounts of EFT. Figure 11 shows the amount of current resulting in the termination of the 15 meters of UTP.

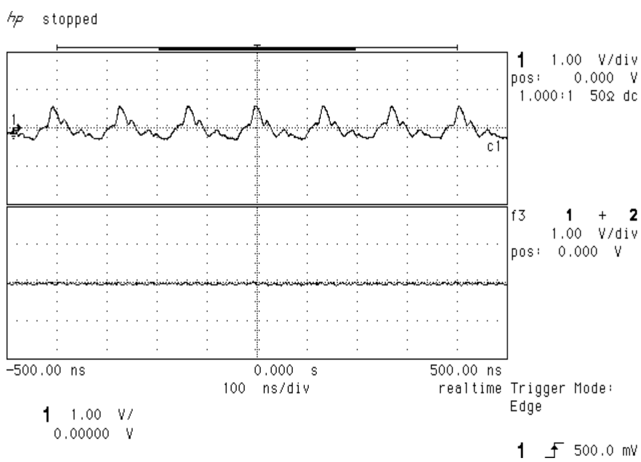

Figure 11. Manufacturer C,
Termination Current, Pencil Sharpener EFT

Note that the amplitude of the current is only about 100 milliamps! The burst rate is a little slower than 10 MHz.

Conclusions and Further Work

There were significant differences in the amount of voltage produced into the terminations for the three manufacturers equipment. The worst case difference was almost 50 percent between equipment that was properly connected.

Some of the differences are attributable to different dimensions of the capacitive clamps. The dimensions deviated significantly from the recommended dimensions in IEC 1000-4-4 in one case.

Care must be taken to connect the capacitive clamp on the EUT cable in the proper direction. Failure to do so can increase the stress on an EUT by almost a factor of two.

The capacitive clamp seems to inject much more noise into the UTP cable than worst case laboratory setups between the UTP and power cables. This effect warrants further investigation and could result in adjustments in the EFT levels of IEC 1000-4-4 or in the design of the coupling clamp.

There is **<u>much</u>** more data available from the tests that were made. Some of it leads to some interesting conclusions about how the test is done. In addition to publishing more of the available data, Auspex Systems, Hewlett Packard, and Barth Electronics expect to continue work in this area.

Acknowledgements:

I wish to thank Darren McCarthy and Ken Hall at Hewlett Packard and Jon Barth of Barth Electronics for their help in generating the data upon which this paper relies.

References

[1] IEC 1000-4-4, Electrical Fast Transient Burst test. This standard evolved from the old IEC 801-4 standard to include faster burst rates to 100 kHz and other modifications to the test procedure. An example is the inclusion of a ground plane on the table top for testing table top equipment similar to that used in ESD testing.

[2] *High Frequency Measurements and Noise in Electronic Circuits*, Douglas C. Smith, 1993, Van Nostrand Reinhold, Chapters 8 and 9.