Measurement Notes

Note 58

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A Comparison of Two Sensors Used to Measure High-Voltage, Fast-Risetime Signals in Coaxial Cable

Everett G. Farr, Lanney, M. Atchley, and Donald E. Ellibee
Farr Research, Inc.

William J. Carey
ARC Technology

Larry L. Altgilbers
U.S. Army Space and Missile Defense Command

Abstract

We consider here two sensors that are commonly used to measure high-voltage fast-risetime signals in coaxial cable. One sensor measures the current in the cable, and is called a Current-Viewing Resistor, or CVR. In this design, the cable jacket is cut, a portion of the cable jacket is removed, and a number of resistors are inserted in parallel across the gap, thereby creating a low resistance in series with the outer cable jacket. The voltage across these resistors is proportional to the current in the coax. The second sensor measures the derivative of the voltage in the coax. It is fabricated from a "sawed-off" SMA connector that is inserted through a small hole in the cable jacket. In this paper we characterize the accuracy of both sensors when used with RG-220 cable, and we discuss the situations when one might prefer one measurement type over the other.

I. Introduction

We consider here two methods of measuring transient voltages in coaxial cables. In particular, we are concerned with voltages in the range of 100 kV or more, and risetimes on the order of one nanosecond or less. We needed this capability recently in order to characterize the output of a Marx generator during the development of the Para-IRA [1-2]. We examine two different measurement methods, a direct measurement using a current viewing resistor (CVR), and a derivative measurement using capacitive coupling into a sawed-off SMA connector.

In this paper we first calibrate the accuracy of the two methods. We then use both methods to measure the output from an ARC Technology Marx generator. Finally, discuss the relative advantages of each technique.

II. Marx Description.

This project was motivated by a need to characterize the output of an ARC Technology Marx generator, shown in Figure 1. The output of the generator is a five-foot RG-220 coaxial cable, shown directly above the Marx. We knew that the output voltage was over 100 kV and the risetime was predicted to be around 250 ps. Farr Research and ARC Technology jointly measured the Marx output voltage using the two different methods, a CVR, and a capacitively coupled pickoff probe built from an SMA panel-mount connector.

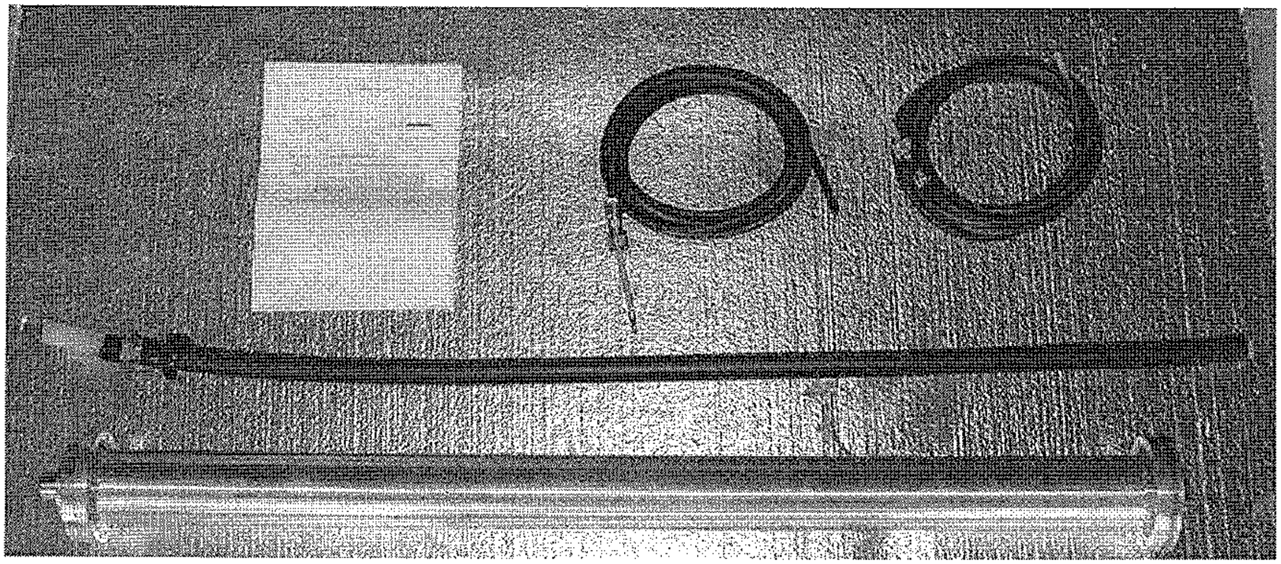

Figure 1. ARC Technology Marx generator.

III. Current Viewing Resistor

The CVR is fabricated from sixty-five 2.2-ohm resistors arranged in parallel across a gap in the outer conductor of the RG220 cable. Because the resistors are all in parallel, we expected that the resistor assembly would be able to handle high currents with low inductance. The resulting 34-milliohm resistor assembly is shown in Figure 2. The CVR is inserted into a circumferential break in the cable shield and held in place with hose clamps on either end. The total cable shield current flows through the CVR, so it forms a resistive voltage divider with the 50-ohm cable impedance. The current through the CVR is directly proportional to the cable current. To measure the voltage across the resistors, we stripped the outer conductor off of the end of a 0.141-inch (3.58 mm) diameter semi-rigid cable and soldered it across the resistors. This functions as a high-impedance (50 ohms relative to 34 milliohms) voltage probe.

We can determine the calibration factor for the CVR by simple math using the rules of voltage division. Alternatively, and more accurately, we can drive the cable with a known input step function and measure the output. We generally use a simple scalar multiplier to characterize the device.

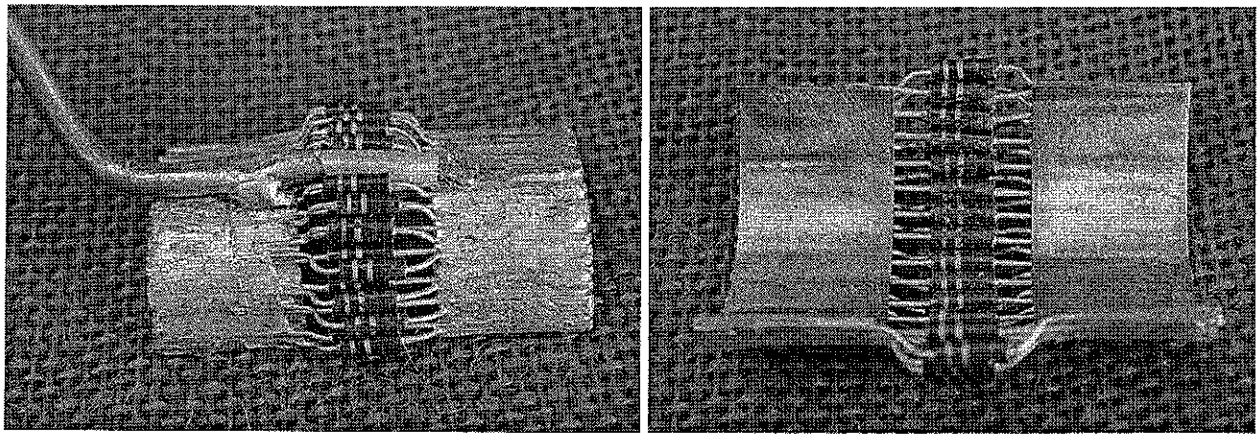

Figure 2. Two halves of the ARC-Tech CVR.

IV. Capacitive Pickoff with SMA Sensor

The SMA sensor is simply an SMA receptacle with the center stud and insulation machined to a height of approximately 0.51 mm (0.020 in). In this case, the connector is a Suhner 23 SMA-50-0-03. The center conductor and insulation extend 0.51 mm (0.020 in) so that it can protrude through a circular gap in the cable braid. The sensor is held in place on the cable with a hose clamp with a hole drilled into it to receive the SMA female connector.

The center stud forms a capacitive pickoff from which the cable voltage can be reconstructed by integrating the output and multiplying by a scalar. This scalar is determined by calibrating the probe with a known source. This class of sensor is similar to that described in [3]. The two sensors were installed close to each other on the Marx output cable as shown in Figure 4, in order to obtain simultaneous measurements.

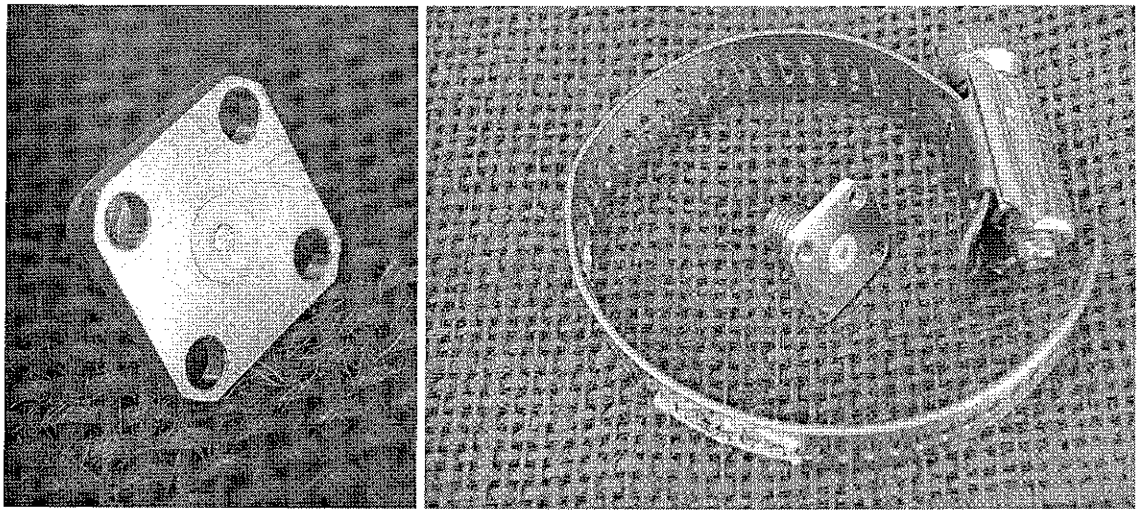

Figure. 3. Left: SMA connector modified as a sensor. Right: Sensor and hose clamp.

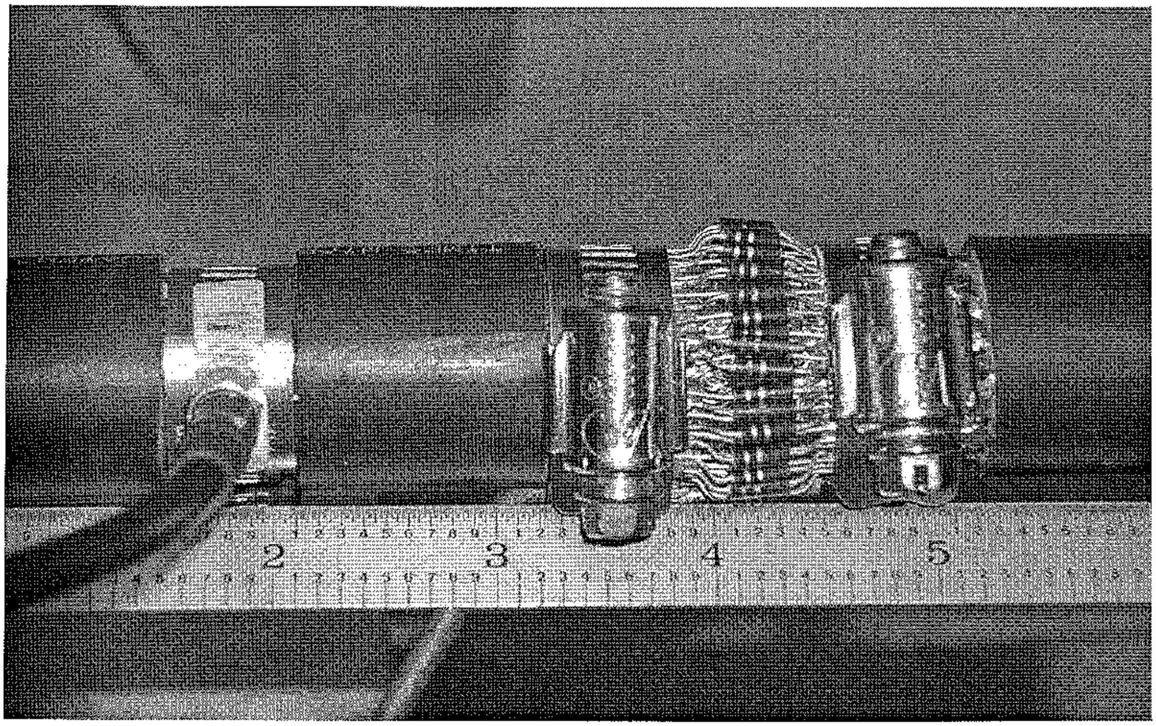

Figure 4. SMA sensor (left) and CVR sensor (right) installed onto the Marx output cable.

V. Sensor Calibration

We calibrated the CVR and SMA sensors by driving the cable with a known source, a Picosecond Pulse Laboratory model 2000D pulse generator. This has approximately a 48-volt output with a 300 ps risetime. We recorded the output from the CVR and SMA sensors on a Tektronix model 7404 oscilloscope operating at 10 gigasamples/second. We numerically integrated the SMA output and found a scalar that matches the integrated SMA data to the driving waveform. Similarly we found a scalar that matches the CVR data to the driving function. The scaled CVR and SMA data are shown in Figure 5, along with the output of the PSPL 2000D pulse generator. The calibration factor for the SMA is 2.7×10^{12} V/V-s, and the calibration factor for the CVR is 1450 V/V.

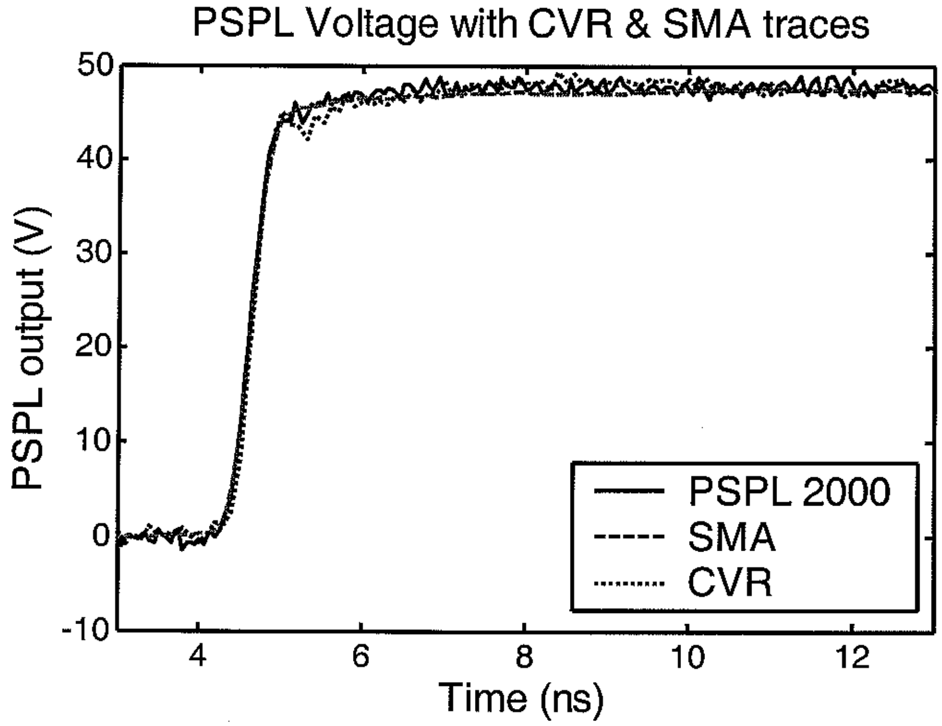

Figure 5. CVR and SMA probe calibration.

We can check our calibration factor for the CVR by carrying out the voltage division calculation. The resistance of the CVR is 2.2 / 65 ohms or 34 milliohms. The 48-volt PSPL 2000D drives 0.96 amps of current through the CVR and 50-ohm impedance of the cable, creating 33 mV across the CVR. That is a calibration factor of 1455 V/V (48/0.033), which is in excellent agreement with the measured scaling factor above.

We then repeated the above calibration process with a different source, with a faster risetime. In this case, we used a Kentech model ASG1, with risetime of 100 ps and peak voltage of 200 V. The results are shown in Figure 6, where we observe that the CVR sensor rings severely when driven with the faster signal. This ringing results in a 50% overshoot of the peak level. On the other hand, the integrated output of the SMA sensor is quite accurate, and it virtually overlays the source function.

We believe the problem with the CVR at faster risetimes is due to the inductance of the resistors. We used a large number of resistors in parallel to reduce the inductance, but at a fast enough risetime the inductance still becomes apparent. We believe that virtually any carbon composition CVR will demonstrate inductive behavior at a fast enough risetime. We found no ringing in the SMA sensors with pulser risetimes as fast as 30 ps. We believe therefore that the SMA pickoff is superior for fast risetime measurements.

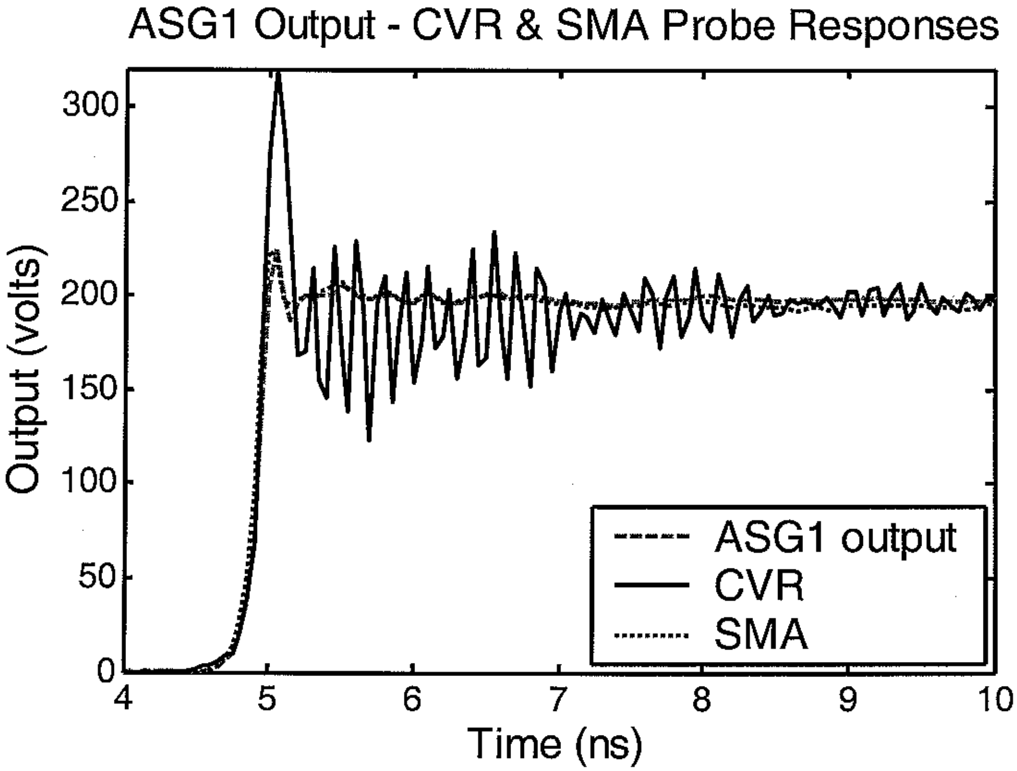

Figure 6. Calibration using a source with a faster risetime, the Kentech ASG1, with 100 ps risetime.

VI. High Voltage Marx Measurements.

We reinstalled the RG-220 cable into the Marx output and then fired the Marx, recording the signals from both sensors on a Tektronix model 7404 oscilloscope, operating at 10 gigasamples/second. We calibrated the measurements from the CVR and SMA sensors as described above. Thus, we multiplied the signal from the CVR by 1455 V/V, and we numerically integrated the signal from the SMA probe and multiplied the result by 2.7×10^{12} V/V-s. Both calculations result in the Marx output in volts.

The output of the Marx is shown in Figures 7 and 8 on two different time scales. Each trace is an average of five data shots to reduce noise. From this data we see that the Marx has a peak level of about 120 kV and a risetime of about 500 picoseconds. The two sensors provide very similar results.

We observe an interesting feature in the data of Figure 7 at late times. There is a short circuit at about 20 ns on this time scale. Because of the two different measurement techniques used, at this point we observe a current reflection coefficient of +1 in the CVR measurement, and a voltage reflection coefficient of –1 in the SMA measurement. So the two sensors respond differently to reflections in the cable, as one would expect. To avoid measuring reflections a concept is available to measure just the forward-traveling wave, and this is described in [4].

There is a difference between the output levels of the CVR and SMA measurements following the initial rise. We suspect that this difference is related to the relatively high voltage (~80 V) across the CVR resistors. We do not see this difference in low-voltage calibration measurements.

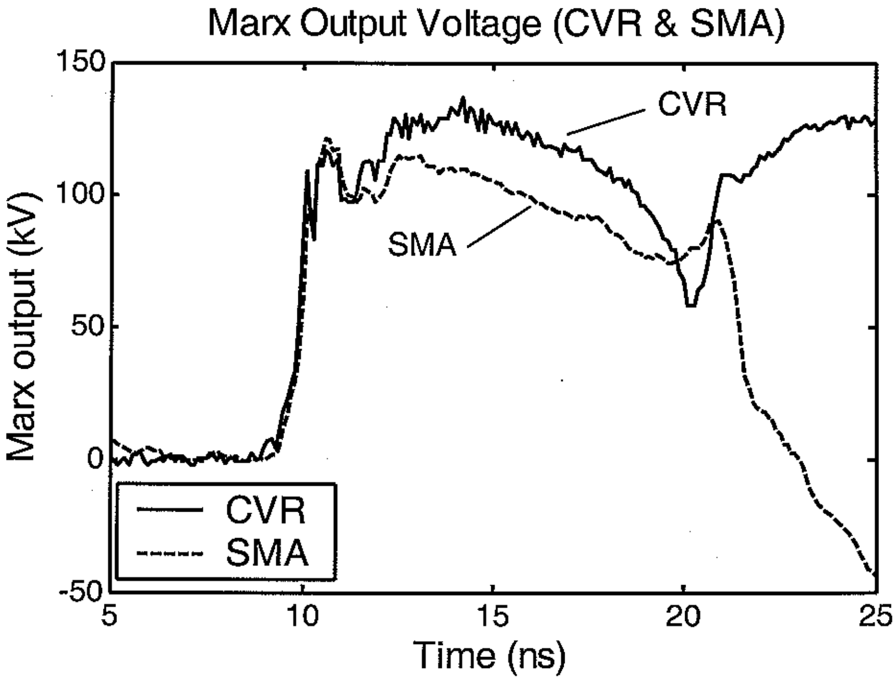

Figure 7. Marx output measured by CVR (solid) and SMA (dashed) probes.

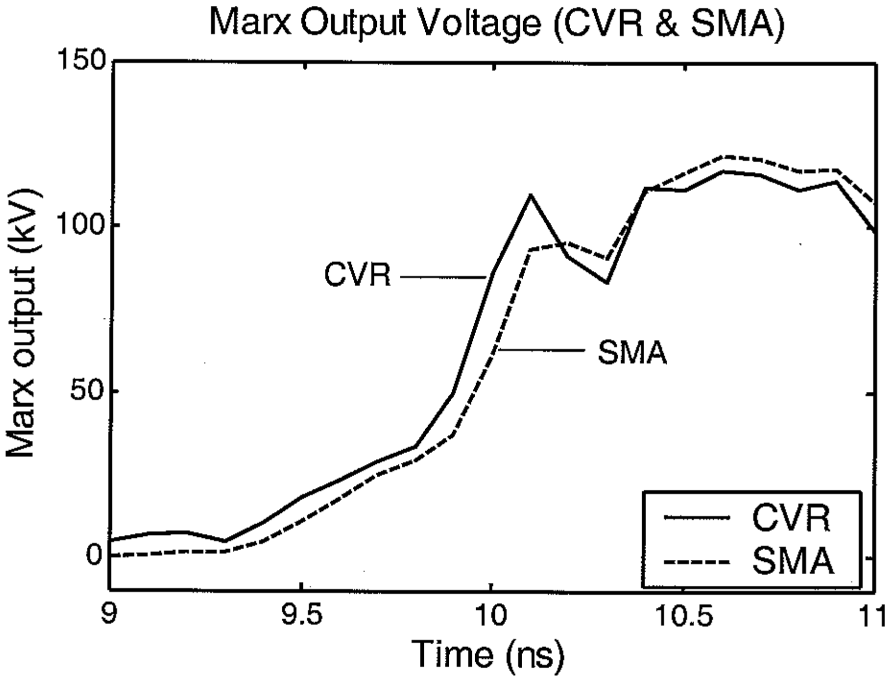

Figure 8. Marx output: CVR (solid) and SMA (dashed) probes, expanded time scale.

VII. Discussion

Despite the observed ringing at very fast risetimes, there are still several reasons why one might prefer using a CVR instead of an SMA. First, many signals of interest are not fast enough for the ringing to become evident. (An example of such a signal was presented in the previous section.) Second, a CVR provides a direct measurement of the signal, without the need for integration. A numerical integration is sometimes inconvenient, while an analog integration may result in either a reduced signal or reduced accuracy of the measured signal. Finally, the CVR has more sensitivity than the SMA sensor. In some applications with low voltages or long risetimes, the SMA sensor may not provide sufficient signal to drive the oscilloscope.

Normally, however, an SMA sensor would be preferred for several reasons. First, for fast signals, this is the only way to avoid ringing. Second, the SMA sensor introduces only a small hole into the cable, which can easily be repaired. The CVR, on the other hand, is more invasive, and it permanently alters the cable. In addition, the SMA is preferable for reasons of EMI integrity. Signal can leak out of the CVR and get out into the surrounding environment. That cannot occur with the SMA measurement. Finally, and perhaps most importantly, the SMA sensor is much simpler to build.

If the pulser risetime is so fast that the integrated and scaled SMA output fails to overlay the calibrated input, then one can always deconvolve the impulse response of the SMA sensor from the output. For the measurements we have made to date we have not found that to be necessary.

VIII. Conclusion

We have investigated two distinct methods of measuring high-voltage fast-risetime signals in coaxial cables. The current viewing resistor, or CVR, provides a measure of the cable current, while the SMA sensor provides a measure of the derivative of the cable voltage. Because of its simplicity and accuracy, the SMA measurement will usually be preferred. However, at low voltages and/or long risetimes, the CVR may be necessary. When carefully performed under selected conditions either sensor provides essentially the same results.

References

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