LOW COST 400-PS RISE-TIME CIRCUIT-BOARD MARX GENERATOR

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Abstract

Some modern pulsed-power applications benefit from a fast-rising trigger pulse which can minimize temporal jitter or ensure a desired mode (e.g. multi-channel spark gap) of breakdown ensues. Applied Physical Electronics, L. C., (APELC) has developed a low-cost 400-ps rise time Marx generator for low-energy triggering applications.

The low-cost Marx is designed into a printed circuit board (pcb) geometry and uses inexpensive, off-the-shelf components. In a typical configuration, the Marx has an erected voltage of 10 kV, a stored energy of 5 mJ, and a risetime near 400 ps. The Marx has been operated at a pulse repetition frequency of 250 Hz. Other potential uses include sourcing compact antennas, driving laser diodes, and biological plasma applications.

I. BACKGROUND

Some modern pulsed-power applications benefit from a fast-rising trigger pulse which can minimize temporal jitter or ensure a desired mode (e.g. multi-channel spark gap) of breakdown ensues [1, 2]. Recent pulsed power demands have placed a greater value on a fast risetime of a low-energy pulse for numerous ultra-wideband applications [3, 4]. In addition, small size, simple charging requirements, and the ability to operate off of a small battery are valued.

APELC has developed a low-cost PCB (printed circuit board) Marx generator (PCBM) for low-voltage fast-risetime applications.

This paper describes the basic design, component descriptions, and pulse characteristics of the PCB Marx generator. When charged to 850V the PCB Marx delivers a 4.7 kV, 380-ps risetime pulse to a 50-ohm cable load. The PCB Marx can erect for charge voltages ranging from 220V to 1000V. Future efforts will investigate scaling considerations, repetition rate limitations, and more potential applications.

A. PCB Marx Description

The PCB Marx is a 10-stage Marx generator which uses surface mount capacitors and inductors as the storage and isolation elements respectively. In Figure 1 (left) the marx is shown as captured by an extended exposure period in which the Marx is operated repeatedly. In Figure 1(right) the Marx is shown populated on its PCB substrate.

"Stray" capacitances from each stage to ground are built into the Marx generator in addition to the actual stray capacitances that exist by virtue of the substrate geometry. By building in SMT pads, the erection of the Marx can be affected by the value or presence of capacitance to ground for a given stage.

Both inductors and resistors have been used as isolation elements in the Marx effectively. Surface-mount inductors are the preferred component for this role so that the repetition rate will not be limited due to ohmic loss in isolating resistors.

The basic circuit schematic for the MG10-1C-1nF PCB Marx is shown in Figure 2.

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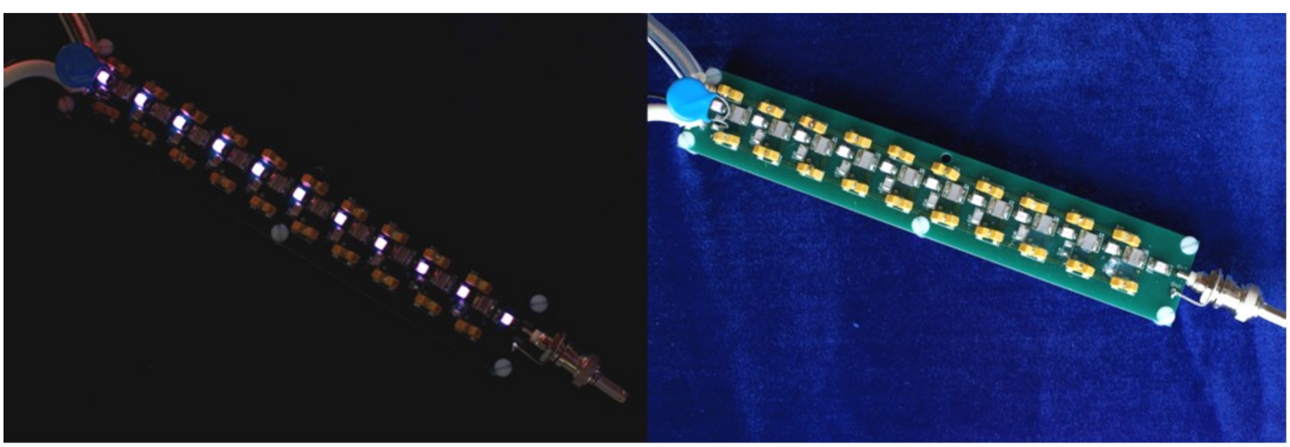

Figure 1 The MG10-1C-1nF PCB Marx generator (left) image by extended exposure of the generator during repeated operation and (right) the generator and the PCB substrate.

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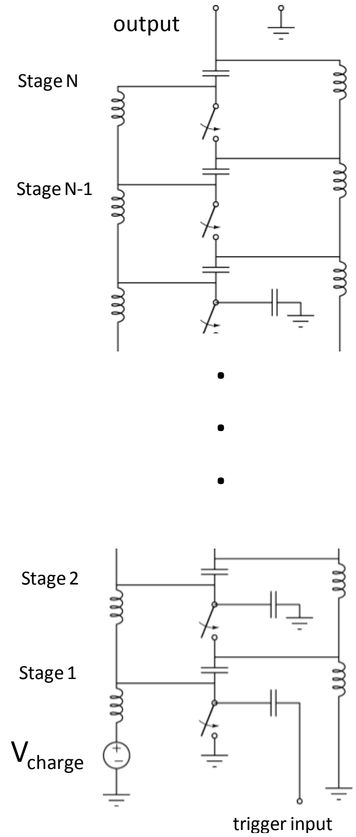

Figure 2 Simplified schematic for the APELC PCB Marx generator MG10-1C-1nF.

An inexpensive IGBT is used to trigger the Marx. The IGBT is isolated from the Marx by a small pulse transformer and capacitively coupled to the first-stage switch as shown in Figure 2. The Marx can tolerate a slow rising trigger pulse since the erection is initiated by the breakdown of the first stage switch.

Table 1 General Parameters of the MG10-1C-1nF PCB Marx generator.

Symbol	Parameter	Value	units
N	Number of stages	10	-
V_E	erected voltage	9	kV
V_{ch}	maximum charge voltage	990	V
V_{ch}	charge voltage range	200-990	V
E_{pulse}	maximum energy per pulse	5	mJ
P_{25}	Peak power on a 50 ohm load	562	kW
C_{stage}	Capacitance per stage	1	nF
	Erected capacitance	100	pF
L_s	Series inductance	65	nH
Z_{source}	Source Impedance	26	Ohms

The general parameters of the PCBM are listed in Table 1. The capacitance per stage can be altered by a factor of 10 and still permit Marx erection. Changing the stage capacitance alters the generator impedance and the output pulse shape.

II. RESULTS

The Marx was configured for bench top operation as described below in order to measure output pulse characteristics and examine the dynamic range of charge voltages.

A. Experimental Setup

The measurement setup for the PCB Marx generator is shown below. The output of the Marx was connected to a 50-ohm cable terminated into a shielded load/CVR enclosure.

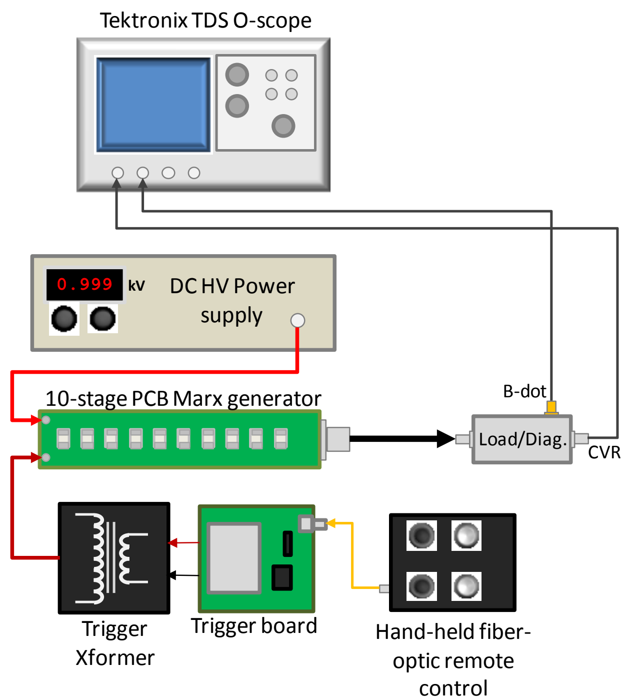

Figure 3 Operation and measurement setup.

The Marx was charged with a benchtop high-voltage power supply and triggered with an APELC solid state trigger board and an isolating pulse transformer. The output waveform was acquired by a Tektonix TDS 2-GHz digital oscilloscope. The oscilloscope was connected to the T&M Research CVR inside the load enclosure, which is depicted in Figure 4.

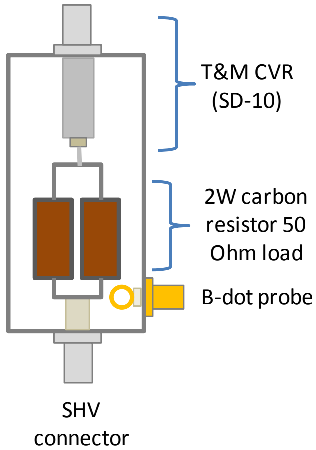

Figure 4 Load and CVR enclosure diagram.

A previous experimental arrangement saw the PCBM output connected directly into RG-400 coaxial cable which was attenuated several times before being terminated through the oscilloscope. This technique was abandoned after several high-power attenuators failed after several hundred shots.

B. Experimental Results

The Marx was discharged into the CVR enclosure with the load resistor removed in order to measure the ringdown frequency and characterize the Marx impedance. The ringdown frequency was estimated to be 62.5 MHz which corresponds to a Marx impedance of 25.5Ω. The ringdown waveform is shown in Figure 5.

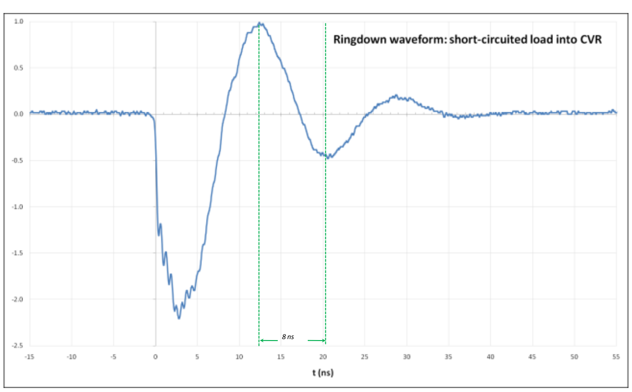

Figure 5 Ringsdown waveform with estimated LC frequency of 62.5 MHz.

Charge voltages were varied in order to record the charge-voltage dynamic range, i.e. the charge voltages that were permitted that resulted in (1) Marx erection and (2) failure to self break the switches during the charging period. This sweep found that the marx would erect via trigger for charge voltages ranging from 220 V to 1000 V. The resultant output waveforms are shown in Figure 6

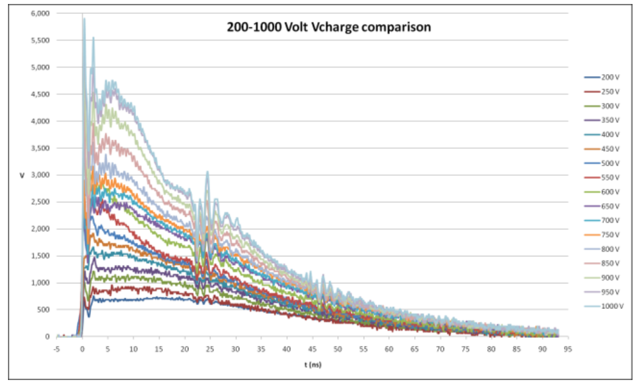

Figure 6 Output waveforms for charge voltages from 220V to 1000V.

Output waveform repeatability was investigated by recording 19 consecutive wavorms for a charge voltage of 850V. First this waveform overlay was recorded with the PCBM sitting on a benchtop in open air conditions. The corresponding waveforms are shown in Figure 7 (top).

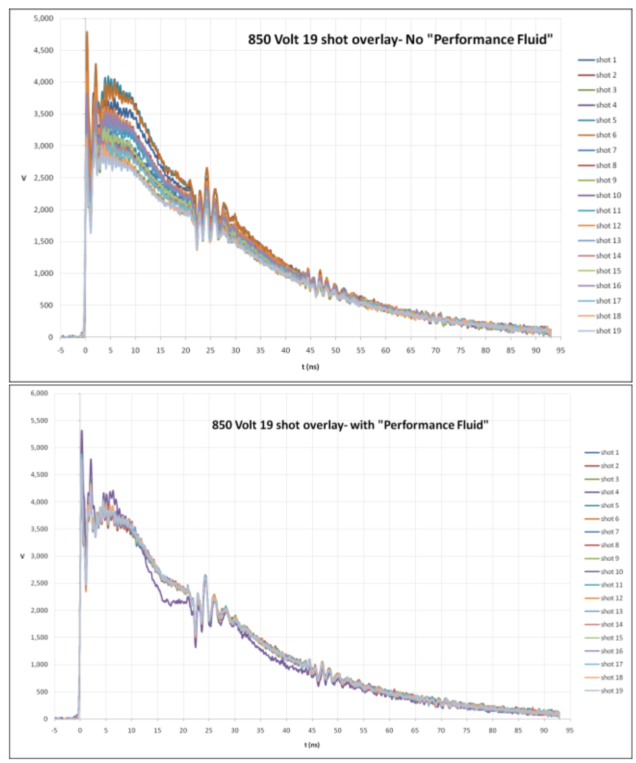

Figure 7 19-shot fast frame overlay of the Marx output waveform when charged to 850V (top) in atmosphere, (bottom) submersed in Flourinert fluid

Next the PCBM was submerged in a Flourinert fluid to prevent unwanted arcing or discharge when the circuit erects. The 19 sequential waveforms are overlayed in Figure 7 (bottom). The much tighter grouping and waveform repeatability indicated that insulation of the isolating circuit elements can be improved. The risetime for an 850-V charge is shown in detail in Figure 8.

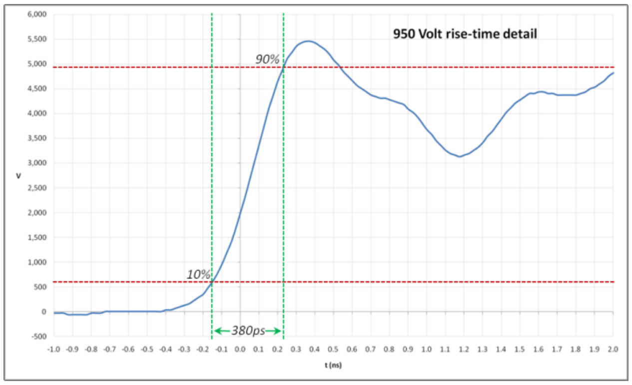

Figure 8 Risetime detail for 850-V charge.

III. CONCLUSIONS

The PCB Marx is built from inexpensive off-the-shelf components. It has a wide dynamic range of charge voltages and exhibits output pulse risetimes below 400 ps into a 50-Ω cable load. Additionally submersing the circuit in insulating fluid improved the output waveform repeatability markedly.

The PCB Marx's characteristics can be useful for very small pulsed-power platforms, low-energy systems, and small ultra-wideband antennas. Future efforts will explore repetition rate limitations and scaling.

IV. REFERENCES

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