A Compact MV Marx Generator

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Abstract

A compact MV Marx generator is presented. The generator employs a modular geometry designed for decreased volume, enhanced performance ease of maintenance. The generator is very well suited for the direct generation of Narrow Band and Ultra Wide Band energy, as a high voltage trigger generator or as a flash x-ray source. The characteristics of the generator are discussed

I. INTRODUCTION

Compact Marx generators have been employed for many years as trigger generators for larger systems and intermediate sources for high voltage pulses designed to pulse-charge pulse-forming lines. These generators are typically designed with pulse characteristics of more than 200 kV in peak voltage, 3 – 4 ns rise times, 1 – 3 ns rms jitter and pulse widths of 10's of ns. However, these systems grow in volume with increases in their erected voltages, since more Marx stages leads to higher source impedances and lower load voltage efficiencies.

However, recent efforts [1] with compact Marx generators have brought faster rise times, higher peak voltages, and increased load voltage efficiencies, making them good candidates for direct RF generation and indirect RF generation.

This paper discusses a relatively compact mega-volt (MV) Marx generator under development by Applied Physical Electronics, L.C. (APELC). The generator compactly adds 40 stages of three ceramic doorknob capacitors in a modular geometry for an erected voltage of more than 1.6 MV. The generator has been tested for impedance and high voltage delivery into a 50 Ω cable load, with load voltages in excess of 800 kV. The results of this testing are presented.

II. Background and Design

A. The Wave Erection Marx Generator

The most efficient, compact and economical method of generating a repetitive, large magnitude, electromagnetic impulse is the wave erection of a spark gap-switched Marx circuit. Wave erection is necessary to obtain the fast voltage rise times from the Marx circuit that generates the ultra-wideband frequencies for direct RF generation and fast rising pulses for explosive emission with cold cathode devices. Wave erection is made possible through the proper design of the stray capacitance and the inter-stage capacitance, in concert with coupling the spark gaps via ultra-violet energy. Rise times from a few hundred ps to several ns result with proper stray element design.

B. Moderate Pulse Generator Design

The APELC MV generator effort stems from the SuperSaver Marx generator developed by David Platts of Los Alamos National Laboratory. APELC has taken Platts' design and moved it into a more modular geometry with minimal changes in the housing dimensions (approximately ½ inch was added to the housing diameter).

The completed design employs three TDK UHV-6A (30 kV, 2.7 nF) capacitors per stage, with a cross-sectional view shown in Figure 1. The capacitors are mounted to an ABS insulator that also fixes the brass electrodes and provides electrical interconnects. The Marx stages, once fixed together, compactly slide inside the insulating medium, which is fabricated with nylon (or epoxy for higher dielectric strengths). The liner has an internal diameter of 5 ½ inches and an outside diameter of 7 ½ inches. The liner is encased in an aluminum pipe that has a wall thickness of ¼ inches. A conceptual view of the housing is shown in Figure 2.

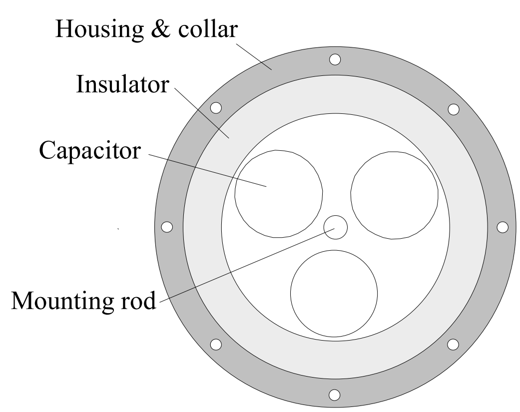

Figure 1. Cross-sectional conceptual view.

Electrically, the generator has a stage capacitance of 8.1 nF, or an erected capacitance of 202 pF for the 40 stages. A series inductance of approximately 1 μH is calculated, which results in a generator impedance of 70 Ω. At a charge voltage of 40 kV, the generator stores approximately 260 J.

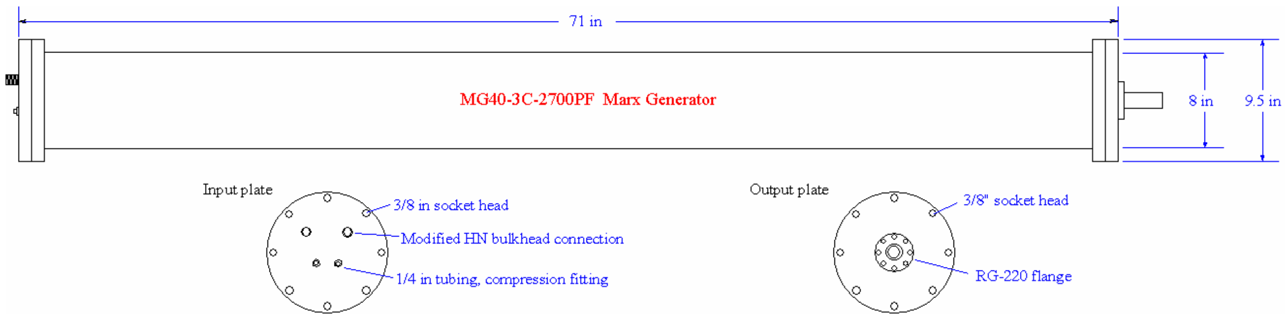

Figure 2. Conceptual view of the APELC MV generator.

The electrical characteristics are listed in Table 1 and the physical characteristics are listed in Table 2.

Table 1. Electrical characteristics of the generator.

Parameter	*Value*	*Unit*
Charge voltage	10 - 40	kV
Stage capacitance	8.1	nF
Stage resistance	330	kΩ
Number of stages	40	
Erected capacitance	200	pF
Series inductance	1	µH
Marx impedance	70	Ω
Charge time	13	sec
Maximum erected voltage	1.6	MV
Maximum energy stored	260	Joules

Table 2. Physical characteristics of the generator.

Parameter	*Value*	*Unit*
Diameter	8 (20)	in (cm)
Length	71 (1.8)	in (m)
Weight	200 (90)	lb (kg)

The generator requires and external, variable voltage power supply (0 – 40 kV), an external trigger source (> 10 kV pulse), and a breathable dry air source capable of pressurizing the housing 100 psi. Electrical feed-throughs are made with RG-213 coaxial cable, with customized HN connectors.

C. *Test Arrangement*

The generator is initially tested for its internal impedance, as defined by its erected capacitance and series inductance. The inductance is calculated from a short-circuit ring-down. The ring-down frequency is measured with a CVR (T&M Research Products [2]) that is directly mounted to the output of the generator , as shown in Figure 3. The CVR has an impedance of only 0.009809 Ω and does not affect the characteristic ring.

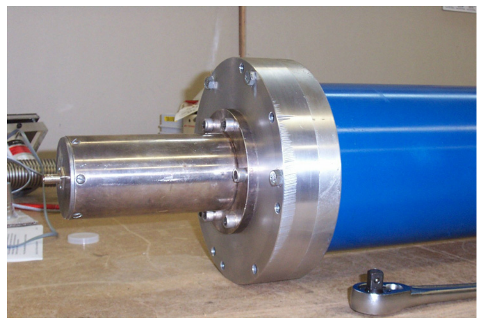

Figure 3. The CVR-based impedance measurement.

The pulsed output characteristics of the generator are measured via cable load, as shown in Figure 4. The CVR load is replaced with a section of RG-220 coaxial cable. Located within the 24 inches of the generator is an in-house, in-line CVR designed for a 75k:1 voltage ratio (including Narda attenuators). The voltage waveforms are measured with a Tektronix TDS 694C digitizing oscilloscope.

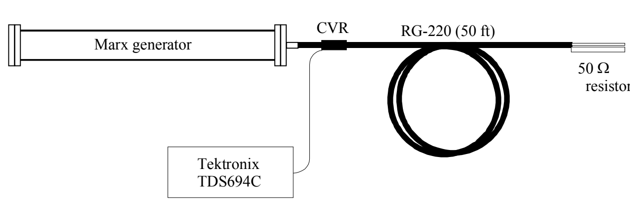

Figure 4. The output pulse measurement testbed.

IV. EXPERIMENTAL RESULTS

The generator was initially tested for its impedance using a T&M Research Products CVR (0.009809 Ω) directly mounted to the output section of the generator, as described by Figure 3. The CVR-measured waveform is shown in Figure 5.

The resulting waveform has a characteristic frequency of approximately 10 MHz. Measuring the frequency of the ring-down, and with the known erected capacitance, the Marx inductance and impedance were calculated as follows:

$$L_{marx} = \frac{1}{(2\pi f)^2 C_{erected}} = 1.19\,\mu H \qquad (1)$$

$$Z_{marx} = \sqrt{\frac{L_{marx}}{C_{erected}}} = 70\ \Omega \qquad (2)$$

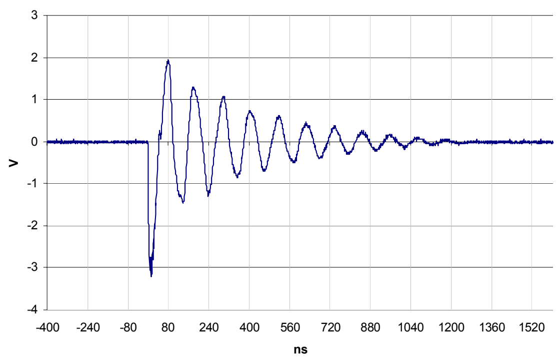

Figure 5. The CVR-measured rign-down.

Measurements of the generator's output are made with the configuration of Figure 4, in which the CVR is replaced with the RG-220 coaxial cable. For the initial measurements, the generator is charged to 30 kV and with a dry air pressure of 70 psi. As shown in Figure 6, the generator delivers a a peak voltage of 450 kV, or 4 GW into a 50 Ω load. In this configuration, a pulse energy of 146 J is delivered with a voltage efficiency of approximately 40%.

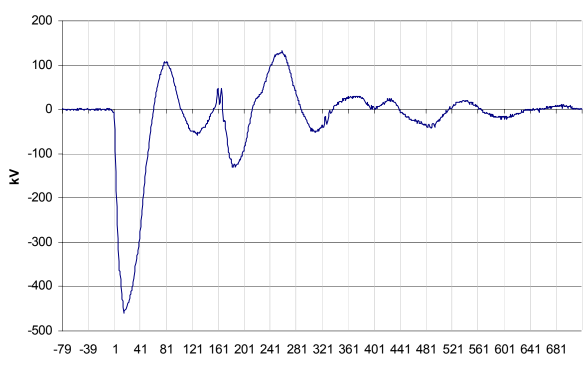

Figure 6. Output waveform with a 30 kV charge.

The charge voltage is increased to 40 kV and the pressure is increased to 90 psi to prevent self-triggering.. As shown in Figure 7, the generator delivers 525 kV, or 5.5 GW into the 50 Ω load. A pulse energy of 260 J is delivered and a 35% voltage efficiency is realized.

Finally, the charge voltage is increased to 45 kV, or 1.5 times the capacitors' rating. As shown in Figure 8, the generator delivers a a peak voltage of more than 800 kV, or 13.45 GW into a 50 Ω load. In this configuration, a pulse energy of 330 J is delivered with a voltage efficiency of approximately 45%.

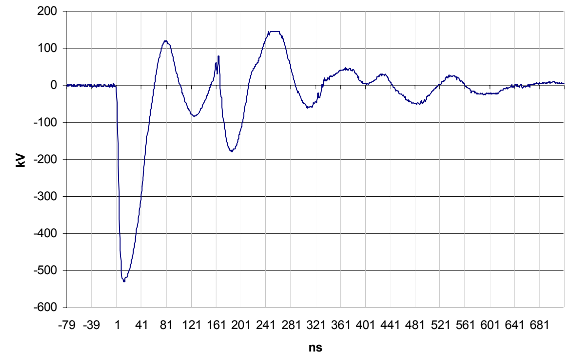

Figure 7. Output waveform with a 40 kV charge.

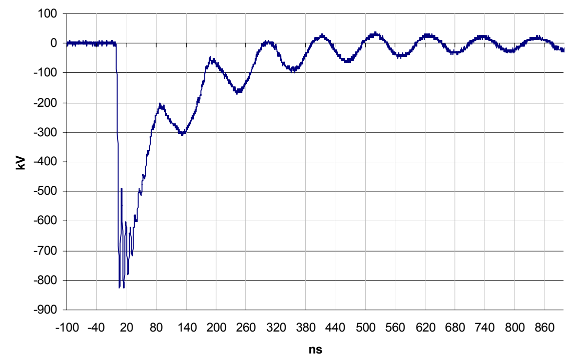

Figure 8. Output waveform with a 45 kV charge.

V. CONCLUSION

This paper has presented preliminary results of a compact MV Marx generator. The generator was initially tested for its impedance using a T&M Research Products CVR (0.009809 Ω) directly mounted to the output section of the generator. Measuring the frequency of the ring-down, and with the known erected capacitance, the Marx inductance was calculated to be approximately 1.19 μH, which leads to an impedance of 70 Ω).

The generator was then tested at various charge voltages and with various pressure levels. Operating at the capacitors' voltage rating, the generator delivers more than 450 kV into a 50 Ω cable load. And as the voltage was increased to 1.5 times the capacitors' rating (or 45 kV), peak voltages in excess of 800 kV were measured.

Future efforts will work to make the generator more compact and more modular. The generator will also be fitted with inductive charging elements for faster charge cycles and higher repetition rates.

VI. REFERENCES

[1] J. R. Mayes and W. J. Carey, *The Marx Generator As An Ultra Wideband Source*, 13th IEEE International Pulsed Power Conference, Las Vegas, NV, July 2001.

[2] T&M Research Products, Albuquerque, NM.