

An Enhanced MV Marx Generator for RF and Flash X-Ray Systems

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Abstract

A compact MV Marx generator has been previously presented for its basic performance[1]. This generator is based on a 40-stage design and has been demonstrated to deliver more than 850 kV onto a 50 Ω cable. Work has continued on this generator to improve its performance, namely with charging efficiency and control, and new efforts are aimed at developing integrated and modular loads. This paper discusses improvements made with the system, as well as its ability to drive a wide variety of loads including a flash x-ray load. Experimental results and discussion conclude this paper.

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 lead to higher source impedances and lower load voltage efficiencies. Recent efforts [2] 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 MG40-3C-2700PF. 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. More recently, the generator has been fitted with inductive charging elements for increased charging efficiency and increased charge rates, and the generator has been fitted with a variety of control mechanisms for increased usability. Current efforts are being made to develop integrate, modular loads, including flash x-ray diodes and RF loads.

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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.

The completed design of the MG40-3C-2700PF 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 tube, having a wall thickness of ¼ inches.

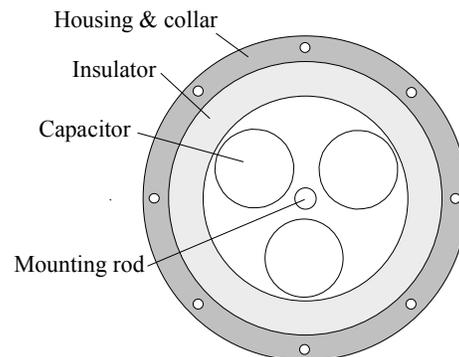


Figure 1. Internal cross-sectional conceptual view.

Electrically, the MG40-3C-2700PF 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 μ H is calculated, which results in a generator impedance of 70 Ω . At a charge voltage of 40 kV, the generator stores approximately 260 J. The charging resistors have been recently replaced with inductors, designed with for values of approximately 100 μ H, or so that the Marx event is less than 10% of the resonant ring between the stage capacitance and the two parallel charging inductors. As a result, charge rates as short as 25 ms are expected, with a 10 kJ/s power supply.

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

Table 1. Electrical characteristics of the MG40-3C-2700PF

Parameter	Description	Value	Unit
V_{open}	Open circuit voltage	1.6	MV
V_{ch}	Maximum charge voltage	40	kV
N_{cap}	Number of stages	40	
C_{stage}	Number of capacitors per stage	3	
C_{marx}	Capacitance per stage	8.1	nF
L_{marx}	Erected series inductance	1	μ H
Z_{marx}	Marx impedance	70	Ω
η_{volt}	Voltage efficiency into a 50 Ohm load	42	%
P_{peak}	Peak power (matched load)	15	GW
E_{marx}	Energy stored in Marx (maximum)	260	J
T_{ch}	time to charge	25	ms
T_{RR}	Maximum repetition rate	30	Hz
P_{ave}	Average power	10	kJ/s

Table 2. Physical characteristics of MG40-3C-2700PF.

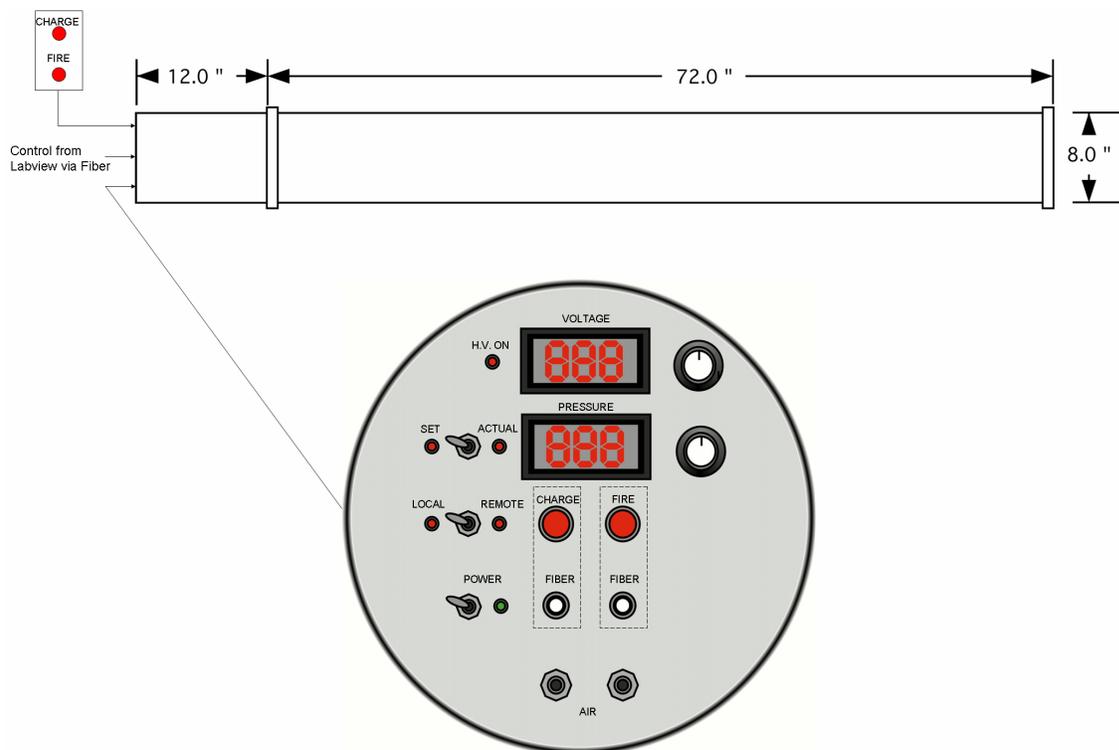
Parameter	Description	Value	Unit
L_{marx}	Marx length	72	in
D_{marx}	Marx diameter	8	in
L_{ps}	Power supply length	12	in
D_{ps}	Power supply diameter	8	in
Wt	System weight	250	lbs

Recent efforts have been made toward developing the generator as a system, integrating ancillary components such as the high voltage power supply, a voltage-controlled pressure regulator and a high voltage trigger source, as well as integrated, and interchangeable load elements. These ancillary supply components are integrated inside an aluminum housing designed to match the generator's diameter and adding 12 inches to the length of the generator, as shown in Figure 2.

The ancillary component module, however, provides much more than the basic supply components. As discussed in *A Modular Compact Marx Generator Design for the Gatling Marx Generator System* [3], the user interface to the generator is based on a smart controller design, enabling a variety of user control mechanisms, including front panel control, local/remote charge and fire control, or through LabView, via fiber optic-based RS-232 communication link.

The generator requires operates under battery power, via an integrated battery pack, and a pressurized source of breathable dry air.

Figure 2. General physical view and interface.



Modular and interchangeable load elements complete the MG40-3C-2700PF system. As presented in previous papers, APELC has worked with efforts toward directly generating RF energy from the Marx generator. The designed antennas, such as spiral and TEM horn antennas connect directly to the generator as a module, or via a short section of RG-220. More recently, APELC has been developing flash x-ray elements, also directly mounted to the Marx generator, as shown in Figure 3.

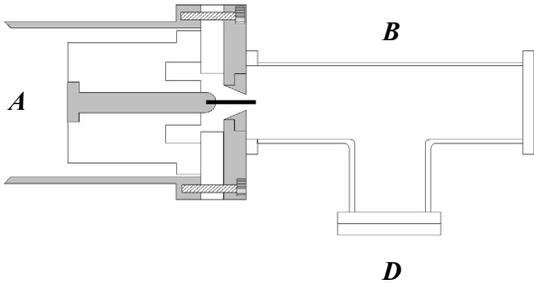


Figure 3. A flash x-ray module integrated into the Marx. Marx (A), stainless vacuum tee (B), Acrylic window (C), vacuum port (D).

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 [4]) that is directly mounted to the output of the generator, as shown in Figure 4. The CVR has an impedance of only 0.009809 Ω and does not affect the characteristic ring.

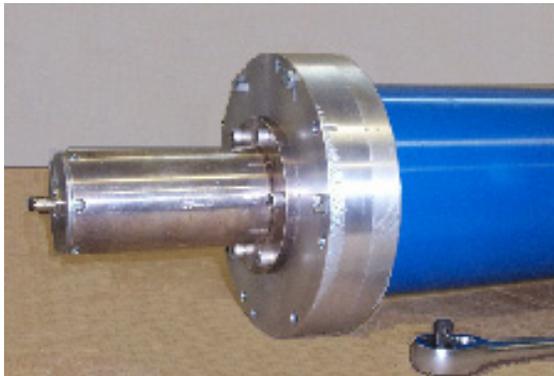


Figure 4. The CVR-based impedance measurement.

The pulsed output characteristics of the generator are measured via cable load, as shown in Figure 5. 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.

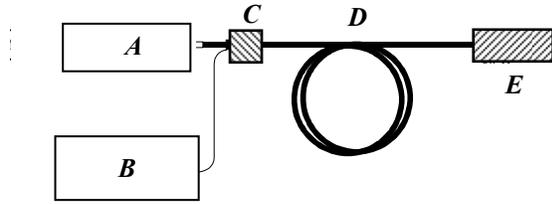


Figure 5. The output pulse measurement testbed. Marx generator MG40-3C-2700PF (A), Tektronix TDS694C (B), CVR (C), fifty ft. RG-220 (D), 50 Ω resistor (E).

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 4. The CVR-measured waveform is shown in Figure 6.

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

$$L_{Marx} = \frac{1}{(2\pi f)^2 C_{erected}} = 1.19 \mu H \quad (1)$$

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

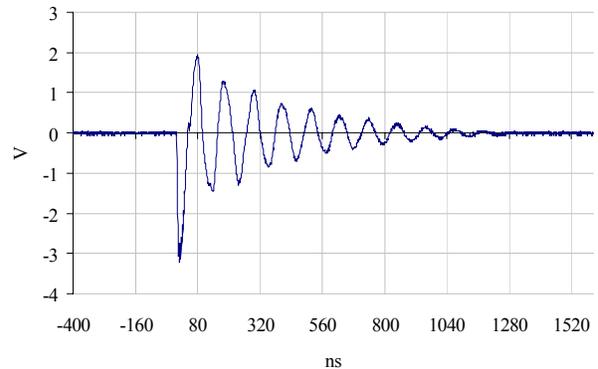


Figure 6. The CVR-measured ring-down.

Measurements of the generator's output are made with the configuration of Figure 5, 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 7, the generator delivers 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%.

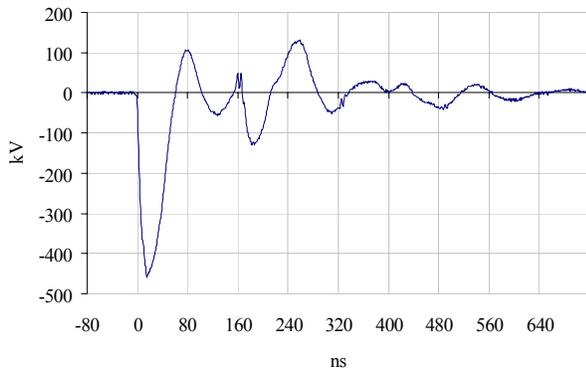


Figure 7. Output waveform with a 30 kV charge.

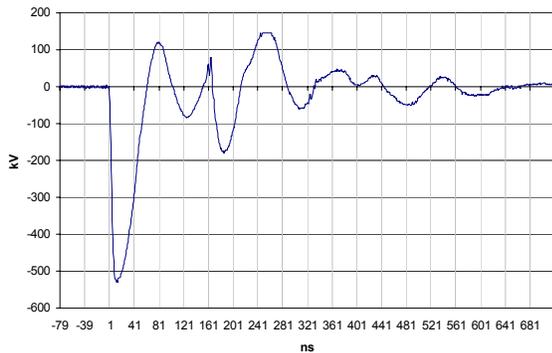


Figure 8. Output waveform with a 40 kV charge.

The charge voltage is increased to 40 kV and the pressure is increased to 90 psi to prevent self-triggering.. As shown in Figure 8, 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 9, the generator delivers 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%.

V. CONCLUSION

This paper has presented new designs and performance results of a compact MV Marx generator. The high voltage generator has been recently reconfigured with inductive charging elements, designed for higher charging efficiencies, as well as high charge rates. Additional efforts have been made to move the generator toward autonomous operation and more toward a laboratory or field tool, instead being a laboratory experiment. Ancillary components, such as the power supply, air regulation and triggering have been integrated, and several modes of operation are now standard, including a Labview interface.

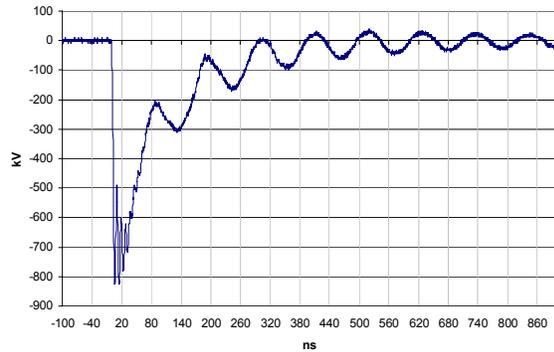


Figure 9. Output waveform with a 45 kV charge.

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 μ H, 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 increase the performance of the generator in its repetition rate. Additional efforts will also focus attention on integrated load development.

VI. REFERENCES

- [1] J. R. Mayes, et al., *A Compact MV Marx Generator*, Conference Record of the 26th International Power Modulator Symposium, San Francisco, CA, 2004.
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