

COMPACT 200-HZ PULSE REPETITION GW MARX GENERATOR SYSTEM

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Abstract

The compact, wave-erection, GW-class Marx generator has been previously reported for use in 5 ns to sub-ns risetime pulsed power applications. This generator topology has recently been adapted for high Pulse Repetition Frequency (PRF) applications and is the basis for a new high-PRF pulsed power system. The 33-J generator is capable of delivering a 300-kV pulse into a matched 50-Ohm load, or 600 kV into an open circuit. The high-PRF system includes an 8 kJ/sec TDK-Lambda high-voltage power supply and an APELC trigger and control unit. The APELC trigger unit contains a 150-mJ thyatron-based pulser and facilitates the synchronous pulse charging of the Marx generator. Additionally, the trigger unit provides analog output signals of the thyatron and Marx charging signals and features LED diagnostics and fault indicators on the front panel. Applications of the high-PRF system include sourcing of High Power Antennas. Design considerations, system architecture, and experimental results of the high-PRF pulsed power system are presented in this paper.

I. BACKGROUND

The 33-J, 600-kV, wave erection Marx generator has been previously reported for its compact and modular design as employed in the Gatling pulse generator [1]. Prior application called for an integrated microcontroller / power supply, GW power output and reliable operation for field use. APELC's MG15-3C-940PF (here called the SM3C) Marx system has been successfully implemented in a number of systems, but until recently only been capable of single-shot or low PRF operation.

Modern directed energy applications benefit from high-PRF pulsed power because of the ability to delivery extremely high peak power to an antenna many times per second, while keeping the source compact and prime power consumption relatively low [2]. Efforts to advance such repetitive pulsed power typically focus on reducing the size, increasing the power, or increasing the PRF.

II. SYSTEM ARCHITECTURE

The component overview for the high-PRF system is shown in Figure 1 and the block diagram is shown in Figure 2. The basis technology is APELC's SM3C wave-erection Marx generator. The Marx is charged by an 802L High Voltage Power Supply (HVPS) made by TDK-Lambda [1]. A delay generator from Berkeley

Nucleonics Corp. (BNC) is used to adjust the PRF and the inter-charge-cycle timing of the trigger generator and the Marx [2].

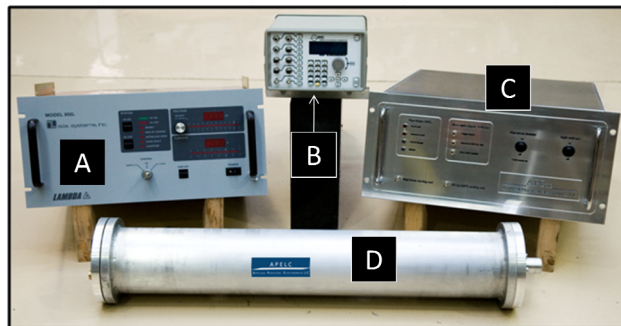


Figure 1. Main components of the high-PRF Marx Generator system: (A) Lambda-TDK 802L power supply, (B) BNC Delay Generator, (C) APELC trigger generator, and (D) APELC SM3C Marx generator.

During typical operation, the user selects the PRF using the delay generator. For a given cycle, a pulse is sent to the trigger generator unit (TGU) which initiates the following control sequence:

- A charge command is issued to the thyatron-based trigger circuit and Marx power supply
- A charge inhibit command is issued once the specified charge voltage is reached for the respective circuit
- An additional pulse is then sent from the delay generator which closes the thyatron and triggers the Marx.

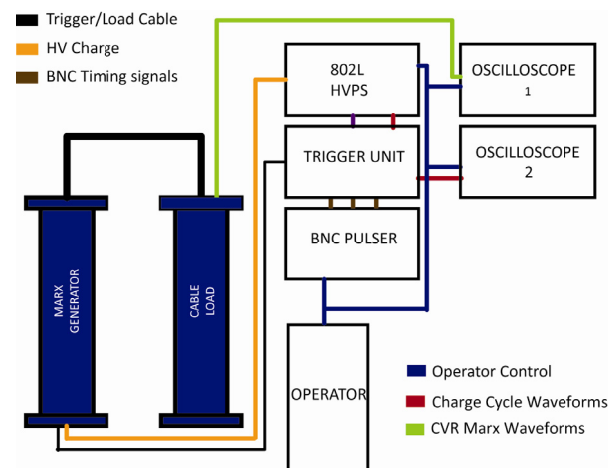


Figure 2. Block diagram for the High-PRF, GW-class SM3C Marx system.

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A. Marx Circuit

The SM3C Marx generator stage consists of three UHV-4A 2.8-nF ceramic capacitors from TDK [3]. These capacitors have performed well, i.e. survived, in high-PRF and high temperature applications compared to similar door-knob style capacitors [4]. The stage capacitors are connected in parallel for a total stage capacitance of 2820 pF. The 15 Marx stages result in an erected capacitance of 188 pF. Each Marx stage is isolated by a 8- μ H, air-core inductor pair. The Marx circuit is housed in a cylindrical aluminum pressure vessel lined with an insulating epoxy compound. Pressurized dry air is used as the insulating medium.

The general specifications for the SM3C are listed in Table 1. The generator stores 33J at the maximum 40-kV charge voltage. With an erected voltage of 600 kV, it can deliver 300 kV to a matched load for a peak power delivery of 1.7 GW.

Table 1. General specification for the SM3C Marx generator

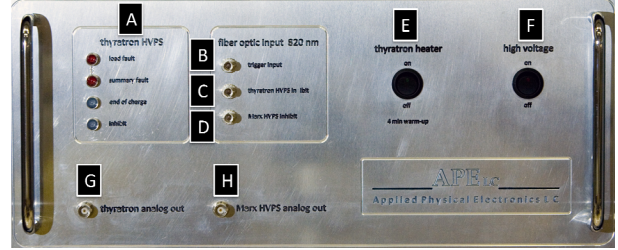
Symbol	Parameter	Value	units
N	Number of Marx generator stages	15	-
E_{pulse}	Maximum Marx energy per pulse	33.0	J
P_{max}	Peak power to a matched load	1.7	GW
V_{ch}	Marx maximum charge voltage	40	kV
V_E	Peak Erected voltage	600	kV
C_{stage}	Capacitance per Marx stage	2.8	nF
C_E	Erected capacitance	188	pF
L_e	Series Inductance	510	nH
Z_m	Marx Impedance	52	Ohm
L	Marx Generator Length	31	In.
D	Marx Generator Diameter	5	In.
PRF_{max}	Maximum Burst-Mode PRF	200	Hz

B. Trigger Generator Unit

The APELC TGU was designed to deliver repetitive, high-voltage trigger pulses to the Marx generator, facilitate synchronous charge/trigger cycles, and provide diagnostic signals to the operator. The front panel of the TGU is shown in Figure 3. The trigger pulse circuit includes a 150-mJ, thyatron-based pulser circuit which is energized by a 500 J/s TDK-Lambda HVPS [5].

Front-panel diagnostics, indicated in Figure 3, include summary fault, load fault, inhibit, and HV-enable LED indicators for the thyatron-circuit HVPS. Charge voltage waveforms from the trigger and Marx HVPS are sent from the front panel of the trigger unit to an oscilloscope. These waveforms are helpful realtime diagnostics for the operator and help identify: (1) Marx self breaks due to low pressure, (2) failure to erect

because of high pressure, (3) charging of a short or open circuit due to a fault, and (4) timing problems. The charge waveforms are easily accessible diagnostics are particularly useful when operating outside the laboratory since they can be sampled by a slow, portable oscilloscope, but can indicate common problems that take place on a much faster timescale.



- | | | | |
|---|---------------------------------|---|---|
| A | Thyatron HVPS LED indicators | E | Thyatron Heater power switch |
| B | Trigger fiber-optic input | F | Thyatron HVPS high voltage power switch |
| C | Thyatron HVPS fiber-optic input | G | Thyatron analog output |
| D | Marx HVPS fiber-optic input | H | Marx HVPS analog output |

Figure 3 APELC high-PRF trigger generator unit front panel.

III. RESULTS

The system was setup as shown in Figure 2 in order to document waveform characteristics and demonstrate the charge-cycle diagnostics. The Marx was discharged into a cable load which was terminated into a 10 kJ/s, 50-Ohm coaxial water load. An inline CVR (Figure 4) was used to acquire the waveform. For PRFs above 50 Hz, the system was limited to burst-mode sequences to prevent thermal damage to components.

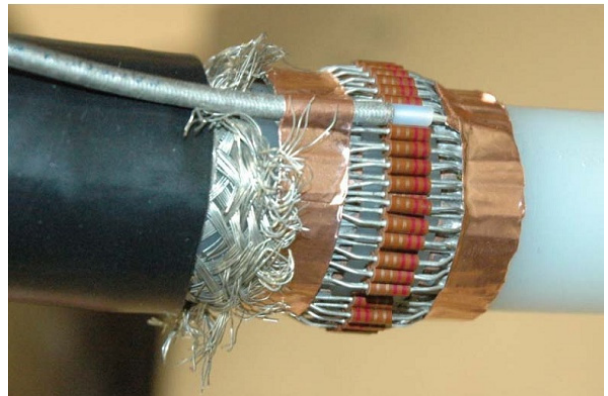


Figure 4. APELC Inline CVR used to measure the Marx pulse on a 50-ohm cable.

Figure 5 shows the charge-cycle waveforms for a 200-Hz burst. The red trace is the thyatron voltage and the green trace is the Marx charge voltage. In this sequence

the Marx was charged to 40 kV and the thyatron circuit was charged to 18 kV.

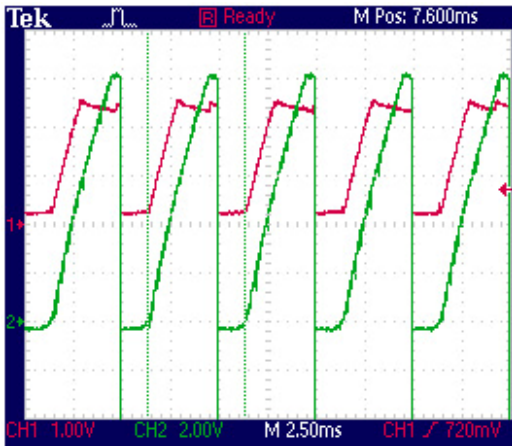


Figure 5. Charge waveforms for a 200-Hz PRF burst: Thyatron pulser voltage (red) and Marx voltage (green).

RG-220 cable is commonly used as the output cable for single-shot SM3C pulses up to 300 kV. However, during testing it was found that RG-220 suffered repeated dielectric breakdown or punch through when transmitting Marx pulses at PRFs above 100 Hz. Dielectric Science's 2158 coaxial cable was used thereafter without incident [3].

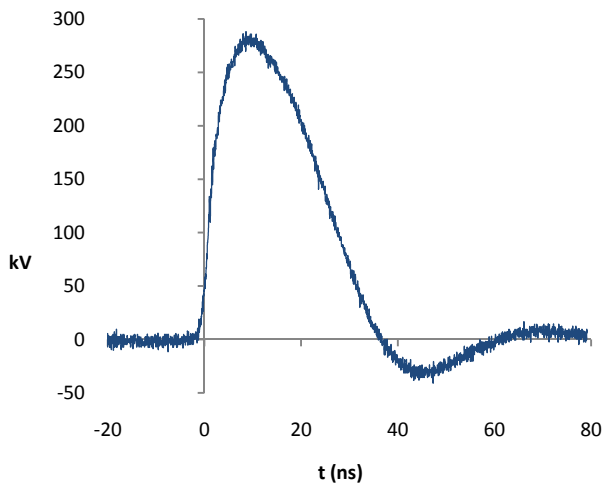


Figure 6. Typical Marx output waveform on a 50-Ohm cable load, for a Marx charge voltage of 40 kV, and a vessel pressure of 77 PSI

Figure 6 shows a typical Marx output waveform on a 50-Ohm cable load, for a Marx charge voltage of 40 kV, and a vessel pressure of 77 PSI. Figure 7 shows 20 Marx output waveforms as measured using the inline CVR during a 200-Hz burst. Each waveform was sampled and stored in less than 5 ms using an 8-GHz Tektronix TDS6804B oscilloscope.

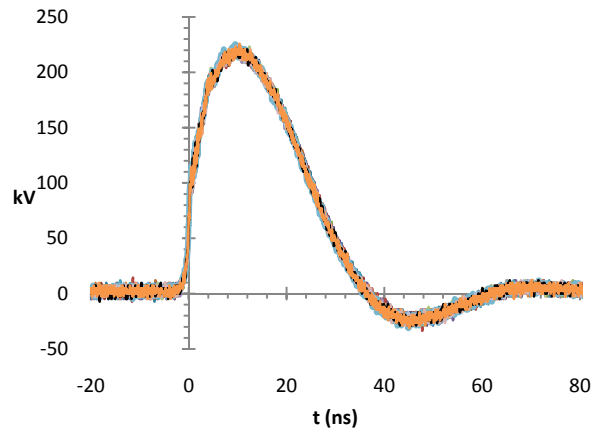


Figure 7. Load-voltage waveform overlay of 20-shot burst, at 200-Hz PRF, for a Marx charge voltage of 30 kV and a vessel pressure of 70 PSI.

IV. SUMMARY

The system architecture, and experimental results of the 200-Hz, GW-class, pulsed power system have been presented. The integrated system demonstrated successfully erected Marx pulses for a 40-kV charge voltage at PRFs up to 200 Hz.

Charge cycle waveforms of the trigger circuit and Marx power supply allowed the user to diagnose common Marx problems. This ease of diagnosis allows simple adjustments to properly tune the Marx operation. The Marx output waveform displays good stability and repeatability even at PRFs up to 200 Hz.

The work described here has resulted in a compact, rack-mounted, pulsed-power system capable of delivering 1.7 GW at a PRF of 200 Hz. Ongoing efforts are focused on identifying modes of failure after extended operation.

V. REFERENCES

- [1] M. B. Lara, J. R. Mayes, et. al. "A Modular Compact Marx Generator Design for the Gatling Marx Generator System," at 15th IEEE International Pulsed Power Conference, Monterey, CA, 2005.
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- [3] TDK-Americas, 901 Franklin Avenue, P O Box 9302, Garden City, NY 11530-9302.
- [4] Berekely Nucleonics Corporation, 2955 Kerner Blvd., San Rafael CA 94901 U.S.A.
- [5] APELC Internal Test Data, Applied Physical Electronics L C., Austin, TX 78669
- [6] Dielectric Sciences, Inc., 88 Turnpike Road • Chelmsford, MA 01824.