A MODULAR COMPACT MARX GENERATOR DESIGN FOR THE GATLING MARX GENERATOR SYSTEM

M.B. Lara*, J. R. Mayes, M.G. Mayes, and C.W. Hatfield
Applied Physical Electronics, L.C.
Austin, Texas 78734

Abstract

The Gatling Marx generator system has been previously discussed for its ability to deliver energy from multiple generators into a single cable with demonstrations of the Gatling Marx in [1]. New efforts with the system bring the need for a modular and compact design, high repetition rate capability, and enhanced controller capabilities, including control over the charge voltage, pressure regulator, and trigger. Control over each component via an embedded microcontroller is necessary to meet the system's promised performance. Design considerations are presented, as well as preliminary results with the ancillary components and loads.

I. INTRODUCTION

For decades users of Marx generators have found themselves plagued with the issues of large footprints, messy and cumbersome ancillary components, and non-intuitive interfaces that require the precise adjustment of imprecise controls, such as mechanical pressure regulators and variacs. Also, with more immediate concerns in the realm of defense, a pulsed-power system must become rugged, compact, reliable, and constructed so that an operator is able to work it in any environment.

Timing, repeatability of results, ease of use, and reliability are very important for both the researcher and end user who require strong, repeatable data to present to their peers and/or their customers. To accomplish this, a generator is needed that not only satisfies the above criteria, but also has integrated controls that incorporate a certain degree of intelligence (i.e. programmability) with an interface that the user finds both transparent and intuitive.

APELC has developed an integrated Marx generator and on-board controller for use in a Gatling configuration, or similar array. The device includes a relatively low-impedance Marx (~50 Ohm) in conjunction with a microcontroller operated front-end, offering operation from traditional panel-mount controls or a fiber-optically connected, remote *LabView* platform.

*matt.lara@apelc.com
This effort is supported under Air Force contract FA9200-04-C-0325

II. Background and Design

A. Traditional Marx Generator Design

Traditional Marx designs utilize a pulse-forming-line (PFL) to deliver energy to the load at a matched impedance. Because of the physical length needed to store a useable amount of energy and deliver a pulse from the ten to hundreds of nanoseconds, PFLs can range from several feet to several dozen feet in length depending on the dielectric used. These dielectrics also serve the dual purpose of providing voltage hold-off between conductors, and consequently are also used inside of the Marx itself. As a result of the insulating media (typically transformer oil) and the large capacitance necessary to rapidly charge the transmission line, the system becomes extraordinarily bulky and difficult to calibrate and control.

B. APELC's Compact Integrated Design

A 15 stage, single-rail Marx generator, APELC part number MG15-3C-940PF, using ceramic "door-knob" capacitors for energy storage and an acrylic liner for voltage hold-off, is charged from 10-40 kV, delivering an output voltage of approximately 75-300kV into a matched load. Attached to the front of the generator is a 9" by 12" cylindrical housing containing the controlling electronics, pressure regulator, trigger generator and internal power supply for single-shot operation. Figure 1 shows the front panel of the device from which the user is able to manually control the pressure and charging voltage at the input of the Marx.

During a typical manual firing sequence, the user performs the following actions to operate the device:

1.) Initialize pressure on the top display/dial.
2.) Toggle the display-select switch into the "set" position and dial in the desired charging voltage (bottom display/dial).
3.) Toggle the display-select switch into the "actual" position so that the display shows "000" indicating no existing charge in the generator.
4.) Depress the momentary button labeled "charge" and observe the voltage rising to the set charge voltage.
5.) When the generator reaches full charge, depress the button labeled "fire", activating the trigger unit and firing the machine

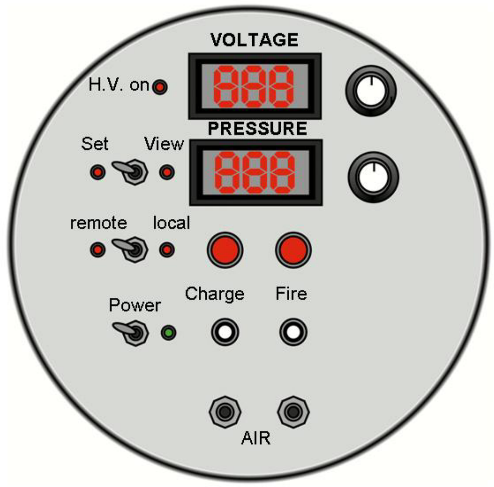

Figure 1. APELC Integrated controller front panel

The most important and unique feature of the controller is its ability to operate from a Laptop or P.C. based *Labview* platform. The two connectors below the "Charge" and "Fire" buttons in Figure 1 are ST, Fiber-optic, bulk-head connectors. The leftmost connector carries bi-directional serial data for pressure, voltage and command-charge, while the right connector is solely for the "Fire" command. This separation of the two signals allows the firing of each MG15-3C-940PF to be sequenced by a delay generator when the generators are placed in the proposed Gatling configuration.

When the selector directly above the power switch is toggled from "local" to "remote", the front panel controls are disabled and the controller receives its commands directly from the host computer.

Figure 2 shows the basic layout for the routing of controls and diagnostics between the microcontroller and the Marx generator. The heart of the controller is a *Freescale MC9S12C32*, chosen for its low cost and on-board Analog-to-Digital converter. The MCU utilizes an onboard serial interface to receive data over fiber. From the serial buffer, the incoming data is routed to three ports: Port A for DAC data, Port B for DAC addressing and port T for general control. This layout allows a simple method for interfacing with a quad-output, 8-bit Digital-to-Analog converter. With 2 bits of data for addressing, and 8 bits for data, a single chip solution allows the user control over 4 analog devices, with 256 increments of change. Although an analog dial offers "infinite" variability, the digital division allows the operator ample granularity, while still having the ability to accurately return to an exact value for verification of results.

While the DAC outputs data to the pressure regulator and power supply, outgoing values are collected from the power supply and pressure transducer and then buffered and sent from the ADC out the TX line of the serial port. Although the port allows full-duplex operation, a half-duplex mode of telemetry is used so that TX and RX data can be sent via a single fiber.

Port T of the microcontroller is used specifically for parallel binary device control. This includes a bit for an onboard electric air-purge valve and a bit for power supply enable/disable, or command-charge.

Currently, all data from the controller unit is converted from optical to electrical and then to RS-232 signaling for use by the host computer.

In the form of a laptop or P.C., the host computer runs a National Instruments *LabView* front panel from where the operator is able to perform all the data taking functions one would typically find in a Laboratory environment. The computer-based firing sequence goes as follows:

1.) The user enters pressure and voltage data via the graphical interface.
2.) Once the "send" control has been activated, data is sent out the RS-232 port and the software immediately goes into an acquisition mode.
3.) Next the computer first compares the pressure transducer value until it equals the set pressure, then sends the voltage data and again compares the acquired value until it reaches the set voltage.
4.) Once both values have reached set points, the front panel indicates a "ready-to-fire" status, at which point the operator is able to depress the "fire" button, sending a trigger pulse to the delay/pulse generator and then to the MG15-3C-940PF.
5.) Once the generator has fired, Labview utilizes a GPIB interface to directly acquire and display waveform information from the oscilloscopes monitoring the output of the generator.

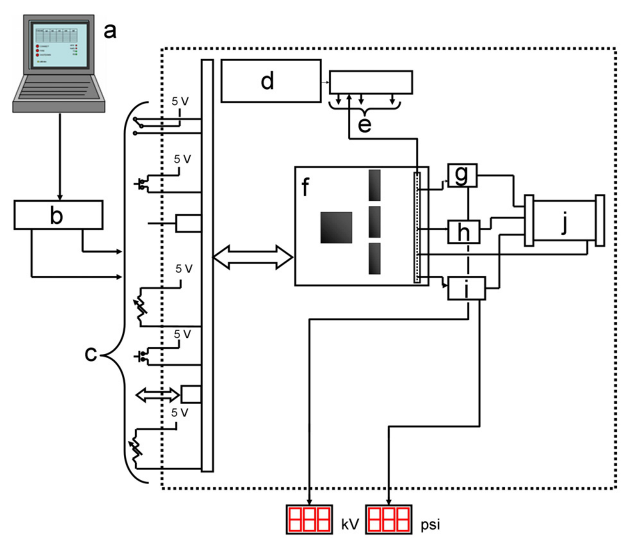

Figure 2. Controller block diagram. (***a***), *LabView* P.C.(***b***), RS-232 to Fiber (***c***), local/remote controls (***d***), 30v battery-pack (***e***), 5,12,28 Volt outputs (***f***),HCS12 Microcontroller (***g***), H.V. Power-supply (***h***), Electronic Pressure-regulator (***i***), Trigger-generator (**j**), Marx Generator

B. Prototype Electrical and Physical Characteristics

Table 1 displays the electrical characteristics of the 15 stage MG15-3C-940PF. Three 940 pF capacitors are connected in parallel forming a single stage capacitance of 2.82 nF. The capacitors are rated at 30 kV, but have proven to operate thousands of shots at 40 kV without risk of failure. At 15 stages, the total erected capacitance of the bank is 188 pF, yielding a stored energy of 33 J.

An erected series inductance of 526 nH was obtained by firing the generator into a short-circuit and observing the characteristic damped oscillation formed by the RLC circuit of the erected Marx. Using this value and the known erected capacitance, a generator impedance of 53 Ohms is calculated.

Inductive charging elements are used in place of resistors allowing for ultra-fast (2 ms), low-loss charging of the device. Using a 4 kW bench-top power supply and a Thyratron-based trigger, repetition rates as high as 200 Hz were observed. Considering the capacitance of a single stage, the inductance of the individual elements was calculated to allow for a wavelength 20 times that of the firing event itself, so that the inductors appear "open" during the erecting of the Marx.

The entire MG15-3C-940PF is contained in a ½ inch-thick aluminum housing measuring 30 inches in length by 5 inches in diameter. Attached to the front of the MG15-3C-940PF is the ancillary component housing, measuring 12 inches in length and 8 inches in diameter. This housing has been standardized for use on any of the existing APELC generator designs.

Table 1. Electrical Characteristics of the MG15-3C-940PF

Parameter	Description	Value	Unit
V_{open}	Open circuit voltage	600	kV
V_{ch}	Maximum charge voltage	40	kV
N	Number of stages	15	--
N_{cap}	Number of capacitors per stage	3	--
C_{stage}	Capacitance per stage	2.82	nF
C_{marx}	Erected capacitance	188	pF
L_{marx}	Erected series inductance	526	nH
Z_{marx}	Marx impedance	53	Ohm
EFF_{volt}	Voltage efficiency into 50 Ohm load	48	%
P_{power}	Peak power	950	MW
E_{marx}	Energy stored in Marx	33	J
T_{ch}^{*}	Time to charge	2	ms
T_{RR}^{*}	Maximum repetition rate	200	Hz
P_{ave}^{*}	Average power	6600	J/s

.

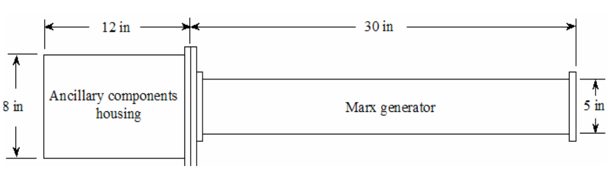

Figure 3. Physical dimensions

Table 2. Physical characteristics of the MG15-3C-940PF

Parameter	Description	Value	Unit
L_{marx}	Marx length	30	in
D_{marx}	Marx diameter	5	in
L_{ps}	Power supply length	12	in
D_{ps}	Power supply diameter	9.5	in
Wt	System weight	30	lbs

C. Load Design and Diagnostics

In order to closely resolve the actual output of the MG15-3C-940PF, a coaxial load was constructed from a five-inch aluminum cylinder, containing an acrylic liner and carbon resistor. A series combination of the load resistor and a 0.009809 Ω, T&M research current-viewing resistor allow for amplitude-calibrated viewing of the waveform. An un-calibrated capacitive probe is placed in line with the ground plane, providing a secondary diagnostic for verification of rise-time.

The load is designed for quick assembly/disassembly, so that multiple values of the Kanthal-Globar, carbon resistors can be placed inside, allowing for a comparison of Marx impedance vs. load impedance.

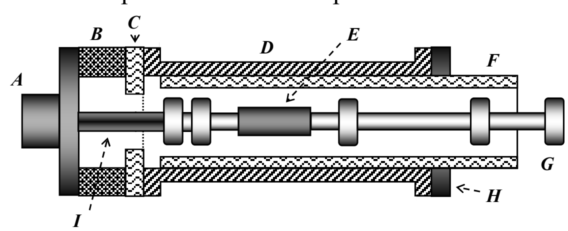

Figure 4. Load design and diagnostic tools for the APELC Marx generator MG15-3C-940PF: T&M Research CVR (***A***), extension collar (***B***), acrylic insulator (***C***), aluminum housing (***D***), Kanthal resistor (***E***), acrylic liner (***F***), aluminum feed (***G***), capacitive voltage probe collar (***H***), internal conductor (***I***)

IV. EXPERIMENTAL RESULTS

By replacing the carbon load-resistor with a 1" metal tube, the generator was fired into a short circuit. A Pearson model 101 current transformer replaced the T&M CVR [3] for the ring-down measurement to shorten the length of the load and consequently lower the load inductance, providing a more accurate measurement of the generator inductance. Figure 5 is the captured data from this event, and shows a wavelength of 62.5 ns, yielding a characteristic frequency of 16 MHz. Using equation 1 and the erected capacitance of the MG15-3C-940PF, a series inductance of 526 nH was obtained. Again, using the known value for total erected capacitance, an impedance of 53 Ohms is calculated.

$$L_{Marx} = \frac{1}{(2 \cdot \pi \cdot f)^2 \cdot C_{erected}} = 526nH \quad (1)$$

$$Z_{Marx} = \sqrt{\frac{L_{Marx}}{C_{erected}}} = 53\Omega \quad (2)$$

$$f = 16MHz$$

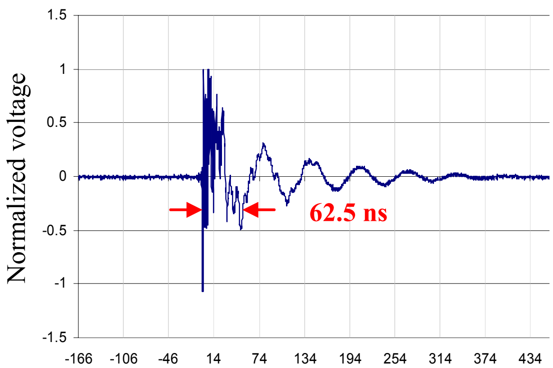

Figure 5. The Pearson-measured ring-down.

Figure 6 displays a comparison of the generator output at 30 kV charge into 15, 35, 50, 100, 150, and 300 Ohm loads. Corresponding peak currents of 6.42, 5.90, 4.89, 4.14, 1.68, and 1.55 kA were observed.

Direct comparison of the 100 Ohm and 50 Ohm waveforms show the 100 Ohm case to be slightly over-damped and the 50 Ohm slightly under-damped. This would lead one to the assumption that the generator impedance is closer to 60-70 Ohms. However, as previously mentioned, the Pearson coil, although saturating at the delivered dI/dT, provided for a more compact load diagnostic and therefore a lower overall inductance- leading to the 53 Ohm measurement.

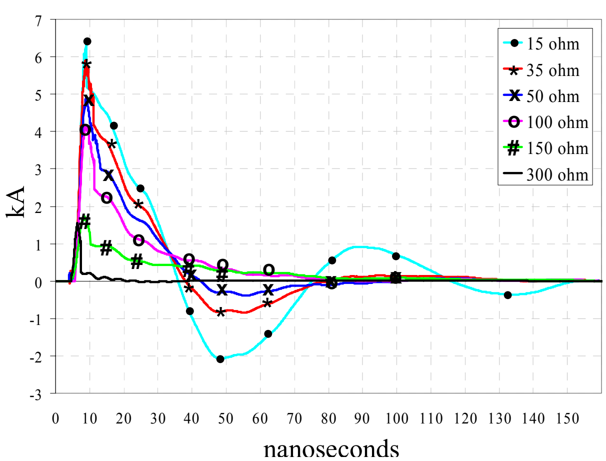

Figure 6. Output waveforms with a 30 kV charge.

The internal, single shot power supply in the ancillary component housing was replaced with an *A.L.E. Systems* 4kW, bench-top power supply. A *Stanford* delay generator was attached to both an external Thyratron trigger-box and the enable line of the power-supply, providing precise control over the timing of charging and firing of the generator. By observing the charging time of the capacitors, a delay of 3 ms was set for the Thyratron trigger. This allowed for suitable charging and refresh times, and therefore stable pulse repetition. Figure 8 plots the charging sequence for 100 Hz, burst mode operation, although repetition rates upwards of 200 Hz were observed during the experimental process.

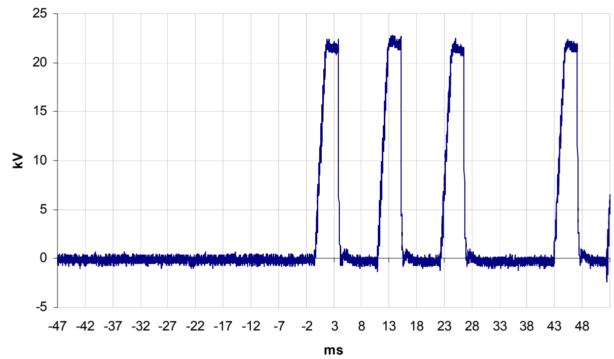

Figure 7. Charging waveform for 100 Hz operation.

V. CONCLUSION

The addition of inductive charging elements to a proven Marx geometry yields a generator that is stable, low-impedance, capable of high repetition rates and compact in its construction.

With the addition of an on-board controller unit, the generator becomes a stand alone test-bed for use in direct-RF generation, Flash X-ray, or any other application requiring a 600kV, fast-rise, short duration pulse or pulse train.

A *LabView*-based graphical interface allows for user-friendly remote operation and data acquisition.

Future development efforts for this system include higher repetition rates (1kHz), and a unit that self calibrates itself by utilizing the existing micro-controller and electronically controllable power-supply and pressure regulator to generate an internal look-up table representing that Paschen-curve for the device.

VI. REFERENCES

[1] J. R. Mayes, et al., *The Gatlin Marx Generator System,* 13th IEEE International Pulsed Power Conference, Las Vegas, NV, July 2001.

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

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