EXPERIMENTAL RESULTS OF A 10-ELEMENT, GATLING-STYLED MARX GENERATOR SYSTEM

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Abstract

A Gatling Marx generator system has been previously presented[1]. This effort focused on the summation of high voltage pulses, delivered by multiple unique Marx generators, by a common adder element. More recent efforts have focused on understanding the system's functionality and uniqueness. This paper discusses the experimental results of a ten-element Gatling system, with discussions and demonstrations illustrating the functionality of the Gatling system. Topics include demonstrating the ability to achieve extreme repetition rates in a burst mode, pulse coding techniques and wave shape synthesis. The Marx generators, for this effort, were supported by a common trigger source and a common charge voltage source configured for discrete voltage pickoffs. Theoretical considerations are made and supported by experimental results.

I. INTRODUCTION

Pulse power systems delivering voltage pulses in excess of 100 kV require spark gap switches for their high voltage/high current capabilities. Unfortunately, these switches are typically limited in their repetition rate to several hundred Hz, employing inert gases at moderate flow rates. Hydrogen has been used as the switching medium for higher repetition rates, well into the kHz realm. In fact, a Marx generator filled with Hydrogen was demonstrated with a repetition rate of 10 kHz in a burst mode by the Naval Surface Weapons Center.[2,3] However, the appeal of using hydrogen in manned vehicles is not great due to its explosive nature.

High repetition rates have also been achieved with high pressure oil systems with repetition rates of 1200 Hz demonstrated.[4] Unfortunately, these systems are large in volume and mass as well as complex in design.

This effort presents the Gatling Marx Generator system as an RF driver, capable of delivering peak powers of 1 GW, and with repetition rates of tens of kHz without using Hydrogen or high pressure oil as the spark gap medium. The Gatling Marx system relies of the continuing development of the Marx generator by APELC, including supporting facilities such as high powered, high voltage power supplies, high voltage trigger units and imbedded controllers. However, instead of each generator having its own load element, as would be the case with a phased antenna array, the Gatling Marx generator system combines the outputs of the driving generators, so that only a single load element is required.

This effort was founded on the desire to demonstrate the functionality of the Gatling Marx generator system. In theory, the generators are completely unique in the operation, which can lead to extremely high repetition rates, and limited only by temporal spacing between the pulses. Since the generators are uniquely triggered, or not triggered, pulse high voltage pulse coding is possible. Furthermore, since the generators can be charged to unique voltage levels, wave shaping is possible by using the individual generators to "build" a desired wave shape, such as a sine wave.

This paper begins with a simple description of the structure to establish operational knowledge. A description of the theoretical performance is then discussed and supported by experimental results.

II. BACKGROUND

The Gatling Marx Generator system, as shown in Figure 1, is a multiple generator system with a common load element, such as an antenna. Each generator operates independently of the other generators, offering uniqueness in output voltage levels and pulse delivery times, and with extreme peak power levels. However, the most outstanding feature of this system lies in the

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redundancy of generators. In essence, the system does not fail due to the loss of any of the Marx generator branches (defined by the Marx generator and its associated power supply and trigger circuit).

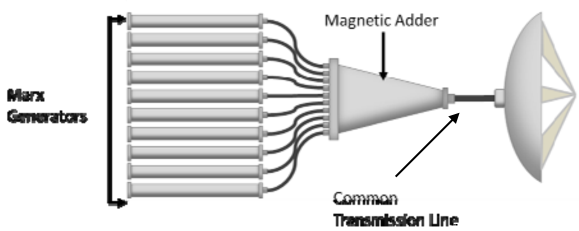

Figure 1. An illustration of the Gatling Marx generator system.

As shown in Figure 1, the system is comprised of the N Marx generators, a magnetic adder, a coaxial transmission line and the load element. Not shown are the individual power supplies for each generator, as well as the single system controller. Note that each generator will have its own built-in high voltage power supply and trigger unit, simply requiring an optical controls for charge level settings and trigger control.

While this system promises the capability of delivering multi-GW pulses at extremely high repetition rates, its strength lies in its pulse-to-pulse agility. As shown in Figure 2 (a), the simplest output from the system is one in which all pulses are equally spaced. For example, a 50 generator system with each generator operating at 300 Hz, results in a pulse-to-pulse separation of 66.7 μs (an effective frequency of 15 kHz).

Figure 2 (b) illustrates the temporal independence of each generator. Although sequential firing is employed, the pulse-to-pulse spacing is varied so as to add temporal jitter, or randomness in pulse-to-pulse spacing.

Figure 2 (c) illustrates a modulated signal employing the independence in charging levels between the individual generators, thus allowing for the system to synthesize various wave shapes, such as a damped sinusoidal waveform.

Finally, Figure 2 (d) illustrates the burst mode function, in which the pulse separation is set to a minimum of 20 ns, or 50 MHz; For example, a burst of 25 pulses could be launched within a 500 ns window, but with a burst repetition frequency of 50 MHz. Pulse coding may also be employed, but is not shown.

Impulse antennas are very well suited for the Gatling system. For example, an IRA antenna mounted on a single 1 MV generator could achieve electric field strengths in excess of 20 kV/m at 100 m. Demonstrations by APELC have also shown that the impulse Marx generator is well suited for driving coil antennas for Wide Band RF energy, as shown in Figure 3. Consider the same coil antenna sourced by the Gatling system delivering the pulse train of Figure 2 (d). The net effect is the Gatling system directly pumping the resonant coil antenna and would result in a 1 GHz burst as shown in Figure 4. These field strengths are comparable to those of Vircator and Milo systems with a fraction of the volume and mass.

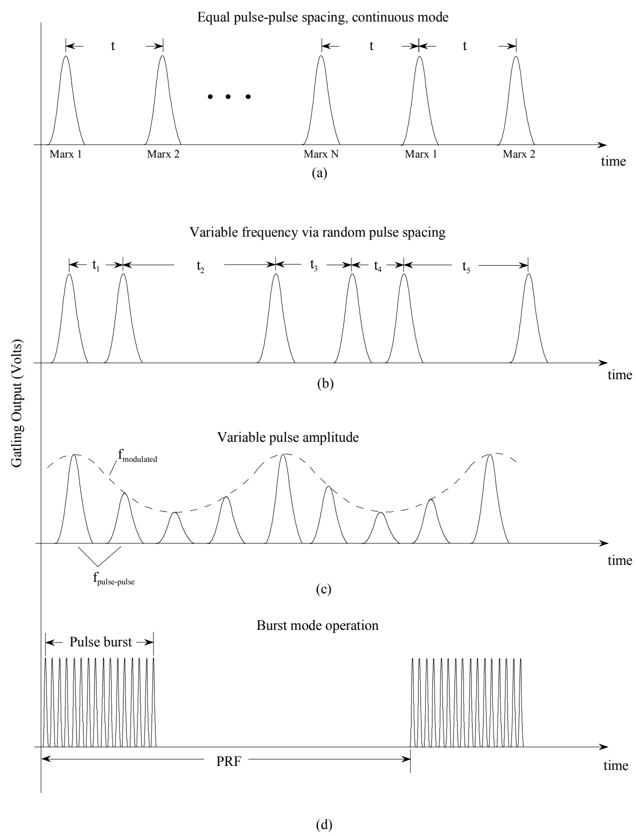

Figure 2. An Illustration of functionality with the Gatling Marx system. (a) equal pulse-to-pulse separation, (b) random pulse-to-pulse separation, (c) modulation of pulse voltage levels, and (d) burst mode operation.

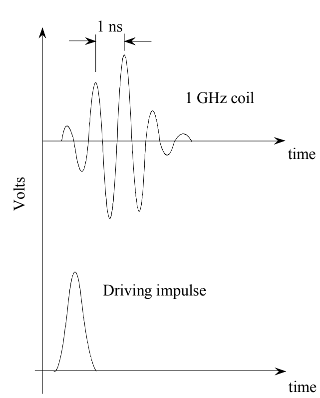

Figure 3. Illustration of a single Marx driving a 1 GHz coil antenna.

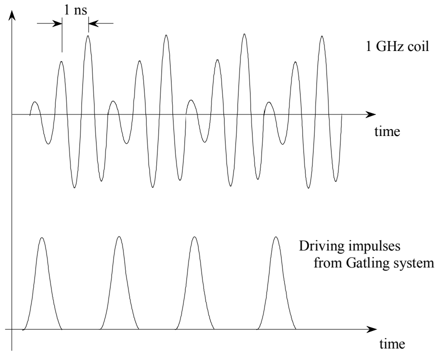

Figure 4. Illustration of the Gatling Marx generator system driving a 1 GHz antenna.

III. EXPERIMENTAL ARRANGEMENT

A ten-element Gatling Marx generator system has been built based on a 15-stage impulse Marx generator design. Table 1 describes the basis generator, described by a stage capacitance of 940 pF, with a maximum charge voltage of 30 kV. An approximate 200 kV pulse is expected to be delivered onto a 50 Ohm load, with a pulse energy of 6 J.

Table 2 describes the Gatling Marx generator system, assuming a 10-generator configuration. A burst mode repetition rate of 33 MHz is predicted, with a peak power of 838 GW and an average power of more than 60 W.

Table 1. Individual generator parameters

Parameter	Description	Value	Unit
V_{ch}	Maximum charge voltage	30	kV
N	Number of stages	15	
C_{st}	Capacitance per stage	940	pF
L_{st}	Inductance per stage	15	nH
C_{erect}	Erected capacitance	63	pF
L_{series}	Approximate series erected inductance	225	nH
Z_{marx}	Approximate Marx impedance	60	Ω
V_{erect}	Erected voltage	450	
V_{load}	Voltage on a 50 Ohm cable	205	kV
E_{marx}	Energy per pulse	6.345	J
P_{paek}	Peak power on 50 Ohm cable	838	MW

Figure 5 describes the experimental arrangement for the experimental Gatling Marx generator system. The system drives a 50 Ohm RG-220 coaxial cable, which is loaded with a 50 Ohm carbon composition resistor. Built into the RG-220 cable is an inline Current Viewing Resistor (CVR), with a 35 mΩ impedance. A Tektronix 694C oscilloscope, with a realtime 6 GHz bandwidth is used to measure the system performance.

Table 2. Gatling system parameters.

Parameter	Description	Value	Unit
M	Number of generators	10	
V_{out}	Voltage from each generator	205	kV
T_{RRmarx}	Maximum rep rate for each generator	1	Hz
$T_{p\text{-}p}$	Minimum pulse-to-pulse spacing	30	ns
T_{RRcw}	Maximum continuous rep rate	10	Hz
$T_{RRburst}$	Maximum rep rate within burst	33	MHz
P_{peak}	Peak power	838	MW
P_{ave}	Maximum average power	63	W

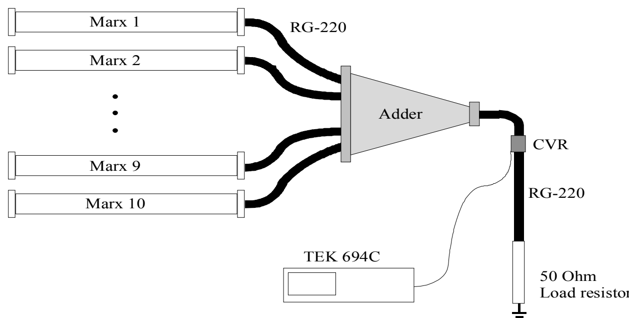

Figure 5. Experimental arrangement.

IV. EXPERIMENTAL RESULTS

A pulse is delivered from a single generator to study the behavior of the magnetic adder and is shown in Figure 6. As illustrated, the rise time was maintained as well as the amplitude. However, the capacitive and inductive characteristics of the adder produce strong oscillations in the trailing edge of the pulse. With a close temporal separation between pulses (< 80 ns), these oscillations will be a problem, and thus will require that the adder be designed for high signal-to-noise ratios than the current prototype.

Testing with all generators employs a single power supply and dry air source. Triggering is accomplished with a single source driving ten coaxial trigger lines, each of a unique length and resulting in a 30 ns separation between the sequential pulses.

Unfortunately, one of the generators proved to be inoperable during the testing phase, meaning that the testing phase would be done with the nine remaing generators.

The resulting waveform with all nine generators delivering maximum peak voltages is shown in Figure 7. Three outstanding characteristics are notable: First, the nine pulses are immediately recognizable, demonstrating the feasibility of adding multiple high voltage pulses. Second, extreme repetition rates are achievable in the burst mode, 33 MHz in this arrangement. And third, signal integrity is highly dependent on the signal-to-noise ratio and the primary pulse width. Note in Figure 6, each successive pulse shows an increasing amount of noise

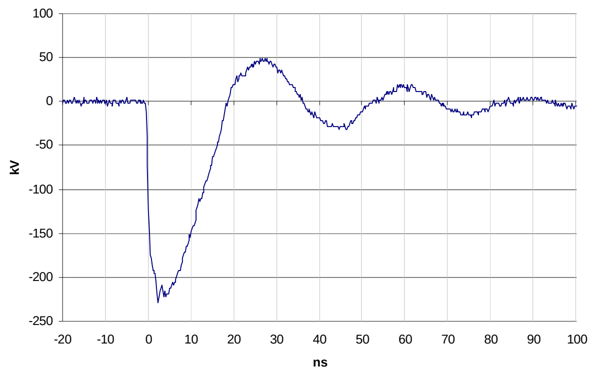

Figure 6. Resulting waveform of a single pulse through the magnetic adder.

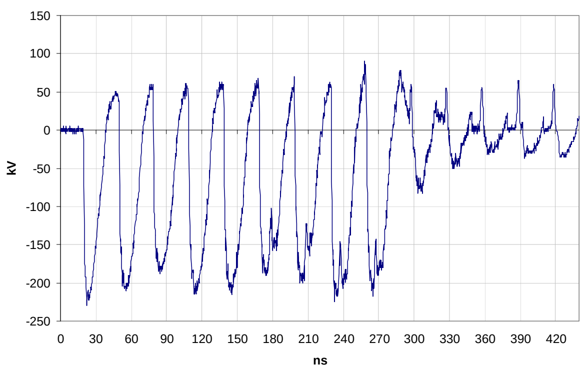

Figure 7. Output waveform of the nine-pulse Gatling system.

Random pulse spacing and pulse coding is illustrated in Figure 8. Since the generators are triggered with a single source for the prototype system, this demonstration is accomplished by simply not triggering particular generators. As shown in Figure 8, generators 2, 5, 6 and 8 are not triggered. It is noted that the shapes of the pulses following a removed pulse appear cleaner than it did in Figure 7.

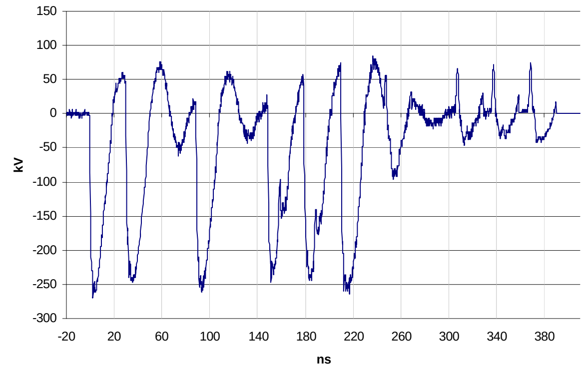

Figure 8. Demonstration of variable pulse spacing and pulse coding.

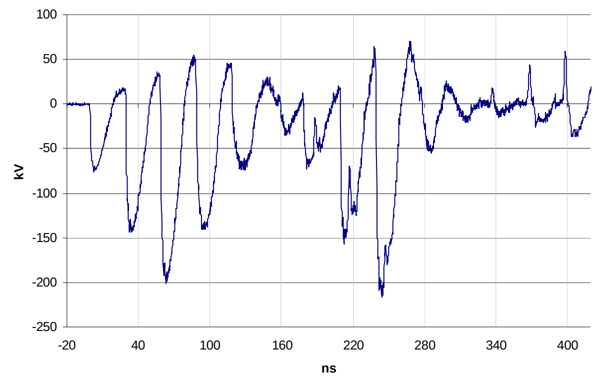

Figure 9. A simulated guassian wave shape produced by the Gatling system.

Finally, variability in pulse amplitude for pulse shaping techniques is demonstrated, with the results being shown in Figure 9. A voltage division of the power supply is used as well as multiple regulators for the necessary pressure requirements. In this experiment, a modulated Guassian wave shape is simulated.

V. SUMMARY

A ten-element Gatling Marx generator system was built and tested, with the purpose of demonstrating its variability in pulsed delivery. The basis Marx generator was capable of delivering a 200 kV pulse, with a 1 Hz repetition rate. 10 identical generators were fed into a common magnetic adder section, which combined the pulses into a single coaxial geometry so as to connect to a single load element. This effort demonstrated the ability to deliver extreme repetition rates of 333 MHz and for a duration defined by the number of individual generators. The system also showed the ability for high voltage pulse coding by predetermining which generators would launch a pulses. And finally, employing a voltage-divided charge voltage scheme, the system was shown to synthesize a sinusoidal waveshape, by varying the charge voltage on the individual generators.

Future work will be focused toward individualizing the generators for true autonomous operation and realtime system functionality.

VI. REFERENCES

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