COMPACT, MEGA-VOLT, REP-RATED MARX GENERATORS

R. M. Ness, B.D. Smith, E. Y. Chu, B.L. Thomas, and J. R. Cooper
Maxwell Laboratories, Inc.
8888 Balboa Ave.
San Diego, CA 92123
(619) 279-5100

Abstract

A concept for compact, Mega-volt Marx generators has been developed, resulting in several functional designs which are approximately 1/2 the diameter and 1/4 to 1/2 the height of conventional units. The customized Marx capacitor assemblies utilize multiple windings which have been incorporated into a single common capacitor case. Spark gap switch electrodes extend directly from the external capacitor terminals, eliminating the need for additional buswork. In order to construct the Marx generator, two such capacitor assemblies are positioned directly opposite each other so that the electrodes line up in a vertical column between the two capacitor assemblies. Because the entire assembly is housed inside a pressurized (20 to 30 psig of SF_6) gas vessel, the need for individual Marx switch housings is also eliminated. A 4 stage, 400 kV output Marx has been tested, operating at a repetition rate of 2-3 pps (power supply limited) continuously for over 5000 discharge cycles at 85 to 100% of the stage charging voltage. More than 10,000 shots have been recorded to date with this particular system with no major system failures. A second design has also been fabricated and tested which utilizes 16 Marx stages to develop a 1.5 MV (open circuit) output voltage. The entire Marx bank, charging inductors, and trigger circuit are contained in a cylindrical gas vessel 30" in diameter and 22" in height, weighing approximately 160 lb. Experimental measurements indicate a stage inductance of approximately 45 nH per 100 kV Marx stage. Additional testing results will be presented in the paper.

Introduction and Concept Overview

In the recent past, many of the applications for power conditioning and pulsed power machines have evolved from laboratory environments into mobile platforms. With the defense services interest in such areas as directed energy weapons [1], including high power lasers, high power microwaves, and particle beam weapons, increasing importance is being placed on making the power sources and high voltage drivers for these systems compact and lightweight. Reducing the size and weight allows the system to be integrated and designed into the maximum number of operational scenarios, including ground mobile, airborne, sea-based, or space-based weapon applications.

Many different techniques exist for the generation of high voltage pulses, including the use of magnetic core pulse transformers, air core dual resonant transformers [2], Marx generators, and vector inversion generators. However, it is difficult to drive low impedance loads using the first two techniques and still achieve fast output pulse risetimes. As a result, transformers are usually used to pulse charge a pulse forming line (PFL) or pulse forming network (PFN), which is then discharged into the load. Because of this, multiple sets of energy storage devices are required, adding to the overall system size and weight. The vector inversion generators also possess significant disadvantages. Marx generators, either configured as components in PFNs or using PFNs in each of the Marx stages, offer advantages over the other approaches since the number of energy transfer stages (and corresponding energy storage elements) and the number of large components which do not store energy (such as transformers) are both minimized. The key to using this approach is to lower the Marx inductance sufficiently so that it does not seriously degrade the output pulse risetime. In order to maintain a low inductance, the circuit physical layout size and enclosed loop area must also be minimized.

Over the last two years, we have developed a concept for compact, Mega-volt Marx generators by reviewing the traditional Marx design and attempting to reduce the number of components and their size and weight to that which is absolutely essential for successful operation. In performing these analyses, it became apparent that redundancies exist within the more standard Marx design. For example, in a conventional Marx, the capacitors and other components are held together with an insulating support structure and immersed in an insulating medium (often transformer oil or insulating gas such as SF_6). Conducting buswork extends from the capacitor terminals to the connections which penetrate the switch enclosure and connect to the switch electrodes. If the capacitors and switch electrodes could be designed to operate in the same insulating medium, then the switch enclosures (along with their contribution to system size and weight) could be eliminated. If the capacitor terminals could be utilized as switch electrodes, then the requirement for the connecting buswork can also be thrown out.

These techniques form the basis of the compact Marx technology. In addition to the component design modifications listed above, we have also attempted to reduce the system size, weight, and inductance through several other measures. Using the standard, commercially available, low inductance, Maxwell Type S plastic case capacitor as a beginning point, we have reduced the case thickness from 2.3" to 2.0" and allowed the width to grow from 5.9" to 8.0". Since the Marx will be mechanically designed with the capacitors in a horizontal orientation, reducing the Marx height has the most impact upon minimizing the circuit inductance. In addition to reducing the thickness of individual capacitor windings, we have also repackaged multiple capacitor windings into a common case. In this manner, the insulation distance between windings is reduced to only that required to support voltage holdoff.

Spark gap switch electrodes extend directly from the external capacitor terminals in the common case. In order to construct the Marx generator, two such multiple capacitor assemblies are positioned directly opposite each other so that the electrodes line up in a vertical column between the two capacitor assemblies. The second capacitor is also slightly elevated from the first (the distance being equal to one-half of the height of a single individual capacitor). The bottom terminal on the first capacitor is then tied to ground and the top terminal on the second unit functions as the output terminal. The entire assembly is housed inside a pressurized (20 to 30 psig of SF_6) gas vessel, eliminating the need for individual Marx switch housings. Adjustment and alignment of the spark gap electrodes are made easier since only the two overall assemblies now need to be aligned instead of each individual electrode pair. Spark gap triggering is also enhanced since UV illumination from the initial switches is provided for the remaining ones which have not yet closed. Marx erection is also improved because of the stray capacitances associated with the physical layout.

As a result of these conceptual analyses, several functional designs have been developed and tested which are approximately 1/2 the diameter and 1/4 to 1/2 the height of conventional units. The stage inductance of these compact Marx generators has also been found to be at least a factor of 2 lower than that found in more standard Marx generators.

In order to generate high voltage square pulses, these compact Marx generators can be combined with anti-resonant LC tank sections to form Type A PFNs. The end result is a high voltage pulse generator which can generate fast risetime (20-30 ns), square, mega-volt class pulses in a state-of-the-art physical package for a variety of applications. If faster risetimes are required, a peaking capacitor and peaking switch may be added at the expense of additional size and weight.

In order to demonstrate and verify these design ideas, a series of tests were developed and performed. These experiments were split up into several tasks in order to address a smaller and more manageable set of technical risks during each phase. Initial brassboard tests were done on a mock-up to estimate the Marx inductance and scaling relationships and to investigate the electrical stresses on the capacitor header and spark gap electrode assemblies. A 1/4 scale, 4 stage, 400 kV output Marx was then fabricated,

CH2839-9/90/0000-0477$1.00 © 1990 IEEE

assembled, and tested to examine Marx performance on a relatively small scale and to provide engineering data for the final proof of concept experiment. This second design utilizes 16 Marx stages to develop a 1.5 MV (open circuit) output voltage. A detailed description of this hardware and a summary of the test results is discussed in the remainder of this paper.

It should be pointed out that this effort was done using technology which is currently commercially available. By incorporating the use of advanced state-of-the-art capacitor dielectric materials, the system energy density can be further increased over what has been accomplished through the re-packaging and re-engineering work done to date.

Mock-Up and Brassboard Testing

Prior to building a compact Marx generator, a mock-up of the capacitor header assembly was fabricated and used to estimate the inductance values which might be achieved in the compact Marx. From these results, we estimated that a stage inductance of 40-45 nH should be achievable. These tests also confirmed that the most important variable in minimizing the inductance is the height of the Marx (the same axis as the Marx voltage gradient).

In addition to the mock-up tests, a second series of tests were performed to determine the best combination of electrode shape and header configuration to minimize inductance and still sustain 100 kV per stage electrical stresses. The header configuration for a typical multiple capacitor assembly is shown in Figure 1. In this case, two capacitors have been housed in the common case. Because multiple capacitors are incorporated into each case, insulating material is required between each set of adjacent capacitor terminals and electrodes. Each terminal and electrode is therefore completely surrounded by a set of insulating material barriers arranged in a box fashion. This eliminates the possibility of insulator flashover around the sides of the barriers between the electrodes. This configuration allows a vertical electric field gradient along the compact Marx bank of approximately 100 kV/inch (per stage capacitor).

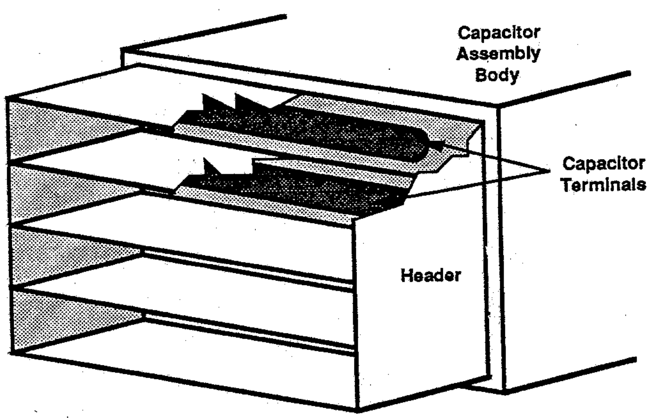


Figure 1. Compact Marx Generator Multiple Capacitor Assembly with Header.

The header mock-ups consisted of two standard Maxwell Series S capacitor headers surrounded on all sides by 2" high walls of the header material. Two header materials were tested: polybutylene terephthalate (PBT) and acetal copolymer (one of the two common materials used for Series S capacitor headers and cases). Electrodes were attached to the modified headers and a header was placed inside a small chamber which could be pressurized with SF_6 to simulate operation in the Marx gas vessel. Voltage was then applied to the two electrodes and gradually increased until a breakdown developed, either along the surface of the header insulator material or through the gas between the two electrodes. Although the PBT header performed slightly better with regards to surface flashover strength, this material required ultrasonic welding techniques to bond. Since hot gas welding can be used to bond the header and capacitor case made up of the acetal copolymer material, it was selected for use in the capacitor assemblies due to its easier fabrication requirements and prior manufacturing and assembly experience base with this material.

The electrode shapes which were tested are shown in Figure 2. The results of these tests indicated that the offset electrodes, shown as configuration number 3 in the figure, performed better with regards to voltage holdoff strength. This design was therefore selected for use in the 1/4 scale and full scale proof of principle compact Marx generators. Results from these tests indicated that the header design was adequate for providing sufficient voltage holdoff when operating at 100 kV/stage voltage levels with at least 10 psig of SF_6 gas.

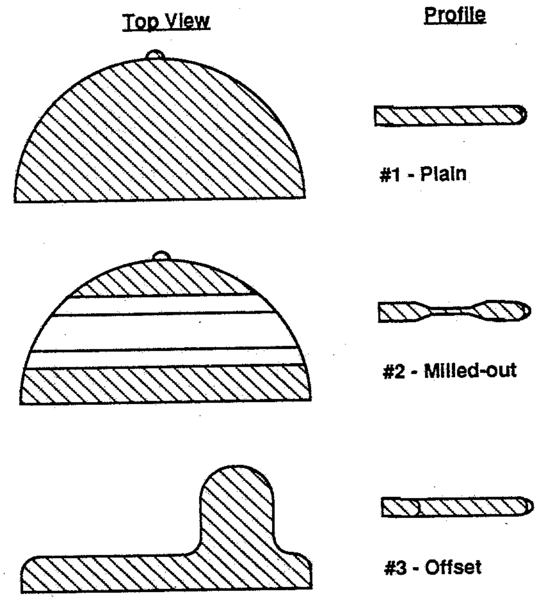


Figure 2. Different Electrode Shapes Examined During Compact Marx Testing.

1/4 Scale Proof of Principle Compact Marx Description

The 1/4 scale proof of principle compact Marx is a four stage, 100 kV/stage, 800 J system. Its purpose was to test design concepts for the higher voltage and energy proof of concept compact Marx bank which is described in the next section. As described above, its principle features include integrated multiple-capacitor assemblies and a geometry in which all the spark gaps are open inside the system gas vessel. In order to further reduce the system size, the use of a separate trigger generator (with its own power supply and support equipment) was eliminated by incorporating a self triggering system scheme. This trigger system will be described later in this section of the paper.

Capacitor Assemblies

The capacitor assemblies for the 1/4 scale proof of principle Marx generator were designed to test several of the most critical performance parameters of the compact Marx, including the voltage stress on the capacitor header. These assemblies utilize the same acetal copolymer plastic case material and similar tabbed windings as the standard Maxwell Series S commercial capacitor line. Each assembly contains two separate 100 kV, 40 nF capacitor windings in a single common case, separated by several stacked sheets of insulator material.

Support Structure

The support structure for the 1/4 scale proof of principle Marx bank was made of fiberglass channel approximately 20" in height and supported not only the capacitors but also the trigger system for the Marx bank. The stands were designed to be very rigid and lightweight. The design of these assemblies provided the basis for the design of the proof of concept structure in the next phase of the program.

Trigger System

The trigger system for the 1/4 scale proof of principle Marx is a unique, passively triggered system which utilizes the Marx bank power supply for charging. This means that the input power connections to charge the Marx are the only electrical penetrations of the pressure vessel required. A schematic of the trigger system is shown in Figure 3. L1 is one of the charging inductors for the Marx capacitors. The power supply for the Marx charges C1 through R1 and R2 to -100 kV. R1 and R2 form a voltage divider which holds the side of C1 nearest S2 to approximately ground potential. The voltage on the load side of S2 is held at approximately -30 kV by R3 and R4, the spark gap trigger bias resistors. The spark gap trigger electrode is biased in a 1/3 - 2/3 configuration. When the voltage across S1 reaches -100 kV, it breaks down, forcing the charging supply side of C1 to ground potential and the S1 side of C1 to + 100 kV. This places approximately 130 kV across S2, which immediately breaks down. C2, the stray capacitance formed by the trigger electrode and one of the main gap electrodes, is then charged by C1 to a voltage which triggers the main gap. C2 is much smaller than C1, so when S1 fires, the stray inductance in the circuit causes C2 to be charged to as much as +200 kV, which ensures fast triggering and good erection of the Marx bank. Two of the three stage switches were triggered in the 1/4 scale proof of principle Marx.

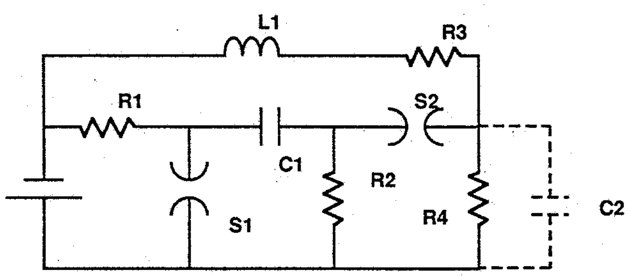


Figure 3. Schematic Diagram of the Compact Marx Generator Trigger Circuit.

Gas Vessel

The gas vessel for the 1/4 scale proof of principle Marx was required to hold at least 30 psig gas pressure and to provide support for the radial resistive water load which was mounted on top of it. The vessel was constructed from a 26" long section of 30" diameter fiberglass reinforced plastic (FRP). The end plates for the vessel were constructed of 1-1/4" thick G-10 plates with circular grooves machined into one face of the plate for rubber gasket seats on which to place the fiberglass cylinder. The end plates are held on the end of the cylinder by twelve 3/8" steel threaded rods which also serve as the current return for the Marx output current. The cylinder and end plate assembly were hydrostatically tested to 50 psig before installation of the Marx bank.

Dummy Load

The dummy load for testing the 1/4 scale proof of principle Marx bank was a coaxial water resistor with an integral voltage probe which is described in the following section. The dummy load/voltage probe assembly is shown in Figure 4. The high voltage is brought into the dummy load inner electrode through a series of 8 radially spaced input cables and the current return is made from the outer electrode to the 12 stainless steel threaded rods which hold the overall gas vessel and system together. The load itself is constructed of two concentric stainless steel cylinders, one with a diameter of 12" and one with a diameter of 30". The length of both cylinders is approximately 4". The cylinders are located between the top end plate of the Marx bank gas vessel and another G-10 plate with the same dimensions. Grooves with gaskets on each plate locate and seal the load. The volume between the two cylinders is filled with salt water to form the load resistor. Because the desired resistance of 40 Ω was too low to be easily achieved using more common water resistor electrolytes such as a copper sulphate solution, normal table salt (NaCl) was used. The concentration of the salt was very low so corrosion was not a problem.

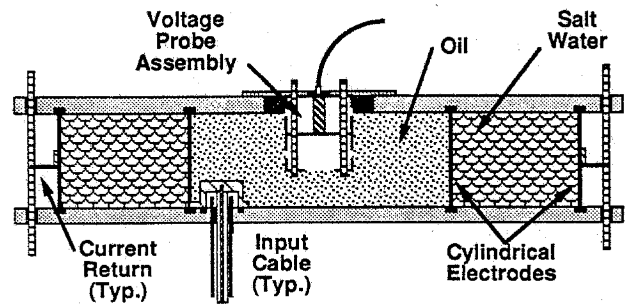


Figure 4. Radial Water Resistor Dummy Load with Integrated Capacitive High Voltage Probe.

Diagnostics

The diagnostics on this system consisted of an input voltage measurement, an output current probe, and an output voltage probe. The input voltage probe is a resistive divider which uses high voltage resistors to measure the dc input voltage (Marx stage charging voltage). The output current measurement was made with a Pearson 110A current transformer situated on one current return leg. This partial current was measured to prevent the Pearson probe from saturating.

As mentioned above, the output voltage probe is an integral part of the dummy load [3]. This coaxial unit is a differentiating probe which is placed in the center of the inner conductor of the dummy load. This volume is filled with transformer oil for insulation purposes. The probe, shown in Figure 5, is essentially a 3" diameter cylinder of aluminum with the center section of the cylinder electrically isolated from the two ends. The two ends are connected together internally and tied to the Marx bank ground. The series capacitance of the probe is formed by the inner conductor of the dummy load and the isolated center section of the probe. Because the probe uses a coaxial capacitor configuration, the probe capacitance value is easily determined. This makes it a simple matter to design the probe for a given required bandwidth and output voltage range. A 50 Ω resistor is connected from the isolated section of the probe to the grounded section and forms the remainder of the differentiating circuit. An integrator at the oscilloscope reproduces the voltage waveform from the differentiated signal.

1/4 Scale Proof of Principle Compact Marx Testing

The 1/4 scale proof of concept Marx testing was initially performed in air without the pressure vessel cylinder in place so that the system could be easily observed. The primary purpose of this part of the testing was to verify that the Marx bank was being triggered properly and erecting with an acceptable risetime. The initial tests showed that the charging voltage to produce self breakdown of the untriggered Marx was 35 kV with the spark gaps spaced at 1.25 cm. The next tests confirmed that the trigger circuit was operating properly and the Marx would erect at a charging voltage of 20 kV or higher with this triggering scheme, giving almost a 2:1 ratio of self break to operating voltage. The Marx erected with approximately the same risetime whether it was triggered or untriggered.

The Marx was then placed inside the pressure vessel. The air tests were repeated with the same results. The vessel was then filled with 1 atmosphere of SF_6. The Marx charging voltage at this point was 71 kV. Several shots were taken at this charging voltage. The current pulse risetime was 50 ns and was limited primarily by the inductance of the current return and the fact that no significant attempts had been made to minimize the circuit inductance during this phase of the testing.

The system was operated at pressures up to 18 psig SF_6 for a number of shots. The charging voltage was 95 kV at that pressure, and the Marx operated properly. After some further

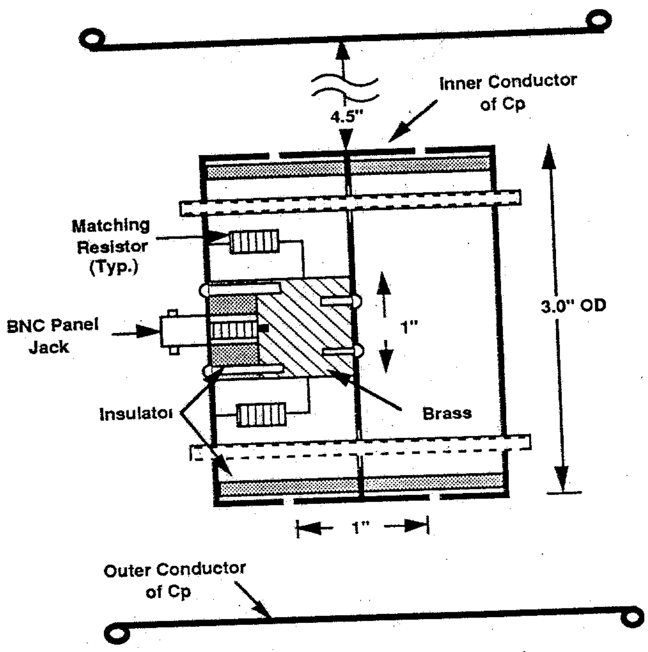


Figure 5. Coaxial Capacitive High Voltage Probe Assembly.

verification testing and work to eliminate some minor problems, the system was run at a 2 Hz repetition rate for 56 minutes at a charging voltage of approximately 85 kV (Vout ≈ 350 kV). The pulse current risetime was about 60 ns into the nominal 40 Ω load. The system pressure was 5 psig and the Marx spark gap spacing was 1.25 cm. This repetition rate was limited by the power capabilities of the commercially procured power supply, and the test was stopped due to a failure in this unit. Figure 6 shows an oscilloscope photograph of the compact Marx output voltage and current. This data was taken just prior to the termination of the experiment and shows an overlay of 10 consecutive discharges, all at a consistent voltage level.

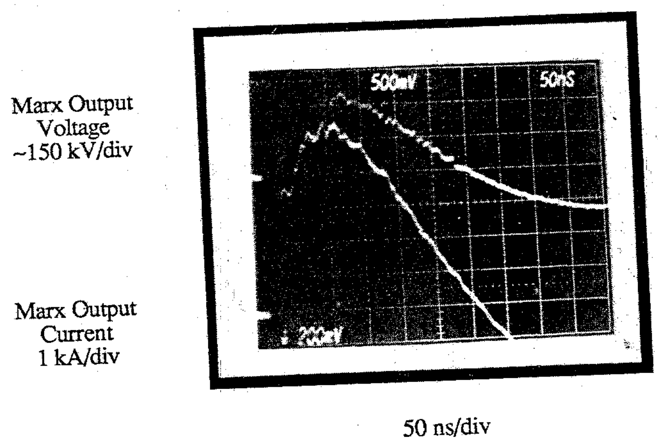


Figure 6. Oscilloscope Photograph of the 1/4 Scale Proof of Concept Compact Marx Output Voltage (upper trace) and Output Current (lower trace).

For the next test, the Marx spark gaps were set to 1 cm and the pressure was 10 psig SF_6. The intent was to lower the inductance of the Marx to produce a faster risetime by reducing the inductance contribution of the arc channel. The repetition rate for this test was much lower than the previous test due to power supply considerations. The pulser was operated for four hours at a rep-rate of approximately 15 shots/min. The current pulse risetime was approximately 45-50 ns, which provided a definite improvement over the previous set of data. At this point, the major goals for the 1/4 scale proof of principle system had been achieved, and attention was then focused on the design and development of the proof of principle system.

Proof of Concept Compact Marx Description

The full scale proof of concept compact Marx is a 16 stage Marx bank consisting of fourteen 40 nF, 100 kV stages which utilize plus and minus charging and two 80 nF, 50 kV stages (one charged positive and one charged negative) which comprise the bottom and top stages of the Marx. Instead of using an output gap, an additional inductor was used to hold the output of the Marx at ground potential during charging. This 3 kJ system was tested into a nominal 40 Ω load. Its purpose was to verify system design and component hardware at a voltage and energy representative of what might be required in potential applications. Construction similar to the quarter scale system was used for this full scale Marx.

The important design specifications for the proof of concept compact Marx are listed in Table 1.

Table 1
Proof of Concept Compact Marx Design Specifications

Parameter	Specification
Output Voltage:	1.5 MV (open circuit)
Output Current:	~40 kA
Pulse Energy:	3000 J
Inductance Budget:	800 nH
Pulse Rep-Rate:	up to ~10 Hz
Lifetime:	> 10^5 shots
Size:	30" o.d. x 22" height
Weight:	160 lbs

Capacitor Assemblies

The capacitor assemblies for the full scale Marx generator were designed to provide the pulse parameters listed previously with minimum size and weight. These assemblies are essentially scaled up versions of those used in the quarter scale system testing with dimensions of 17" tall, 8" wide, and 10 5/8" deep and a weight of approximately 75 pounds each. Each assembly contains 8 separate sets of capacitor windings in a single case with one capacitor winding designed for twice the capacitance and half the voltage of the other windings.

The proof of principle Marx was designed to have the minimum possible inductance per stage. The inductance of the capacitor windings and the connection to the header is fixed at approximately 20 nH. The additional inductance in the Marx comes from the connections to the switch electrodes, the electrodes themselves, and the arc inductance in the switch. The arc inductance is minimized by operating at the highest pressure possible.

Support Structure

The Extren angle support structure for the full scale Marx bank is approximately 20" tall, 24 1/2" wide and 9 1/2" deep. This structure was bolted to a 1/2" thick G-10 base plate which could, in turn, be bolted to the gas vessel. The Extren structure allowed set screw location adjustment of the two capacitor assemblies for spark gap spacing adjustment and alignment. The trigger circuit components and charging inductors were also mounted on the G-10 base plate. The support structure was designed to be very rigid in order to minimize fluctuations in the spark gap electrode spacing.

Trigger System

The trigger system for the full scale Marx is similar to that used in the quarter scale system with appropriate changes made to utilize the plus and minus charging scheme. The major advantage of this triggering system is the utilization of the Marx power supply for charging the trigger circuit so that an additional dedicated supply is not required for the trigger system. The bottom three gaps of the full scale Marx were triggered.

Gas Vessel

The gas vessel for the full scale system utilizes similar construction to that used in the quarter scale system. The length of the full scale system gas vessel is 37" in this case to accommodate the additional height of the compact Marx and allow sufficient space for the dummy load assembly.

Dummy Load

A parallel arrangement of six water resistors, each constructed using a solution of sodium thiosulfate and a section of Tygon tubing, was used as a dummy load. Each resistor had a resistance of approximately 240 ohms, giving a nominal parallel resistance of 40 ohms. The ~14" by 2" resistors were connected at one end to a circular metal plate which was attached directly to the output stage of the Marx. A low inductance current return was maintained by bringing the load resistors out concentrically from the center plate to the outer support rods of the gas vessel which were connected to the ground plane of the Marx at the bottom of the overall assembly.

Diagnostics

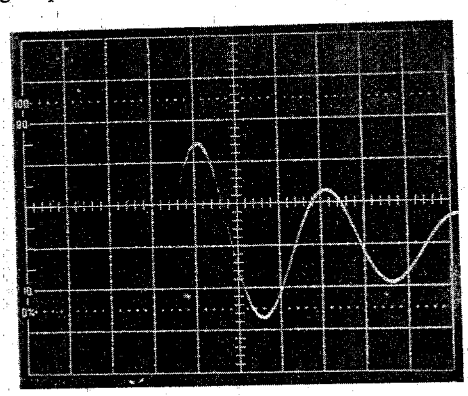
A Pearson 110A current transformer measured the Marx current at the grounding tab which connected the first stage of the Marx bank to the ground plane. The load voltage was monitored by a voltage divider, constructed from a solution of sodium thiosulfate and Tygon tubing, connected in parallel with the load resistor.

Proof of Concept Compact Marx Testing

Inductance Testing

An initial estimate of the Marx inductance was made by simulating the normal discharge of the capacitor assemblies which were mounted in the support structure. The capacitors were connected serially with bus wire between the electrodes to simulate the arc channels. Circular copper sheets were placed above and below the assembly and were electrically connected with 12 copper straps placed symmetrically around the circumference of the plates, enclosing the capacitor assemblies in a cylindrical arrangement. The series-connected capacitor stack was grounded to the lower plate, charged through a low voltage power supply, and then shorted to the upper plate with a mechanical switch. The total circuit inductance was determined to be approximately 800 nH from analysis of the ringing output current waveform shown in Figure 7.

Marx Output
Current
0.4 A/div



100 ns/div

Figure 7. Oscilloscope Photograph of the Proof of Concept Compact Marx Output Current During Inductance Measurements.

After the complete Marx generator had been assembled, the inductance was once again measured by shorting the load resistors and discharging the Marx in the normal manner. A section of grounding braid shorted each load resistor along the length, therefore maintaining the same approximate inductance geometry. The total inductance was determined to be approximately 1.03 μH from a computer analysis of the Marx current waveform. The increase in inductance for the assembled proof of concept Marx over the initial tests is due to the changes in the return path which were made in the addition of the dummy load.

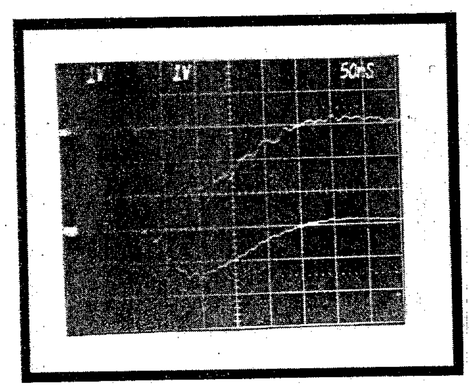
Marx Testing

As with the 1/4 scale Marx, the initial testing of the proof of concept Marx was performed in air without the pressure vessel installed. The Marx self break voltage in air was determined to occur at a charge voltage of 25 kV with a gap spacing of 0.95 cm (3/8") and the trigger pins removed and trigger circuit disconnected. The self break voltage did not change significantly with the trigger pins biased and in place and with the trigger circuit disconnected. With the trigger circuit connected, the Marx was triggered at 20.4 kV yielding an operating M-value of approximately 1.22. During additional testing, the trigger pins were disconnected from the trigger circuit and the Marx successfully erected when the trigger gaps fired, indicating that UV irradiation from the trigger gaps assisted in the breakdown of the Marx switches. The operating range of the Marx was found by varying the main spark gap electrode spacing with a constant trigger spark gap spacing of 0.25". The initial main gap spacing was 3/8" and the Marx could successfully be erected with a main gap spacing of up to 5/8". At the larger gap spacings some degradation in the rise time of the Marx was observed.

The Marx was then installed in the pressure vessel and an air test was repeated, verifying that the Marx was operating as before without the pressure vessel. At one atmosphere of SF_6 the Marx erected consistently at a charge voltage of approximately 45 kV which corresponds to an open circuit voltage of 675 kV. The Marx was tested over a range of pressures up to 10 psig, and demonstrated a consistent pulse shape with a rise time of approximately 50 ns into the ~40 Ω load. At 10 psig, the charging voltage was 70 kV, corresponding to an open circuit voltage of 1.05 MV. Typical current and voltage waveforms are shown in Figure 8. In this case, the data was taken at a Marx stage charging voltage of 63 kV. The results from the test are in agreement with the results from a computer model of the Marx bank shown in Figure 9. Further testing was not completed on the Marx due to a mechanical failure of one of the capacitor assemblies. This failure was a crack along the plastic weld between the capacitor header and capacitor case which resulted in the loss of dielectric fluid from within the capacitor.

Marx Output
Current
8 kA/div

Marx Output
Voltage
~500 kV/div



50 ns/div

Figure 8. Oscilloscope Photograph of the Proof of Concept Compact Marx Output Current (upper trace) and Output Voltage (lower trace).

Summary and Conclusions

In summary, a concept for compact Marx generators has resulted in several designs which have been developed and tested, reducing the height and diameter of traditional Marx generators by factors of 2-4 and 2, respectively. These compact, lightweight units have applications for driving high power lasers, high power microwave sources, and particle beam devices in a variety of mobile platforms. In order to generate a high voltage square pulse, a single anti-resonant section may be added to form a Type A PFN. For

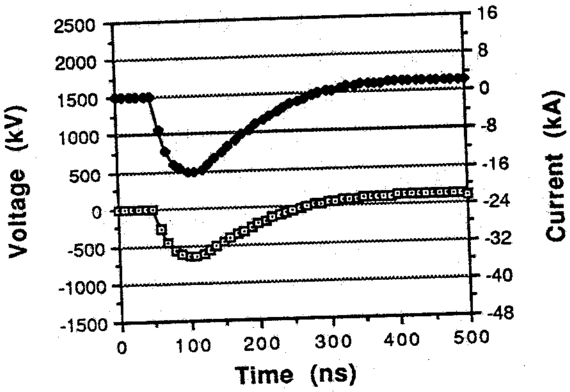


Figure 9. Computer Simulation Results of the Proof of Concept Compact Marx Output Current (upper trace) and Output Voltage (lower trace).

short pulse (~100 ns or less) applications, previous data from other programs suggests that the capacitors may be designed to provide a "PFL-like" discharge without the need for additional pulse shaping components. Further improvements in increasing the overall energy density can also be achieved by using more exotic, state-of-the-art capacitor dielectric systems.

References

[1] J.W. Rawles, "Directed Energy Weapons: Battlefield Beams", Defense Electronics, August, 1989, pp. 47-54.

[2] G.J. Rohwein, "Design of Pulse Transformers for PFL Charging", 2nd IEEE Pulsed Power Conference, Lubbock, Texas, 1979, pp. 87-90.

[3] J.R. Cooper, E.Y. Chu, and R.M. Ness, "An Innovative, Fast Response, Co-Axial, Capacitive High Voltage Probe", 7th IEEE Pulsed Power Conference, Monterey, California, 1989, pp. 390-392.