

SHORT PULSE MARX MODULATOR*

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Abstract

Under a U.S. Department of Energy grant, Diversified Technologies, Inc. (DTI) has developed a short pulse, solid-state Marx modulator. The modulator is designed for high efficiency in the 100 kV to 500 kV range, for currents up to 250 A, pulse lengths of 0.2 to 5.0 μ s, and risetimes <300 ns. Key objectives of the development effort are modularity and scalability, combined with low cost and ease of manufacture. For short-pulse modulators, this Marx topology provides a means to achieve fast risetimes and flattop control that are not available with hard switch or transformer-coupled topologies.

INTRODUCTION

Under a DOE SBIR grant and based on research begun under the Next Generation Linear Collider (NLC) program, Diversified Technologies, Inc. (DTI) has developed a short pulse, solid-state Marx modulator relevant to the Compact Linear Collider (CLIC) and numerous X-Band accelerator designs (Fig. 1). The modulator is designed for high efficiency in the 100 kV to 500 kV range, for currents up to 250 A, pulse lengths of 0.2 to 5.0 μ s, and risetimes <300 ns (Table 1). This fully optimized, transformer-less modulator design is capable of meeting the demanding requirements of very high voltage pulses at short pulsewidths.

Table 1: Yale Marx Design Parameters

| Item | Specification |
|---------------------------|---------------|
| Pulse Voltage | 500 kV |
| Pulse Current | 250 A |
| Pulse Width | 1.8 μ s |
| Repetition Rate | 20 Hz |
| Module Voltage | 12.5 kV |
| Module Capacitance | 0.6 μ F |
| # Modules for Base Pulse | 40 |
| Total # Modules in System | 48 – 50 |
| Expected Risetime | 300 ns |
| Heater Voltage | 24 VDC |
| Heater Current | 21 A |
| Insulation | Oil |

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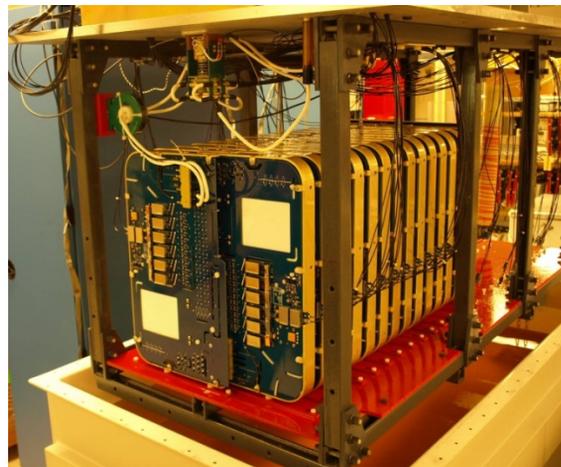


Figure 1: The Yale Marx 500 kV modulator charges many stages in parallel at low voltage, then discharges in series at high voltage. Each 12.5 kV, 250 A “flat pack” module is identical, providing for low fabrication and assembly cost.

A Marx generator is a system with energy storage capacitors which are charged in parallel at low voltage and discharged in series to provide high voltage output. This is a legacy idea, practiced for decades using resistor charging networks and spark-gaps for discharge. Constrained by the limits of closing switches, such systems required pulse forming networks and crowbars, with their attendant limitations.

The Marx topology allows a new degree of freedom unavailable to other architectures – DTI can intentionally underdamp the series snubbing within the pulse circuit. This cannot be done conventionally – the reactive overshoot endangers the load. In a Marx, we can compensate for the overshoot by initially firing only a subset of the switches – thus “sling-shooting” the leading edge faster than otherwise possible. We can tune the number and timing of subsequent module firings to counter the reactive ringing, and hold a flattop pulse to the desired voltage and accuracy.

Similarly, additional modules may be added to fire sequentially later in the pulse to compensate for capacitor droop. This is a critical enabling technology motivating Marx use for long-pulse accelerators (such as ILC), and yields valuable optimization even for very short-pulse systems. The reduction of capacitor size afforded by this flexibility further reduces parasitic capacitance, and thus reduces equipment size and cost while increasing power efficiency.

REDUCED MODULE COSTS

Through the use of PC board trace shielding and RF cans in sensitive areas of the circuit, we were able to collocate controls directly on the board within reasonable proximity to pulsed current sections of the same board. By exposing the IGBTs directly to the oil, we can cool the devices effectively while eliminating machined parts and hardware, further reducing the module parts count, associated materials, and assembly costs. Since the flat-pack design significantly reduces voltage gradients from module to module within the Marx bank, the only significant need for corona and field reduction geometry is at the interface between the Marx bank stack and the walls of the tank. We anticipate more than a four-fold reduction in module mechanical costs, with the potential for additional reductions in manufacturing costs, compared to earlier designs.

SIMPLER INTERCONNECT

Each module in the redesigned Marx bank plugs directly into the two adjacent modules. We oriented the connectors and offset the board components and corona shields to allow any individual module to be added or removed from the stack, much like a book on a shelf, without any significant disassembly of support structures or disruption of the rest of the Marx bank. Since all module electrical connections and buswork are integral to the modules, only the fiber-optic control line (and optional fiber-optic monitor) needs to be externally connected. The first module in the stack plugs into a connector supplying charging HV, core bias current, auxiliary housekeeping power, and ground. A connector on the final module is connected to the Marx output coaxial cable, and includes a loopback for the common-mode choke bias current.



Figure 2: Output pulse voltage with 48 plates, showing 500 kV with staggered plate switching to optimize flat top. 106.2 kV/div, 500 ns/div.

SCALABILITY

The flat-pack Marx design is inherently modular and scalable, as additional plates may be added for a wide range of voltages. Whether at 100 or 500 kV, a Marx bank can use the same modules. The primary impact of additional plates is an increase in the charging current at the first plate, since it carries the current for all subsequent plates as well. Stray capacitance is also greatest at higher voltages, assuming constant spacing to the tank.

PROTOTYPE TESTING

During preliminary testing of the prototype bank, we ran four modules with all four modules simultaneously switched for a 1.5 μ s pulse, with a 10 kV pre-charge into the system, resulting in a 40 kV output. The prototype modules performed flawlessly into high voltage, with none of the chatter or jitter that would otherwise be associated with gate drives impacted by noise coupling at high voltage.

DTI has now completed full testing of a stack of 48 plates into a resistive load (Fig. 2). Installation is set to occur at Yale University Beam Physics Laboratory. DTI will continue carefully constructing and testing modules to ensure the reliability and safety of the equipment.

FUTURE PLANS

In Phase III, DTI will extend this design to future short-pulse, high voltage modulators for the next generation of planned accelerators, as well as transition this design to industrial / medical accelerators. We believe that the same combination of modular, low cost elements demonstrated in this Phase II effort will allow solid-state modulators to finally reach a price level that will supplant traditional (but low cost) thyratron / PFN designs currently used in these systems.