ILC MARX MODULATOR DEVELOPMENT PROGRAM STATUS*

C. Burkhart#, T. Beukers, M.A. Kemp, R. Larsen, K. Macken, M. Nguyen, J. Olsen, T. Tang,
SLAC National Accelerator Laboratory, Menlo Park, CA 94025, U.S.A.

Abstract

A program is underway at SLAC to develop a Marx-topology klystron modulator for the International Linear Collider (ILC) project [1]. It is envisioned as a smaller, lower cost, and higher reliability alternative to the bouncer-topology baseline design. The application requires 120 kV (±0.5%), 140 A, 1.6 ms pulses at a rate of 5 Hz. The Marx constructs the high voltage pulse without an output transformer, large at these parameters, by instead combining a number of lower voltage cells in series. The modularity of the Marx topology can be further exploited to achieve a redundant, high-availability design. The ILC Marx employs solid state elements; IGBTs and diodes, to control the charge, discharge and isolation of the cells. The SLAC designs are oil-free; air is used for high voltage insulation and cooling. Integration of the first generation prototype, P1, into an L-band test station for life testing of klystron and modulator is nearing completion. Development of a second generation prototype, P2, is underway. Status updates for both prototypes are presented.

INTRODUCTION

The International Linear Collider (ILC) will require 576 RF stations. Each 10 MW L-band klystron will require a modulator capable of 120 kV, 140 A, 1.6 ms (27 kJ) at a 5 Hz repetition rate. The existing Baseline Conceptual Design (BCD) is a transformer-based topology. The large size, weight, and cost of this transformer, owing to the long pulse length, have motivated research into alternative topologies that do not employ power magnetics.

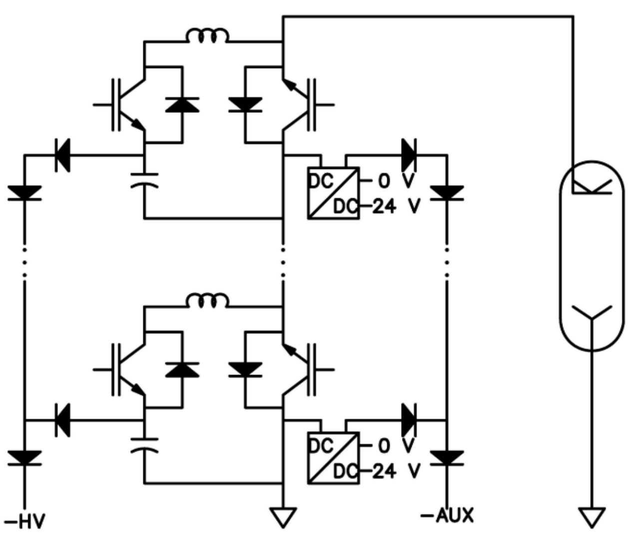

Figure 1. Simplified schematic of the ILC Marx.

*Work supported by the U.S. Department of Energy under contract DE-AC02-76SF00515
#burkhart@slac.stanford.edu

DESIGN OVERVIEW

The reliability/availability requirements for ILC systems mandate the use of solid state switching elements to control the klystron modulator output. The Marx topology provides an approach to array solid state switches to the voltage and power levels required for this application. A simplified schematic of the Marx topology selected for the ILC application is shown in Figure 1. The Marx is composed of cells, which form the basic Power Electronics Building Block (PEBB) [2]. Each cell contains an energy storage capacitor, an IGBT switch to control the discharge of the capacitor, and an inductor to limit dI/dt in the event of a fault. A second IGBT switch and the diodes provide the path to charge the energy storage capacitor, and the auxiliary power supply, of all the Marx cells in parallel while isolating these paths during the series discharge of the Marx. There are several variations on this topology, however the design illustrated in Figure 1 is used for both the P1 and P2 designs.

P1 MARX MODULATOR

The details of the P1 Marx design and operational behavior have been presented elsewhere [3]. The P1 has 16 cells, each charged to 11 kV. Eleven cells are initially triggered to produce the full output voltage. As the 50 μF energy storage capacitors discharge, the output voltage drops. Once it decreases by 11 kV, after ~0.35 ms, an additional cell is triggered to restore the output to 120 kV. This proceeds sequentially through the remaining five cells to provide coarse, ±5%, pulse flattening.

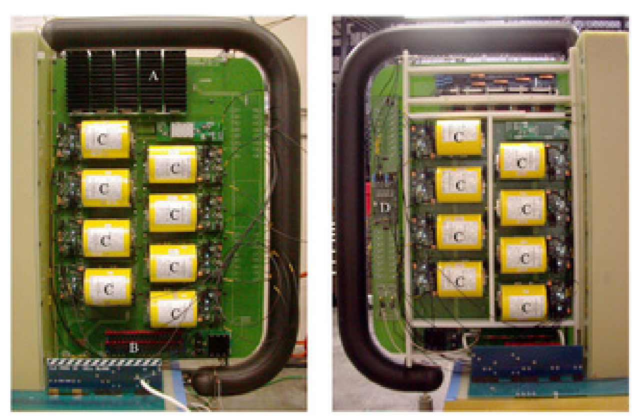

Figure 2. Photograph of the vernier Marx cell, front side (left) and back side (right), noting major elements. A: 11 kV IGBT modules, B: 11 kV by-pass diodes, C: vernier Marx cells, D: control board, E: isolation board for 11 kV IGBT.

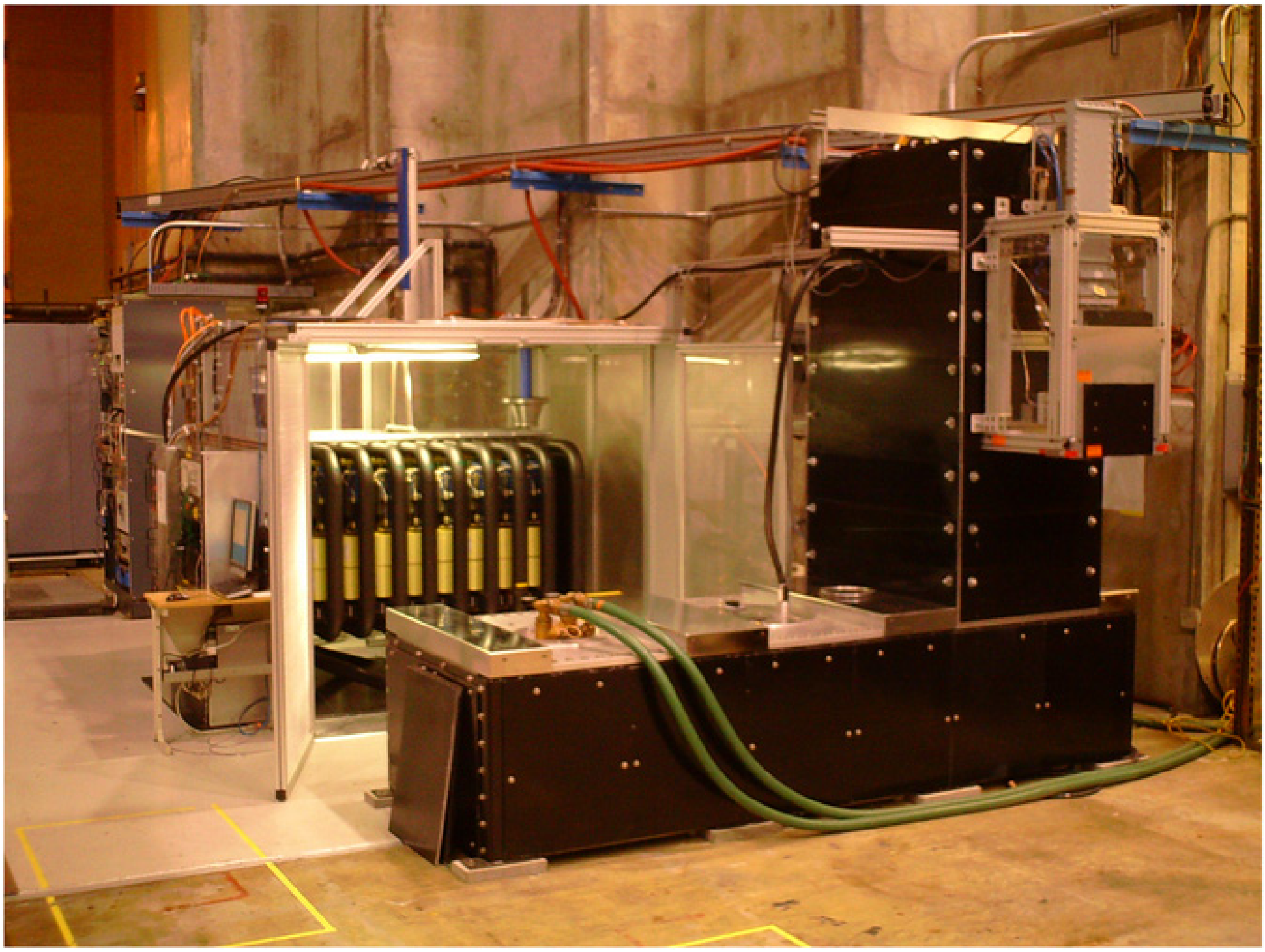

Figure 3. L-band test station; 10 MW klystron (right), Marx modulator (center), Rf controls (left).

A vernier regulation scheme, adding a second Marx in series with the main Marx, will be applied to further regulate the output to ±0.5%. The topology of the vernier Marx is similar to the main Marx, however each of the 16 cells is charged to 1.2 kV. These will be fired sequentially to generate a stair-step waveform, which will add to the main Marx to maintain an approximately constant output voltage. Each time a delayed main cell is added, the vernier Marx will open (cell output goes to zero) and the process repeats.

Developmental testing of the vernier Marx is nearing completion, but it has not yet been integrated into the P1. The vernier, shown in Figure 2, has the same footprint as a main Marx cell. It uses the same serial protocol fiber optic communication and CPLD-based control board as the main Marx cells. In addition to the 16 vernier Marx cells, an 11 kV by-pass diode stack and charge switch are integrated into the vernier to allow charging of the main Marx.

P1 MARX STATUS

The bulk of the developmental testing and integration into a 10 MW L-band Rf test station, shown in Figure 3, has been completed. The modulator has operated for a few hundred hours with a water load. Once control system upgrades to allow unattended operation have been completed, the Marx will be connected to the klystron for extensive life testing of the modulator and klystron.

P2 MARX MODULATOR

The P2 Marx builds on the experience gained during development of the P1. The two major changes are: (1) the cell voltage is decreased to 4 kV and (2) droop compensation is integrated into each cell. Reducing the cell voltage eliminates the need to electrostatically array IGBTs within a cell (each P1 switch is a 5 series by 3 parallel IGBT array). This simplifies the cell design and improves diagnostic access to evaluate switch performance. A PWM regulated voltage source is added in series with the energy storage capacitor to compensate for the capacitor voltage droop and maintain a constant cell voltage throughout the pulse. Incorporating the voltage regulation into each cell allows true redundancy. With 32 cells, N+2 redundancy is achieved, which will promote high system availability. The specifics of the cell design are discussed elsewhere [4].

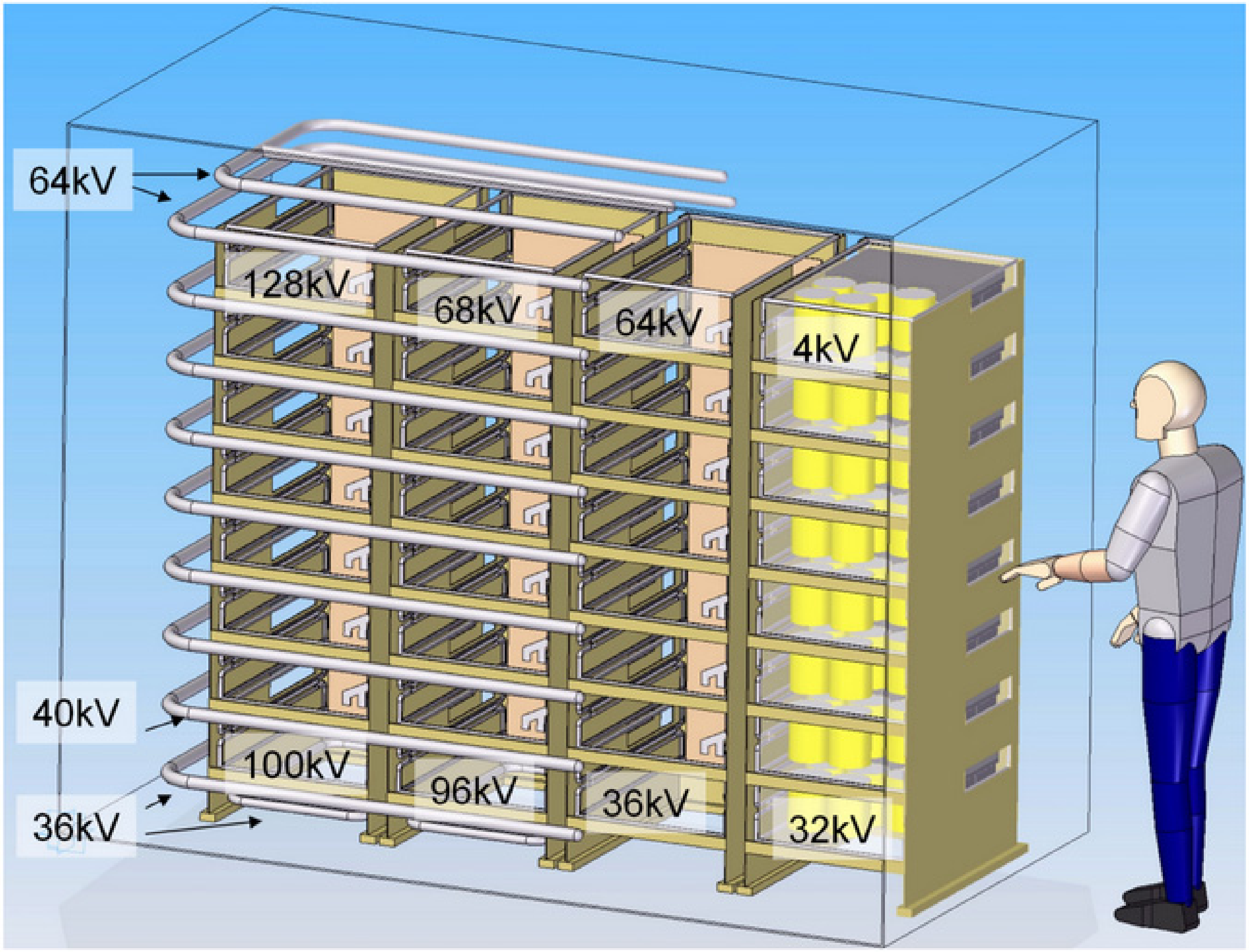

Figure 4. Conceptual design of the P2 Marx.

A conceptual design of the P2 is presented in Figure 4. Each of the 32 cells (only 8 are shown) slide into a support structure. In addition to physical support, this structure provides the electrical interconnection between cells, flow channels for air cooling, and field shaping elements to control the electrostatic fields. The field shaping elements are essential to achieving a compact modulator. The enclosure is 2.7 m long, 1.5 m deep, by 2.2 m tall. The electric field is less than 18 kV/cm.

CONCLUSIONS

The SLAC P1 Marx modulator will begin life testing during FY09-Q3 to demonstrate the reliability of this klystron modulator design. Single cell testing of the second generation P2 Marx will occur during FY09 with construction of the full modulator to follow in FY10.

ACKNOWLEDGMENT

The authors wish to acknowledge the significant contributions of D. Anderson, C. Brooksby (LLNL), R. Cassel, E. Cook (LLNL), G. Leyh, D. Moreno, P. Shen, and A. Viceral to the SLAC Marx development program.

REFERENCES

[1] ILC Reference Design Report, http://www.linearcollider.org/cms/?pid=1000437

[2] T. Ericsen, “Power Electronic Building Blocks - A systematic approach to power electronics,” in Proc. IEEE Power Eng. Soc. Summer Meeting, Seattle, WA, 16-20 July 2000, pp. 1216-1218.

[3] C. Burkhart, T. G. Beukers, R. S. Larsen, M. N. Nguyen, J. Olsen, T. Tang, “ILC Marx Modulator Development Program Status,” Linac 08 Conference, Sept 29 – Oct 3, 2008, Victoria, Canada, http://trshare.triumf.ca/~linac08proc/Proceedings/.

[4] K. Macken, T. Beukers, C. Burkhart, M. Kemp, M. Nguyen, T. Tang, “Towards a PEBB-Based Design Approach for a Marx-Topology ILC Klystron Modulator,” in these proceedings.