ILC RF SYSTEM R&D*

Chris Adolphsen
SLAC National Accelerator Laboratory, Menlo Park, CA 94025 USA

Abstract

The Linac Group at SLAC is actively pursuing a broad range of R&D to improve the reliability and reduce the cost of the L-band (1.3 GHz) rf system proposed for the ILC linacs. Current activities include the long-term evaluation of a 120 kV Marx Modulator driving a 10 MW Multi-Beam Klystron, design of a second-generation Marx Modulator, testing of a sheet-beam gun and beam transport system for a klystron, construction of an rf distribution system with remotely-adjustable power tap-offs, and development of a system to combine the power from many klystrons in low-loss circular waveguide where it would be tapped-off periodically to power groups of cavities. This paper surveys progress during the past few years.

MODULATORS

The modulator specification for the ILC Linac klystrons calls for 120 kV, 140 A, 1.6 ms pulses at a 5 Hz repetition rate. SLAC is pursuing a Marx-topology modulator to fulfill this requirement. A full-scale prototype, the SLAC P1 Marx, has been designed, fabricated, and is currently undergoing lifetime testing, driving a 10 MW Toshiba Multi-Beam Klystron (MBK) for about 1500 hours with no chronic problems [1-3]. A second-generation Marx, the SLAC P2 Marx, is currently under development [4, 5].

The Marx is made up of many identical, and ideally, redundant cells. If a cell becomes inoperable, it can be bypassed. Increasing the applied charge voltage or turning on 'spare' cells allows the modulator to continue operation. In addition, a modular design gives flexibility to better utilize high-volume manufacturing techniques, thereby reducing costs. Finally, portable cells allow maintenance staff to quickly replace inoperable cells with pre-tested replacements, reducing the mean time to repair.

The SLAC P1 Marx operates in air, has no output transformer, and is air-cooled (see Fig. 1). The Marx utilizes an FPGA-based control system. A diagnostic module on each cell, along with the ground station and a cell control board, coordinate the timing of the cells. The diagnostic card has four analog input channels monitored at 20 kS/s with a resolution of 16 bits. A fast transient recorder can also be used at 30 MS/s with 8-bit resolution.

In the SLAC P1 Marx, sixteen, 11 kV Marx cells are arranged with a single "Vernier" Marx. The triggering sequence of the main Marx cells is designed to promptly

Figure 1. Photograph of the SLAC P1 Marx modulator showing its cantilevered support structure, high-voltage grading rings, and sixteen installed cells.

turn-on eleven cells, then stagger turn-on the remaining five cells to coarsely compensate the storage capacitor droop. The Vernier Marx (with cells charged to ~ 1 kV) staggers its turn-on and turn-off to further regulate the output to the specified level of +/-0.5%. Fig 2. shows the resulting rf waveform.

Building upon the success of the P1 Marx, the SLAC P2 Marx is currently in the final stages of design. It includes thirty-two, 3.75 - 4 kV cells. The modulator will be able to produce the specified power with up to two of the cells offline.

There are several differences between the P1 and P2 modulators. First, a nested droop correction scheme is employed in the P2 Marx. Each cell individually regulates its output, removing the need for a separate compensation

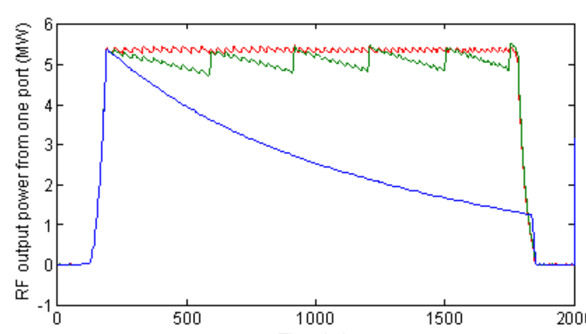

Figure 2. RF waveforms from one of the two klystron ports: Blue: no droop compensation, Green: with only delay cells, Red: with delay cells and Vernier, producing a flat pulse with a 3% saw-tooth pattern.

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element (like the Vernier in the P1 Marx). Second, there is no arraying of solid-state switches within a cell, simplifying the control and protection schemes. Third, the modulator layout is redesigned to have a single side access.

SHEET BEAM KYSTRON

As an alternative to the baseline 10 MW MBK, the SLAC Klystron Group is developing a Sheet Beam Klystron (SBK) [6]. A flat beam is used to reduce the space charge forces to produce an efficiency similar to that of the MBK. The design goals were to be 'plug compatible' with the MBK, have a 40:1 beam aspect ratio and utilize permanent magnets for focusing.

Fig. 3 shows the klystron design that was initially envisioned, and a 'Beam Tester' that has been built and operated to verify the gun beam profile predicted from the simulation program MICHELLE. A vertical asymmetry was observed in the measured current density profile that was partially corrected using a 900 V and 0 V bias on the upper and lower focus electrodes, respectively. The resulting current density is shown where an ideal elliptical beam profile outline is superimposed in white.

Much of the SBK work during the past year has focused on understanding beam instabilities due to modes trapped in the drift tube between adjacent cavities. A two cavity instability example is illustrated in Fig. 4. After trying many methods to suppress the modes in simulation, the drift tube height was doubled to decrease cavity coupling, and the magnetic field was changed to a 3x Brillouin solenoid (~ 1 kG) to achieve stability.

A two-cavity oscillation device has been built using the Beam Tester and parts from the original permanent magnet focusing system. It will be operated to verify the predicted regions of stability versus magnetic field (and so validate the MAGIC PIC code). The plan is to test this device by the end of FY10. However, given the long development time still required for a full klystron, and the smaller cost saving and weight reduction with the switch to solenoidal focusing, the program will end after FY10.

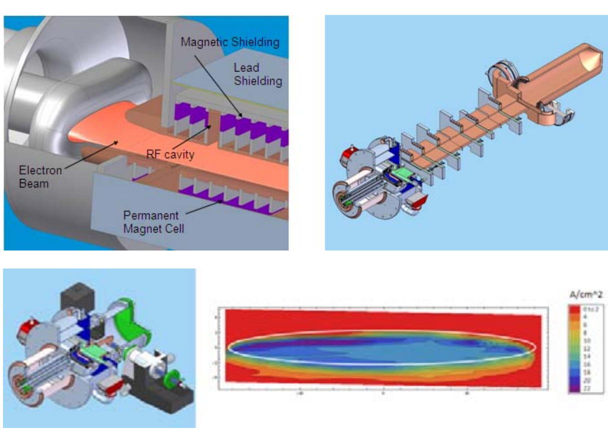

Figure 3. Top: layout of the original SBK, bottom: Beam Tester and measured beam current density after the gun.

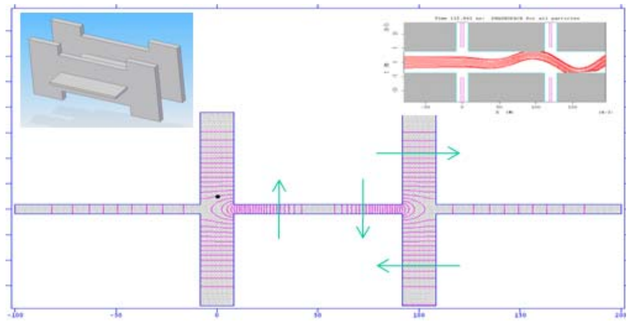

Figure 4. Example of a two cavity (top left) instability. Bottom: field pattern of a 1.47 GHz beam-induced mode, top right: resulting deflection of the beam.

RF DISTRIBUTION

Klystron Cluster Scheme

To reduce the ILC cost, two rf distribution schemes are being considered that would allow the elimination of the Main Linac service tunnel. In one option, the Klystron Cluster Scheme (KCS) [7], power from 10 MW klystrons that are located in surface buildings are combined in circular waveguide and transported down to and along the beam accelerator tunnel. The klystrons are grouped in clusters of ~35 and the combined power feeds a 1.25 km linac section. At 38 m intervals along the linac, 10 MW is tapped off from the circular waveguide to feed three cryomodules, just as in the baseline design. The high power would be transmitted in the low-loss TE01 mode in 0.48 m diameter waveguide where the average power loss would be about 7%. Coaxial Tap-Offs (CTOs) have been designed to transfer power in to or out of the TE01 waveguide without perturbing the axial symmetry of the inner, high power region.

At SLAC ESB, a KCS test bed is under construction in which 10 m of aluminum waveguide will be resonantly charged through a single CTO to the field-equivalent of a 350 MW travelling wave. Figure 5 shows the layout of the facility (with a CTO on each end in this case for transmission tests), and details of the CTO design. Tests will be done both under vacuum and in nitrogen at two bar absolute pressure to see which environment is less prone to rf breakdown (note there are no surface electric fields in the main pipe and coaxial gap region of the CTO).

Four, 2.4-m-long sections of the "big pipe" waveguide are ready for installation. Each pipe consists of two aluminum plates that were rolled, welded longitudinally and then precision machined (to ~ 1 mm for the inner diameter). The rf specifications for roundness were met, and all passed hydrotesting for operation under pressure. Double grooves on one face of each flange joint allow for pressure/vacuum sealing with a rubber O-ring and rf sealing with a canted coil gasket. A perforated vacuum pump-out insert is near completion as are two step tapers

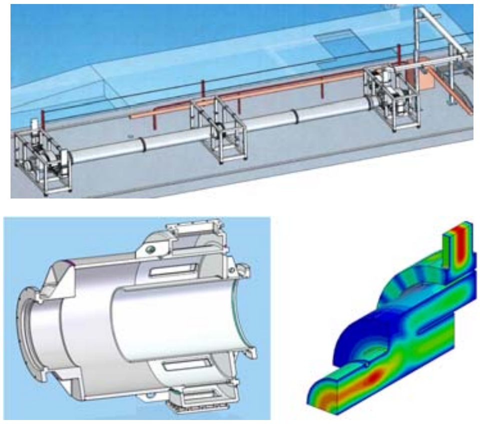

Figure 5. Top: Layout of the KCS test bed, bottom: CTO cross section and electric field pattern.

from 0.48 m to 0.35 m diameter for interfacing with the CTO.

For the high power test, the desired CTO coupling will be achieved by shorting one end with the proper length waveguide, and the resonance condition will be achieved by shorting the far end of the waveguide at an appropriate length. RF windows on the CTO rectangular ports isolate the test system from the input rectangular waveguide.

Future work includes developing and testing a high-power waveguide bend, demonstrating the matched tap-off function of the CTO and combining of two or more sources into the large TE01 mode waveguide. Beam physics issues are also being studied, such as the effect on the beam emittance given the energy errors associated with the coarser energy control.

Local Distribution

At SLAC, a system for distributing up to 3.3 MW of rf power to eight SC cavities was built for the first cryomodule that will be tested at FNAL [8]. This system makes use of a novel, adjustable directional coupler called the Variable Tap-Off (VTO), which, by means of mode rotation, allows tailoring of the power distribution among pairs of cavities (see Fig. 6). This functionality is desireable given the wide range of sustainable cavity gradients (+/- 20%) that will be accepted to increase the production yield for ILC.

A second such distribution system with a different power tailoring scheme is being prepared for FNAL's next cryomodule [9]. The VTO requires loosening two large bolted flanges to make coupling changes, which is fine for the ILC where such adjustements should be rare. For an R&D facility, however, a system that can be adjusted more quickly is perferred. For this purpose, the equivalent of a remotely controllable VTO will be provided by a pair of folded magic-T's connected by a pair of motorized U-bend phase shifters (see Fig. 6). Each of the phase shifters contains an inner waveguide turn-around inside a pressurizable outer shell, movable by means of motorized feed-throughs. The broadwall edges of the inner U-bend are shorted to the outer WR650 by

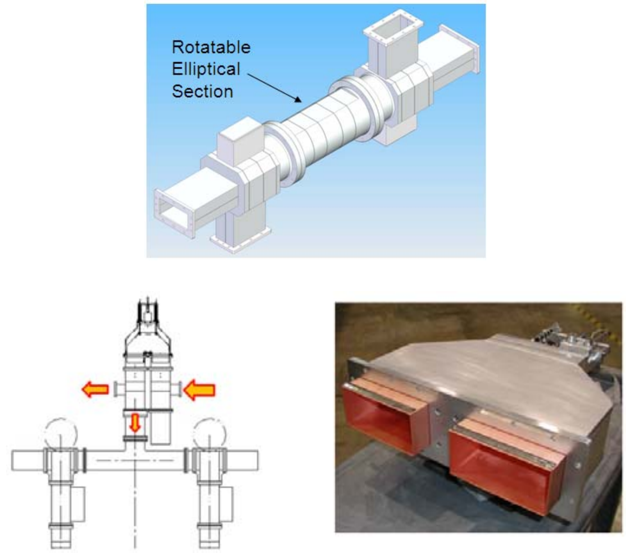

Figure 6. Top: Variable Tap-Off power splitter, bottom: system with same functionality that employs U-bend phase shifters (prototype on right).

stainless steel fingerstock. A prototype has been tested up to 2 MW, and eight more are in fabrication.

ACKNOWLEDGMENTS

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