DESIGN OF A MARX-TOPOLOGY MODULATOR FOR FNAL LINAC

T.A. Butler, F.G. Garcia, M.R. Kufer, H. Pfeffer, D. Wolff, FNAL, Batavia, IL 60510, USA

Abstract

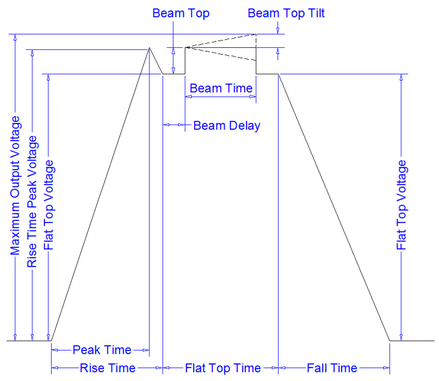
The Fermilab Proton Improvement Plan (PIP) was formed in late 2011 to address important and necessary upgrades to the Proton Source machines (Injector line, Linac and Booster). The goal is to increase the proton flux by doubling the Booster beam cycle rate while maintaining the same intensity per cycle, the same uptime, and the same residual activation in the enclosure. For the Linac, the main focus within PIP is to address reliability. One of the main tasks is to replace the present hard-tube modulator used on the 200 MHz RF system. Plans to replace this high power system with a Marx-topology modulator, capable of providing the required waveform shaping to stabilize the accelerating gradient and compensate for beam loading, will be presented, along with development data from the prototype unit.

Fermilab Linac RF Systems

- H- beam pulses from 750keV up to 400 MeV.
- Two linear accelerating sections.
- 201.25 MHz Alvarez drift tube cavities accelerate beam from *750 keV to 116 MeV, powered by 5 MW triode power tube (7835).*
- 805 MHz Side Coupled cavities accelerate beam from *16 MeV to 400 MeV, powered by 12 MW klystron (L5859).*

Present Modulator Topology & Specifications

- The 7835 is plate modulated using hard-tube topology modulator.
- High voltage capacitor bank is switched via three parallel grid-controlled electron tubes to regulate the anode on the triode.
- Series-pass tubes (F1123) are discontinued.
- Requires precise waveform to regulate the cavity gradient.
- Need to regulate the cavity fields with ~ 0.2%.



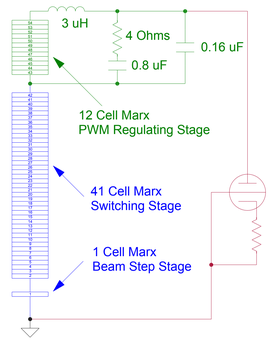
Linac Marx Modulator Specification	Value	Units	Limit
Pulse Repetition Rate	15	Hz	max
Rise Time	150	usec	max
	50	usec	min
Fall Time	150	usec	max
	70	usec	min
Flat Top Time	160	usec	max
	50	usec	min
Beam Length/Time (Adjustable)	110	usec	max
Beam Time Delay (Adjustable)	100	usec	max
Peak Voltage Time (Adjustable)	150	usec	max
	35	usec	min
Output Voltage (Adjustable)	35	kV	max
	8	kV	min
Output Current	375	A	max
Beam Voltage Step Size	10	kV	max
	5	kV	typ
Flat Top Voltage Regulation / Slope (within 150us pulse)	± 25	V	max
Flat Top Repeatability (Pulse to Pulse)	± 25	V	max
Flat Top Resolution (Setpoint Adjustment)	± 5	V	max
Beam Top Repeatability (Pulse to Pulse)	± 10	V	max
Beam Top Tilt (Adjustable)	± 5	kV	max
Slew Rate (Beam Voltage Step)	15	kV/usec	min
Slew Rate (Rising Edge)	1	kV/usec	max
Slew Rate (Falling Edge)	0.5	kV/usec	max
Step Size (Rising or Falling Edge)	1.5	kV	max
Modulator Emergency Turn Off (< 2 usec in pulse)	400	Amps	max
Modulator Emergency Turn Off (< 2 usec out of pulse)	100	Amps	max
Linearity	± 20	%	max
Gain	10000	NA	min

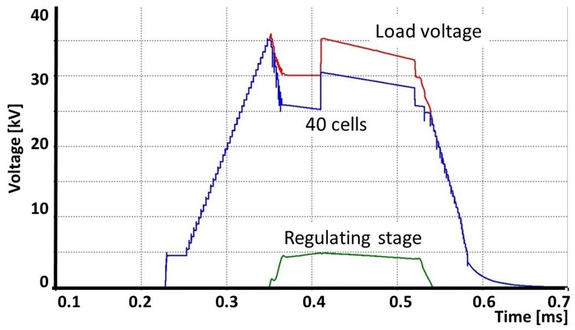
Marx Modulator Topology

Typical Marx Topology
Charge cell in parallel
Discharge cell in series

Total of 54 Cells

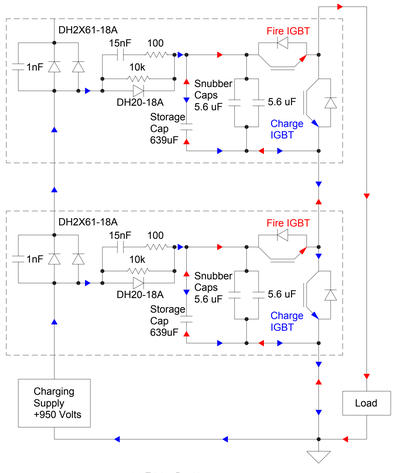
- 1kV per cell
- 41 Switching Cells
  Overall Waveform
  Locked during flattop
- 12 Regulating Cells
  Run in PWM mode
  100 kHz Praeg Filter
- 1 Beam Step Cell
  Precise Voltage Adjust

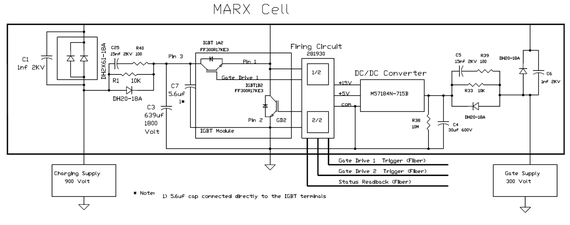




Single Switching Marx Cell

- Charge Main 639 µF Capacitor with 1kV Power Supply.
  (Storage Capacitor is AVX #DNCFM1K8B6396)
- Charge Control Power DC/DC Converter with 300 Volts.
- Fire and Charge Insulated-Gate Bipolar Transistor (IGBT).
  (Infineon #FF300R17KE4 1.7 kV half-bridge)
- Snubber 5.6 µF Capacitors *(Electronic Concepts #MP80CM565K).*



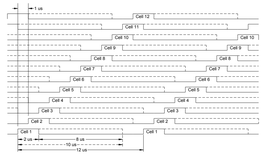


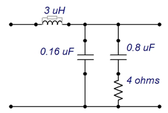
Regulating Cells PWM

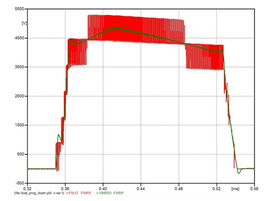
- Each regulating cell is fired via pulse width modulation (PWM).

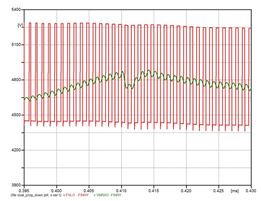
1. Compensating the main capacitor droop during flattop.
2. Provides either rising or falling tilt on beam step.
3. Implements limited voltage range real-time feedback.

- Cells fired at a 83.3 kHz repetition rate for each cell, with a minimum ON and OFF time of 2 µs selected.
- Each cell interleaved every 1 µs, repeated every 12 µs.
- Result is a minimum of 2 and maximum of 10 cells on at any time, giving a total of 8 cells, or 7.4 kV of adjustable range.

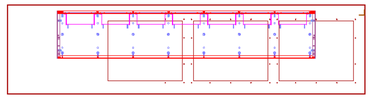


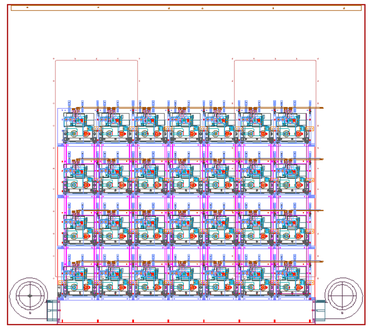


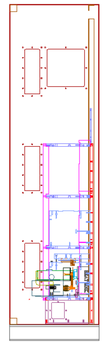




28 Cell Half Voltage Protoype Modulator

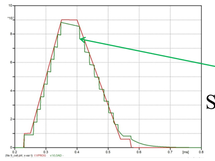


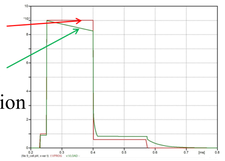


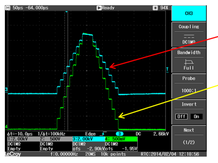


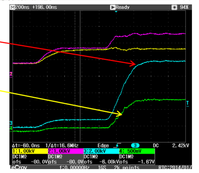
9 Cell Low Voltage Prototype Modulator

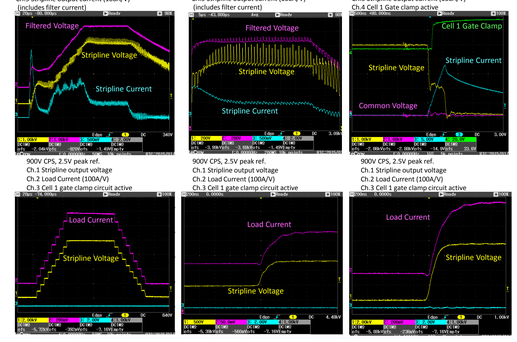
- Tested main switching cells by firing in a staggered turn on to show performance and simultaneously show that slew rate > 15kV/µs.
- Added filter and ran in PWM mode to show ripple < ±25 Volts.











54 Cell Full Voltage Prototype Modulator