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Fermilab Linac 201.25 MHz LLRF

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USPAS 2017 LLRF Class

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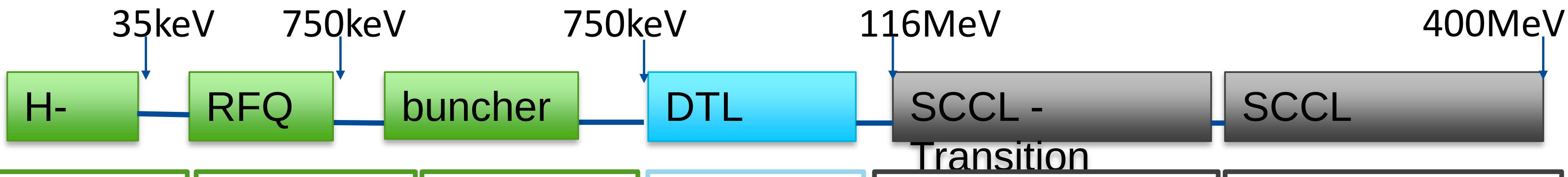
Fermilab Linac Topology



magnetron ion source	Radio Frequency Quadrupole	Buncher dual-gap cavity	Drift Tube Linac	Side-Coupled Cavity Linac	Side Coupled Cavity Linac
35 kV	201.24 MHz	201.24 MHz	201.25 MHz	805 MHz	805 MHz
extractor	1.2 m	0.2 m	75 m	4 m	60 m
	1 Tetrode	1 pentode	5 tanks	2 modules	7 modules
	175 kW	5 kW	5 Triodes	2 klystrons	7 klystrons
			5 MW	200 kW	12 MW
			200 EMQ	4 EMQ	28 EMQ

Total Linac: 145 m
5 Triodes
10 klystrons

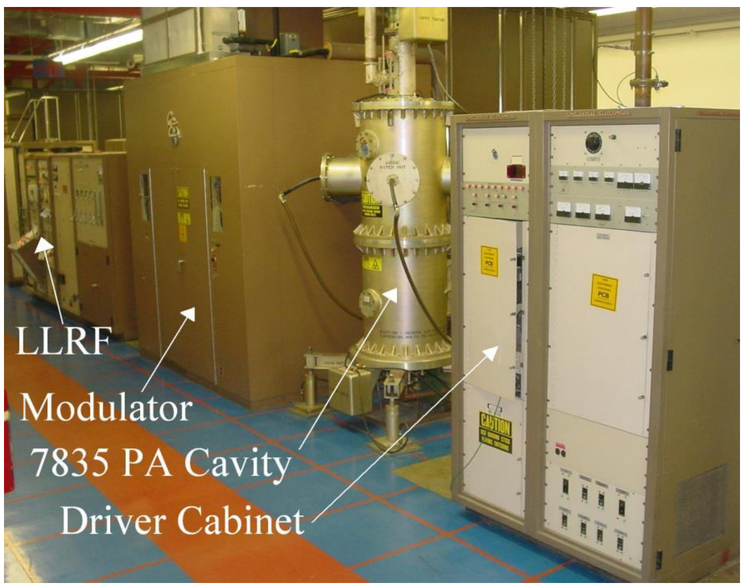
Duty cycle:
0.5% RF
0.04% beam

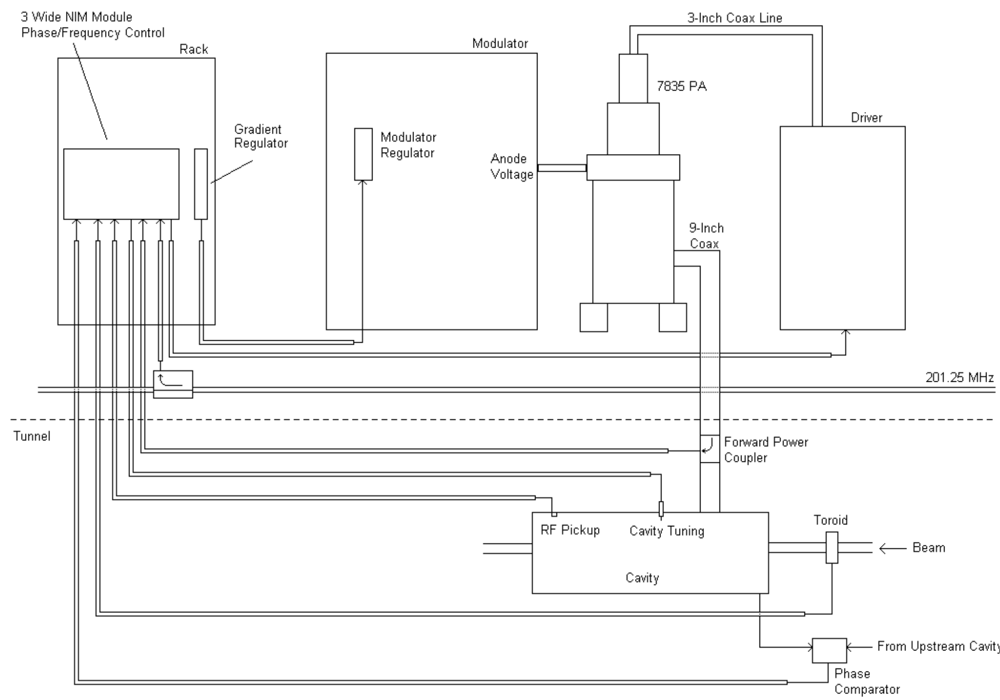
3 different structures
(RFQ, DTL, SCCL)
2 frequencies

Beam current:
34 mA (avg. in pulse)

Fermilab 201.25 MHz Overview

- 201.25 MHz Drift Tube Linac LLRF
- LLRF system was upgraded from analog phase feedback system
- VXI based LLRF system was been designed to replace the present analog system





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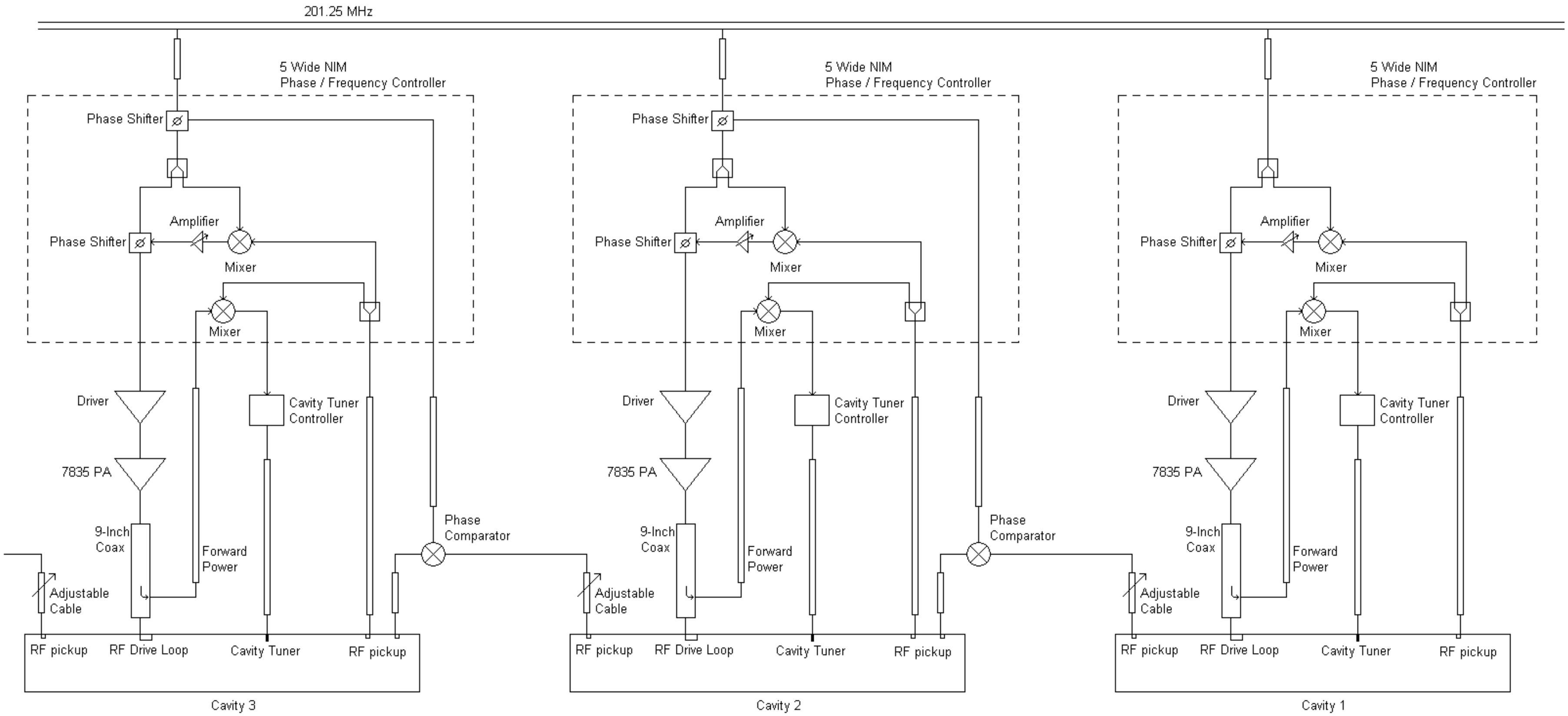
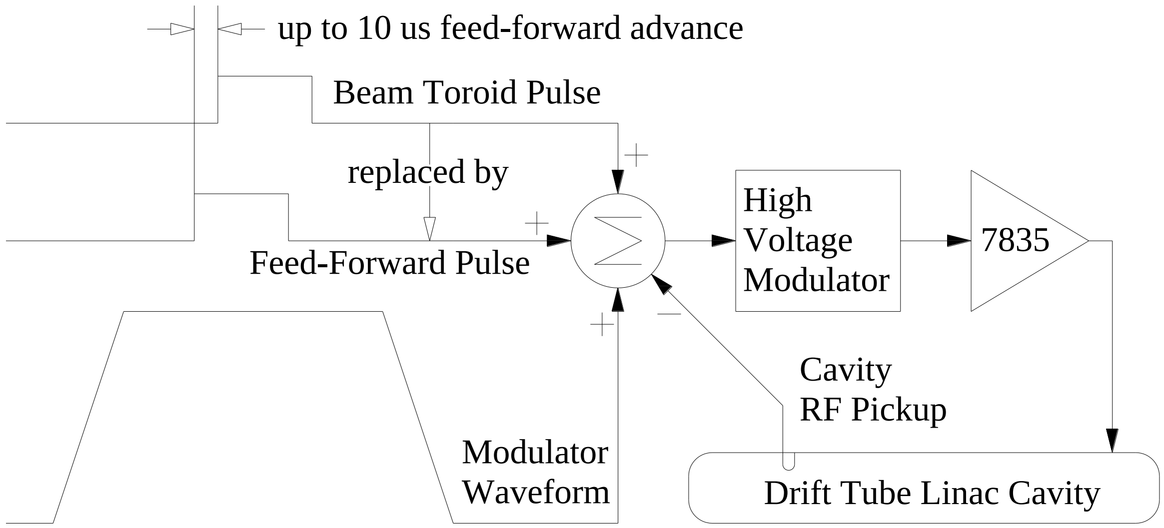
Old 201.25 MHz Linac LLRF System



RF Amplitude Feed-Forward Control

- The 5 MW, Triode tube amplifiers are run near saturation to reduce line to pulse to pulse variations
- Amplitude control cannot be done effectively using direct RF feedback through RF driver.
- Instead, amplitude of the RF is controlled by regulating the modulator voltage applied to the anode of the Burle 7835 power amplifier.
- Old LLRF used Beam Toroid to compensate for beam loading
  - not optimal because of 2 us delay/time constant of present system
- New LLRF System designed to add Feed-Forward Pulse before beam is detected, allowing the system to compensate for the delays in the system.



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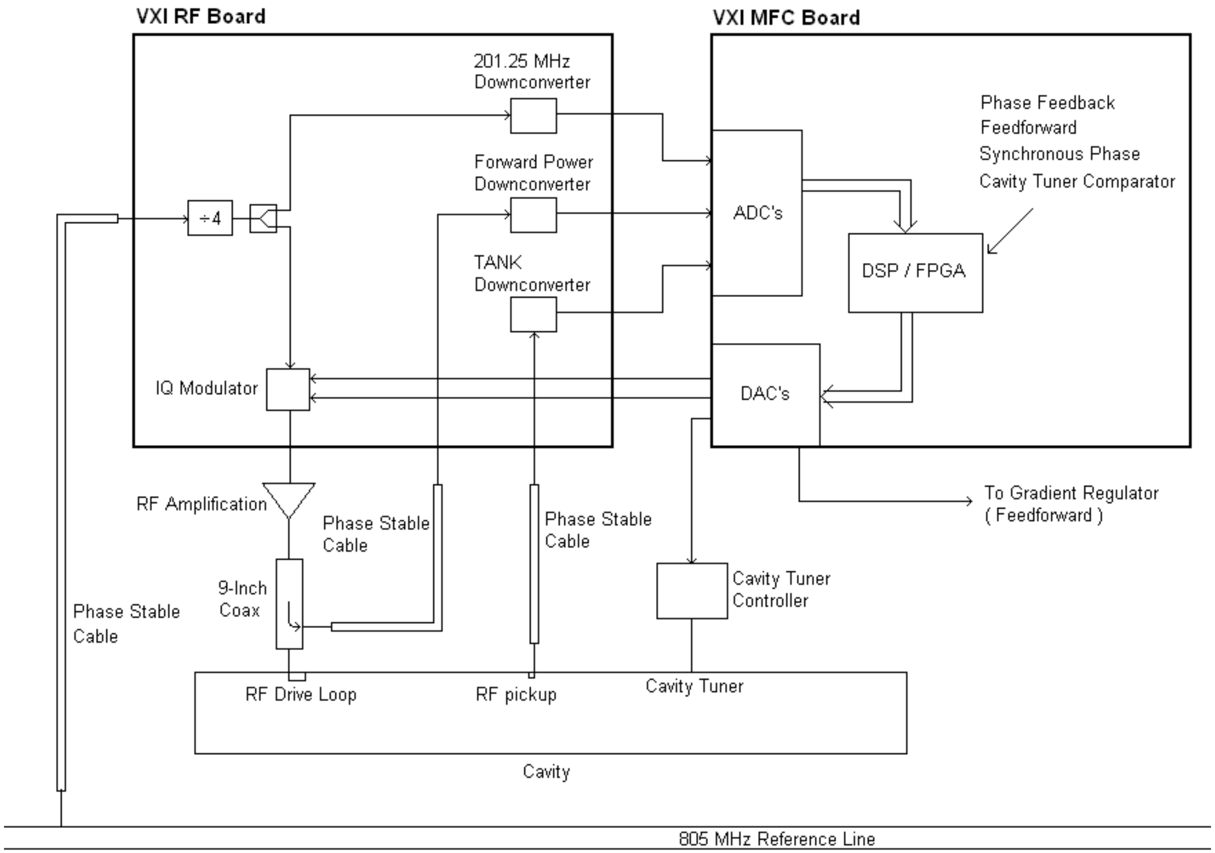
Fermilab 201.25 MHz LLRF Goals and Feature

- Goals
  - Install a new VXI based LLRF system to replace analog system
  - Improve cavity vector regulation and reduce beam losses.
  - Adaptive feedforward system for beam loading compensation
  - Digital Phase feedback system
  - Digital phase comparator for cavity tuning.
  - Phase locked to temperature stabilized 805 MHz reference line
  - Reduce amplitude variations to < 0.2%
  - Reduce the beam setting time to < 2 us.

- New LLRF Features
  - Adaptive feed-forward system to improve beam loading compensation
  - Digitally controlled phase feedback system that replaces the present analog RF phase feedback
  - 201.25 MHz RF reference generated from the HE Linac 805 MHz reference line
  - Synchronous phase lock system that replaces the present inter-tank phase regulation system
  - Digital phase comparator to control the position of the cavity resonant frequency tuner

VXI LLRF System

- Slot 0 controller is used to connect the Fermilab controls network (ACNET) with the LLRF system.
- MFC Board uses a modern Digital Signal Processor (DSP) and Field Programmable Gate Arrays (FPGA) to implement the phase loop, perform feed-forward calculations, and execute other digital control loops.
- Analog RF module is responsible for all of the analog RF signal processing and control. Working together, the new VXI LLRF system provides the following features:



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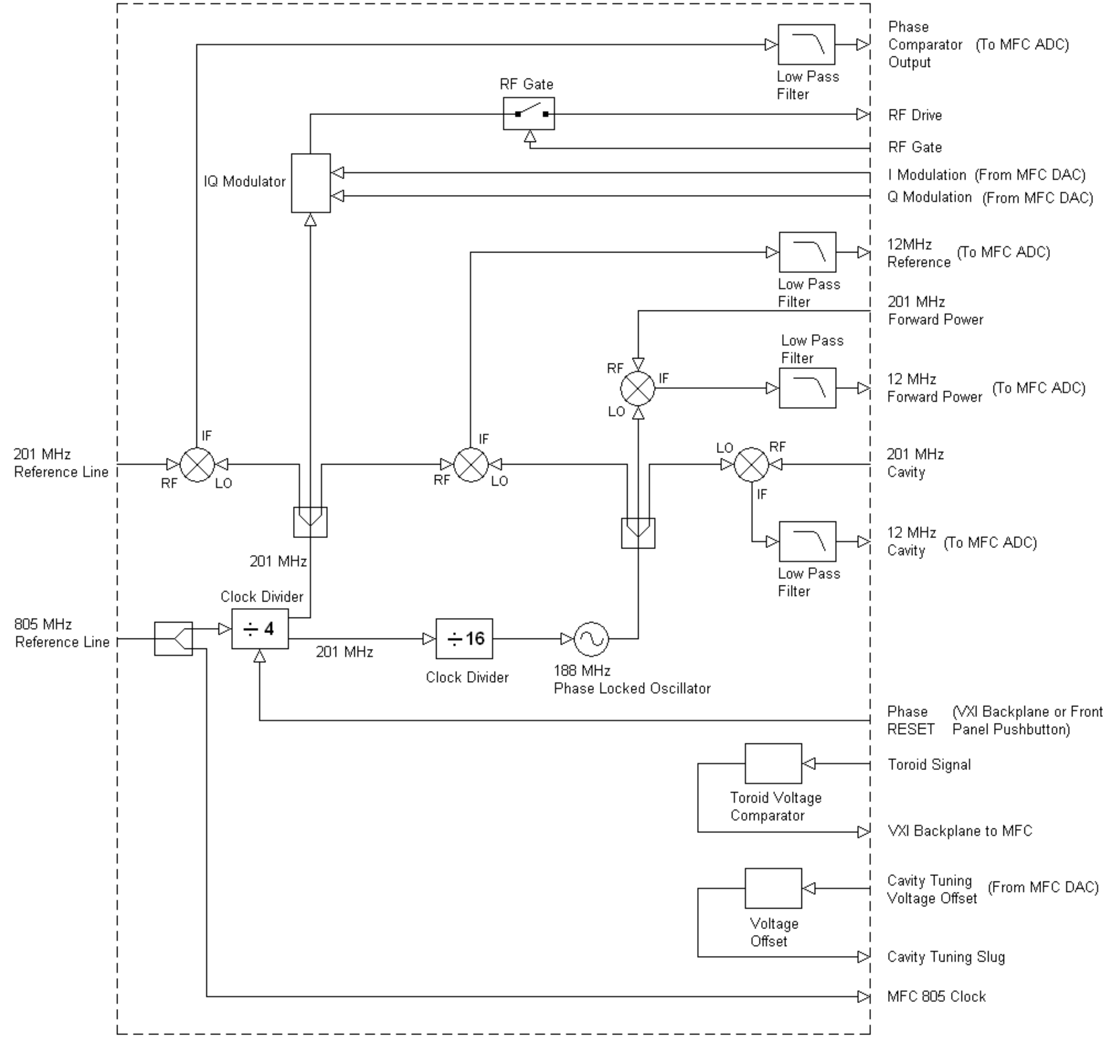
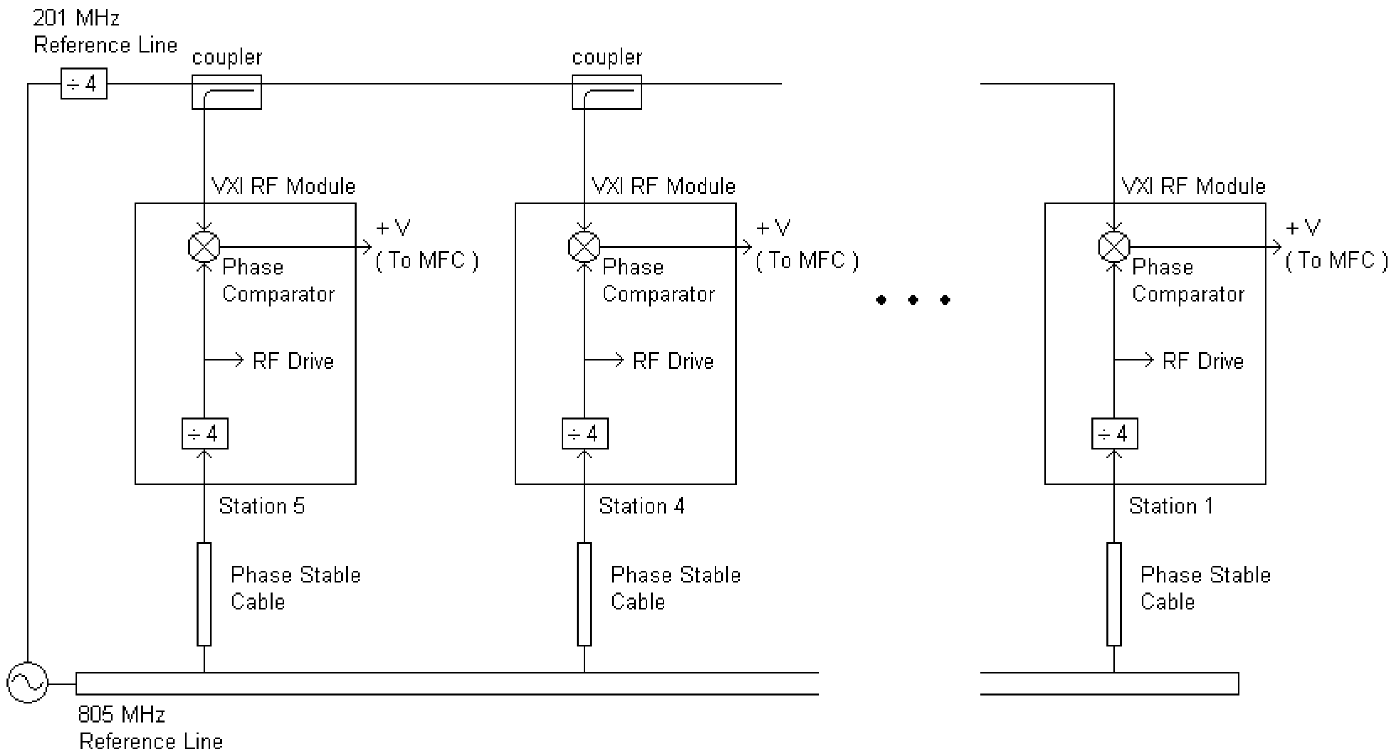
VXI RF Board

- RF module down converts RF signals to an intermediate frequency (IF) of 12.578 MHz for processing by the MFC module.
- The 805 MHz reference line and divides it by 4 to generate the 201.25 MHz at each accelerating cavity.
- This 201.25 MHz signal provides the RF drive for the cavity.
- In-phase/quadrature (IQ) modulator on board allows vector control of the magnitude and phase of the RF drive.
- Preforms other analog tasks
    - RF gating
    - Clock division
    - phase comparison



LLRF Phase Stable Cabling

- Uses the 805 MHz reference line in the new LLRF system is to provide an independent, phase stable RF drive for each accelerating cavity
- This new system allows the phase of each cavity to be adjusted independently.
- LLRF system uses phase matched, phase stabilized 3/8" Heliax cable or equal lengths and following the same rout for each LLRF station.



Conclusion

- This new LLRF design was prototyped and installed at the final LE Linac RF Station.
- After extensive fine tuning on phase and amplitude control parameters, the design goals of the Proton Plan where exceeded, with amplitude variations < 0.2% and beam setting time < 2 us.
- System has been in operation for over 5 years and has worked successfully, reducing losses and keeping the phase stable with respect to the reference line