Status of the ALS and APEX RF Systems at LBNL

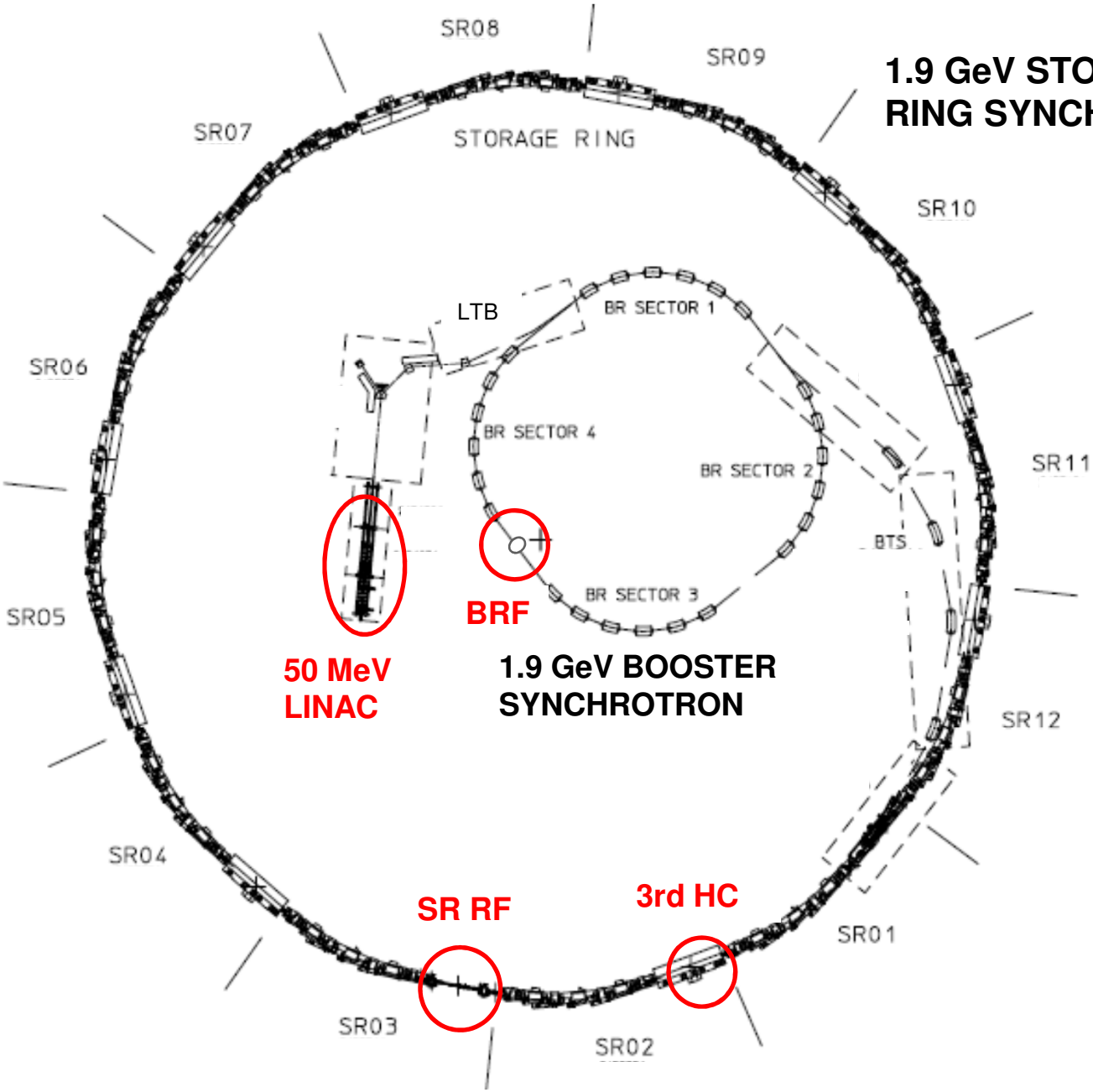
RF Group: K. Baptiste, S. Kwiatkowski (retired), Q. Du, M. Vinco, J. Julian (retired)

ME Group: P. McKean (retired), G. Harris

Scope

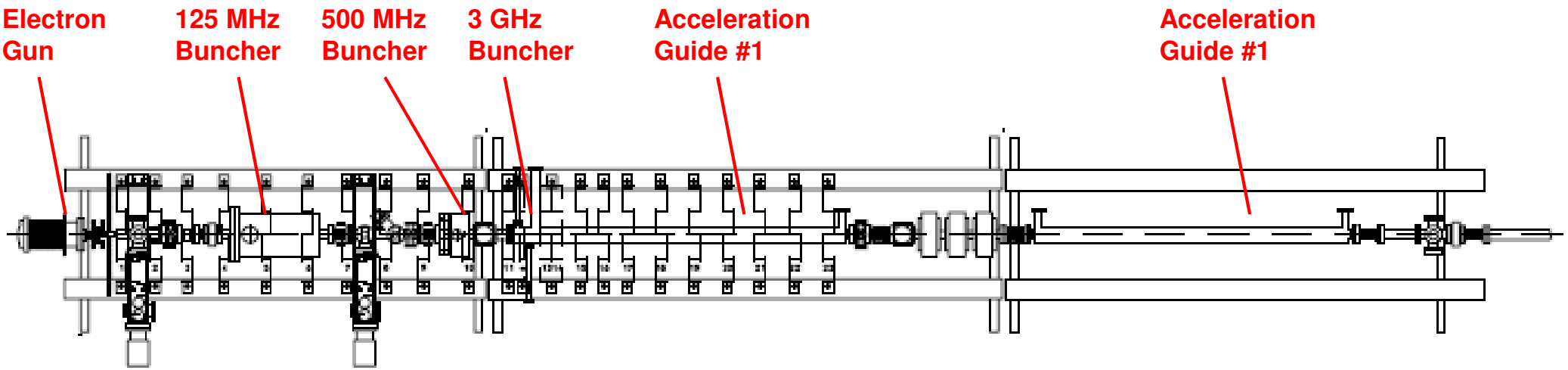
- ALS RF Systems
  - Injection System
    - Electron Gun (125 MHz)
    - GTL Sub-Harmonic Bunchers (125 MHz & 500 MHz)
    - S-Band Linac Modulators (2.998GHz)
    - Booster RF System (500 MHz)
  - Storage Ring
    - Storage Ring RF System (500 MHz)
    - SRRF Reliability
    - 3rd Harmonic Cavities
- APEX RF Systems
  - VHF Photo-Cathode Gun
  - L-Band Buncher
  - L-Band Linac Modulator

ALS's RF Systems

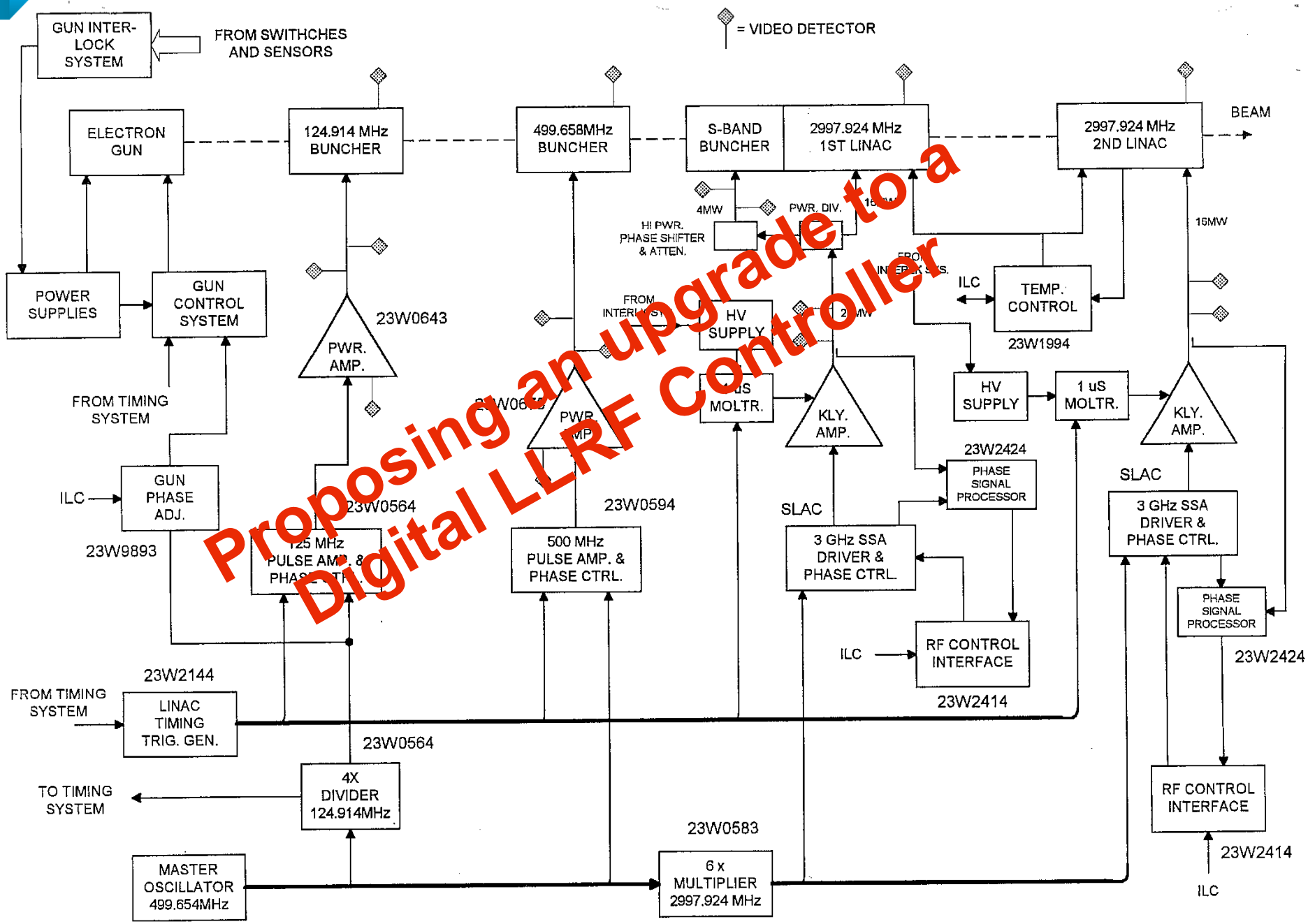


1.9 GeV STORAGE RING SYNCHROTRON

Injection System – Electron Gun & Linac



Gun thru 3 GHz LINAC RF System

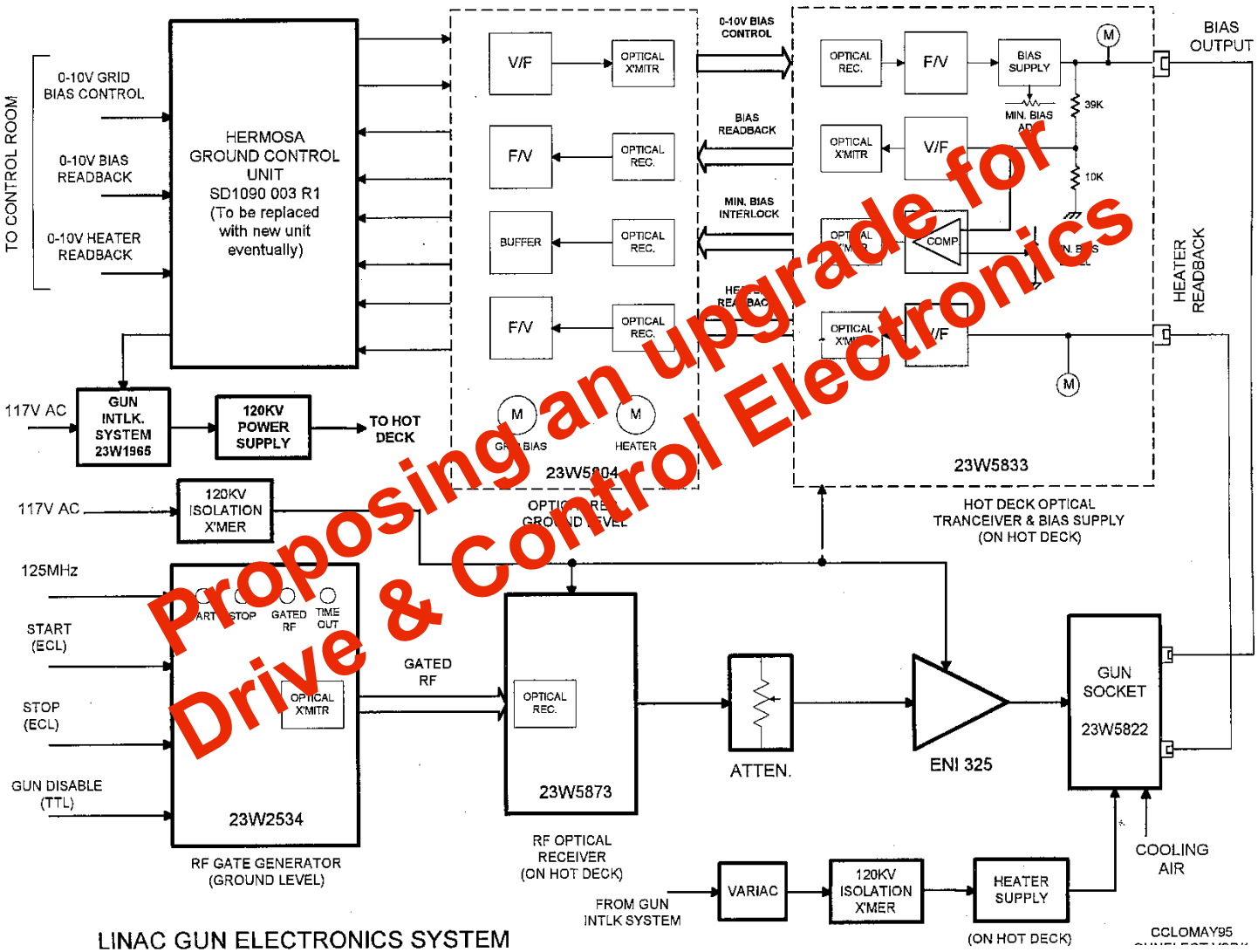


Proposing an upgrade to a Digital LLRF Controller

E. Gun Electronics Rack & Block Diagram

E. Gun Rack (LI01)

In Service: 1989

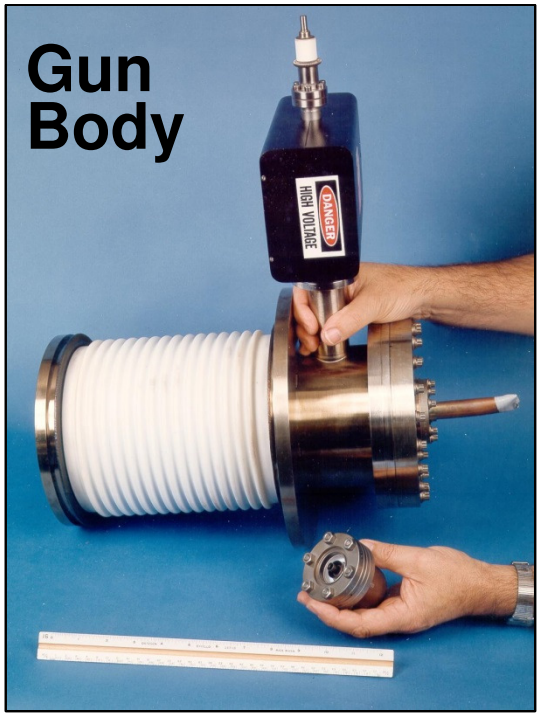


Proposing an upgrade for Drive & Control Electronics

Block Diagram

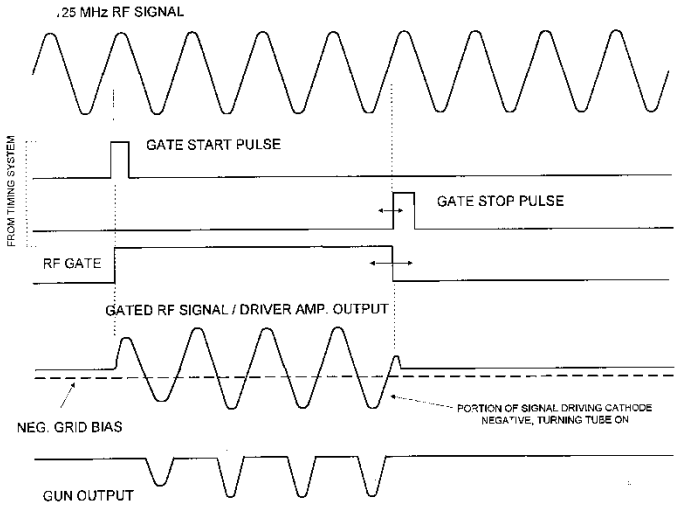
E. Gun Hot Deck, Gun Body & Cathode

Gun Electr. Cart, Hot Deck



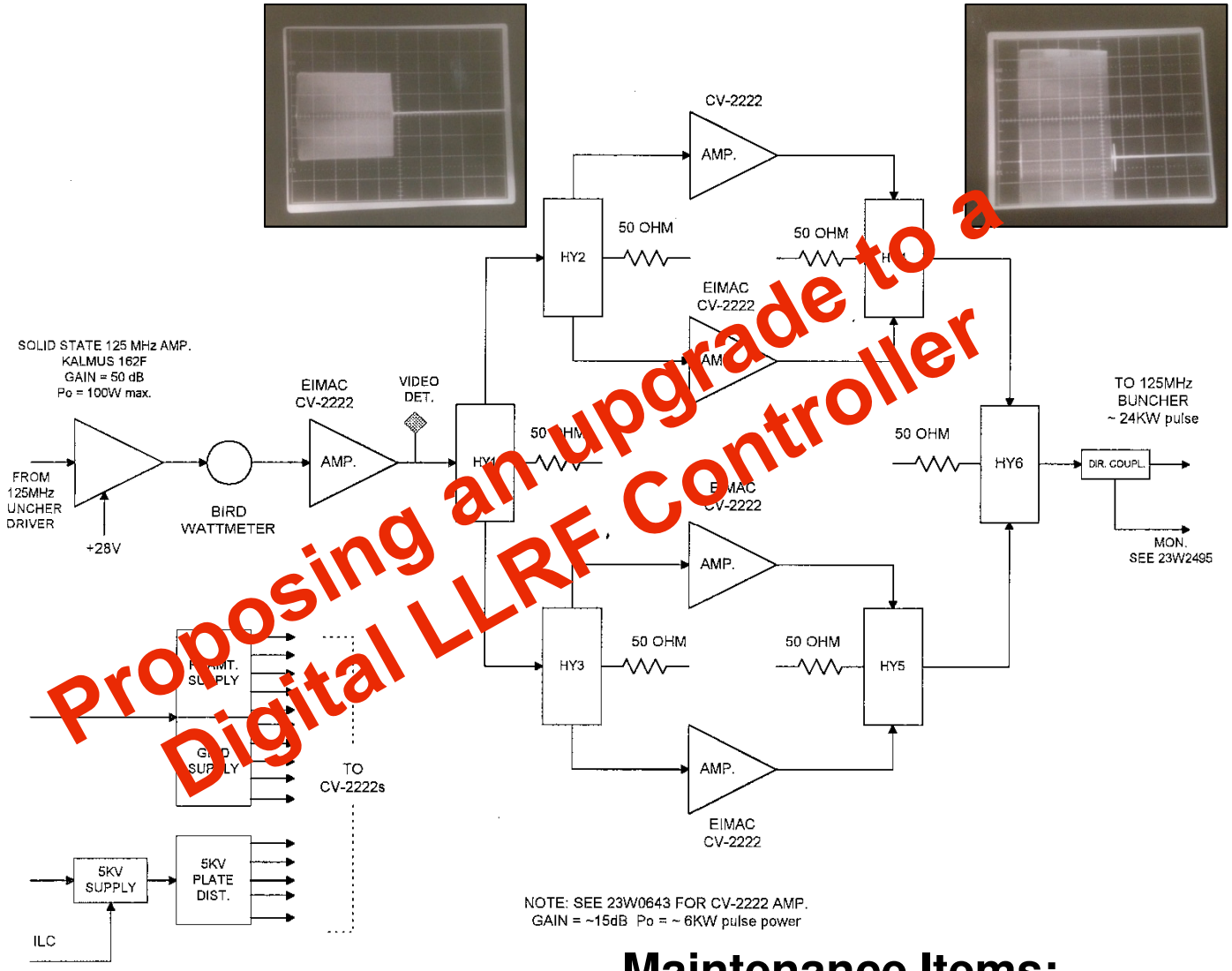
Cathode Eimac YU-171

Cathode Lifetime: ~4 yrs



Gun Pulse Generation

125 MHz & 500 MHz Sub-Harmonic Bunchers



Proposing an upgrade to a Digital LLRF Controller

In Service: 1989

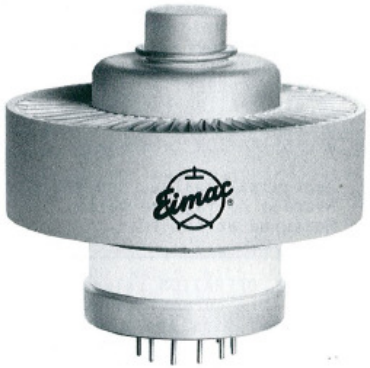
Maintenance Items:

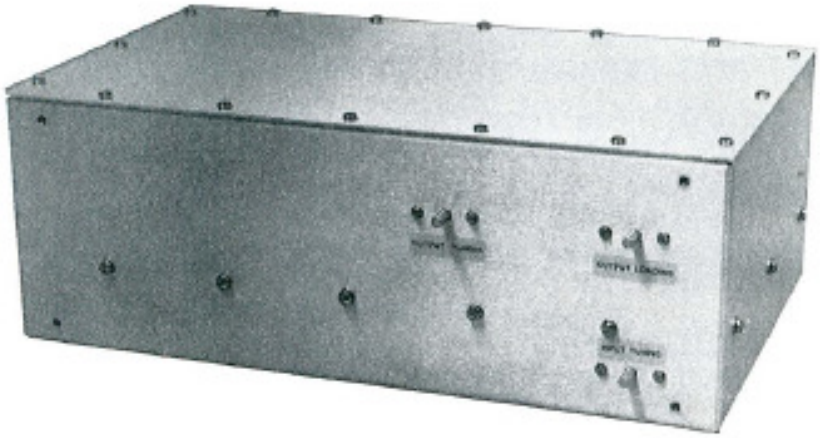
- **Amplifier Air Cooling**
- **SS Drive amplifier**
- **HVPS**

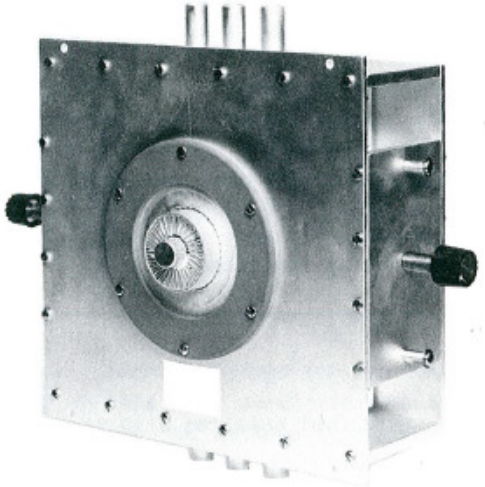
Sub-Harmonic Buncher Amplifiers

125 MHz Cavity Amplifier

500 MHz Cavity Amplifier





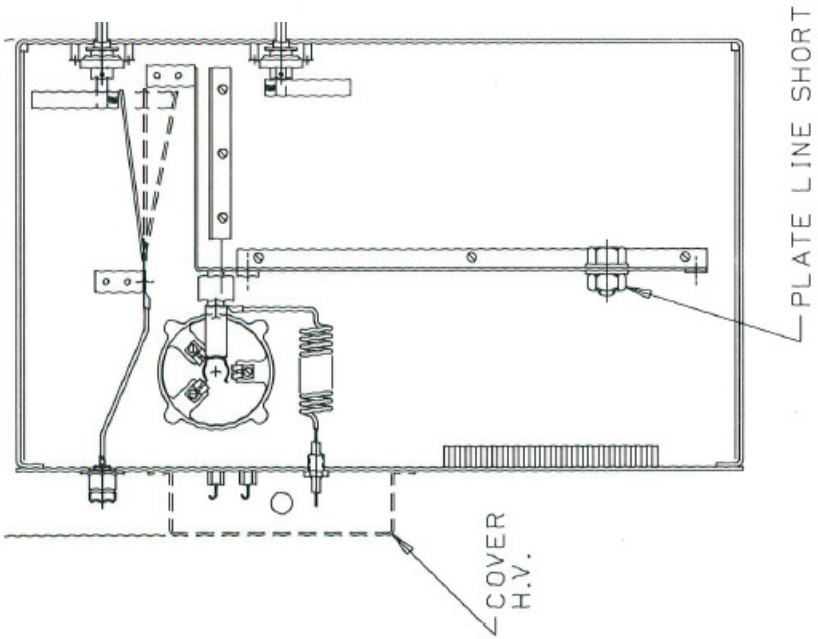


Eimac 3CPX800A7

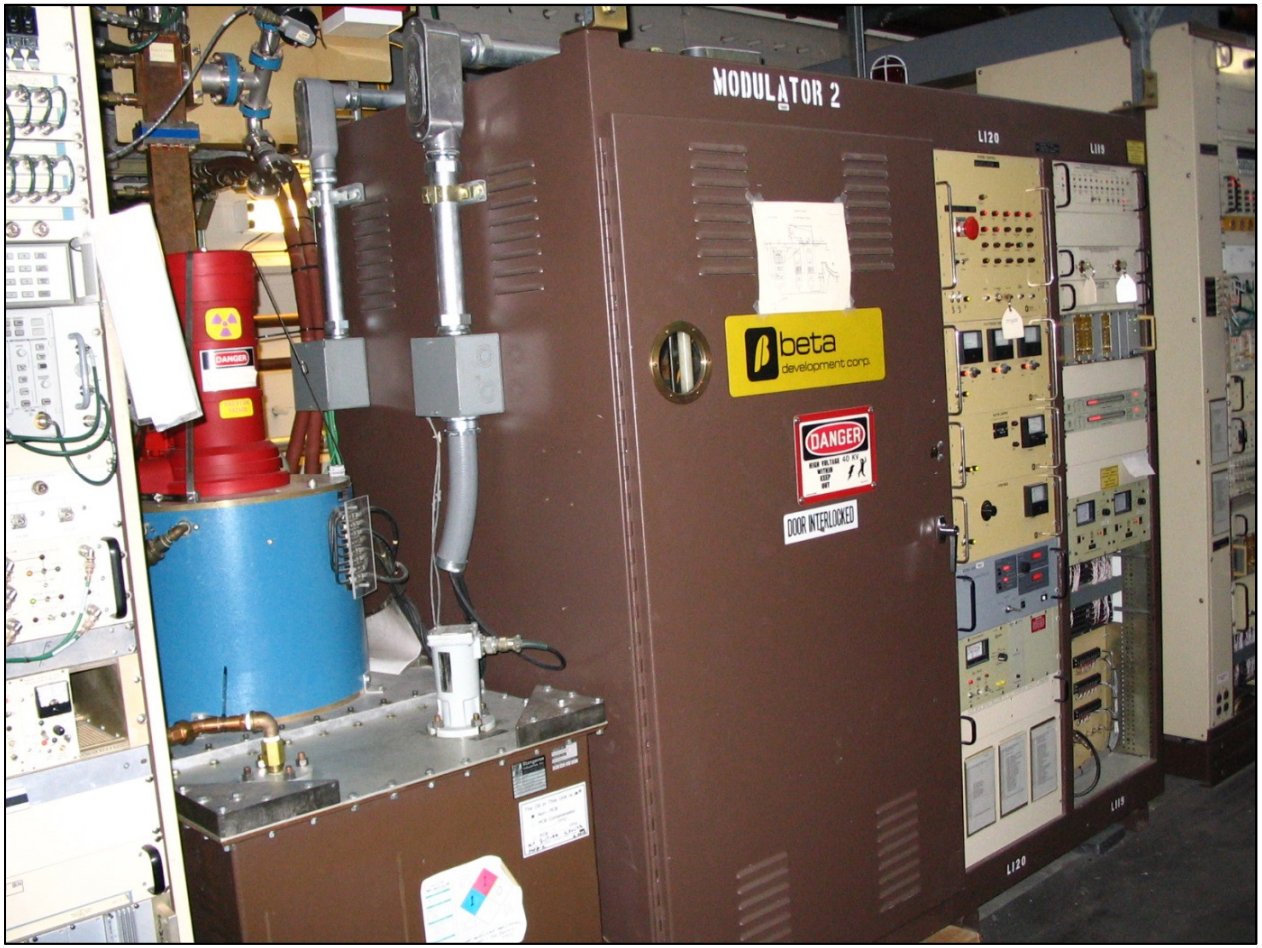
Eimac CV-2222

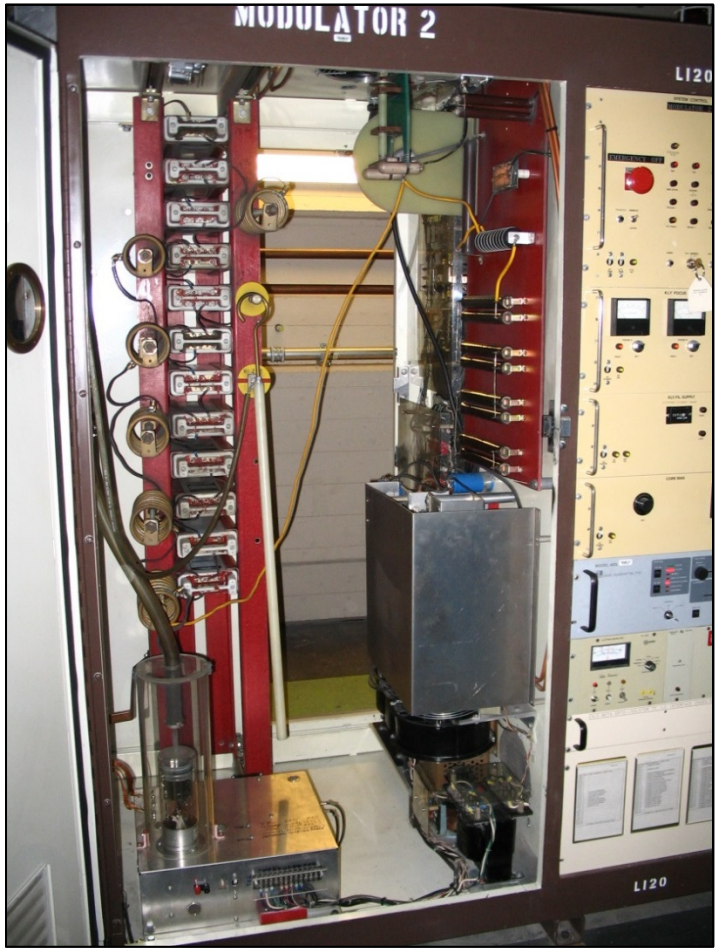
Eimac CV-2404

Triode
Gain = 15dB
Up to 20kW Pulse, 6 kW
In service: 1989
Lifetime: 10-25 yrs
Cost: $1550 ea



LINAC PFN Modulators





Thales TV-2002 DoD: 24MW, 2us, 1 Hz
Lifetime: Mod #1: 17 yrs, 10 yrs, 2+ mo
Mod #2: 9 yrs, 14 yrs, 2 yr, 2+ yrs

In Service: 1989

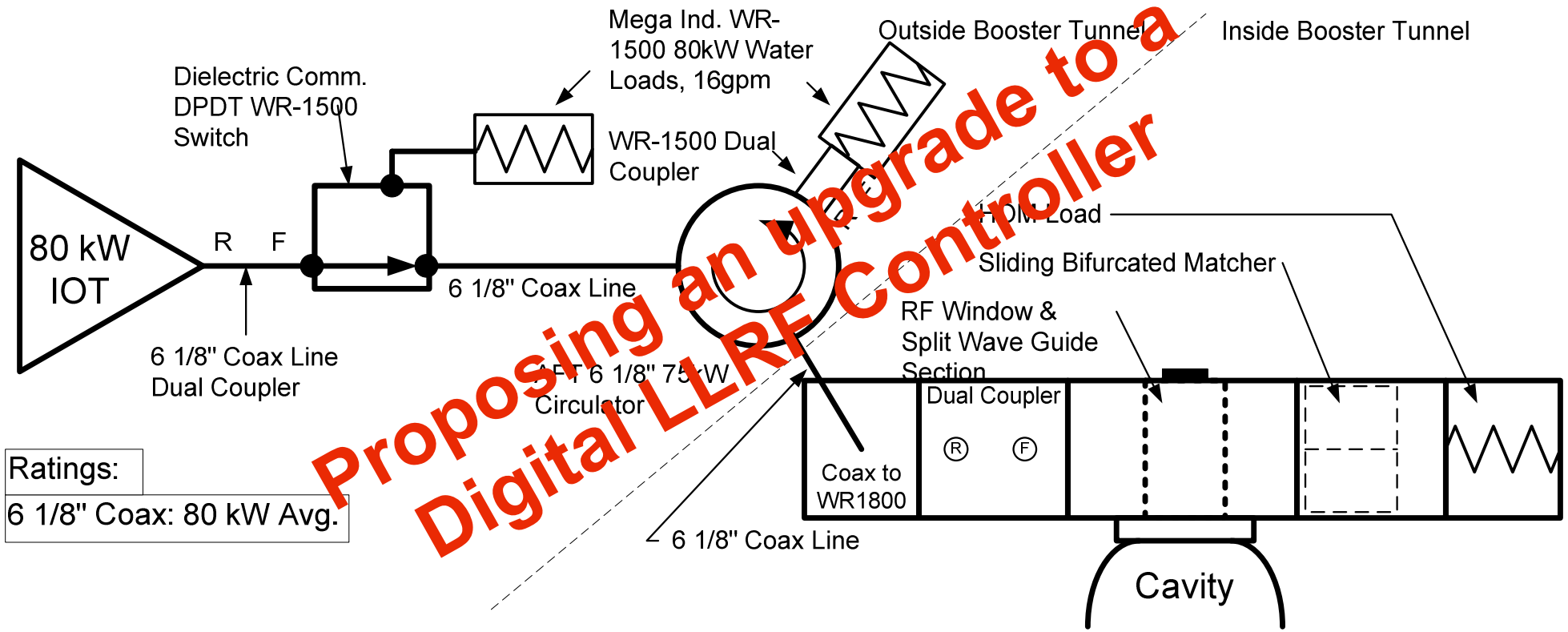
Low Gain Klystrons

Failures:
- **Thyratron CX-1666**
- **HV Caps**
- **HVPS & Cable**
- **Focus PS & Magnets**

Booster Ring RF Parameters for 1.9 GeV

	Present
Beam current	4 mA
Dipoles Radiation	< 5 kW
Cavity Dissipation	43 kW
W.G. & other losses	< 6 kW
Total RF Power Reqr'd	54 kW
Total RF Power Installed	80 kW

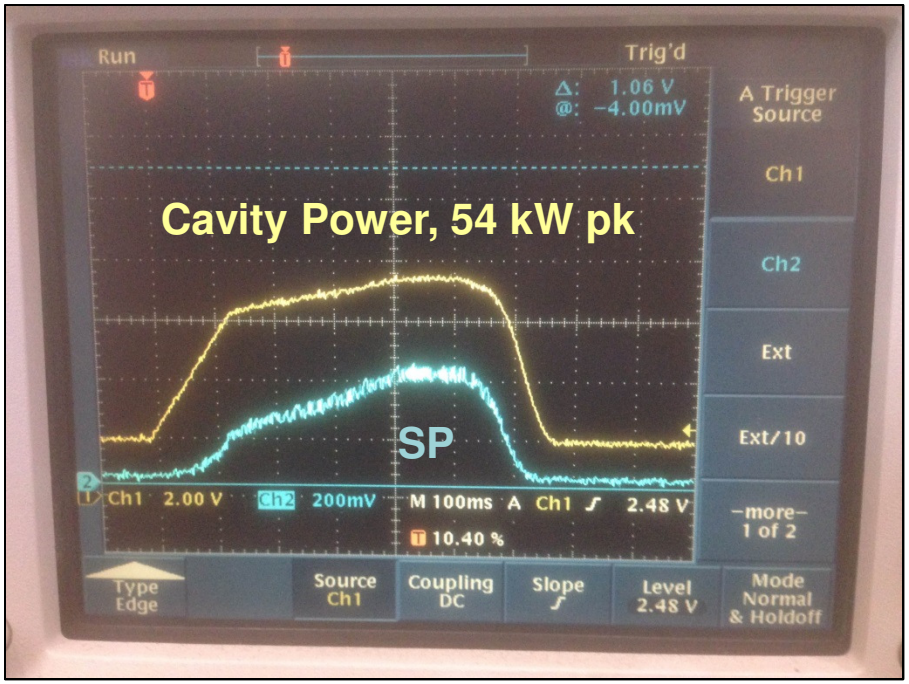
Booster Ring RF System



Proposing an upgrade to a Digital LLRF Controller

Booster Ring RF Amplifier

Commercial IOT Based Broadcast TV Transmitter (modified)



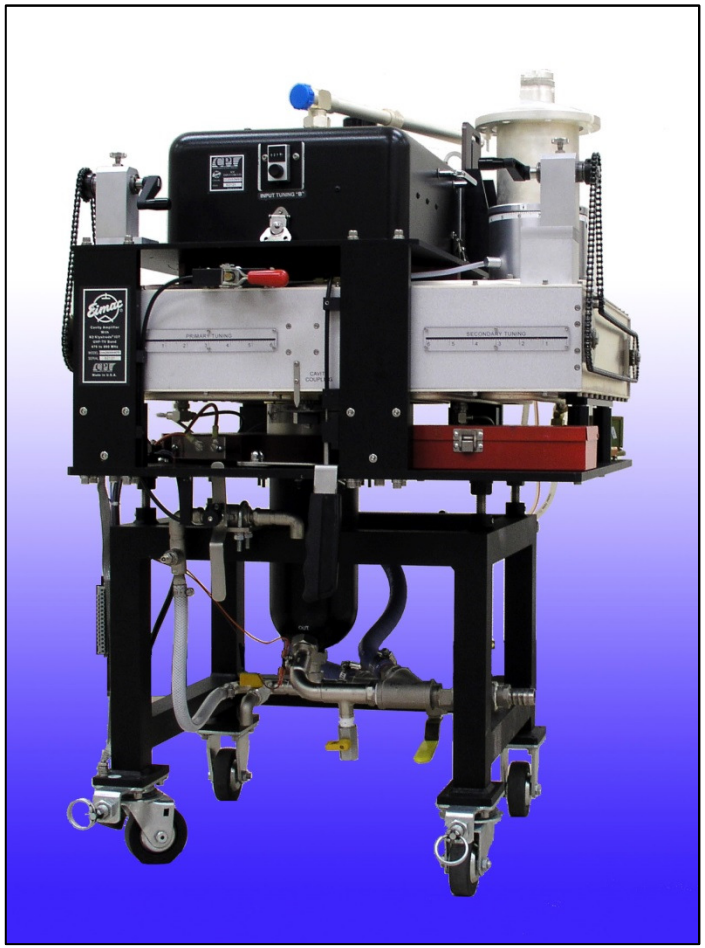
Failures:

- **Grid Bias PS**
- **HV Cable which led to an IOT failure**
- **HV Isolation Transformer**
- **Thyratron**

In Service: 2006

IOT Amplifier

CPI CHK2800W
Tuning Range: 473-750 MHz



CPI K2H80W
470-860 MHz

Specification:
80 kW CW
130 kW pk
Gain = > 23dB
Eff. > 65%

Operating Parameters

V_k = 32.1 kV
I_k = 2.8 A
Eff = 60.3%
Gain = 23.1 dB
RF Out = 54 kW pk

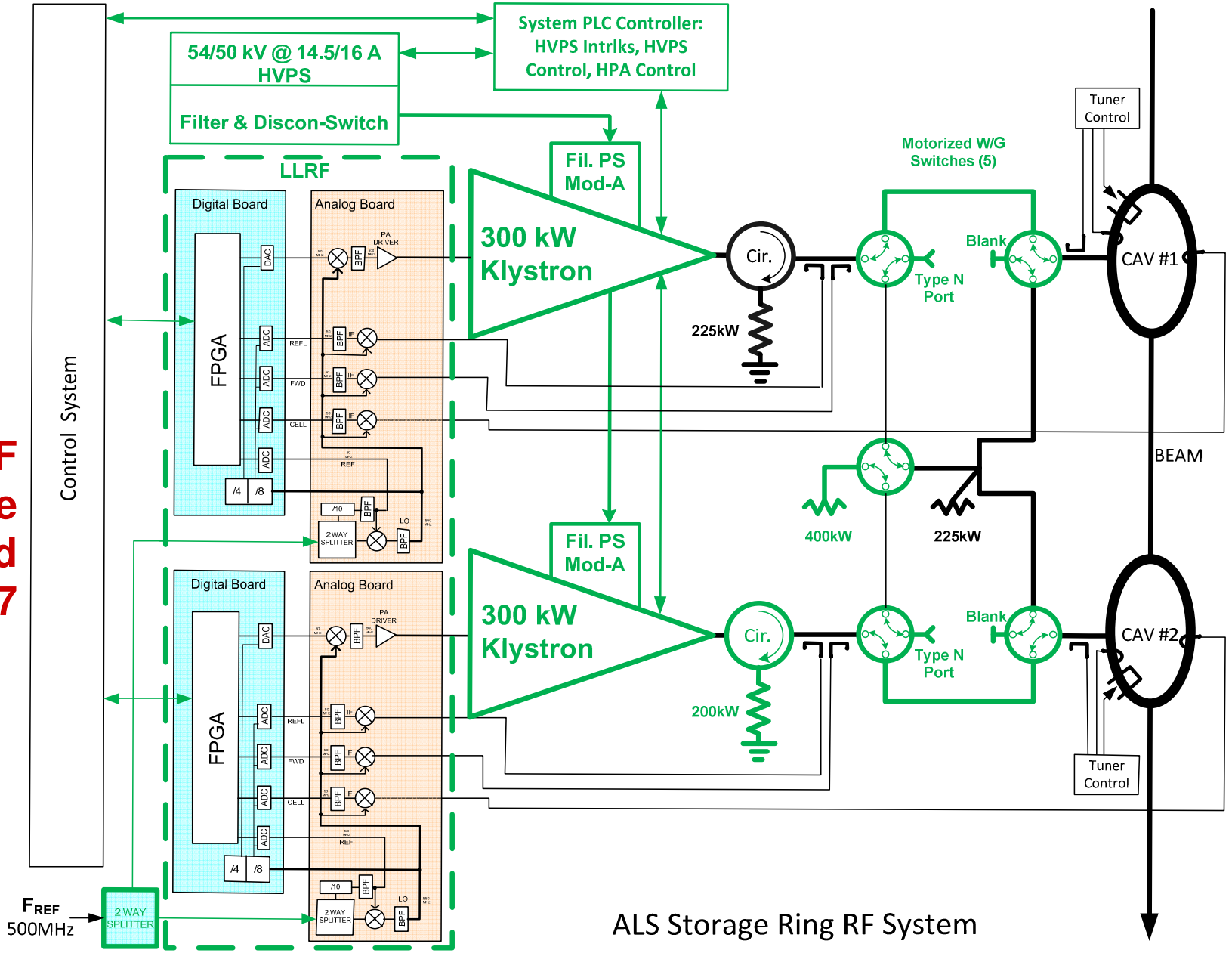
IOT #1: 3 yrs (18k hrs) Failed due to poisoned cathode from HV cable fault
IOT #2: 7+ yrs (+45k hrs)

SR Ring RF System Parameters for 1.9 GeV

	Present		Future	
Beam current (mA)	500		500	
Number of Insertion Devices	11		13	
Gap Positions	Nom	Min	Nom	Min
Dipoles Radiation (kW)	142	142	142	142
Insertion Device Radiation (kW)	25	46	46	55
Power Loss for 3rd HC (kW)	6	9	9	9
Cavity Dissipation (x2) (kW)	43	43/50	43/50	43/53
W.G. & other losses (kW)	7	8/10	8/10	10/12
Total RF Power Reqr'd (kW)	266	293/305	293/305	304/322
Total RF Power Installed (kW)	300	300	~360	~360
Cav/Window Power Limit (kW)	330		330	

Upgraded SR RF System

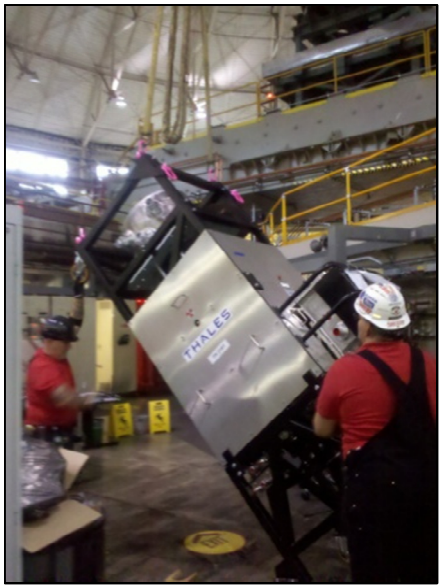
DLLRF to be installed Jan-2017



ALS Storage Ring RF System

Upgrade Sequence

Phase I



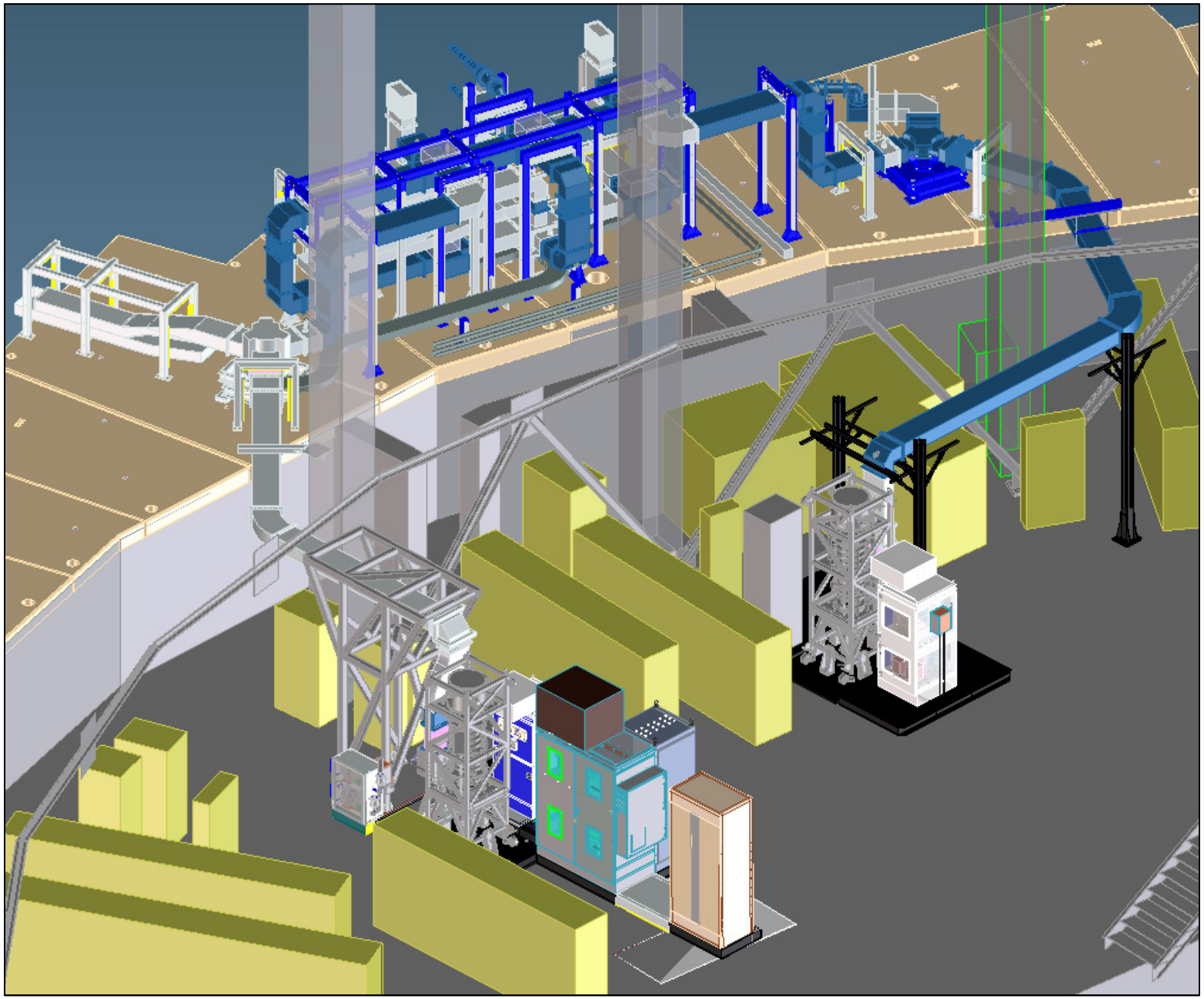
Establish New Klystron Site #2

Phase II

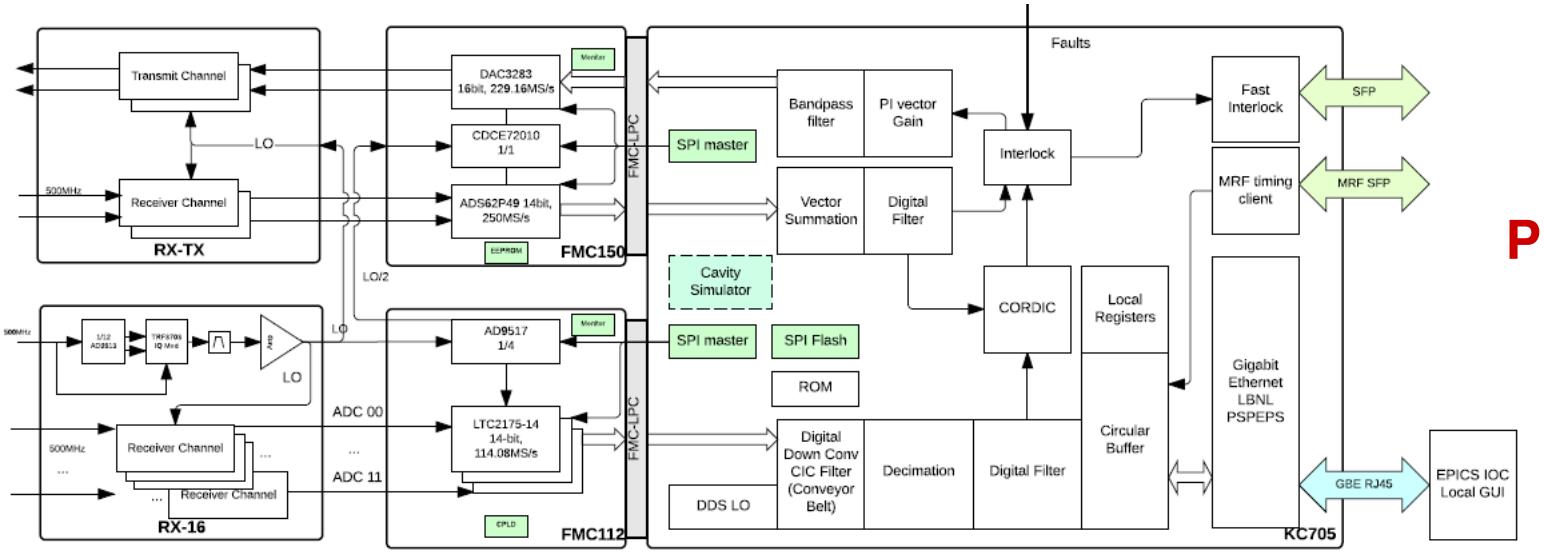
Upgrade HVDC PS, Replace Crowbar with HV Dis-Conn SW, New Klstron in Site #1

Waveguide Switch Matrix

Phase IIIa

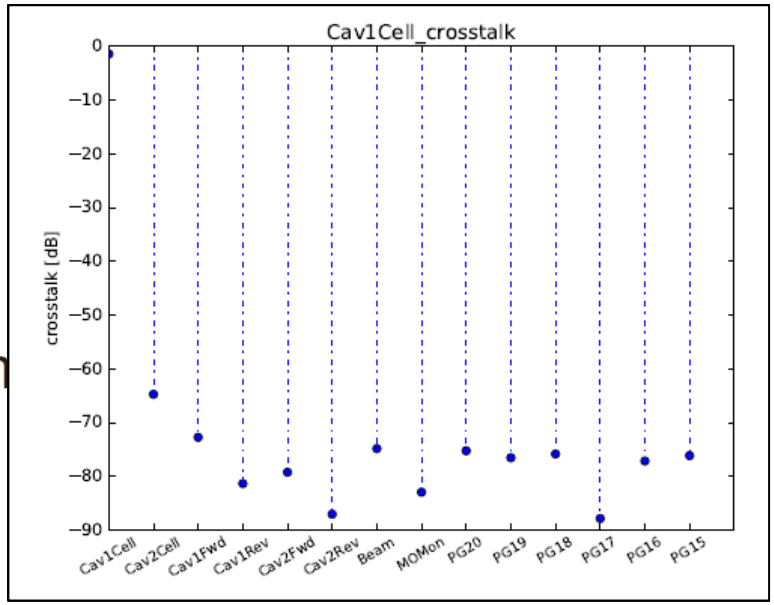


Digital LLRF & Controls



Phase IIIb, Jan 2017

- Commercial FPGA carrier and digitizer
  - Xilinx KC705 + 4DSP FMC150 + 4DSP FMC112
- $F_{LO} = 11/12 F_{RF} = 458.33\,\text{MHz}$
- Compact analog frontends, channel isolation
- MRF timing, fast interlock



SR Klystron, Thales 2161L

Operational Hours

- Black Heat 4773
- Standby 29605
- HV 29126
- Transmit 27736

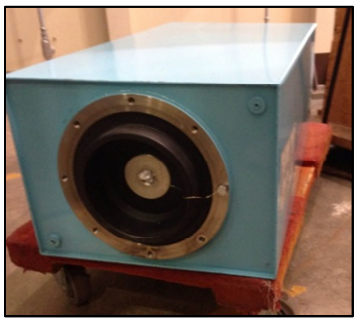
Klystron Operating Parameters

- V_k = -53.1 kV I_k = 9.55 A
- V_a = 32.8 kV I_a = 1.6 mA
- Eff = 51.53% Gain = 41.41 dB
- µP = 1.61 RF Output = 261.7 kW

In Service: 2012

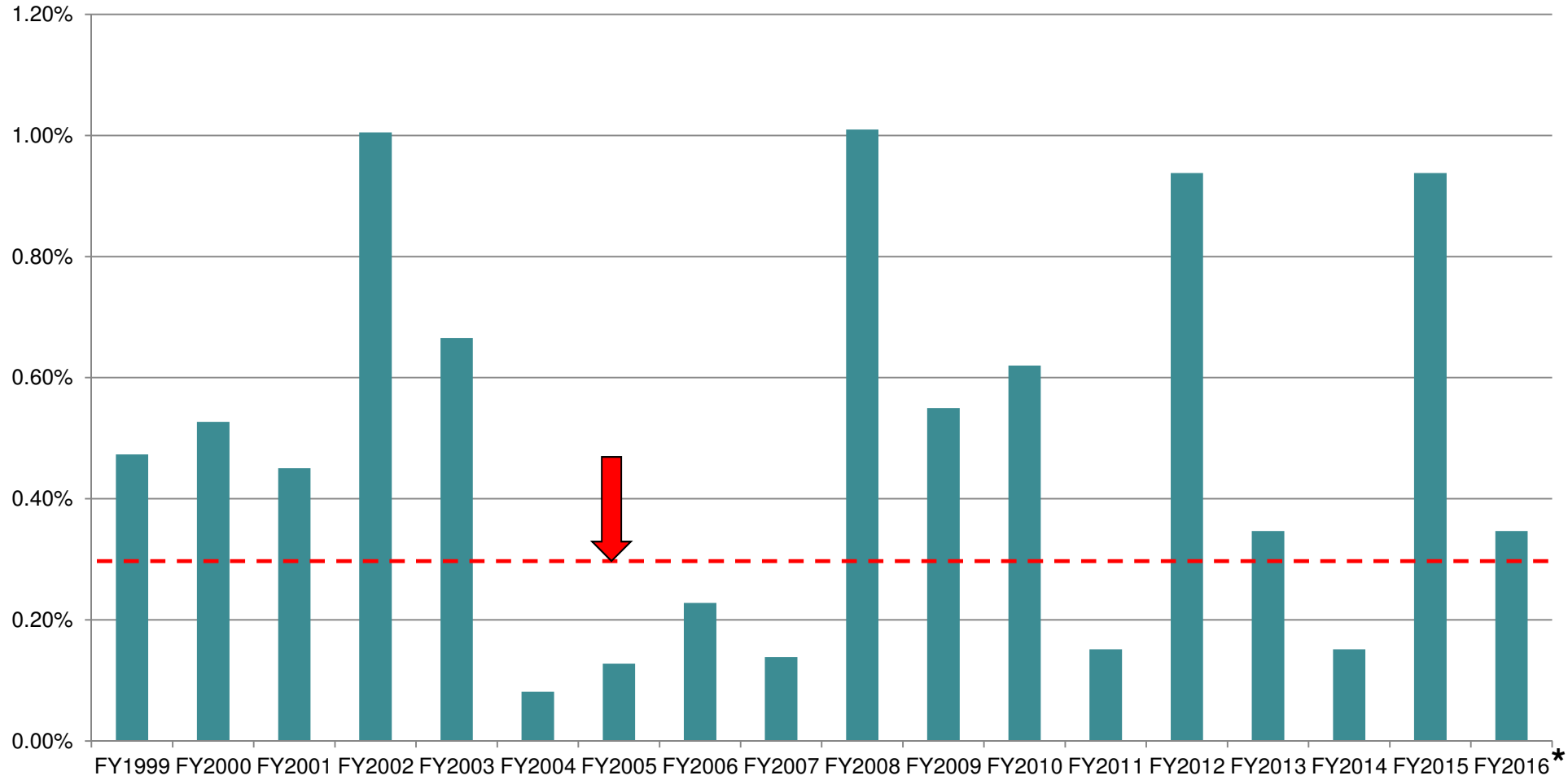
Failures:

- Mod-Anode PS
- PLC SP zeroing
- Filter Capacitor



SR RF Reliability

Percentage of Scheduled Beam Time Lost to SRRF & Non-Latching Faults by Fiscal Year

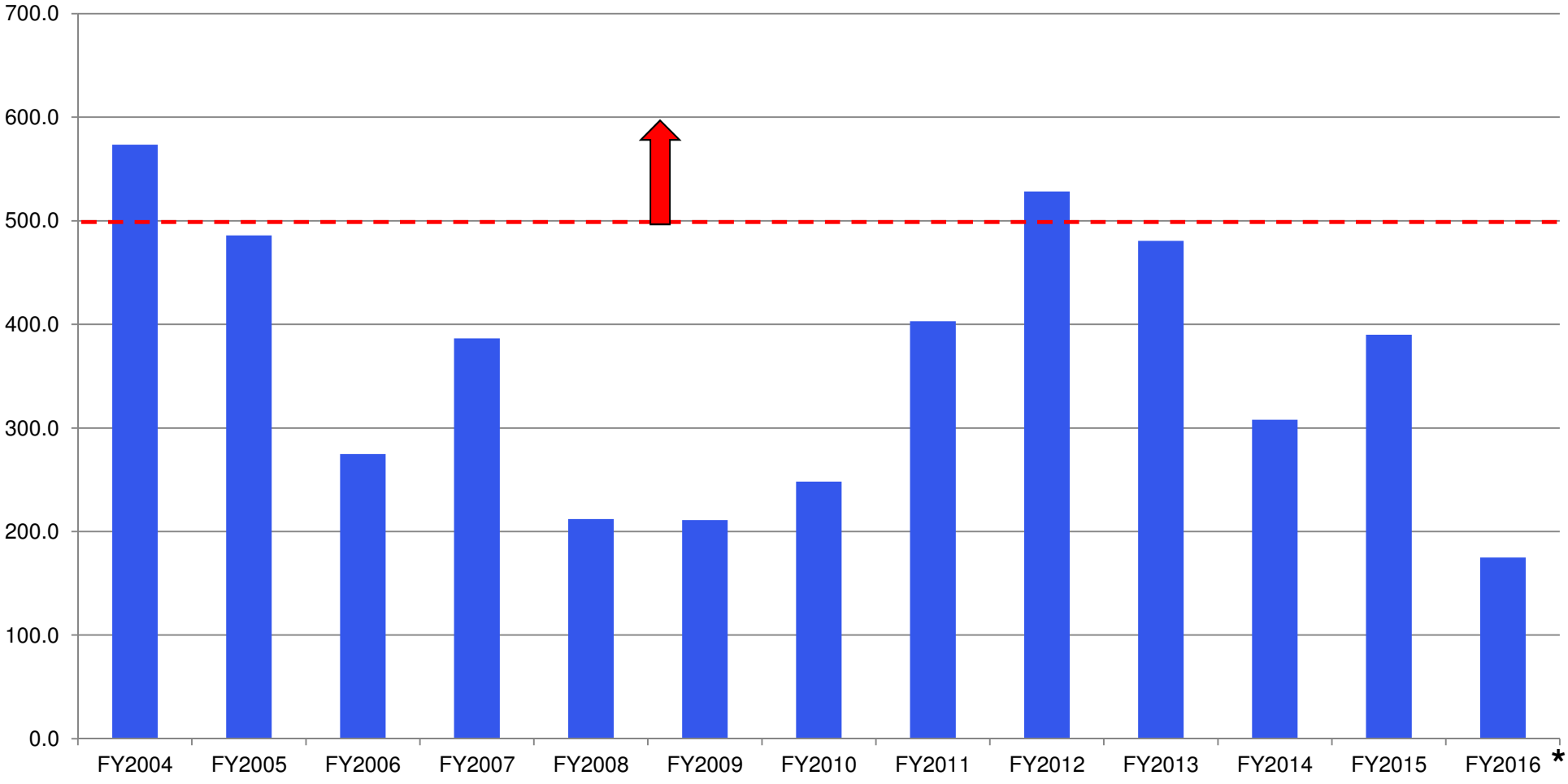


* Data for partial year

Goal for SRRF system based on 5000 hours of User Beam time: 0.3%

SRRF Reliabilty

SRRF Faults, MTBF (in hours): Mean time between faults, FY2004 - FY2016*

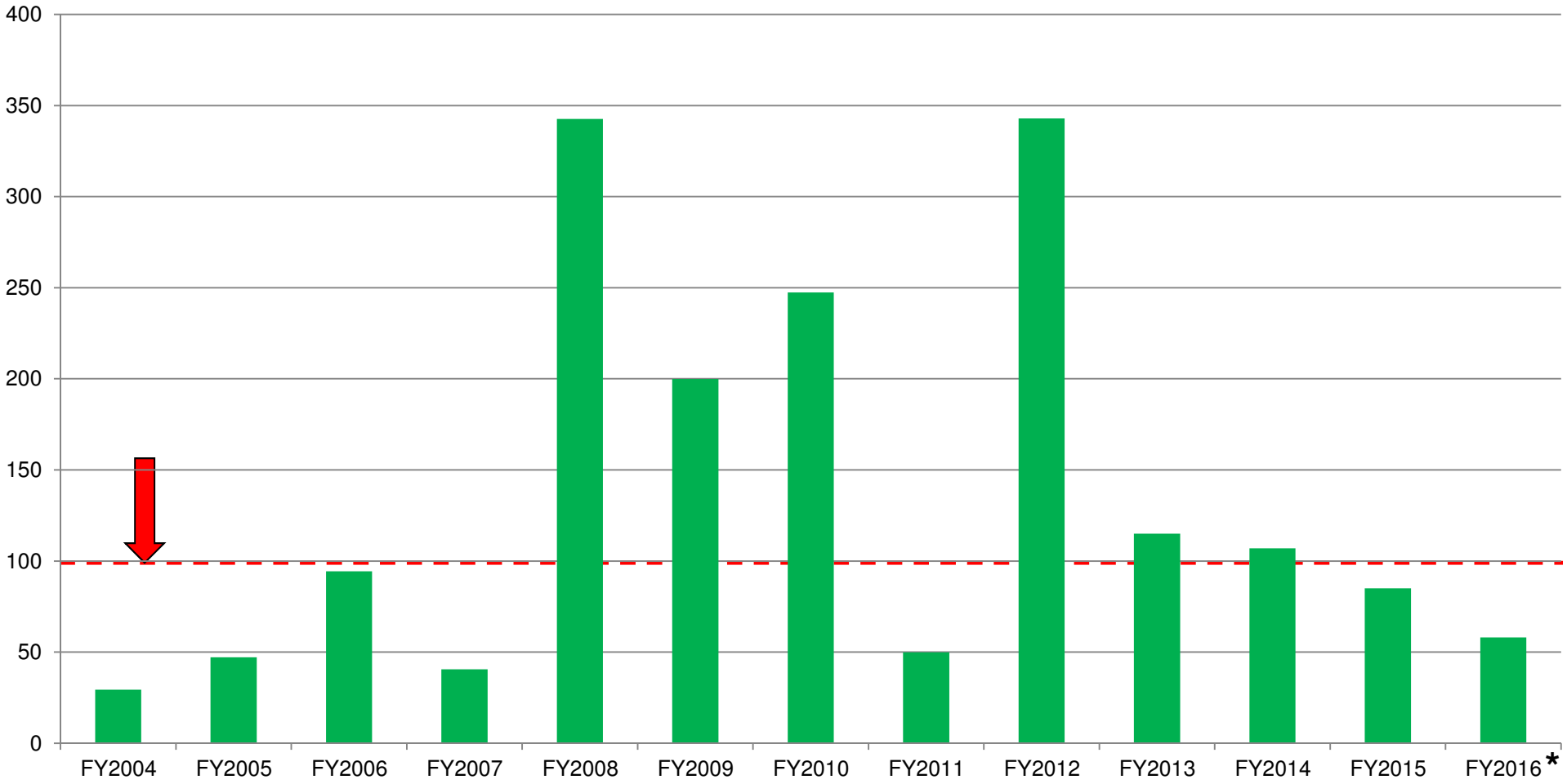


*** Data for partial year**

Goal for SRRF system based on 5000 hours of User Beam time: 500 hrs

SR RF Reliability

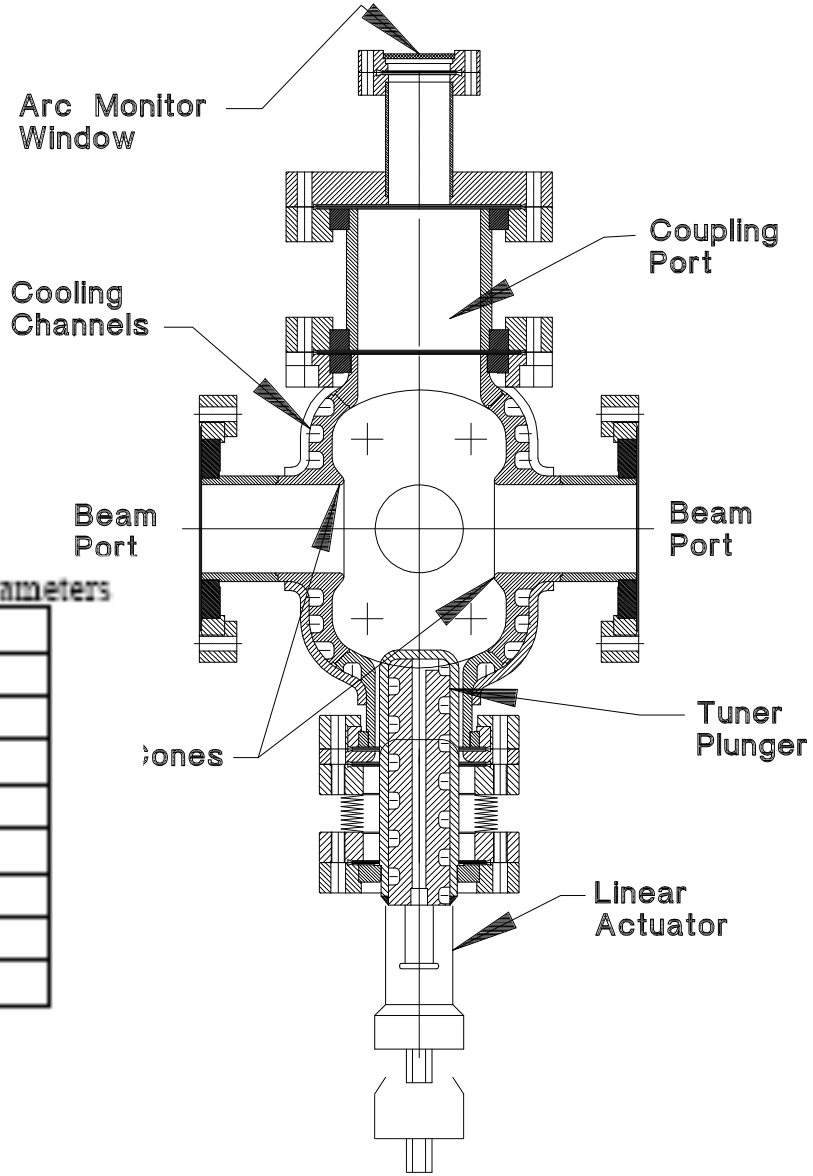
SRRF Faults, MTTR (in minutes): Mean time to recovery, FY2004 - FY2016*



*** Data for partial year**

Goal for SRRF system based on 5000 hours of User Beam time: 1.5 hrs

3rd Harmonic Cavities (passive)



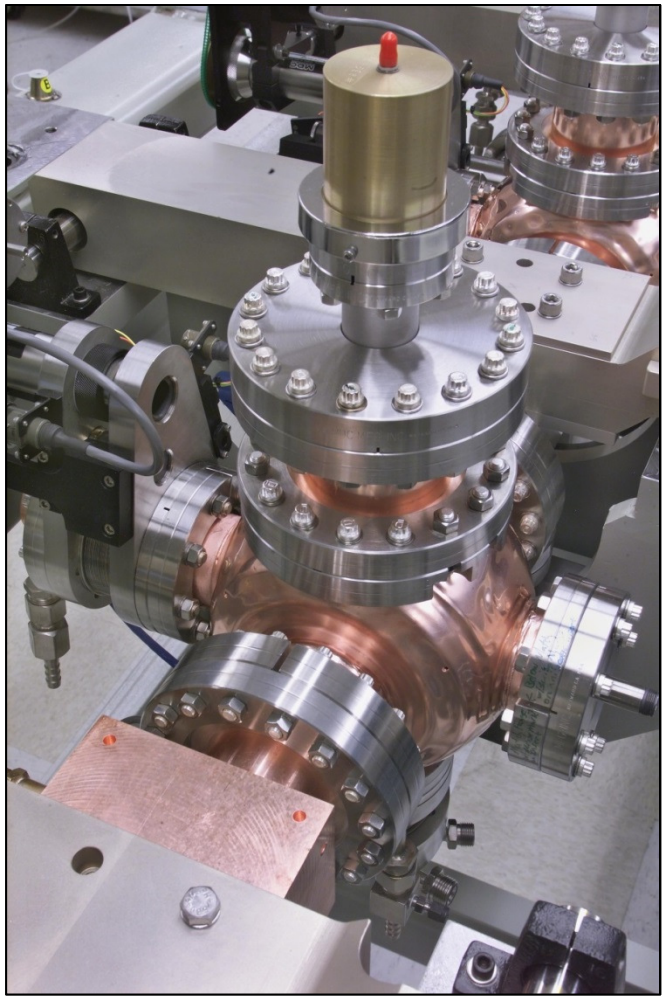


Table 1: Harmonic cavity system parameters

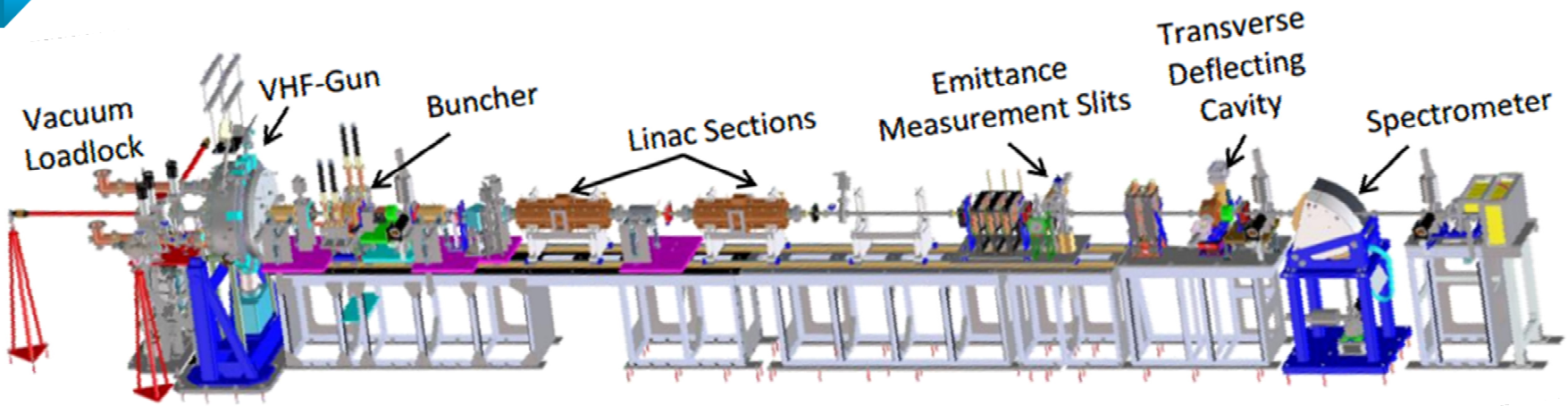
Frequency	1.5 GHz
total voltage	500 kV
bore diameter	5 cm
cavity R/Q*	80.4
calc. Q	27677
calc. Rs	2.23 MΩ
Rs x 70%	1.56 MΩ
number of cells	4
power per cell	5.01 kW

*$R=V^2/2P$

Failures:

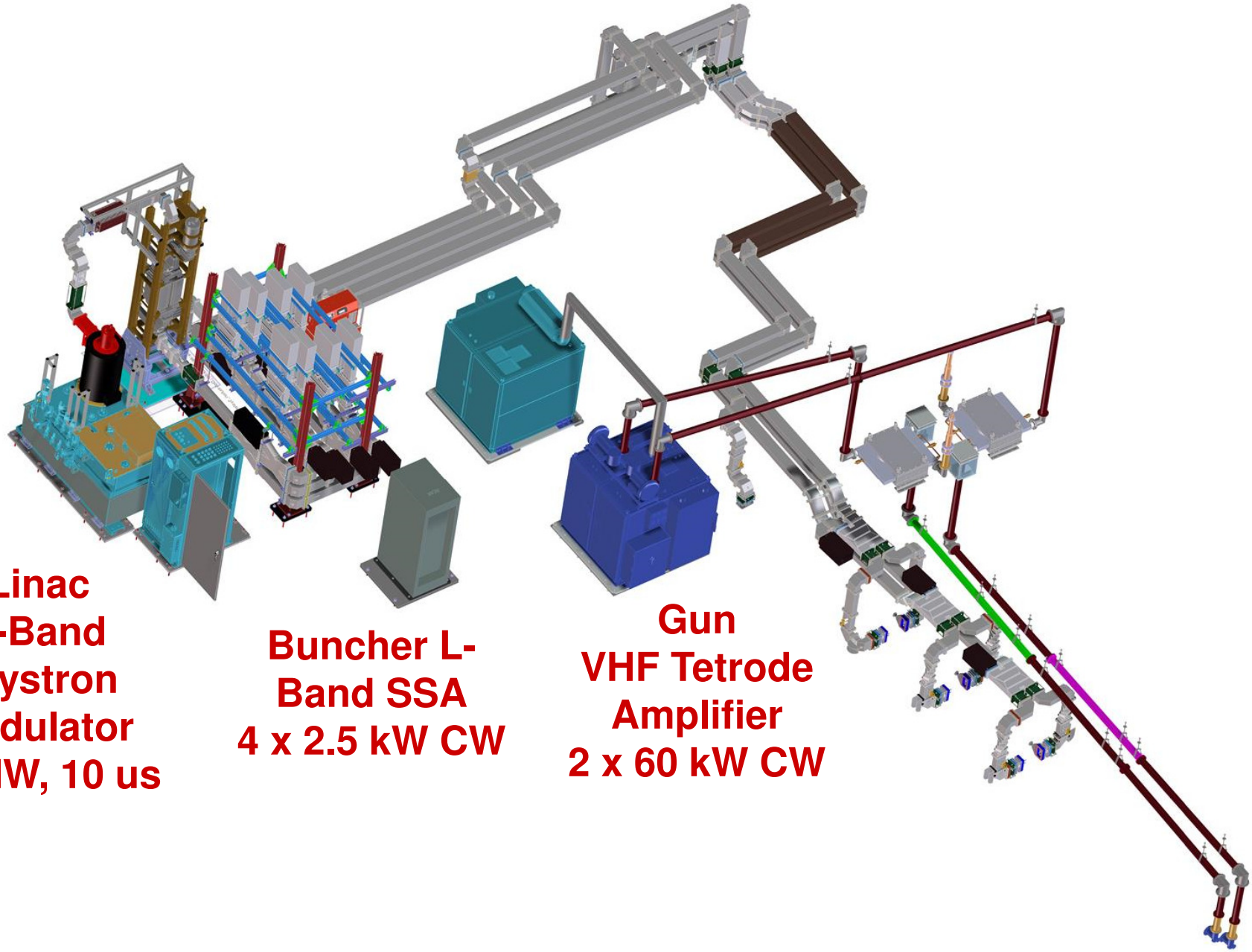
- **Vacuum Feedthru**

APEX RF (Advanced Photocathode Experiment)



Repetition rate	Up to ~ 1 MHz	
Charge per bunch	~ 10 – 300 pC	Different modes of operation
Normalized emittance	~ 0.2 – 0.6 μm	Lower value for lower charge
Beam energy at the gun exit	>~ 500 keV	For controlling space charge
Cathode electric field at photoemission	>~ 10 MV/m	Space charge limit; maximum brightness limit
Bunch length and shape control	From < 1 to ~ 60 ps	Space charge control; different modes of operation
Cathode/gun area magnetic field compatibility		Emittance compensation; (exotic modes)
Dark current at nominal gun energy	< ~ 1 μA	SRF quencing; rad. damage
Operational vacuum pressure	~10^{-10} –10^{-9} Torr	High QE cathode lifetime
Loadlock cathode vacuum system		"Quick" cathode exchange
Reliability	High (>~98%)	Required for an user facility

APEX RF Systems



Linac
L-Band
Klystron
Modulator
25 MW, 10 us

Buncher L-Band SSA
4 x 2.5 kW CW

Gun
VHF Tetrode
Amplifier
2 x 60 kW CW

APEX Gun RF Tetrode Amplifier System

Operational Hours

	Tube #1	Tube #2
• Black Heat	30027	29895
• Standby	7348	7300
• HV	5007	4957
• Transmit	4910	4867

Proposing to build a SSA version of this system for the LCLS II ptoject

Tetrode TH 571B Parameters

- V_a = 9.7 kV I_a = 7.47 A
- V_s = 692 V I_s = 165 mA
- V_g = -140 V I_g = 10 mA
- Eff = 62.5% RF Out = 45 kW

Failures:

- Filament PS
- SSA Drive Amp Fan Control
- SSA Drive Amp PS Fail Intrlk
- SSA Drive Amp Pre-Amp
- SSA Drive Amp Output Module
- HV Current Limiting Resistors

HPA

HVPS

In Service: 2011

APEX Buncher SSA RF Amplifier

Operation:
- 2.0 kW
- ~200 hrs

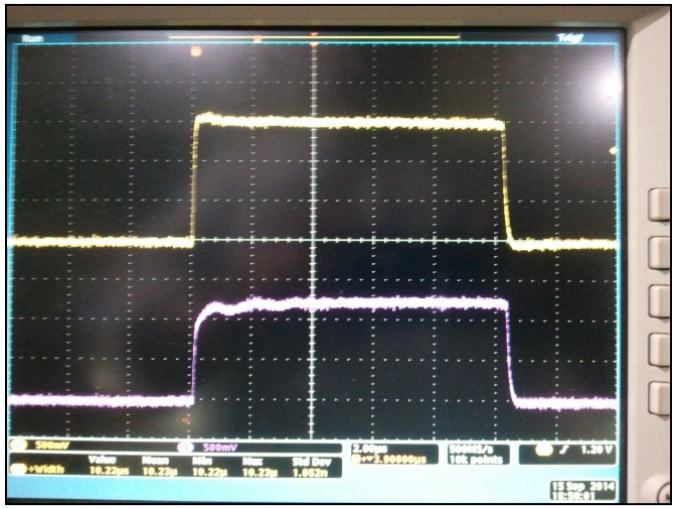
Parameters:
- 1.3 GHz
- 2.5 kW CW
- AB Linear

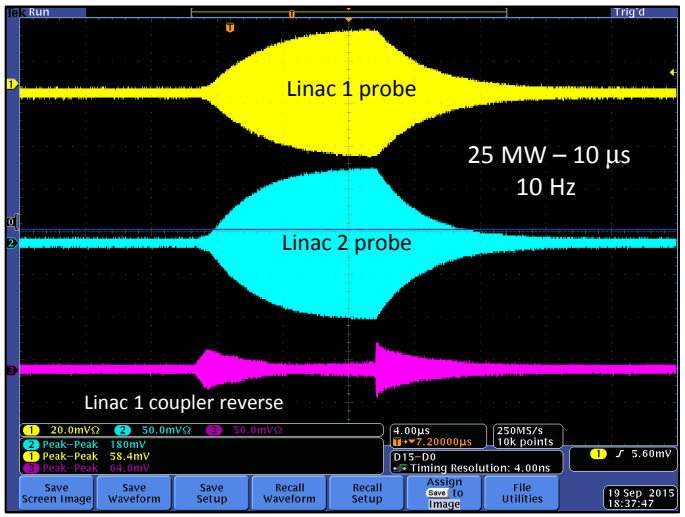
Failures:
- Logic card modification

In Service: 2015

APEX Linac RF System (Klystron and Modulator)

Solid State L-Band Modulator





Operation:

- 1-10 Hz
- 25 MW pk
- 250 W avg
- 10 us pulse
- ~300 hrs

Parameters:

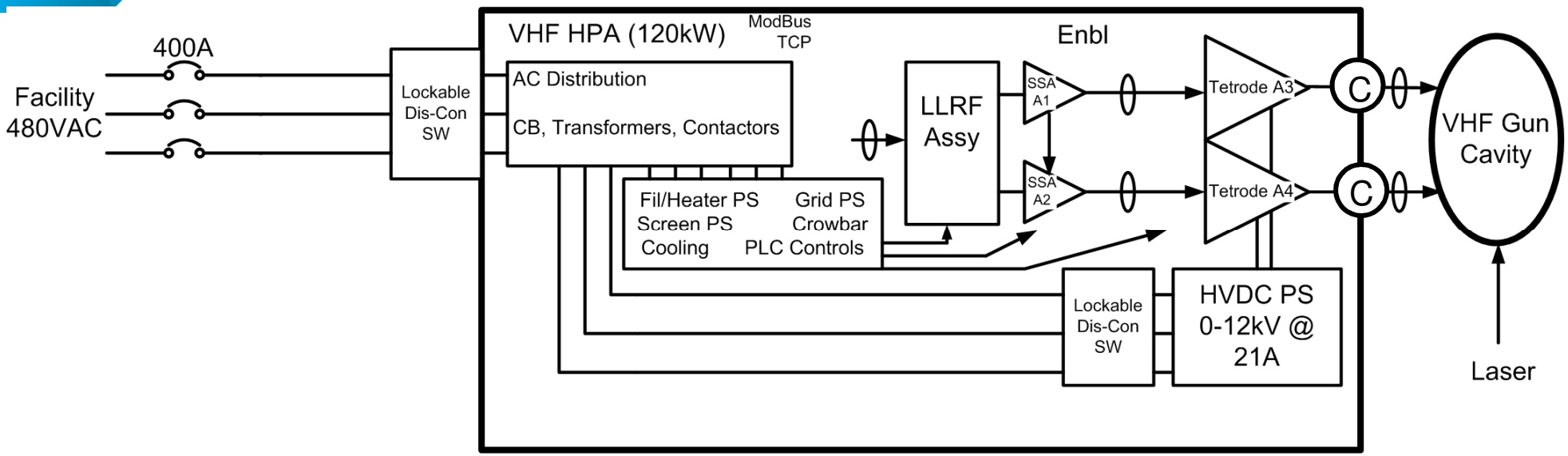
- 1.3 GHz
- 25 MW pk
- 25 kW avg
- 10 us pulse

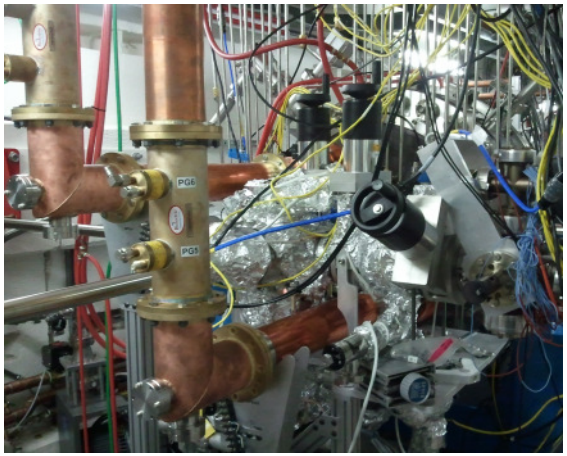
Failures:

- Harmonic output

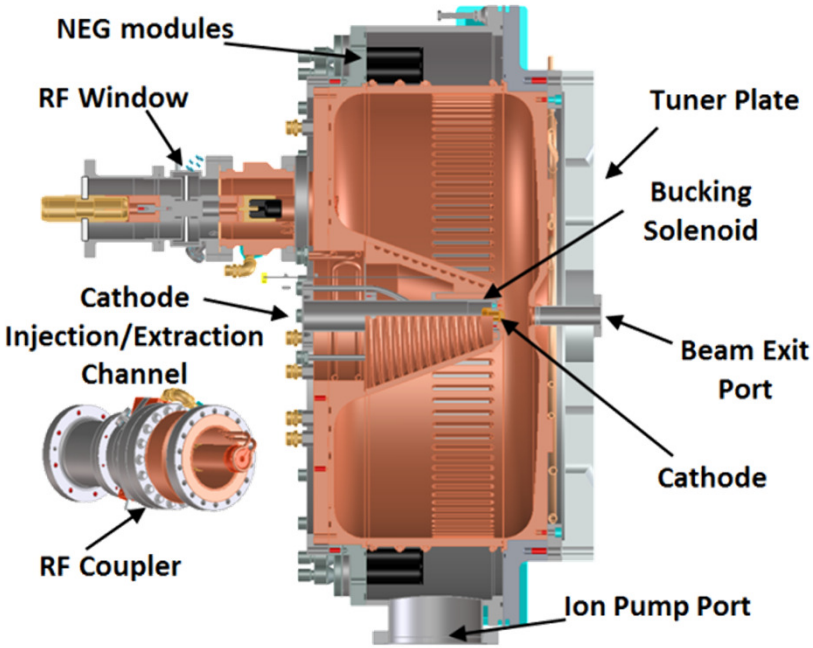
In Service: 2015

APEX RF (Advanced Photocathode Experiment)



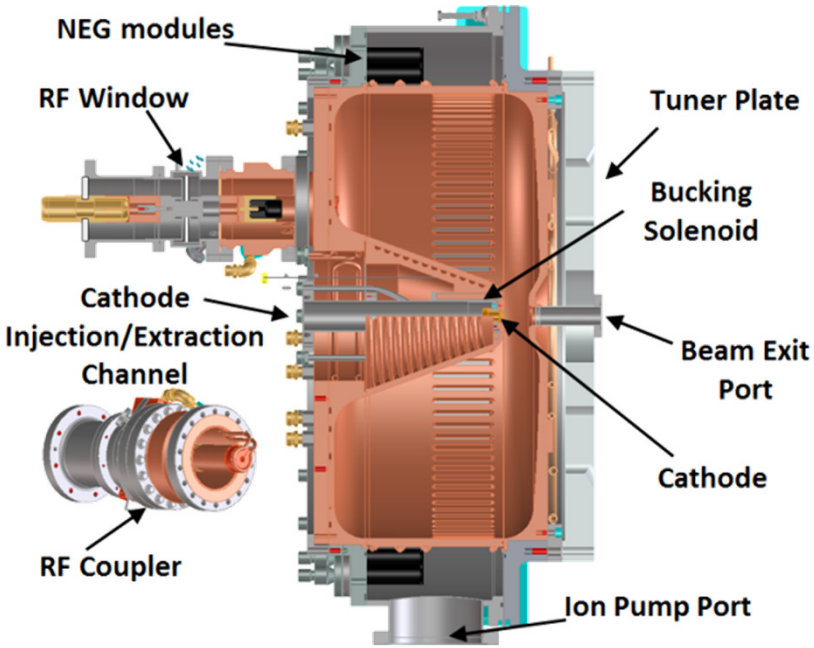


Overheated area



APEX RF (Advanced Photocathode Experiment)

$\lambda_{RF}/4 \sim 15.9$”



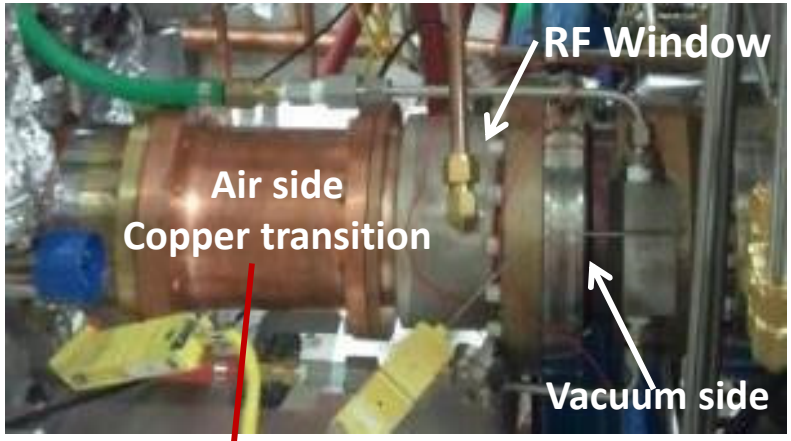
Missing from measurements, additional ~5” for length of coupling loop

This hole is at a current node. The copper is melting here not arcing.

The internal conductor

This hole would then be at 27” + 5” = 32”, ~ $\lambda_{RF}/2$

APEX RF (Advanced Photocathode Experiment)



Facing parts

These arc marks are at a voltage maxima. There is no sign of overheating due to high currents. This arcing being ~3" from window would then be at 19" - ~3" = 16", ~ $\lambda_{RF}/4$

EHT (Enhanced Heat Transfer coax line) rating from company:

De-rating for 0 PSIG in line = 0.885
Average Power Rating = 89 kW derated to 78 kW
Peak Voltage Rating = 13 kV
Peak Power Rating = 3,685 kW (Ppk = Vpk^2/Zo). Not specified for how long.

APEX max operation conditions:

Power per coax line = 60 kW CW max (50 kW nominal).
Peak Voltage in line = 1.414*sqrt(Pavg * Zo) = 1.414*sqrt(60000 * 50) = 2.45 kV
Peak Power in line = Vpk^2/Zo = 2449^2 / 50 = 120 kW
Peak Power in line from standing wave: Vpk = 4.9kV, Ppk = 480kW

The RF power remained ON for > 4 minutes in this condition due to improperly configured intrlks and a lack of synchronization when in pulse mode. Many watt-seconds were delivered during this time.

APEX RF (Advanced Photocathode Experiment)

Thank you