Status of the ALS RF Systems and Upgrade Plans for Storage Ring RF System

12th European Synchrotron Light Sources RF Meeting
October 1, 2008

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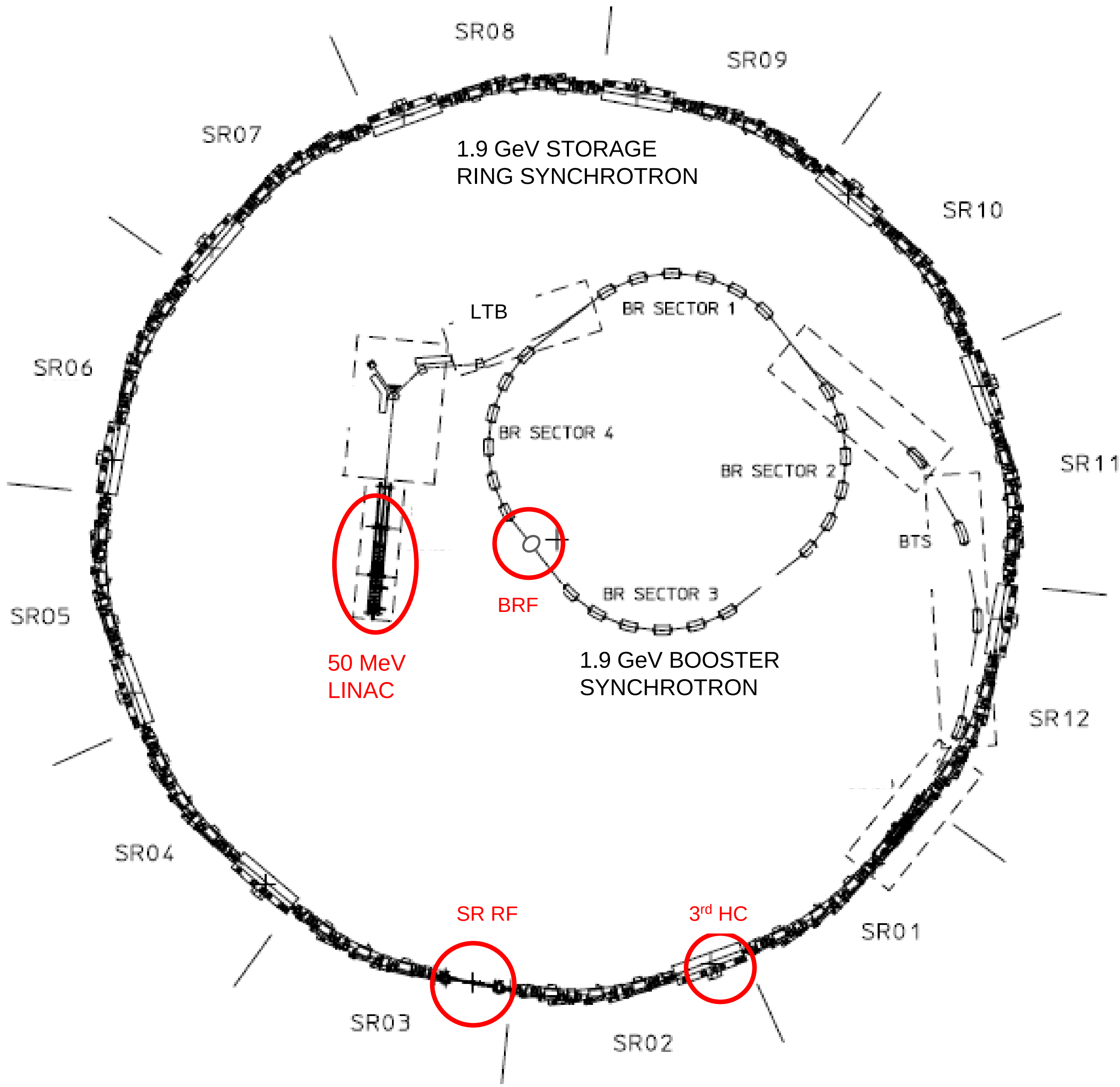
Scope

- ALS's RF Systems
  - Injection System
    - Electron Gun (125 MHz)
    - GTL Bunchers
      - ➢ 125 MHz Sub-Harmonic Buncher
      - ➢ 500 MHz Sub-Harmonic Buncher
    - S-Band Linac (2.998GHz)
      - ➢ S-Band Buncher
      - ➢ S-Band Accelerating Sections
    - Booster RF System (500 MHz)
  - Storage Ring
    - Storage Ring RF System (500 MHz)
    - 3rd Harmonic Cavities, passive (1.5 GHz)

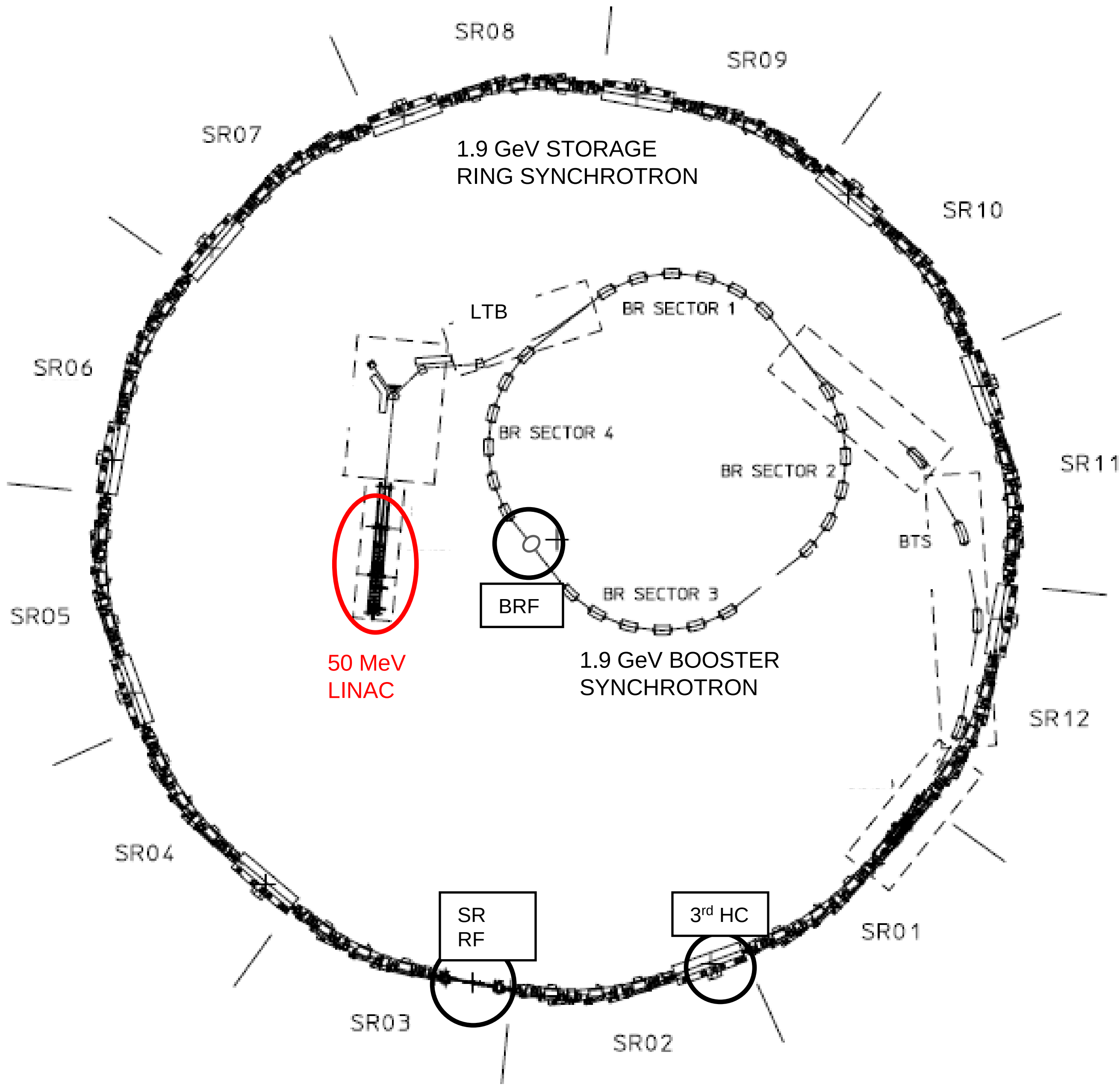
Scope, continued

- ALS RF Teststand
    - 66kW 500MHz Teststand
    - Titanium-Nitride Window Coating System
- HOM Dampening
    - Fundamental Cavities
    - 3^{rd} Harmonic Cavities
- Storage Ring RF System Upgrade Plans
    - Transmitter Installation (Step I)
    - HVPS Modification (Step II)
        - Crowbar Replacement with HV IGBT Switch
    - LLRF Upgrade (Step III)

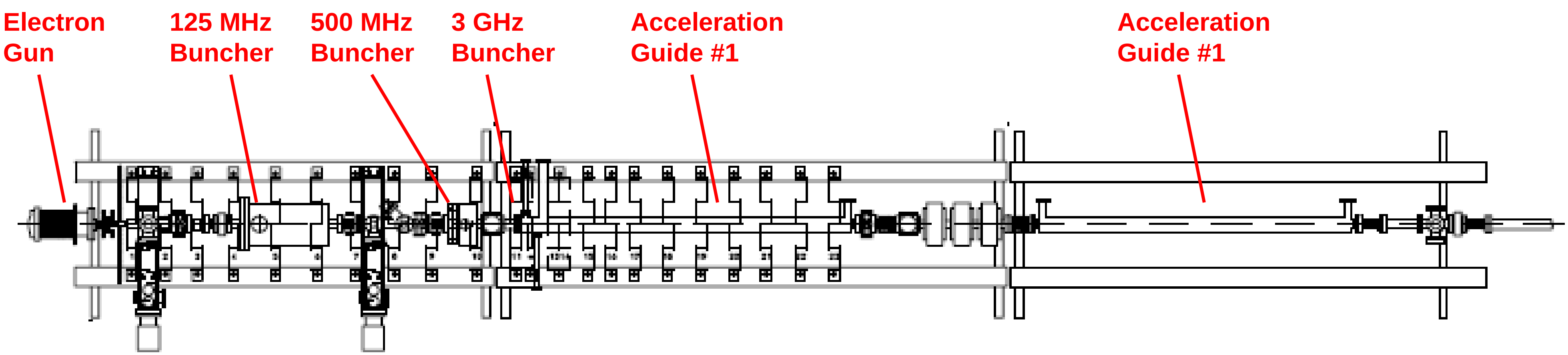
ALS's RF Systems



Linac RF Systems

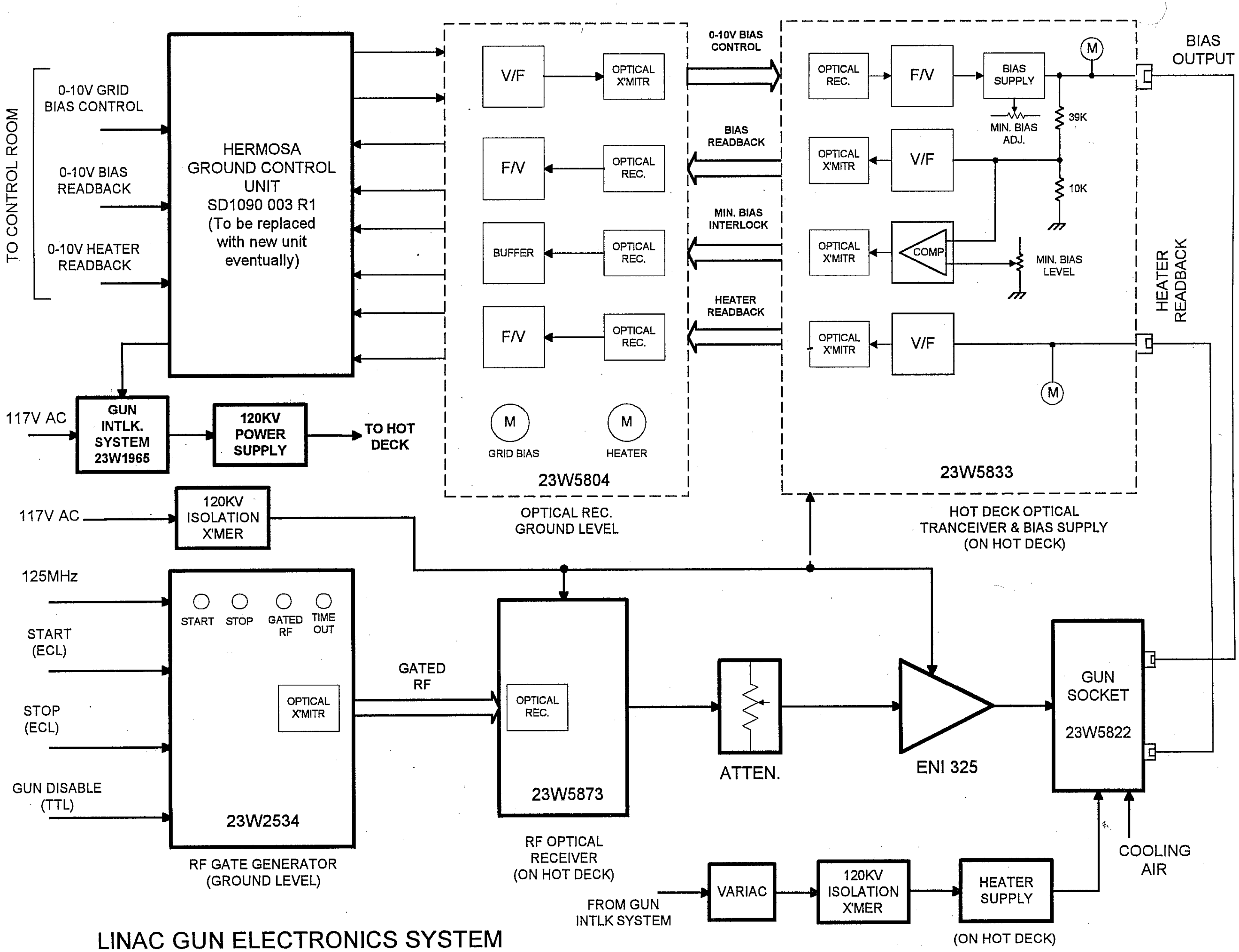


Injection System – Electron Gun & Linac



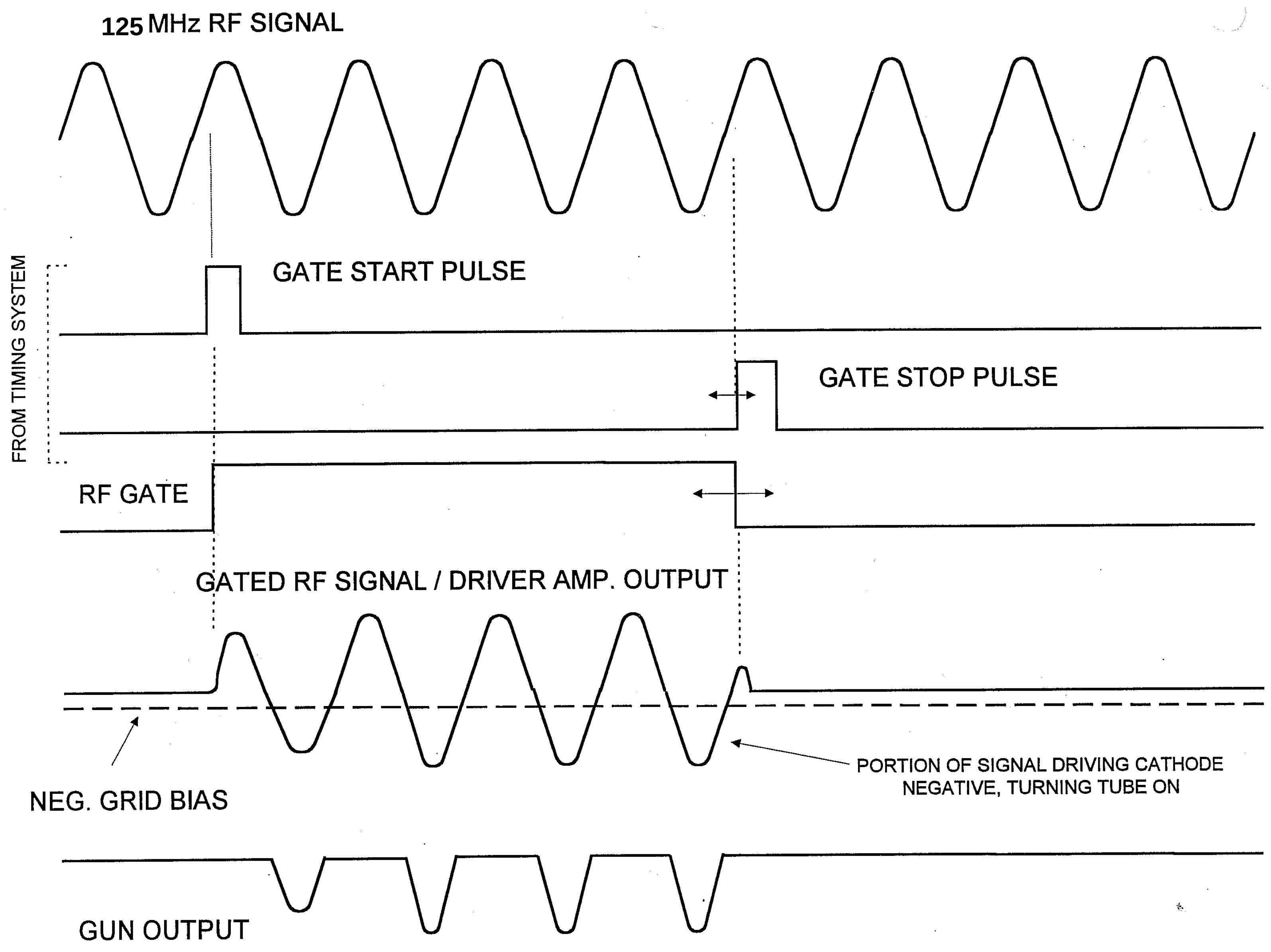
E. Gun Electronics Equip Rack & Block Diagram

E. Gun Rack (LI01)



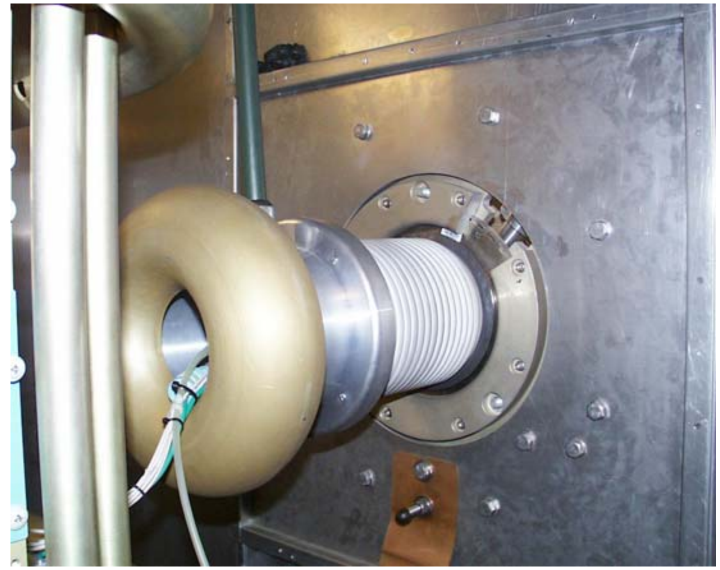
Block Diagram

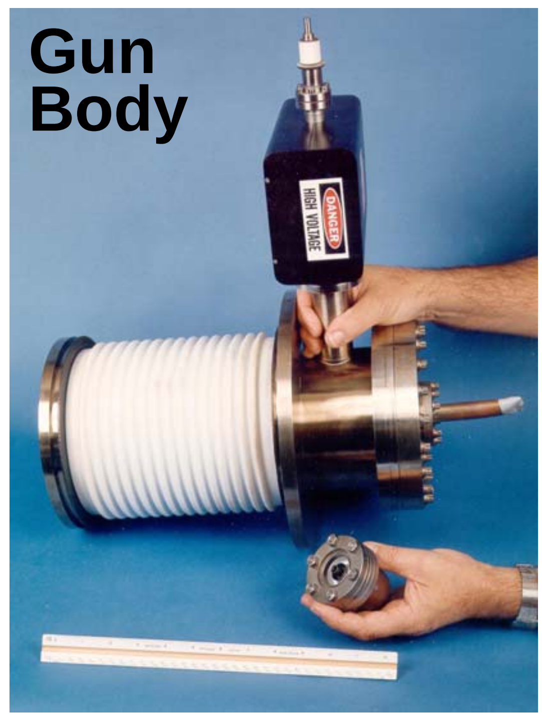
E. Gun Pulse Train Generation



Electron Gun Hot Deck, Gun Body, Cathode

Hot Deck

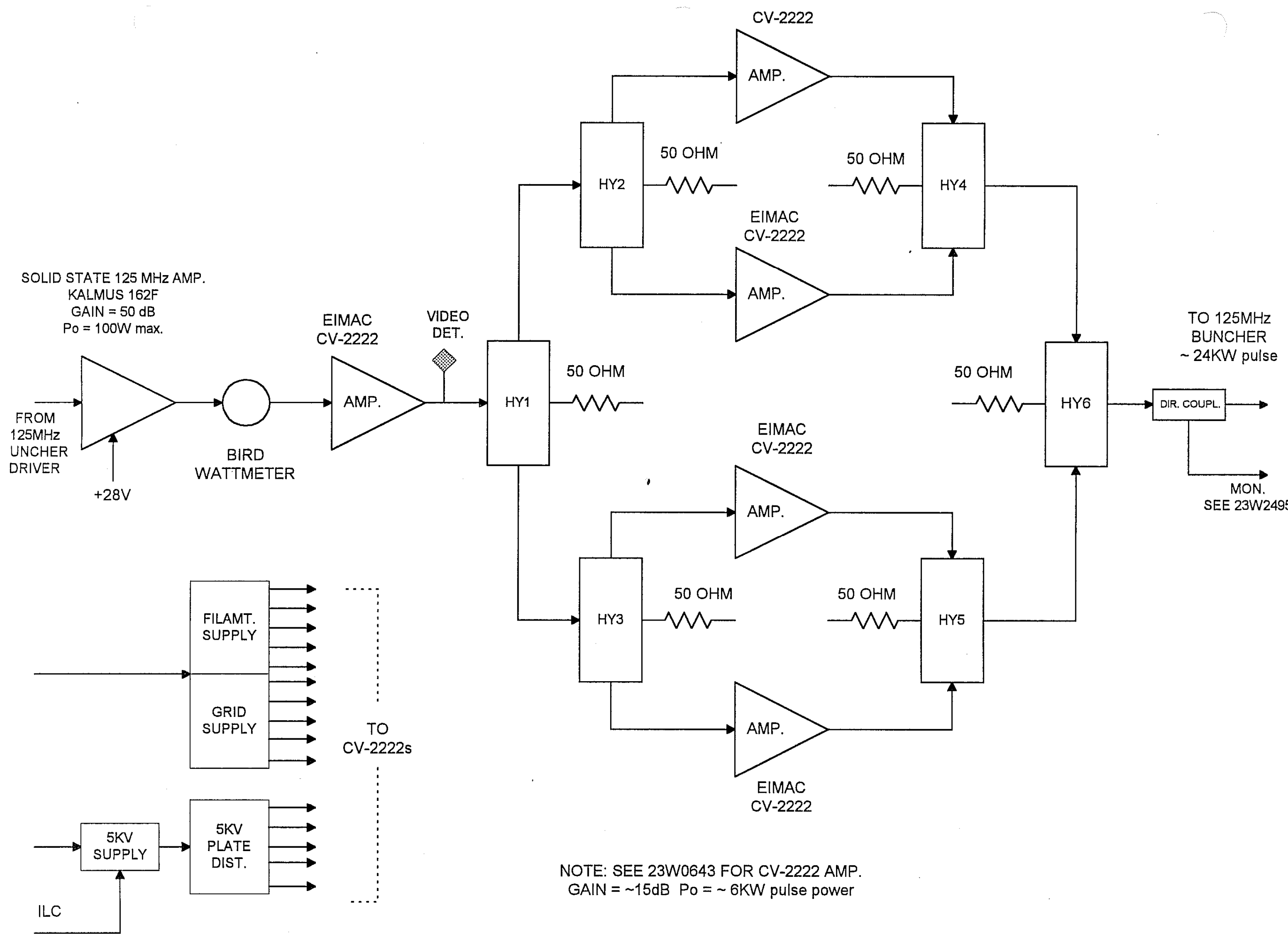




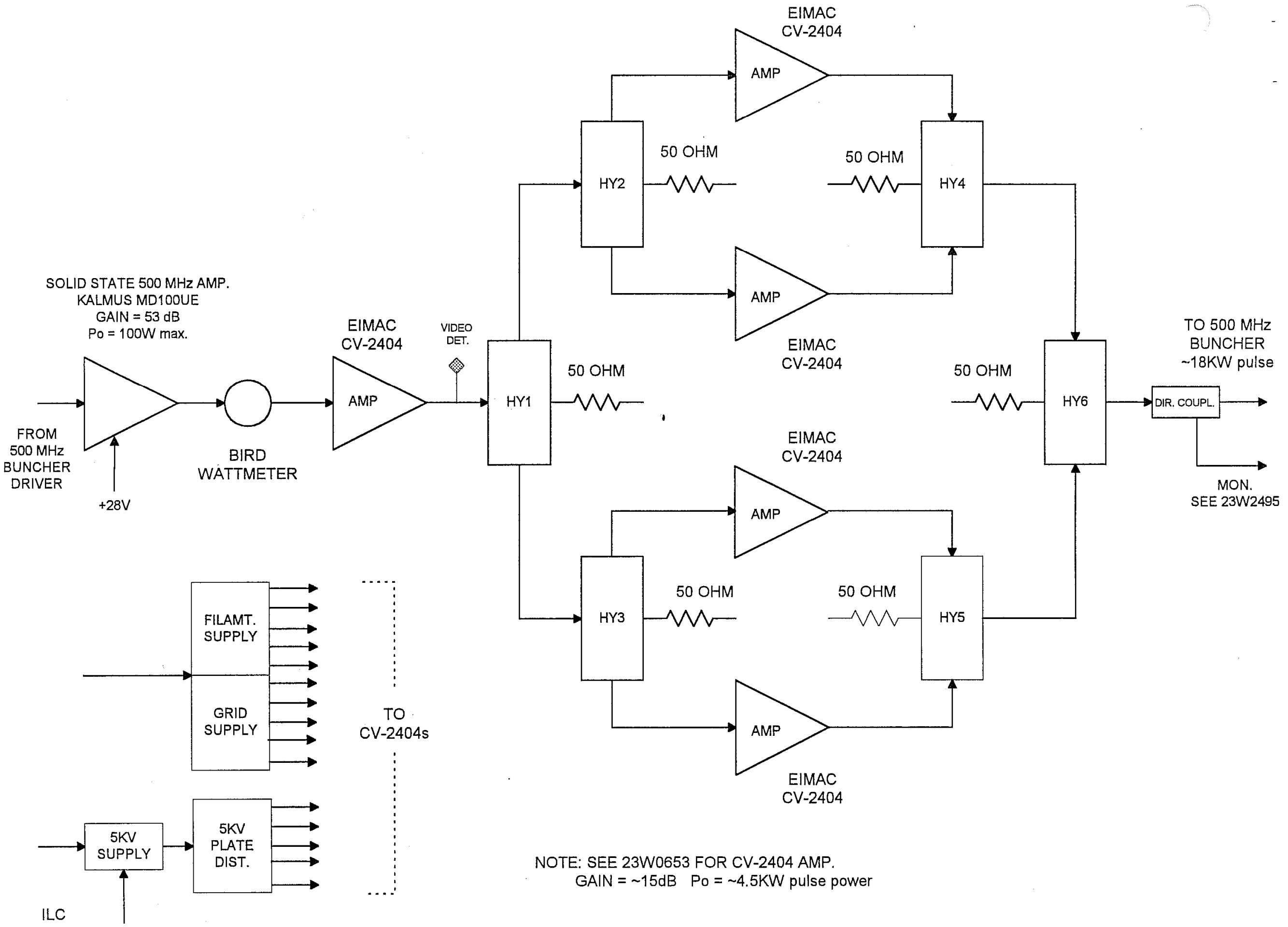
Gun Body

Cathode

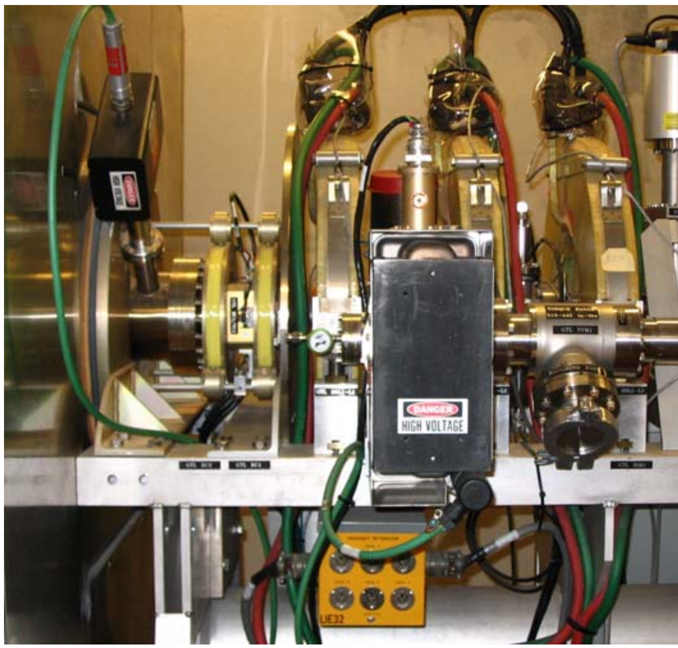
125MHz Sub-Harmonic Buncher (GTL SHB1)

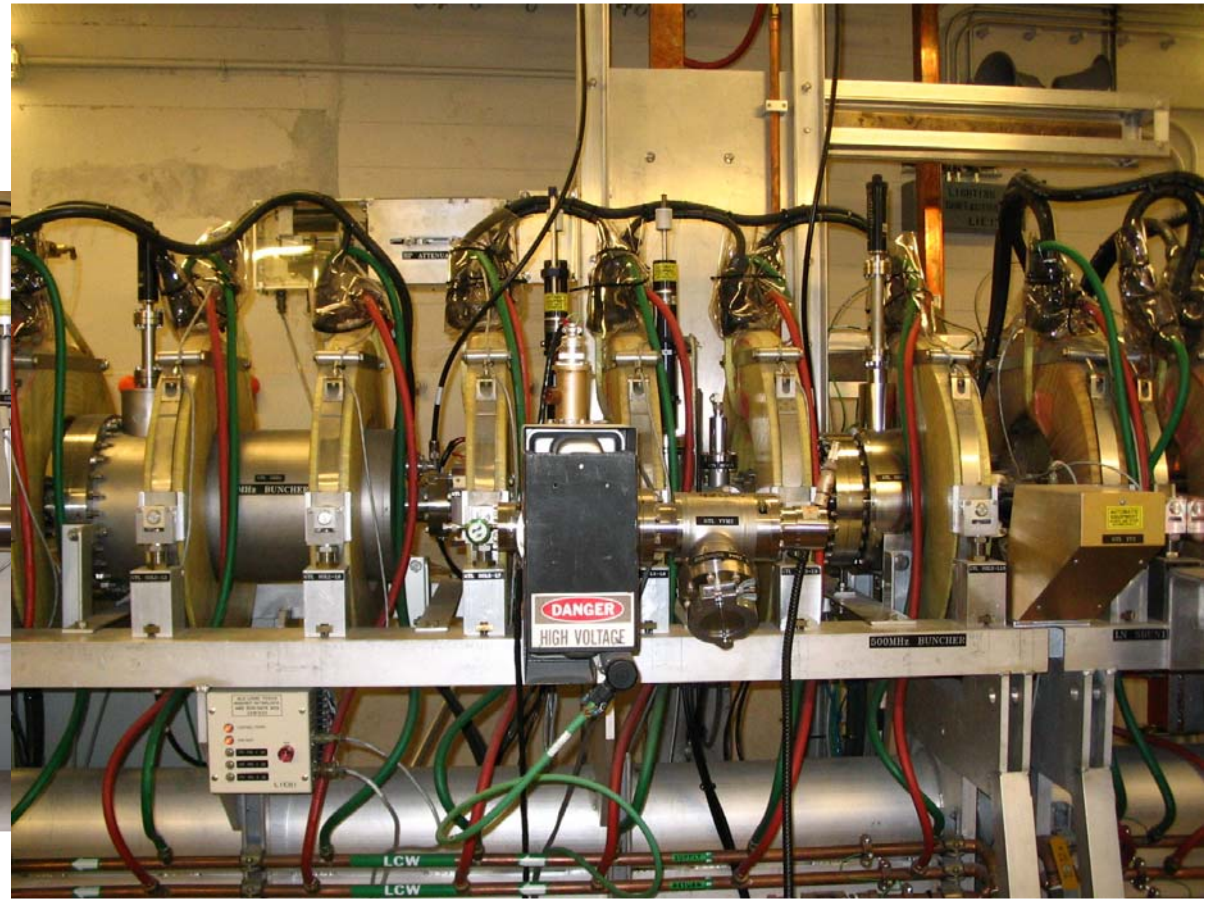


500MHz Sub-Harmonic Buncher (GTL SHB2)

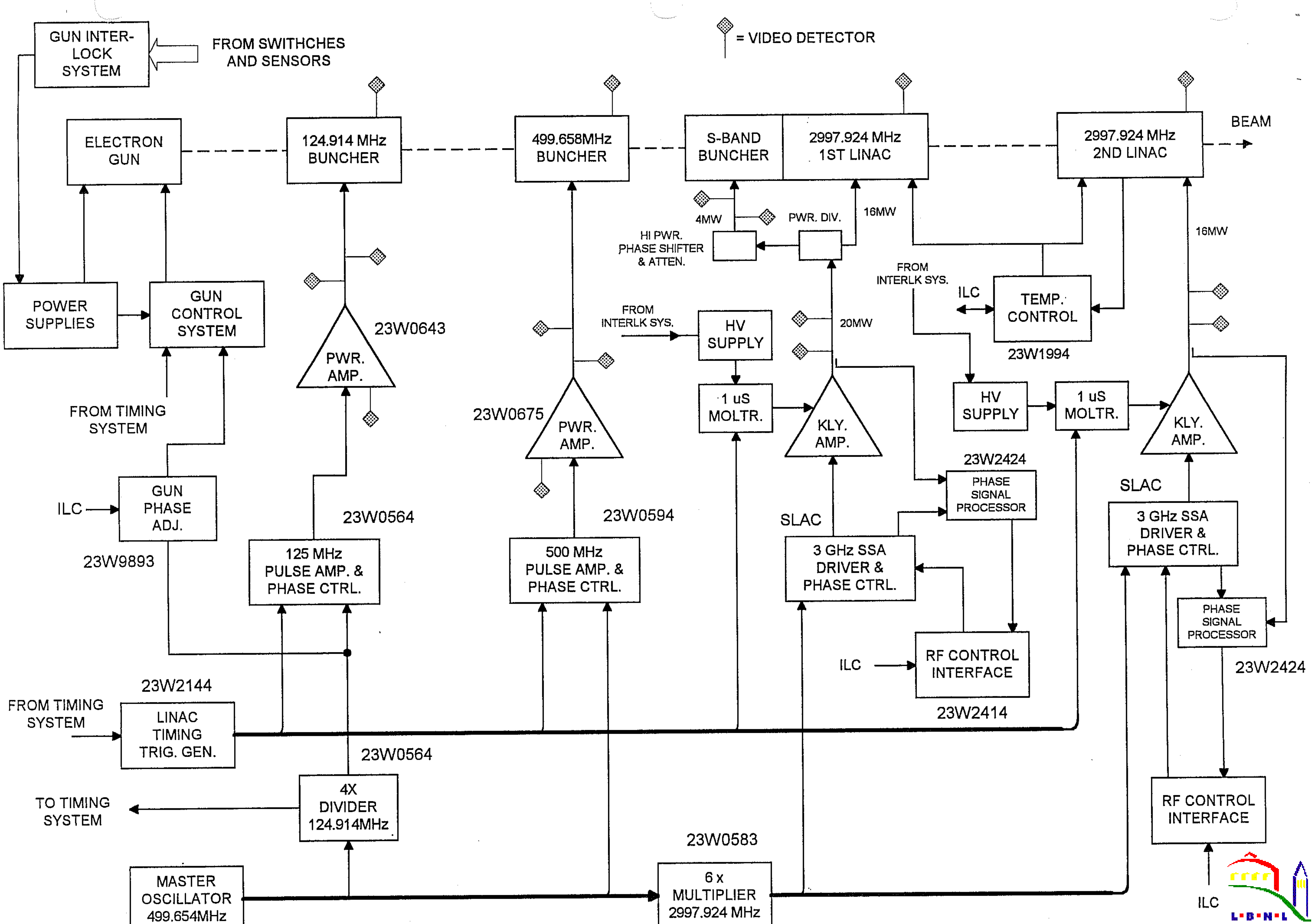


Photos of (GTL)

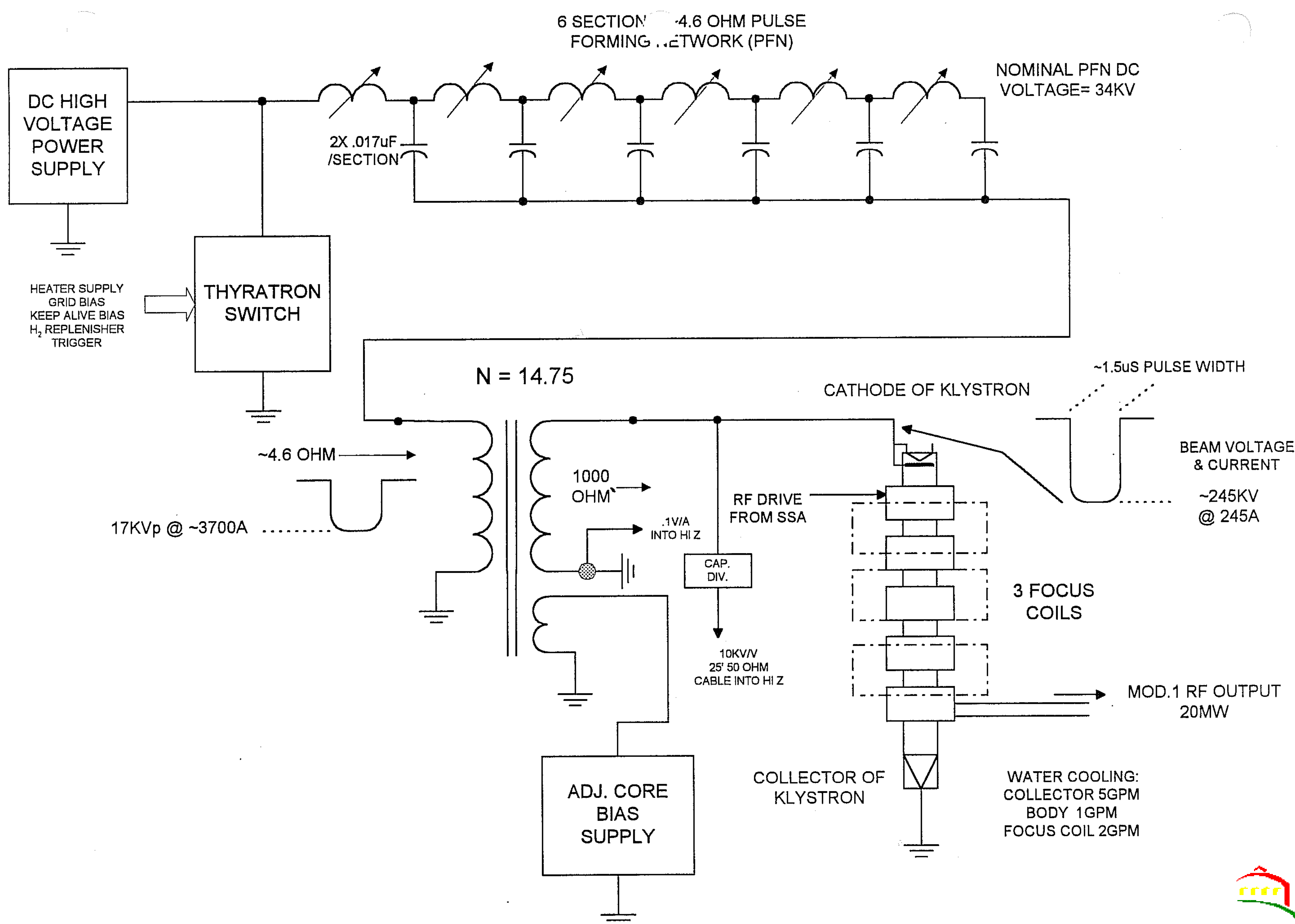




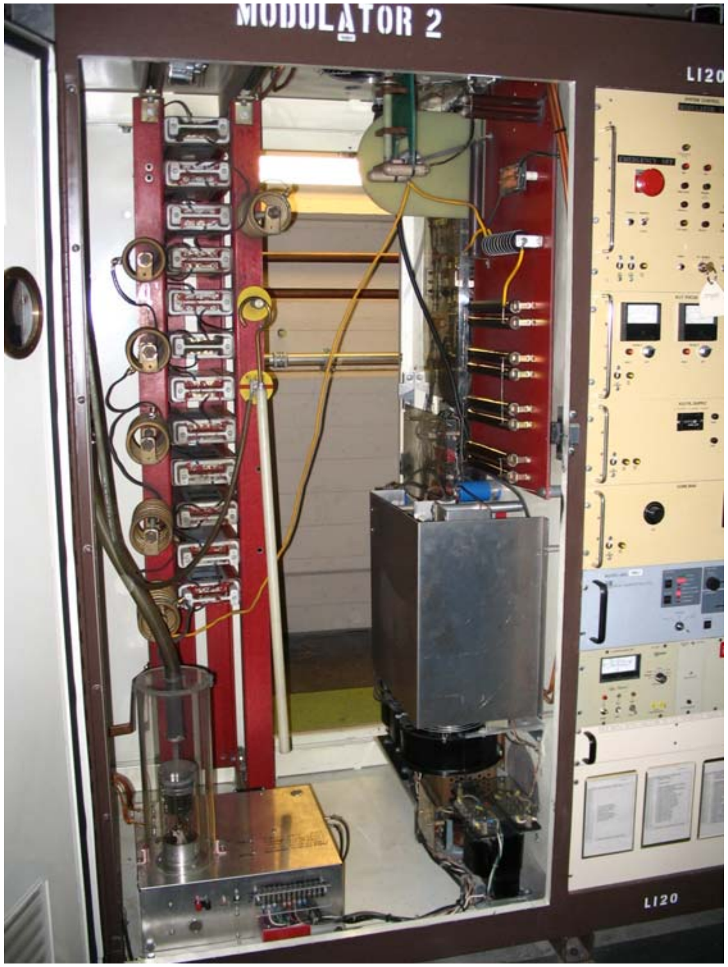
3GHz LINAC RF System



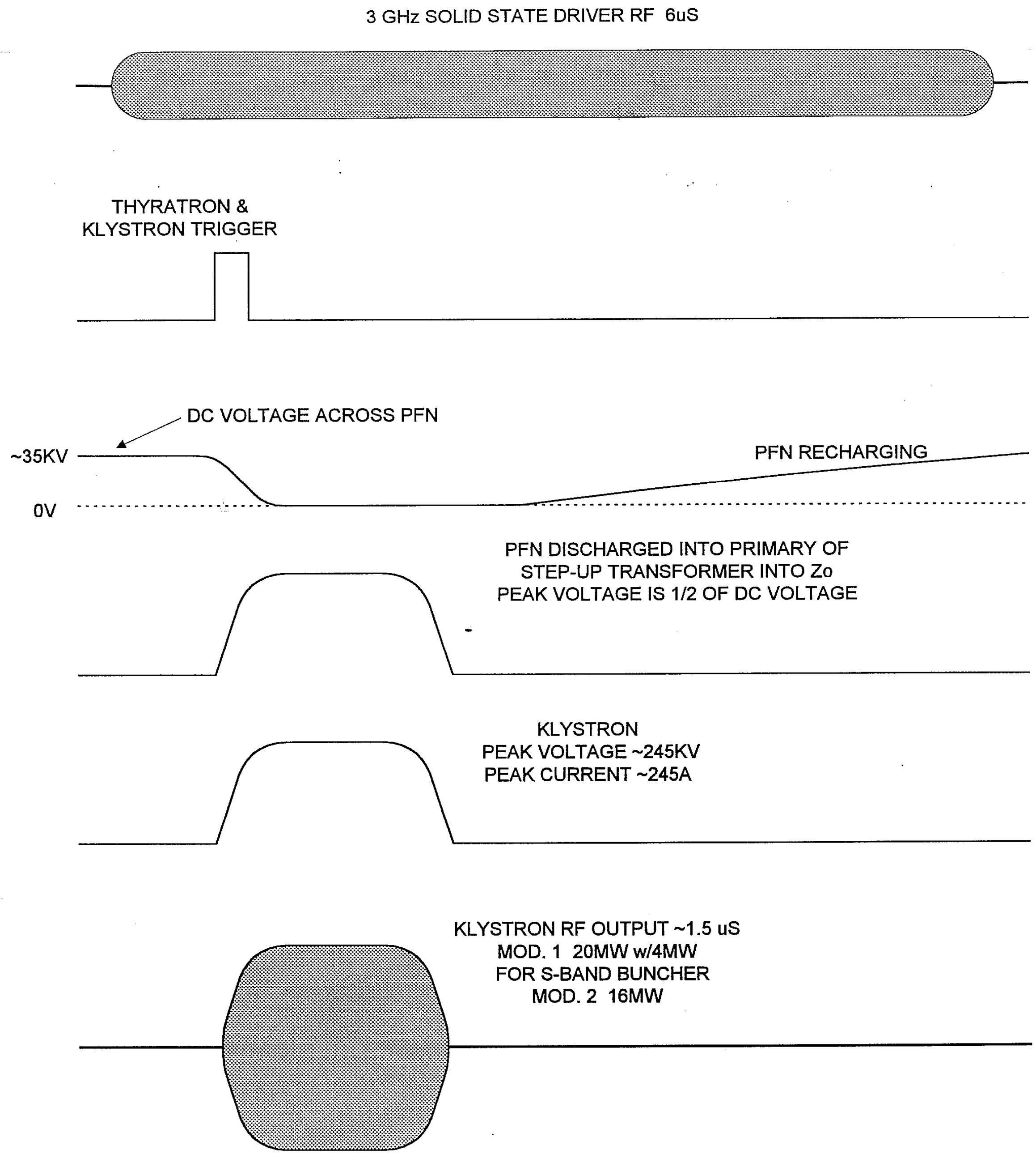
LINAC Modulators 1 & 2 for LN SBUN1, LN AS1 & LN AS2



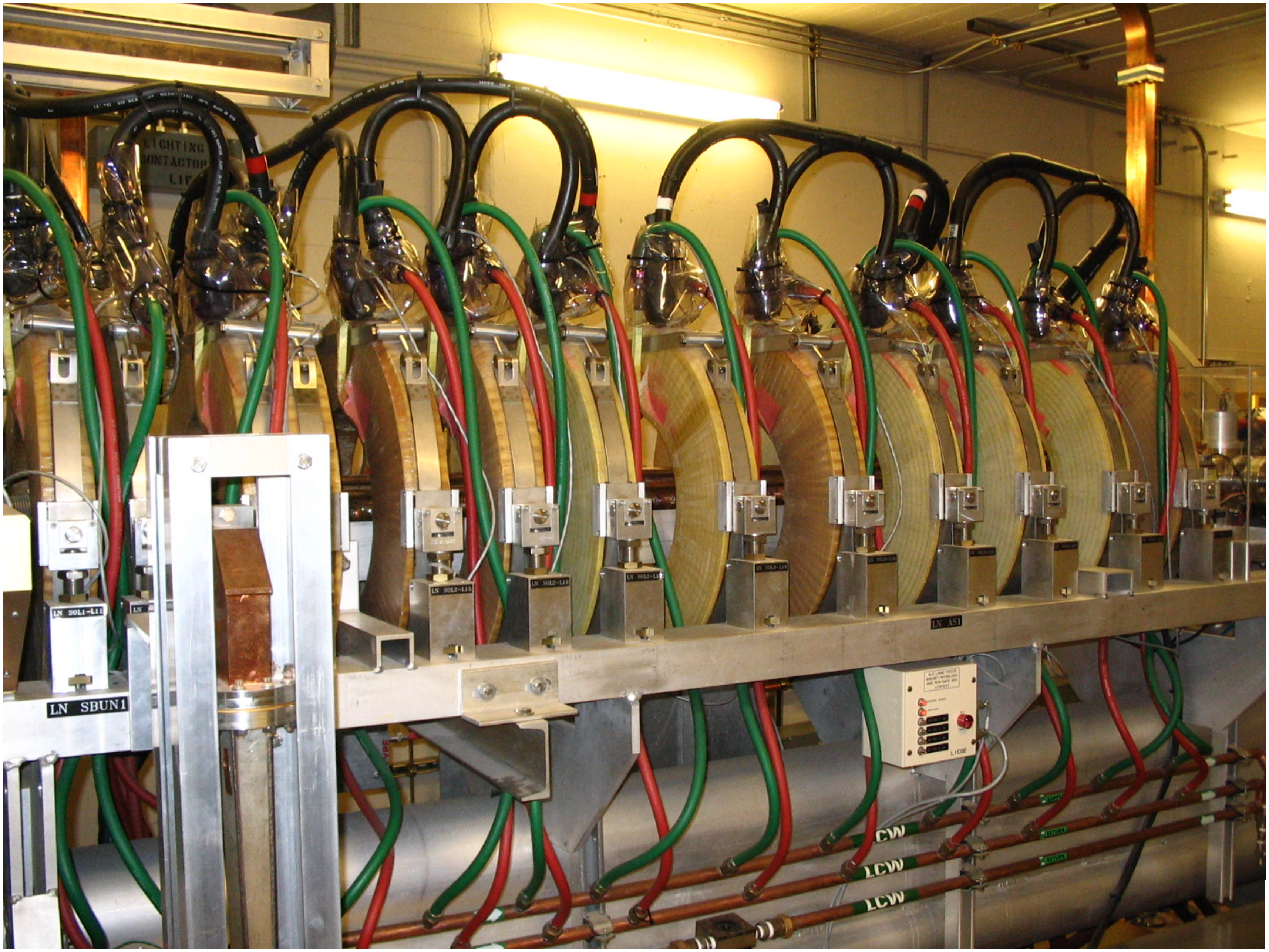
LINAC Modulators & Klystron



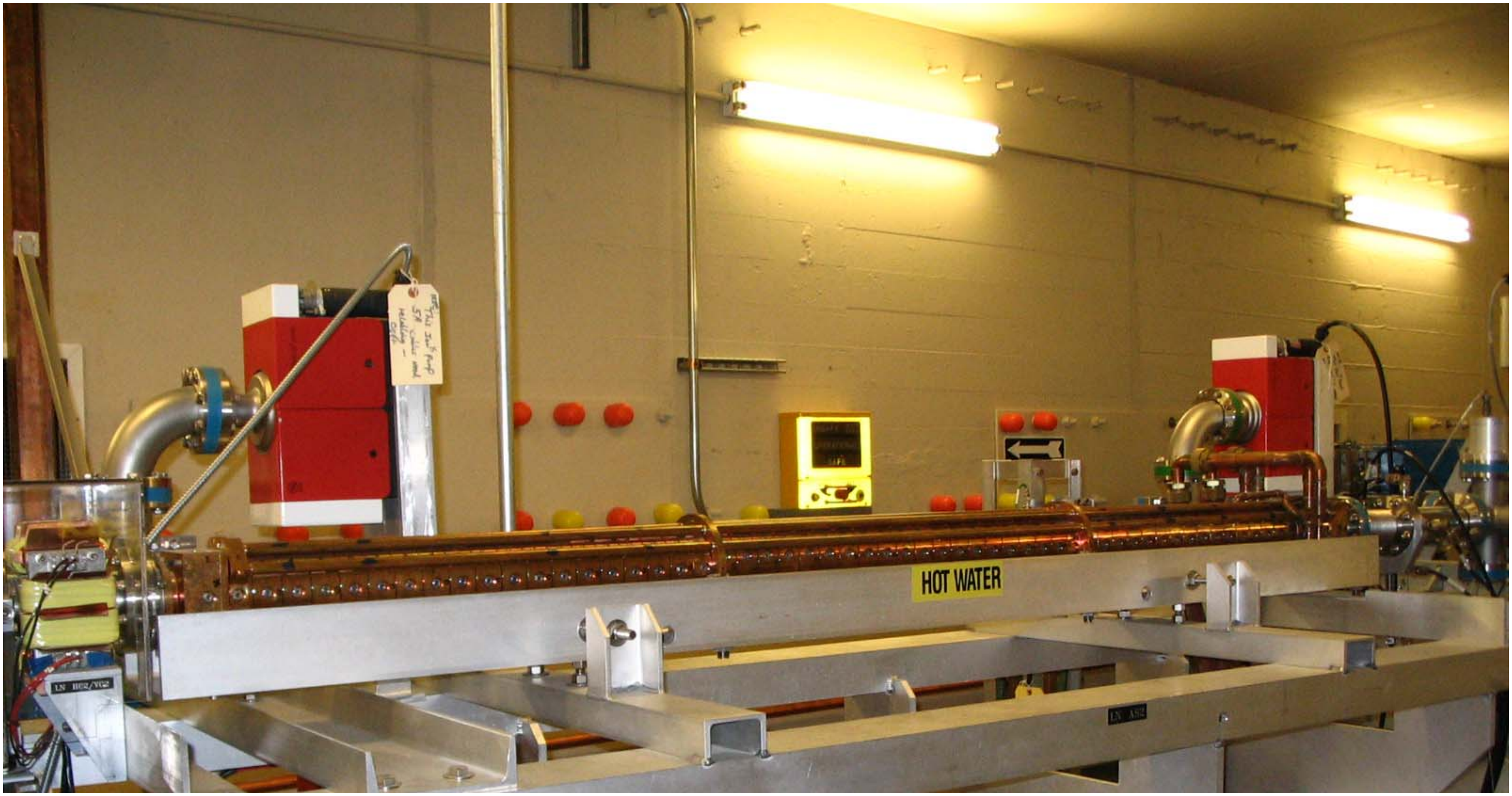
LINAC Modulators & RF Timing



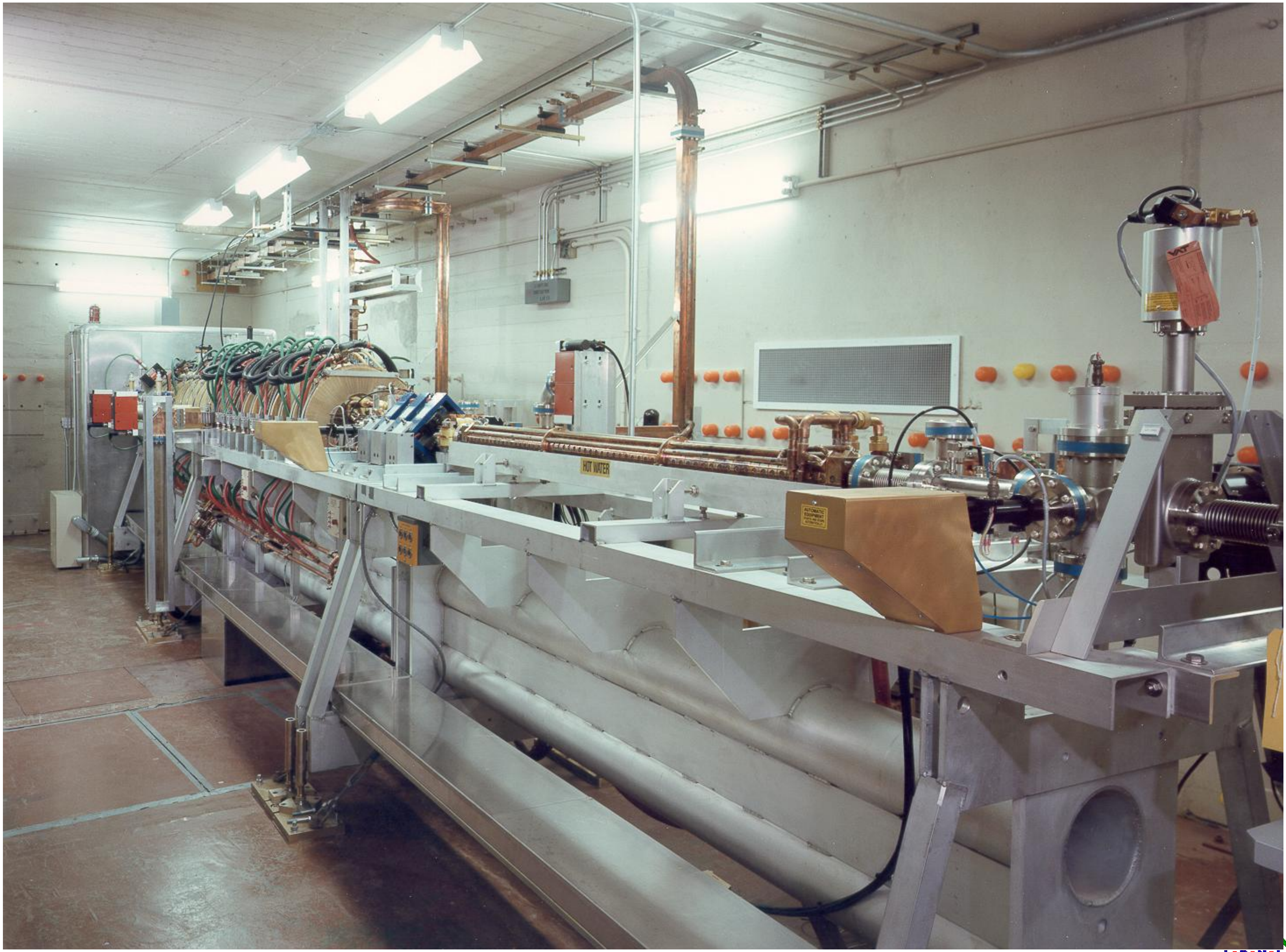
LN AS1 (girder #2)



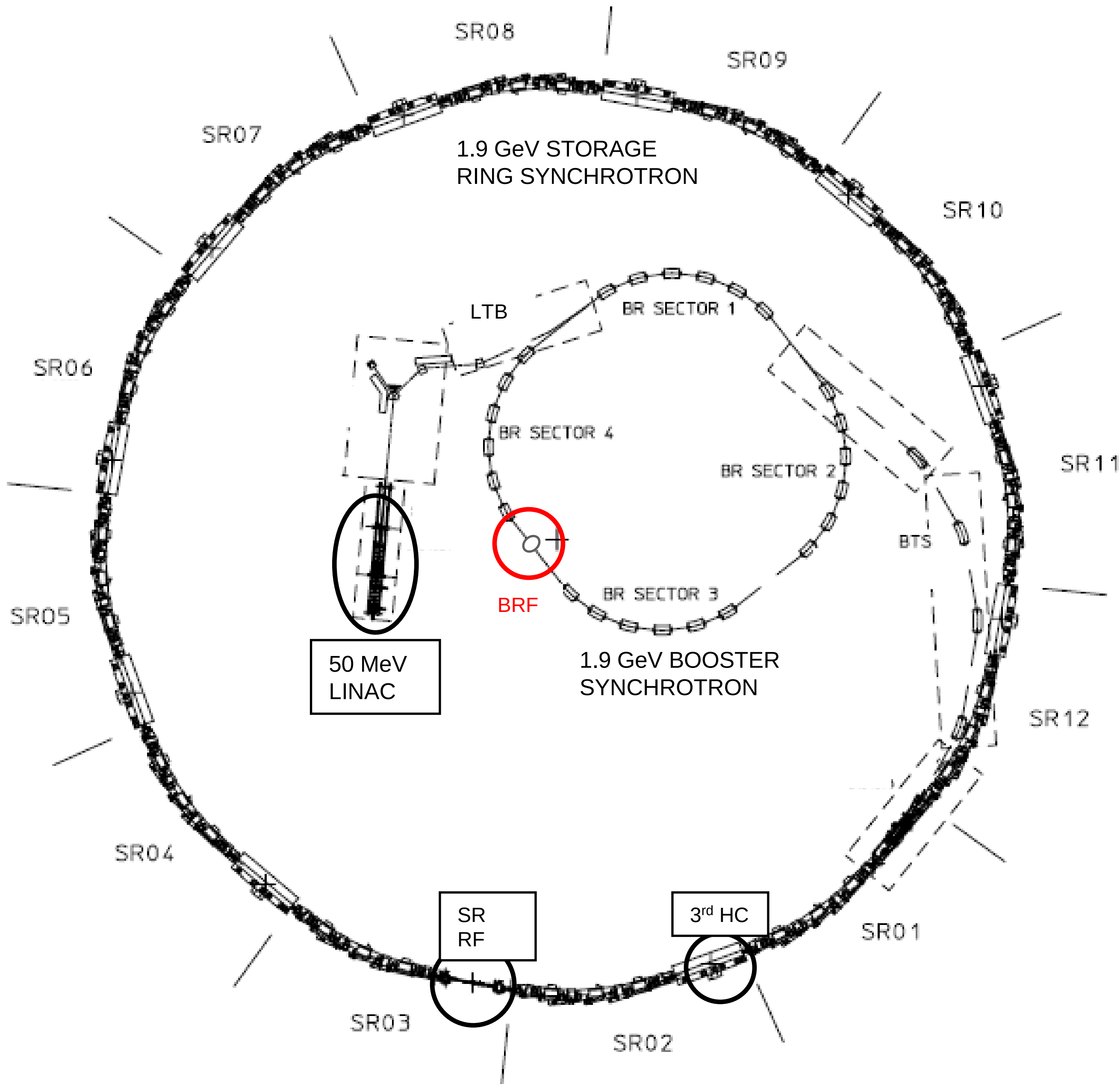
LN AS2 (girder #3)



LINAC



Booster RF System



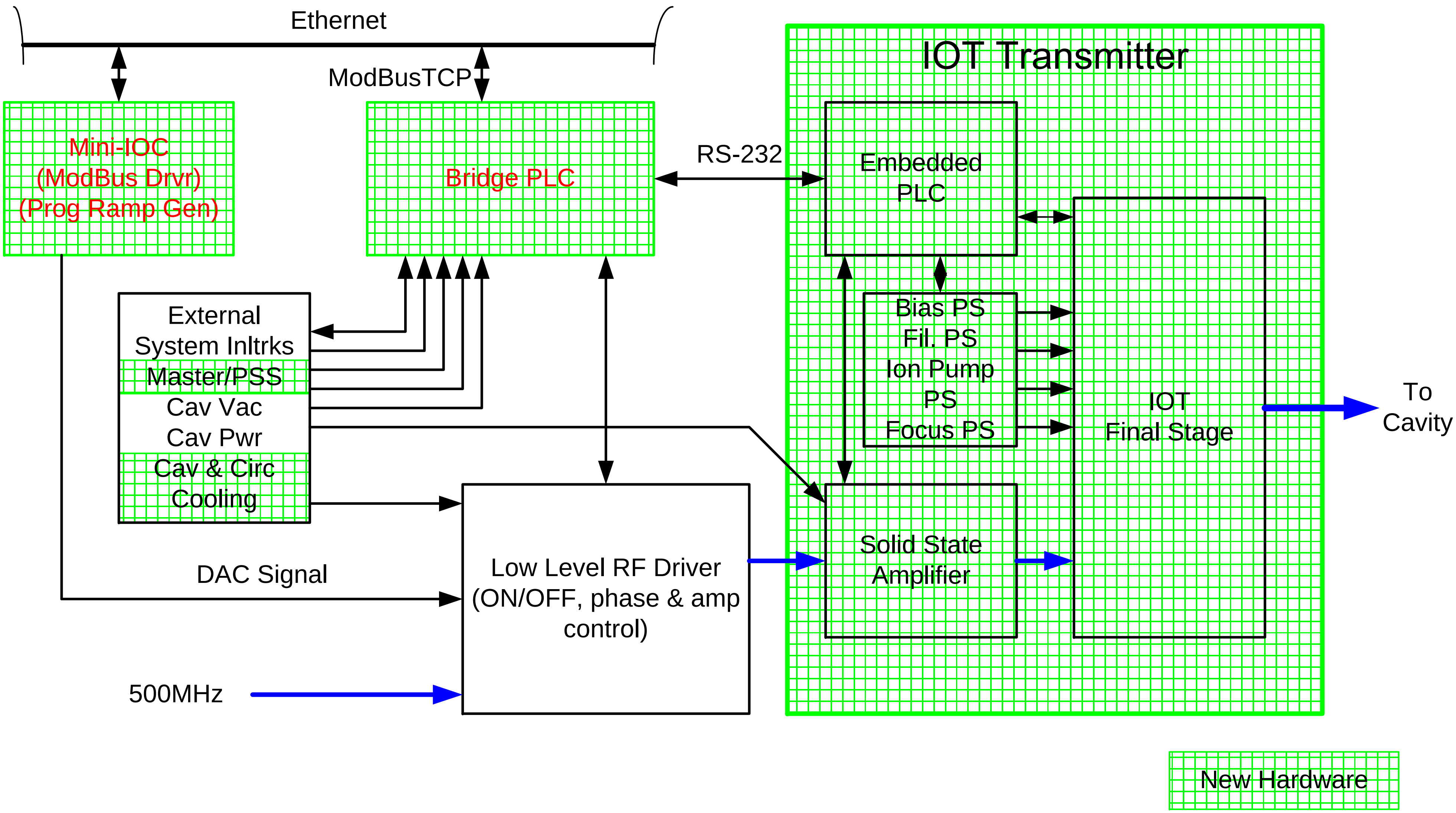
Booster RF System Parameters for 1.9 GeV

Frequency (MHz)	499.64
Harmonic number	125
Peak effective voltage[a] (kV)	813
Beam current, multibunch mode (mA)	4
Synchrotron radiation loss, dipoles (kW)	5
Total effective shunt impedance, ZT^2 (MΩ)	5
Fundamental-mode cavity dissipation (kW)	66
Waveguide and other losses[b] (kW)	3.1+2.6=5.7
Total RF power (kW)	71.7
Total RF power installed (kW)	80

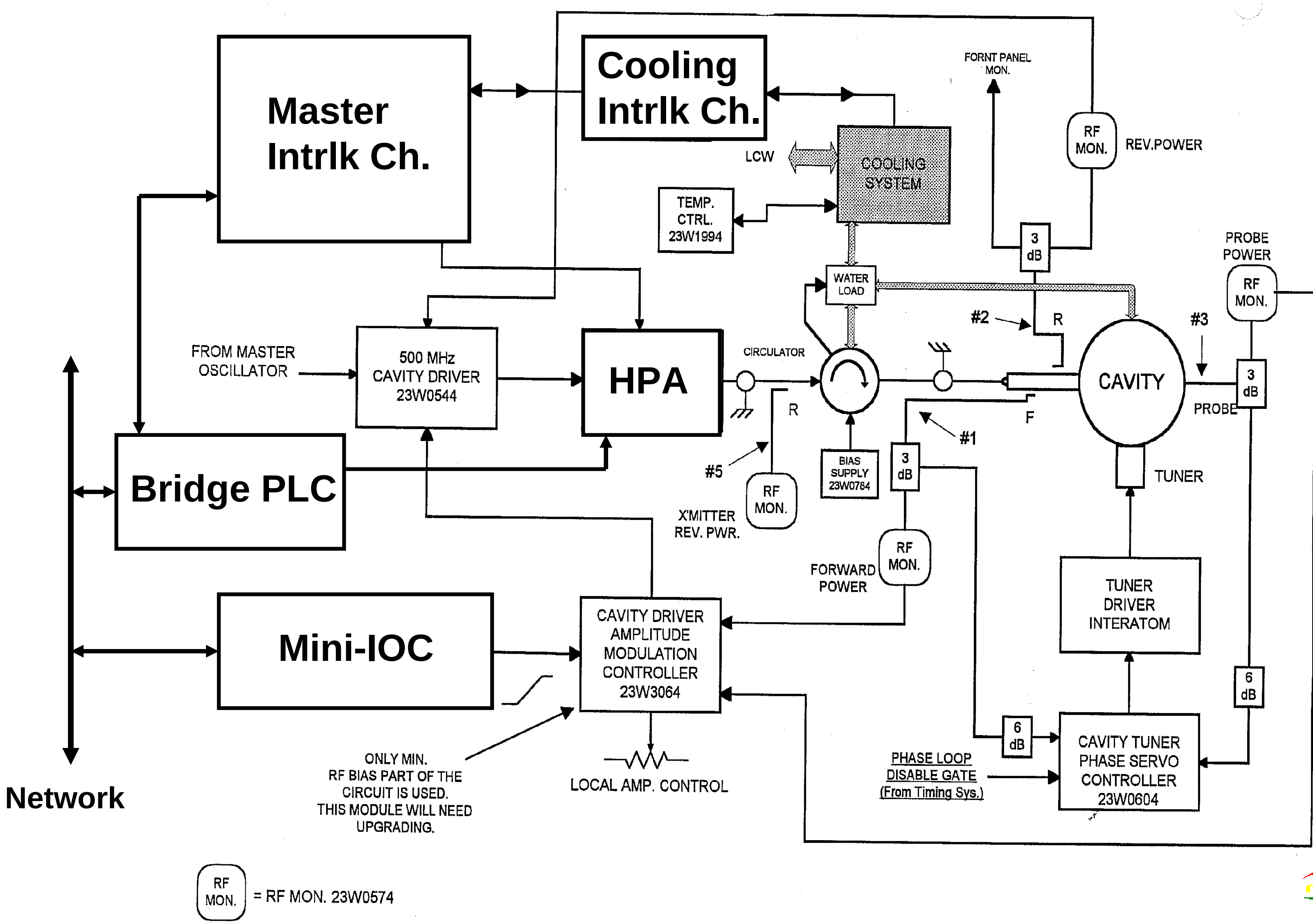
[a] based on 66kW dissipation

[b] estimated to be ≤ 0.2dB transmission loss & 4% RL for $\beta=1.5$

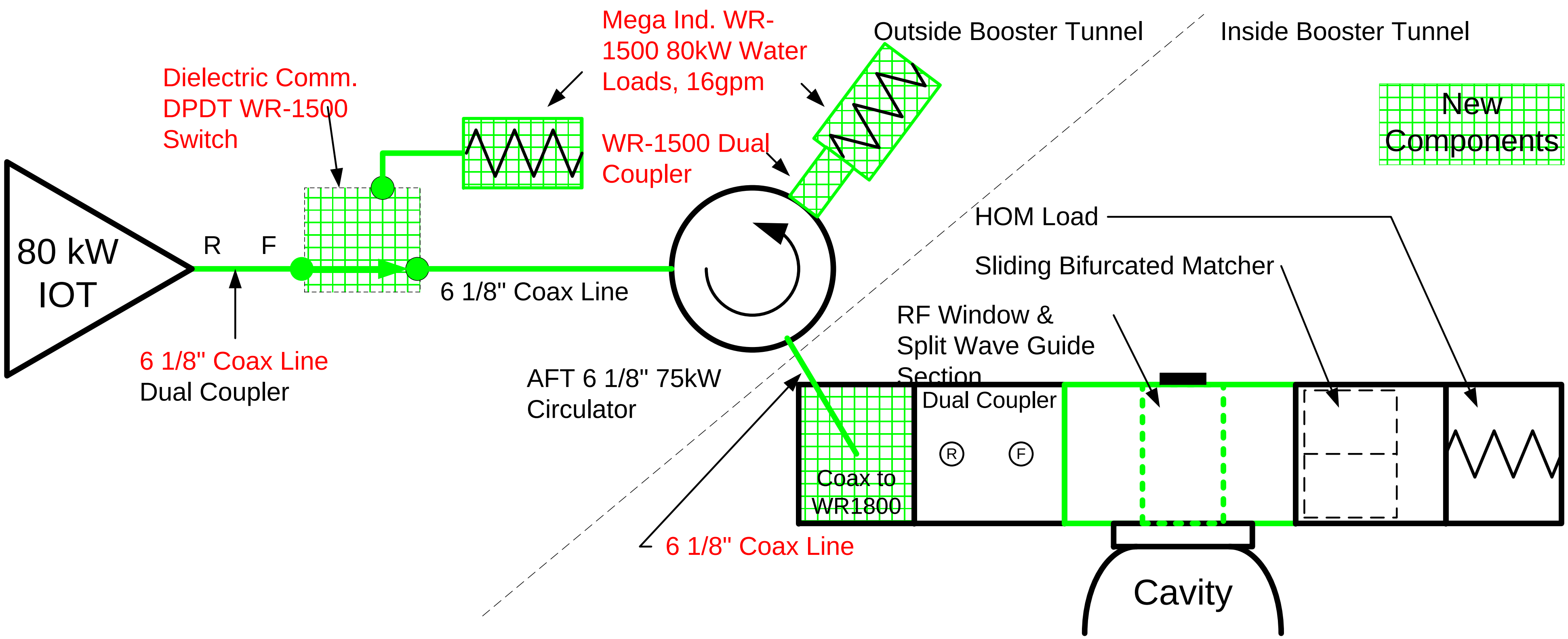
BRF System Block Diagram



BRF System Block Diagram



BRF Transmission Line Sketch



BRF HPA/XMTR

AI, Acrodyne Industries

(commercial broadcast transmitter, modified)

CPI, Communications & Power Industries

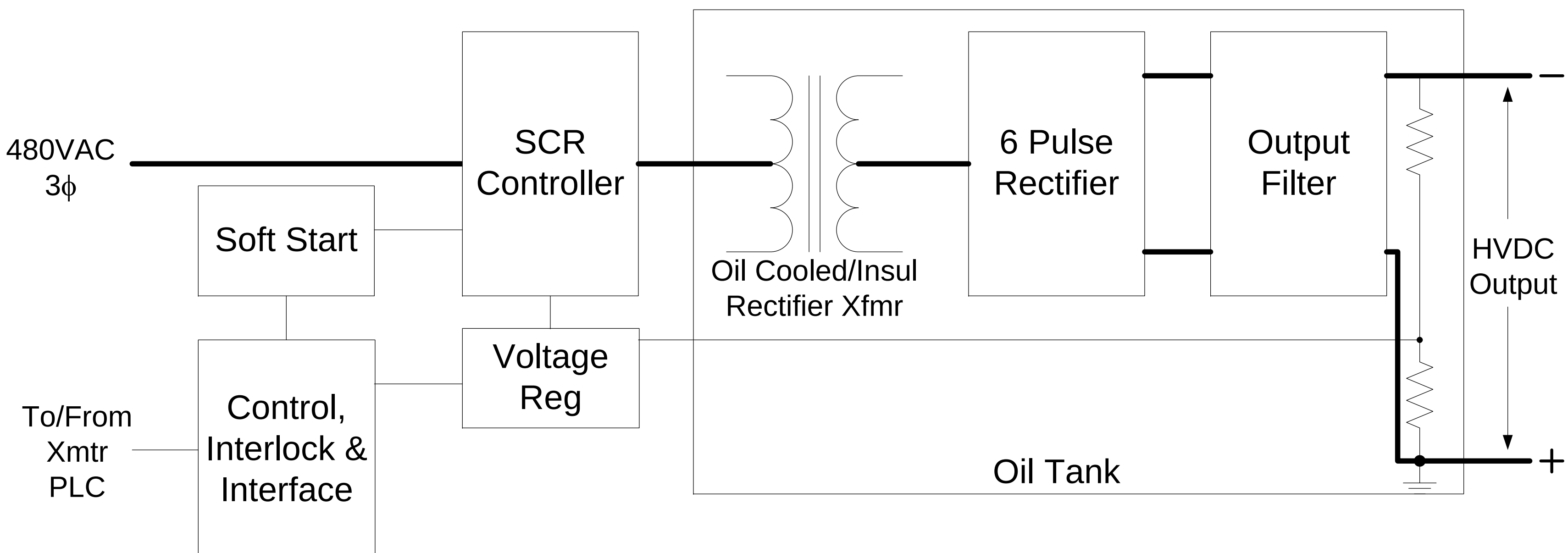
(commercial broadcast IOT, K2 series, 80kW)

Gain >23 dB

Eff. >65 %

E_B <36 kV

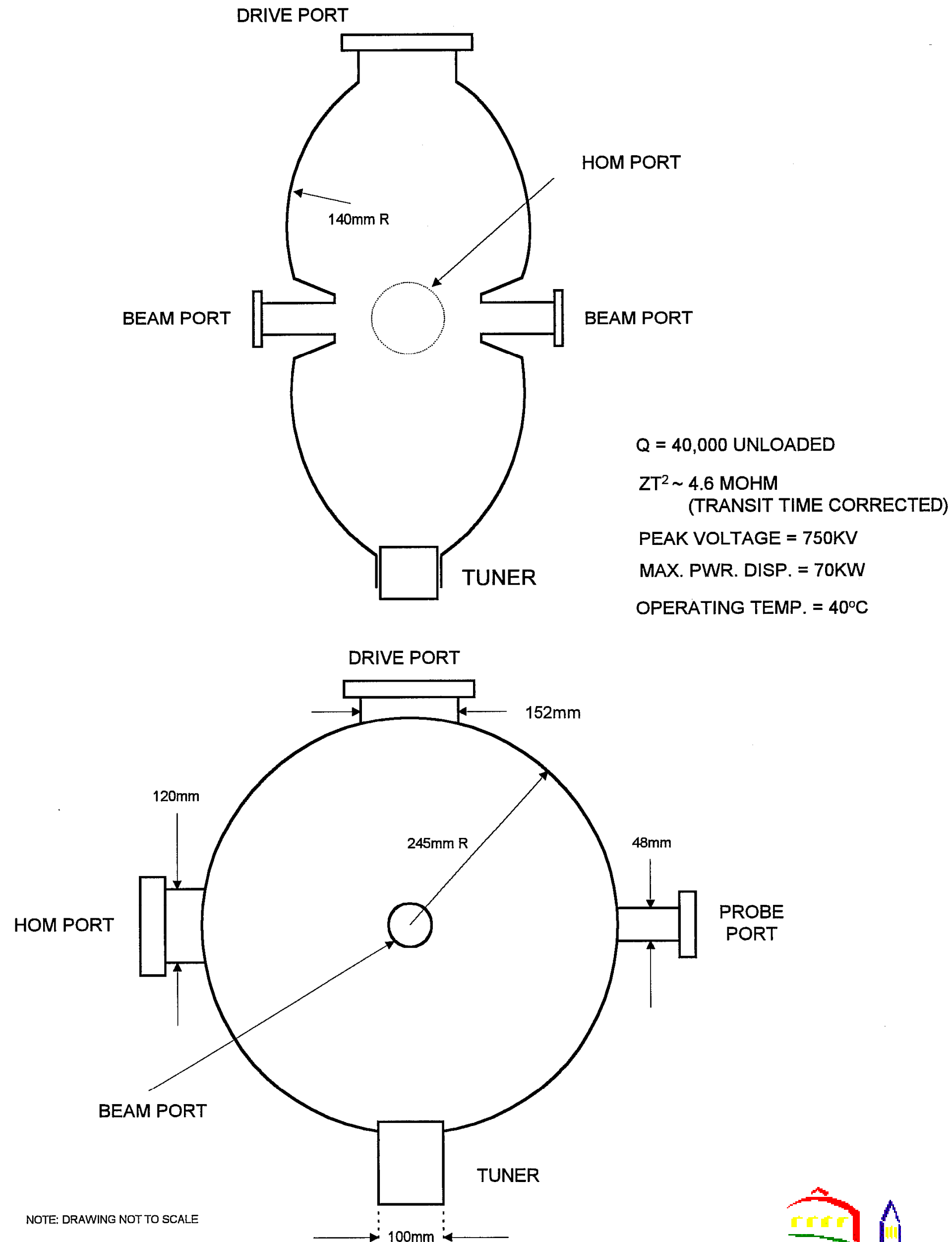
BRF HVPS (High Voltage RF Pad, outside Bldg.6)



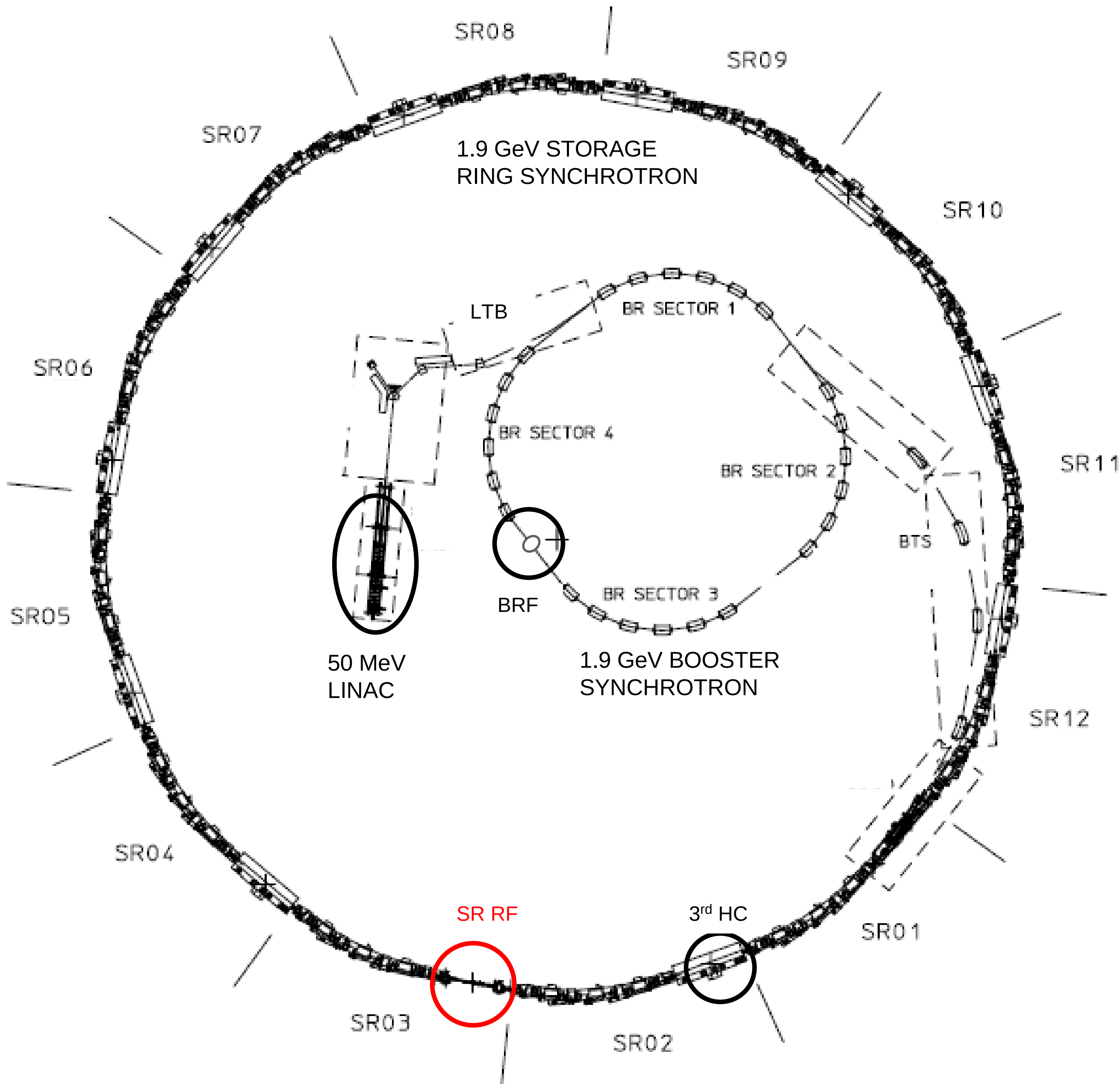
BRF Wave Guide Switch & HPA Test Load

BRF Circulator & Reject Load

BRF Cavity


DRIVE PORT
HOM PORT
140mm R
BEAM PORT
BEAM PORT
TUNER
Q = 40,000 UNLOADED
ZT^2 ~ 4.6 MOHM
(TRANSIT TIME CORRECTED)
PEAK VOLTAGE = 750KV
MAX. PWR. DISP. = 70KW
OPERATING TEMP. = 40°C
DRIVE PORT
152mm
120mm
245mm R
48mm
HOM PORT
PROBE PORT
BEAM PORT
TUNER
NOTE: DRAWING NOT TO SCALE
100mm

SR RF System

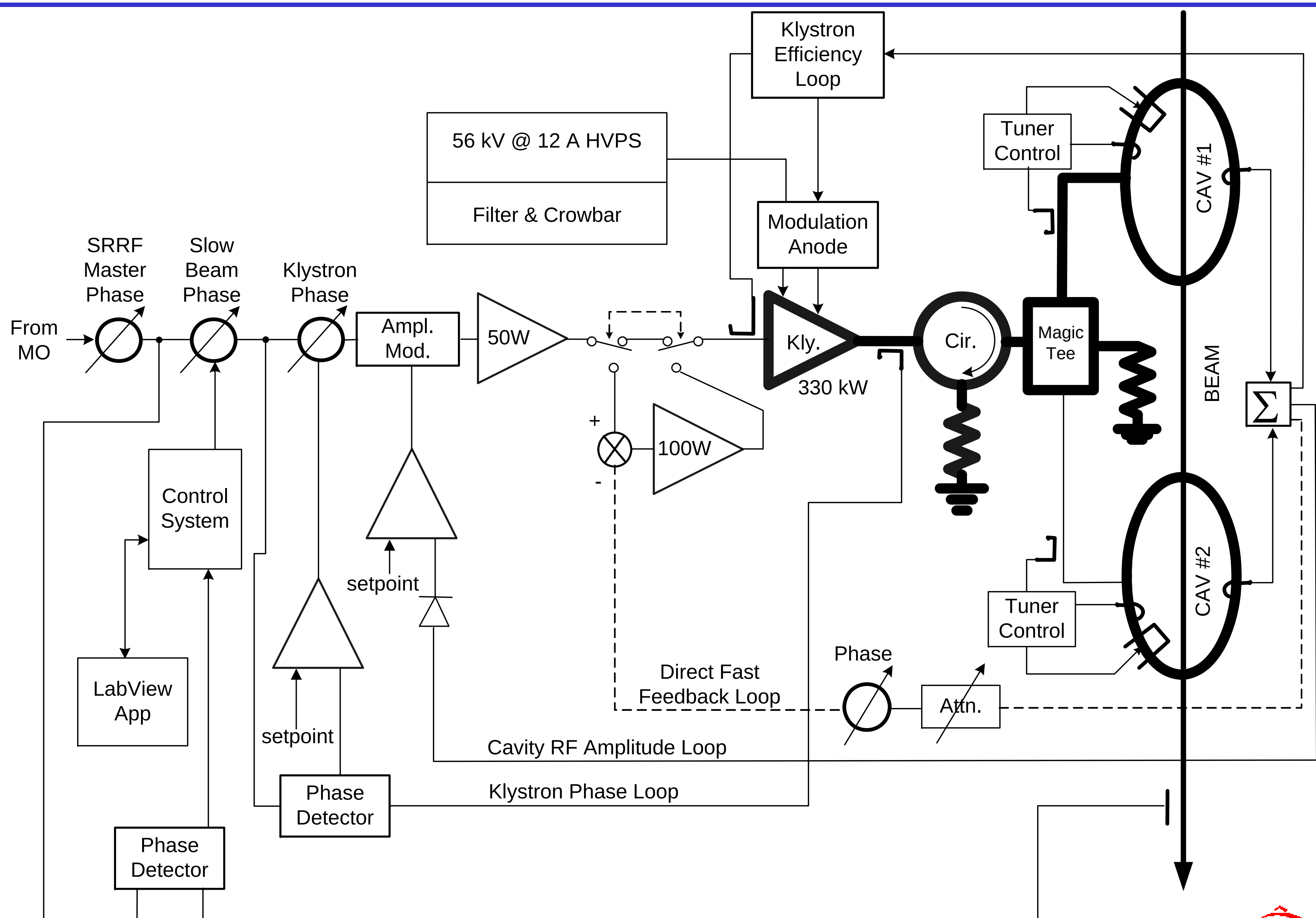

SR08
SR09
SR07
1.9 GeV STORAGE
RING SYNCHROTRON
SR10
BR SECTOR 1
LTB
SR06
BR SECTOR 4
BR SECTOR 2
SR11
BTS
BRF
BR SECTOR 3
SR05
50 MeV
LINAC
1.9 GeV BOOSTER
SYNCHROTRON
SR12
SR04
SR RF
3rd HC
SR01
SR03
SR02

Storage Ring RF System Parameters for 1.9 GeV

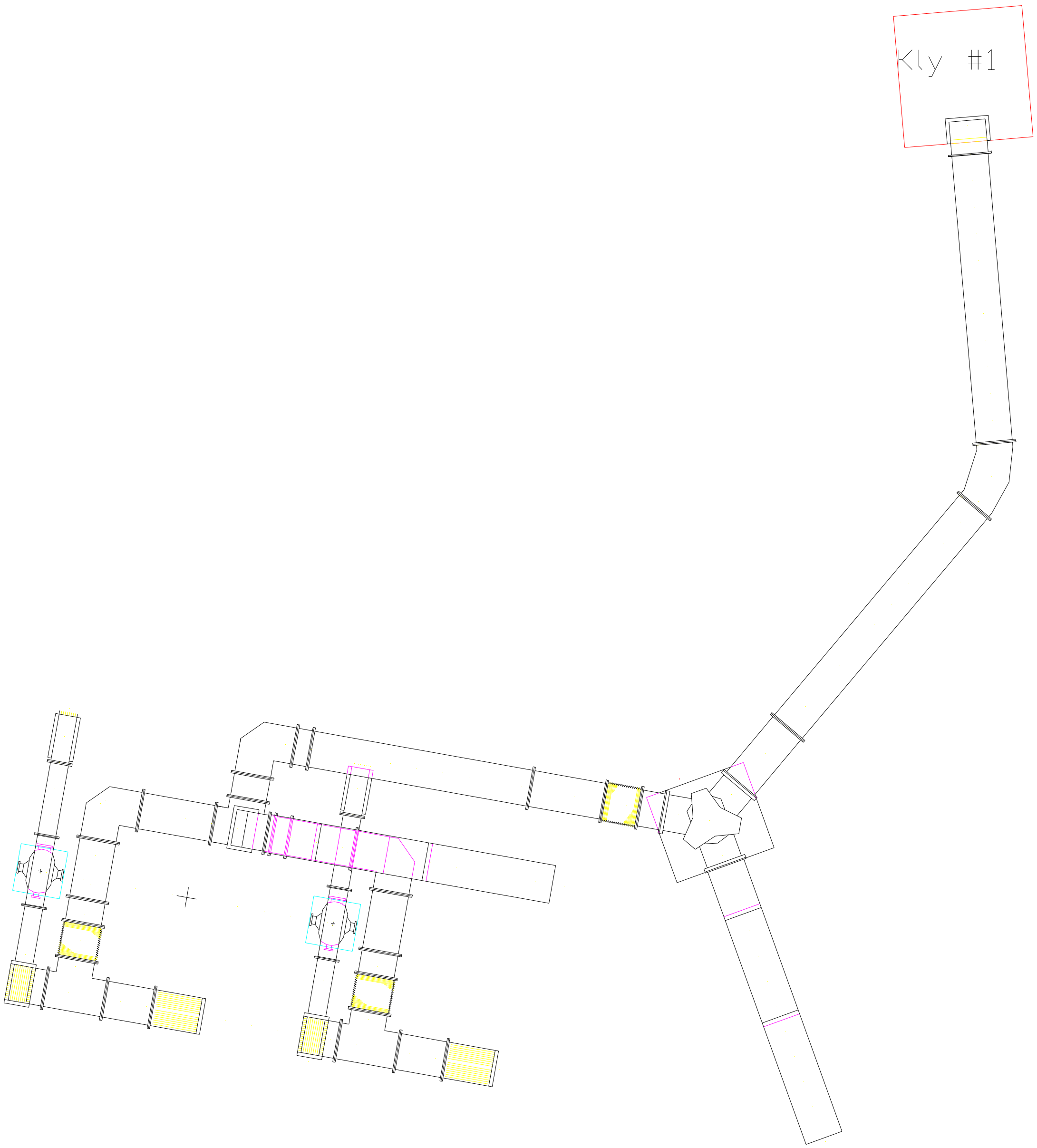
Frequency (MHz)	499.64	499.64
Harmonic number	328	328
Peak effective voltage (kV)	656	693
Beam current, multibunch mode (mA)	400	500
Synchrotron radiation loss, dipoles, ID (kW)	132.5	165.6
Power loss for 3rd HC, parasitic mode (kW)	8.1	8.6
Total effective shunt impedance, ZT^2 (MΩ)	5	5
Fundamental-mode cavity dissipation (kW)	43	48
Waveguide and other losses[a] (kW)	7.5	9
Total RF power (kW)	234	279.2
Total RF power installed (kW)	330	360

[a] estimated to be ≤ 0.15dB transmission loss

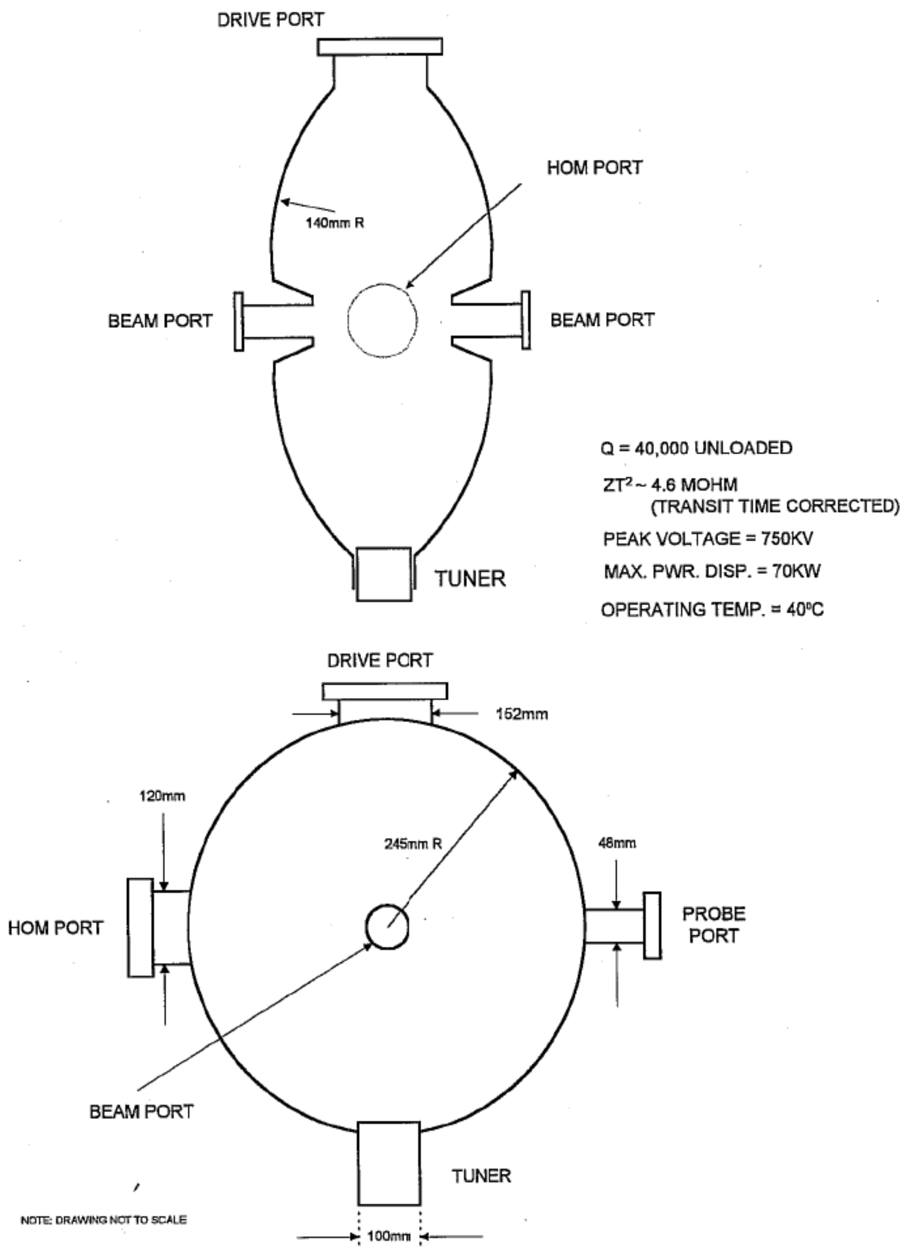
Existing SR RF System Block Diagram



Existing SR RF System Layout



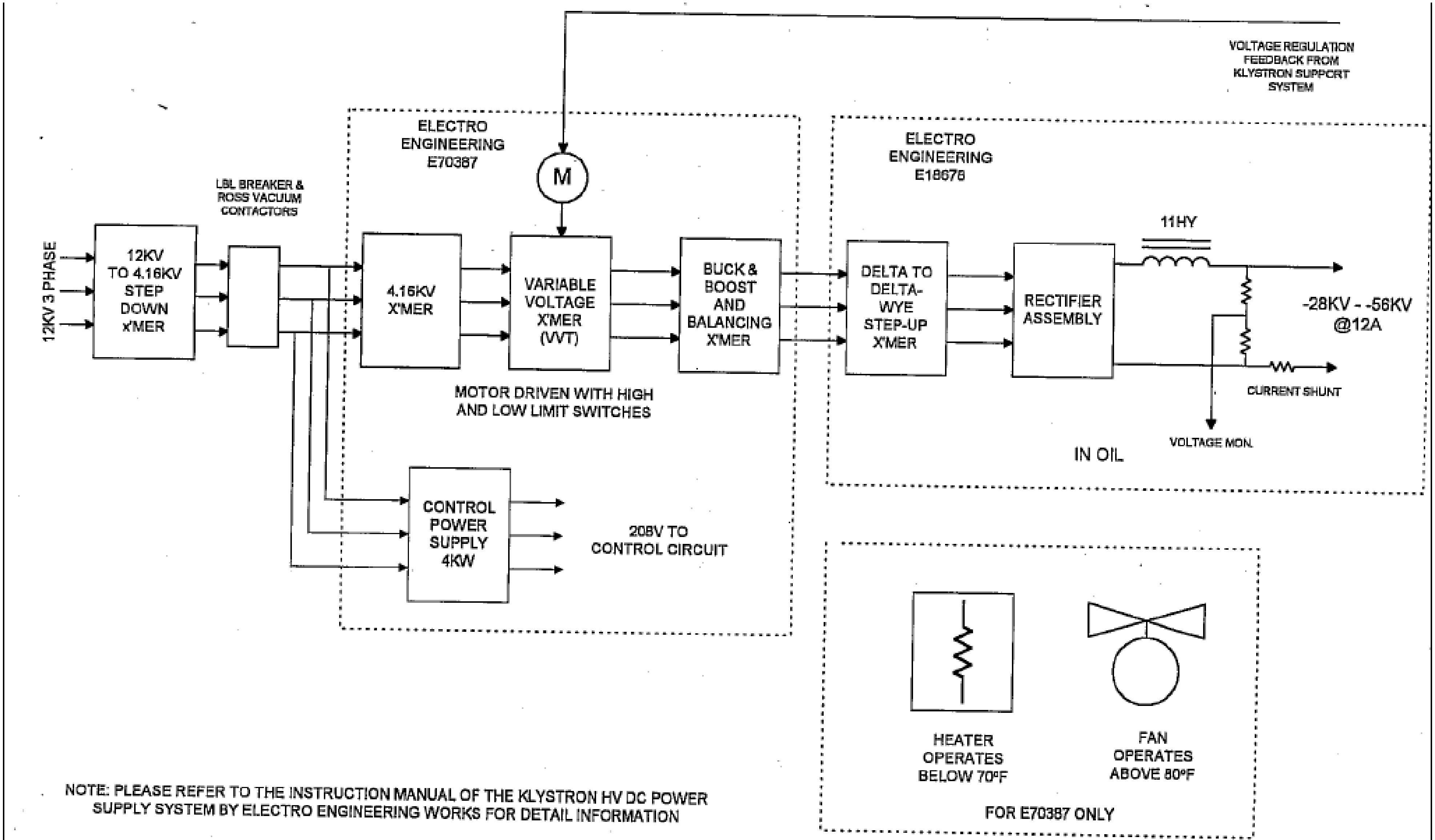
SR RF Cavities



SR RF System Layout

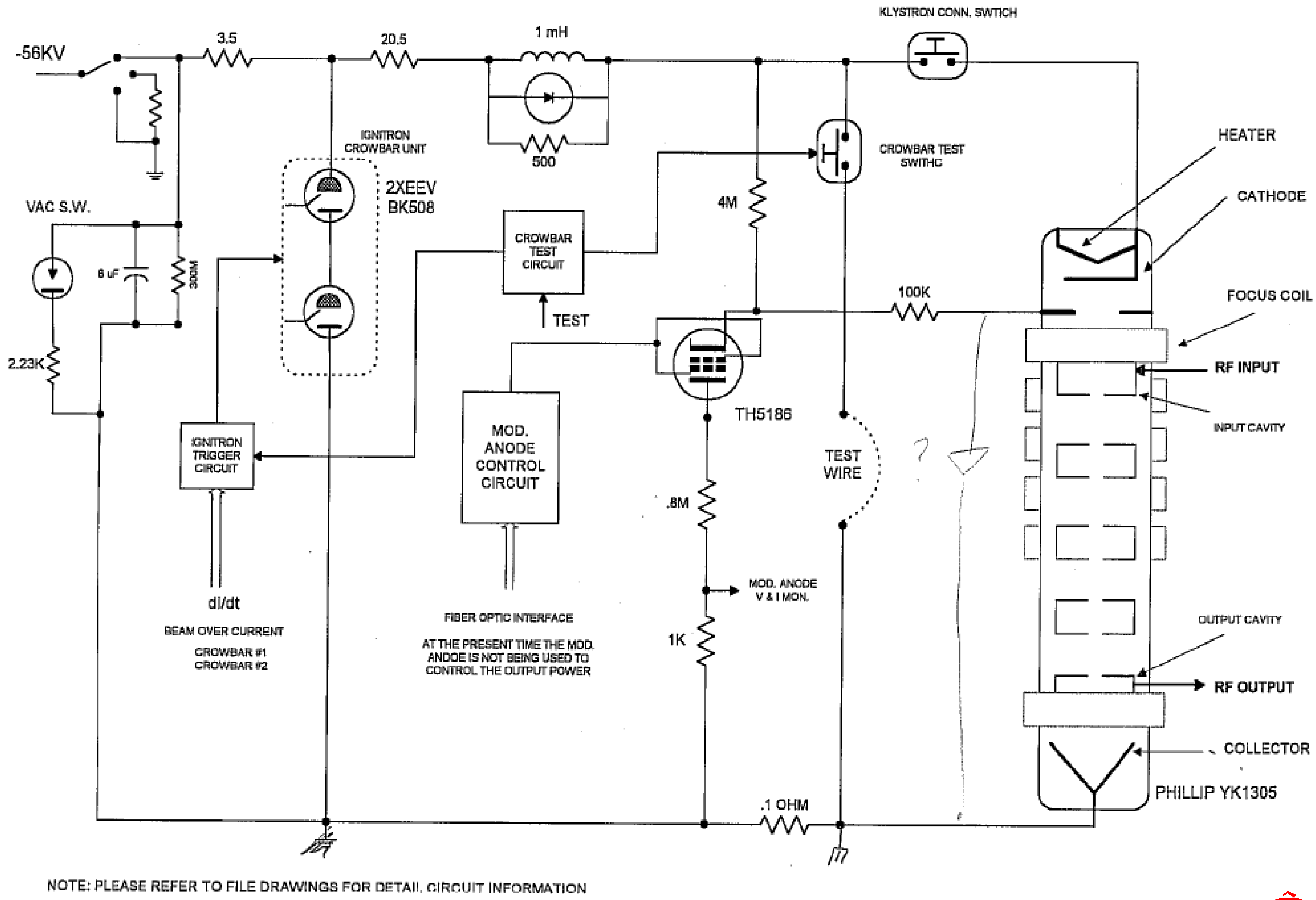
SR RF Klystron & HVPS Filter/Crowbar Cabinet

SR RF HVPS



ALS SR KLYSTRON HV POWER SUPPLY SYSTEM (OUTDOOR UNIT)

SR RF HVPS Filter & Crowbar System

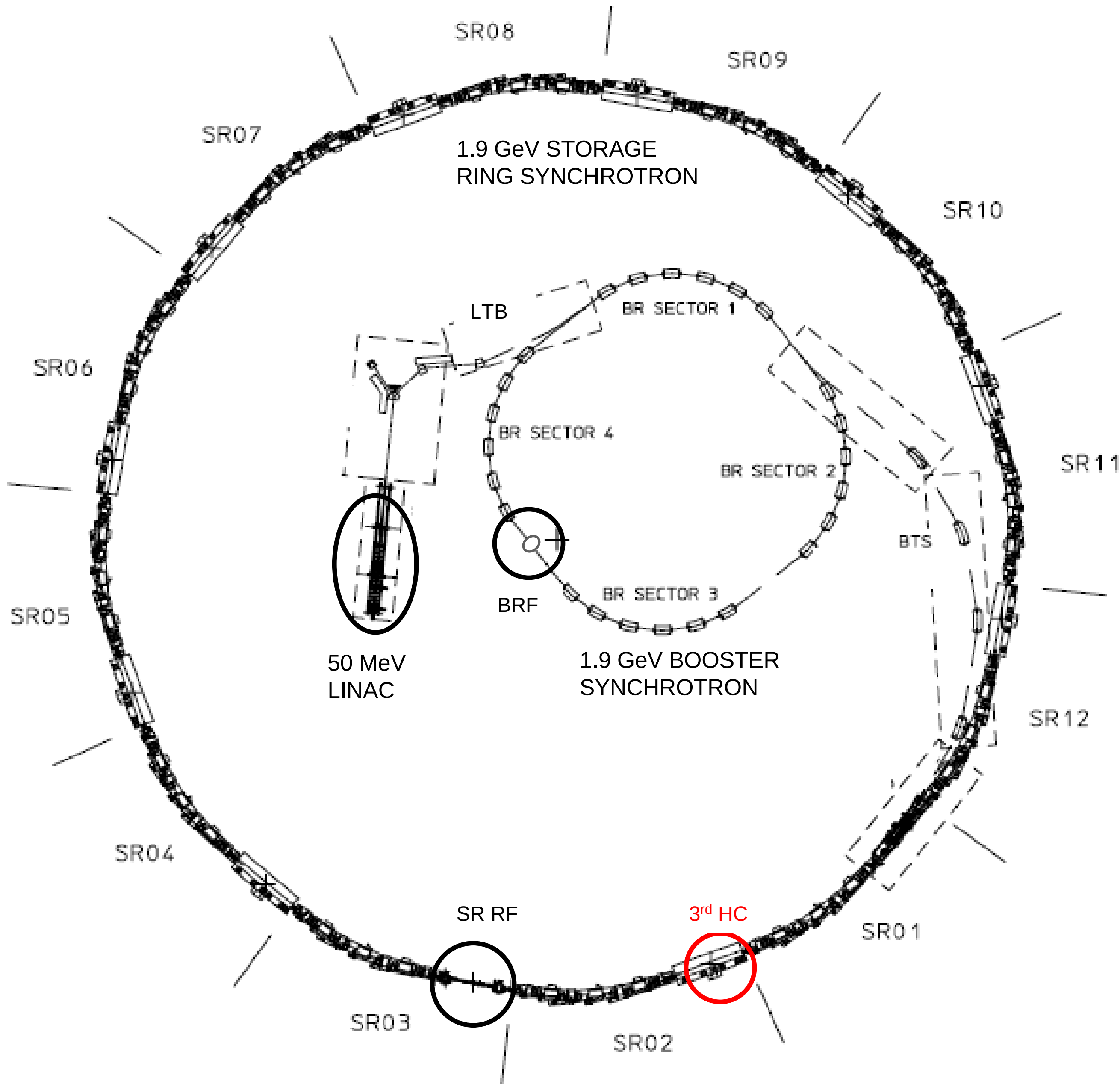


SIMPLIFIED CIRCUIT DIAGRAM FOR THE ALS SR KLYSTRON AMPLIFIER

SR RF HVPS


HVE01
SR - RF -HVPS
CONTROL EQUIPMENT
AND JUNCTION BOX
HVJ01
SR-RF-HVPS
PULL CAN

3rd Harmonic (Landau) Cavities System

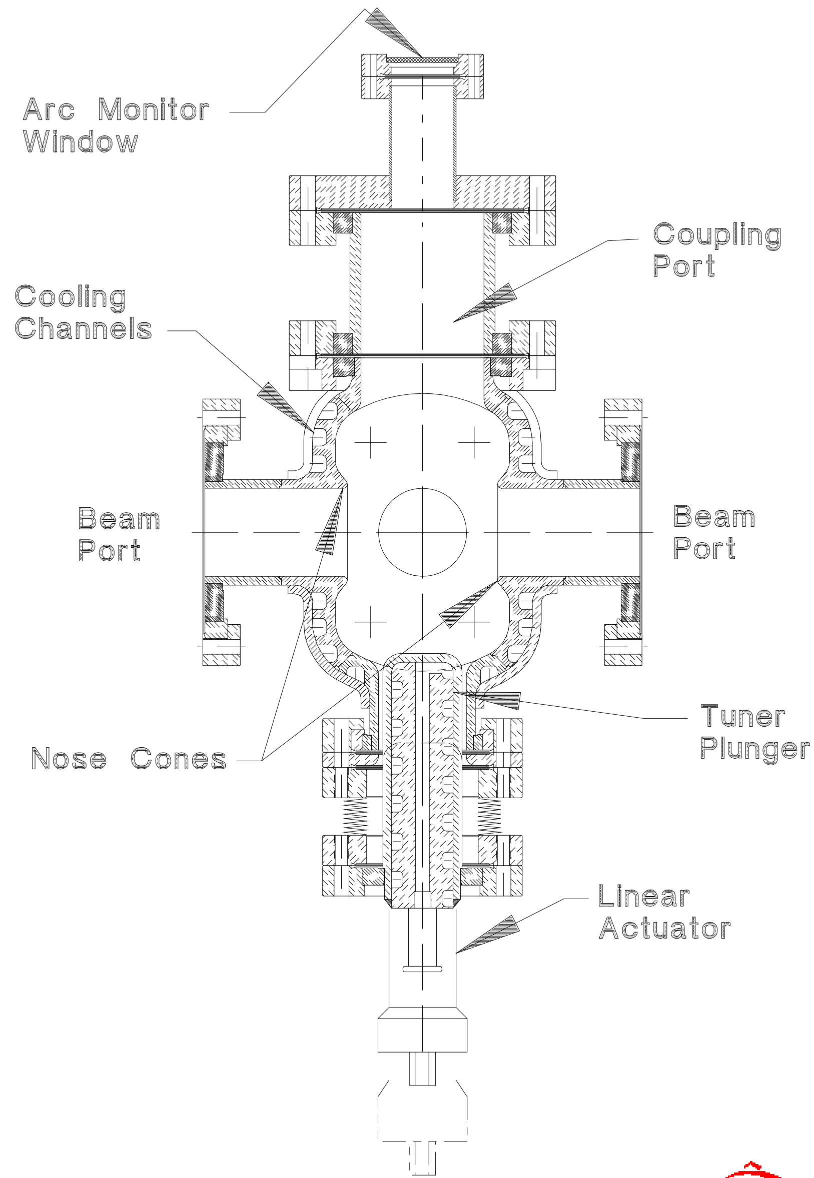


3rd Harmonic (Landau) Cavities System

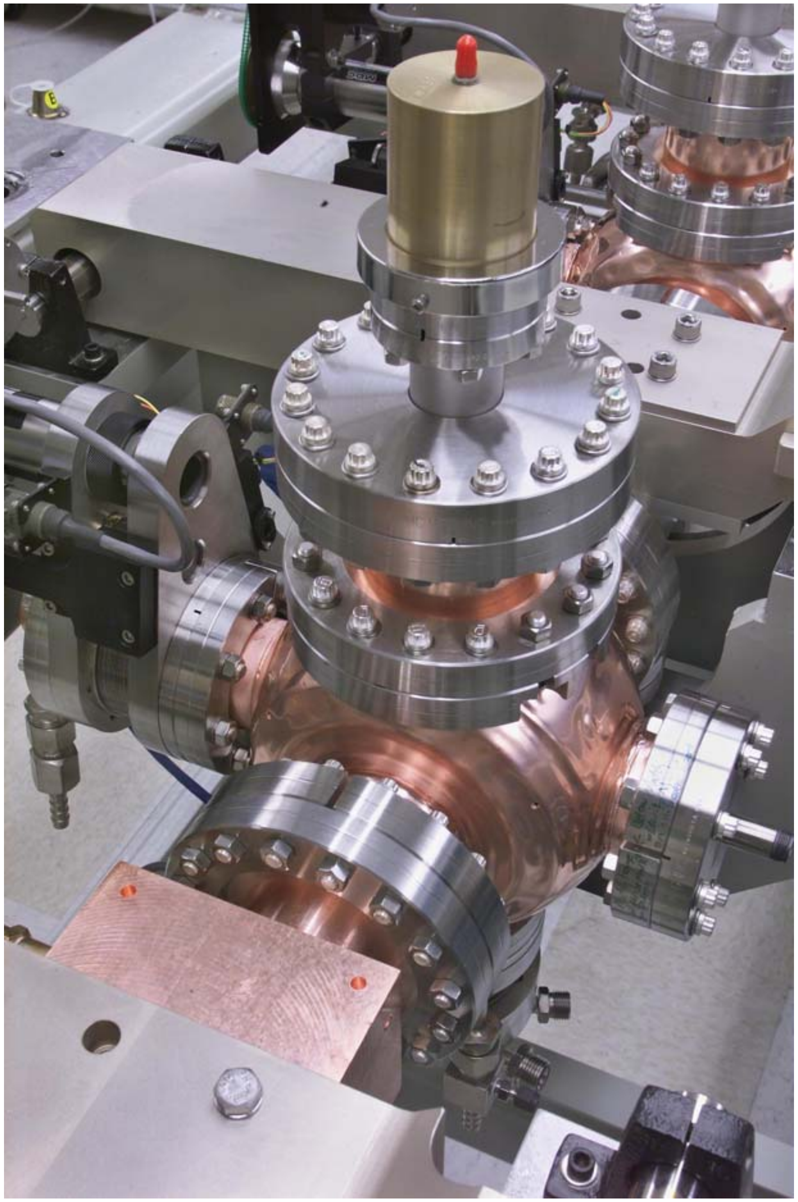
Table 1: Harmonic cavity system parameters

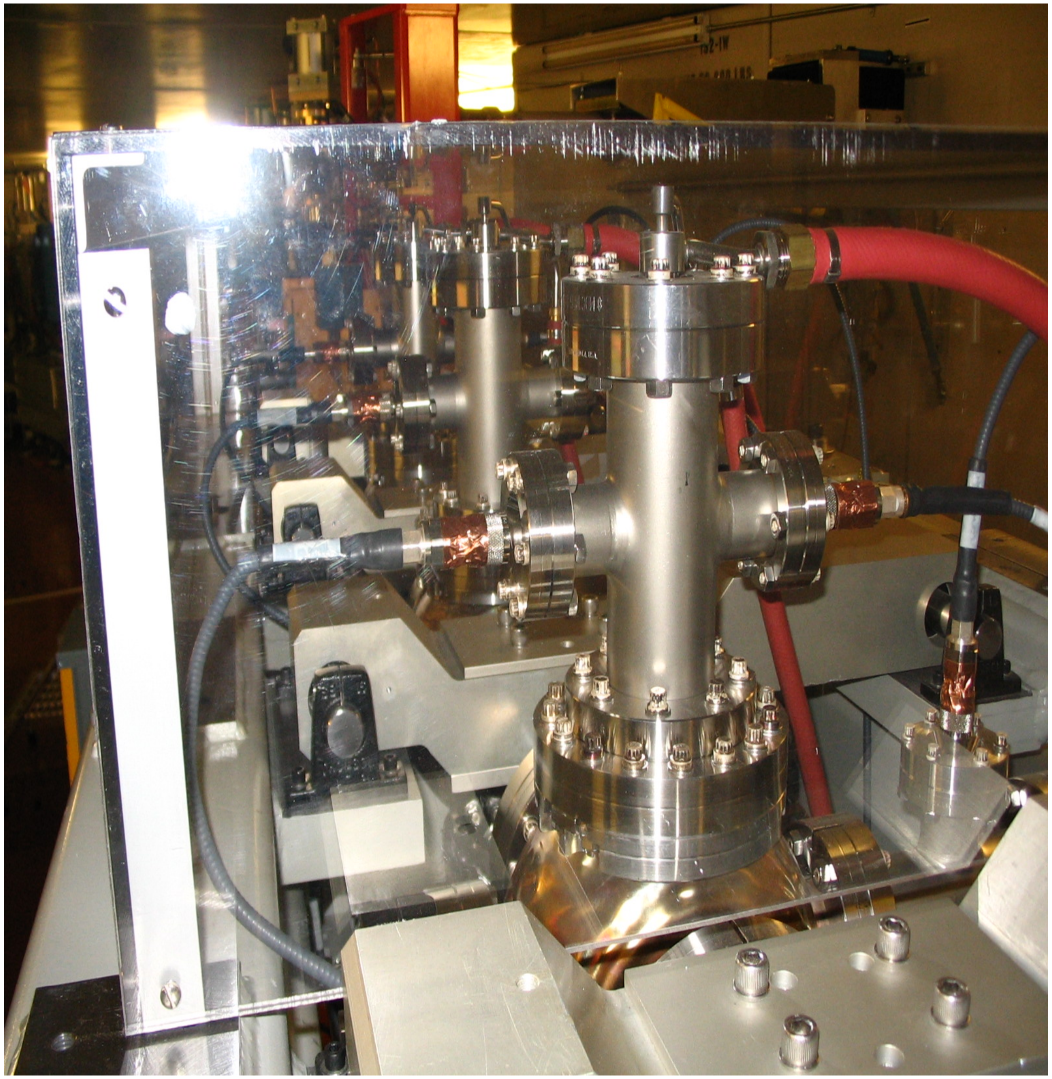
Frequency	1.5 GHz
total voltage	500 kV
bore diameter	5 cm
cavity R/Q*	80.4
calc. Q	27677
calc. Rs	2.23 MΩ
Rs x 70%	1.56 MΩ
number of cells	4
power per cell	5.01 kW

*$R=V^2/2P$

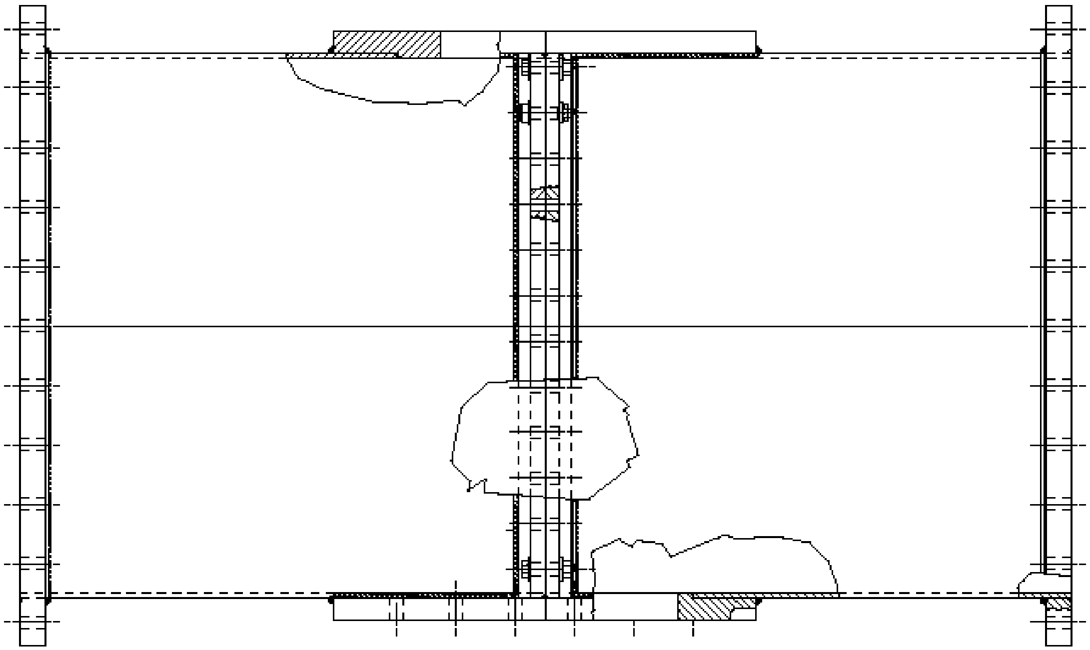


3rd Harmonic (Landau) Cavities System

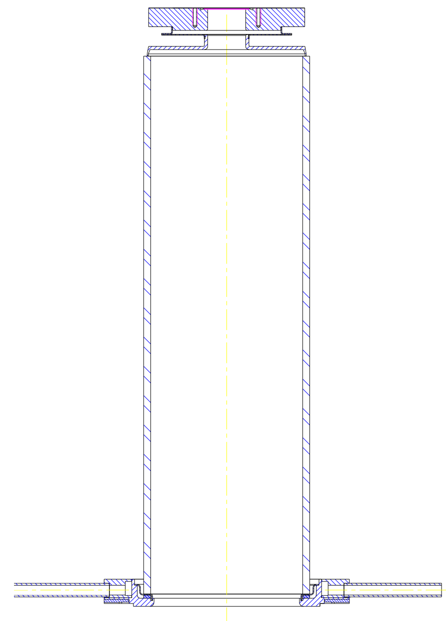




Bldg. 27 RF Cavity Teststand, RF Window Development

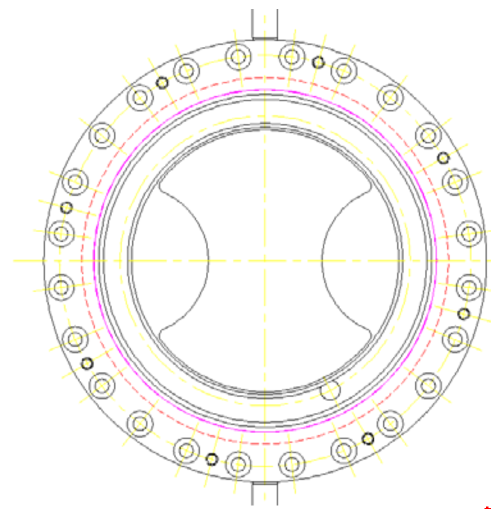


Split WR1800 Waveguide to Cavity Transition



<u>Current Design:</u>

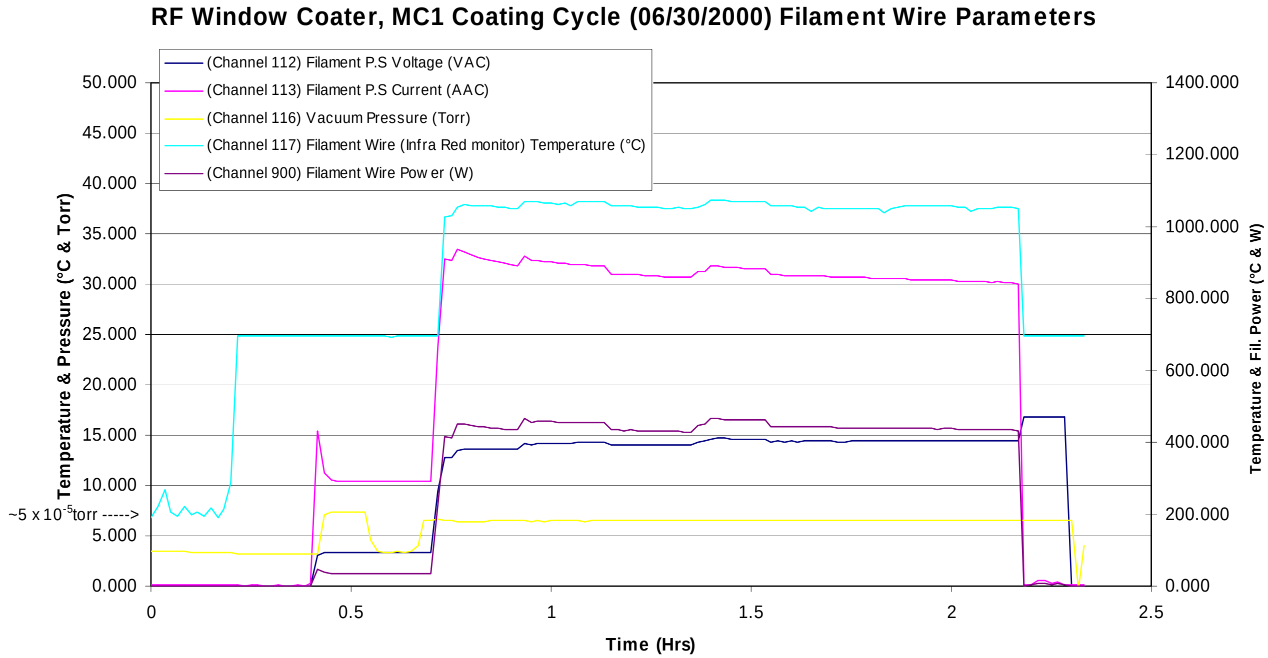
- 2 in SRRF operating at 43kW CW, 1 fully tested spare
- Manufacture(E2V), TiN coating & test to 66KW CW at LBNL
- **2 RF windows manufactured, awaiting TiN coating and power testing.**
- **1 Split waveguide section manufactured, awaiting testing.**
- **Will use current disc-type window (Daresbury), which is capable of 40kW avg.**

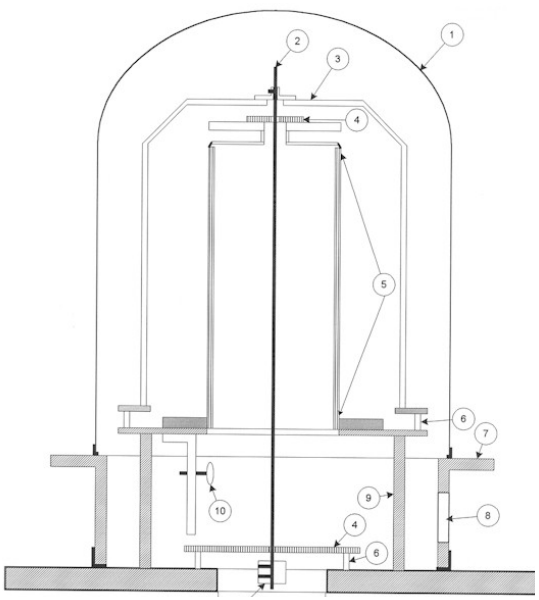


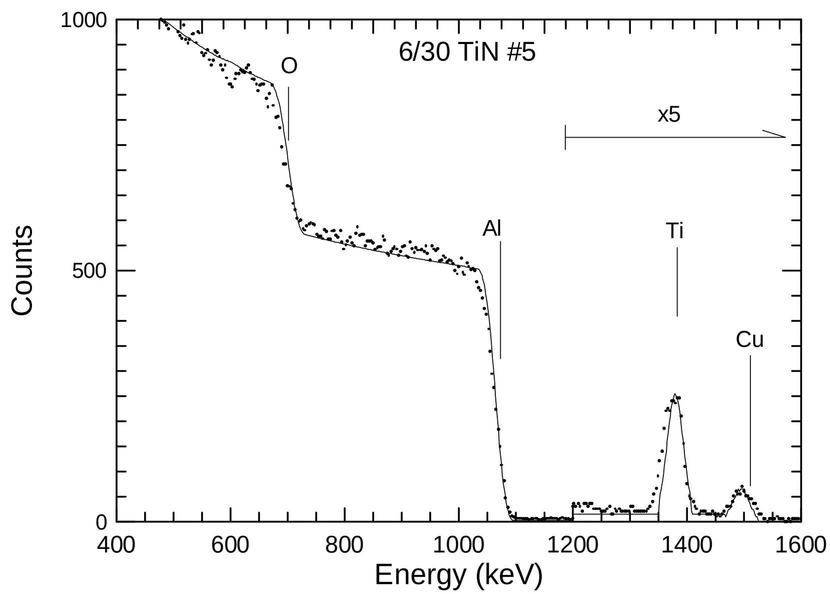
Iris Flange Profile

β: 0 to 3.2

Bldg. 27 RF Cavity Teststand, Titanium-Nitride Coating



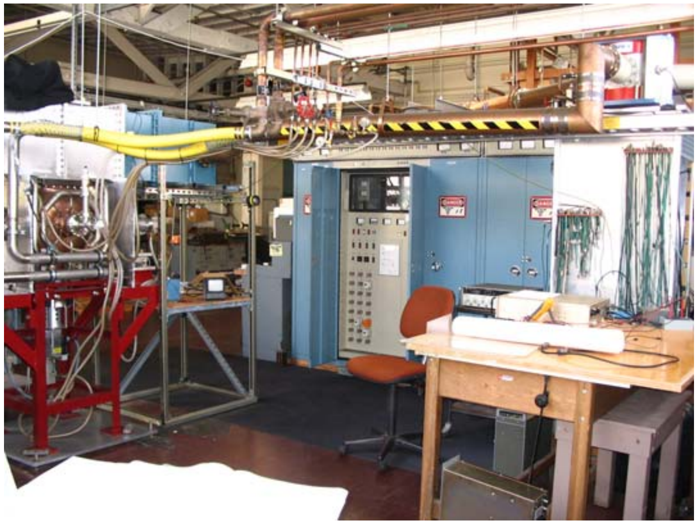




Coating thickness determined by Rutherford Back Scattering (RBS) performed on site at LBNL.

This sample measured 15 angstroms. Our target range is 10 – 20 angstroms.

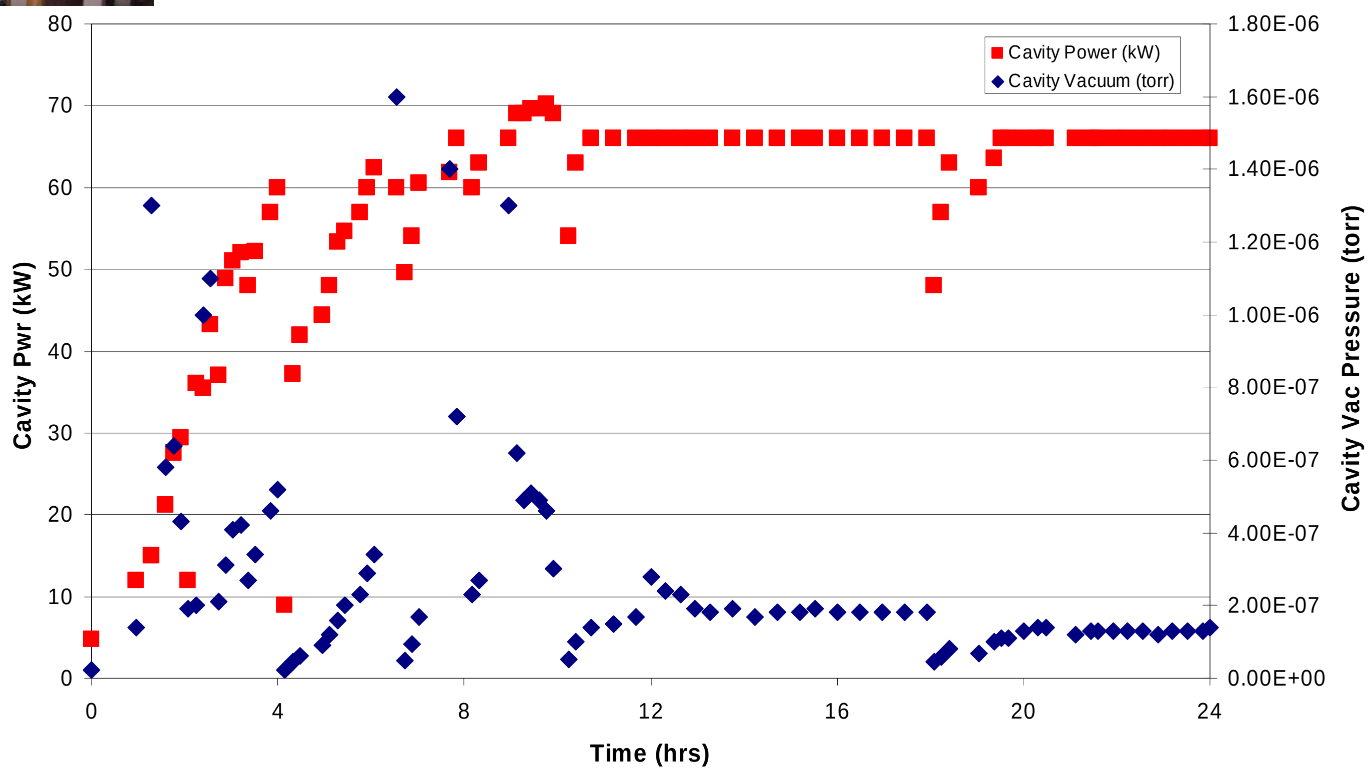
Bldg. 27 RF Cavity Teststand, Power Test/Condition Window



B27 Cavity Teststand, 66kW @ 500MHz

- Identical cavity to Booster and Storage Ring

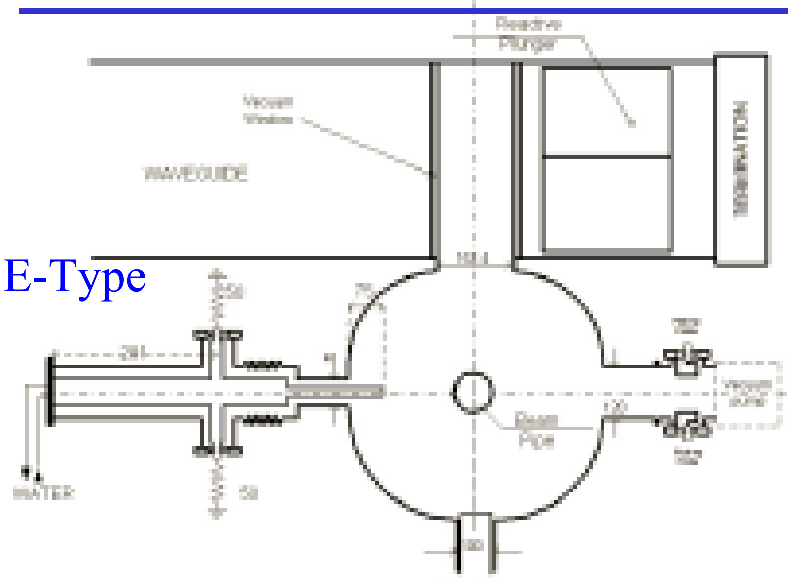
MC1 Power Test & Conditioning Cycle



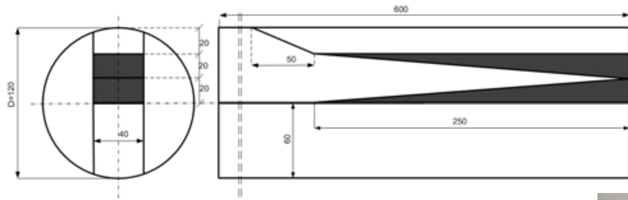
- Power Conditioned in 24 Hrs over a 4 day period.
- 21 Rev Pwr Trips
- 5 Vac Trips
- Window Temp ran < 80°C

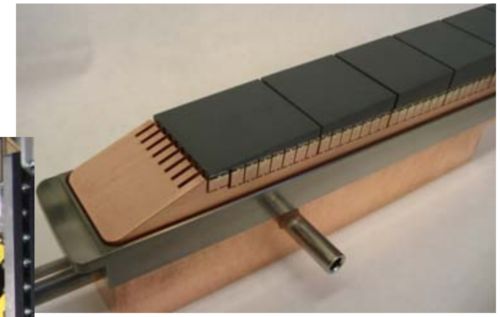
HOM Dampening in Fundamental Cavities

E-Type



Ridged Waveguide Type





Longitudinal Modes

Without damper			With damper		
F	Q	R_{sh}	F	Q	R_{sh}
MHz	-	kΩ	MHz	-	kΩ
499.6	40400	5000	499.8	40000	4960
809	**38700**	**1970**	**810.6**	**100**	**5.1**
1026.6	8250	9.9	1027.1	940	5.9
1310.8	10300	159	1327.8	280	4.3
1353.4	4000	39.2	1379.5	110	1.1
1554.1	5600	41.4	1560	940	7.0
1808.5	2850	13.1	1806.5	240	1.1
1883.7	1650	4.6	1886.2	540	1.5
2130.4	16800	58.8	2129.6	7200	25.2
2271.6	1800	6.8	2274.3	1500	6.5
2350	27500	99	2348.1	16300	58.7
2850	33500	142	2850	5360	22.8

Dipole Modes

	Without damper				With damper			
Mode	F_H	Q_H	F_V	Q_V	F_H	Q_H	F_V	Q_V
	MHz	k	MHz	k	MHz	k	MHz	k
1-M-1	707	36.2	708.4	46.5	723	2.8	709	44.2
1-E-1	810	51.1	796	0.9	811	48.3	796	0.9
1-M-2	1122	7.4	1123	38.1	1102	2.1	1123	38.1

HOM Dampening in Fundamental Cavities

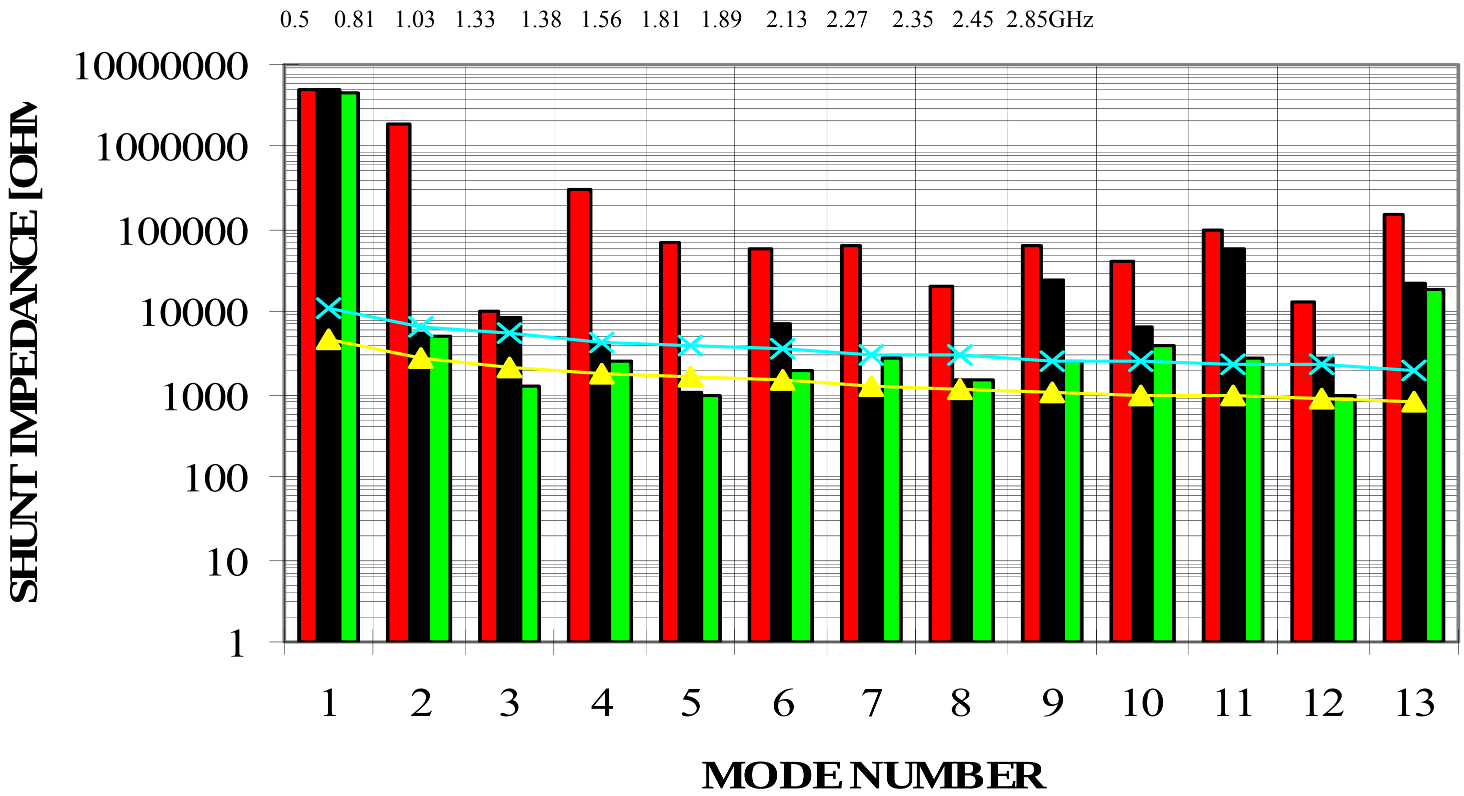
Longitudinal HOM spectrum of the ALS main RF cavity

red-no dampers

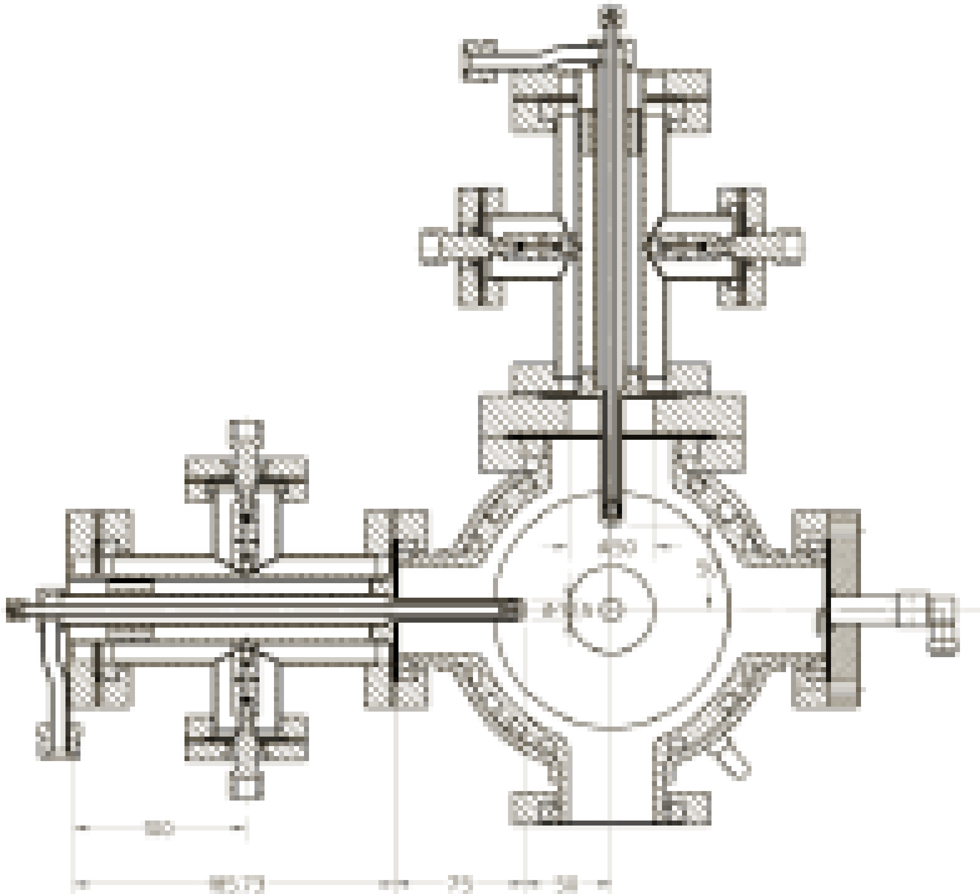
black-with E-type HOM damper

green-with E-type and waveguide dampers

blue/yellow lines- ALS long. stability threshold for 1.9/1.5 GeV



HOM Dampening in 3rd Harmonic Cavities



Single odd longitudinal mode (TM_{011}) effectively damped by one E-type damper

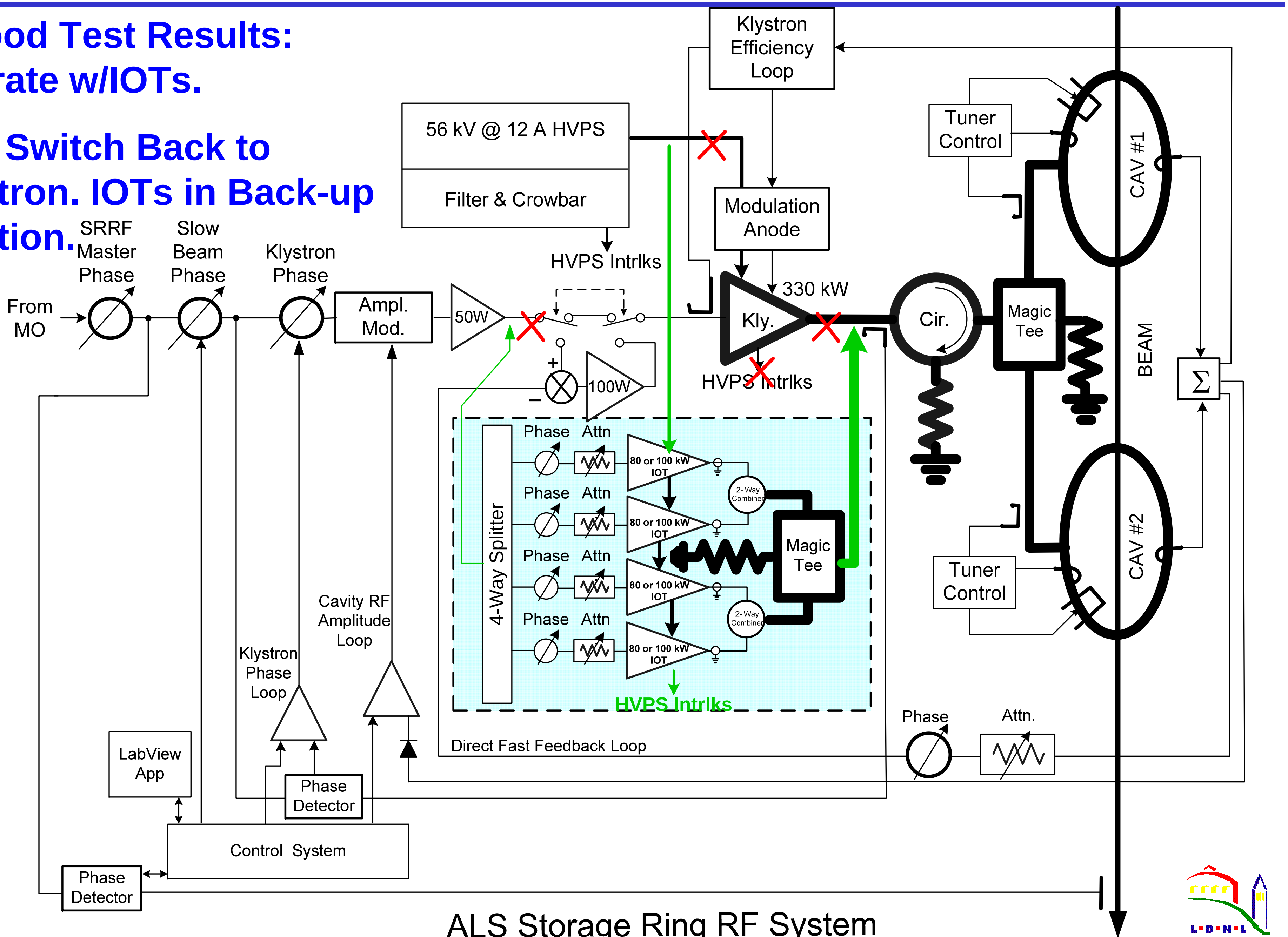
Storage Ring RF System Upgrade

- Transmitter Installation (Step I)
- HVPS Modification (Step II)
  - Crowbar Replacement with HV IGBT Switch
- LLRF Upgrade (Step III)

UPGRADE: STEP I (2009 SHUTDOWN)

If Good Test Results: Operate w/IOTs.

Else Switch Back to Klystron. IOTs in Back-up Position.



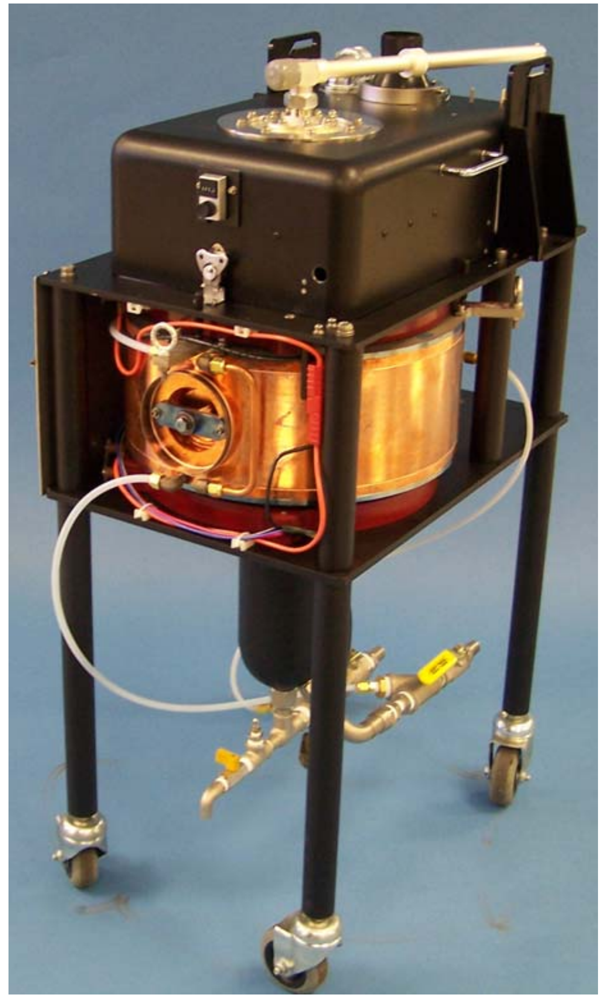
UPGRADE: STEP I (2009 SHUTDOWN)

AI, Acrodyne Industries

(commercial broadcast transmitter, modified)

CPI, Communications & Power Industries

(commercial broadcast IOT, K5 series, 90kW)



Gain >23 dB

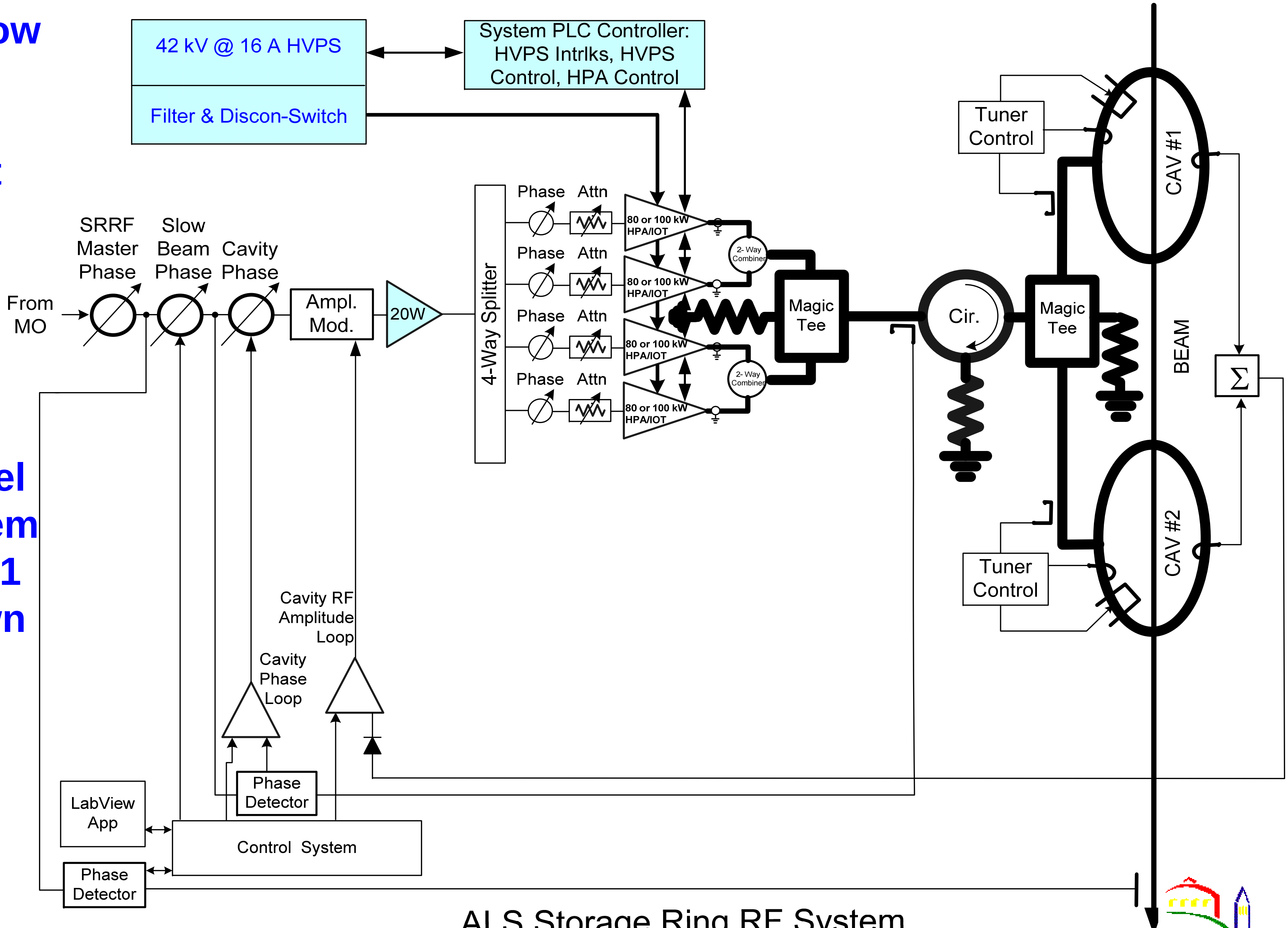
Eff. >70 %

E_B <40 kV

UPGRADE: STEP II (2010 SHUTDOWN)

If New Low Level RF System Ready: It will be Installed

Else will run Existing Low Level RF System Until 2011 Shutdown

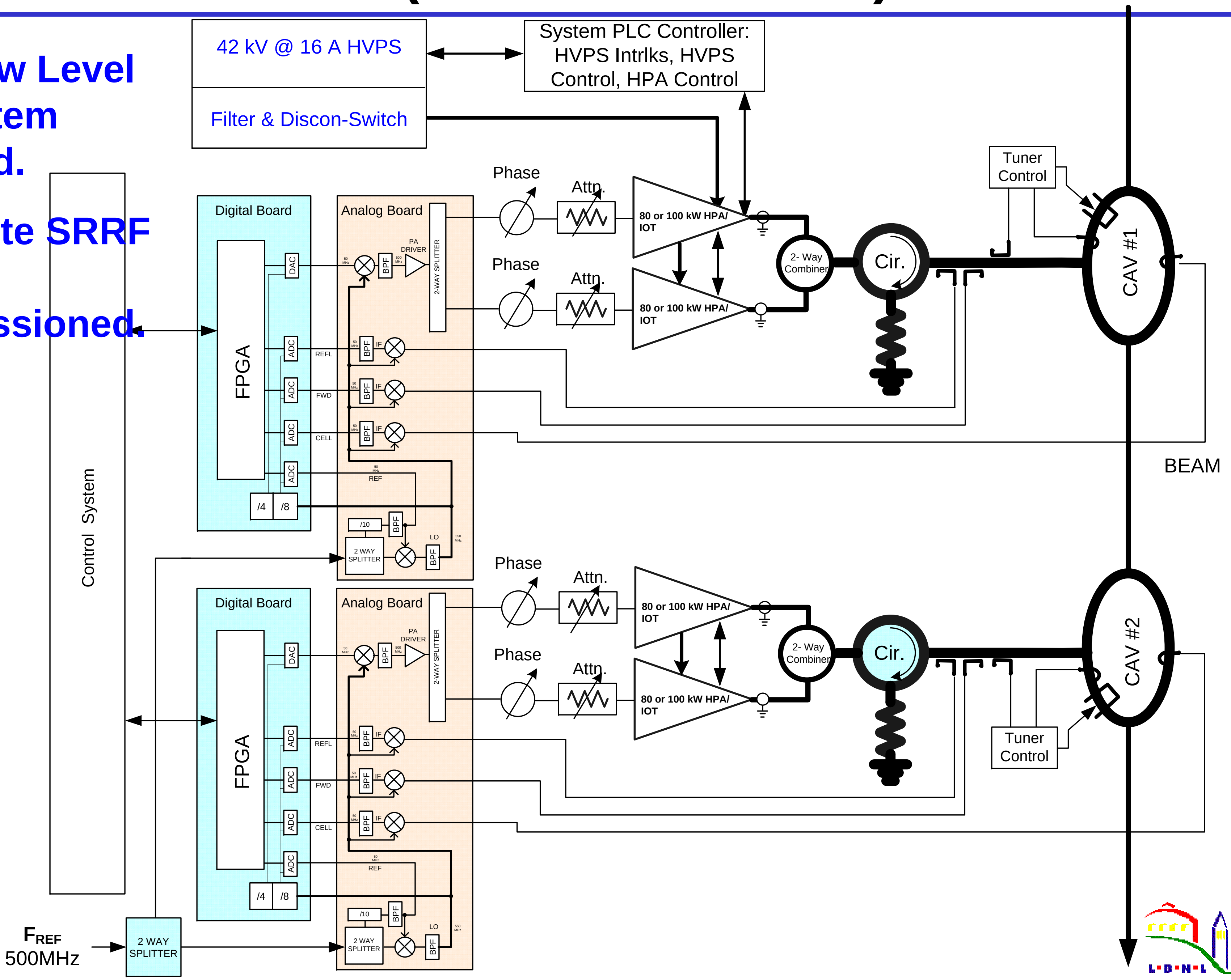


ALS Storage Ring RF System

UPGRADE: STEP III (2011 SHUTDOWN)

New Low Level RF System Installed.

Complete SRRF System Commissioned.



High Voltage Power Supply & HV Switch Upgrade

- **High Voltage Power Supply for the Y1305 Philips Klystron**
  - ➢ **Classical layout, 12 pulses rectifier with a Voltage Variable Transformer (VVT)**
  - ➢ **DC Output Voltage regulated from -30 to -56kV with stability within +/-0.5%**
  - ➢ **Current Rating of the unit is 12A DC**

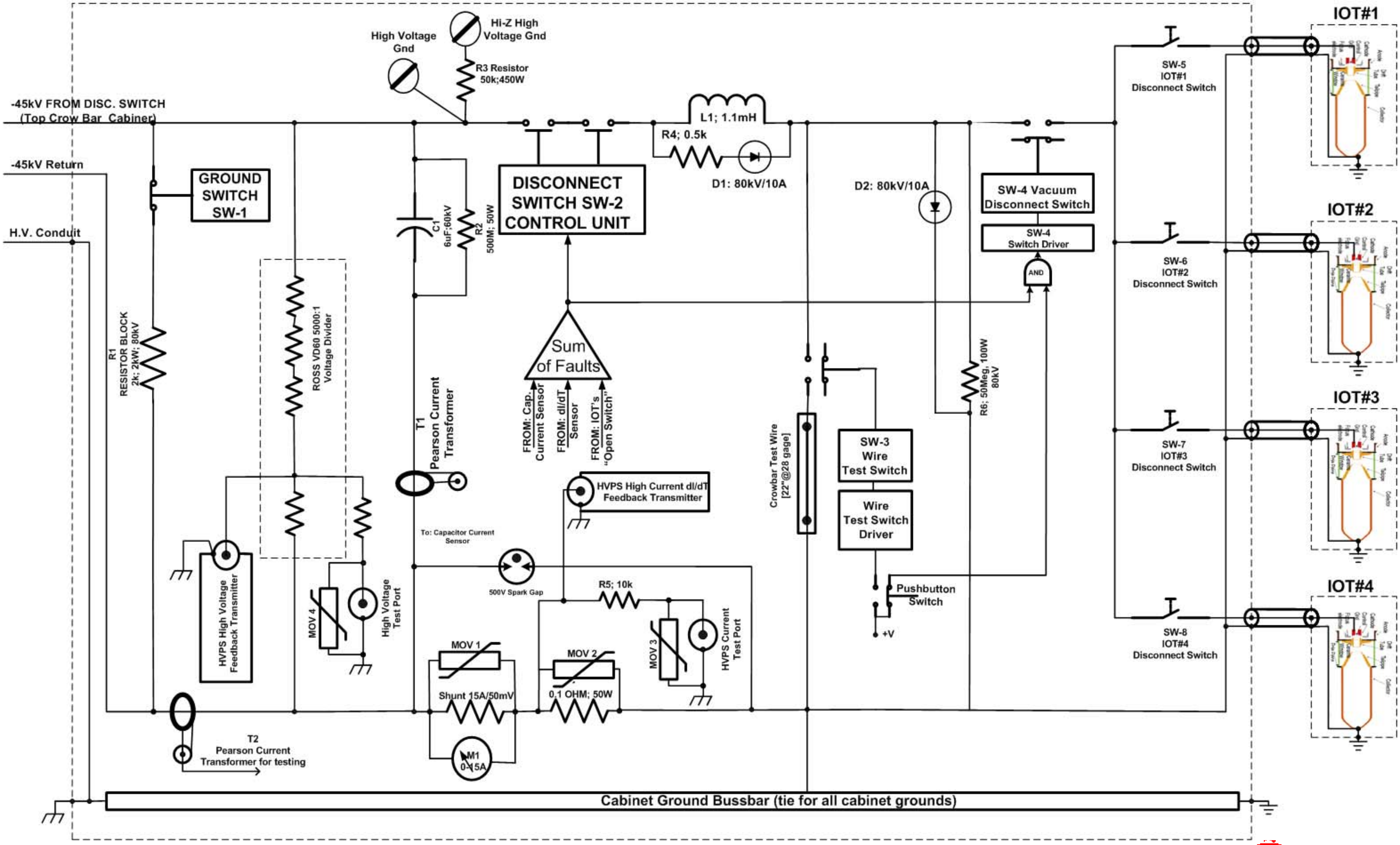
Since the unit was very reliable for over 16 years of operation and we have a full set of spare parts, there is no reason to replace it for an upgraded system. The only inconvenience we will experience during the first year (Step I) of operation of the new system is the 12A dc current limit which will slightly limit maximum power available from the IOT based Power Amplifier (PA) unit.

- **Upgrade**
  - ➢ **During the second phase of the upgrade the final HVPS transformer will be replaced by one with a lower voltage transformation ratio and the same power rating as the old one which will eliminate the PA power limitation problem.**
  - ➢ **The existing relay-based HVPS control system will be replaced by a PLC-based integrated PA logic control system.**
  - ➢ **Lastly during the second stage of the SRRF system upgrade, the existing ignitron based Klystron Crow-Bar system will be replaced with an in-house made High Voltage Disconnect Switch (HVDS).**

Crowbar System Replaced by IGBT Based HVDS

- **Advantages:**
  - ➢ **Lower stress during emergency action on HVPS components**
  - ➢ **Faster switching time**
  - ➢ **Simpler driving circuit**
- **Our new HVDS will use a stack of 16 IXYS 4kV 40A (170A peak) IGBTs**
- **The major operational challenge when using the stack of IGBTs is to maintain the equal voltage distribution across each unit in static and dynamic transient conditions.**
- **To achieve this goal our switch will be equipped with a simple RC voltage balancing circuit [1].**
- **Spice simulations indicated significant improvement in the voltage drop across the stack of 4 IGBTs in the function of the unequal gate drive delay.**
- **Each IGBT unit will be driven by a single MOTOROLA MC33153 gate driver with an active desaturation protection.**
- **Optoisolators will be used to deliver the triggering signals to the IGBT gate drivers and to transfer output fault signals to the switch protection unit.**
- **The construction of the prototype of the 40kV, 20A unit is under way and the estimated cost of the switch will be a small portion of the cost of the commercially available unit.**

ALS Storage Ring RF System HVPS Disconnect Switch Cabinet



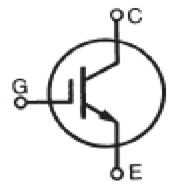
IGBT Data Sheet

IXYS Advance Technical Data

Very High Voltage IGBT

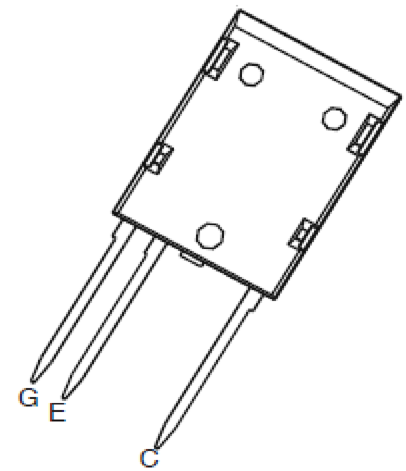
IXEL40N400

V_{CES}	=	4000	V
I_{C90}	=	40	A
$V_{CE(sat)}$	=	4.0	V
$t_{fi(typ)}$	=	450	ns



Symbol	Test Conditions	Maximum Ratings	
V_{CES}	T_J = 25°C to 125°C	4000	V
V_{GES}	Continuous	±20	V
I_{C90}	T_C = 90°C	40	A
I_{CM}	Limited by T_J	170	A
P_C	T_C = 25°C	380	W
T_J		-40 ... +125	°C
T_{JM}		125	°C
T_{stg}		-40 ... +125	°C
Maximum Lead temperature for soldering 1.6 mm (0.062 in.) from case for 10 s		300	°C
Maximum Tab temperature for soldering SMD devices for 10 s		260	°C
F_C	Mounting Force	30..170 / 7..36	N/lb
V_{ISOL}	I_{ISOL} < 1 mA, 50/60 Hz, t = 1 minute	2500	V~
Weight		10	g

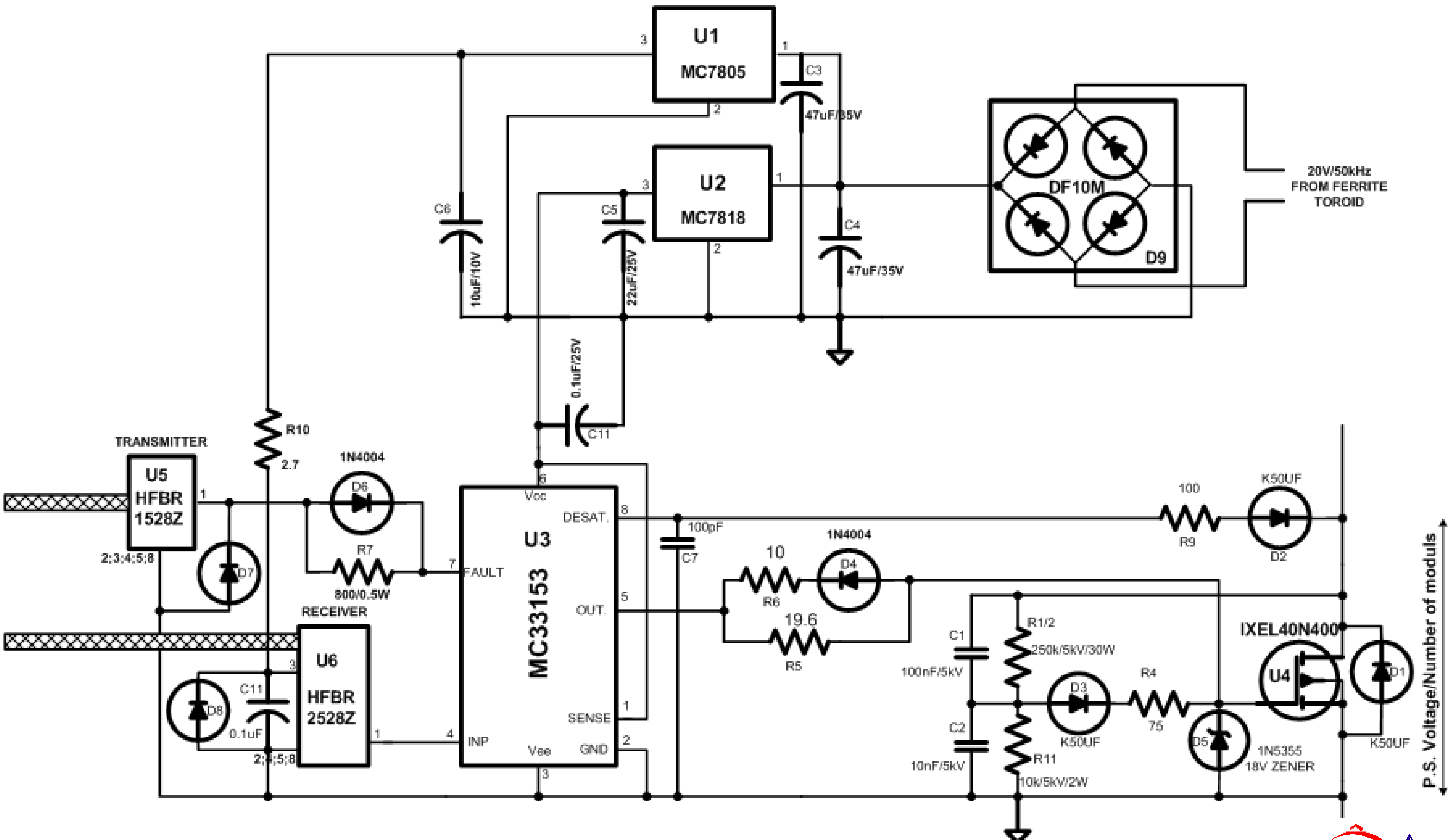
ISOPLUS i5 (HV)



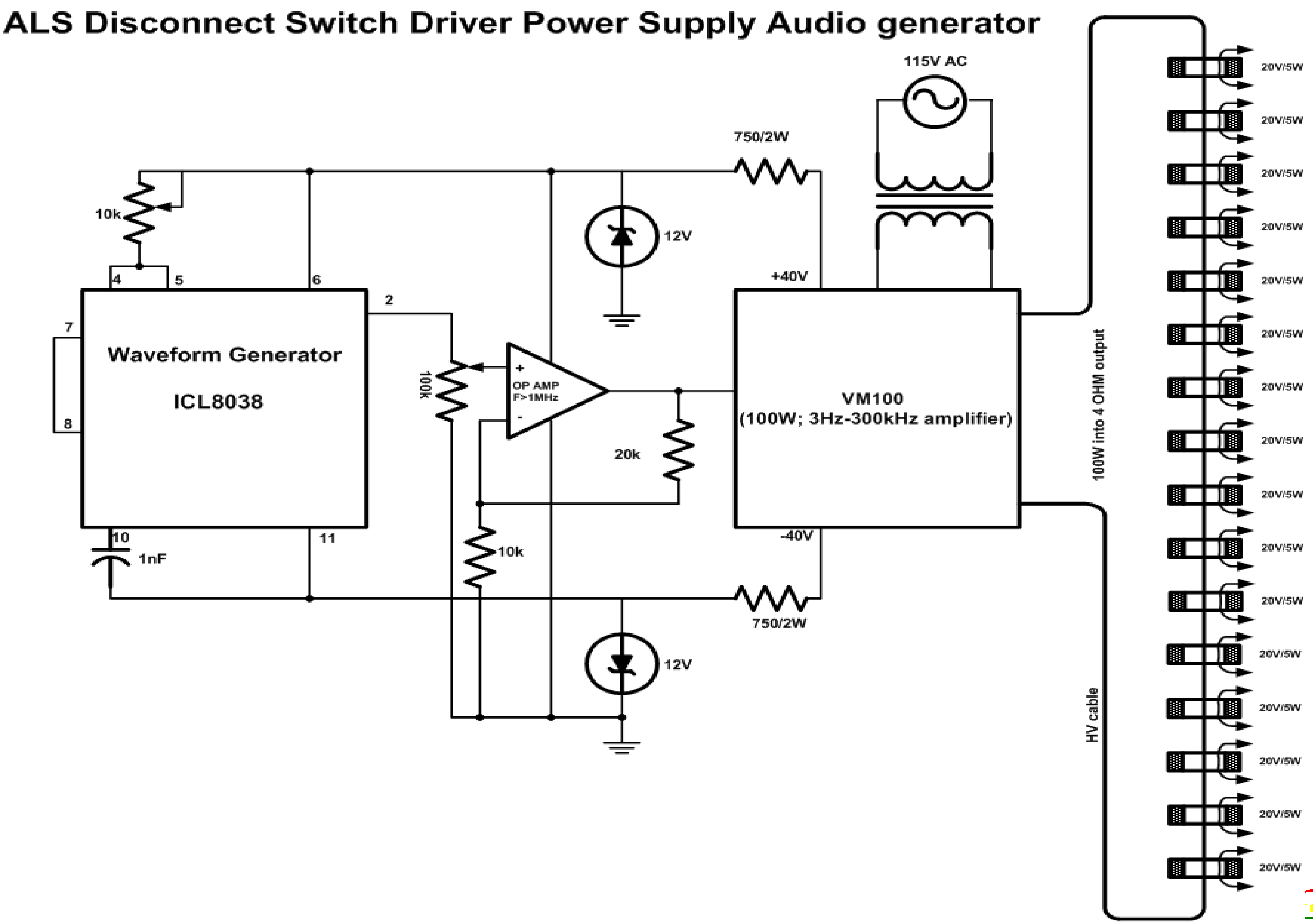
Features

- High current handling capability
- MOS Gate turn-on
  - drive simplicity
- Rugged NPT structure

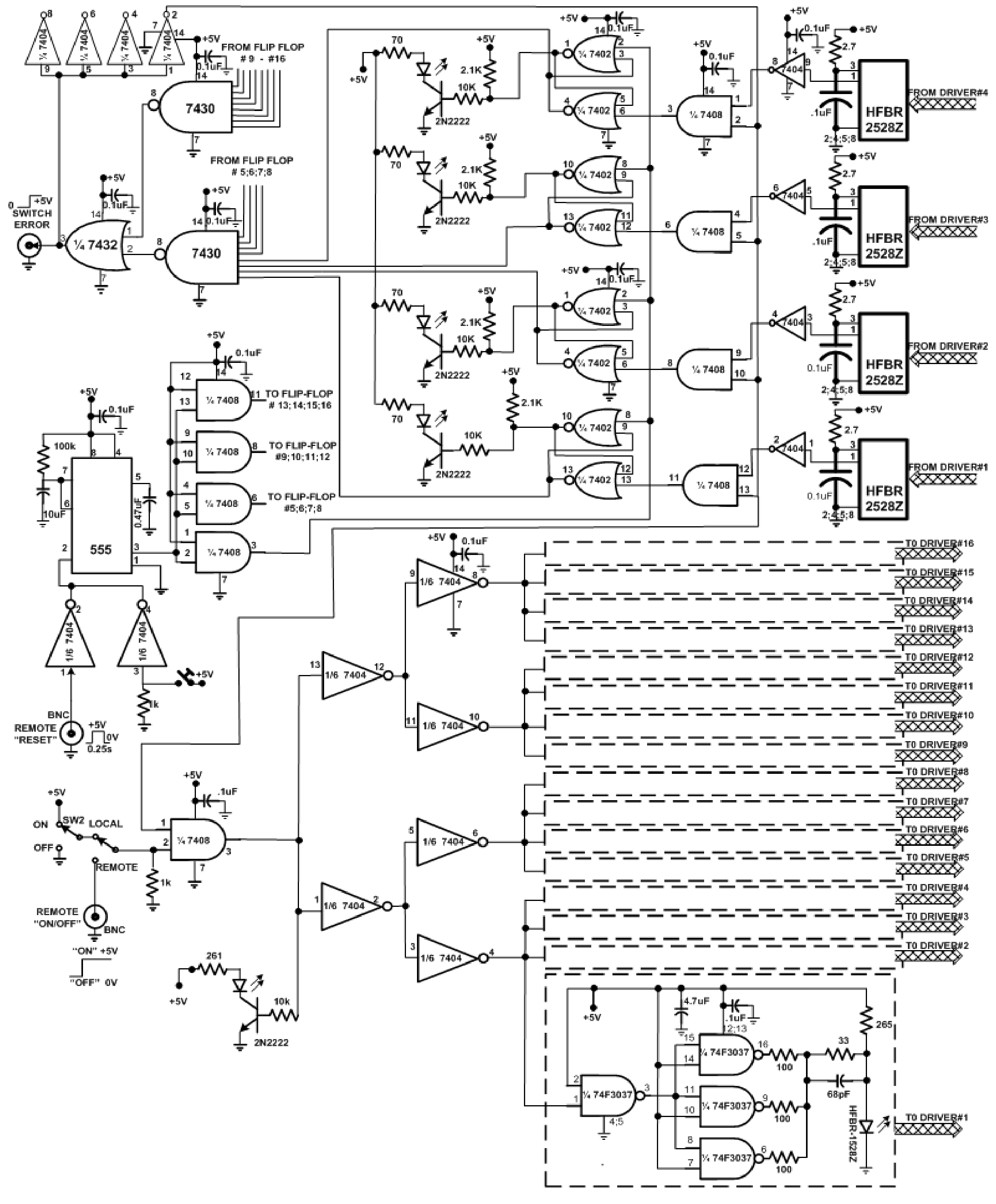
ALS DISCONNECT SWITCH IGBT DRIVER BOARD



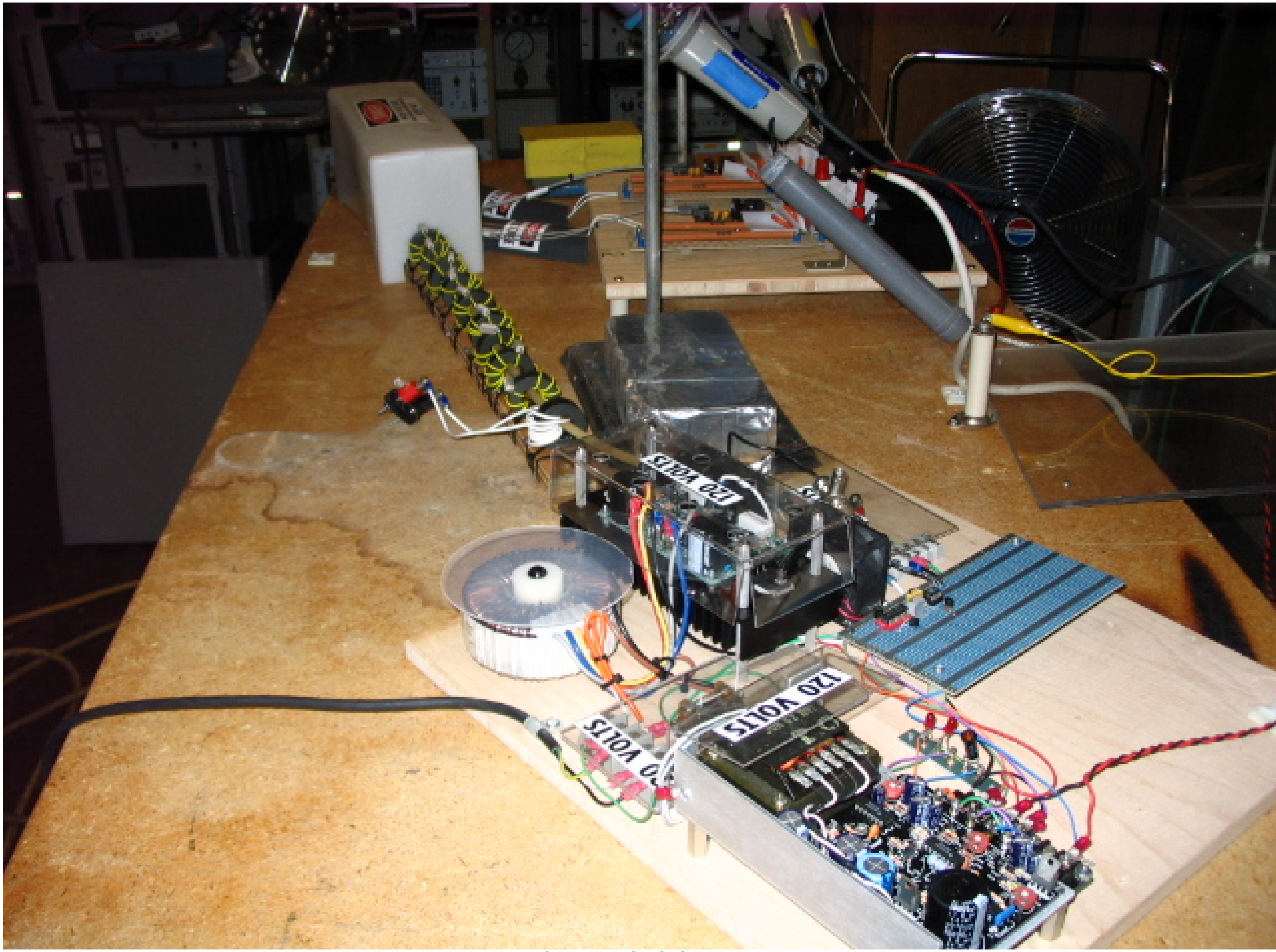
Driver Board Power Supply Unit



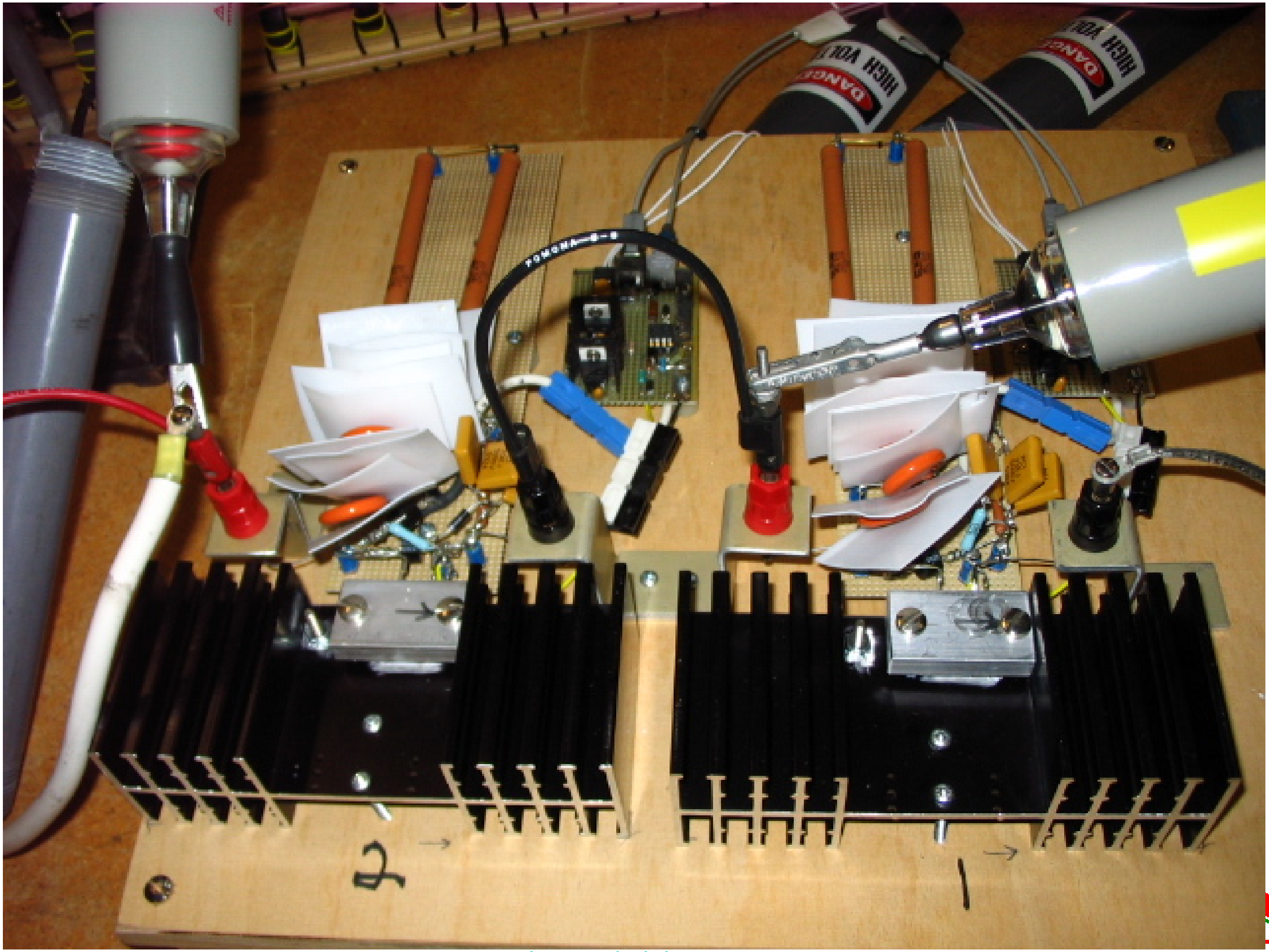
HVPS Disconnect Switch Control Unit



HVPS Disconnect Switch "Proof of Principle" Test Stand



"Proof of Principle" Test Stand, 2 IGBT's w/Drive Circuits



References

[1] High-Voltage switch using Series-Connected IGBTs with Simple Auxiliary Circuit Ju Won Baek, Dong-Wook Yoo, Heung Kim; IEE Transaction on Industry Application, Vol. 37, November 2001