

5 GHz LHCD

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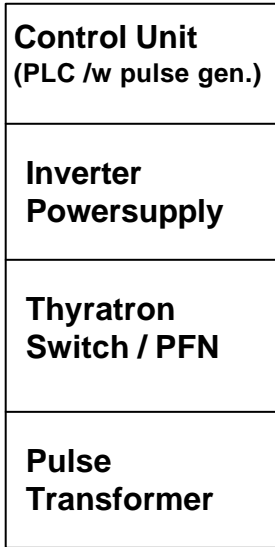
Abstract

KSTAR 가 ECH LHCD , ECH
, LHCD MHD
(steady state) . LHCD 5 GHz
4 500 kW cw klystron, 2 MW Launcher .
Launcher ,
1.5 MW, 4 us . C-band
4-port circulator, dry dummy load, dual directional coupler, E-bend, arc
detector . soft-tube modulator
45 kV, 90 A, 4 us . modulator 가 1:4
, 7 PFN section, thyatron (E2V CX1191D) .

* Work supported by MOST-Korea and KBSI-KSTAR project.

Layout of The Test System

PFN Pulse Modulator
(Max 45 kV, 96 A, 4 ms)

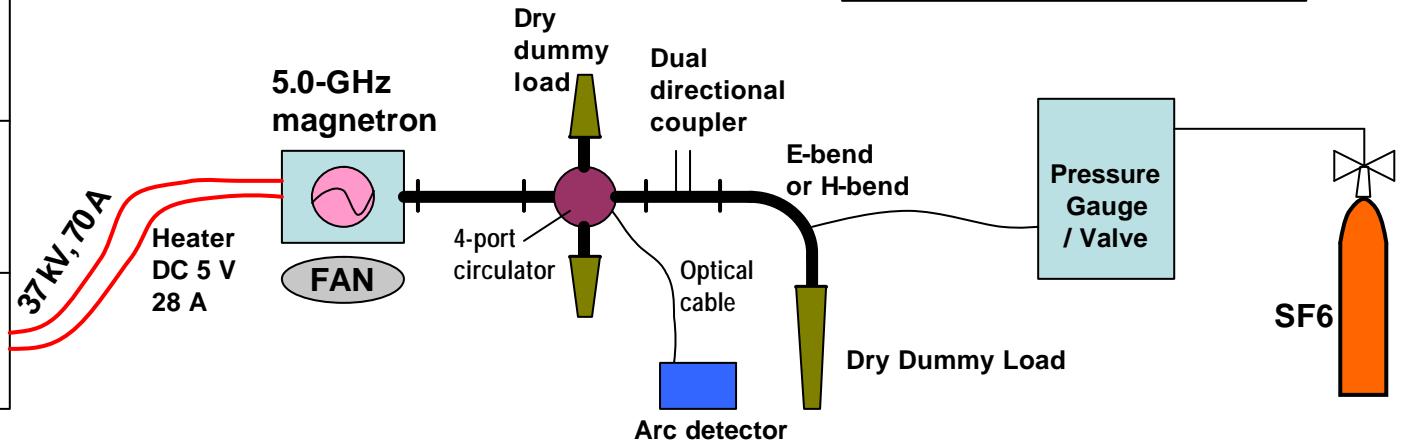


19" rack

- Trigger pulse (Internal & External DG535)
- Interlock signals (Contact Closures)
- RS232 comm port (for remote control)

Interlock signals

- Reflection power > 50 %
- Arc signal (in waveguide)
- SF6 gas pressure < 30 psig
- Magnetron cooling fan off



Air cooled magnetron

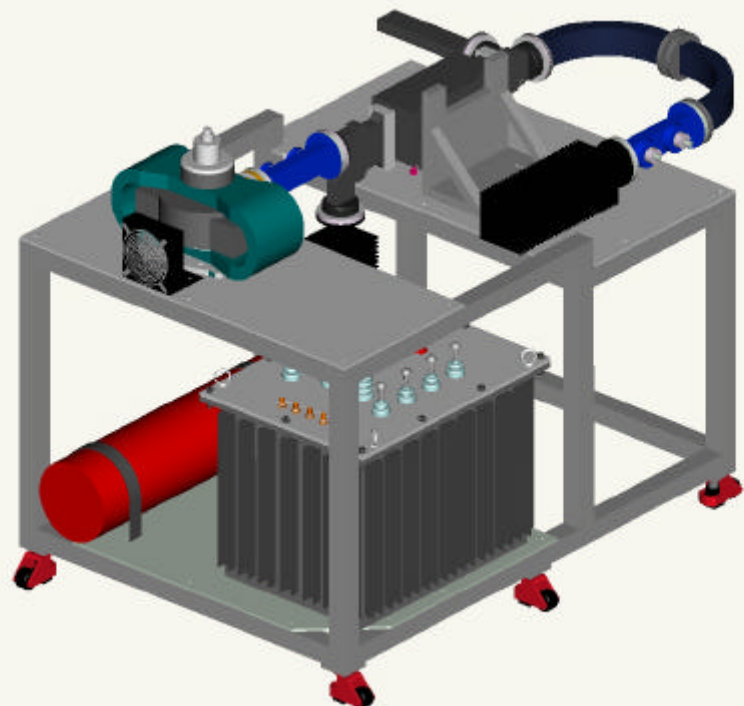
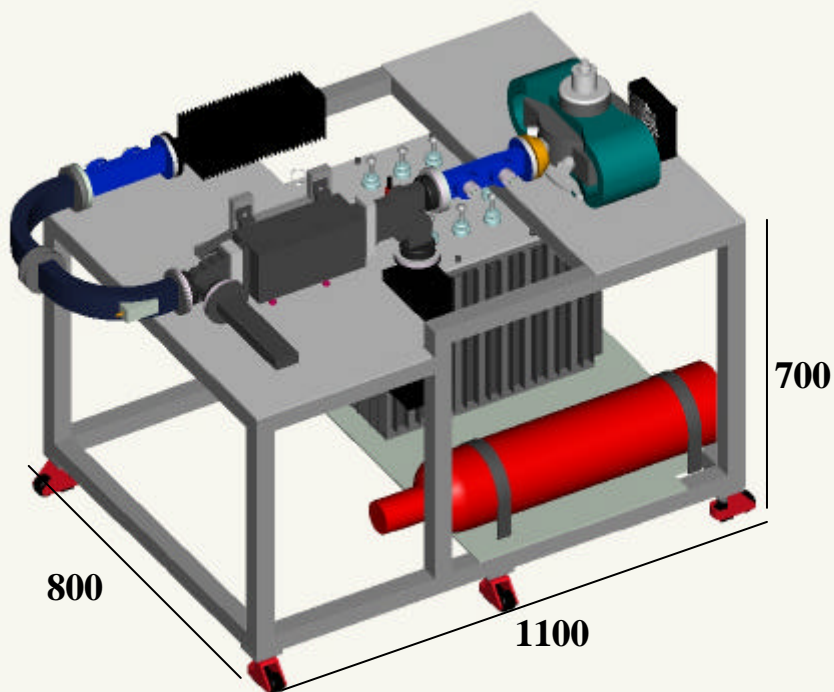
- SFD369
- Frequency : 4.9 – 5.1GHz
- Peak power output: 1.5MW
- Duty Cycle: 0.001 (1 kHz repetition)
- Peak Anode Voltage Max: 40.5 kV
- Peak Anode Current Max: 90 Amps
- Pulse Width: 0.4~1.4 ms



WR187 w/g components

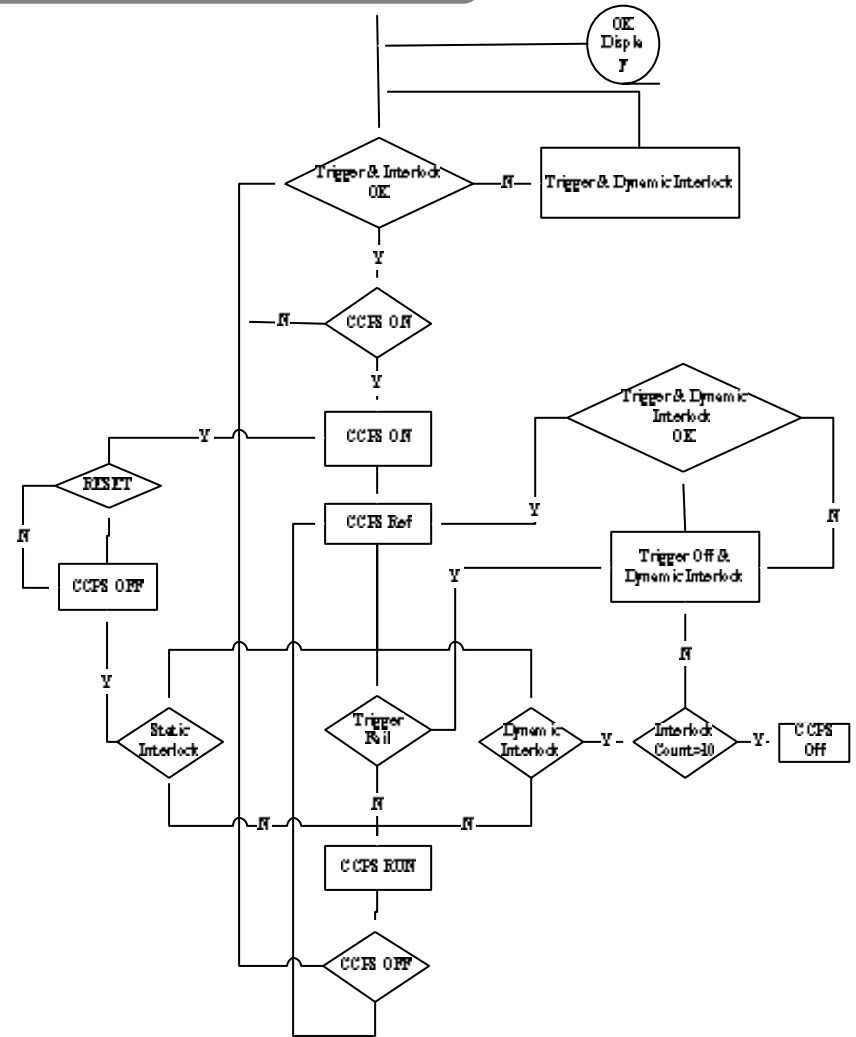
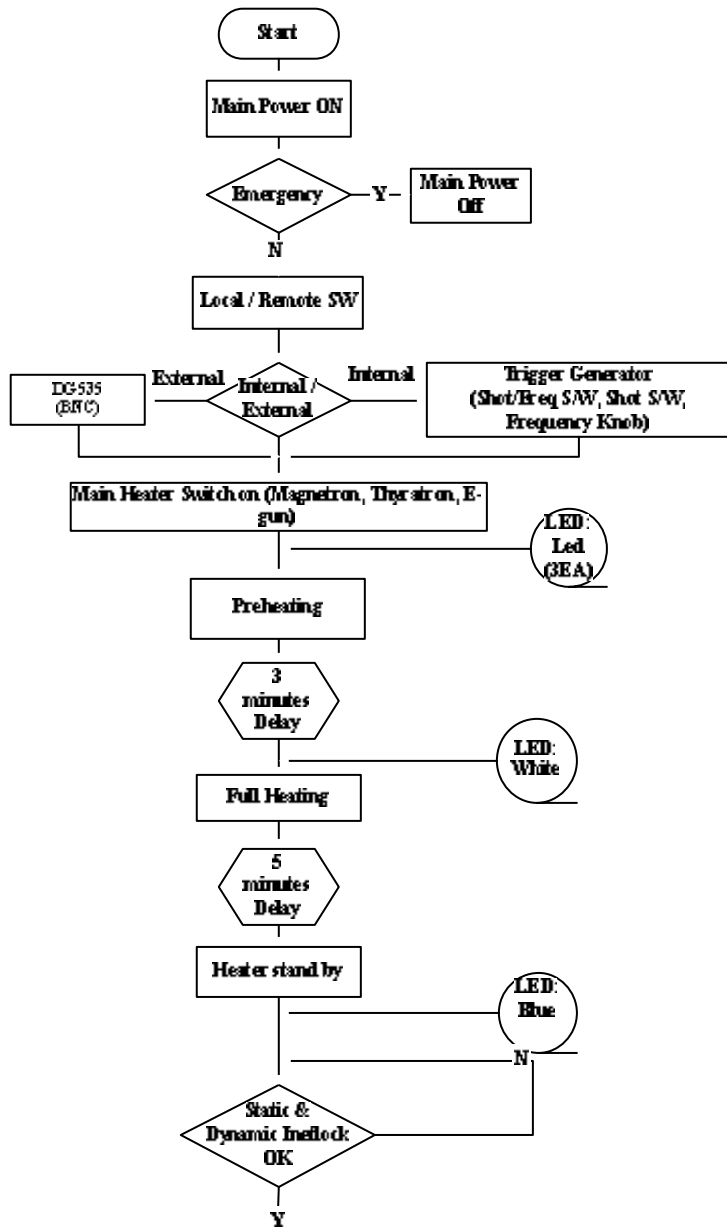
- Straight waveguide
- E-bend
- H-bend
- Dual directional coupler
- 4-port circulator

LHCD Low Power Test Setup



Unit: mm

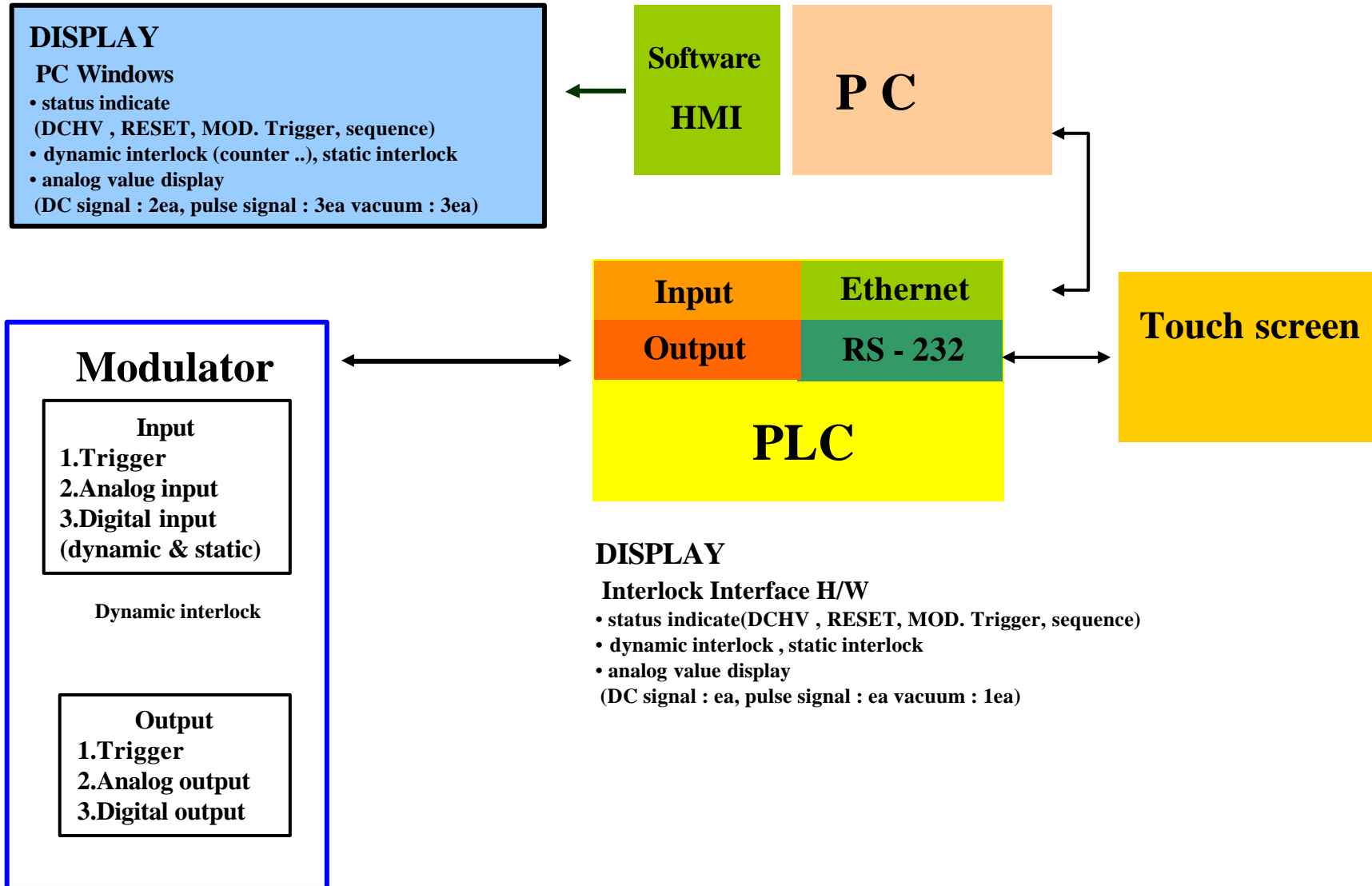
Operation Sequence of Modulator



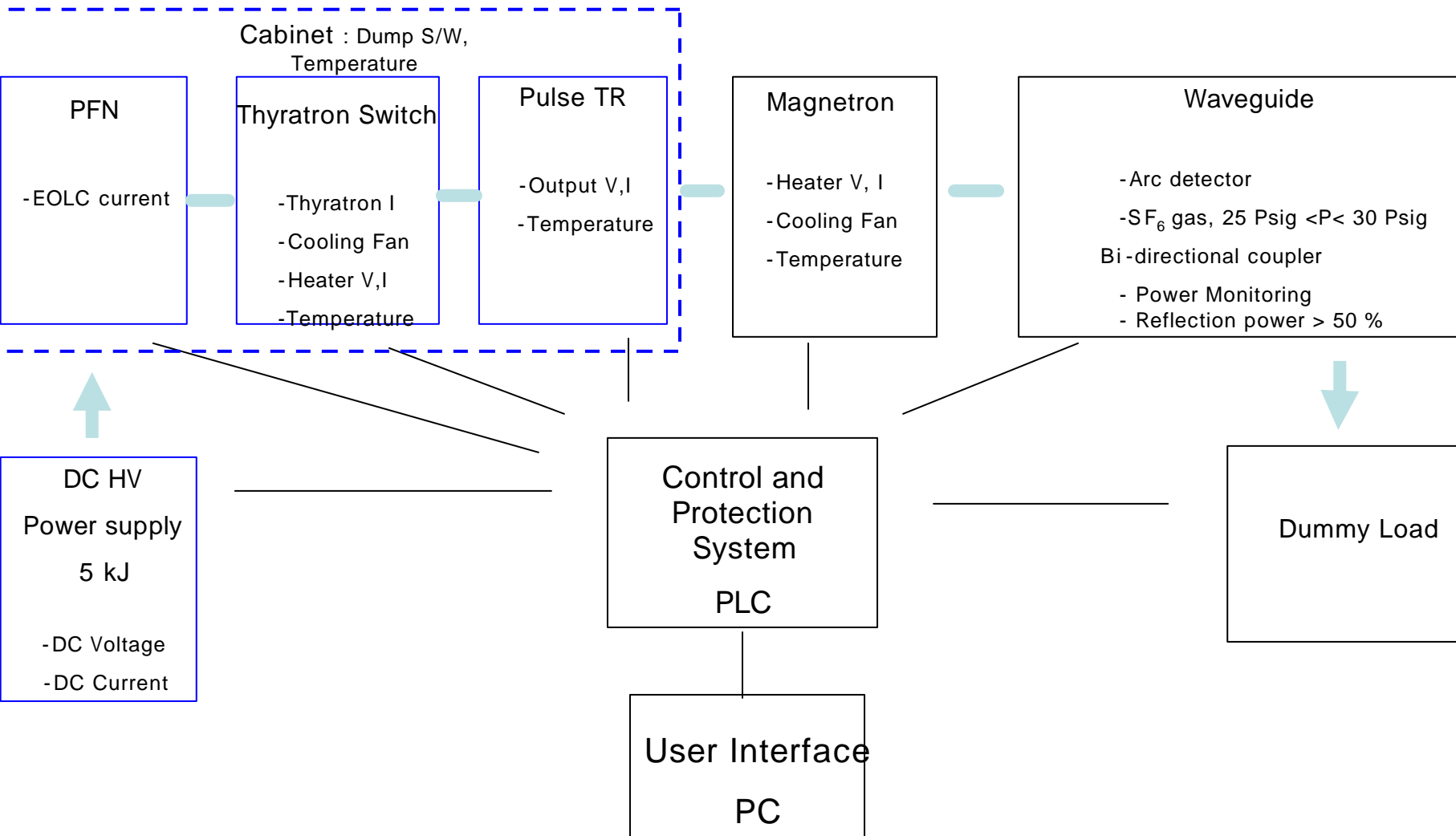
Dynamic Interlock (7): Beam Voltage, Beam Current, EOLC Current, S.F. Gas, Vacuum, Arc Detector, Reflection power

Static Interlock (24): Heater, Cooling Door, Safety, etc.

Modulator Controller Configuration



Development the Magnetron Modulator Control System



Signal Types of the Magnetron-Modulator System

Type		signal
Analog Control (4)		Heater Voltages(3) , HVDC Voltage
Analog Monitor (13)		Heater Voltages(3), Heater Currents(3), CCPS Voltage, CCPS Current, EOLC Current, Magnetron Voltage, Magnetron Current, RF power(2)
Digital Monitor	Dynamic Interlock (7)	Magnetron Voltage, Magnetron Current, EOLC Current, SF ₆ Gas, Vacuum, Arc Detector, Reflection power
	Static Interlock (19)	Heater, Cooling, Door, Safety, etc.
Digital Control (5)		CCPS On/Off, Reset, Heater Rocal/Remote (3)
Trigger (2)	Input	Modulator Trigger
	Output	Thyratron Trigger

- ❑ **Signals category : analog monitor and control signals, digital monitor and control signals, trigger signals**
- ❑ **Total number of signals is 50 for one Magnetron Modulator system.**

Pulsed Magnetron

CPI SFD-369



Anode Voltage (kV)	39
Anode Current (A)	83
Magnetron Impedance ()	470
Pulse Width (ms)	4
Average Output Power (kW)	1.65
Peak Output Power (MW)	1.68
Duty	0.0008
Heater V, I (V, A)	5, 28
Frequency (MHz)	4900-5100
Efficiency (%)	52

Circuit Diagram of Modulator

5GHz, 1.5MW Magnetron & Pulse Modulator System

Pulse Modulator

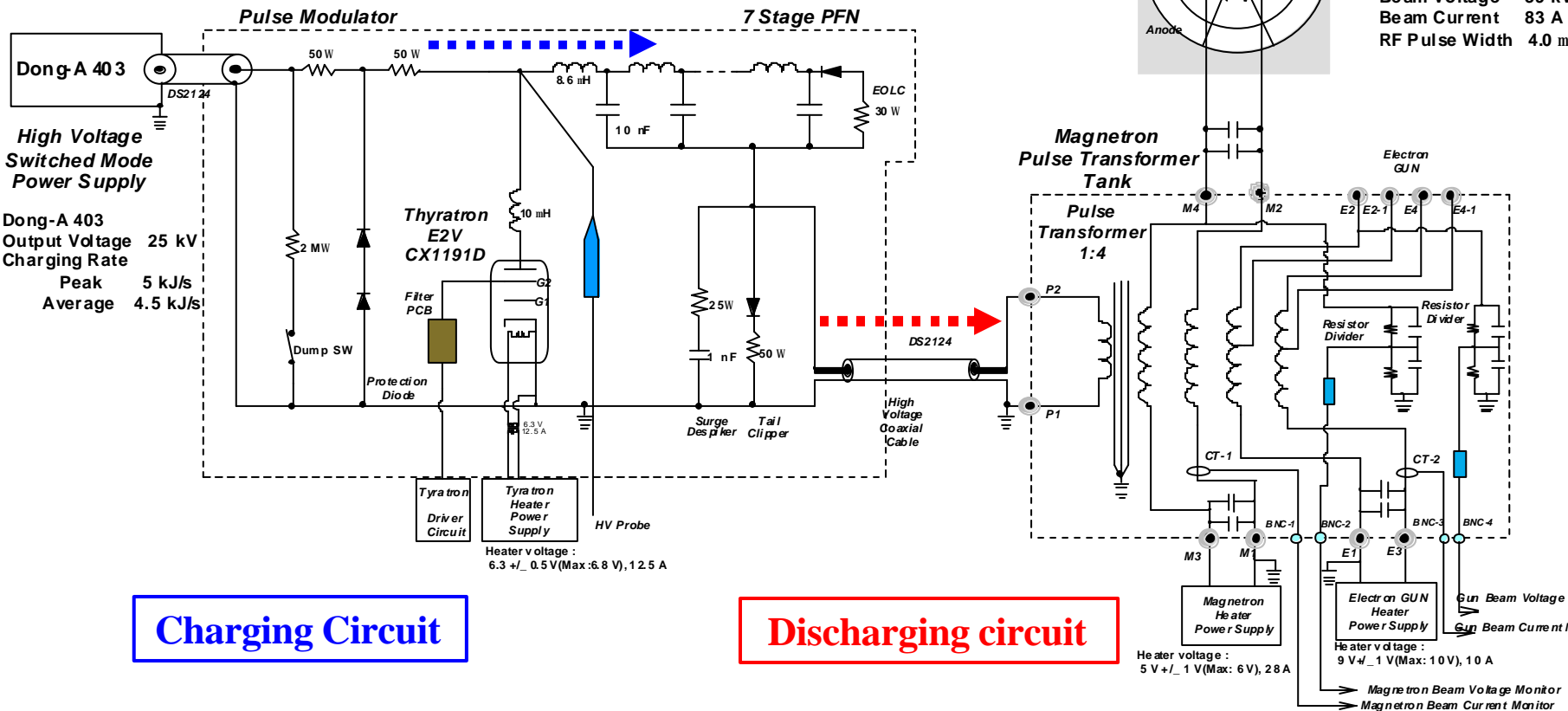
Peak Power 3.6 MW
 Charging Voltage 22.5 kV
 PFN Output Voltage 11.25 kV
 PFN Output Current 382 A
 HV Pulse Width (70% Voltage) 4.0 ms
 Repetition Rate 200 pps

PFN impedance 29.37 W
 Total Capacitance 68.26 nF
 Total Inductance 51.6 mH
 Single Capacitance 10 nF

C-Band 1.5MW Magnetron

CPI SFD369

Frequency 5100 MHz
 Output Power 1.5 MW
 Repetition Rate 200 pps
 Efficiency 52 %
 Beam Voltage 39 kV
 Beam Current 83 A
 RF Pulse Width 4.0 ms



Design Parameters of Modulator

Peak Voltage [kV]	45
Peak Current [A]	96
Load Impedance [O]	470
HV Pulse Length [μs]	4
Pulse Energy [J]	17.3
Repetition Rate Max [Hz]	200
Step-up Ratio	4
PFN Charging Voltage [kV]	25
PFN Impedance [O]	29.37
PFN Section Cap [nF]	10
PFN Section Inductance [μ H]	8.63
PFN Section Number	7
Charging Resistance [O]	100
Thyratron (CX1191D)	8 MW, 35 kV, 500 A,

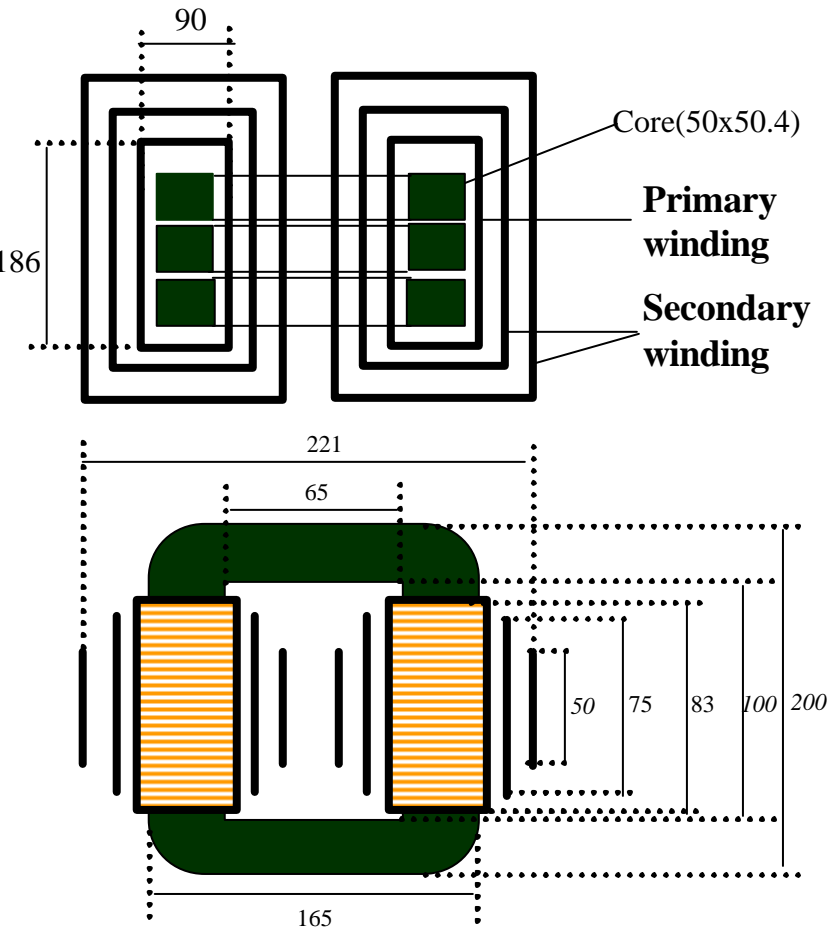
Specification of Pulse Transformer

Pulse Droop[%/ms]	1
Rising Time [ms]	0.2
Step of Ratio	1 : 4
Primary Voltage [kV]	22.5
Primary Current [A]	375
Secondary Voltage [kV]	45
Secondary Current [A]	96
Output Impedance [Ω]	470
Plat Top pulse width [ms]	3.2
Pulse Repetition Rate [Hz]	200

Electrical Parameters of Pulse Transformer (In Air)

Item	Model calculated Value	Measured Value
Primary Inductance [mH]	1.271	1.268
Secondary Inductance [mH]	20.342	19.85
Leakage Inductance [mH]	79.3	42.2
Distributed Capacitance [pF]	44.2	38.7

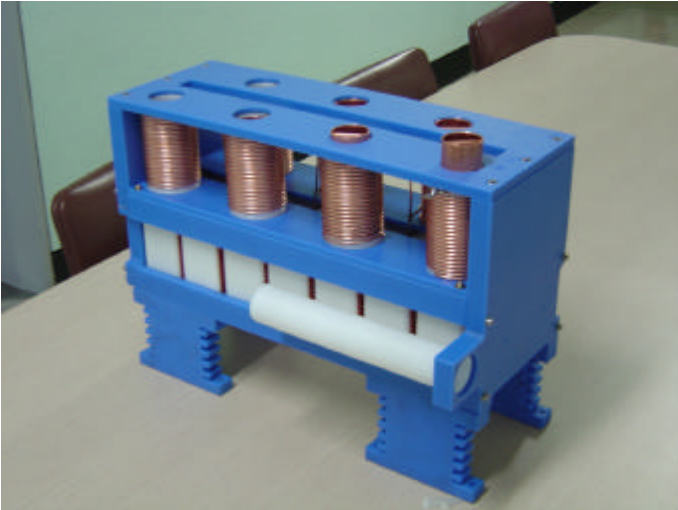
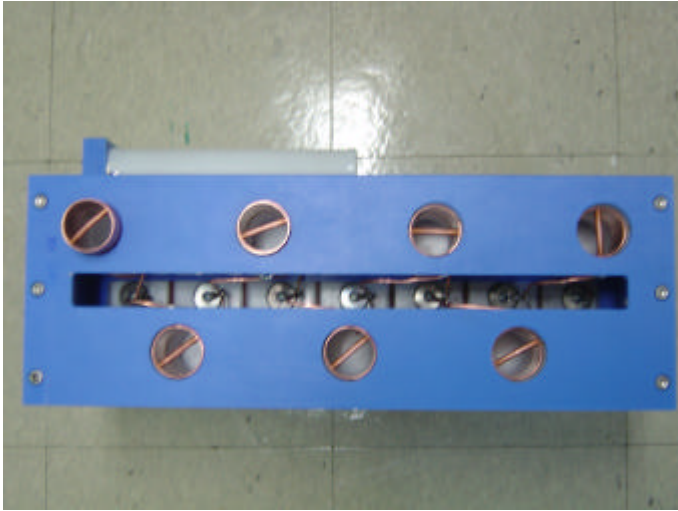
Parameters of Pulse Transformer



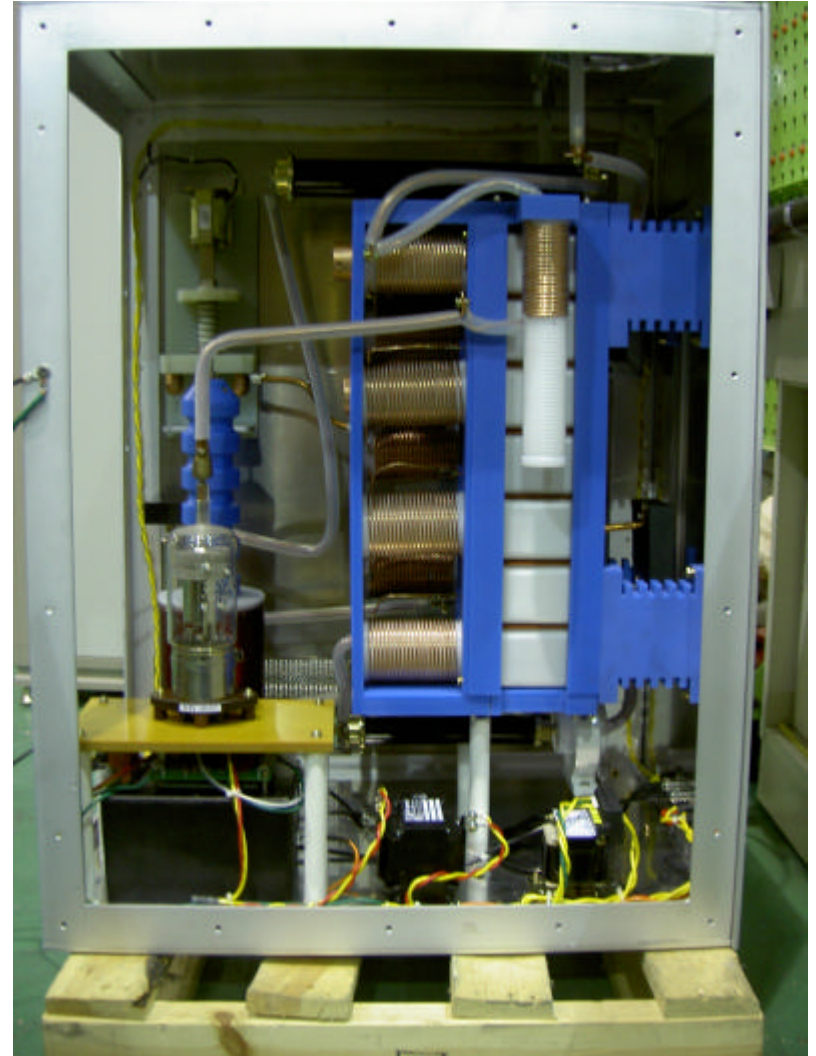
Total magnetic flux density swing [T]	0.746
Effective magnetic Permeability	800
Core Packing factor [%]	0.88
Magnetic Cross section Area[cm²]	76.2
Mean Magnetic Path Length [cm]	53
Distance between layers [cm]	1
Winding length [cm]	7.5
Mean circumference between layers [cm]	59.2
Primary Turn Number	10
Secondary Turn Number	40

Unit: mm

PFN & HV Box

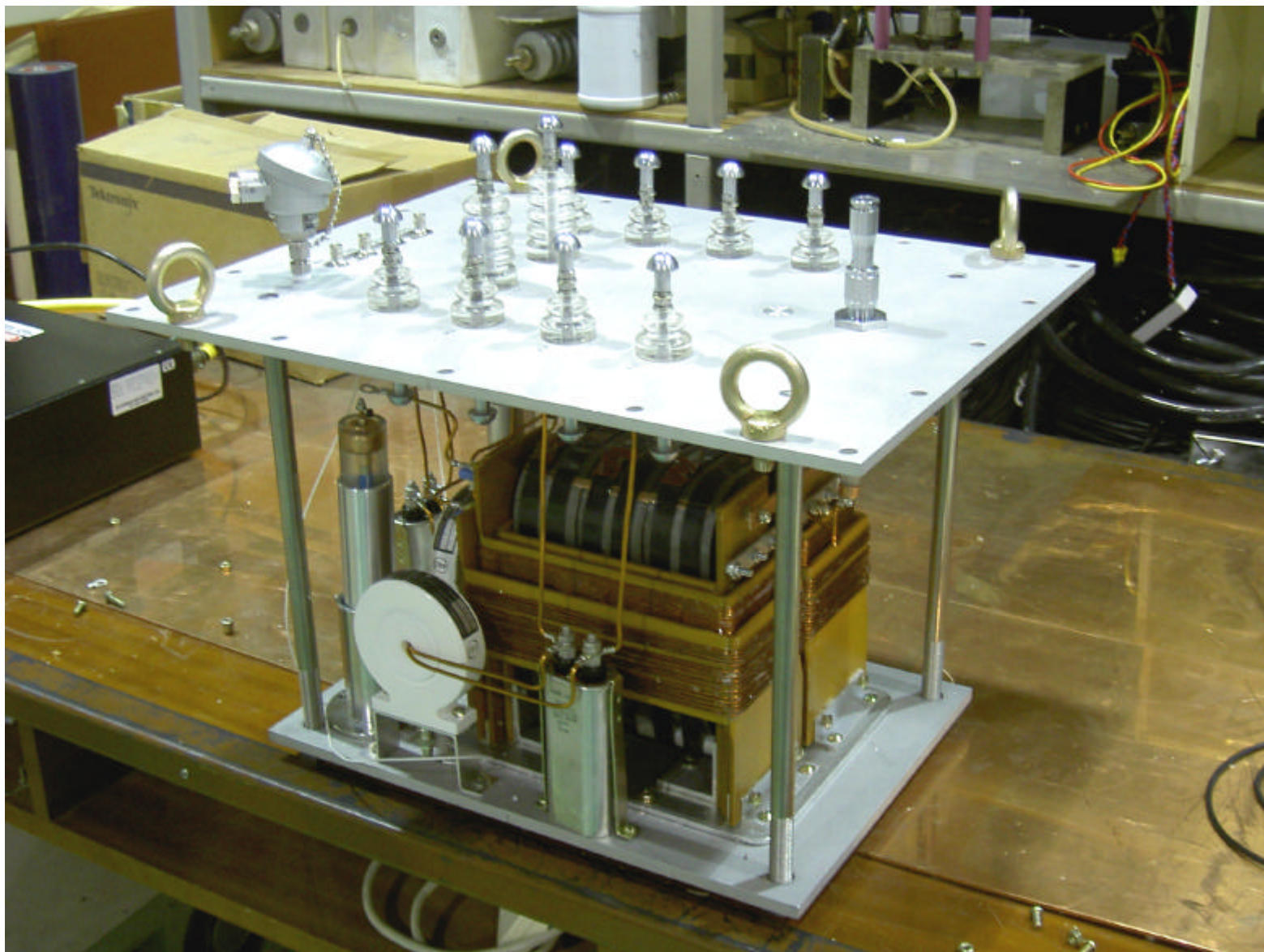


PFN



HV Box

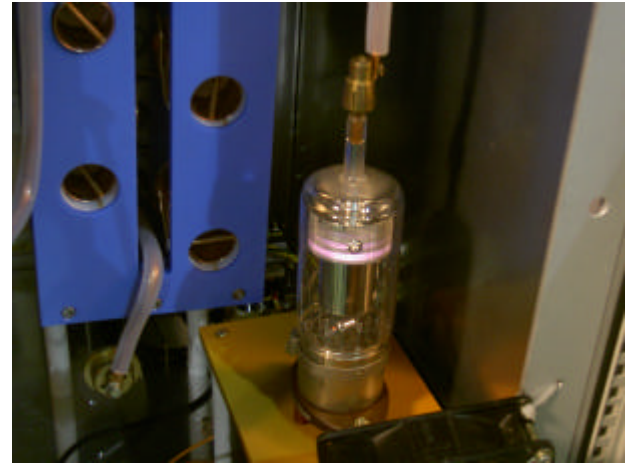
Pulse Transformer



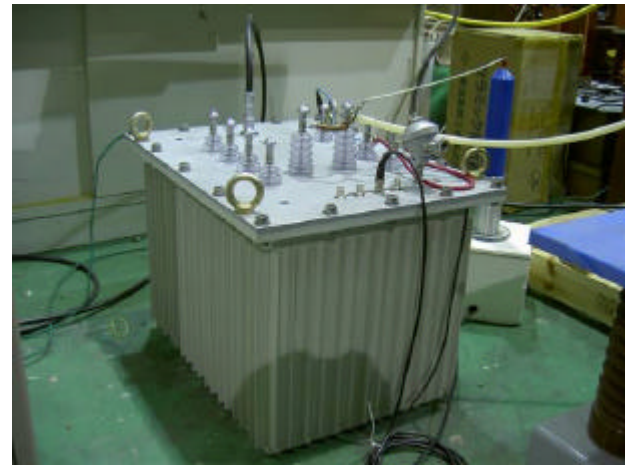
Modulator



Modulator



Thyratron

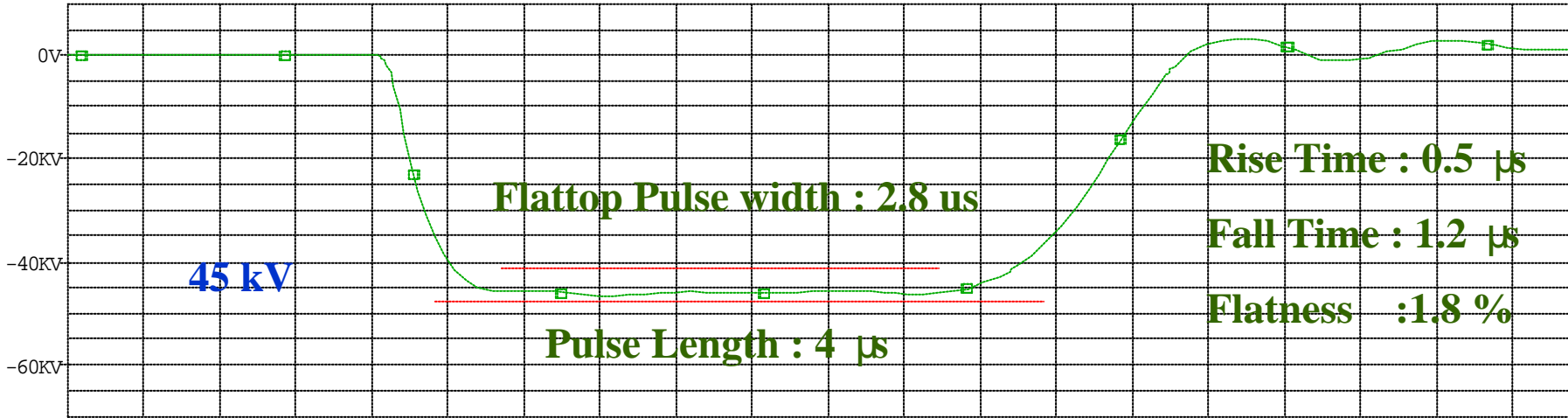


Pulse TR

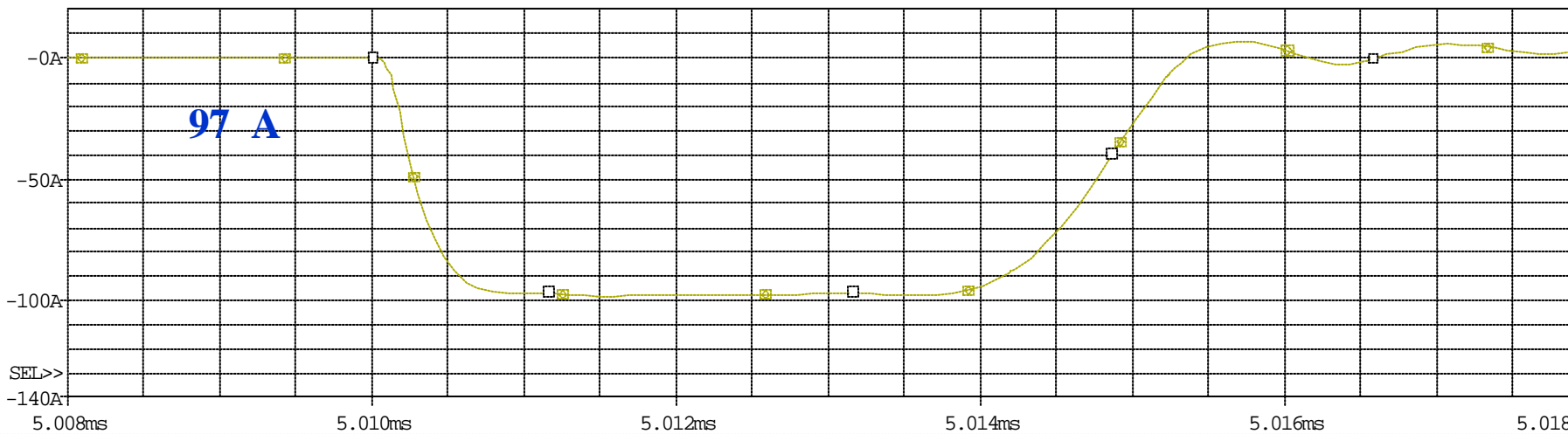
Modulator Test Setup



Simulation Result



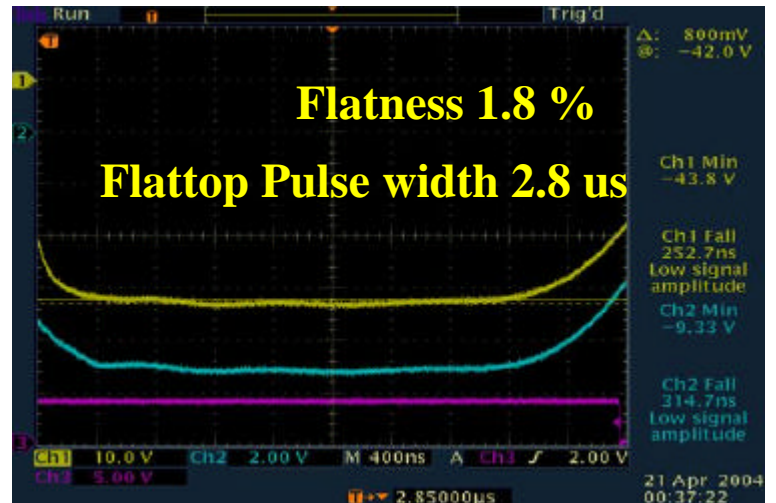
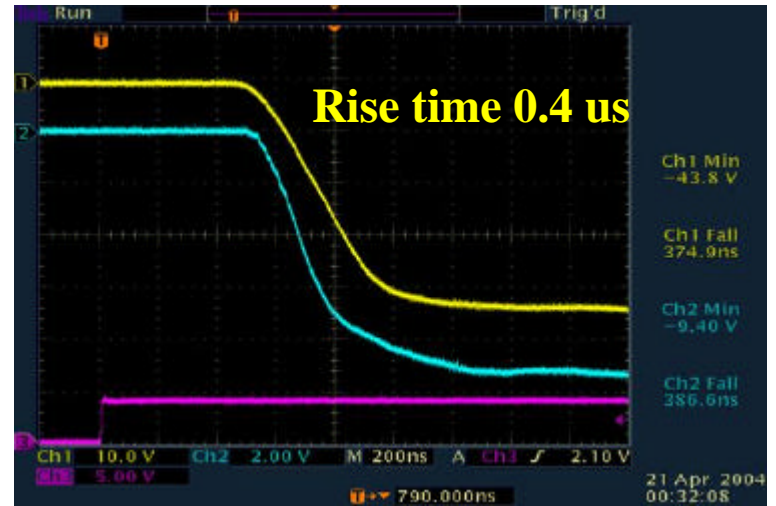
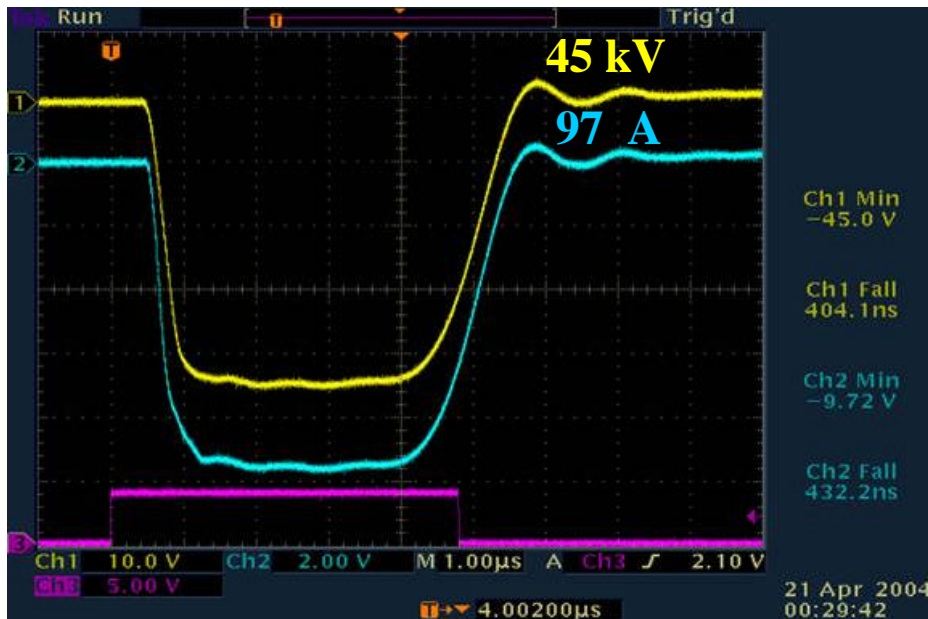
V(R3:2)



-I(R3)

Time

Test Result



Conclusion & Future Work

1. LHCD, C-Band 4-port circulator, Dry dummy load, Dual directional coupler, E-bend, Arc detector .
2. 4 us PFN, CPI 가 1.5 MW, .
3. PLC Remote Control & Interlock .
4. PFN 가 LHCD 5 GHz, 1.6 MW .