PAL-XFEL Linac RF System

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Heung-Soo Lee,
PAL-XFEL RF Group

H.S. Lee Pohang Accelerator Laboratory, lhs@postech.ac.kr

Outline

- Introduction
  - Modulator & Klystron
  - High Power RF System
  - LLRF
- Installation & Test
  - Modulator & Klystron
  - High RF System
  - LLRF
- RF Phase Tuning
- RF Conditioning
- Beam Commissioning
- Summary

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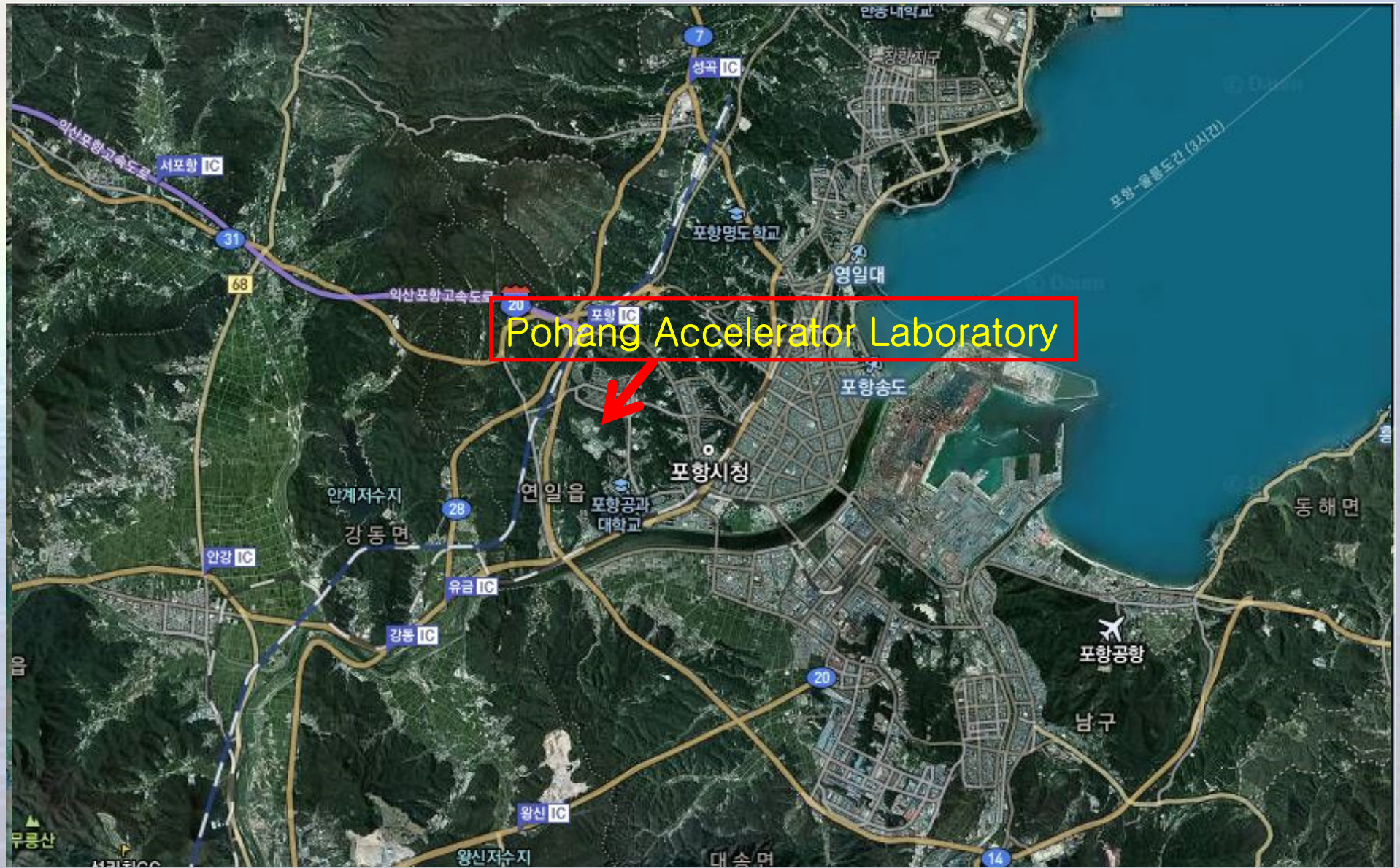
Worldwide FEL Projects

4GLS at Daresbury (124 Å)
TESLA XFEL at DESY (0.86-64 Å)
SASE-FEL at BESSY (12-600 Å)
FERMI at ELETTRA (12-15 Å)
SPARX in INFN Rome (15-135 Å)

PAL XFEL at PAL (1-50 Å)
SACLA at SPring-8 (Å)

Worldwide FEL Projects

Worldwide FEL Projects



Aerial View of PAL

- 0.1-nm Hard X-ray XFEL
- Project Period: 2011 ~ 2015
- Total Budget: 400 M$
- 10-GeV Electron Linac (Normal Conducting S-band, 60 Hz)
- Total Length: 1.1 km

July 2012

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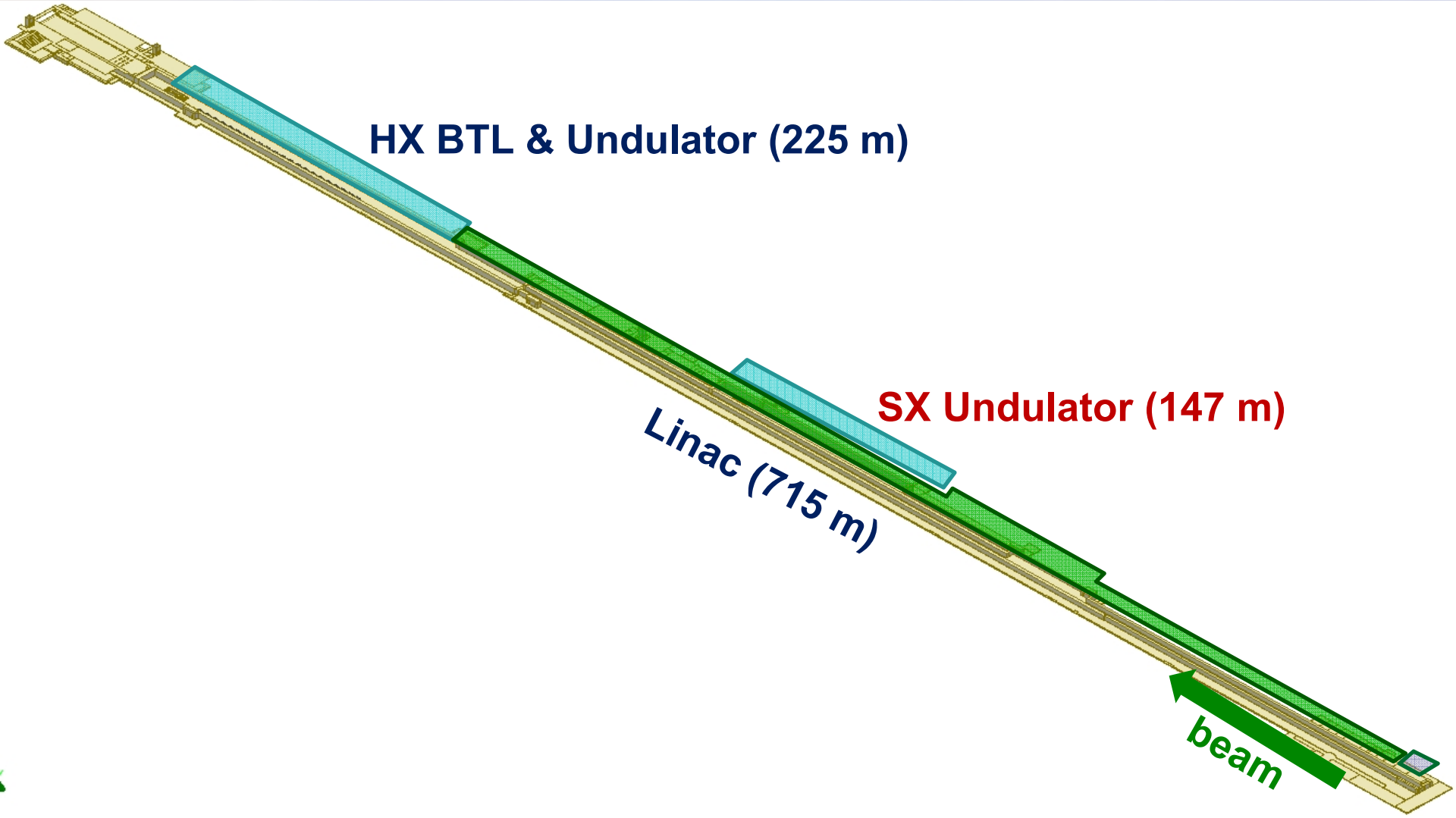
January 2015

Building Layout



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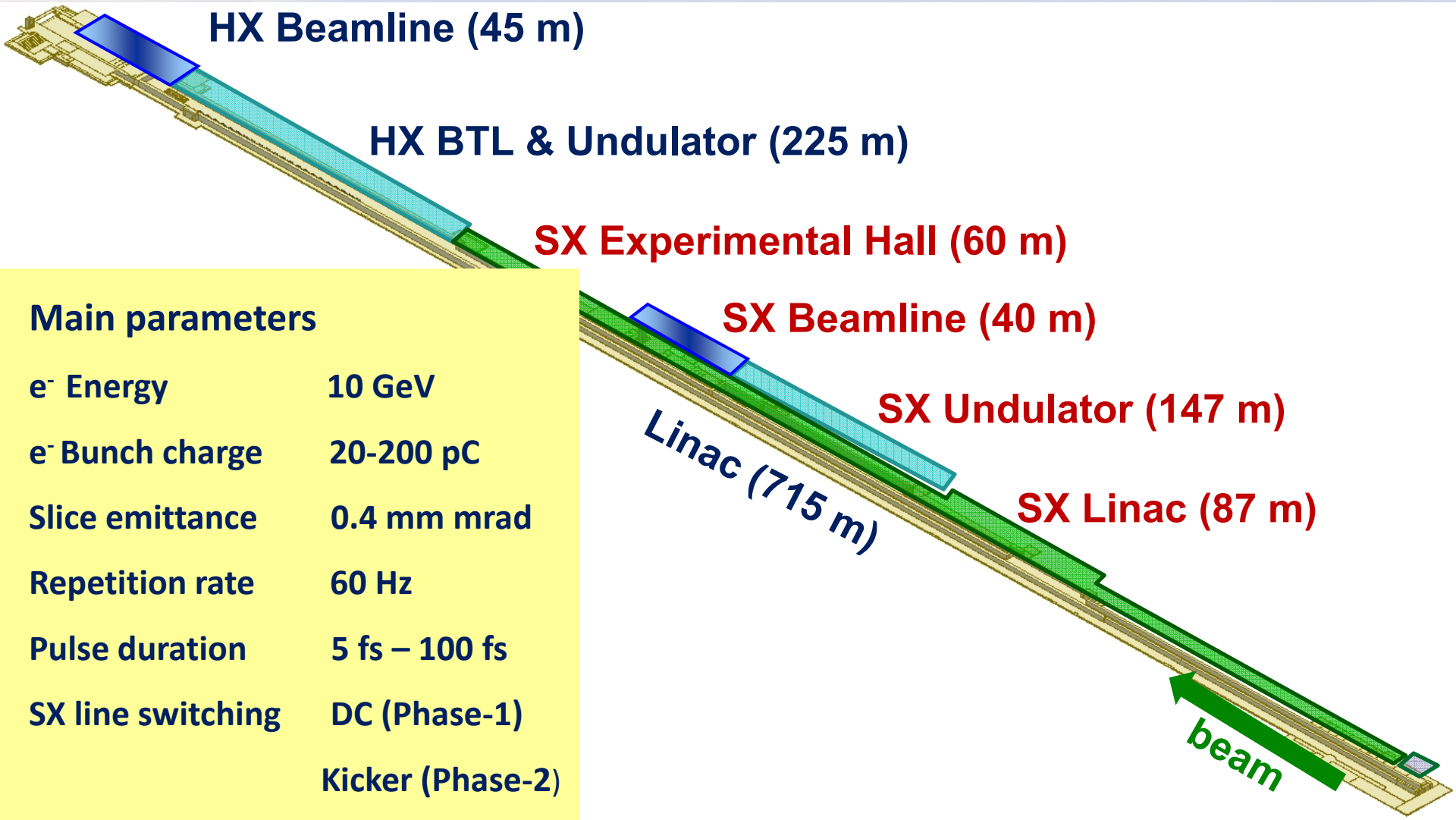
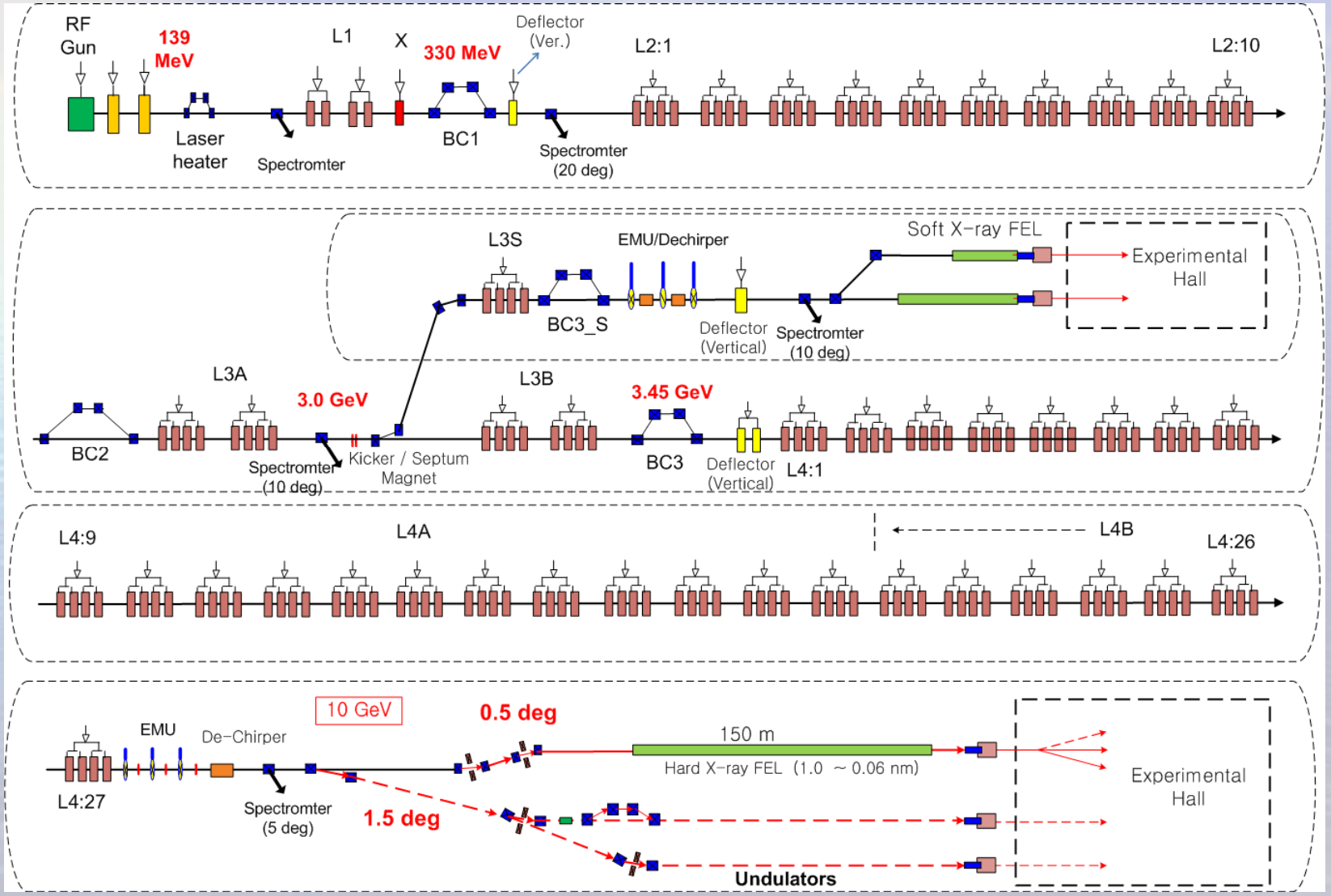


Main parameters

e^- Energy	10 GeV
e^- Bunch charge	20-200 pC
Slice emittance	0.4 mm mrad
Repetition rate	60 Hz
Pulse duration	5 fs – 100 fs
SX line switching	DC (Phase-1)
	Kicker (Phase-2)

PAL-XFEL Layout



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Linac Major Devices

Classification	Section	K&M	A/S	Energy Doubler
Injector linac		3	2	0
Hard X-ray main linac	L1	2	4	0
	L2	10	40	10
	L3A	2	8	2
	L3B	2	8	2
	L4	27	108	27
Soft X-ray linac		1	4	1
Deflector (S-band)	L1, L3	3	4	0
Linearizer (X-band)	L1	1	1	0
Total No.		**51**	**181**	**42**

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Stability Measurement

Modulator type		S-band type1	S-band type2A	S-band type2B	S-band type3A	S-band type3B	X-band type4
RF Output Power	MW	80	80	80	25	25	50
Modulator Peak Power	MW	200	200	200	62.5	62.5	162.9
Beam Voltage	kV	400	400	400	245	245	450
Beam Current	A	500	500	500	255	255	362
Beam pulse width	μs	7.5	4.0	4.0	5.0	4.	3.2
Modulator Average power	kW	90.0	48.0	8.0	18.7	2.5	31.3
Repetition Rate Max.	Hz	60	60	10	60	10	60
RF Pulse width(Flattop)	μs	4.0	1.5	1.5	2.5	1.5	0.7
Load Impedance	Ω	800	800	800	960	960	1,243
Pulse Transformer Turn ratio		17	17	17	11	11	20
RF Average Power	kW	19.2	7.2	1.2	3.75	0.375	2.1
PFN impedance	Ω	2.7	2.7	2.7	7.9	7.9	3.11
PFN Voltage	kV	46	46	46	46	46	46
Beam Voltage Stability, rms	%	0.005이하	0.005 이하	0.005 이하	0.005 이하	0.005 이하	0.005 이하
Klystron micro perveance	μp	1.98	1.98	1.98	2.1	2.1	1.2
Klystron Model		E37320	E37320	E37320	E37308	E37308	XL-4
Mod. Cabinet Size(WXDXH)	M	1.6X1.6X2.2	1.6X1.6X2.2	1.6X1.6X2.2	1.4X1.6X2.2	1.4X1.6X2.2	1.6X1.6X2.2
수량		42	3	2	2	1	1
공급 구분		양사각21Set	포스코ICT	Dawonsys	Dawonsys	Dawonsys	포스코ICT

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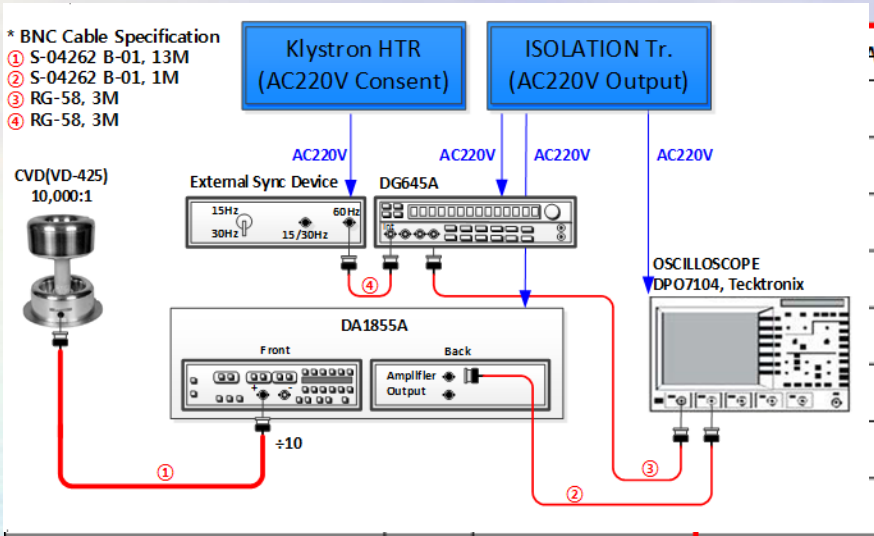

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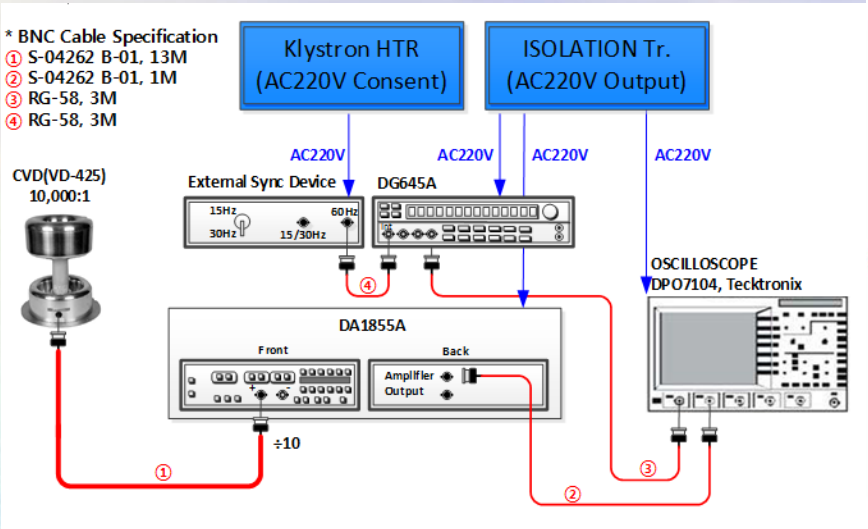

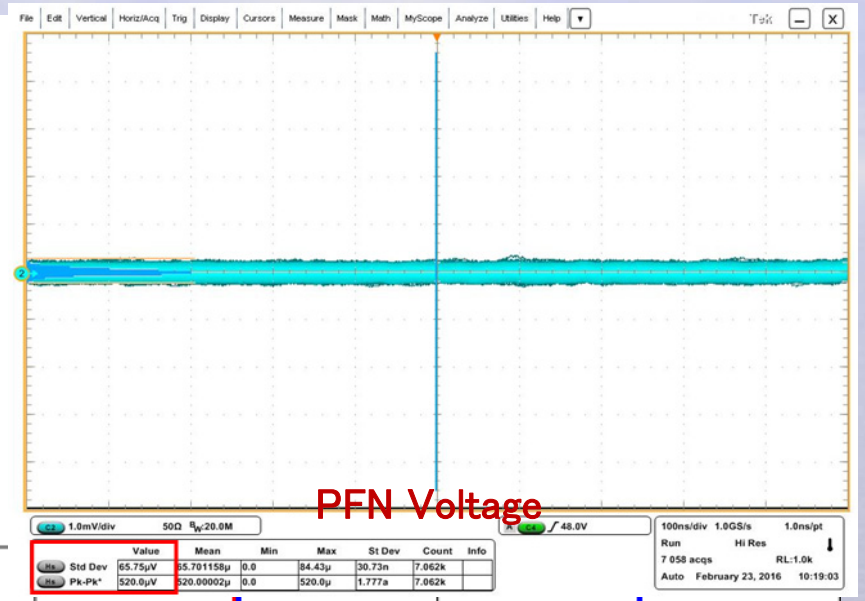

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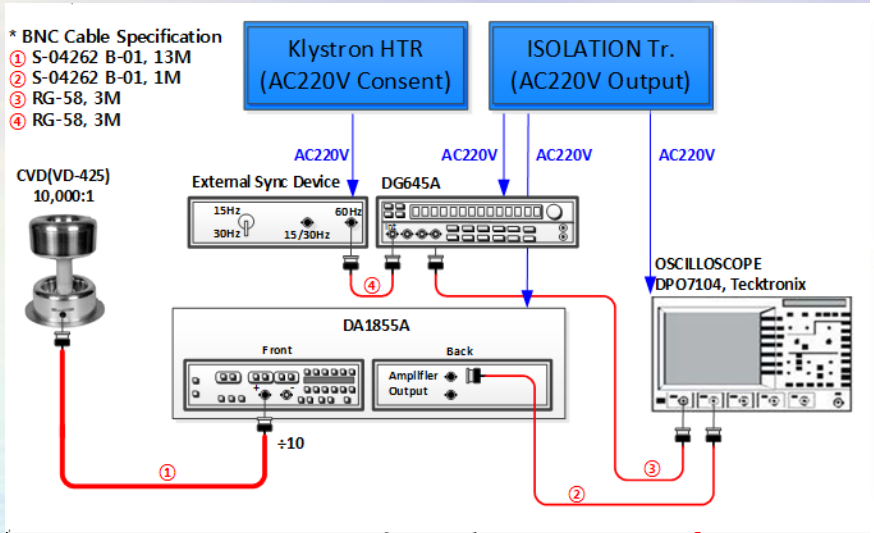

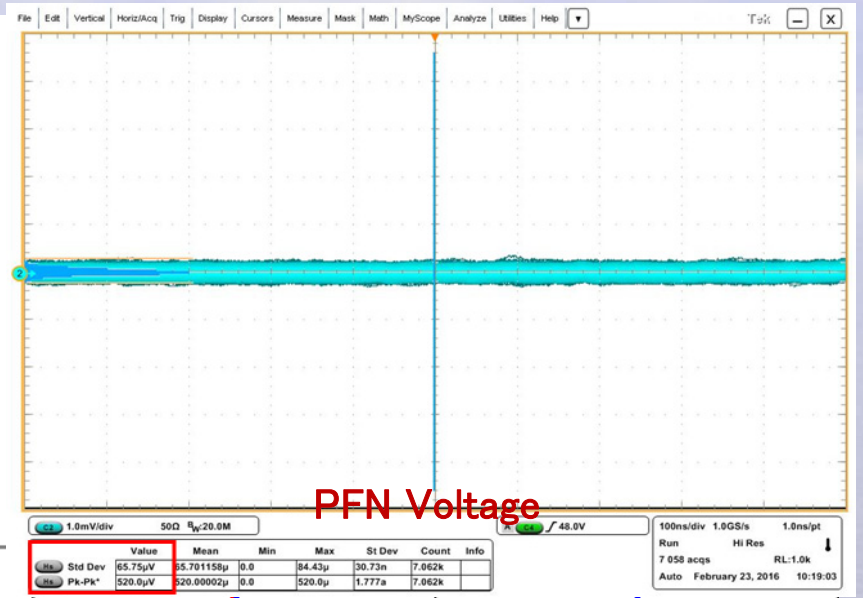

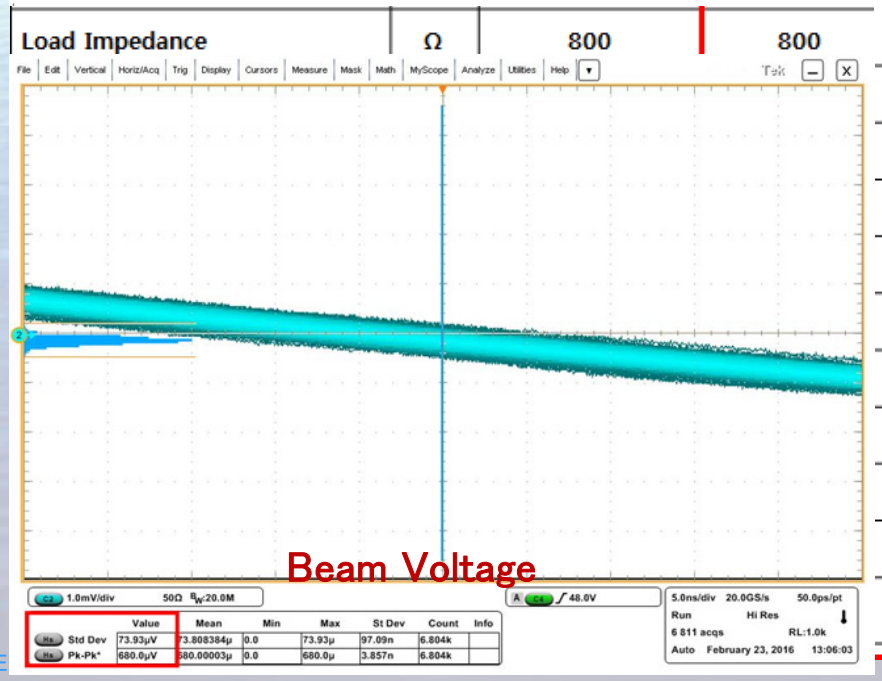

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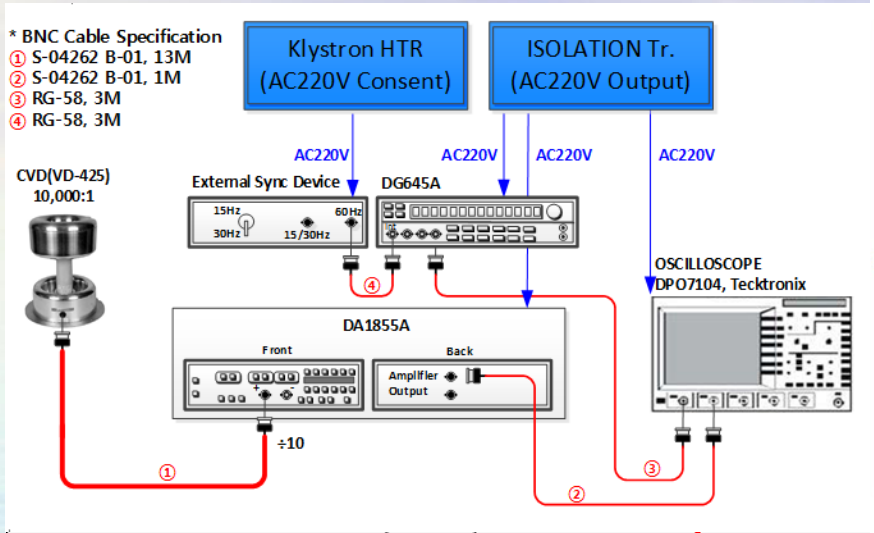

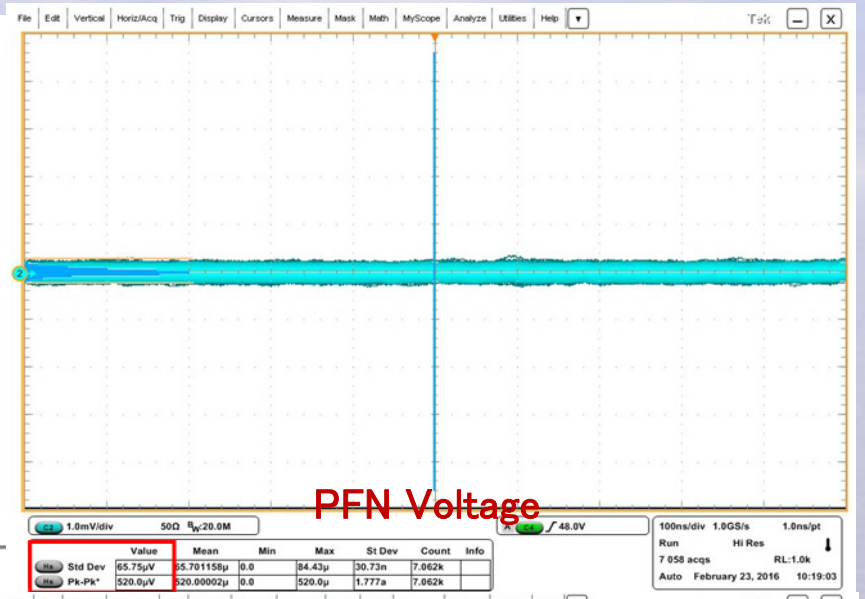

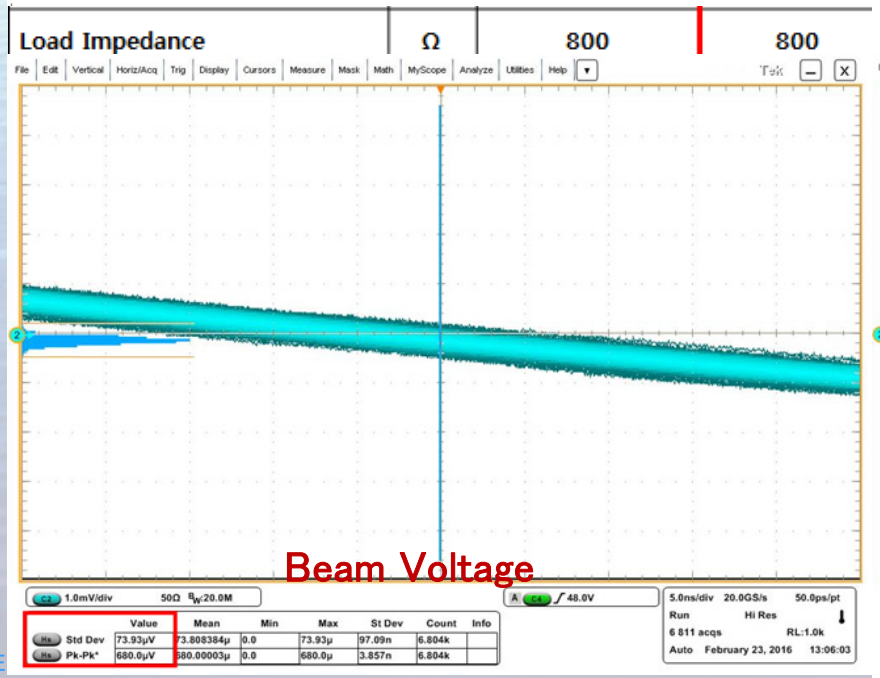

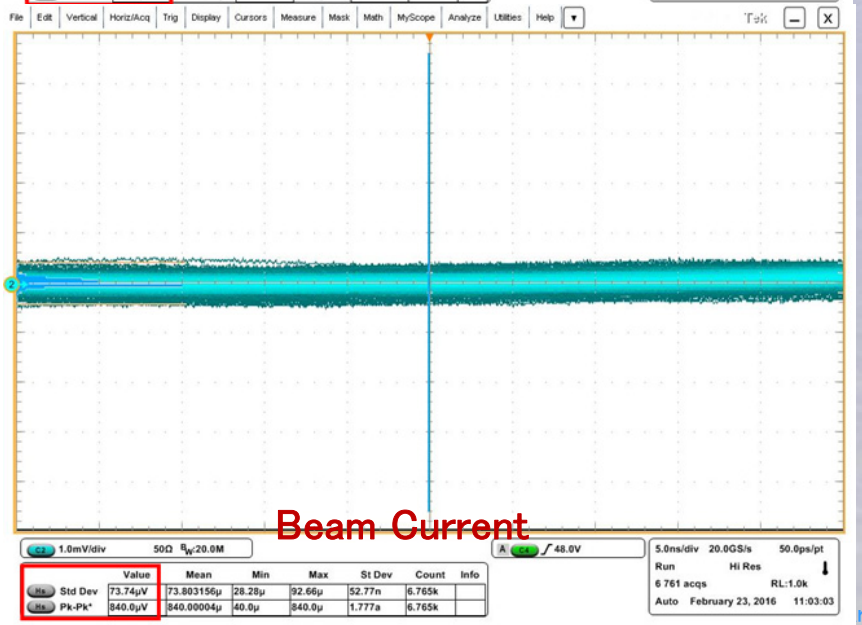

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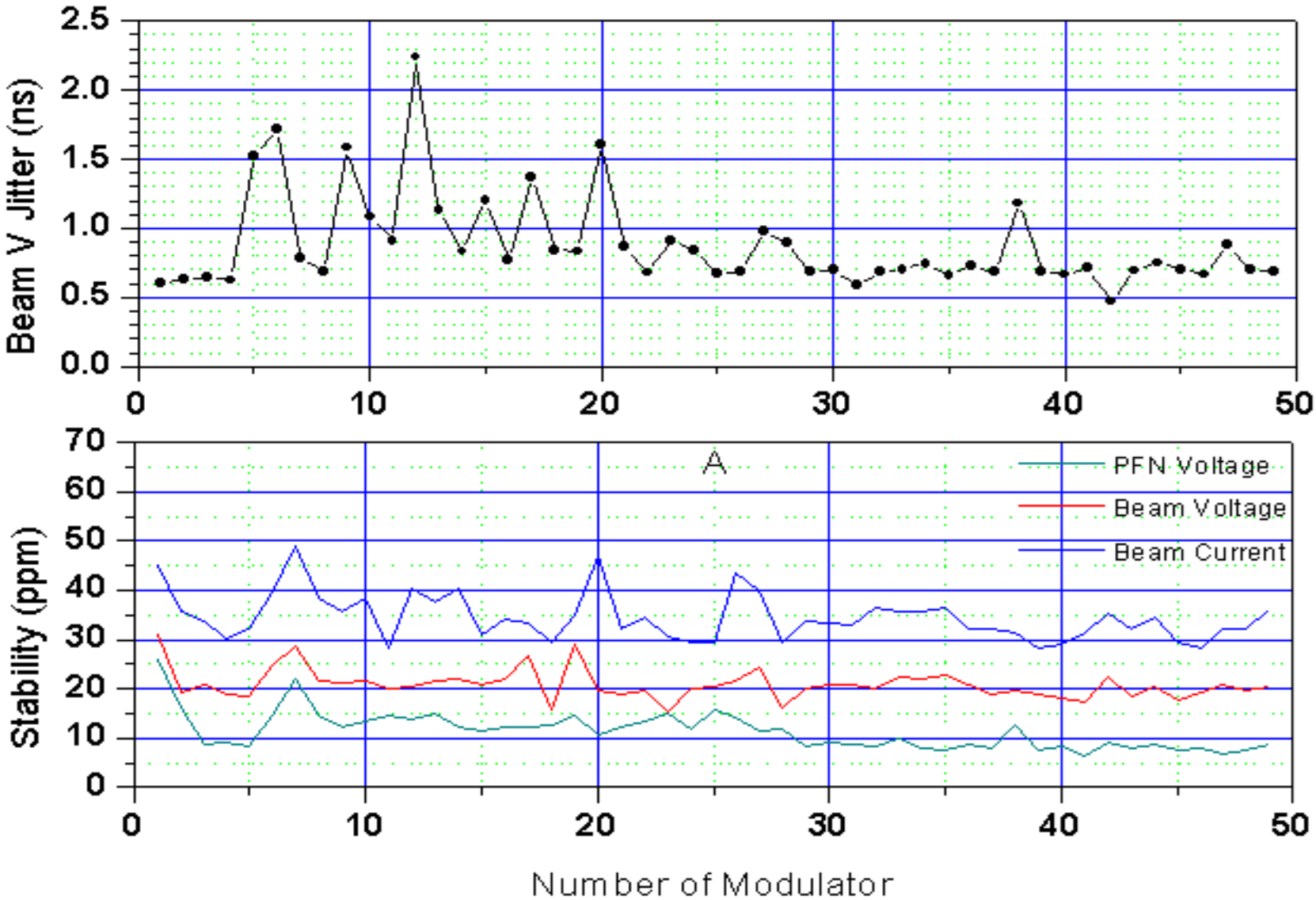

Gallery View

4/1

Gallery View

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Gallery View

6/1

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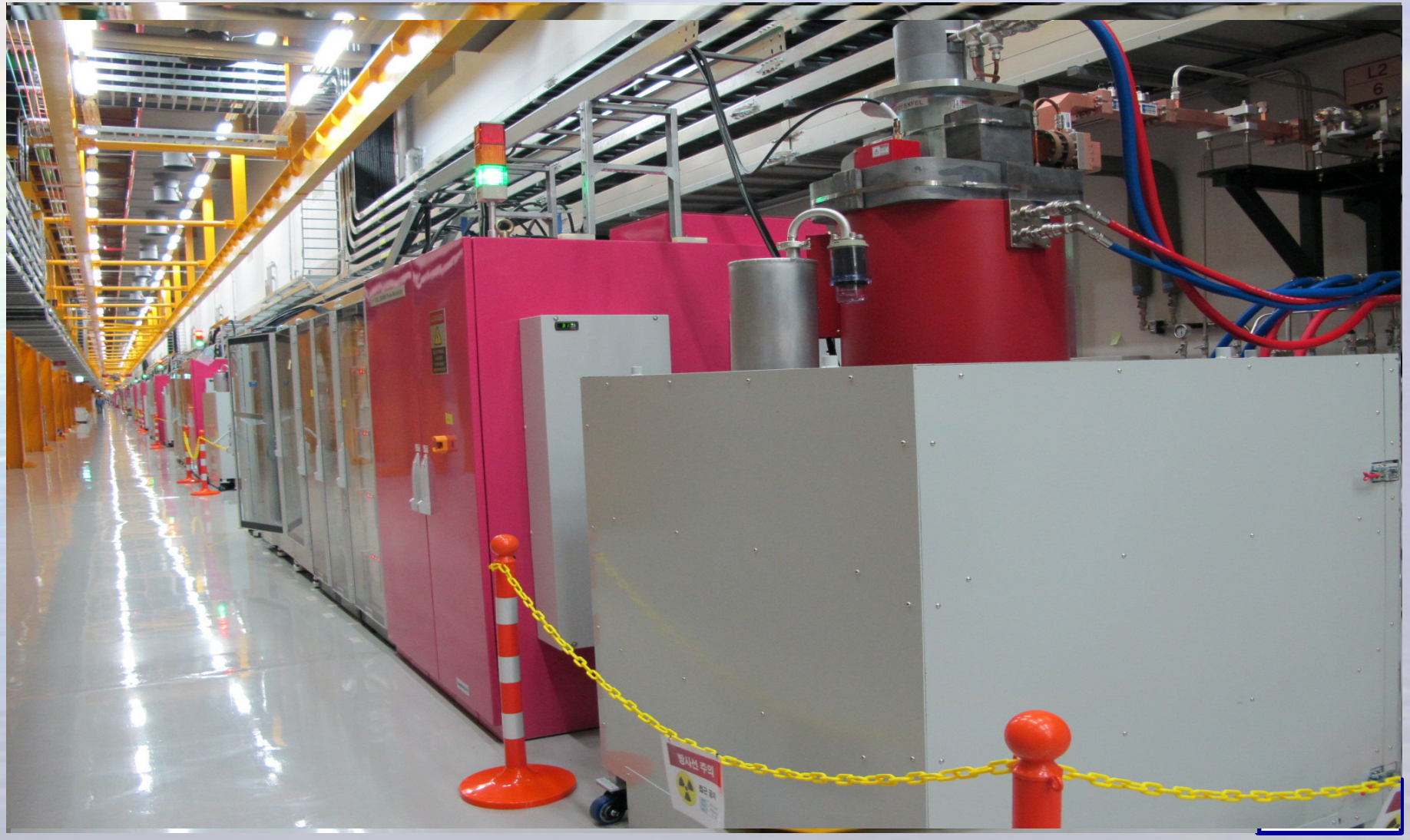

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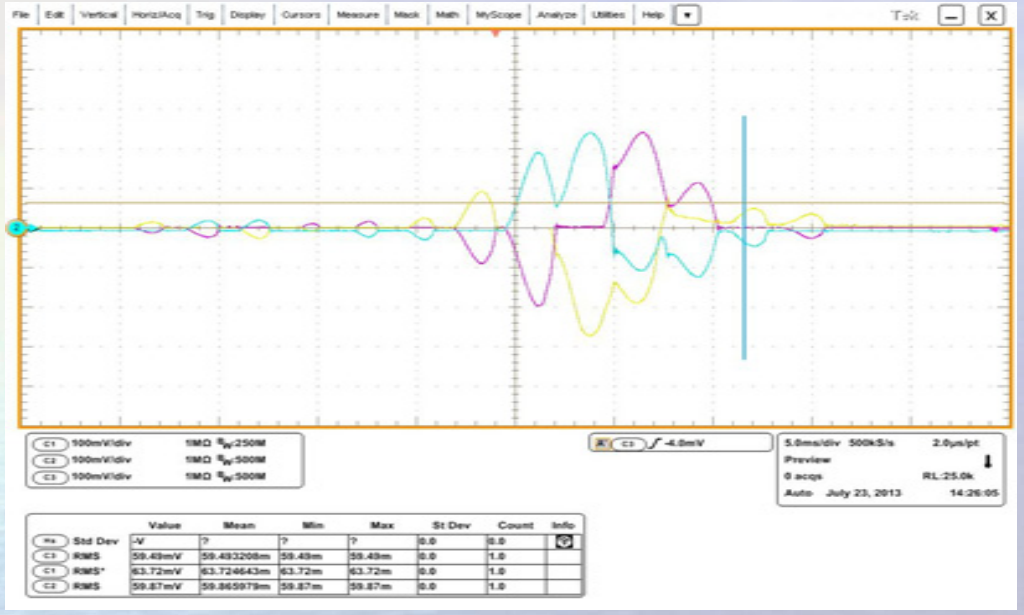
Electric Power Distortion



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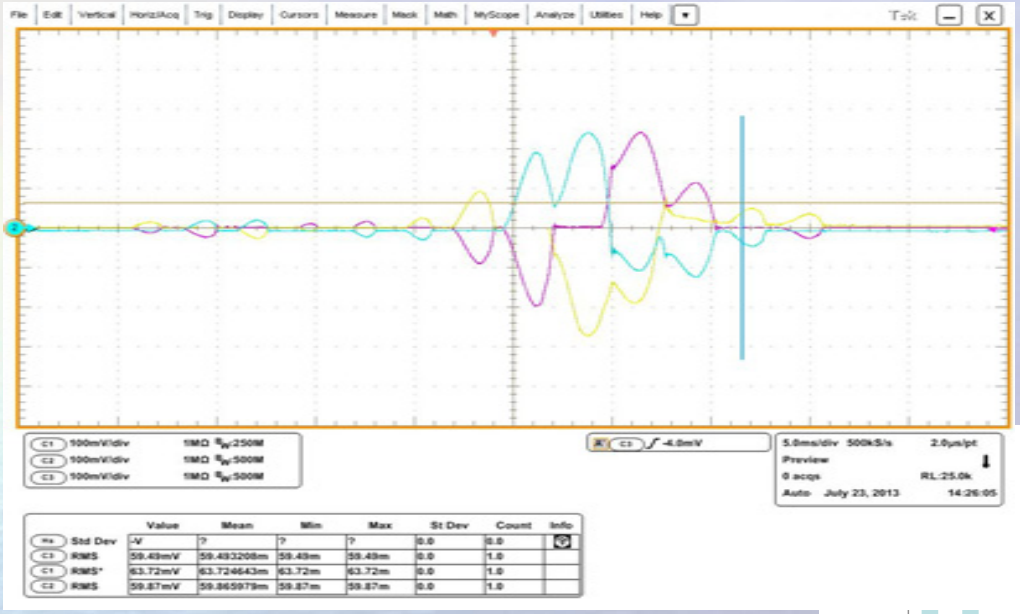

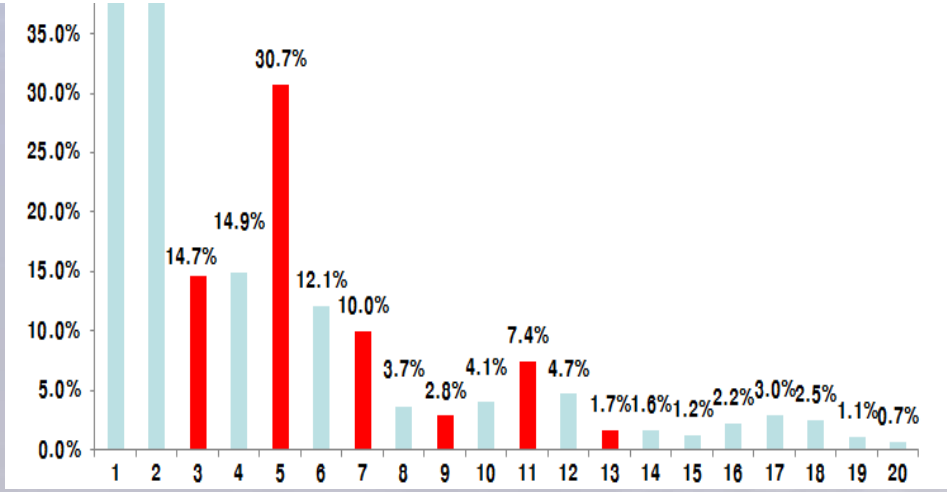

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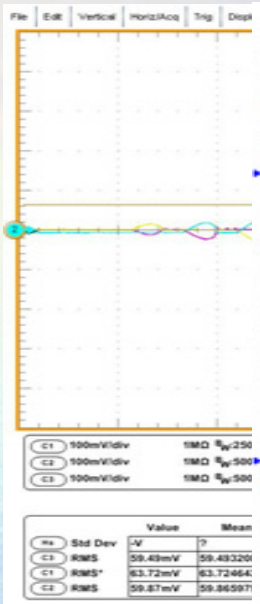
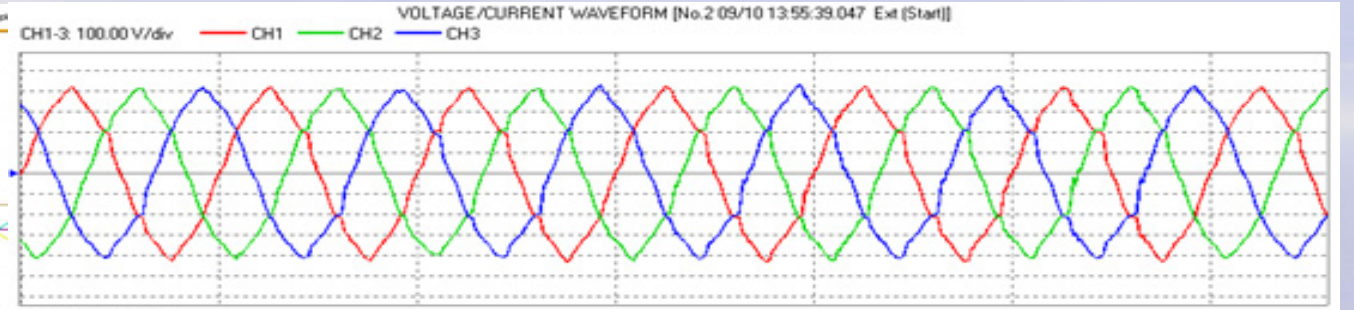
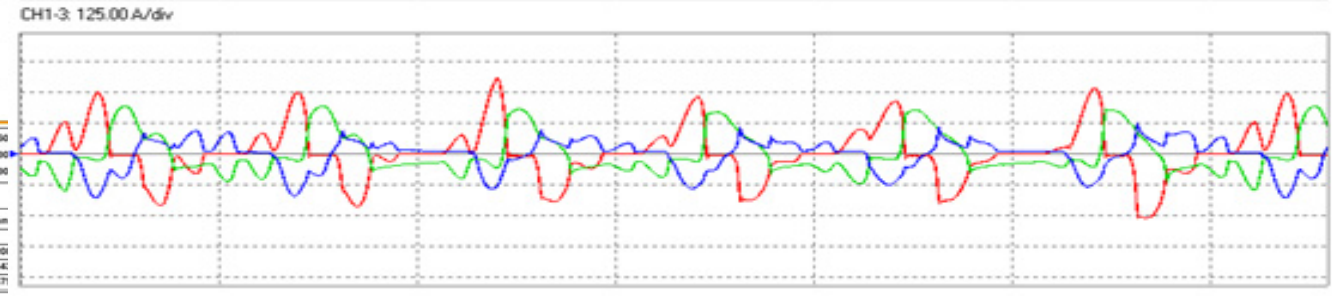
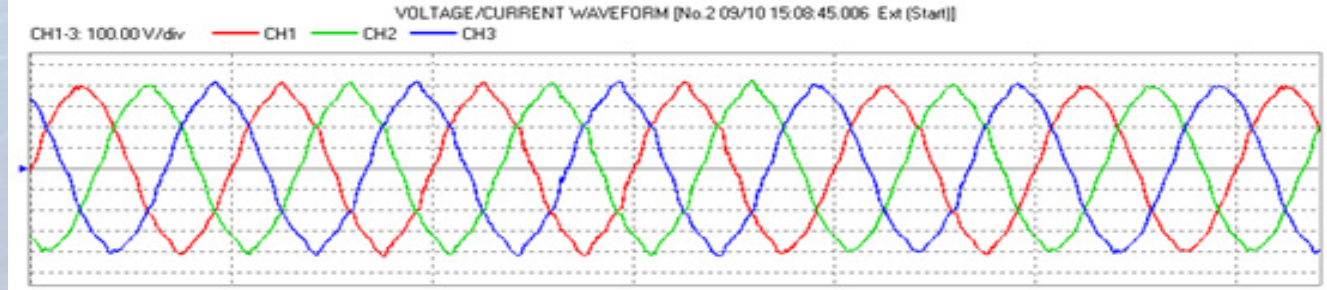
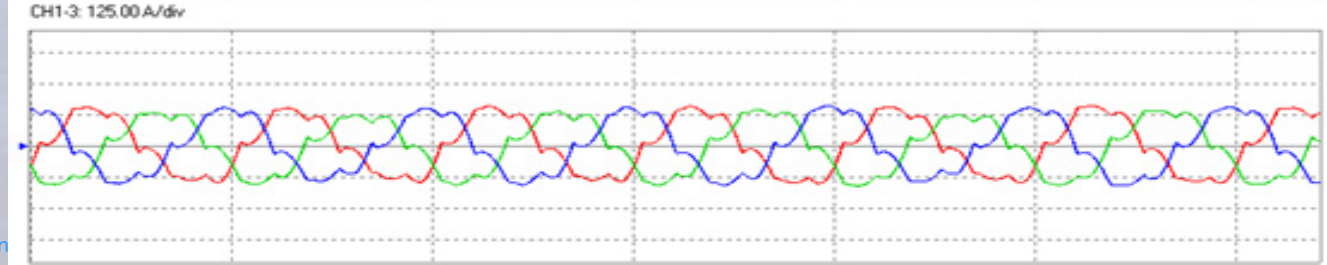
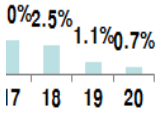








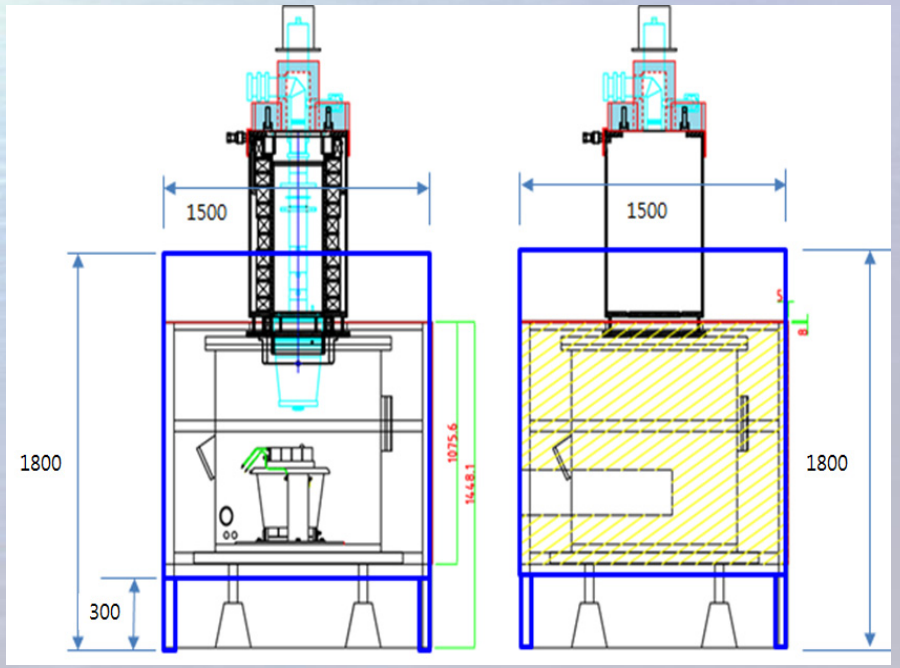


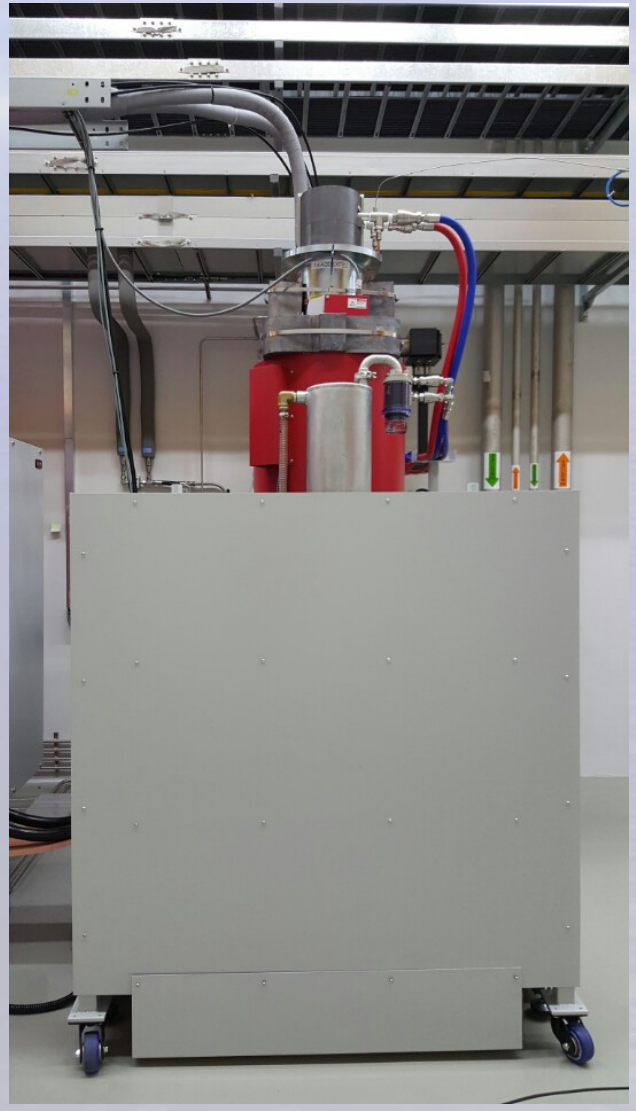


Electric Power Distortion

Radiation Shield

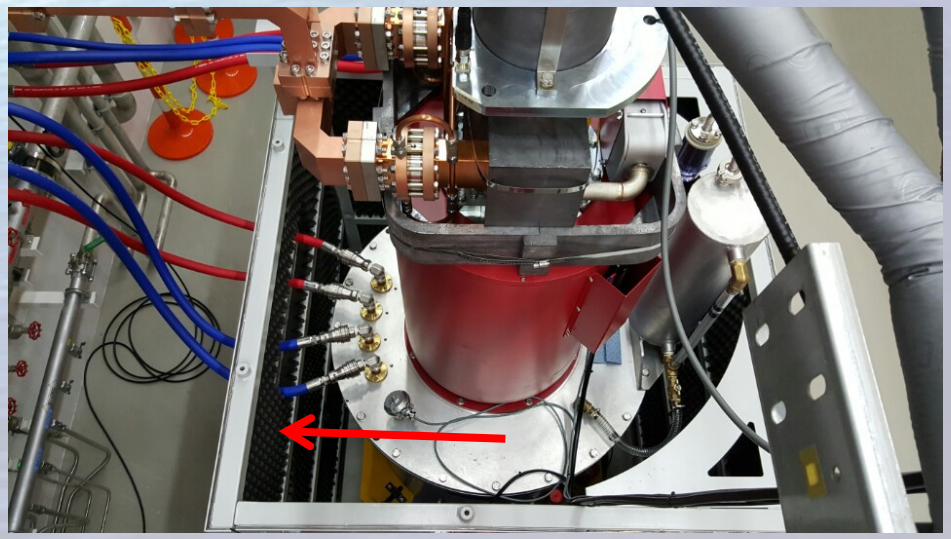
- Tank shield size: 1500X1500X1800
- Steel thickness: 3.5 mm
- Lead thickness : 5.0 mm
- Main ingredient of lead
  - ✓ Lead ingredient : Lead (Pb) 97% , Stibium (Sb) 3%
  - ✓ Density : 11.19 g/cm^3
- Figure

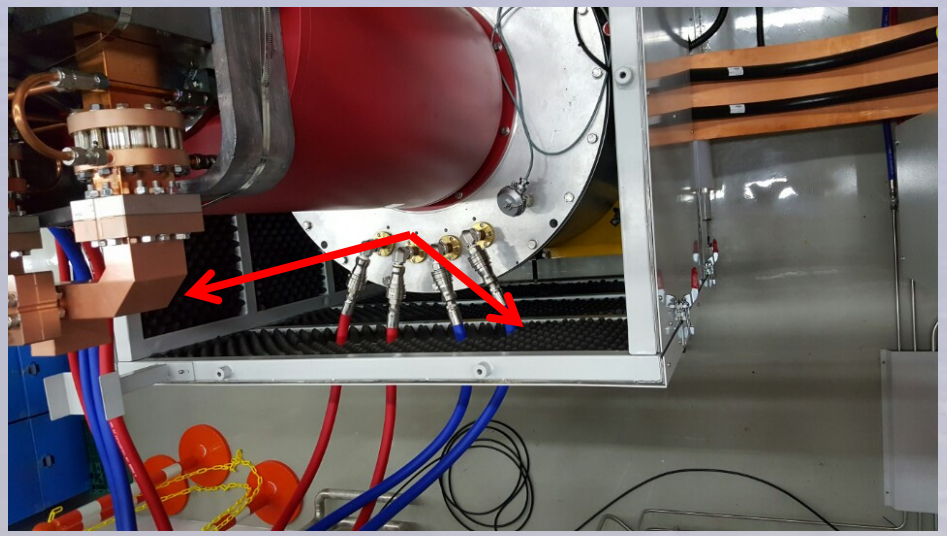




Sound Noise Protection

- Specification of sound absorbing material
  - ✓ Installation at the inside walls of the radiation shield
  - ✓ Size : 1500 X 1500 X 1800 mm
  - ✓ Thickness : 50mm
  - ✓ Type : Eggs soundproofing





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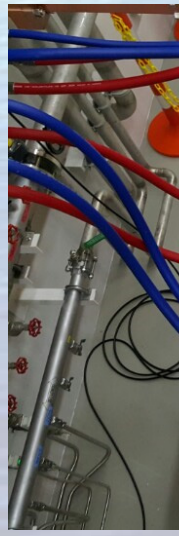
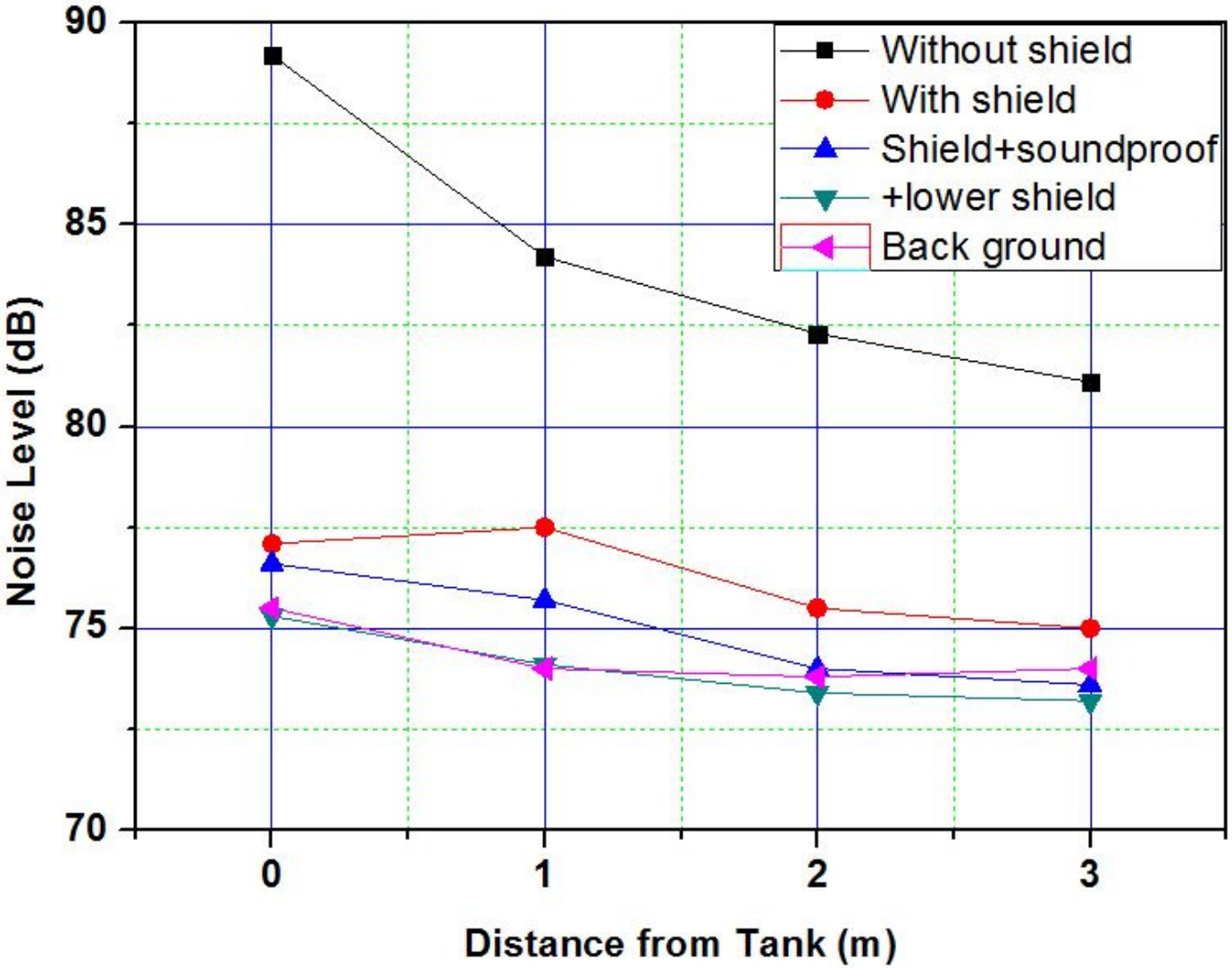
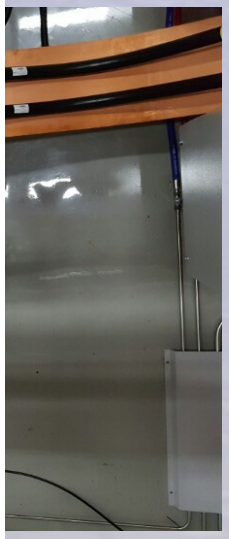
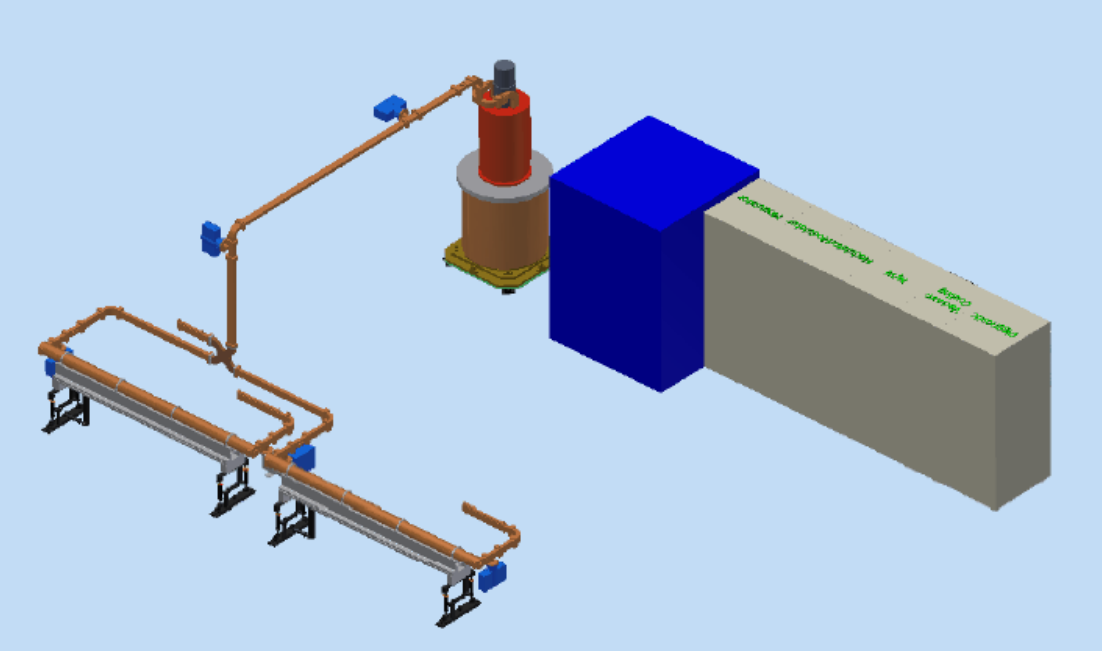






Linac High Power System



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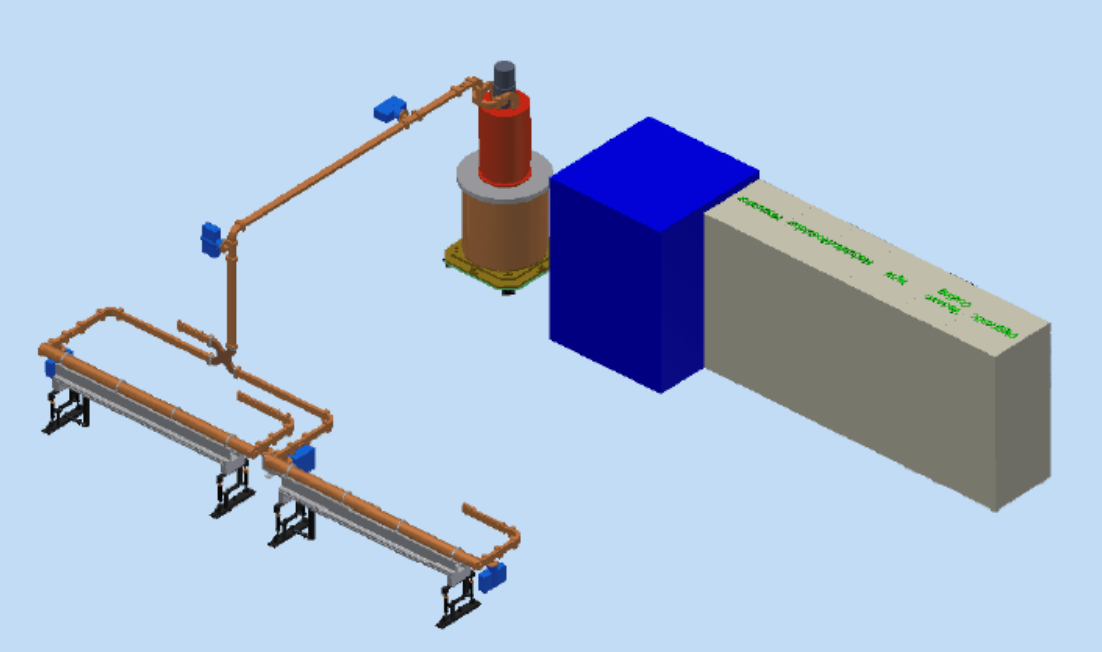

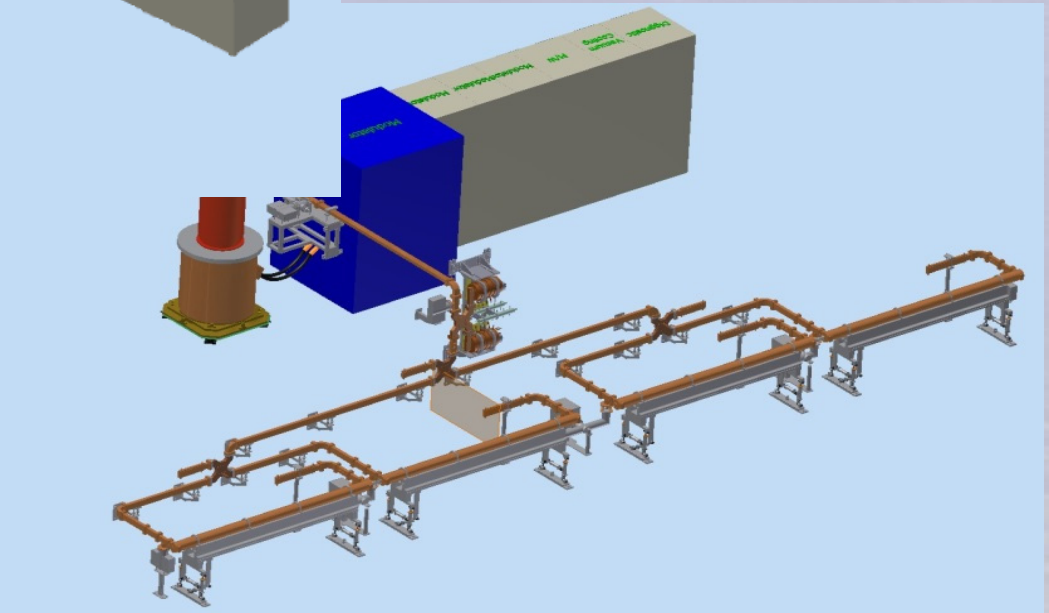

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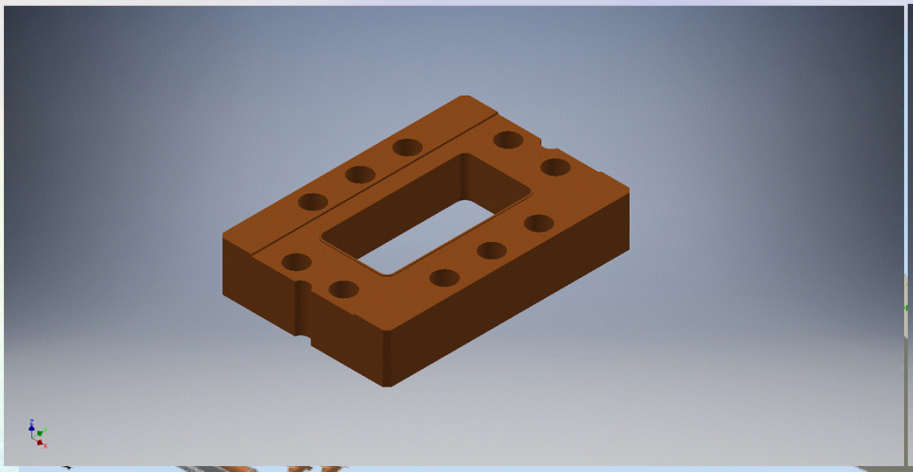
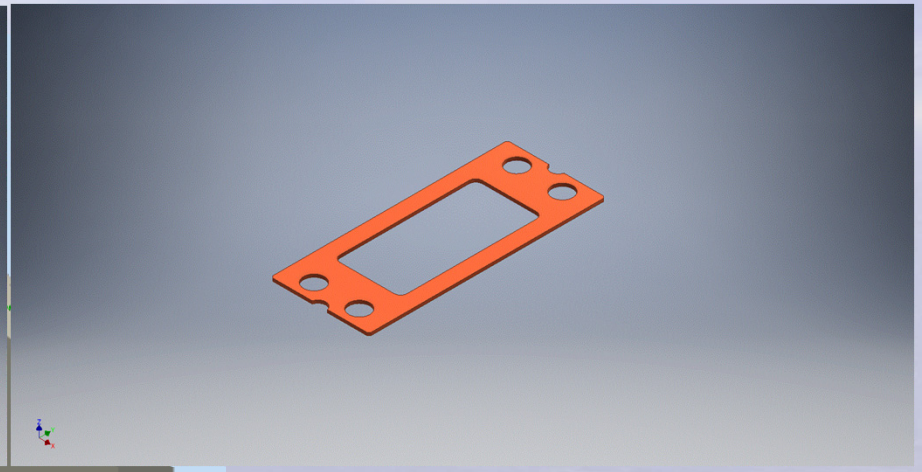
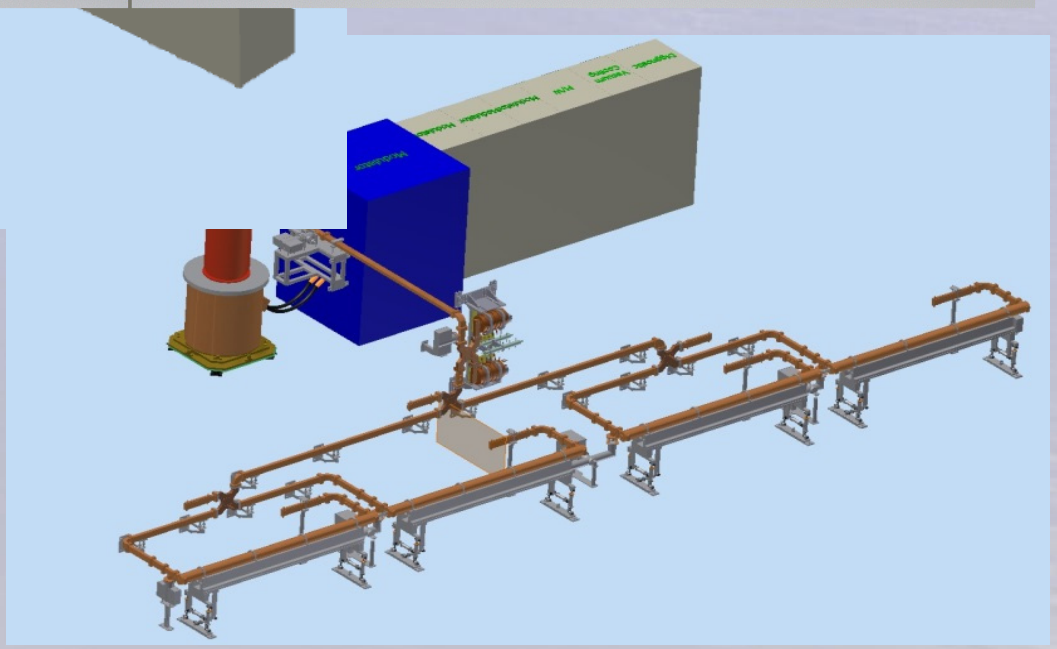
Linac High Power System







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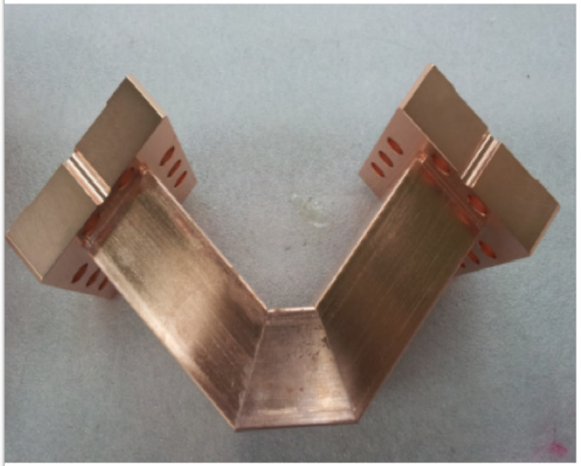
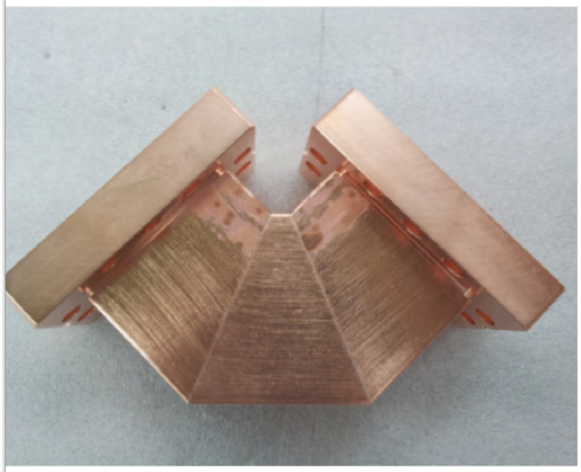
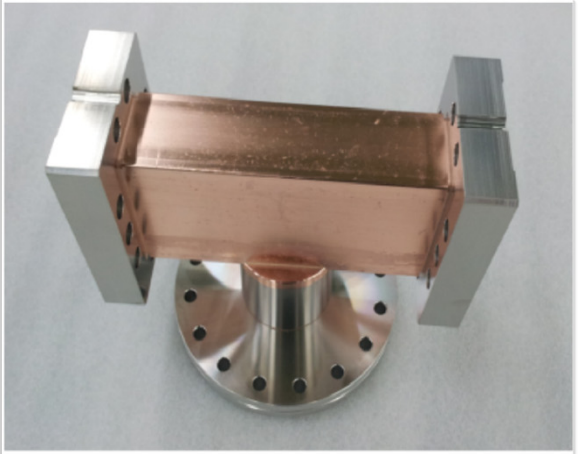
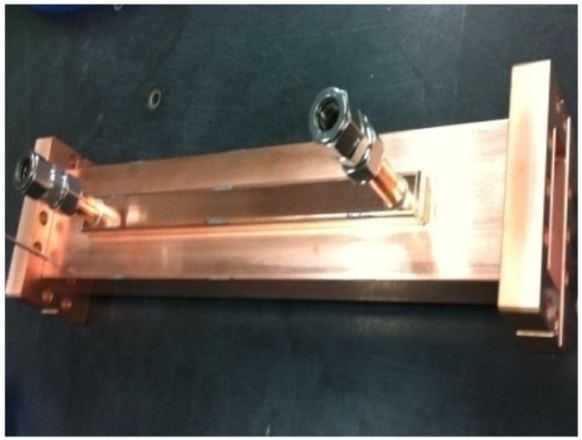
Linac High Power System

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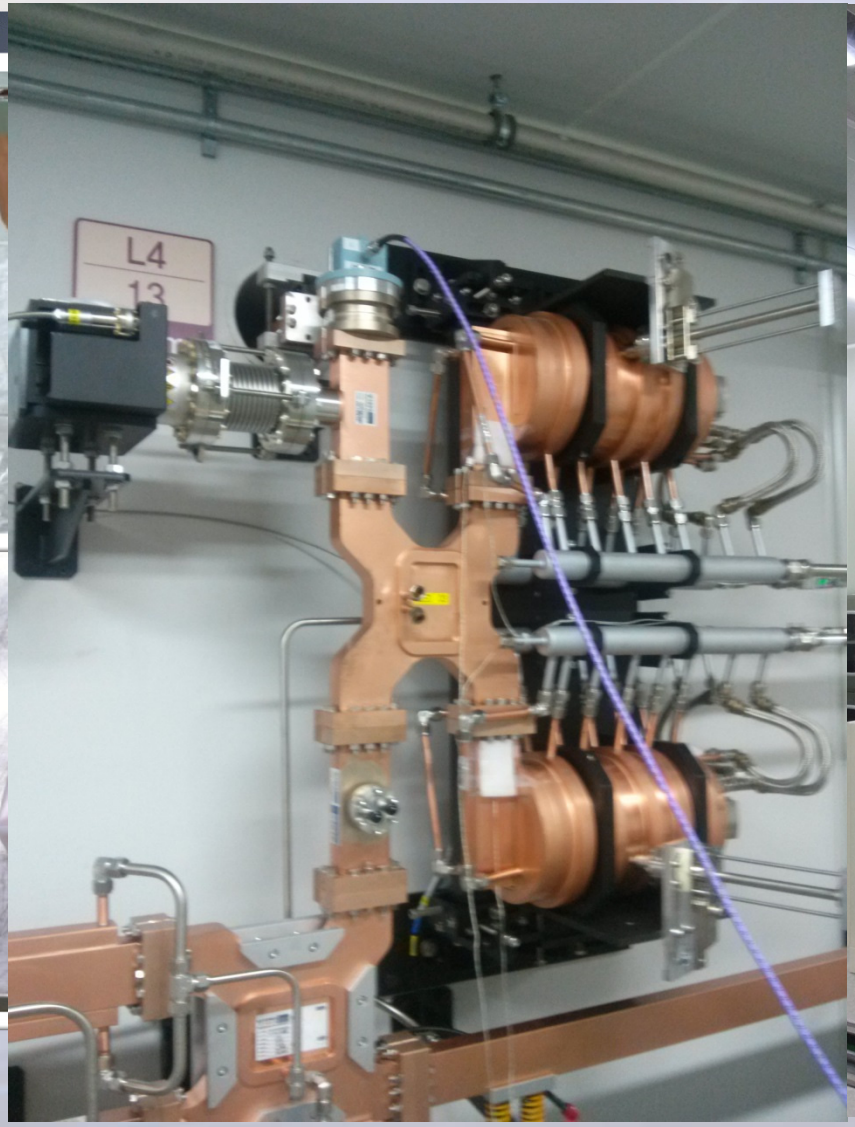
Linac High Power System



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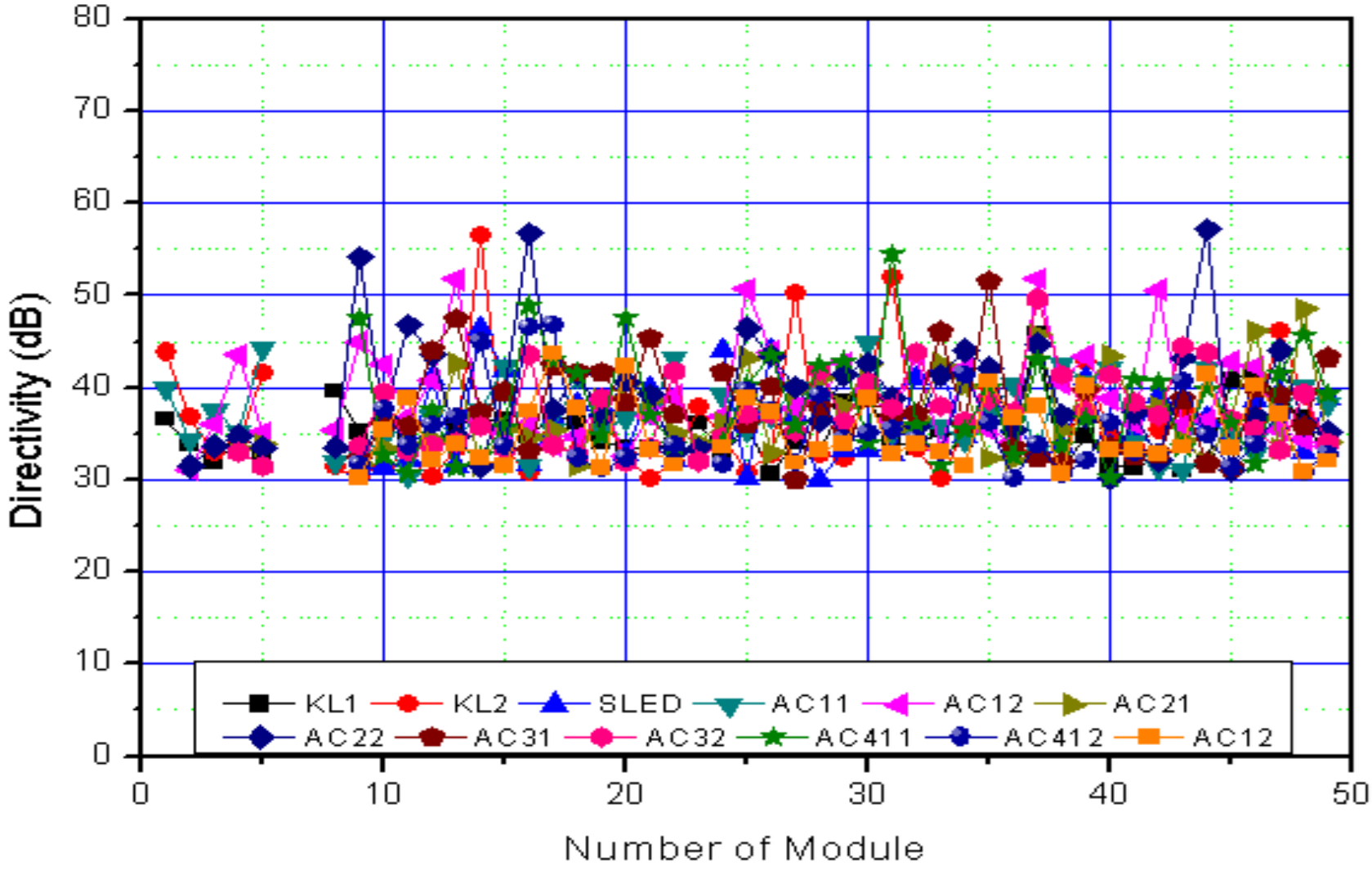
Linac High Power System



Linac Tunnel View (L2-1)

Linac Tunnel View (L2-1)

Linac Tunnel View (L2-1)

Linac Tunnel View (L2-1)

Linac Tunnel View (L2-1)

Linac Tunnel View (L2-1)

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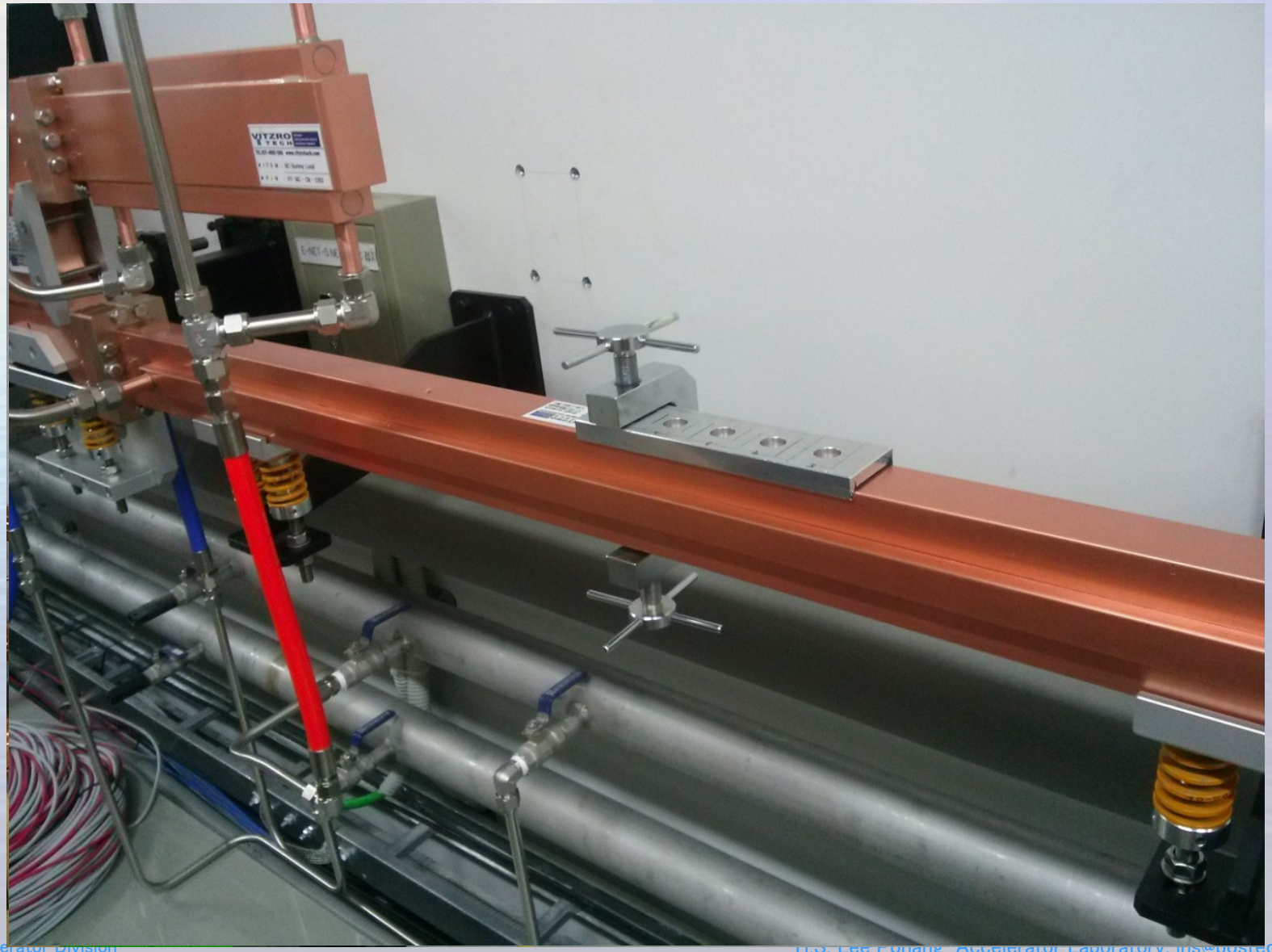
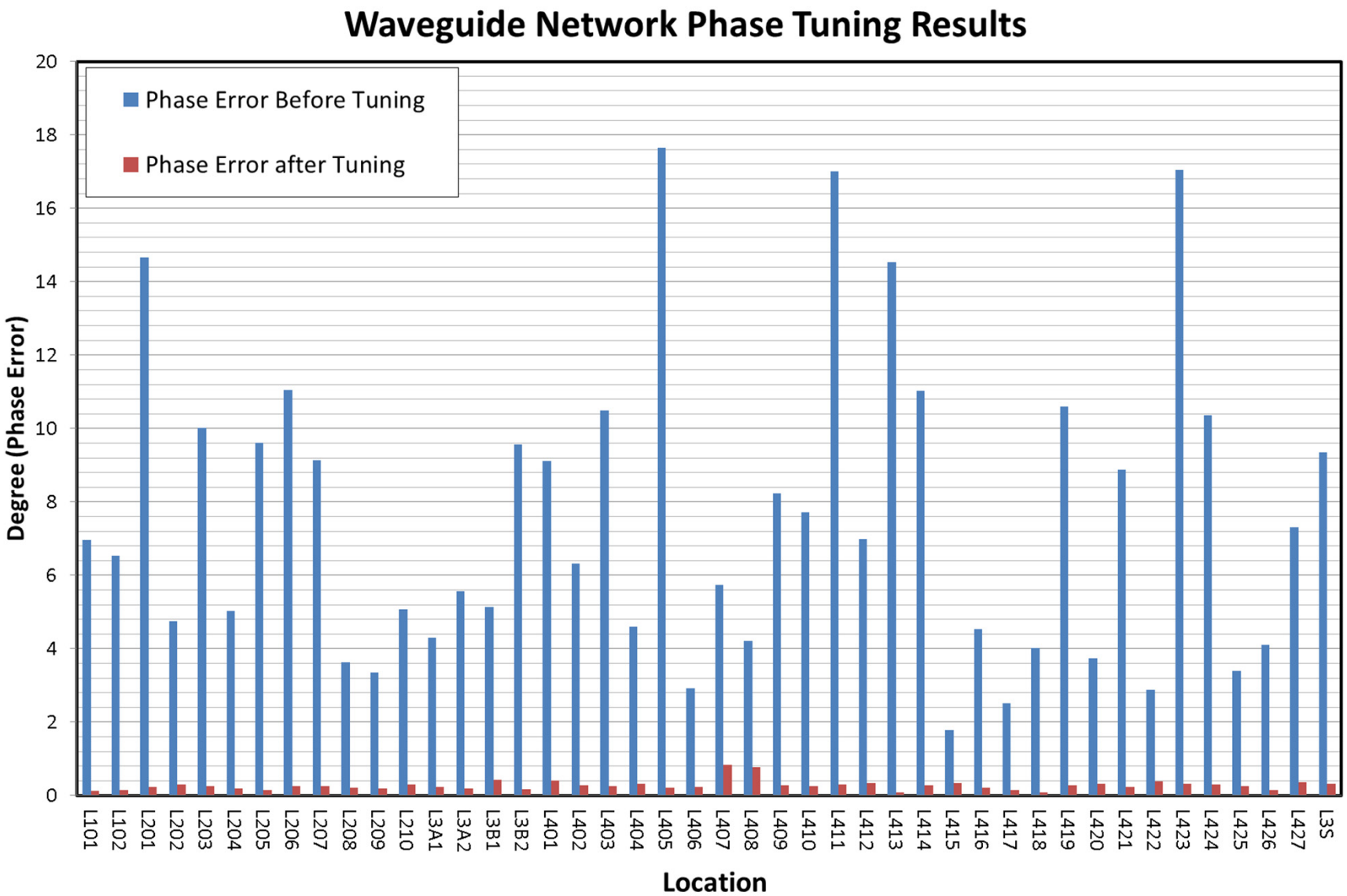
Waveguide Tuning

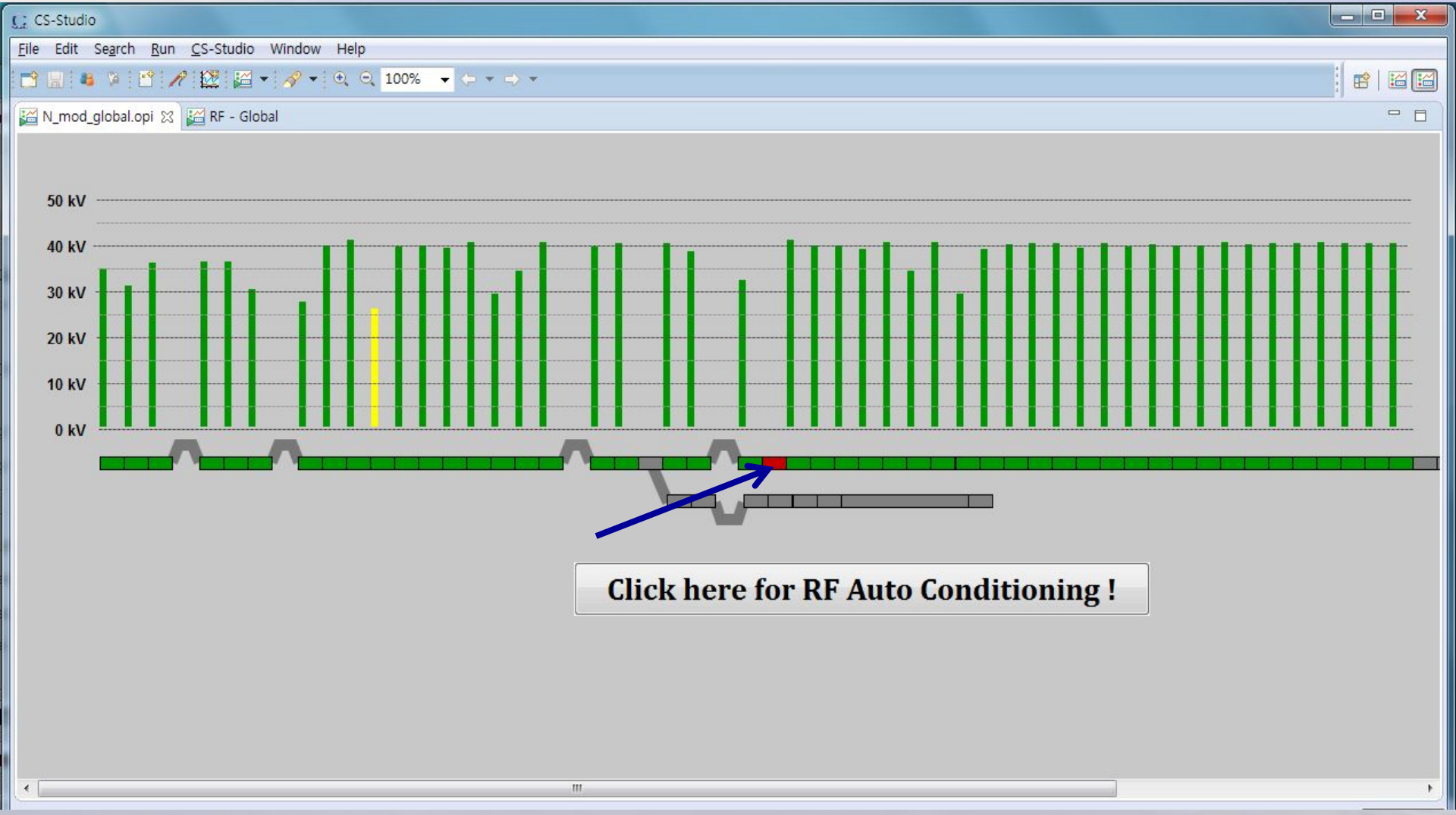
Waveguide Tuning



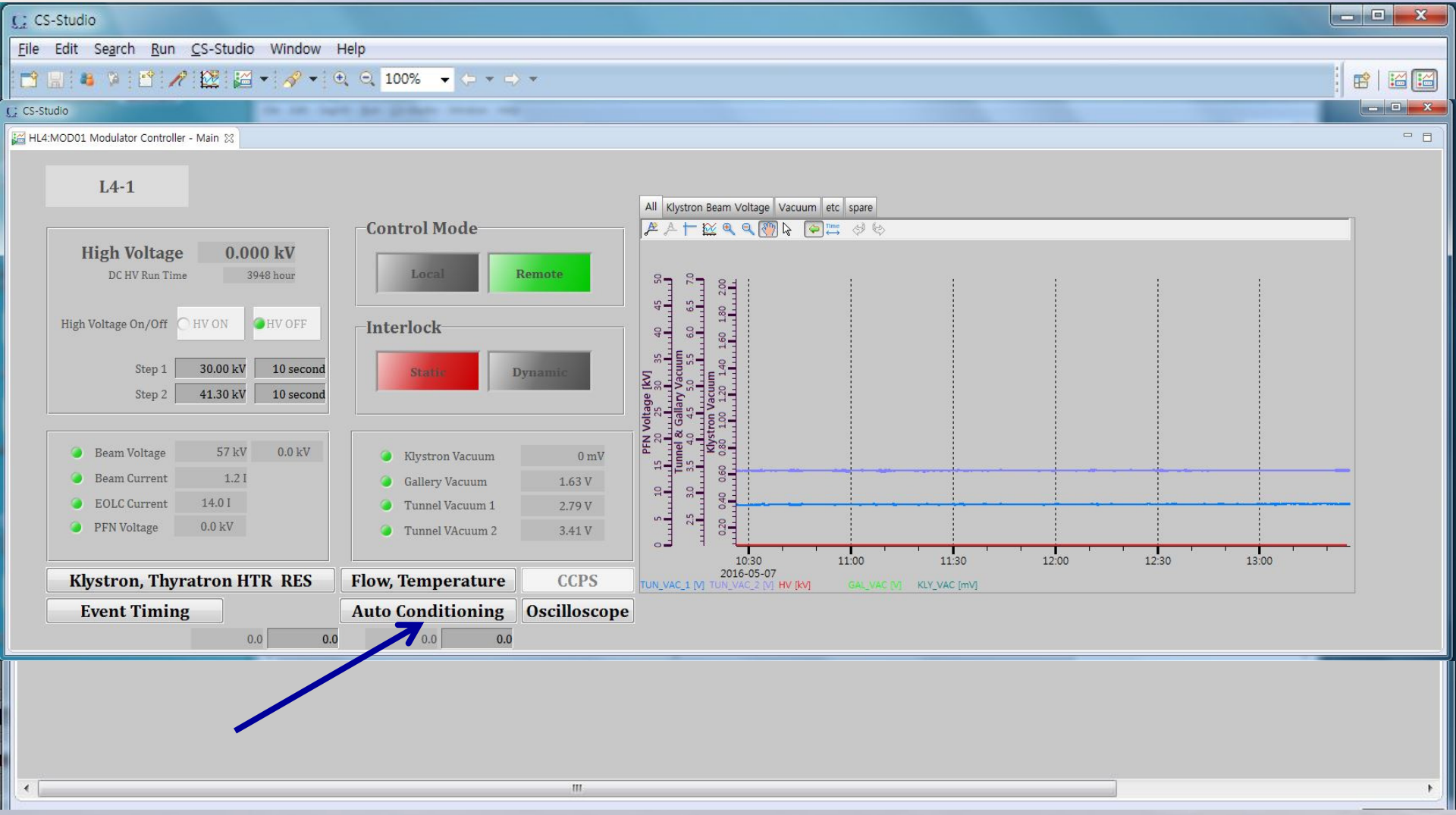
Waveguide Tuning



RF Conditioning



RF Conditioning



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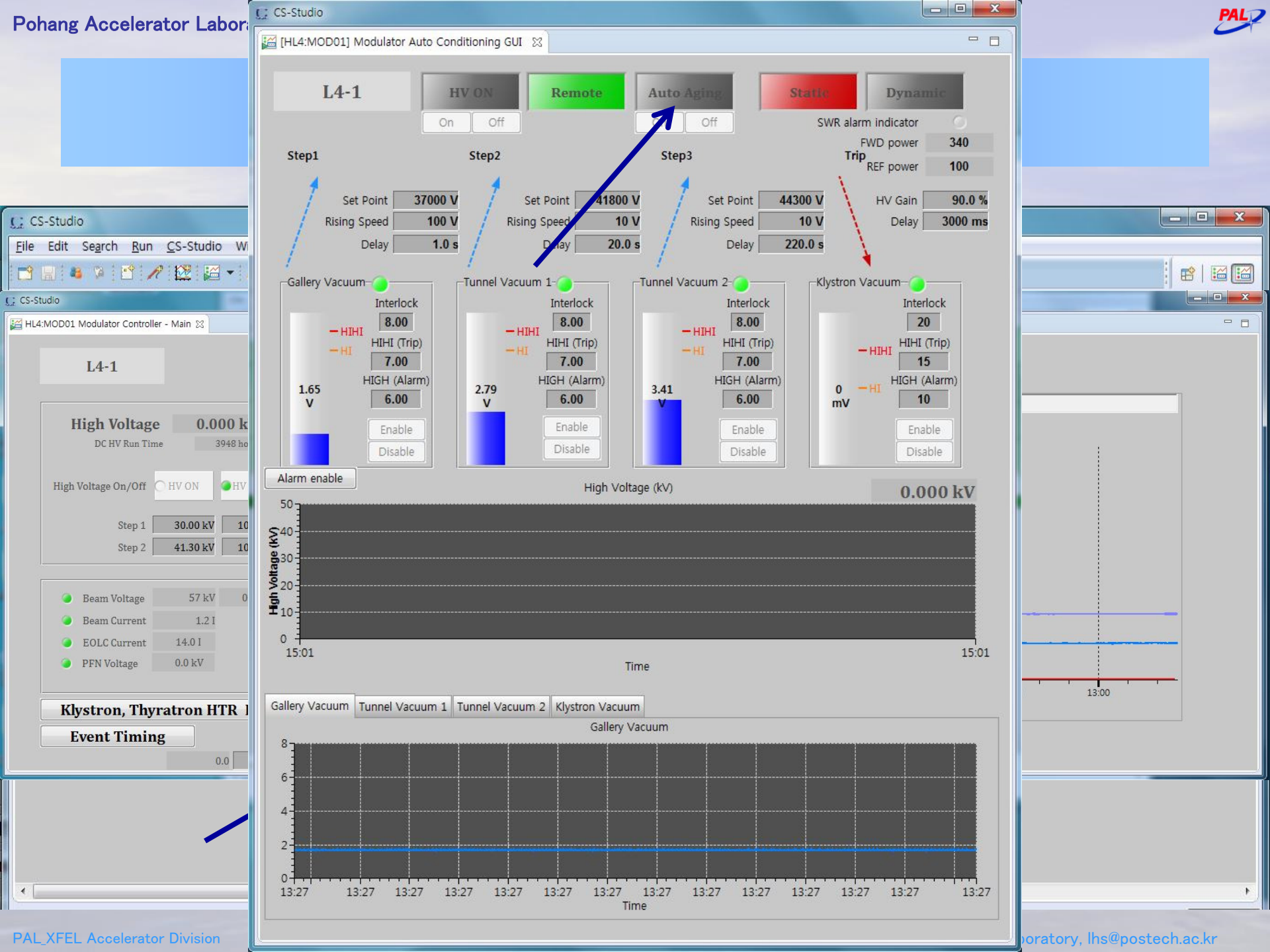
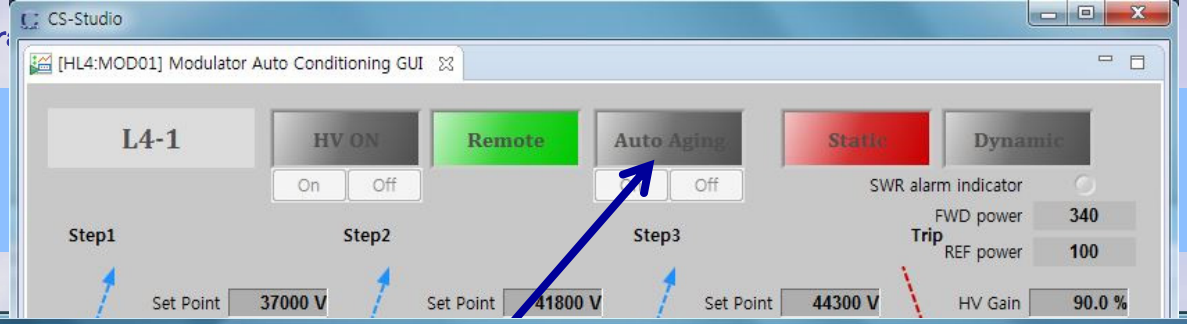

CS-Studio
[HL4:MOD01] Modulator Auto Conditioning GUI
L4-1
HV ON
On
Off
Remote
Auto Aging
Off
Static
Dynamic
SWR alarm indicator
FWD power 340
REF power 100
Trip
Step1
Set Point 37000 V
Rising Speed 100 V
Delay 1.0 s
Step2
Set Point 41800 V
Rising Speed 10 V
Delay 20.0 s
Step3
Set Point 44300 V
Rising Speed 10 V
Delay 220.0 s
HV Gain 90.0 %
Delay 3000 ms
Gallery Vacuum
Interlock 8.00
HIHI (Trip) 7.00
HIGH (Alarm) 6.00
1.65 V
Tunnel Vacuum 1
Interlock 8.00
HIHI (Trip) 7.00
HIGH (Alarm) 6.00
2.79 V
Tunnel Vacuum 2
Interlock 8.00
HIHI (Trip) 7.00
HIGH (Alarm) 6.00
3.41 V
Klystron Vacuum
Interlock 20
HIHI (Trip) 15
HIGH (Alarm) 10
0 mV
HIHI
HI
Enable
Disable
Alarm enable
High Voltage (kV)
0.000 kV
High Voltage (kV)
Time
15:01
Gallery Vacuum
Tunnel Vacuum 1
Tunnel Vacuum 2
Klystron Vacuum
Gallery Vacuum
Time
13:27
HL4:MOD01 Modulator Controller - Main
High Voltage 0.000 k
DC HV Run Time 3948 ho
High Voltage On/Off
Step 1 30.00 kV
Step 2 41.30 kV
Beam Voltage 57 kV
Beam Current 1.2 I
EOLC Current 14.0 I
PFN Voltage 0.0 kV
Klystron, Thyratron HTR
Event Timing
13:00


CS-Studio
[HL4:MOD01] Modulator Auto Conditioning GUI
L4-1
HV ON
On
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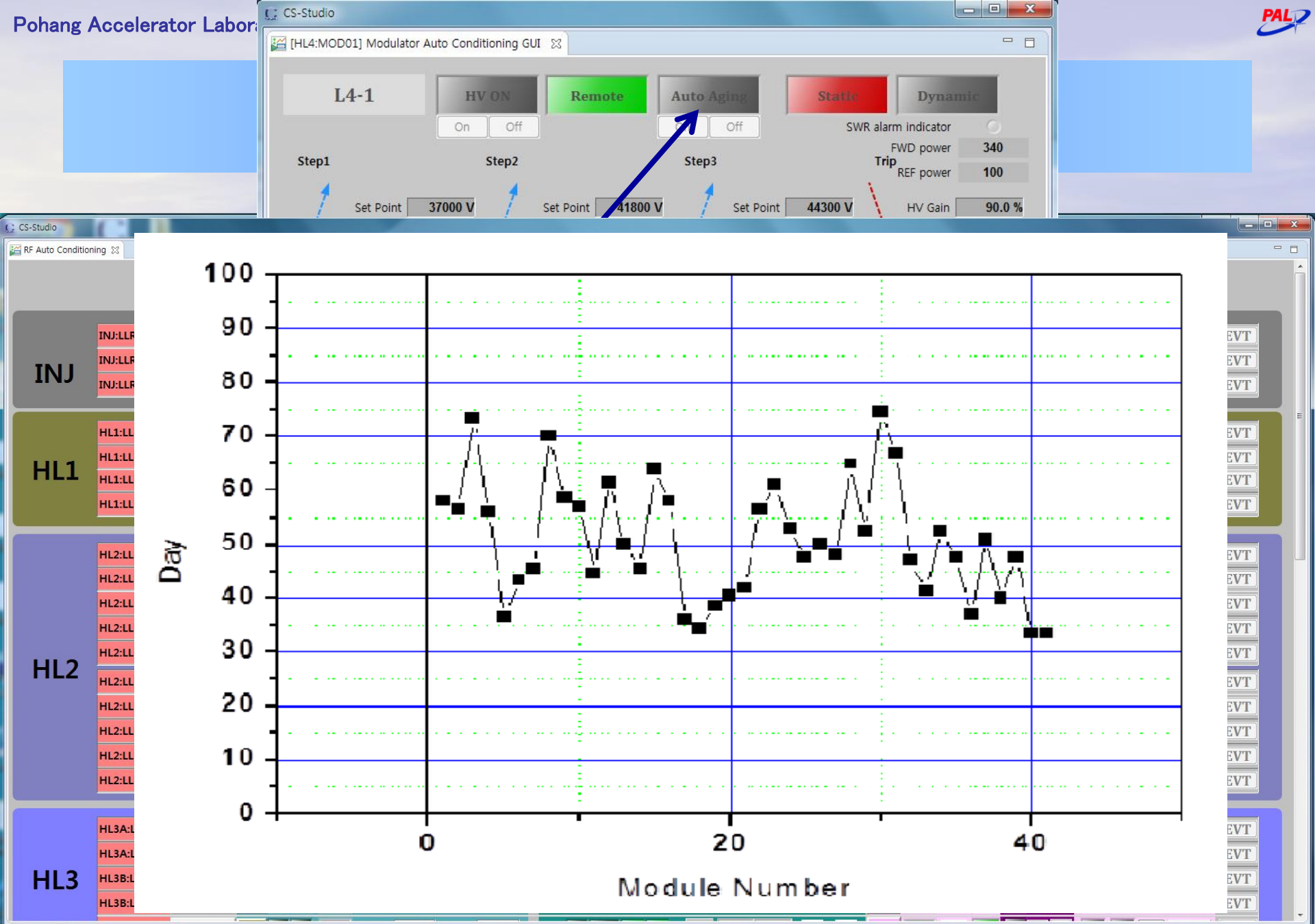
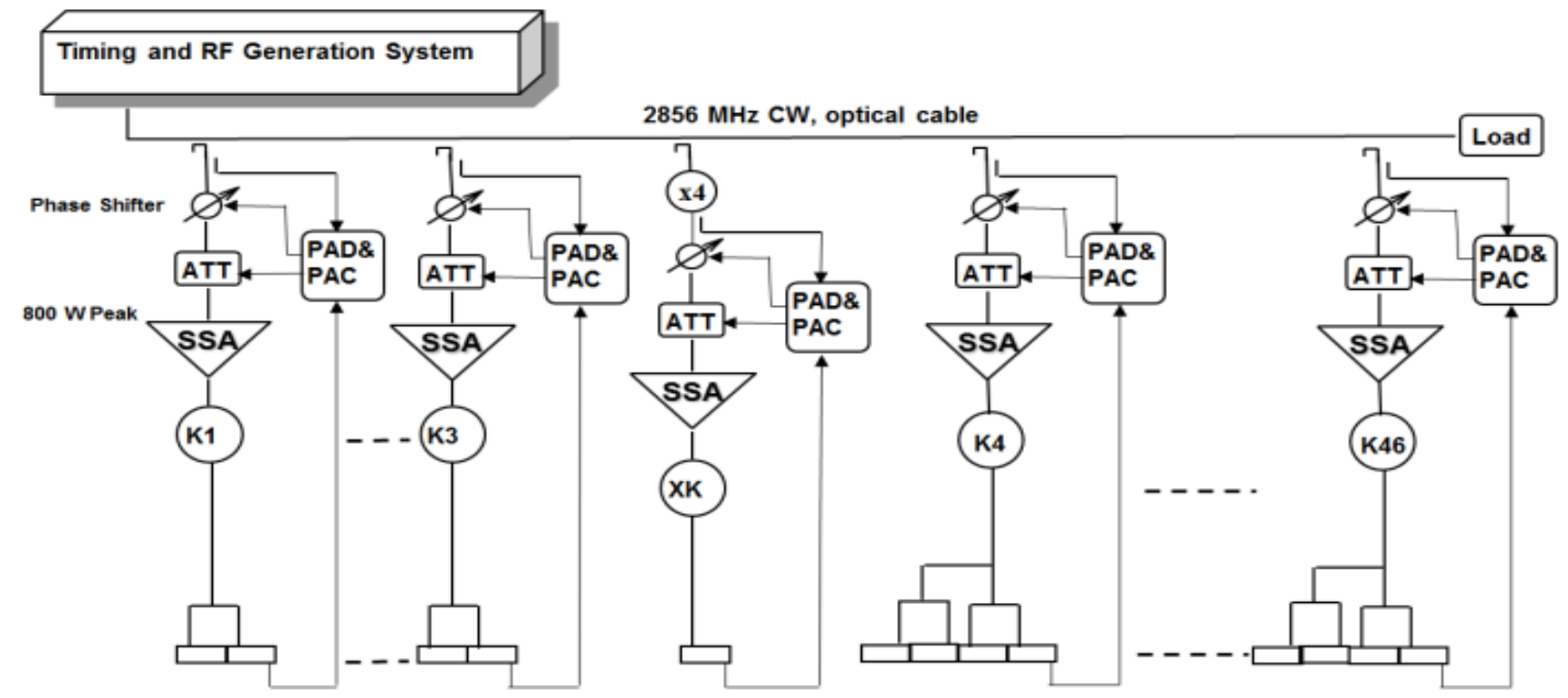
Remote
Auto Aging
Off
Static
Dynamic
SWR alarm indicator
FWD power
340
Trip
REF power
100
Step1
Step2
Step3
Set Point
37000 V
Set Point
41800 V
Set Point
44300 V
HV Gain
90.0 %

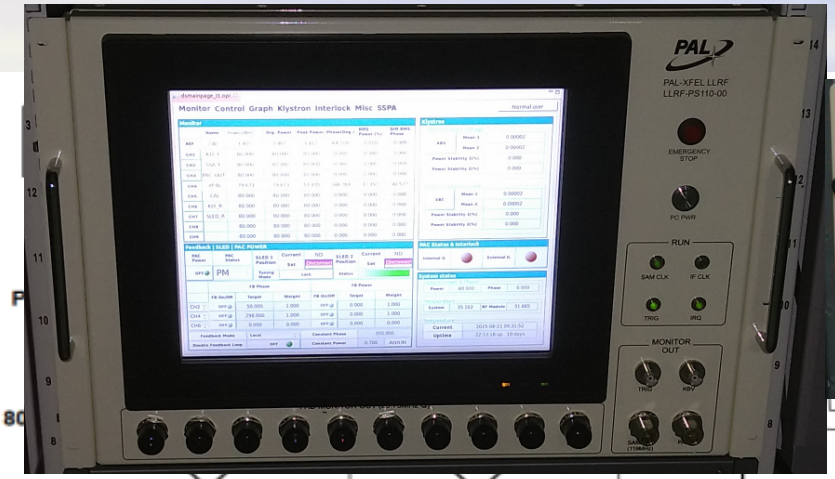
CS-Studio
RF Auto Conditioning
2015.12.5 Ver.1 (JYH, SYB, GYM)
2016. 4. 1 (JYH)
RF AutoConditioning
INJ
INJ:LLRFGUN Auto Con LLRF Int Ext RF Pset(dBm) 0 PW (us) 2.5 SSA All SWR PS RF RESET PS RF F 760 R 10 MOD HV 35.494 RM Age On Off IntS IntT Reset Vacuum.. EVT
INJ:LLRF01 Auto Con LLRF Int Ext RF Pset(dBm) 0.6 PW (us) 1.5 SSA All SWR PS RF RESET PS RF F 480 R 50 MOD HV 31.595 RM Age On Off IntS IntT Reset Vacuum.. EVT
INJ:LLRF02 Auto Con LLRF Int Ext RF Pset(dBm) 7.7 PW (us) 1.5 SSA All SWR PS RF RESET PS RF F 700 R 30 MOD HV 36.889 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL1
HL1:LLRF01 Auto Con LLRF Int Ext RF Pset(dBm) 4.4 PW (us) 1.5 SSA All SWR PS RF RESET PS RF F 740 R 30 MOD HV 37.142 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL1:LLRF02 Auto Con LLRF Int Ext RF Pset(dBm) -0.4 PW (us) 1.5 SSA All SWR PS RF RESET PS RF F 420 R 30 MOD HV 37.143 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL1:LLRFXLI Auto Con LLRF Int Ext RF Pset(dBm) 4.8 PW (us) 0.2 SSA All SWR PS RF RESET PS RF F 0 R 0 MOD HV 30.983 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL1:LLRFDF1 Auto Con LLRF Int Ext RF Pset(dBm) 5.2 PW (us) 0.5 SSA All SWR PS RF RESET PS RF F 640 R 60 MOD HV 27.996 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL2
HL2:LLRF01 Auto Con LLRF Int Ext RF Pset(dBm) 6.8 PW (us) 4 SSA All SWR PS RF RESET PS RF F 470 R 60 MOD HV 40.699 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL2:LLRF02 Auto Con LLRF Int Ext RF Pset(dBm) 6.4 PW (us) 4 SSA All SWR PS RF RESET PS RF F 440 R 80 MOD HV 41.996 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL2:LLRF03 Auto Con LLRF Int Ext RF Pset(dBm) 4.8 PW (us) 4 SSA All SWR PS RF RESET PS RF F 390 R 40 MOD HV 29.998 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL2:LLRF04 Auto Con LLRF Int Ext RF Pset(dBm) 4.8 PW (us) 4 SSA All SWR PS RF RESET PS RF F 380 R 70 MOD HV 40.398 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL2:LLRF05 Auto Con LLRF Int Ext RF Pset(dBm) 7.3 PW (us) 4 SSA All SWR PS RF RESET PS RF F 570 R 70 MOD HV 40.796 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL2:LLRF06 Auto Con LLRF Int Ext RF Pset(dBm) 5.6 PW (us) 4 SSA All SWR PS RF RESET PS RF F 500 R 50 MOD HV 40.097 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL2:LLRF07 Auto Con LLRF Int Ext RF Pset(dBm) 6.7 PW (us) 4 SSA All SWR PS RF RESET PS RF F 450 R 50 MOD HV 41.497 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL2:LLRF08 Auto Con LLRF Int Ext RF Pset(dBm) 5.1 PW (us) 4 SSA All SWR PS RF RESET PS RF F 360 R 40 MOD HV 29.997 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL2:LLRF09 Auto Con LLRF Int Ext RF Pset(dBm) 5.8 PW (us) 4 SSA All SWR PS RF RESET PS RF F 370 R 70 MOD HV 34.997 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL2:LLRF10 Auto Con LLRF Int Ext RF Pset(dBm) 5.7 PW (us) 4 SSA All SWR PS RF RESET PS RF F 440 R 130 MOD HV 41.597 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL3
HL3A:LLRF01 Auto Con LLRF Int Ext RF Pset(dBm) 4.8 PW (us) 4 SSA All SWR PS RF RESET PS RF F 440 R 60 MOD HV 40.397 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL3A:LLRF02 Auto Con LLRF Int Ext RF Pset(dBm) 6.1 PW (us) 4 SSA All SWR PS RF RESET PS RF F 480 R 60 MOD HV 41.197 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL3B:LLRF01 Auto Con LLRF Int Ext RF Pset(dBm) 2.7 PW (us) 4 SSA All SWR PS RF RESET PS RF F 340 R 70 MOD HV 41.197 RM Age On Off IntS IntT Reset Vacuum.. EVT
HL3B:LLRF02 Auto Con LLRF Int Ext RF Pset(dBm) 4 PW (us) 4 SSA All SWR PS RF RESET PS RF F 380 R 160 MOD HV 39.397 RM Age On Off IntS IntT Reset Vacuum.. EVT
Time

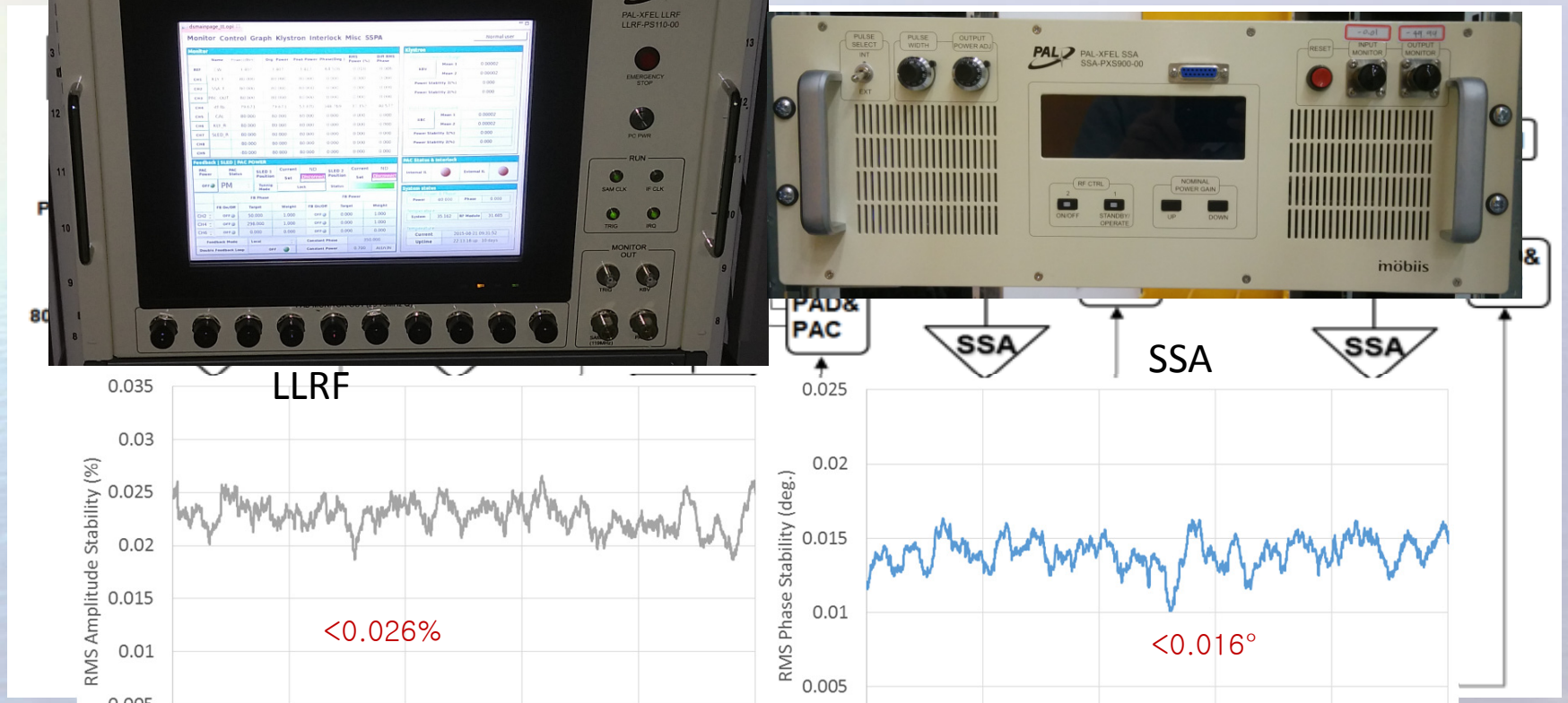

CS-Studio
[HL4:MOD01] Modulator Auto Conditioning GUI
L4-1
HV ON
Remote
Auto Aging
Static
Dynamic
On
Off
Off
SWR alarm indicator
FWD power
340
Trip
REF power
100
Step1
Step2
Step3
Set Point
37000 V
Set Point
41800 V
Set Point
44300 V
HV Gain
90.0 %
CS-Studio
RF Auto Conditioning
INJ
HL1
HL2
HL3
Day
Module Number
Time

S-band LLRF System



S-band LLRF System





Amplitude Stability @LLRF out

Phase Stability @LLRF out

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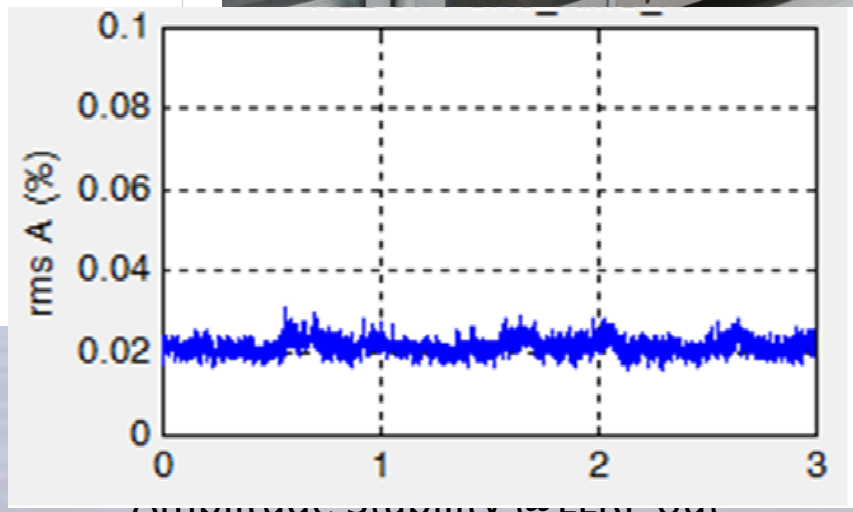
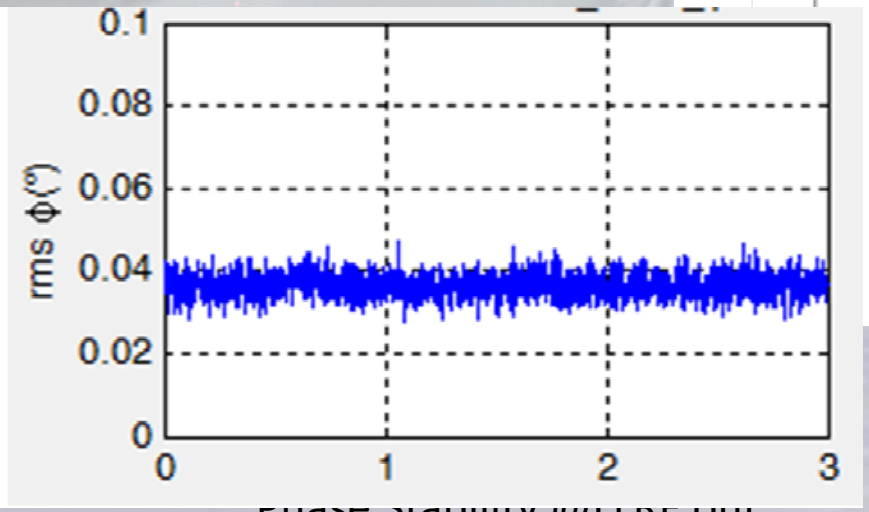
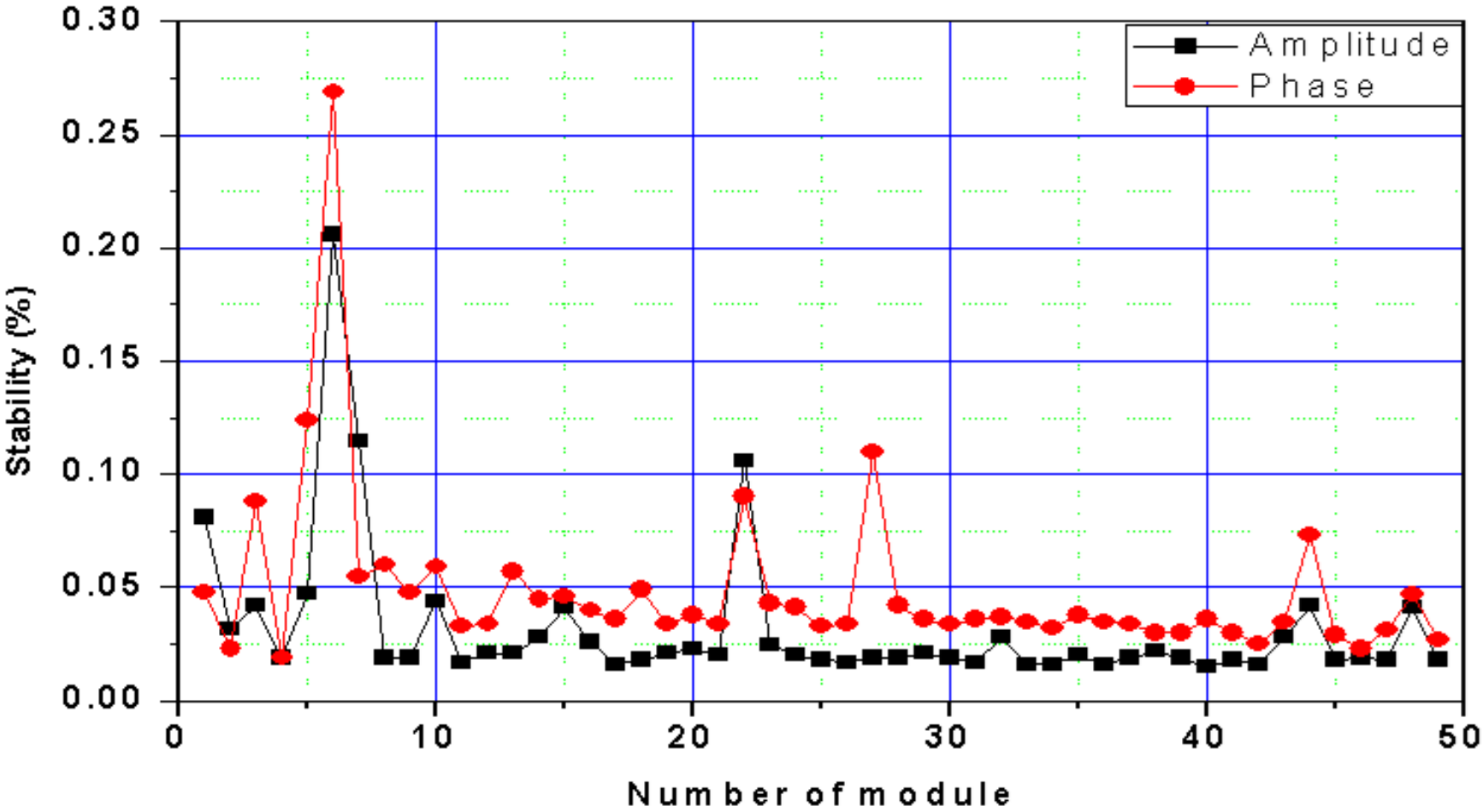


Amplitude Stability @LLRF out



Phase Stability @LLRF out



Amplitude Stability @LLRF out

Phase Stability @LLRF out

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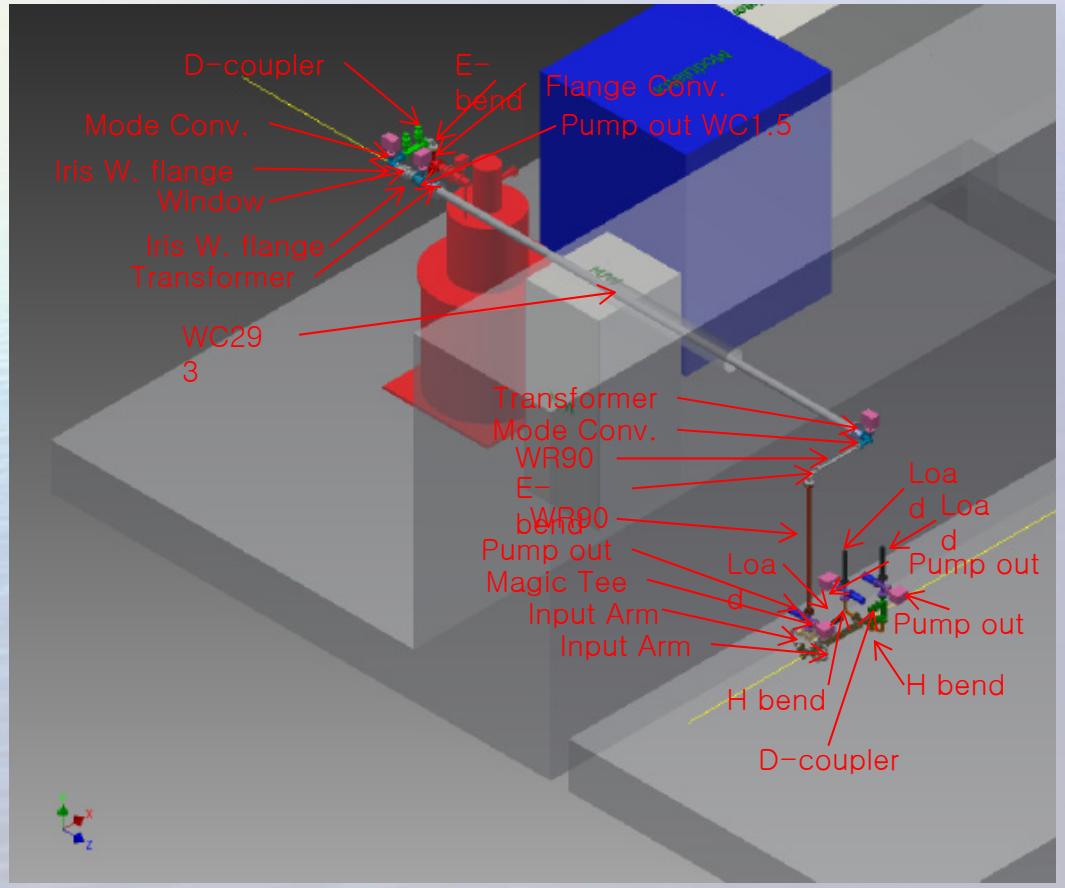
X-band LLRF System



	Length (mm)	Quantity
WR-90 Straight*	1223	1
	450	1
WC-293 Straight*	4579	1
WR-90 E-bend		2
WR-90 H-bend		2
Input Arm		2
Magic Tee		1
WR-90 Pump out		3
55dB D-coupler		2
Mode converter		2
Transformer		2
Iris window flange		2
Window		1
Pump out spool WC1.5		1
Dry load		3
Flange Conv.(F2F)*		1

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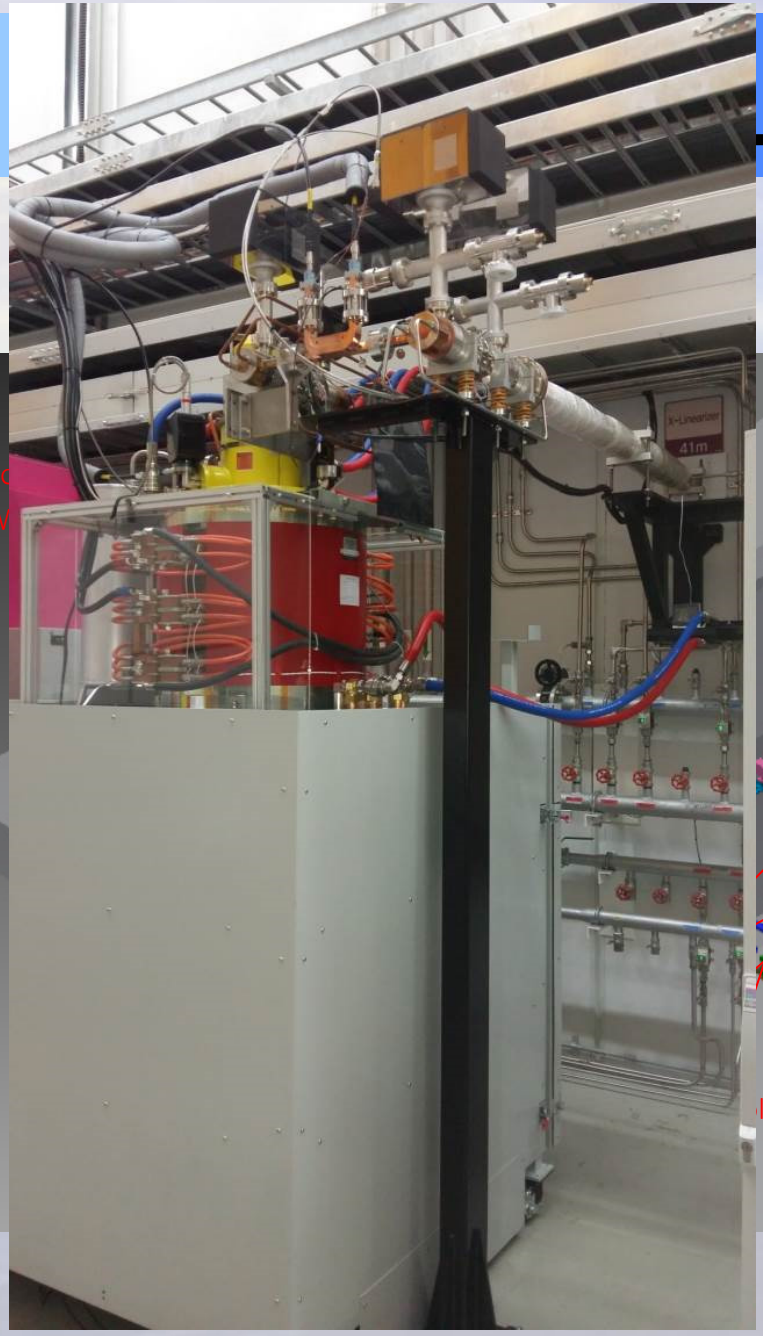

ntity
1
1
1
2
2
2
1
3
2
2
2
2
1
1
3
1

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Specification		
Frequency	REF : 2.856 PAD & PAC : 11.424	GHz
PAD Ch. number	10 (2 REF)	
Phase stability	0.1	(RMS, Degree)
Amp. stability	0.04 @<-5dBm	(RMS, Voltage(%))
PAC pulse rising time	< 15ns	
PAD input power range	Ref : 0 ~ 5	dBm
	CH : -8 ~+8	dBm
PAC output power range	-8 ~ +8	dBm

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Specification

Frequency Range	11.424 ± 10 MHz
Pulse Repetition Rate	5 ~ 120 Hz
Pulse rise/fall time	< 30 ns
Pulse width range	0.1 ~ 2.0 μs
Small signal gain	+59.0 dB
Max. Output Power	> 1000 W
Harmonics	-40.0 (max.)
Spurious	-65.0 (max.)
Input return loss	<1:1.5
Output return loss	<1:1.5

Feature

Main TR	GaN HEMT
Power Combiner	20 ways Radial Power Combiner

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KM Control Rack 1
KM Control Rack 2
KM CCPS Rack
XFEL X-band Pulse Modulator
CnCR

First 10 GeV Beam

CS-Studio

PAL-XFEL HOME

HX | SX | Glo... | INJ | HL1 | HL2 | HL3A | HL3B | HL4 | HBTL | HU1 | HU1E | SBL | SL3 | SBTL | SU1 | SU1E

Operation Parameter | Event Trigger | RF Timing | Laser | RF | SLED / ACC Temp. | MPS | BPM | Screen / Wire | BCM / BAM / DCM | BC / COL / DECH | LH / Undulator | Vacuum | Feedback / Matching | EBPM / CRM | BAS / TDS / DUMP | WPS / HLS | BLM / RPBLM | GUN / X_LIN | Utility | MIS | Photon Diagnostics

Operation Parameters 1/2 | Operation Parameters 2/2 | Trip Control

FEL Operation Mode

- HX only mode
- SX only mode
- HX & SX mode

Linac Operation Mode

Status: Test mode

- Off
- FEL mode
- Tuning mode
- Test mode
- RF only mode

Beam Energy

Injector		
BC1	0.3300	Gev
BC2	2.5200	Gev
BC3	3.4500	Gev
S-branch	3.0000	Gev
HX beam energy	10.0000	Gev
SX beam Energy	0.0000	Gev

Beam End Point

HX

BAS0	0.1370	Gev	MPS BAS0 Init
BAS1	0.3380	Gev	MPS BAS1 Init
BAS2	0.3300	Gev	MPS BAS2 Init
BAS3H	3.1000	Gev	MPS BAS3H Init

- Beam abort dump
- HX Tune-up dump
- HX main dump

SX

- BAS3S
- SX Tune-up dump
- SX main dump

Beam Energy: 10.066

Injector Energy	0.133	0.136
BC1 Energy	5.000	0.351	0.319
BC2 Energy	3.000	2.597	2.602
BC3H Energy	0.000	3.752	0.000
HX Linac	10.101	7.009

Gun, BAS0, BC1, BAS1, BC2, BAS2, BC3H, BAS3H, L0, L1, X, L2, L3A, L3B, L4, Stopper 1, Stopper 2, Stopper 3

Beam Charge 197.835

S-branch Energy 3.162 Disconnected

BC3_S, BAS3S, L3S, De-Chirper, Tune-up dump

BC3S Energy 0.000 0.000 0.000

HL4:SCMB3:

dump

BAS0	0.004	0.000
BAS1	0.000	0.000
BAS2	0.000	0.000
BAS3H	190.099	10.066
BAS3S	0.000	0.000
Tunu up dump	150.001	

Beam : ON

RF : ON

RF Control

Acc ● ACC All On | ACC All Off

ALL ● ON | OFF

Beam Ready ●

Beam Control

Beam	On	
Beam Pulse Rate	2 Hz	2 Hz
RF Pulse Rate	10.0	10Hz
Beam Charge	200	200 pC

Beam Stopper

Beam Stopper 1	Closed
Beam Stopper 2	Closed
Beam Stopper 3	Closed

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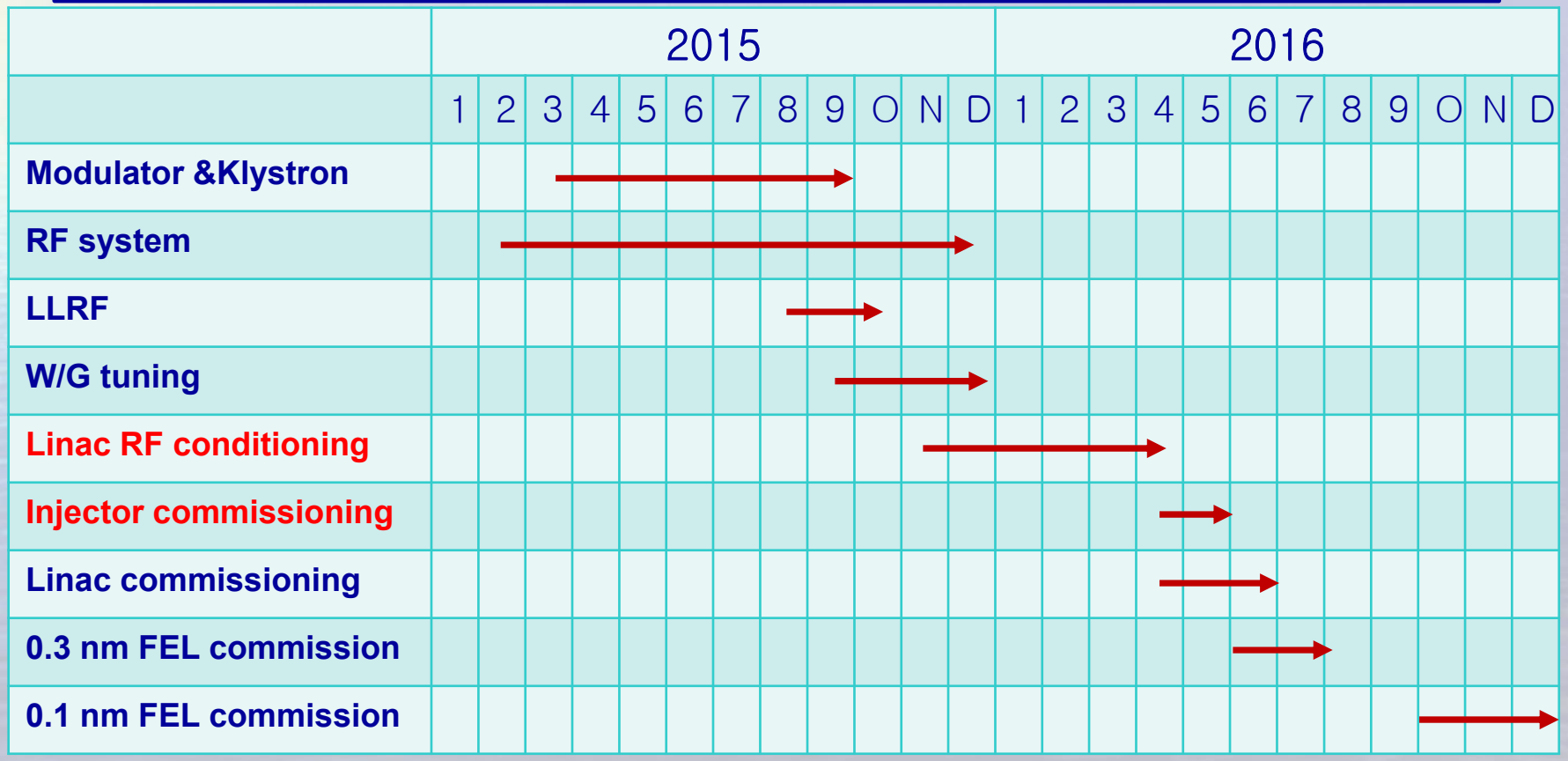
Installation & Commissioning

- Linac RF conditioning / Injector commissioning 2015. 11 ~ 2016. 04
- 1st FEL commissioning for 0.3 nm HX @10 Hz 2016. 04 ~ 2016. 08
- 2nd FEL commissioning for 0.1 nm HX @10 Hz 2016. 08 ~ 2016. 12



Thanks for Your Attention!

H.S. Lee Pohang Accelerator Laboratory, lhs@postech.ac.kr