X-band Solid State Amplifier for the PAL-XFEL

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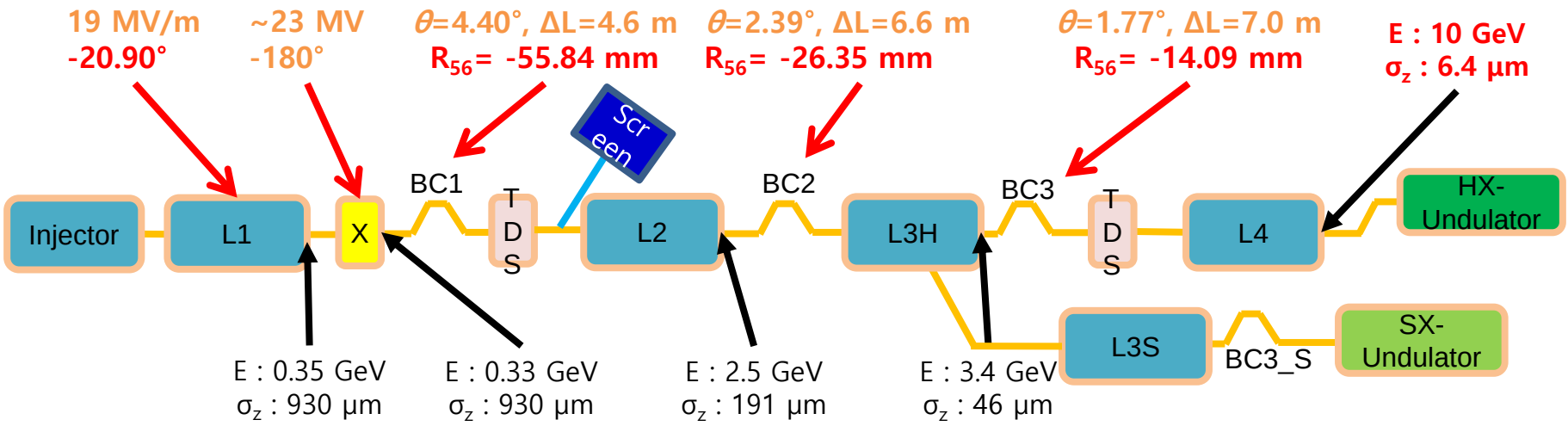
Contents

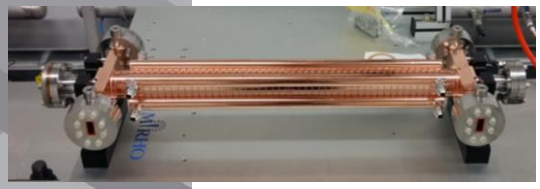
- X-band linearizer for the PAL-XFEL
- Design of a SSPA for the PAL-XFEL
- Performance of the SSPA
- Future plan for a better SSPA for XFEL
- Summary

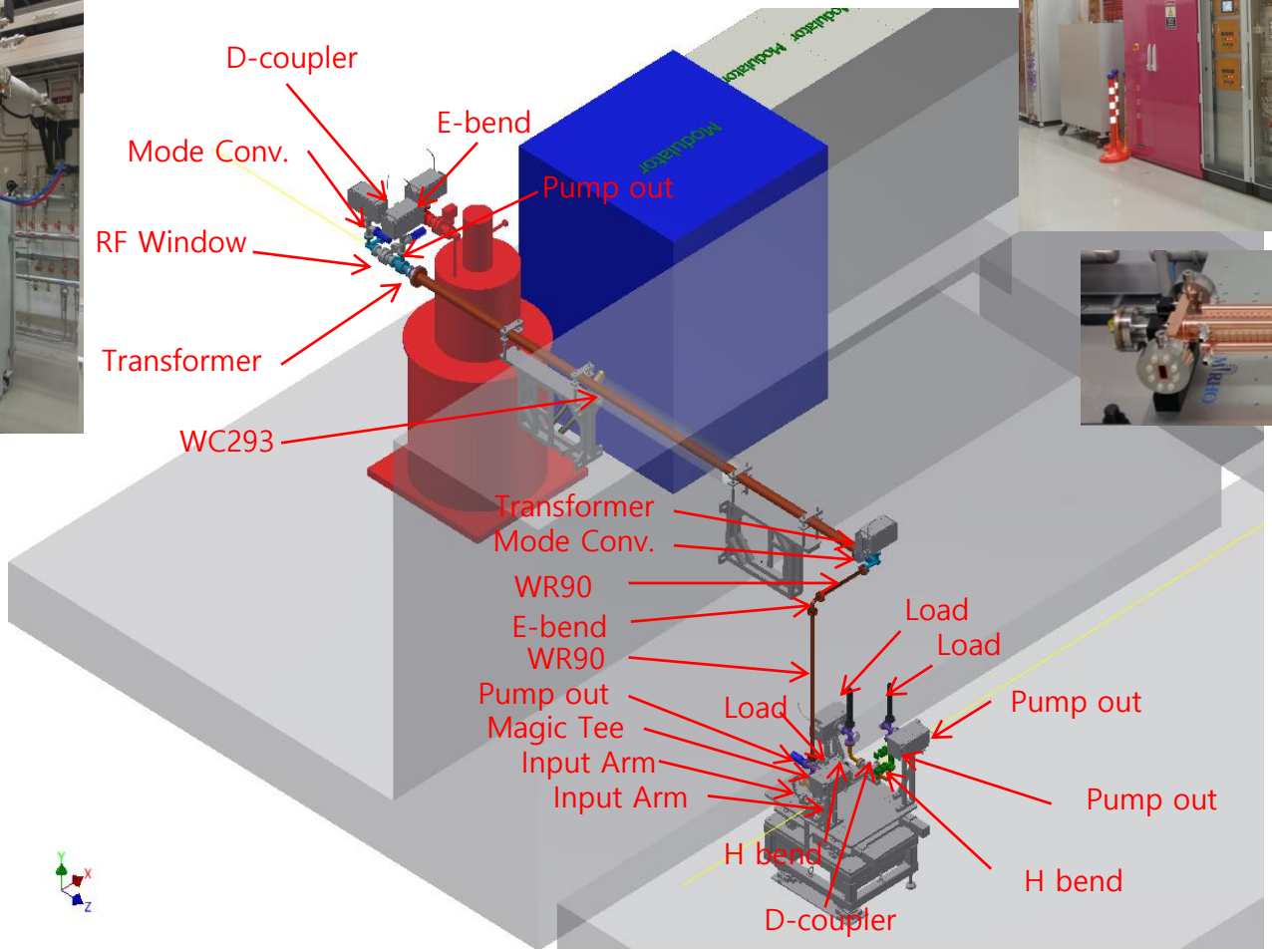
PAL-XFEL Layout



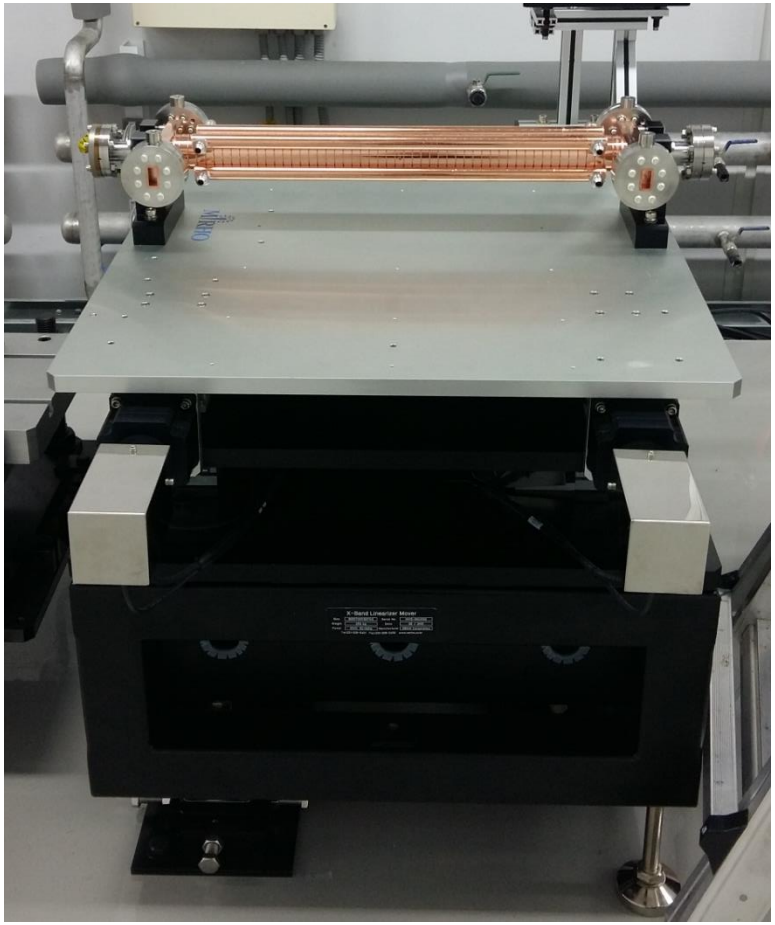
Sector	# of klystrons	Tolerance(rms)	
		Phase [deg.]	Voltage [%]
L1 (S-band)	2	0.02	0.015
X band linearizer	**1**	**0.06**	**0.05**
L2 (S-band)	10	0.04	0.025
L3 (S-band)	4	0.1	0.05
L4 (S-band)	27	0.1	0.05

X-band RF System





X-band Accelerating Structure

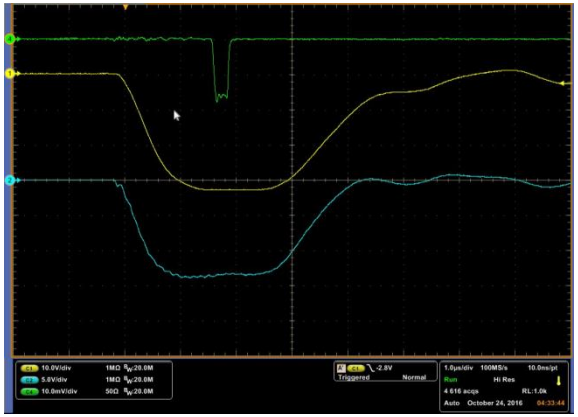


H60VG3 X-band Accelerating Structure		
Operating Frequency	11.424	GHz
Length	60	cm
Phase advance per cell	5π/6	MW
Filling time	105	ns
Shunt impedance	48.8~78.8	MΩ/m
Group velocity	3.2 ~ 1.2	vg/c (%)
Fundamental mode Q	~6955	
Attenuation	0.54	Np
Power needed acc. gradient of 50 MV/m	37.4	MW
Gain	50	dB

Moving Stage

Dir.	Moving range	Moving resolution	Position accuracy
X	±2mm	5μm	20μm
Y	±2mm	5μm	20μm
Pitch	±0.4˚	0.005˚	0.01˚
Yaw	±0.4˚	0.005˚	0.01˚

X-band Klystron & Modulator

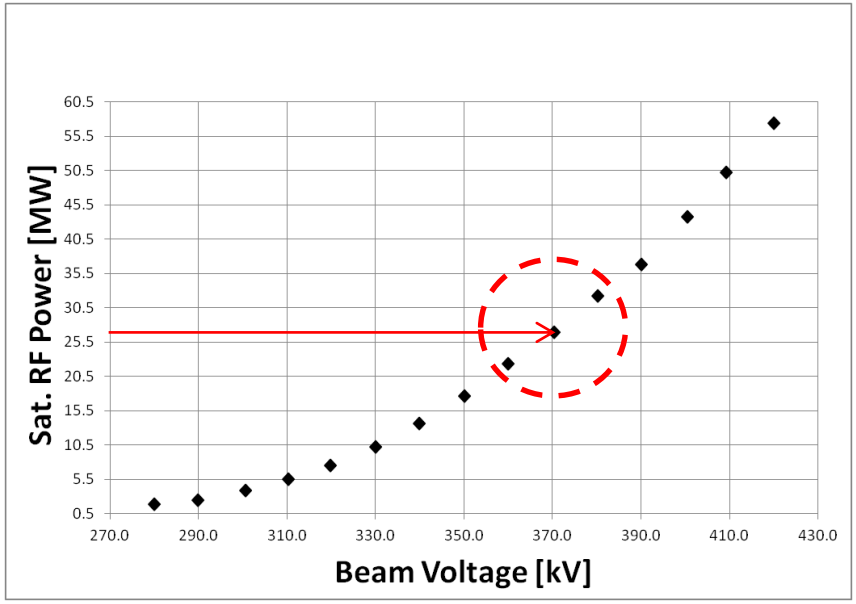


XL-4 Klystron		
Operating Frequency	11.424	GHz
RF Pulse Length	1.5	μs
Peak Output Power	>50	MW
Repetition rate	60	Hz
RF Efficiency	40	%
Bandwidth	120	MHz
Max. Beam Voltage	440	kV
Perveance	1.2	μP
Gain	50	dB

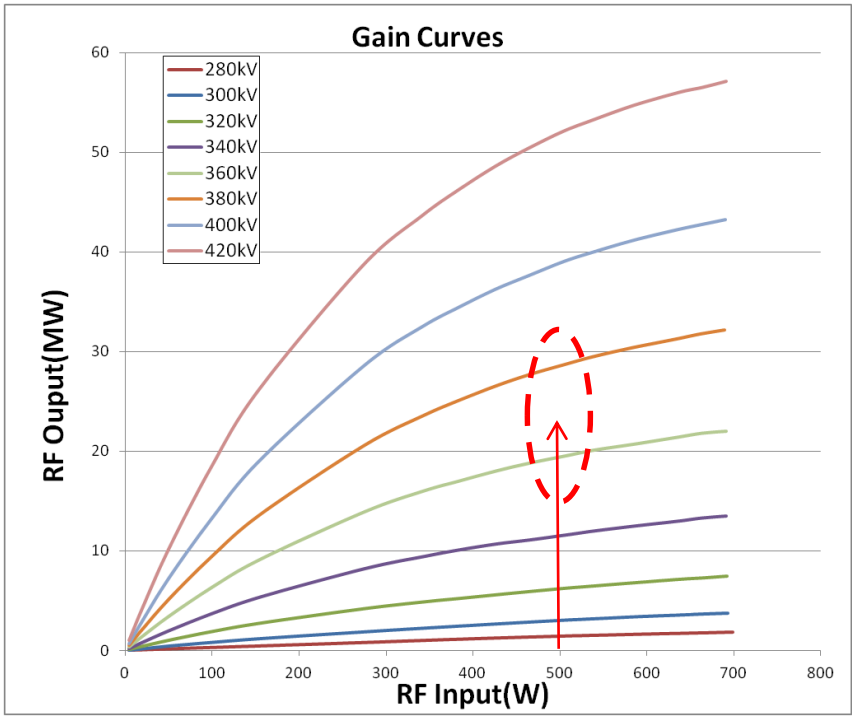
Klystron Modulator		
Max. Voltage	> 410	kV
Pulse Length	2	μs
Max. Repetition rate	60	Hz
Focusing Magnet Power supply	300	A
Voltage stability	< 30	ppm

X-band Klystron Test

Saturation RF Power



Gain



Required driver power > 1 kW

X-band LLRF Controller

X-band LLRF		
Frequency	REF : 2.856	GHz
	PAD & PAC : 11.424	GHz
PAD Ch. number	10 (8 Ch + 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

X-band Klystron Drive Amp.

TWTA

SSPA

X-band TWTA		
Max. RF Power	1.2	kW
Max. Repetition rate	100	kHz
Amplitude Variation	< 0.1	dB
Phase stability	+- 1	Deg.

X-band SSPA		
Max. RF Power	1.4	kW
Max. Repetition rate	60	Hz
Amplitude Variation	< 0.1	dB
Phase stability	< 0.1	Deg.

Key Design Features

- Main amp. transistor type : GaN HEMT
- Power combining : 20 ways radial power combiner
- Bias class : Near B class
- Band width : Narrow band
- Cooling : Forced air
- Protection : Isolator and temp. sensor

Main Amp. Transistor

TOSHIBA

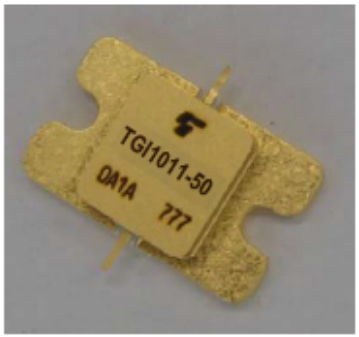
MICROWAVE SEMICONDUCTOR TECHNICAL DATA

MICROWAVE POWER GaN HEMT

TGI1011-50-771

FEATURES

- **BROAD BAND INTERNALLY MATCHED HEMT**
- **HIGH POWER**
  Pout= 47.0dBm at Pin= 41.5dBm
- **HIGH GAIN**
  GL= 9.0dB at 11.424GHz
- **HERMETICALLY SEALED PACKAGE**



RF PERFORMANCE SPECIFICATIONS (Ta= 25°C)

CHARACTERISTICS	SYMBOL	CONDITIONS	UNIT	MIN.	TYP.	MAX.
Output Power	Pout	VDS= 24V IDSset= 1.5A f= 11.424 GHz @Pin= 41.5dBm	dBm	46.0	47.0	—
Drain Current	IDS		A	—	5.0	6.0
Power Added Efficiency	ηadd		%	—	30	—
Linear Gain	GL	@Pin= 20dBm	dB	7.0	9.0	—
Channel Temperature Rise	ΔTch	(VDS X IDS + Pin – P1dB) X Rth(c-c)	°C	—	130	160

Recommended Gate Resistance(Rg): 13.3 Ω

Main Amp. Transistor

ELECTRICAL CHARACTERISTICS (Ta= 25°C)

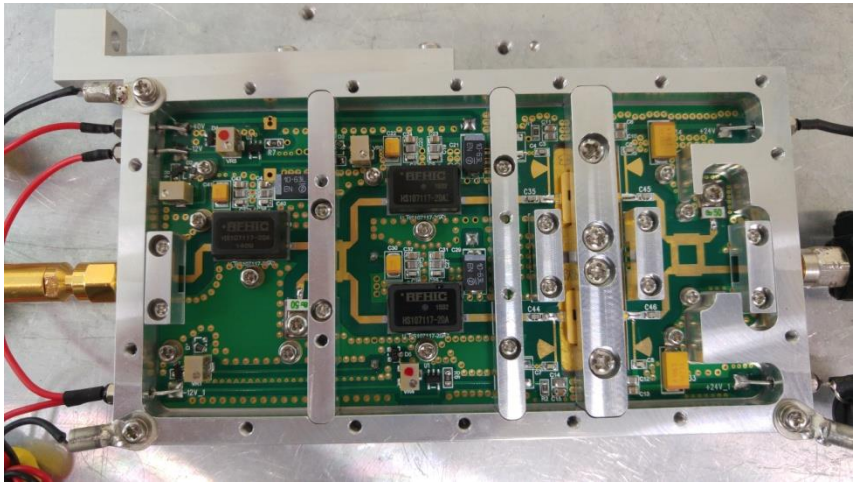
CHARACTERISTICS	SYMBOL	CONDITIONS	UNIT	MIN.	TYP.	MAX.
Transconductance	gm	VDS= 5V IDS= 5.0A	S	—	4.5	—
Pinch-off Voltage	VGSoff	VDS= 5V IDS= 23mA	V	-1.0	-4.0	-6.0
Saturated Drain Current	IDSS	VDS= 5V VGS= 0V	A	—	16.0	20.0
Gate-Source Breakdown Voltage	VGSO	IGS= -10mA	V	-10.0	—	—
Thermal Resistance	Rth(c-c)	Channel to Case	°C/W	—	1.4	1.6

ABSOLUTE MAXIMUM RATINGS (Ta= 25°C)

CHARACTERISTICS	SYMBOL	UNIT	RATING
Drain-Source Voltage	VDS	V	50
Gate-Source Voltage	VGS	V	-10
Drain Current	IDS	A	15.0
Total Power Dissipation (Tc= 25°C)	PT	W	140
Channel Temperature	Tch	°C	250
Storage Temperature	Tstg	°C	-65 to +175

Main Module

Main Module Test

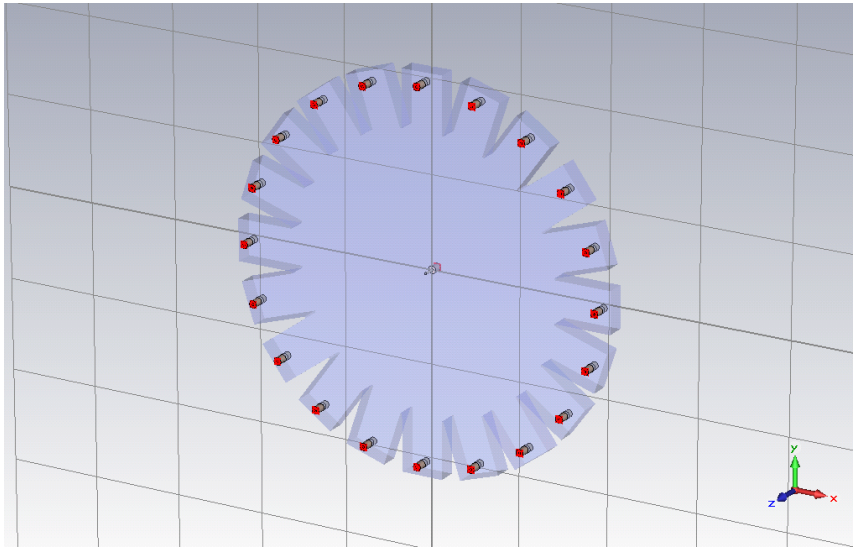


Test Results

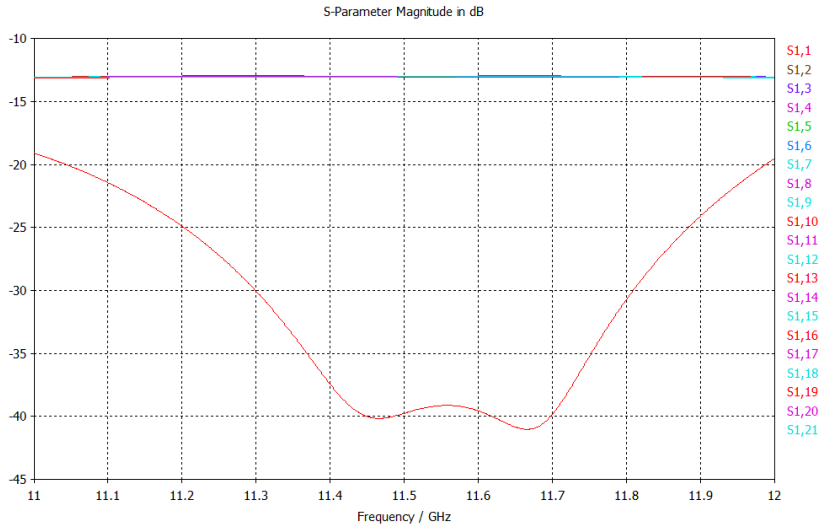
Test module	Pout [dBm]	Gain [dB]	Phase [deg]
# 1	49.21	29.16	149.06
# 2	49.40	29.73	155.81
# 3	49.30	29.54	157.06

Radial Power Splitter Design

Design model

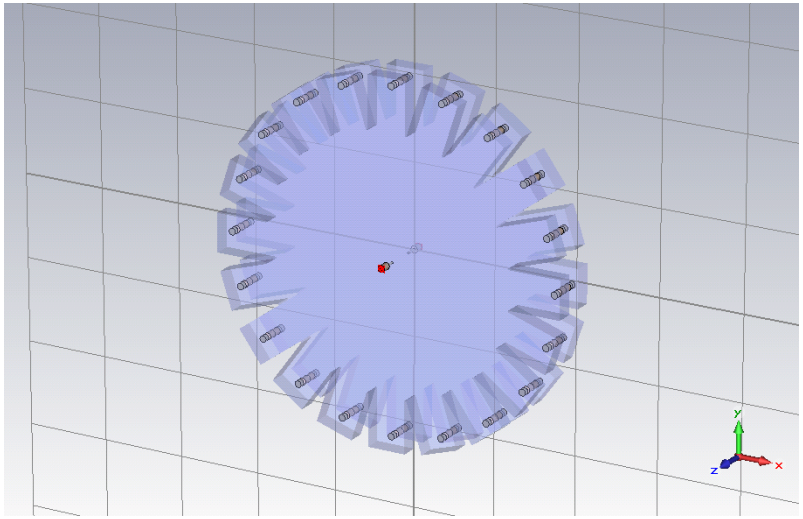


Simulation result

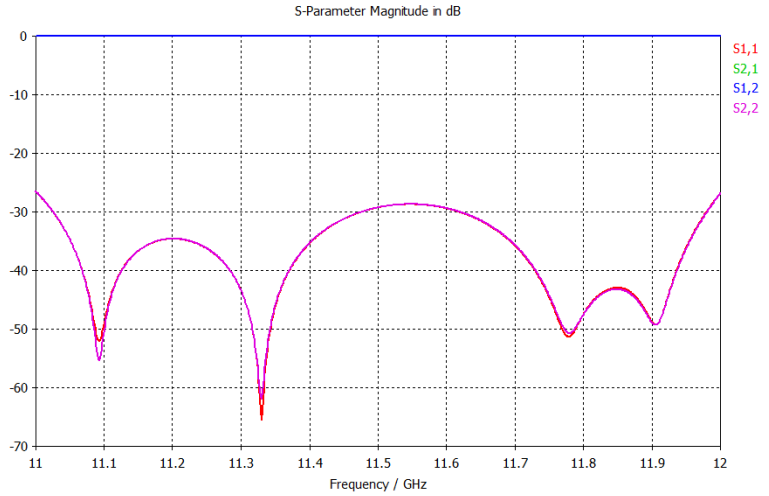


Radial Power Combiner Design

Design model

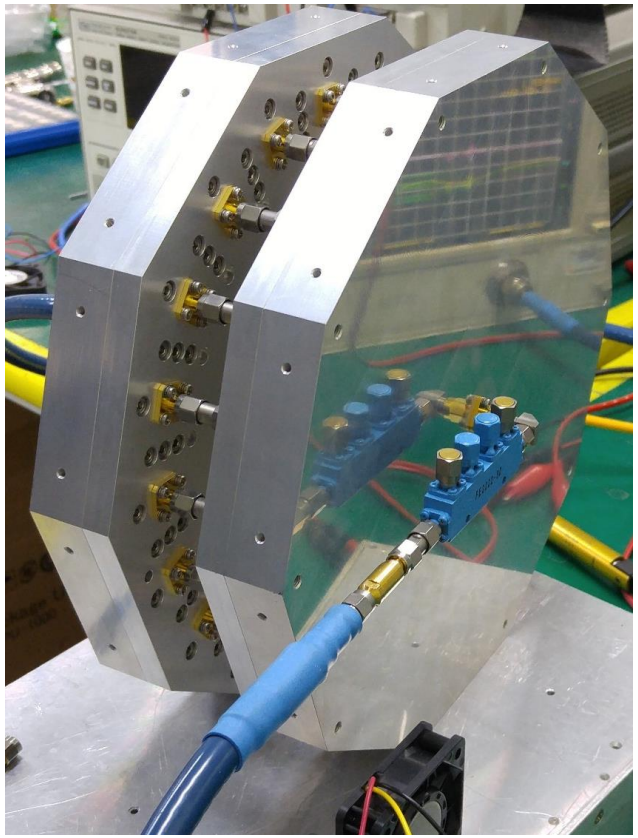


Simulation result

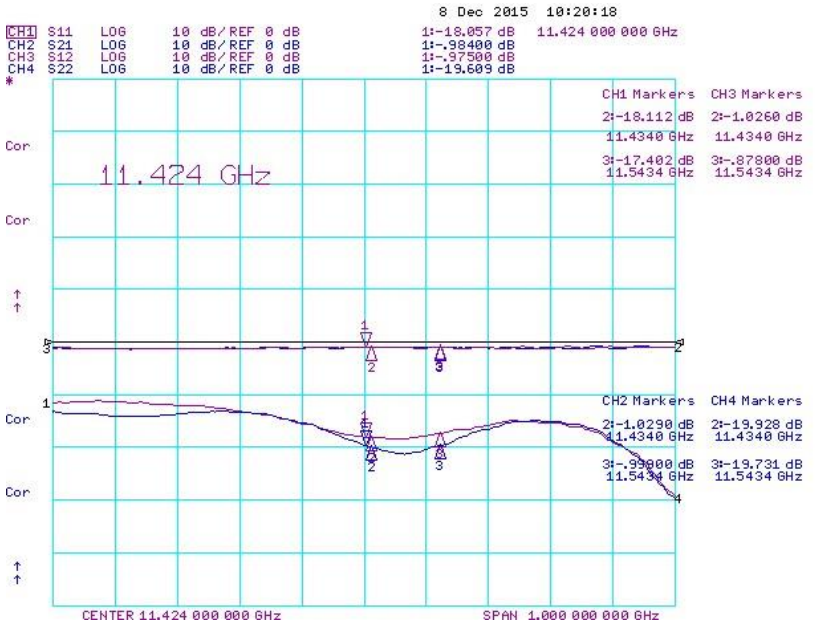


Radial Power Combiner Test

Back to Back test

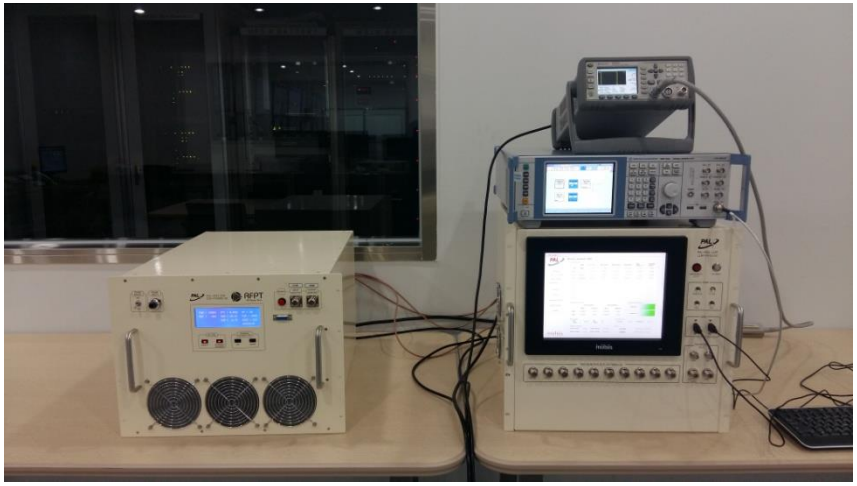


Test result



Pulse to Pulse Stability Lab Test

Test setup



Test Equipment

- Signal source : Rodhe&Schwarz signal generator
- Pulse RF generator : X-band LLRF PAC
- Pulse RF stability measurement: X-band LLRF PAD

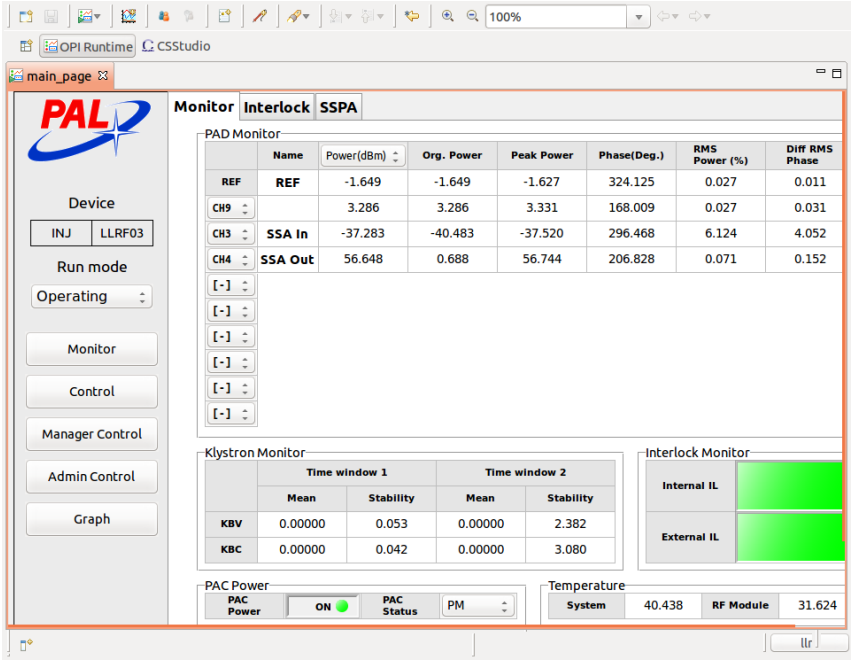
Typical Lab Test Result

Parameter	Design target	Unit	Measured Results			Note
			Min	Typ	Max	
Band width		MHz	11423.95	11424	11424.05	
Power gain	60dB ±	dB	60.01	59.99	60.01	@1.2kW Pout
Input power range	+4 ~ -10	dBm	-10	0	4	
Saturation power @ P_{SAT}	≥1kW	W		1200		
Pulse rise time	< 30nsec	nsec		8.53		
Pulse over shoot	< 10%	%		–		
Pulse droop	< 0.1dB	dB		0.55		
Pulse to pulse amp. stability	< 0.05%	%		0.08		
Pulse to pulse phase. stability	< 0.06°	°		0.07		
Harmonics level	< -40dBc @ P1dB	dBc		-68.93		
Spurious signal level	< -60dBc @ P1dB	dBc		-62.02		
Noise Figure	< 10dB	dB		-		9.73
Input VSWR	< 1.22:1		1.0213	1.0216	1.0219	
Output VSWR	< 1.22:1		1.1297	1.1291	1.1293	

TWTA V.S. SSPA

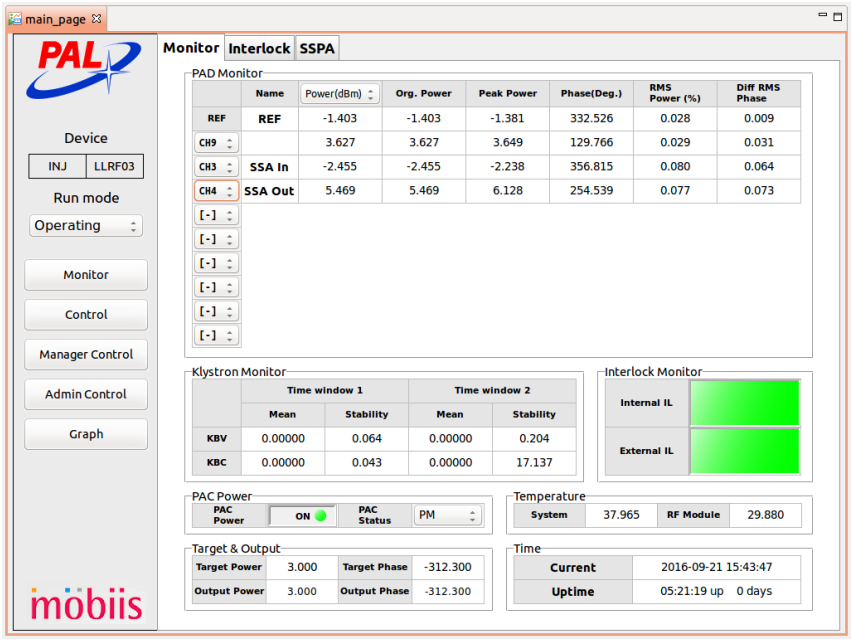
TWTA Stability

Amp. : ~ 0.07 %
Phase: ~0.15 °



SSPA Stability

Amp. : ~ 0.08 %
Phase: ~0.07 °

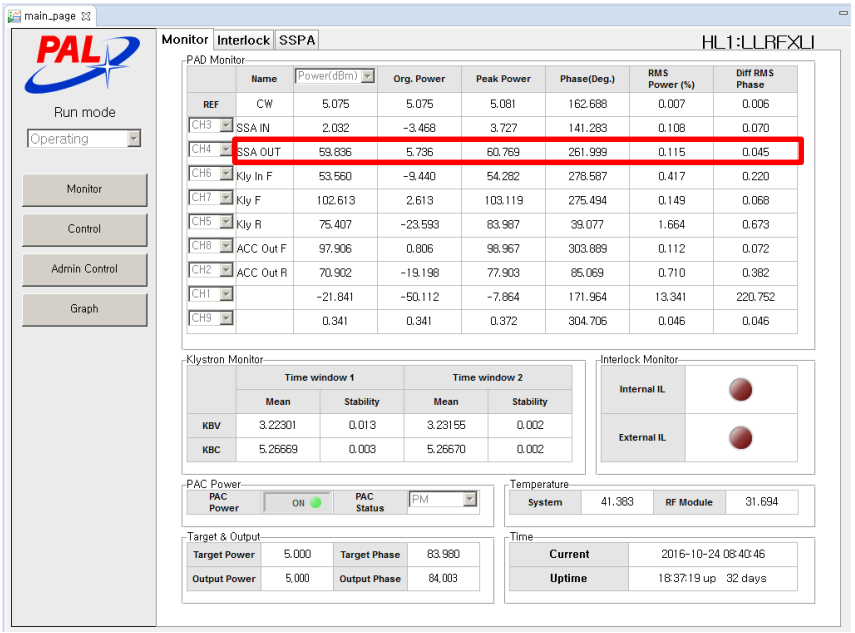


But Pulse to Pulse Stability at Linac Gallery

DRO, SSPA, and LLRF in a Rack

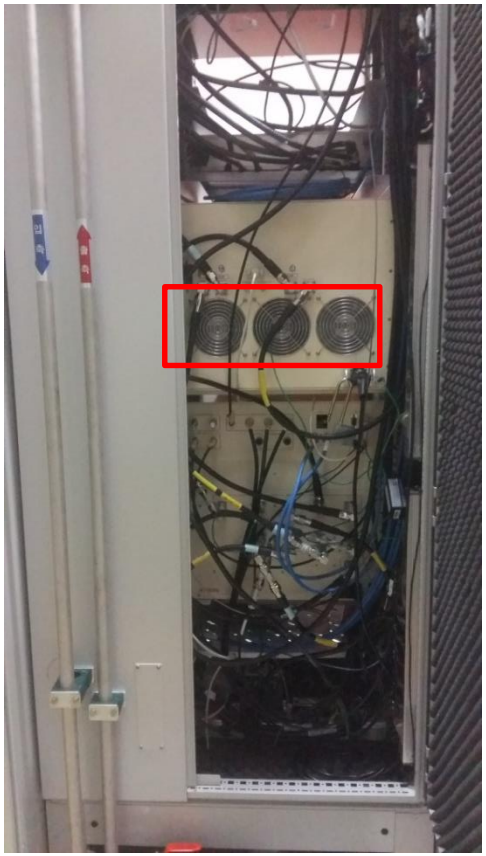
Amp. stability degrade

Amp. : ~ 0.12 %
Phase: ~0.05 °



Amp. Stability Degrade

Rear View Inside RF rack



Some Degradation Sources

- Vibration from the cooling fans
- Case distortion due to its weight

Summary

- This SSPA shows successful performance for our application, comparing the TWTA.
- But it is required to fix the degradation problem in amplitude stability by reinforcing the mechanical stability.