Early Results of the 186MHz (2x) 60 kW CW Solid State Amplifier for the LCLS II Gun B System

K. Baptiste, S. Virostek, F.Sannibale, J. Corlett,
R&K Company

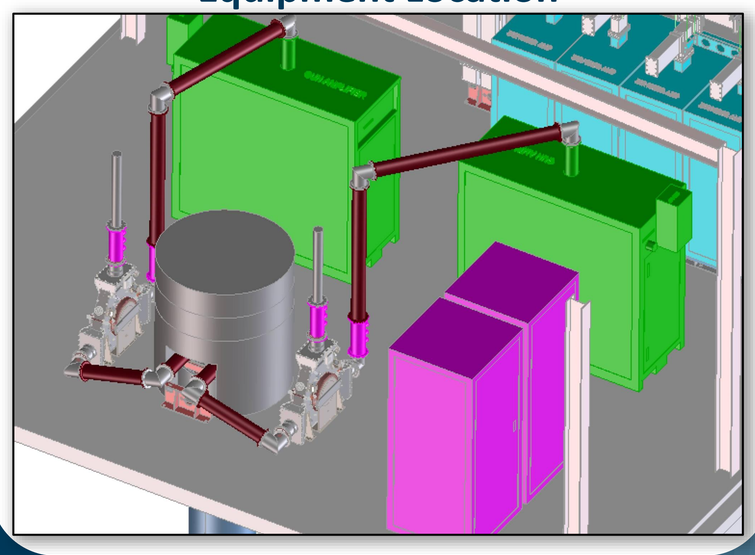
Scope

VHF High Power Amplifier (HPA) system consisting of two rack-mounted 185.7 MHz, CW Solid State RF Amplifiers (SSAs) with an output power rating of 60 kW each for a total of 120 kW CW. The SSAs will provide controlled, stable, radio frequency (RF) power that will drive a normal conducting cavity via two 6 1/8" EIA coaxial lines and a pair of 75 kW 3-port circulators for the injector of a second generation Linac Coherent Light Source (LCLS-II) at the SLAC National Accelerator Laboratory (SLAC).

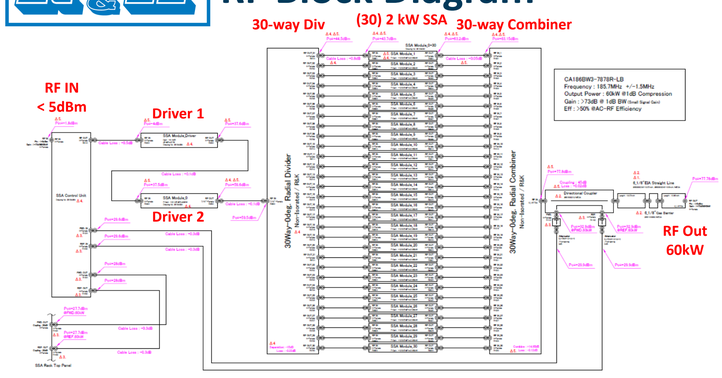
Requirements

RF Parameters	Value
Frequency	185.7 MHz
Bandwidth (1 dB)	+/- 1.5 MHz
Output Power	60 kW CW
Input Power	+5 dBm max
Gain Stability (O.L.)	0.1 % rms (1s)
Phase Stability (O.L.)	0.1 ° rms (1s)
Transfer Function	Monotonic
Delay	< 300 ns
Phase (1-60 kW)	< 10 °
2nd & 3rd Harmonics	< -30 dBc
Spurious Power	< -70 dBc
Noise Figure	< 10 dB
Efficiency (1 dB comp)	< 50 % @ 60 kW
System Parameters	**Value**
SSA Module Rev Pwr	Protected
SSA Module Failure	Full Pwr w/< 8% final stage transistor failure
DC Power Supplies	Redundant
SSA Module Control Interface	Fault tolerant
SSA Module Temperature	Warning, Power Limit, Shutdown
Main Input Voltage	480 VAC
Control Power	120 VAC
LCW Cooling	< 25 gpm @ 30 ° +/-0.5 °C
Environment Temp	4 ° C – 45 °C
Elevation	900 ft above sea level
Humidity	10 % to 100 %, 10 °C dew point

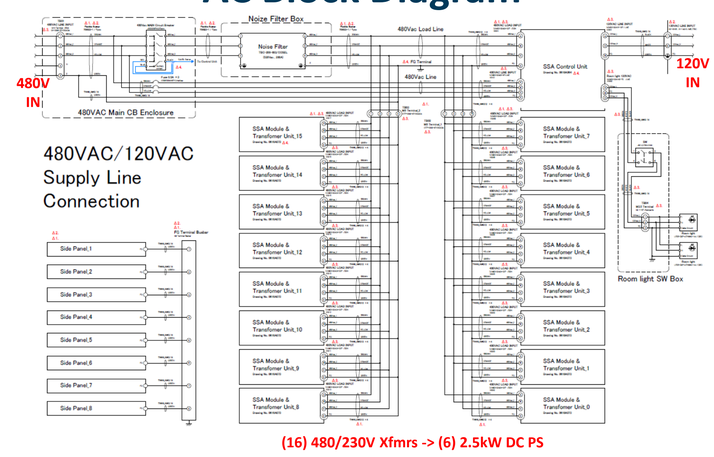
Equipment Location



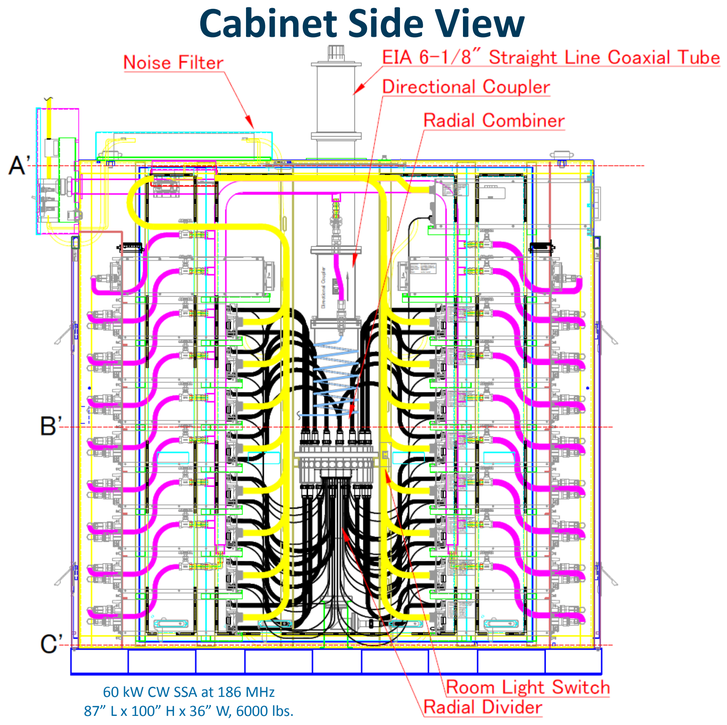
RF Block Diagram



AC Block Diagram

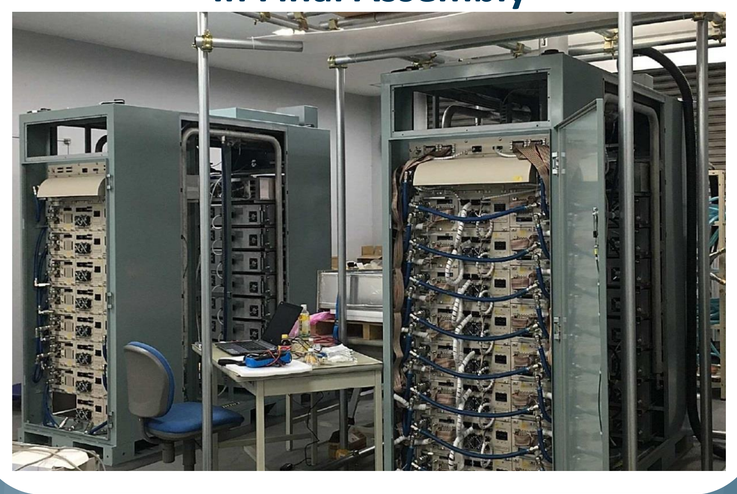


Cabinet Side View



SSA Modules (2) and Transformer Unit

In Final Assembly



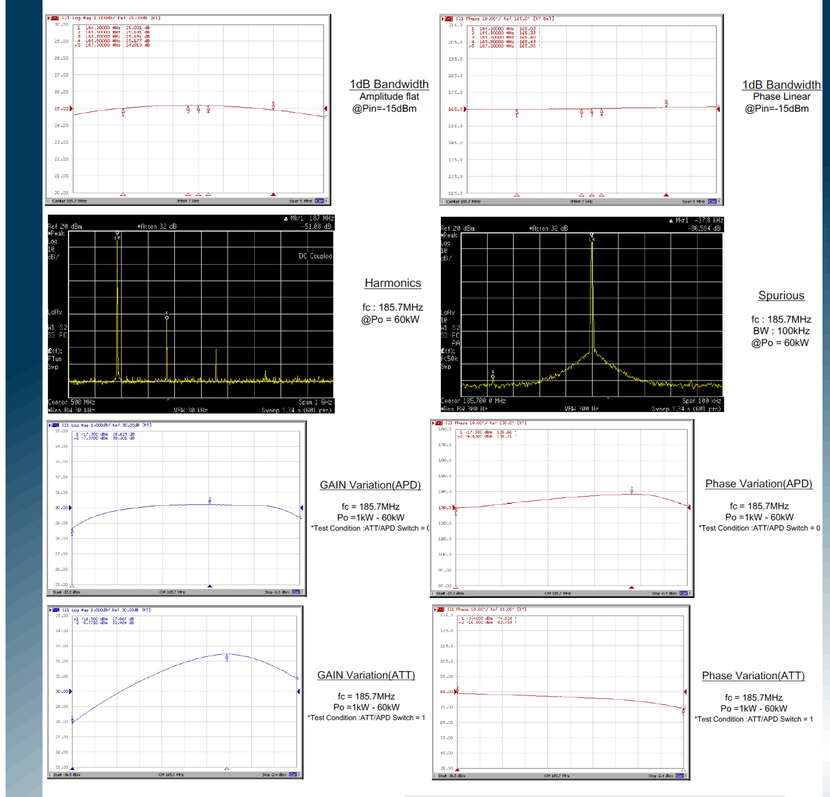
Factory Acceptance Test

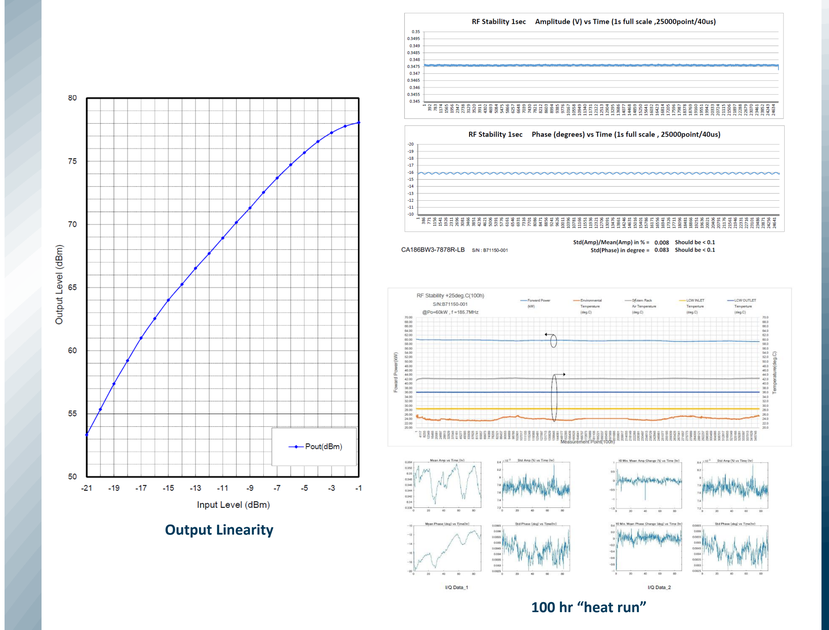
RF Solid State Power Amplifier

I. RF Characteristics

*Test Condition :ATT/APD Switch = 0

	Item	Frequency	Specifications		Measured value	Criteria
1	Output Power	184.2MHz	60kW(min.)	*Output Power Linearity_1	See Attachment	pass / fail
		185.7MHz		*Output Power Linearity_2	See Attachment	pass / fail
		187.2MHz		*Output Power Linearity_3	See Attachment	pass / fail
2	Output Power	184.2MHz	50kW(min.)	SSA Module_1-30	-1.60dB @Po=50kW	pass / fail
		185.7MHz		90% operation	-1.58dB @Po=50kW	pass / fail
		187.2MHz		(SSA Module 3pcs power off)	-1.18dB @Po=50kW	pass / fail
3	1dB Bandwidth @Pin=-15dBm	184.2MHz - 187.2MHz	Amplitude flat : 1dBp-p(max.)	*BW +/- 1.5MHz *Waveform_1	0.28dBp-p	pass / fail
			Amplitude flat : 5%(max.)	*BW +/- 200kHz *Waveform_1	0.0459%	pass / fail
			Phase Linear : 5deg.p-p(max.)	*BW +/- 200kHz *Waveform_2	0.02deg.p-p	pass / fail
4	Gain	184.2MHz	+73dB (min.) @Po=60kW , f=185.7MHz , Pin=-1.74dBm		+79.56dB	pass / fail
		185.7MHz			+79.52dB	
		187.2MHz			+79.18dB	
5	Gain Stability	185.7MHz	Amplitude stability : 0.1%(max.)	@1sec , Po=60kW *60kW RF Stability 1sec	See Attachment	pass / fail
			Phase stability : 0.1deg.(max.)	@1sec , Po=60kW *60kW RF Stability 1sec	See Attachment	pass / fail
			Amplitude stability : +/-0.5dB(max.)	@8h , Po=60kW	See Attachment	pass / fail
			@1°C change in the cooling water or external air temperature.		*Test data is RF Stability +25deg.C(100h)	
6	Group Delay @Pin=-15dBm	184.2MHz	300ns(max.)	*Waveform_4	177.0ns	pass / fail
		185.7MHz			175.5ns	pass / fail
		187.2MHz			175.1ns	pass / fail
7	Gain Variation	184.2MHz	Gain Variation : 2dB (max.)	*Waveform_25	1.64dBp-p	pass / fail
	*Test Condition :ATT/APD Switch = 0	185.7MHz	@1kW - 60kW output power change.	*Waveform_27	1.58dBp-p	pass / fail
		187.2MHz		*Waveform_29	1.61dBp-p	pass / fail
8	Gain Variation	184.2MHz	Gain Variation : 6dB (max.)	*Waveform_31	4.70dBp-p	pass / fail
	*Test Condition :ATT/APD Switch = 1	185.7MHz	@1kW - 60kW output power change.	*Waveform_33	4.60dBp-p	pass / fail
		187.2MHz		*Waveform_35	4.48dBp-p	pass / fail
9	Phase Variation	184.2MHz	Phase Variation : 10deg.(max.)	*Waveform_26	8.50deg.p-p	pass / fail
	*Test Condition :ATT/APD Switch = 0	185.7MHz	@1kW - 60kW output power change.	*Waveform_28	8.55deg.p-p	pass / fail
		187.2MHz		*Waveform_30	8.97deg.p-p	pass / fail
10	Phase Variation	184.2MHz	Phase Variation : 10deg.(max.)	*Waveform_32	9.84deg.p-p	pass / fail
	*Test Condition :ATT/APD Switch = 1	185.7MHz	@1kW - 60kW output power change.	*Waveform_34	9.63deg.p-p	pass / fail
		187.2MHz		*Waveform_36	9.09deg.p-p	pass / fail
11	Harmonics	185.7MHz	-30dBc(max.)	@Po=60kW *Waveform_7	-46.99dBc (2nd)	pass / fail
	*The worst values of Second(2nd) and third (3rd) harmonics are entered.		-30dBc(max.)	@Po=30kW *Waveform_8	-44.56dBc (2nd)	pass / fail
			-30dBc(max.)	@Po=6kW *Waveform_9	-47.92dBc (2nd)	pass / fail
12	Spurious	185.7MHz	-70dBc(max.)	@Po=60kW *Waveform_12-14	< -80.00dBc	pass / fail
			-70dBc(max.)	@Po=30kW *Waveform_15-17	< -80.00dBc	pass / fail
			-70dBc(max.)	@Po=6kW *Waveform_18-20	< -80.00dBc	pass / fail
13	Noise Figure	184.2MHz - 187.2MHz	10dB(max.)	*Waveform_41	9.41dB	pass / fail
14	RF Switch ON/OFF Ratio	184.2MHz - 187.2MHz	Attenuation : 40dB(min.)	*Waveform_40	>90dB	pass / fail
15	RF FWD.MONITOR	184.2MHz	-50dB +/-1dB(max.)	*Waveform_21-22	49.53dB	pass / fail
		185.7MHz			49.46dB	pass / fail
		187.2MHz			49.39dB	pass / fail
16	RF REF.MONITOR	184.2MHz	-50dB +/-1dB(max.)	*Waveform_23-24	49.72dB	pass / fail
		185.7MHz			49.62dB	pass / fail
		187.2MHz			49.54dB	pass / fail
17	In-rush current	-	400A(max.) *<200% of full line current for all conditions.		230A	pass / fail
18	Power consumption	184.2MHz	120kW(max.)	@Po=60kW	111.0kW	pass / fail
		185.7MHz		@Po=30kW	76.8kW	pass / fail
		187.2MHz		@Po=6kW	38.2kW	pass / fail
		RF OFF		@RF OFF	8.6kW	pass / fail
19	Efficiency	185.7MHz	50%(min.) @Po=60kW		54.1%	pass / fail





Conclusion

Each VHF 60 kW Solid State RF Amplifier (SSA) went through a rigorous FAT that took ~3.5 days not including the 100 hr "heat run". Both amplifier units passed all parameters except for non-ionizing radiation leakage found internal to the cabinet near the output combiner. Later at SLAC during SAT, 60 Hz noise was found in all SSA module outputs due to transformer unit fields coupling to SSA module circulator. This noise will be managed by D-LLRF.