ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPTS006

UPGRADE OF THE CANADIAN LIGHT SOURCE BOOSTER RF SYSTEM TO SOLID STATE

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Abstract

The Canadian Light Source synchrotron (CLS) had first light in 2004. For the last 14 years of operation we have exclusively used klystrons to provide RF power to our LINAC, booster, and storage ring. The klystrons represent a single point of failure for the operation of our booster and storage ring. This is especially poignant in the case of our booster ring klystron which is no longer manufactured. We have chosen to move to solid-state amplifier (SSA) RF technology for its implicit high redundancy, modularity, ease of maintenance, and efficiency. Herein we review the performance parameters of our upgraded booster RF to a 100 kW 500 MHz transmitter built by Cryoelectra (Fig. 1).

INTRODUCTION

The CLS is a 2.9 GeV synchrotron with multiple RF systems. The LINAC is a 250 MeV linear accelerator that operates at 2856 MHz with 6 klystrons powering 2 Varian and 4 SLAC sections. The 2.9 GeV storage ring operates with a single CESR-B superconducting RF cavity operating at 500 MHz and powered by a CW 310 kW klystron. The Booster ramps from 250 MeV to 2.9 GeV using an E2V klystron with a peak power of 75 kW at 500 MHZ to provide RF to two PETRA five cell cavities.

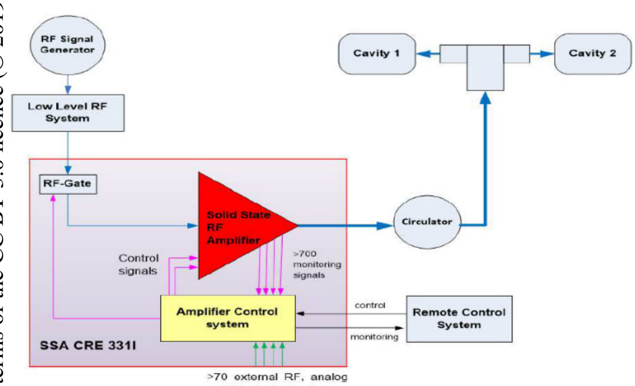

Figure 1: CLS booster solid-state amplifier RF block diagram [1].

There were operational limitations imposed by the booster klystron, the tubes are no longer manufactured which equates to a high risk single point of failure, but there is also one remaining spare. Based on quantum lifetime calculations, we also determined that increasing the voltage in the cavities decreases the current lost during extraction from booster (See Fig. 2) [2]. The overall power from the transmitter is presently limited by the cavity couplers which are rated for 40 kW CW.

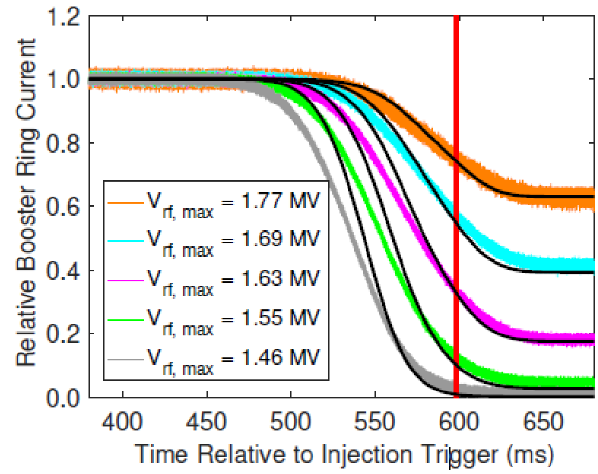

Figure 2: Comparison of measure booster current (coloured traces) with calculations based on quantum lifetime (black curves) for various cavity gap voltage with extraction time marked with red line [2].

The new SSA for the booster was designed and manufactured by Cryoelectra to CLS specifications. It includes 21 RF power modules, each with an output power of (1.1 x 4) kW, at a drain voltage of 46 V, P1 operating point. A module consists of eight LDMOS BLF578XR power transistors soldered on copper carrier which are bolted onto the surface of a massive water cooled copper heat sink. Each pair of transistors are summed in a stripline combiner, to produce four 1.1 kW outputs per module. The RF output of the modules are combined in four 21-to-1 way coaxial combiner. These four combiners feed a waveguide combiner to give amplifier output power of 104.4 kW through WR1800 waveguide.

The cables selected to run from RF module output to 21-to-1 way combiner are robust and have high safety rating for operation at high temperature. The trade-off for robustness and safety is high cable losses.

The SSA is a closed cabinet assembly. Figure 3 shows the SSA amplifier installed at CLS. The first cabinet from left is the mains cabinet followed by control cabinet, ACDC station, RF station and Combiner cabinet. All the cabinets are air cooled, while the RF power modules are water cooled.

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Figure 3: Booster solid-state amplifier installed at the CLS.

Table 1: Amplifier Parameters

Parameters	Value
P1 operating point	104.4 kW, CW
RF Frequency	500.04 MHz
Modes of operation	CW, ramped and pulsed
Dynamic range	1 to 100 kW
Bandwidth at 100 kW	> ±1 MHz
Input drive power at 100 kW	0 dBm
Module output power	4 x 1.1 kW
Number of modules	21
Transistor	LDMOS BLF578XR
Nominal transistor drain voltage	46 V
Harmonics	< 55 dBc
AC line input efficiency (60 – 100 kW)	42.4 – 50.2% at 46V DC

SSA control system, interlocks, and diagnostic monitors

The SSA control system is delivered with the ability to control the amplifier from a local Graphical User Interface (GUI) and provides ability to control the amplifier from a remote interface. Experimental Physics and Industrial Control System (EPICS) based remote control interface will be developed by the CLS in near future. PLC is the heart of amplifier local control system. It provides state machine for amplifier, amplifier internal and external signal monitoring, diagnostics, interlocking and communication with other controllers associated with the amplifier. External interlocking signals are connected to the amplifier through a patch panel located on top of the amplifier control rack. Personnel safety related interlocks and other fast interlocks are hardwired and are controlled by the base controller. In the event of the hardwired interlock, the base controller opens RF switch in 1.1 us to drop RF output of the amplifier to 0 kW.

The local GUI (Fig. 4) provides status of amplifier, interlocks, transistors, dc power supplies and monitoring outputs. It also displays traces for RF signals, transistor currents and voltages during operation. The monitoring signal measurements are synchronized relative to the CLS booster ramp trigger signal and could also be measured using trigger signal generated by the amplifier. The measurements could also be made at user defined delay with respect to the trigger signal. Another patch panel on top of combiner rack provides sample points to measure forward and reverse RF power at the four 21-to-1 way combiners and at the output of amplifier waveguide combiner.

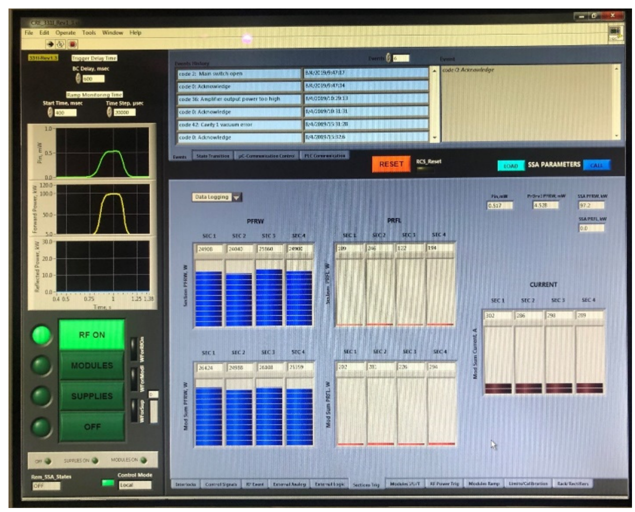

Figure 4: SSA GUI during ramp operation. On the left-hand side, Pin, amplifier forward power and amplifier reflected power traces are shown. Forward and reflected power for all the four sections and total transistor current for each section is shown on the right-hand side

AMPLIFIER PERFORMANCE

Gain/efficiency and P1 point at 46V transistor drain voltage.

The efficiency of the SSA at P1 point and 46 V transistor drain voltage is 50.10% with a gain of 82.68 dB. Gain, efficiency, and compression plots in the range of 54-111 kW for 46 V drain voltage are shown in Fig. 5

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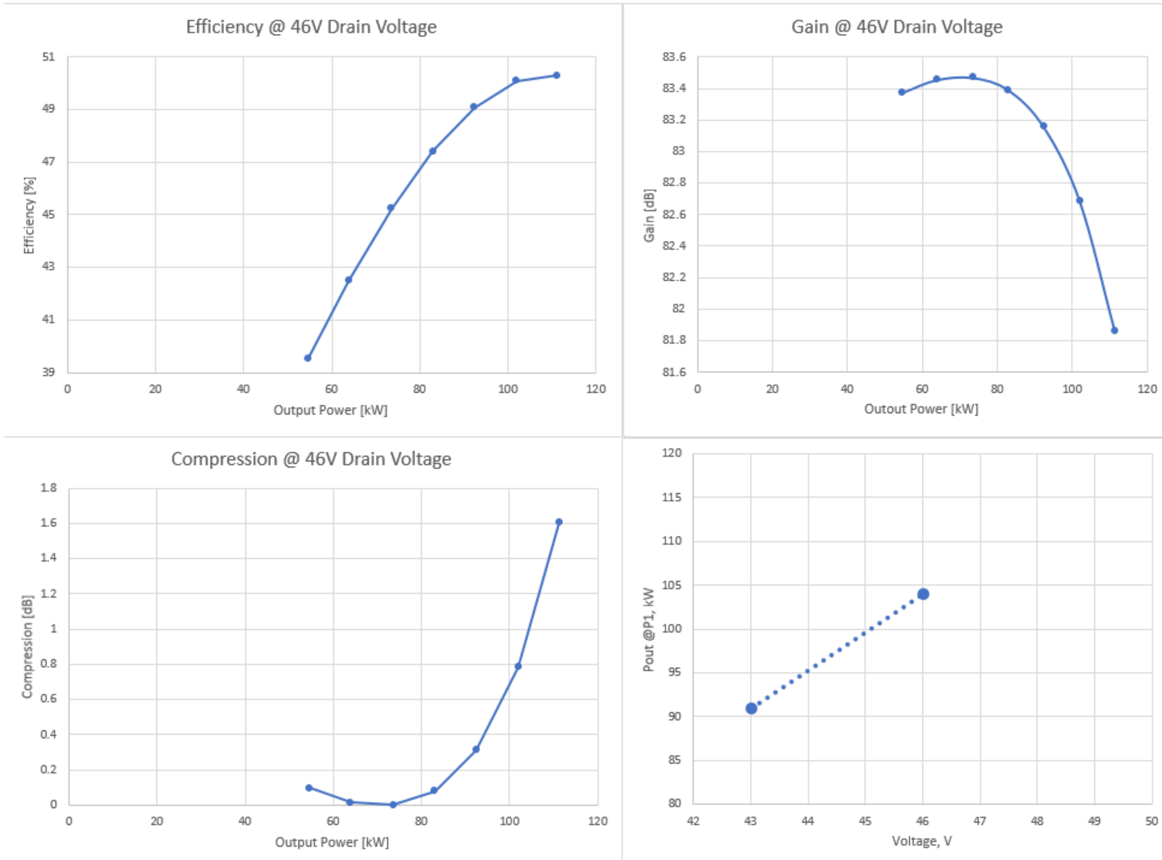

Figure 5: (clockwise starting from top left) Output vs efficiency, output vs gain, transistor drain voltage vs output power and output vs compression.

Long term stability test

24 hour long stability test was run at 100 kW during acceptance testing. No failures were observed during this test and the SSA output and temperatures were monitored for stability. Amplifier forward power was observed to be stable throughout the test run. The maximum temperature observed in the SSA cabinets was 39 °C, which is well below the specified limit.

Other parameters

1 dB bandwidth of the SSA is 25 MHz. Over 1dB bandwidth, the noise figure of the SSA is 6 dB. The spurious power is 76.6 dBc at and below 100 kW. The group delay of the amplifier is 145 ns and the variation in group delay over ± 1MHz bandwidth and in the range of 10 to 100 kW is 2 ns. The phase and gain variation from 1W to 100 kW is 8.73 degrees and 2 dB respectively.

Redundancy

The amplifier has high redundancy. The amplifier operation is not interrupted if up to 14 transistors fail, which would drop the output power to 83.2 kW. If more than 7 transistors fail within one section, the amplifier operation is interrupted. Similarly, there is extremely high redundancy for the transistor DC power supplies. The amplifier runs without any interruption up to 35 power supplies failure. In this case the transistor voltage drops to 42 V and the amplifier output drops to 86.4 kW.

CONCLUSION

The solid-state amplifier was installed and tested in our spring 2019 maintenance shutdown. The site acceptance test was successfully completed in April, 2019. The next step is to commission the circulator and test the amplifier with beam into the two 5-cell PETRA cavities prior to our next operation run. Circulator is used at the output of the amplifier as an additional protection from cavity reflected power. The circulator commissioning and amplifier operation with beam will be discussed in future publications.

ACKNOWLEDGEMENTS

The author is grateful for Cryoelectra's support and commitment in working with the CLS staff in successful installation and commissioning of the booster solid-state amplifier. Special thanks to P. Hartmann for providing his expertise and sharing his incredible knowledge with us.

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