SOLID STATE AMPLIFIERS FOR LINEAR ACCELERATORS AT TRIUMF

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Abstract

Solid state amplifiers are being used for linear accelerators at TRIUMF which are either being upgraded or under development. The Radioactive Ion Beam (RIB) facility at ISAC II which is being upgraded with additional 20 quarter wave superconducting bulk niobium cavities will employ twenty 141 MHz solid state amplifiers. A 650 MHz solid state amplifier for electron gun development and an 1.3 GHz solid state amplifier for characterization of an elliptical superconducting niobium cavity are being used for the 50 MeV electron linac being planned at TRIUMF.

INTRODUCTION

ISAC II superconducting linac is being upgraded with addition of 20 MV accelerating potential. Twenty new solid state amplifiers will provide rf power for additional twenty quarter wave superconducting cavities operating at 141 MHz for the ISAC Radioactive Ion Beam (RIB) facility [1]. These solid state amplifiers have maximum output power capability of 600 watts cw although around 200 watts will be required for regular beam operation. 600 watts is required for cavity conditioning. TRIUMF has also proposed a 10mA, 50 MeV E-linac to be built at TRIUMF [2] and is in process of funding by the Federal government. The electron gun of the E-linac operates at 650 MHz and employs gridded thermionic source with rf modulation. The rf modulation of the gun is provided by a 200 watts rf amplifier. The main E-linac accelerating structure employs multi cell cavities which operate at 1300 MHz. The total beam power of 500 kW will be provided by suitable rf generators. A 500 watt 1.3 GHz cw amplifier is being purchased in order to characterize both single cell and multi-cell elliptical superconducting niobium cavities.

RF POWER AMPLIFIERS

Three different solid state amplifiers from three different manufacturers will be described in this paper. The 141 MHz, 600 watts cw amplifier for ISAC II superconducting linac, 650 MHz, 200 watts cw amplifier for the rf gun and 1.3 GHz, 500 watts cw for E-linac are bought from different manufacturers and have been tested to the specified maximum output power. Both amplitude and phase linearity have been measured for all of them

141 MHz Solid State Amplifier

These amplifiers have been manufactured by QEI, NJ, USA with TRIUMF specification after a prototype was tested extensively [3]. Twelve of these units have been received and remaining 8 are expected soon. The amplifiers are all tested thoroughly and have met the required specification. Measurement results are reported for six out of twelve amplifiers. Figure 1 shows output power for different input drives. They all have a gain > 60 dB. Figure 2 shows the phase linearity of these amplifiers. Table 1 shows the measured and specified values of gain and phase linearity.

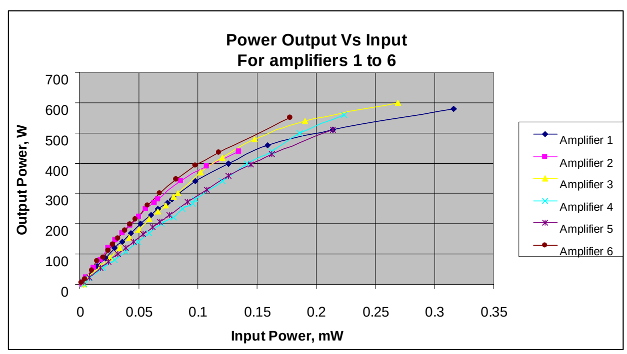

Figure 1: The power output vs input drive power for six amplifiers.

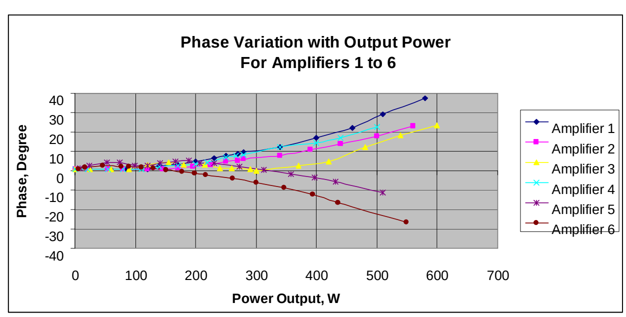

Figure 2: The phase variation as a function of output power for the same set of amplifiers

The solid state amplifiers have been successfully used to condition and characterize quarter wave superconducting cavities for ISAC II SCC. Preliminary test of a SCC cavity is shown in figure 3.

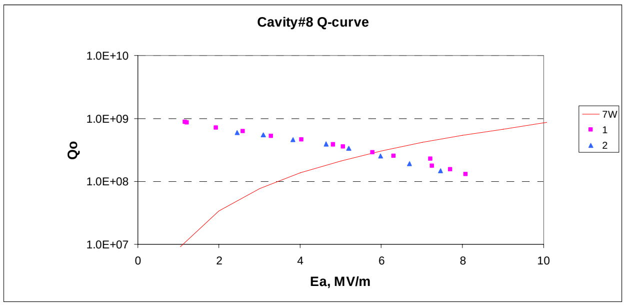

Fig. 3 . Q-curve after RF conditioning (1) and He RF conditioning (2)

Figure 4: Four amplifiers installed in the power supply room in their final position

Table 1: Measured and specified values of gain and phase linearity

Parameters	Value Specified	Value Achieved
Over all Gain	55 ± 2 dB	63 ± 1.8 dB
Gain linearity from 1 to 250 Watts	< ± 0.5 dB	1 to 400 W
Gain linearity from 250 to 600 Watts	<± 2.0 dB	> 400 W
Phase linearity from 1 to 250 Watts	$< \pm 5^0$	1 to 300 W
Phase linearity from 250 to 600 Watts	$< \pm 20^0$	> 300 W

650 MHz Solid State Amplifier

The gridded thermionic source with rf modulation for E-linac uses a 650 MHz rf amplifier. The rf amplitude and dc bias on the grid of the gun determine the bunch length of the beam emitted from the gun. The amplifier, as shown in figure 5, has been specified with a voltage controlled attenuator such that the rf can be modulated at 1 KHz with varying duty ratio. The amplifier has been tested with different dc voltage on the modulator. Figure 6 shows the family of graphs that can be used to operate the amplifier to optimize the performance of the rf gun. An Agilent Arbitrary Waveform generator provides the modulating frequency and duty cycle for the pulse which will be programmed via EPICS control system for remote operation. The amplifier has been manufactured by Amplifier Systems Inc, USA and has been fully tested for rf performance against the specification. The over all gain of the amplifier is 57±0.2 dB, specified minimum gain was 53 dB. The maximum power output of 180 watts is obtained with input drive at - 4.5 dBm and 12 V dc voltage on the modulator. However the Agilent generator can only provide 10 V peak, hence during pulse operation the maximum output power of the amplifier is reduced to 150 W. Since the rf gun requires about 100 watts, this reduction in power is not a concern.

Figure 5: Photo of 650 MHz amplifier

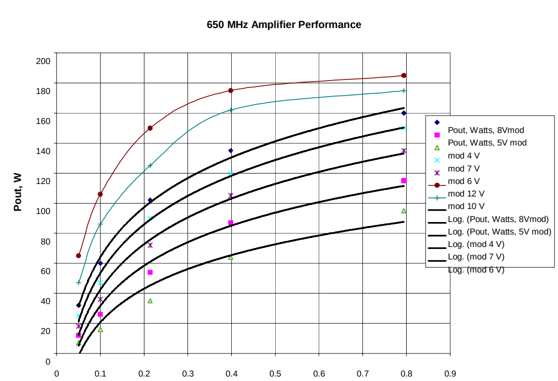

Figure 6: Gain characteristic of 650 MHz amplifier with dc modulation voltage

1.3 GHz Amplifier

The main E-linac accelerating structure uses both single cells and multi cell cavities operating at 1300 MHz. Presently, single cell cavities are being characterized using 1.3 GHz solid state amplifier. For single cell conditioning, less than 100 watts is sufficient however for multi cell cavities, 500 watt amplifier will be useful for initial characterization. This amplifier has been procured from Dirk Fischer Elektronik, Germany and has been tested to meet the rf specifications. The amplitude and phase response of the amplifier is shown in figure 7.

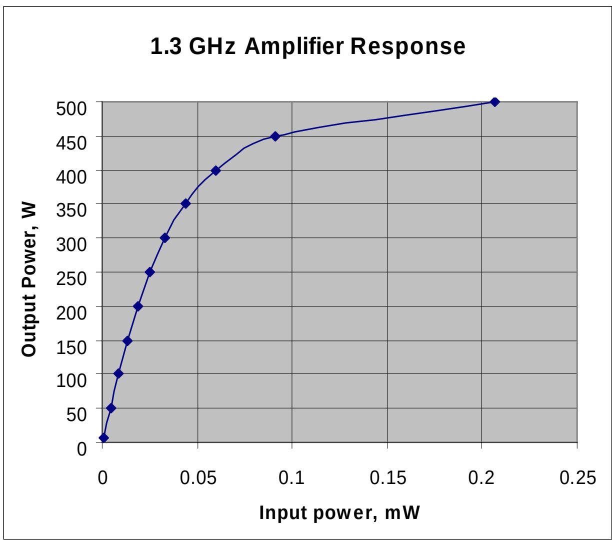

Figure 7: 1.3 GHz amplifier test on a 50 Ohm dummy load

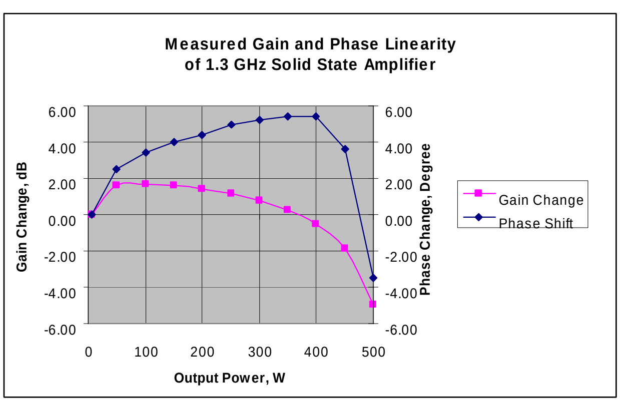

Figure 8: Gain and phase characteristics of the 1300 MHz, 500 Watt CW amplifier

SUMMARY

All the rf amplifiers have been tested on a 50 Ohm dummy load to full rated output power and they have met both amplitude and phase linearity requirements and attained minimum gain as specified. Both 141 MHz and 1.3 GHz solid state amplifiers showed tendency of oscillation when tested with superconducting cavities. This oscillation is due to impedance mismatch between the input of the amplifier and the output of the LLRF control system. A 10 dB pad in the input of the amplifiers resolved the problem of oscillation. Further investigation will be made to improve the impedance matching of the amplifiers.

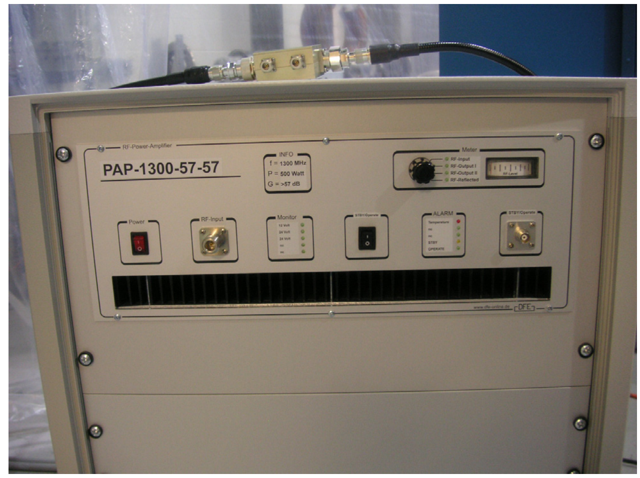

Figure 9: Photo of 1.3 GHz amplifier

Safety System

The ISAC Safety System ensures that the additional twenty 141 MHz rf amplifiers for ISAC-II SCC (high beta linac) meet the same safety that was implemented when twenty 106 MHz were installed for ISAC-II medium beta linac. Thus, in total there will be 40 amplifiers for ISAC II superconducting linac which will be daisy chained. Functional Requirements for the safety interface are: First, the RF amplifiers must provide a single, reliable VAULT RF OFF closed contact to the ISAC Safety System for use in the previously approved access control interlocks. Second, the ISAC Safety System must provide a +24 Vdc VAULT RF SAFETY ENABLED signal to ISAC II RF. The loss of the signal must reliably trip all RF amplifiers OFF and prevent them from turned on. Third, ISAC Control system will provide a VAULT RF SAFETY ENABLE REQUEST contact to the ISAC Safety System at the end of one bay. The REQUEST signal will be generated for a short period and then removed. All the amplifiers in ISAC II linac are controlled and monitored through EPICS control system.

REFERENCES

[1] R.E. Laxdal, et al, “ISAC-II Superconducting Linac Upgrade - Design and Status”, LINAC08, Victoria, Canada, September 29 – October 3, 2008.

[2] I. Bylinskii, et al, “An Electron Linac Photon-Fission Driver for the Rare Isotope Program at TRIUMF”, PAC09, Vancouver, Canada, May 4-8, 2009

[3] A.K. Mitra, et al,” Performance of the ISAC-II 141 MHz Solid State Amplifier”, LINAC08, Victoria, Canada, September 29 – October 3, 2008.