PERFORMANCE OF THE ISAC-II 141 MHZ SOLID STATE AMPLIFIER

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Abstract

The ISAC-II linac extension requires an additional 20 rf amplifiers to power twenty 141 MHz quarter wave superconducting cavities. Solid state amplifiers will be used for this extension as compared to tube amplifiers which have been employed for the existing ISAC-II linac section, operational since 2006. These solid state amplifiers are rated to an output power of 600 W. A prototype amplifier of the production series has been tested for gain and phase linearity. Phase noise of this amplifier has been measured on a 141 MHz superconducting cavity and compared with phase noise measured with a tube amplifier. The test results and general rf interlock and interface requirements are verified against tendered specification before series production of the remaining amplifiers can proceed. Benchmarking tests of the prototype amplifier will be reported.

INTRODUCTION

An upgrade of the ISAC-II superconducting linac, operational since April 2006, is in progress. Additional 20 MV accelerating potential will be added to the ISAC Radioactive Ion Beam (RIB) facility by the end of 2009 [1]. The new installation consists of twenty 141 MHz quarter wave cavities at a design beta of 11%. The cavities will be housed in three cryomodules with six cavities in the first two cryomodules and eight cavities in the last. These additional 20 cavities will be powered by 20 solid state amplifiers which have been purchased from QEI Corporation, NJ, USA. The first amplifier of the production series is tested rigorously before production of final amplifiers can proceed. The medium beta linac which employs 20 quarter wave cavities operating at 106 MHz uses 20 triode tube amplifiers to power the cavities [2,3]. The limited tube life and marginal phase noise led to the option of using solid state amplifiers. Also, the tube amplifiers were rated for 1 kW however, only 600 watts was used for conditioning the cavities and around 200 watts was used for regular beam operation. The solid state amplifiers were therefore specified for maximum 600 watts output along with gain and phase linearity and phase noise requirements.

GAIN AND PHASE MEASUREMENT

The amplifier output is terminated into a 50 ohms dummy load in order to measure the gain and phase characteristics and other basic functions. Figure 1 shows the gain and the phase characteristics which satisfy the specification outlined in table 1. Amplifier gain is measured to be 65 ± 0.75 dB (specified 55 ± 2 dB). Higher gain is acceptable since it can be lowered by addition of external 10 dB attenuator. The 1dB bandwidth is 8 MHz which is much higher than the specified 1 MHz bandwidth.

Table 1: Gain and Phase Linearity Requirement

Parameter	value
Gain Linearity from 1 to 250 Watts	< ± 0.5 dB
Gain Linearity from 250 to 600 Watts	< ± 2.0 dB
Phase Linearity from 1 to 250 Watts	< ± 5°
Phase Linearity from 250 to 600 Watts	< ± 20°
Phase noise in 2 – 200 Hz range	< 0.3° rms.

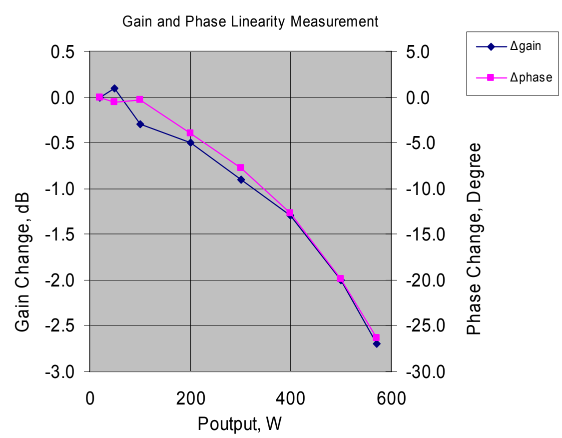

Figure 1: Gain and phase linearity measurement

PROTECTION AND INTERFACE

The amplifiers are housed in the power supply room which is above the linac vault. These amplifiers are remotely operated from the control room via EPICS interface. These amplifiers are also interlocked with TRIUMF safety system which enables operation of the amplifiers when all safety requirements to operate the linac are satisfied. Table 2 outlines the alarm indications that are displayed on the front panel of the amplifier and are also sent to EPICS interface. Amplifier status and some of the rf parameters are also read by the EPICS system and are available at the EPICS page of the ISAC control system. This will help to debug the problems in the event of amplifier fault. This interface is similar to the existing 106 MHz amplifier. As an added new feature, these solid state amplifiers are protected for input over drive up to 10 dBm for a short period of time. If the maximum input power is exceeded a threshold comparator opens a fast RF GaAsFET switch at the RF input, which remains open until the operator resets the amplifier. The amplifier is also protected against excessive output forward and reverse power. The fast shut off of the DC supply to the amplifier modules against over voltage or over current at the transistor drains and case over temperature provides additional amplifier protection.

Table 2: Front Panel Alarm Indications

Front Panel Alarm indication (LED)
High Input Power
High Output Forward Power
High Output Reflected Power (VSWR)
Power Amplifier Over Temperature
Power Amplifier Drain Voltage Alarm (summary)
Power Amplifier Drain Current Alarm (summary)
DC Power Supply Over Current
Loss of Cooling
Loss of External Interlock

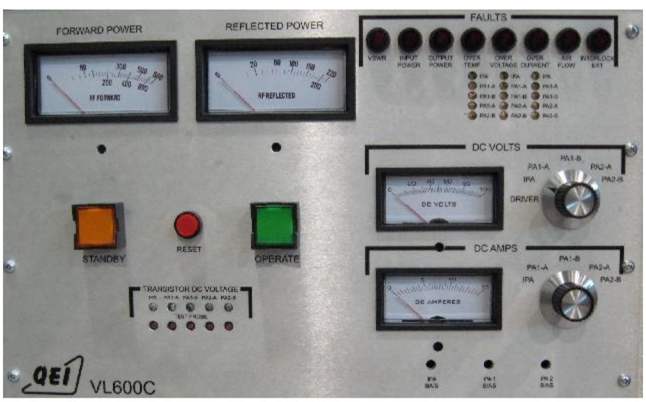

Figure 2. Photo of the front panel of the amplifier

Safety System

The ISAC Safety System (ISS) ensures that the rf amplifiers are disabled when the linac is cold and vault door is open. The safety system provides a +24 vdc vault rf safety enable signal to the ISAC II rf amplifier only when all safety criteria are met. For external interlock a fail safe logic with Normally Open contacts is used. Only when these contacts are closed the amplifier can be put into the READY state. All amplifiers will be daisy chained through this contact. The safety system has already been implemented for the existing linac operating at 106 MHz. The new 20 solid state amplifiers will be daisy chained with the existing system.

PHASE NOISE MEASUREMENT

The phase noise of the prototype amplifier was tested under two different conditions.

50 Ω Load

The phase noise was measured with a 50 Ω load connected to the output of the amplifier. Figure 3 shows the basic scheme of the phase noise measurement. Similar measurement was done for a 141 MHz tube amplifier and results are compared. The signal generator output was set to provide +7 dBm signal level to the LO input of the double balanced mixer after the 3 dB power splitter. The attenuator before the input of the test amplifier was chosen such that the output of the power amplifier was at 200 watts. A -40 dB directional coupler and a suitable attenuator provides 0 dBm to the RF terminal of the double balanced mixer. The mixer sensitivity was measured with the same power levels that was used for measuring the phase noise voltage of the amplifier. The low pass filter cut off frequency was designed at 1 KHz.

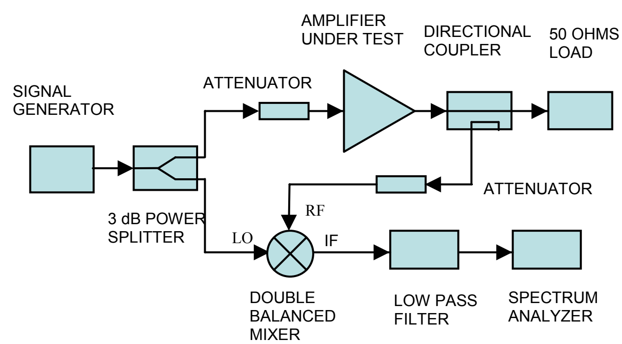

Figure 3: Basic block diagram of phase noise measurement

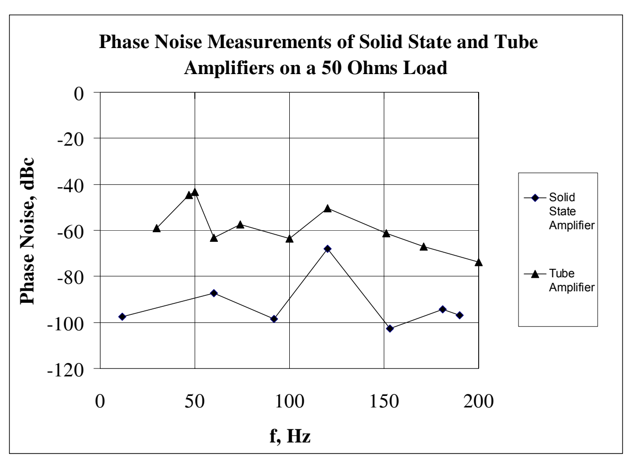

Figure 4: Phase noise measurement with a 50 ohms dummy load

Figure 5: Photo of 141 MHz superconducting cavity used for the test

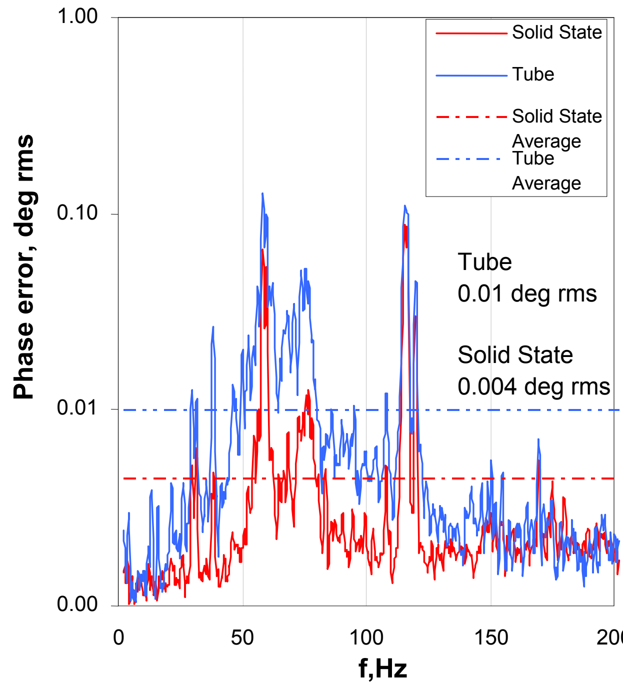

Figure 6: Phase noise measurements with the superconducting cavity

The spectrum analyzer measurement range was set from 1 Hz to 200 Hz. The tube amplifier was tested under same set up. The results of the phase noise measurements are shown in figure 4. The solid state amplifier has 20 dB less noise in the frequency range of 1 to 200 Hz. The noise at 120 Hz was most predominant.

High Q Load

Phase noise measurement with the 141 MHz superconducting cavity [4] as a load for the amplifier was carried out with the rf control system which ran in closed amplitude and phase feedback loop. Figure 5 shows the photo of the 141 MHz cavity with coupling loop and pick up probe mounted. The same measurements were done with a 141 MHz tube amplifier and results were compared. Tests were done under the following cavity parameters:

Frequency, f =141.457 MHz
Unloaded Q, Q_o= $9e^8$
Loaded Q, Q_l = $4.8e^6$
Forward power, Pf = 200 W
Loaded Bandwidth =f / Q_l =30 Hz

Phase error signal was measured with a Spectrum Analyzer in the range 2-200 Hz and is shown in figure 6. 60 Hz and 120 Hz noise spectrum are due to ac power frequency and its second harmonic respectively. The other peaks in this frequency spectrum are due to mechanical resonances of the cavity, mechanical resonances in the cryovessel and cryogenic system. It can be seen from figure 6 that the solid state amplifier is significantly less noisy than tube amplifier. For the solid state amplifier the average noise value is 0.004° rms in the frequency range 2-200 Hz. The average noise for the tube amplifier in the same range is 0.01° rms.

SUMMARY

The prototype solid state amplifier has been tested thoroughly and found to satisfy all the specifications requested. The solid state amplifiers provide lower phase noise by a factor pf 2.5 than tube amplifiers and at the same time will provide long device life than tube amplifiers. The long device life will lead to lower running cost of the linac. The ISAC linac will be equipped with two types of devices, tubes and solid state for all 40 quarter wave superconducting cavities. This will provide an unique opportunity to compare performance of these two types of amplifiers in the long run.

REFERENCES

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