# INTEGRATION OF 31.6MHZ, 1KW SOLID STATE RF POWER AMPLIFIER IN THE BOOSTER RF SYSTEM

Radio Frequency System Division
Raja Ramanna Center for Advanced Technology Indore 452013 India
Pritam S. Bagduwal*, Nitesh Tiwari, M.Lad, S.J.Buhari, N. Sriniwas and P.R. Hannurkar
**email: pritam@rrcat.gov.in**

*Abstract*

Like the conventional high power RF amplifier of early age, RF amplifier for injector Booster Synchrotron of Indus complex was tetrode tube based high power RF power amplifier. A 1 kW RF power Amplifier based on the solid state technology has been designed developed, tested and commissioned in Booster RF system. In addition to traditional advantage of solid state amplifier over tube based MOSFET RF devices have rare chance of thermal runway and secondary break down.1 kW 31.613 MHz Solid state RF amplifier system was developed with 45% efficiency and -30dB second harmonic level. The basic building block is 250 watts RF power module combined together using Wilkinson type power combiner to get the 1 kW RF power. The installation of solid state RF power Amplifier has not only improved the efficiency and eliminated the high voltage problems but has also brought down the audio noise which was there in earlier air cooled tetrode tube based RF power amplifier. 1 kW RF Amplifier has been successfully installed and integrated in the Booster Synchrotron to energise RF cavity with Amplitude control loop (ACL),Phase Control Loop (PCL) and frequency tuner loop in place. With new solid state RF amplifier in Booster, Indus-1 and Indus-2 Storage rings are being regularly operated at 120 mA @ 450 MeV and 100 mA. @ 2 GeV respectively.

## INTRODUCTION

In Booster synchrotron the energy of electron is ramped from 20Mev to 450Mev and to 550Mev in case of Indus-1 and Indus-2 respectively. At injection energy the cavity gap voltage requirement is around 2kV only whereas at final energy of 450Mev (550Mev) it is around 15kV therefore booster RF system operates in ramp mode with 1Hz repetition rate. Because of heavy beam loading in booster at injection a fast Amplitude control loop is used. Apart from fast ACL the bandwidth of the amplifier should also be sufficient to allow these fast changes. Phase control loop and Frequency tuning loops are also used to keep the phase of RF signal stable and to keep the cavity tuned to the resonance frequency respectively.

## 1 KW 31.613MHZ SOLID STATE RF POWER AMPLIFIER

### *Scheme of RF power Amplifier*

Schematic diagram of Booster RF power flow is shown in Fig.1. RF generator is placed in the Indus control room. A phase compensated RF coaxial cable is used to provide RF signal to Booster RF system in Booster Hall. A three stage driver amplifier is used to amplify

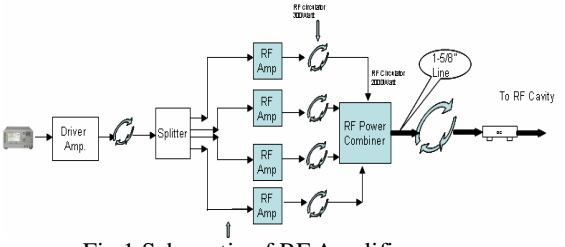
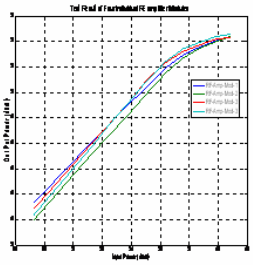



Fig 1 Schematic of RF Amplifier.

the source RF signal. This amplified signal after splitting is feed to all four high power amplifier modules. Each high power amplifier modules provide 250watt RF power. Coaxial cable based high power combiners were designed to get 1 kW RF power. This 1kW power is fed to the RF cavity via circulator for acceleration and synchrotron loss compensation of the beam.

### *High Power Amplifier Modules*

Four 250W high power amplifier modules were developed, tested and characterized for high power operation. Each amplifier is individually characterized for amplitude & phase matching by adjusting the biasing. Each amplifier module was characterized for input v/s output power relation, important parameter of amplifier module are shown in the Fig.2



| | |
|---|---|
| Operation Frequency | 31.613MHz |
| Out Put Power | 250W |
| Efficiency | 45% |
| Gain | 13dB |
| Bias Voltage | 24V |
| Peak Current | 18A |
| Cooling | Water |
| Harmonic | -35dBc |

Fig.2 Input V/S. Output Characteristic & Parameter of High Power RF module

### *RF Power Splitter and combiner*

Lumped component based Wilkinson type power splitter are designed, developed, characterised and tested up to 30 watt. This is used for splitting the power of driver amplifier to feed all four high power amplifier modules. Low power characterization and photograph of the splitter is shown in Fig.3

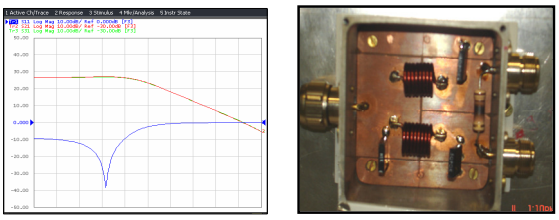


Fig.3 Lumped RF Splitter characteristic and photograph

Coaxial cable based high power combiner was designed to combine the high power RF signal. Transmission line RG 59 based Wilkinson type power combiner is used to combine two 250 W modules to get 500 watts RF power. To get the 1kW RF power RG-11 based high power combiner is used to combine two 500 watts signal. Characterization of 1kW RF power combiner along with photograph is shown in Fig. 4

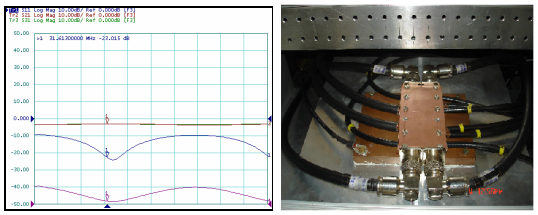
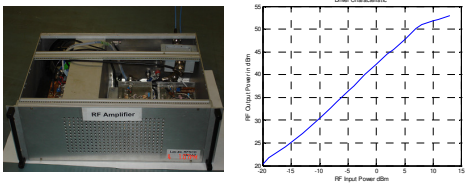


Fig.4 1kW RF power combiner characteristic and Photograph

### *Driver Amplifier*

A driver RF Amplifier is designed using two stage of MRF317 with 27 dB gain and one stage of MRF141G with gain of 13 dB giving total RF driver power of 60 watts. This driver drives all four high power amplifier using splitters. Important parameter, gain characteristic and photograph of the driver amplifier is shown in Fig.5



| | | | |
|---|---|---|---|
| Frequency | 31.6Mhz | Max. RF Power | 200Watt |
| Cooling | Air | Harmonic | 40dBc |
| Bias voltage | 20V | Efficiency | 45% |
| Gain | 40dB | Current | 18Amp. |

Fig.5 Photograph, gain Curve and important parameter

### *Filter*

A high power low pass filter for harmonic rejection is also designed, developed, tested and implemented at the out put of each amplifier. Characteristic and photograph of high power Filter is shown in fig.6

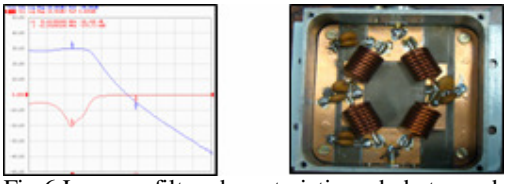


Fig.6 Low pas filter characteristic and photograph.

## INTEGRATION OF SSPA IN BOOSTER

Booster Synchrotron is injector to Indus-1 and Indus-2 both. To minimize the down time of both machines, before shifting the RF amplifier to actual site complete RF amplifier system was tested in lab under various conditions. In booster the RF power is ramped from 6 watt to 800 watt, testing of 1 kW RF amplifier was done in RF lab in ramp mode with max.20Hz repetition rate Spectrum purity of output RF signal in complete power range & bandwidth measurement was also done. 3dB bandwidth of RF amplifier was found to be 2 MHz app. Photograph of lab test set up and ramp profile test results is shown in Fig. 7

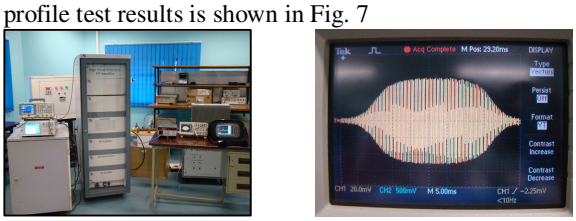


Fig.7 Test setup and ramp testing results in RF lab.

### *Safety interlock*

To protect the MOSFET devices against any malfunctioning in Amplifier system provision for different safety interlock was made. An interlock card was designed for different interlock like four channels of temperatures, and five channels of over current. Safe limit of operation of this interlocks was decided during the lab test run. These interlocks along with safety interlock of cavity water, machine access control, cavity vacuum etc. were rigorously tested in lab

### *Commissioning of RF Amplifier with Booster RF System*

After rigorous testing RF amplifier was integrated in Booster RF system. First the testing of amplifier was done with 50 Ω dummy load. After characterization and tuning of high power circulator, 1kW RF amplifier was connected with circulator and high power testing with of circulator & dummy load was done. Once the Amplifier is tested with circulator, RF power was feed to the RF cavity with first only FTL in operation. Calibration of power and gap voltage reading at Indus Control Room (ICR) was done. After complete RF signal test and calibration at full power, ACL and PCL loops were implemented. With this new RF amplifier remote operation from ICR was restored. Ramp profile was generated with trigger from booster dipole. Phase matching between Indus-1 and Booster RF signal is done and with in 5 days of shut down Booster RF system was handed over for regular shift operation.

## CONCLUSION

Indigenously built RF power amplifier was successfully integrated within very short shutdown of one week & was handed over for shift operation of Booster Synchrotron. SSPA has not only increased the availability & reliability but has also reduced the audio noise level to 65dB from earlier 95dB. This amplifier was installed in March 2010 and since then it is in continues round the clock shift operation and no amplifier related fault is observed.

## ACKNOWLEDGMENT

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## REFERENCE

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