Development of 650 MHz Solid State RF Amplifier for Proton Accelerator

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Abstract. Solid State High Power amplifier technology is a cutting edge technology to replace klystron or tube technology. Design and development of 30 kW high powers RF source at 650 MHz, using solid RF state technology, has been initiated at RRCAT. The indigenous technology development efforts will be useful for the proposed high power proton accelerators for SNS/ADS applications. Presently RF amplifiers delivering 30W and 250 W at 650 MHz has been fabricated and tested. Towards development of high power RF components, design and engineering prototyping of 16-port power combiner, directional coupler and RF dummy loads has been completed. Detailed experiments showed good performance in accordance with theory.

Keywords: RF Amplifier, Solid State Amplifier, Power combiner and divider, Directional coupler.

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INTRODUCTION

With the advent of superconducting accelerating structures [1], solid state technology has also crossed kW level power regime as demonstrated in particle accelerators like Soleil synchrotron [2], Indus-2 [3] and ESRF [4]. Along with getting clean RFM power (free from phase noise and spurious) solid state device failure rate reported from Soleil is 3% per year including infant mortality. Numerous advantages [4] of SSPA, compared to vacuum tube counterpart, is the main driving force behind rapid development of kW level SSPA.

Output power of individual solid state device is rather modest, being of the order of few hundred of Watts. Hence kW level RF power is obtained by summing power output of multiple devices [5] developed in the form of amplifier modules. Power summing action is achieved by power divider and combiner (PDC) structures. In 650 MHz amplifier scheme 30 kW CW RF power will be generated using modular combination of 8 kW amplifier units (Fig. 1).

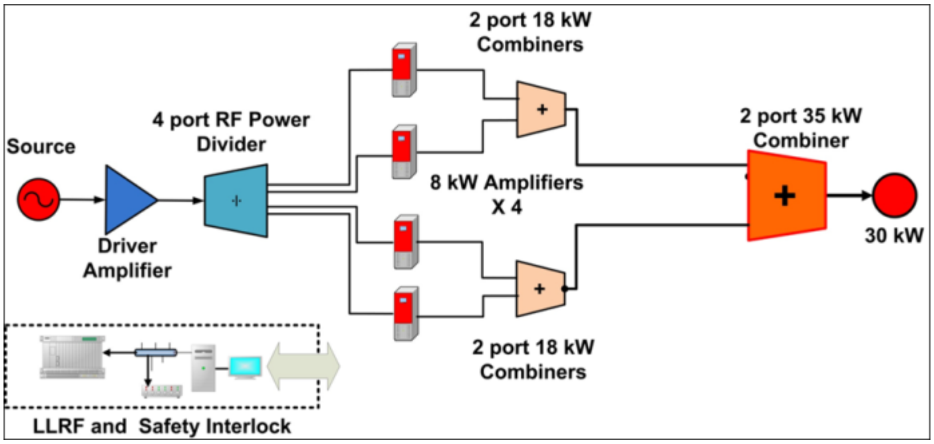

FIGURE 1. 30 kW Solid State High Power RF Amplifier Scheme at 650 MHz.

As per designed plan, each 8 kW amplifier unit will be housed in a standard euro cabinet employing 32 numbers of 300W RF amplifier modules , 2 power dividers, 2 power combiners and high power directional coupler. Apart from RF components, this unit will be complete in all respect including safety interlocks, data acquisition system [6] and water cooling circuit.

In this paper design and engineering prototyping of RF amplifier module, 16-port power combiner and directional couplers is described. Detailed experiments showed good performance in accordance with design calculation.

RF AMPLIFIER MODULES

Two amplifier modules at 30W and 250W (Fig. 2) were designed and tested for initial investigation.

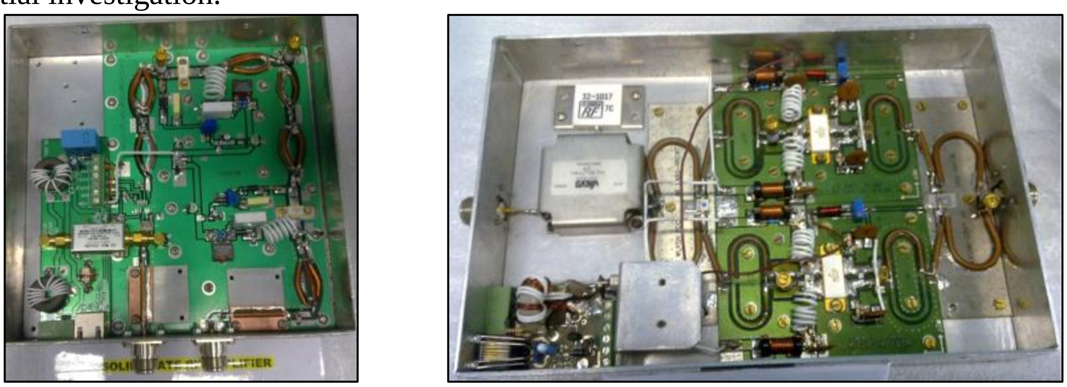

FIGURE 2. 30 W and 250 W Solid state amplifiers modules

30W module is being used as driver amplifier. It was designed as three cascaded stages of RF amplifier designed around MRF 9030. Design parameters for 250 W amplifier module include power gain of 15 dB, bandwidth of 10 MHz and spurious response below 30 dB from fundamental signal. Based on the results of circuit simulation studies and engineering prototyping of amplifier module, RF transistor 6VP3450H was selected to serve as solid state active device. Impedance matching network designed for this module is based on balanced push pull configuration [7] with transmission line balun. Two such push-pull stages were combined using Wilkinson divider and combiner on same board with water cooled heatsink. Use of microstrip line provides ease of tuning at high power, required even after circuit simulation, under real operating conditions. 300 W circulator from Valvo was used to protect the LDMOS from reflected power. Measured result of these amplifiers are satisfactory.

RF POWER COMBINER AND DIRECTIONAL COUPLERS

For high power solid state RF source, Among different combining approaches, radial combiners, proved to be efficient for summing n (>2) amplifiers. At 650 MHz based on simplified method [8], design and prototype development of 4 kW 16-way power combiner incorporating radial stripline structure (Fig. 3(a)); without isolation resistor and external tuning mechanism, was carried out. This design is similar to one adopted for combiner in 15 kW 505.8 MHz solid state amplifier, successfully commissioned recently for Indus-2 synchrotron radiation source.

For developed combiner return loss of feed port, insertion loss, coupling from feed port to branch port and phase imbalance were measured. Return loss for feed port (assigned port zero) was -27 dB against the calculated value of -35dB. Measured power coupling (Fig. 3(b)) S_{n0}, expressed in dB, is assumed as power ratio between any of the n (n varies from 1 to 16) branch port and feed port, when all other ports are matched terminated.

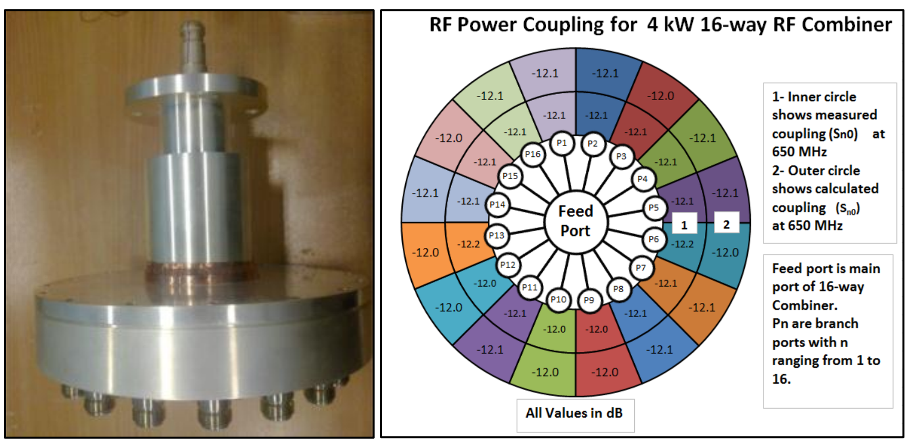

FIGURE 3. 16-way RF power combiner (a) and its measured coupling distribution for 16 ports (b).

For measuring output forward power, two types of directional coupler (Fig.4) were designed based on procedure outlined by Teppati [9]. First one is for measurement of forward power up to 1 kW and second one is up to 4 kW CW RF power.

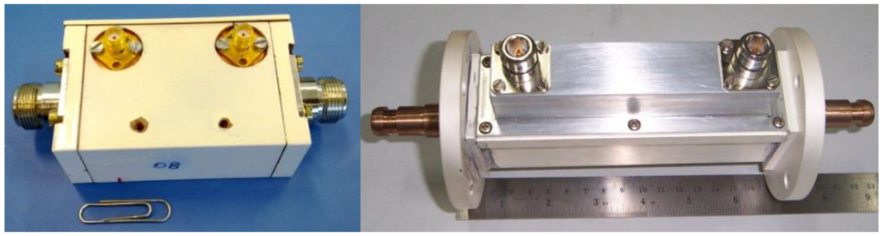

FIGURE 4. 1 kW (a) and 4 kW (b) directional couplers

In this design a rectangular coaxial transmission (main) line with 1-5/8" EIA flange as terminal ports, was coupled to another rectangular coaxial (auxiliary) line. For low power (1kW) design, a small rectangular line section (length 60mm) was used. For coupling purpose a small air suspended strip line was used. For high power (4kW) coupler, design calculation [10] gives final length nearly 170mm (between EIA flanges) achieved using HFSS™. For directional coupler, low power measurement carried out is shown in Fig. 5.

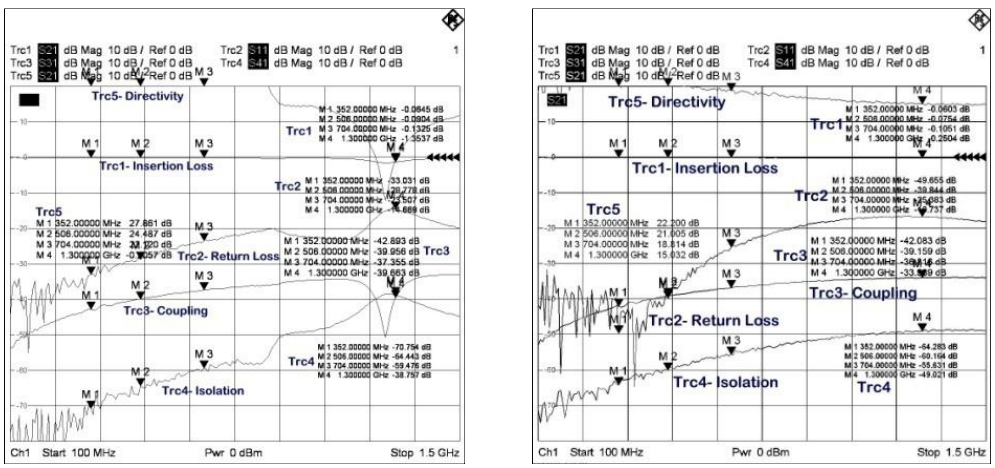

FIGURE 5. Measured performance (insertion loss, coupling, return loss, isolation and directivity) of 1kW (a) and 4kW (b) directional couplers

CONCLUSION

At 650 MHz, a modular kW level solid state RF amplifier has been designed. Using suitable design methodology, power amplifier module, the multi-way power combiner and directional couplers were designed and tested. The measured and predicted results are in good agreement. Successful development of these key RF components adds confidence for future development for selecting solid state RF source in particle accelerator, among other tube based radio frequency and microwave sources.

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