HIGH POWER, LOSSLESS, RIGID LINE 2-WAY RF POWER COMBINERS

Alok Kumar Gupta*, Deepak Kumar Sharma, Akhilesh Jain, P. R. Hannurkar
RRCAT, Indore INDIA

Abstract

Development of 30 kW Solid State RF Power amplifier is under progress at RRCAT for particle accelerator applications. Efficient power combining is basic requirement for amplifier, as output of solid state RF devices is power limited. As a part of this system, 10 kW 2-Way RF power combiners were designed and fabricated at 352, 505.812 and 650 MHz. These power combiners have output and two inputs at 3 1/8" and 1 5/8" rigid coaxial line respectively. Being lossless in nature, these combiners exhibit negligible insertion loss which leads to no efficiency degradation and lesser heat dissipation. Measured performance of these power combiners is in excellent agreement with theoretical results.

Introduction

Solid state RF power amplifiers (SSPA) are viable solution of moderate power level required for energizing superconducting resonating structures for various particle accelerator applications. Due to their inherent advantages of graceful degradation, low maintenance, better quality of signal and absence of high voltage points as compared to traditional tube based RF amplifiers, SSPAs of several tens of kW of RF power level are being successfully deployed in many particle accelerator laboratories worldwide [1]. In this respect, we have also successfully developed 4 kW and 2 kW solid state RF power amplifiers operating at 352 MHz and 505.8 MHz respectively [2][3][4]. Development of 30 kW SSPA at 352 MHz as well as 505.8 MHz is also under progress. Power combing is a mandatory requirement for SSPA due to power limitation of individual solid state RF devices. For 4 kW 352 MHz SSPA, 16 amplifier modules of 270 watt have been combined by a 16 Way power combiner [5] and for 2 kW 505.8 MHz SSPA 8 amplifiers of 300 Watt are combined by 8 Way power combiner [6] to achieve desired RF power output level.

To upscale the output power of SSPA further, lossless 2-Way power combiners at 352 MHz, 505.8 MHz and 650 MHz have been successfully developed and are discussed in this paper. This power combiner will combine two nos. of 4 kW SSPA at respective frequencies to achieve 8 kW of RF power level. This RF combiner can also be well utilized as Power divider also due to reciprocity of the structure. Unlike Wilkinson power combiner, isolation resistor is absent in these lossless 2-Way power combiners which results in reduced insertion loss, lesser heat dissipation and enhanced power combing efficiency. Actual photograph of developed 2-Way power combiner at 352 MHz is shown in figure-1.

Figure 1: 2- Way RF power Combiner at 352MHz

DESIGN

To design this power combiner, first of all input impedance at the junction of its two 50 ohm 1 5/8" coaxial line combining ports is calculated with respect to 50 ohm 3 1/8" output coaxial line using ANSOFT's 3-dimensional High Frequency Structure Simulator (HFSS). Generally, this input impedance comes out to be complex in nature and cannot be easily matched to system impedance of 50 ohm with single section of coaxial line. Stepped impedance matching technique is utilized to match this computed complex input impedance of the combined port junction to the system impedance. This has been achieved using various small sections of different lengths of coaxial lines whose characteristic impedances increase in a stepped manner. A computer program in Matlab is developed to calculate the lengths and characteristic impedances of these impedance matching coaxial line sections. After designing impedance matching sections, complete 3-dimensional structure comprising of combing ports and matching sections is created in HFSS and simulated for optimization to accommodate several discontinuities arsing at the junctions of coaxial lines.

MEASURED PERFORMANCE

Rigorous Low power and High power RF measurements have been performed on all of these three fabricated 2-Way RF power combiners. Low power Vector RF measurements are performed using Rhode and Schwarz's Vector network analyzer (VNA) ZVB4. Here, Port 1, 2 and 3 are being referred to output port at 3 1/8" coaxial line and two input ports at 1 5/8" coaxial line of 2-Way power combiners respectively. Return loss (s11) characteristics for all three 2-Way power combiners are shown in Figure 2. Return loss measured using VNA for these combiners at 352 MHz, 505 MHz and 650 MHz are

* alok_gupta@rrcat.gov.in

32.3dB, 30.4 dB and 23.8 dB respectively. It is quite evident that Return Loss for all these combiners is better than 20 dB which corresponds to reflected power being less than 1% of incident power.

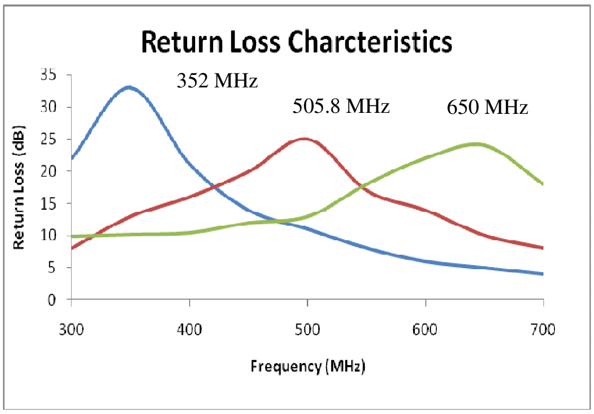

Figure 2: Return loss (s11) characteristics of power combiners at 352MHz, 505.8MHz and 650 MHz.

Sr. No.	Frequency (MHz)	Coupling coefficients	
		Port 2 (s21) Mag./phase (dB/deg.)	Port 3 (s31) Mag./phase (dB/deg.)
1.	352	-3.04 /59.4	-3.03/59.1
2.	505.8	-3.06/-27.7	-3.03/-27.2
3.	650	-3.03/-175.6	-3.05/-174.7

Table 1: Coupling coefficients of 2-Way combiners

Coupling coefficients (s21 and s31) for two combining input ports, measured using VNA, are also arranged in table-1 for these combiners. For efficient power combining, it is must that amplitude and phase of s21 and s31 should be identical. It is clear from table- 1 that measured s21 and s31 for all of these three 2 Way power combiners are fairly identical. Amplitude variation in s21 and s31 is less than 0.05 dB and phase variation in s21 and s31 is less than 2 degree which reflects excellent symmetry of both the combining input ports. A computer program using Matlab is also developed that uses measured s-matrix of these 2-Way power combiners using VNA and gives overall combining efficiency and this comes out to be better than 99% for all of these three power combiners.

High power RF measurements at 200 watt for these power combiners are also performed. 200 watt RF power from indigenously developed SSPAs at 352 MHz, 505.8 MHz and 650 MHz is fed to output port of respective 2Way combiners. Now in this case this structure acts as a power divider. Powers at both the input ports and output port of the 2 Way combiner are measured using 100 Watt NRT Power sensor and 1 kW NAP power sensor from Rohde and Schwarz. Efficiency calculated from these measurements also comes out to be better than 99%. These power division results are equally valid for combining case also due to reciprocity of the structure.

CONCLUSION

10 kW 2-Way lossless power combiners at three different operating frequencies 352 MHz, 505.8 MHz and 650 MHz have been successfully developed and characterized. All these combiners have return loss better than 20 dB and excellent amplitude and phase symmetry between their combining input ports desired for efficient power combining. Measured performance is in excellent agreement with theoretical results. Successful development of these 10 kW 2-Way power combiners imparts confidence for future development of 20 kW and 40 kW 2-Way power combiners to increase the output power of solid state RF amplifier to 30 kW.

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