COMBINING CAVITY FOR RF POWER SOURCES: HIGHER POWER TESTING AND FURTHER SIMULATION

E. Wooldridge, P. Corlett, J. Rogers, ASTeC, Daresbury Laboratory, Warrington WA4 4AD, UK

Abstract

A combining cavity for RF power sources has been investigated previously reported in EPAC'04 [1] using computer simulations in CST's Microwave Studio© and by building a low power model out of aluminium. The model has now been tested at higher power in a number different configurations and compared with earlier results. This paper discusses the results of the higher power test and options for a combiner that can be used at the high power required for particle accelerators. It discusses further design and future modelling.

FOUR PORT TEST

Set-up

The combining cavity was connected to a network analyser, type HP8753C with HP85047A s-parameter test set. The output from the analyser was split with a Mini-Circuits ZC4PD-18 four way splitter at low power and each line was then fed to a variable attenuator and phase shifter before being attached to a directional coupler and connected to the cavity. After the initial investigation a 50W amplifier was added into increase the power.

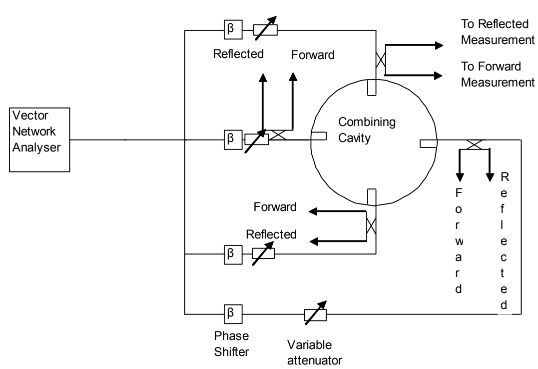

Figure 1: Four Port Set-up

Initial Results

Using the set up in figure 1 above the forward and reverse power measurements were taken for each path from the analyser to the cavity coupler. The port were labelled A, B, D and F using the same nomenclature as [1]. A significant amount of loss was measured in each path, recorded in table 1 below, using the variable attenuator and the phase shifter the output for each path was equalised and the losses calibrated out. The losses for each port are given in table 1.

Table 1: Path Losses

Path	Power Loss (dB)
A	1.16
B	0.85
D	0.91
F	0.86

The network analyser was set to produce 73.0mW of output power. The forward and reflected power for each input was measured, given in table 2, and it can be seen from this table that there is a discrepancy of 6.96mW between the cavity input and output.

Table 2: Forward and Reflected Power

Path	Forward Power (mW)	Reflected Power (mW)	Combiner Output (mW)
A	8.99	2.79	**17.77**
B	7.97	2.64	
D	9.70	1.26	
F	6.77	2.01	
Total	**33.43**	**8.70**	

This result is far lower than expected so the resonant frequency of the cavity was investigated. From previous measurements the cavity frequency was taken to be 1.27630 GHz. The inputs were measured and recalibrated and the frequency was altered the results are shown below in figure 2a.

This change in frequency is thought to be due to the interchangeable parts of the cavity making a different electrical contact each time they are altered. Although the cavity was designed to minimise this effect it is thought that the malleability of aluminium, coupled with the weight of the parts and the tolerance of the fit, has produced imperfections to the surfaces which are believed to be causing this effect.

The same test was then carried out again except with couplers B and F 180° out of phase with A and D. These results are shown in figure 2b. As expected 99.9% of the power is reflected at the ports and virtually no power is measured out the top of the cavity.

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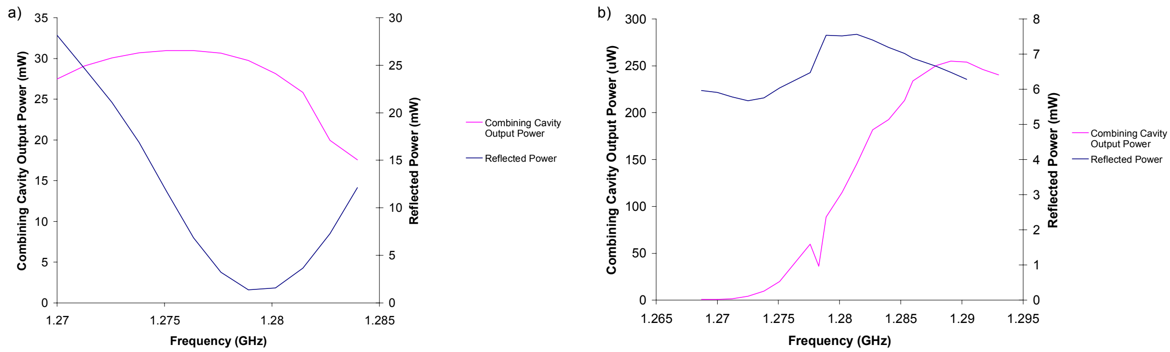

Figure 2: a) Cavity frequency response all ports with equal phase, b) Cavity frequency response with ports B and F 180° out of phase.

Increasing the Power

In order to increase the input power to the cavity, a 50W amplifier was included before the four way splitter, shown in figure 3 below.

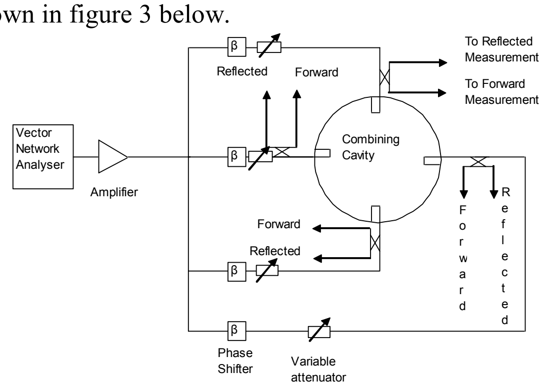

Figure 3: Four Port Set-up with Amplifier

The splitter was changed from a four way splitter to 3 matched splitters so the power could be increased without damaging the splitter.

Table 3: Increasing the Power

Analyser Output (dBm)	Single Port Forward Power (W)	Single Port Reflected Power (mW)	Combining Cavity Output Power (W)
5	1.5	7.1	4.65
7.5	2.7	12.0	8.23
10	4.5	21.51	13.90
12.5	5.72	47.0	18.13
15			20.83
17.5			21.82

Comparing the single port results with the combining cavity results in table 3 approximately 25% of the power is being dissipated in the cavity. The causes for this loss of power and possible solutions are discussed in future modelling and further design section.

TWO PORT TEST

Set-up

To increase the power to the cavity further the input was split into two after the network analyser and the input fed into two 300W amplifiers. The resonant frequency was measured to be 1.27756 GHz. A Mini-Circuits ZFSCJ-2-4 two way splitter was used to split the signal from the analyser. This is not the ideal splitter for this frequency as it suffers from greater losses above 1GHz.

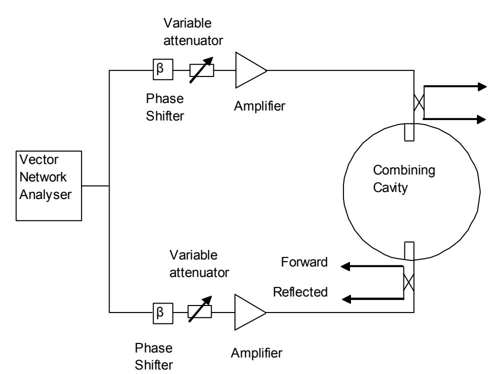

Figure 4: Two Port Set-up

The phase and amplitude of the signals were equalised and the input power was increased. For a total input of 99.77W, 12.65W was lost in the cavity, 12.6% to the total power, and about 1W was reflected at each port. The power was increased till the output of the cavity was 200.00W. The total input to the cavity was 227.09W with 2W being reflected at each port. This is a loss of 11.1% within the cavity.

Further increases in power were not possible as the cavity was found to be leaking RF through a piece of PTFE in the lid, see figure 5. The PTFE was used to insulate the stub coupler from the cavity body and for mechanical rigidity. This was initially spotted at low powers and temporarily repaired but as the power increased the leak was seen again and further testing was stopped.

Figure 5: Combing Cavity with PTFE Close-up

FUTURE MODELING AND FURTHER DESIGN

This combining cavity was designed as a 'proof of principle' cavity and therefore requires several areas to be improved. It is made of bulk aluminium and is therefore heavy and somewhat soft which is thought to cause this shift in resonant frequency. Also the since the cavity is in air the aluminium gains a thin oxide layer which increases surface resistivity. Using copper or coating the surface of the aluminium may lessen these effects.

The cavity will require cooling, probably by water, to achieve a useful level of power output. Further modelling will investigate the thermal effects along with electromagnetic effects.

The lid needs a small amount of mechanical redesign to remove the source of the RF leak. Further modelling of the couplers may also improve the response of the cavity. In the prototype cavity, the input couplers were constructed as shown in figure 6. Due to the presence of sharp corners and construction issues, the couplers are not optimised. In future versions, the couplers will be constructed from a single curved loop to reduce these effects.

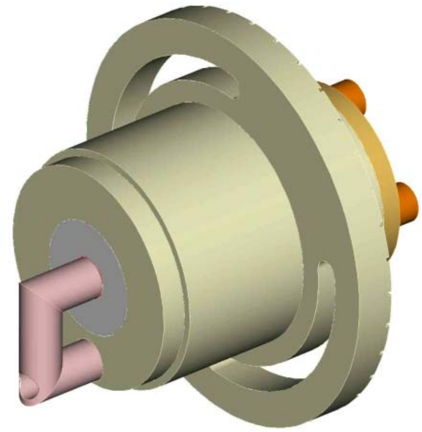

Figure 6: Cavity Coupler Close-Up

SUMMARY

The combining cavity has been tested with two and four ports and has combined power with an efficiency of 75-85%. It is believed that this can be greatly improved with further mechanical, thermal and electromagnetic design.

ACKNOWLEDGEMENTS

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REFERENCES

[1] E. Wooldridge, S. Appleton, B. Todd, "Combining Cavity For RF Power Sources: Computer Simulation And Low Power Model", EPAC'04, Lucerne, July 2004, p1060

[2] http://e2vtechnologies.com/

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