COMBINING CAVITY FOR RF POWER SOURCES: COMPUTER SIMULATION AND LOW POWER MODEL

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Abstract

A combining cavity for RF power sources has been investigated as a way of saving space, in comparison to waveguides, and as a way of combining power with graceful degradation if one or more component were to fail. The cavity has been investigated as the maximum power output of an Inductive Output Tube (IOT) for CW is 80KW at 500MHz and a proposed output of 20KW at 1.3GHz and most RF systems for particle accelerators require much more than this. Although 1.3GHz klystrons do exist they are vastly more expensive to purchase and maintain. Also the down time could be minimised to minutes in the even of a single IOT failure where as a klystron has a minimum downtime of several days in the event of a failure. Initially the cavity and its inputs were simulated in CSTs' Microwave studio. After optimising the cavity to ensure the minimum reflection at the input ports and maximum transmission at the output port, a low power model was then created from aluminium. Signal generators were used to power the model and a network analyser was used to check the output. The model was used to compare the results gained from the computer simulation and to obtain results from asymmetric positioning of the ports, which was not possible in the simulation.

ELECTROMAGNETIC MODELLING

The combining cavity was designed using Microwave Studio. The inner cavity dimensions were modelled as air and the cavity walls and conductors as perfect electrical conductors. The central cavity was optimised to 1.3 GHz and then after inserting the couplers the cavity was re-tuned to 1.3GHz. The model was then optimised to ensure that all the power coupled into the cavity and measured via the stub coupler at the top. Figure 1 shows an image of the model.

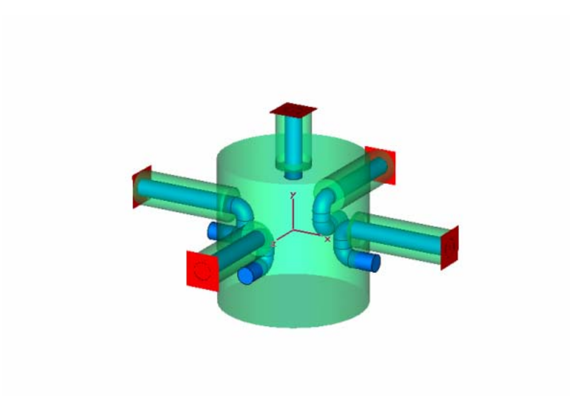

Figure 1: Combining cavity model

The cavity was modelled with 2, 3 and 4 inputs to obtain data for the combining of one or more inputs. For the 3 input version the couplers were placed 90º apart to compare the loss of an input from the 4 input model. The output of these three models shows the graceful degradation of power as modelled in [1] and is shown below in figure 2. The measurements have been standardised to the power from 1 input. The total power out of the stub coupler (port1) was measured to be 6.00dB, 3.94dB and 2.55dB for 4, 3 and 2 couplers respectively

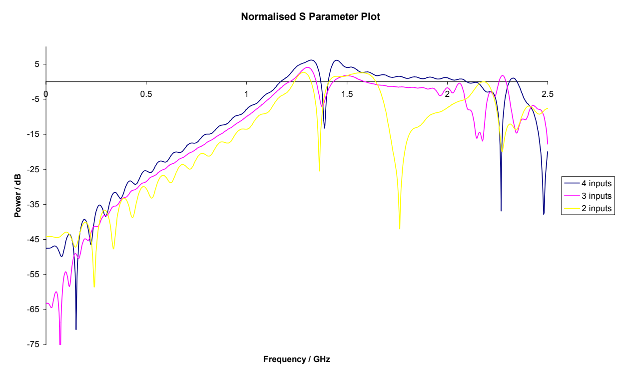

Figure 2: Graceful degradation of power

PRODUCTION

From the computer simulations a mechanical drawing was produced for the production of a technical demonstrator by the mechanical engineering department and the mechanical workshop (figure 3c). The body of the combiner is made of aluminium and the couplers from brass. The air in the coax coupler in the model has been replaced by PTFE for mechanical rigidity. To allow the cavity to be tested with ports in asymmetrical positions two further holes were created in the cavity wall. Four dummy ports (figure 3a) were made which were shaped to fit the inside of the cavity wall. These were created to be inserted into the holes where the couplers were not being used.

For mechanical stability the wall of the combiner increased to include all of the length of the coupler (figure 3e). The coupler is held in position by a screw in the shorter prong. This will also steady the coupler in position whilst it is moved further in and out of the cavity. The couplers have been made in three pieces and braised together to save time on the manufacture. The shape of the coupler can be seen in figure 3b below. This change was modelled and was found to lower the expected output of the cavity with 4 inputs to 5.76dB.

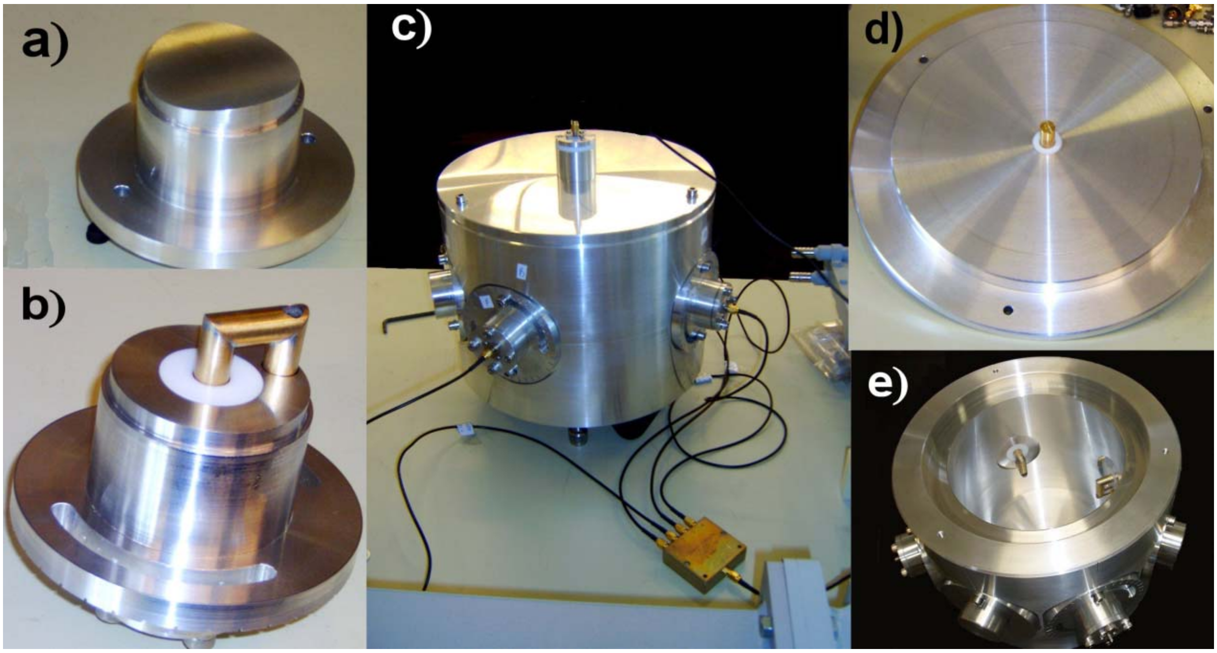

Figure 3: Cavity images a) dummy port, b) port with brass coupler, c) finished cavity d) lid with stub coupler e) inside of the cavity.

TESTING THE CAVITY

The cavity was connected to a network analyser, type HP8753C with HP85047A s-parameter test set. The output power was split using 3 mini-circuits ZFSCJ-2-4 two way splitters. Using this setup the cavity was tested. The cables were calibrated and all measurements were calibrated to the power for one input. The holes with the cavity were labelled as below in figure 4. The standard set up for 4 couplers in the cavity was for them to be in the positions ABDF.

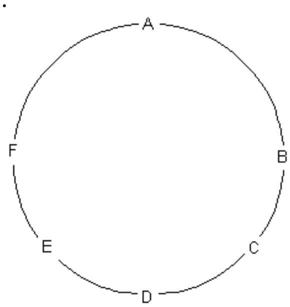

Figure 4: Position of gaps within the cavity

Comparison to the Model

The technical demonstrator shows the graceful loss of power as expected and the peaks at 5.71dB, 3.84dB and 2.81dB, for 4, 3 and 2 couplers respectively are close to those predicted. In the plot below shows the output from the cavity for 4, 3 and 2 couplers along with the results of the modelling data.

From figure 5 it can be seen that the peak data from the test corresponds to the modelled line although there rest of the response is different. The peak is not at 1.3 GHz as predicted but a 1.283GHz. Differences in the s-parameter plots may be due to ohmic loses with the system.

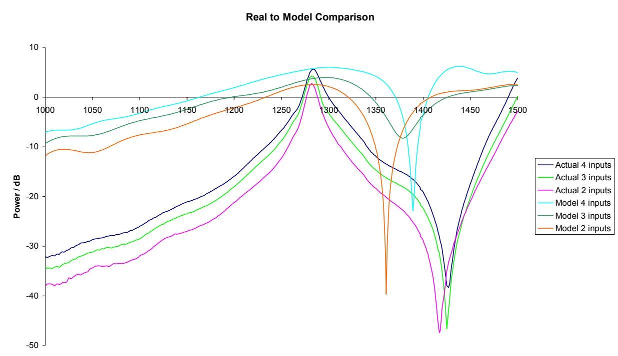

Figure 5 Comparison of model and actual data

If the coupler is disconnected from the power source but left connected to the cavity it then acts as a source for loss within the cavity.

Asymmetric Testing

The couplers were tested in many different combinations. The results show that cavity performs best in symmetrical or close to symmetrical conditions. In asymmetrical configurations the couplers show signs of cross-talk. The position of the couplers should not be this critical and this effect may be due to the size of the couplers relative to the cavity. At higher power larger couplers are required but at lower frequencies the cavity must be increased in size, using this and increasing the size of the couplers fractionally less than the factor for the cavity both of these aims maybe achieved.

Rotating Couplers

The couplers were rotated round their axis to 90º in 10º steps. As expected when the couplers were moved 90º to their original position all of the power was lost within the cavity. There is a slight increase in the power when the couplers are rotated by 30º. This data is shown below in table 1 below. This is also thought to be due to the shape and size of the couplers.

Table 1: Rotating coupler data

Angle	4 couplers ABDF	4 Couplers ABEF	2 Couplers DF
0	4.922	4.639	1.423
10	4.949	4.607	1.274
20	4.985	4.657	1.174
30	5.005	4.717	0.946
40	4.808	4.57	0.422
50	4.419	4.11	-0.735
60	2.279	2.82	-2.264
70	0.878	0.191	-4.733
80	-3.421	-3.964	-8.605
90	-15.421	-18.174	-18.02

As more experiments were done with the cavity the peak power was found to be decreasing. The cavity was cleaned using propan-2-ol which increased peak values back to there original values.

Altering the Coupler Length

The output stub was moved 5mm further into the lid and 10mm further into the cavity in 1mm steps. In the default position the resonant frequency is 1.28GHz, with the stub 5mm into the lid this changes to 1.291GHz and 10mm further into the cavity it becomes 1.27GHz giving a tuning range of 21MHz.

Moving all the curved couplers further into the cavity lowers the peak power, causes a 3 MHz shift in the peak frequency and a broader peak. The moving of just one of these couplers makes a negligible difference.

Using as a Splitter

The cavity can also be used to split the power from a source with the same efficiency as a combiner. Power was fed into the cavity through the stub coupler in the lid and out through the curved couplers in the centre of the cavity. The measurements were calibrated in the same way as for the combiner. The data is shown with the data for the combiner in figure 6.

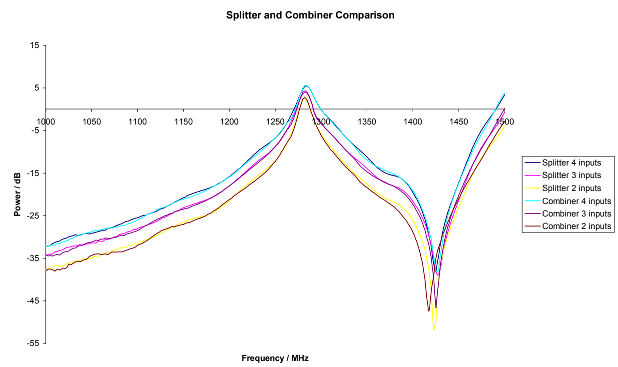

Figure 6: Splitter combiner comparison

SUMMARY

The cavity can be used efficiently both as a combiner and as a splitter. The graceful degradation of power has been observed as inputs and their couplers have been removed. The couplers require further work so that the couplers they can be placed asymmetrically. The cavity may be better suited to lower frequency applications where the couplers can be larger.

REFERENCES

[1] H. Bohlen, Some aspects of combining the output of several IOTs via a common cavity, Report prepared for Daresbury Laboratory 2002.

[2] H. Bohlen, Inductive Output Tubes – Status and Future Direction, Displays and Vacuum Electronics, Garmisch-Partenkirchen, 2-3 May 2001.