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WAVEGUIDE SPLITTER FOR LOWER HYBRID CURRENT DRIVE

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Plasma Science and Fusion Center
Massachusetts Institute of Technology
Cambridge MA 02119 USA

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WAVEGUIDE SPLITTER FOR LOWER HYBRID CURRENT DRIVE

P. Koert[1], P. MacGibbon[1], R. Vieira[1], D. Terry[1], R. Leccacorvi[1], J. Doody[1], W. Beck[1]

[1]*Massachusetts Institute of Technology Plasma Science and Fusion Center, Cambridge MA, pkoert@psfc.mit.edu*

We have developed high power four and eight way splitters for a new Lower Hybrid launcher. The motivation for the new launcher was the need to provide more power and reliability to the launcher structure. In addition there was a desire to simplify and increase the reliability of the implementation of the alumina windows. The launcher consists of 64 waveguide apertures powered by 8 klystrons with maximum power of 250 kW each at 4.6 GHz. Hence, it is necessary to split the power from each Klystron into eight separate waveguides. The outputs of the splitter have a difference in power less than 0.1dB and phase less than 2 degree. The design analysis of the splitter was done with the computer code CST. Structure analysis was performed using Ansys. The splitter is fabricated by machining an open cavity into a thick stainless steel plate creating the specified internal geometry. It is machined to a tight tolerance of +/- 0.005". A fitted lid is then welded on top of the open cavity using electron beam welding. The excess metal is removed with Electro discharge machining (EDM) creating the external geometry. The waveguides are then butt-welded to the splitter. Welding fixtures/parameters are being developed to achieve the desired tolerances. Two methods for attaching the ceramic windows are being evaluated, brazing and electro-forming.

I. INTRODUCTION

The lower hybrid current drive (LHCD) system recently installed on Alcator C-Mod is a key component of operation in advanced tokamak regimes[1]. The system launches 4.6 GHz lower hybrid waves into the plasma from a phased array of 96 reduced height waveguides. Although the present Alcator C-Mod launcher has been successful there is a need for a higher power and more reliable launcher. To accomplish this goal a new simplified launcher with 64 waveguides is being proposed. The conceptual drawing of this launcher is shown in figure 1. The new launcher is based on a four way splitter shown in figure 2. The splitting of the guides just before the aperture has greatly simplified the guide plumbing. (Fig. 1) This also simplifies and increases the reliability of the alumina windows (Fig. 2) which are brazed in the guides to facilitate the transition from insulating gas to the vacuum conditions in the tokamak.

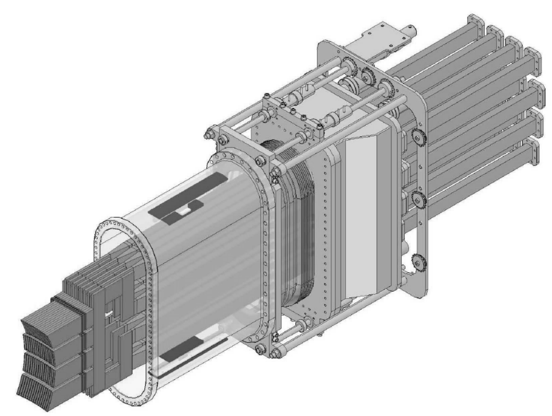


Fig. 1 Conceptual New Launcher Design

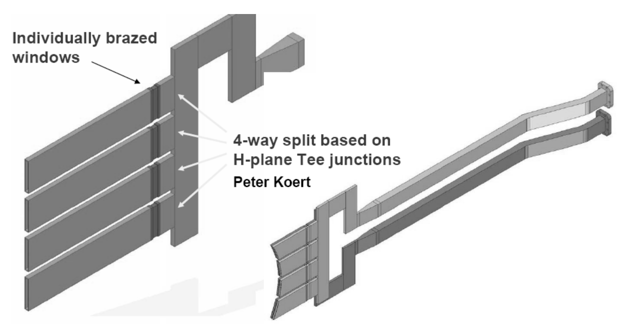


Fig. 2 Four-way Splitter

II General Description

The four and eight splitters are microwave guide devices designed to divide the power to the Lower Hybrid launcher on Alcator C-Mod. They are designed for the LH operating frequency of 4.6GHz. The splitter mechanism is accomplished by inserting apertures in the narrow side of the guide in order to couple power into the attached guides. Figures 3 show an example of this arrangement.

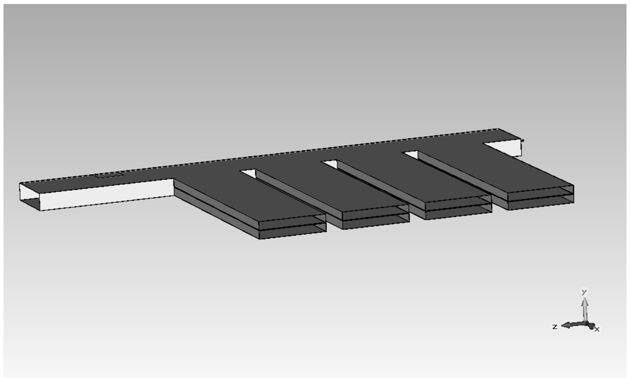


Fig. 3 waveguide splitter with eight outputs

The spacing of the apertures and attached guides is equal to a guide wavelength in the input guide. The guide wavelength is determined by the aperture size, size of the attached guides and spacing Thus determination of the spacing is an iterative process in the design. Since the spacing is equal to a guide wavelength not only is equal power coupled into the attached guide, but there is very small phase difference between them (less than one degree). The short on the end of the input guide is approximately a multiple of a half of a guide wavelength from the center of the last attached guide.

This splitter can work equally well with 3, 4 to 20 or more splits. The splitter will work with multiple guide wavelengths between the guides. Thus if one or more guides are shorted out the remaining guides will work as a splitter minus the shorted ones.

The results of an eight way splitter simulation on the field code CST (Microwave Studio) are shown in figure 4.

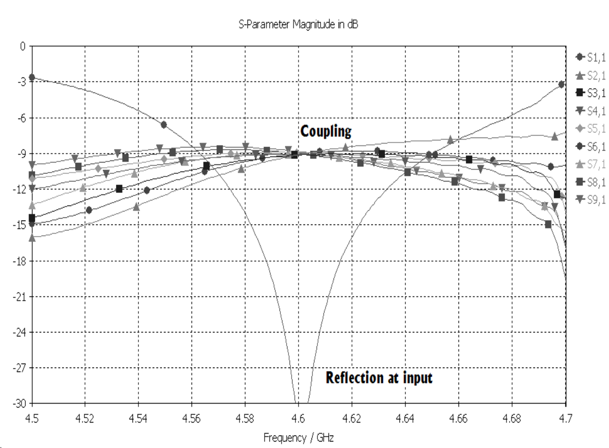


Fig. 4 S-parameters of input reflection and divided split.

The plot shows that there is equal split at 4.6 GHz; this is the only significances of the plot. The rest of the details are not important. The reflection at 4.6 is -30db or a VSWR of 1.06:1. The split shows all guides at -9db at 4.6GHz or 1/8 of the power in the input guide. The cross coupling between guides is -18 db. All of these results are for matched impedance conditions.

III. Launcher Splitter Design

A splitter designed for the new Lower Hybrid Launcher is shown in figure 5. The outputs of the splitter are shaped to conform to the plasma cavity. The different apertures must be in phase in order to achieve equal power split. So indentations in the outside guides to increase guide wavelength are added to give equal phase at the apertures. Figures 6 though 10 are the CST results. Figure 6 shows the cross of 6 db and a reflection at input greater than -27 db at 4.6GHz. Figure 7 shows the phase corrected at the aperture, This can be corrected to within +- one degree. Figures 8 and 9 shows the contour of the E field and power in the splitter. Figure 10b and 10c shows more accurately the E field along a monitor line. Figure 10b shows the standing wave in the splitting section. Figure 10c shows the E field in one of the branches with a large standing wave in the alumina window (dielectric constant 9.4) and the increase along the phase correcting dent.

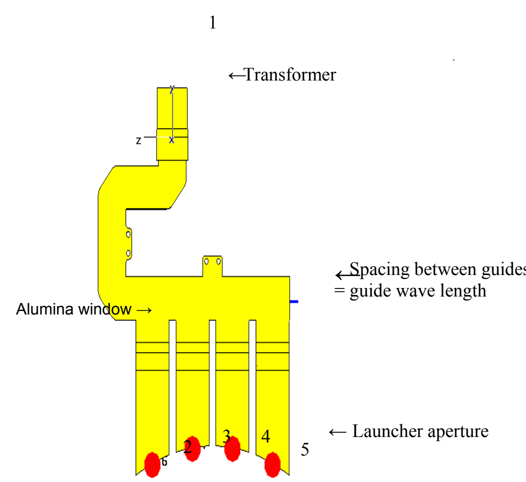


Fig. 5 Splitter for launcher

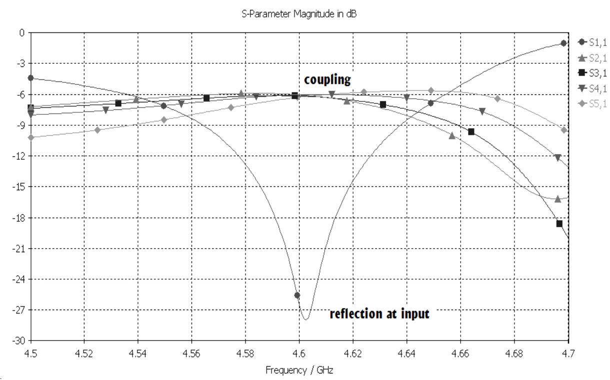


Fig. 6 S parameters for Launcher Splitter

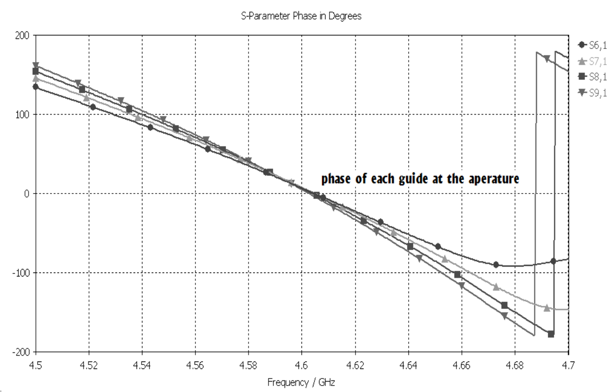


Fig 7 Phase at launcher aperture.

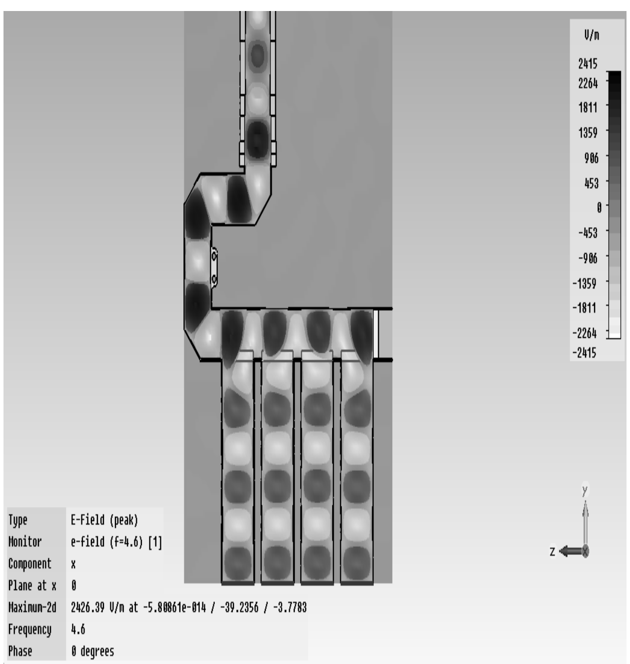


Fig.8 Flow of E field in Launcher Splitter

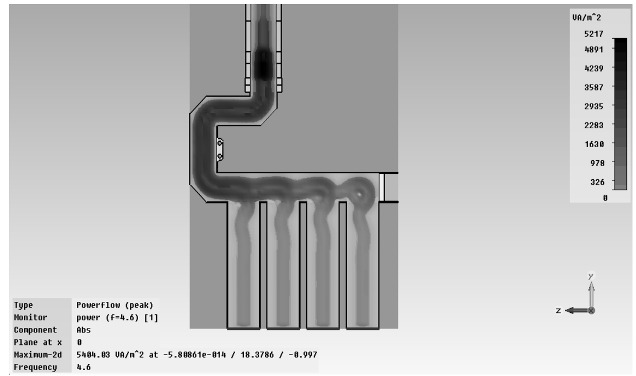


Fig. 9 Power flow in Launcher Splitter

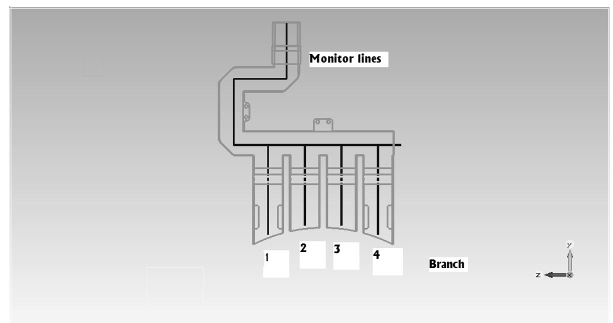
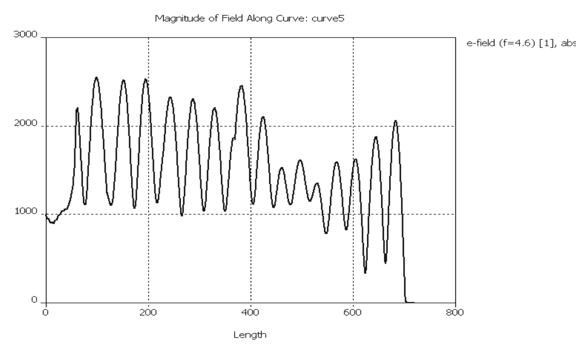


Fig. 10a E field monitor lines



Fig, 10b E field in main guide

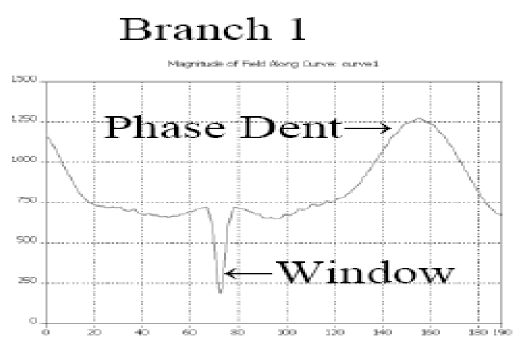


Fig. 10c E field along branch 1

The result of an increase in reflection at the input due to variation in phase of the reflection at the launcher aperture is shown in figure 11. Two cases are shown on the smith chart both have 50% reflection at the aperture but one has 90 phase difference on the outer splitter guides.

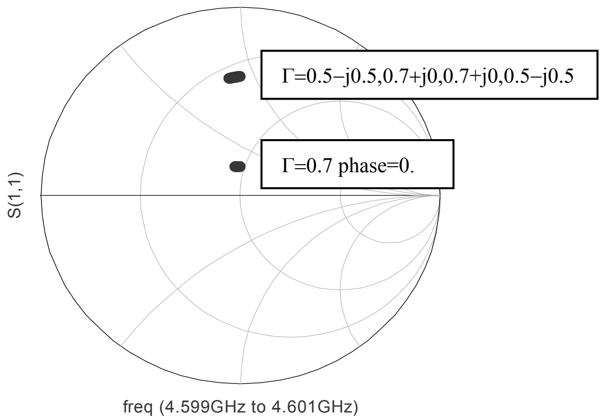


Fig. 11 Input impedance due to reflections at aperture

IV TEST RESULTS

A prototype fixture shown in Figure 12 was fabricated to test out the power handling capabilities. The prototype was constructed of stainless steel and had a temperature rise of 55 degrees C for 190KW input for 0.5 seconds. The actual launch will be copper plated and will have 2.5 times less loss. The Figure 13 and 14 show the measured and simulated S-parameters which are in good agreement. The equal power crossover is off 0.4% because the waveguide spacing was off 0.4mm in the fabrication. The prototype was able to conduct 190KW for 0.5 second without breakdown for matched loads. The insulating gas was dry nitrogen and the power density was over 45kW per square centimeter. Figures 15 to 17 show the forward and reverse powers for conditions of matched, one short and three shorts on the outputs. These graphs illustrate the unique response of this splitter to transmit most of the power out of the remaining guides when one or more of the guides are shorted.

The measured loss in the splitter and output guides which are copper plated is 0.5 dB. The equivalent portion of the current launcher exceeded 1 db. The total loss in the current launcher complex is around 3 db. Since the new launcher with the splitter will have fewer bends and longer WG187 guides with no stacked plate narrow guides, the expectation is that the losses in the new launcher will be less than 2dB.

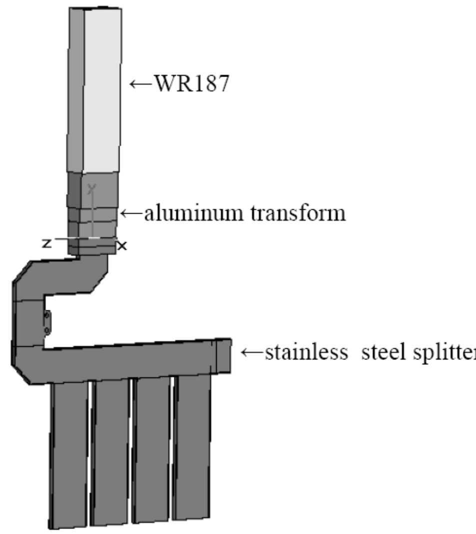


Fig. 12 Prototype test fixture

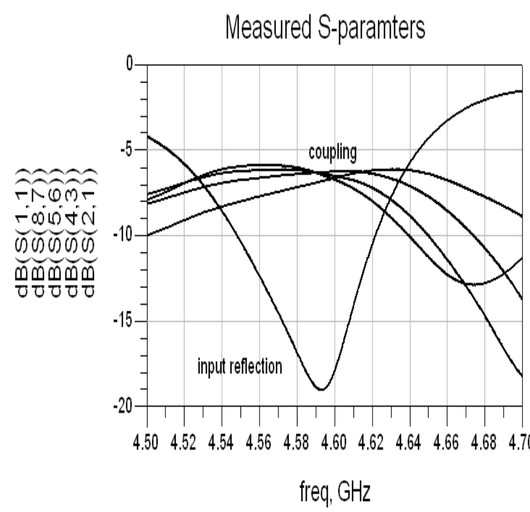


Fig. 13 Measured S-parameters of Prototype

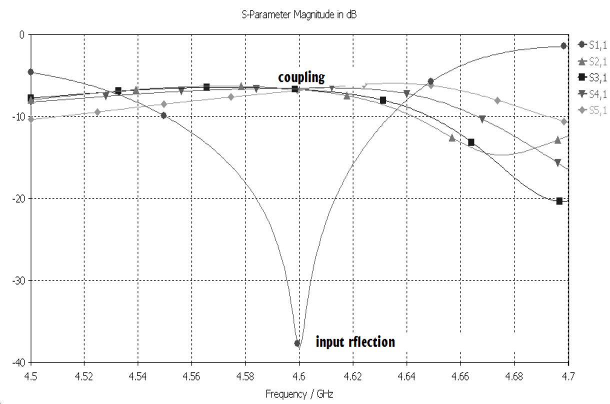


Fig. 14 Simulated S-parameters of Prototype

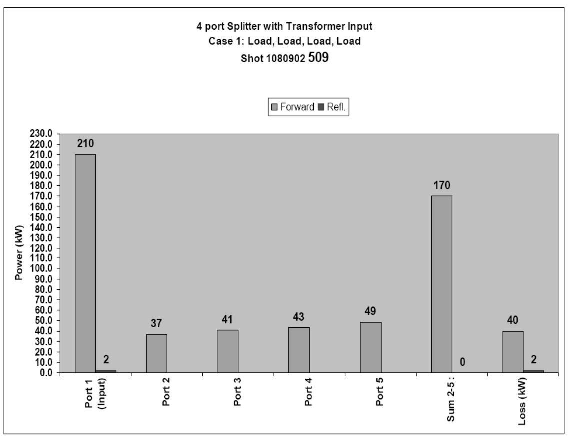


Fig. 15 Measured Power in prototype for matched loads.

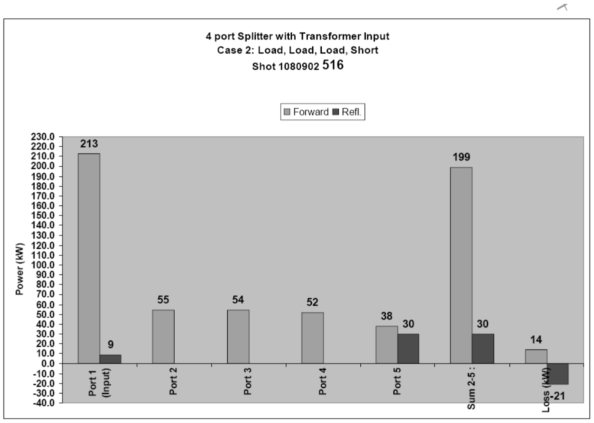


Fig. 16 Measured Power into prototype for short on fourth output.

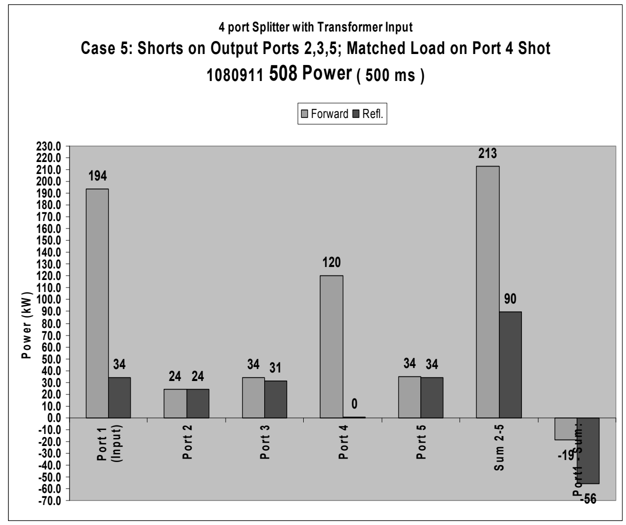


Fig. 17 Measure Power into prototype for shorts on three outputs.

V. CONCLUSIONS

A four way splitter has been proposed for a new Lower Hybrid Launcher which significantly simplifies the launcher design and fabrication. Test results show that there is good agreement between measurements and design generated from CST simulation. The prototype splitter was subjected to 190kW for 0.5 seconds without breakdown. For the size of the splitter waveguide this corresponds to 45 kW per centimeter squared. In addition, power flow in low reflection guides is increased when one or more guides have high reflection. The losses in the new launcher should be 1dB or more less then the current launcher.

ACKNOWLEDGMENTS

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1. P. BONOLI, et al, “Wave-particle studies in the ion cyclotron and lower hybrid ranges of frequencies in Alcator C-Mod”, Section VI, *Fusion Science and Technology, vol.51, pp. 401-436, April 2007*.