ADJUSTABLE HIGH POWER COAX COUPLER WITHOUT MOVING PARTS*

M. Neubauer#, A. Dudas, R. Sah, Muons, Inc. Batavia, IL 60510, USA
A. Nassiri, R. Bolgov, ANL, Argonne, IL 60439, USA

Abstract

A high power fundamental RF power coupler (FPC) with an adjustable in situ coupling factor would be highly desirable for a number of applications: for example, the 352 MHz light source at APS, and Project X. A Phase I project has been completed with a prototype constructed and modelled. The prototype includes a coaxial Tee with two windows a quarter wavelength apart, and a ferrite tuner. Two materials were tested and their characteristics measured in terms of loss and magnetic field requirements to produce the desired change in coupling. A VSWR of better than 1.05:1 and a bandwidth of at least 8% at 1.15:1 were measured. The tradeoffs of a final design are proposed based upon these results.

INTRODUCTION

Previous design details were presented last year at IPAC11 [1]. The variable coupler is composed of three fundamental elements:

1. A magnetically tuned variable ferrite or garnet tuner.
2. Double coax windows, λg/4 center to center.
3. EIA 6-1/8 Standard Coax Tee and components.

A Muons, Inc. Phase II grant for work on a dual coaxial window coupler is still underway, and the windows portion of this project will be based on knowledge gained during that work.

The majority of the work discussed in this paper will deal with the selection of the ferrite material, and the design of the ferrite section, both electrically and thermally.

FERRITE TUNER

Ferrite tuners are not a new concept. They all make use of the principle that a biasing magnetic field is applied to the ferrites orthogonal to the RF fields and as a result the permeability of the ferrites can be varied by changing this biasing magnetic field. In only one of the tuner designs are the ferrites cooled by immersion (in water). In the rest of the designs, the heat is dissipated through the walls, via a cooling jacket that surrounds the tuner portion of the device [2].

The tuner in the design discussed here is a coaxial cavity with ferrite or yttrium garnet disks immersed in a liquid dielectric. The dielectric liquid is circulated through a heat exchanger, as describe in Dr. Popovic's invention [3]. This section of coax is surrounded by a solenoid to provide the magnetic field orthogonal to the TEM fields in the coax. Changing the solenoidal magnetic field changes the characteristics of the cavity, the Q_{ext}, and therefore the β of the system. Experimental results from a test fixture designed to measure the magnetic fields required, and the losses expected for representative materials, are discussed below.

A schematic of the tuner section of the proposed device is show in the Figure 1.

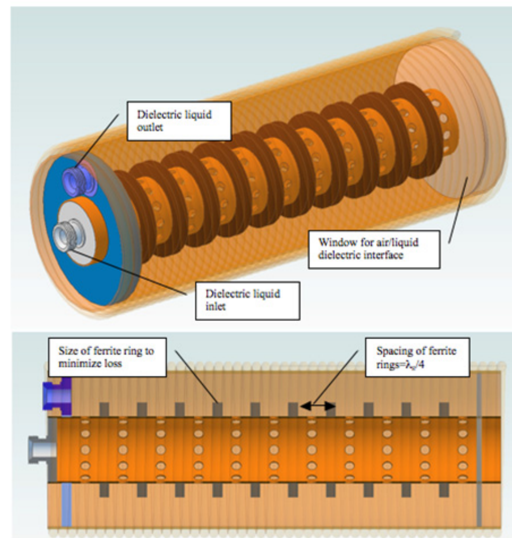
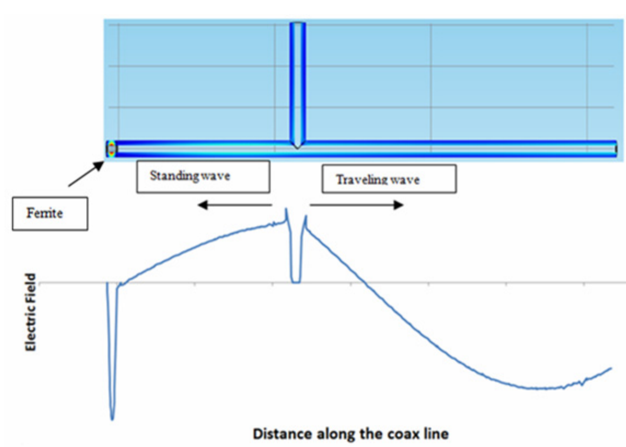


Figure 1: Schematic of the tuner section.

Concept

The ferrite tuner device works in the following manner. Varying the solenoidal field causes a permeability change in the ferrite(s) and thus a change in the standing wave in the tuner portion. The fields at the junction are thus varied, and the amount of power arriving at the output port (S21) is adjusted. This can be seen from a Comsol model of the low power experimental set-up in Figure 2.



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#mike@muonsinc.com

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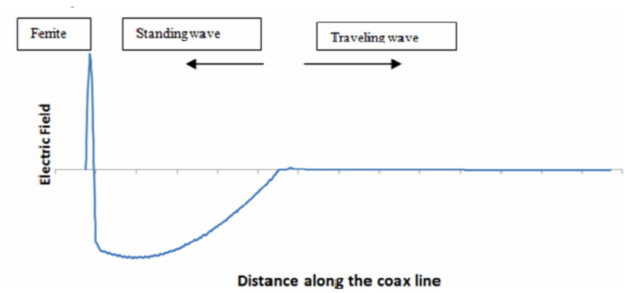


Figure 2: Shows how the tuning concept works by adjusting the standing wave in the tuner portion. The upper trace shows power flow to port 2. The lower trace shows the tuner portion adjusted such that the power at port 2 is zero.

Test Fixture

The test fixture was designed based upon the work of G. Bush [4], and is shown in Figure 3.

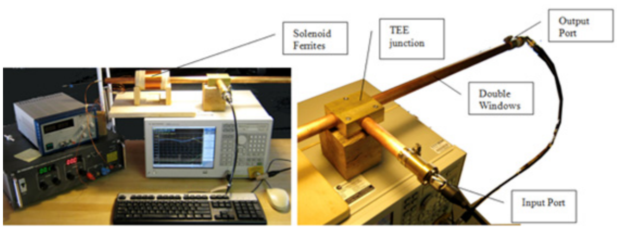


Figure 3: Experimental set-up used to evaluate ferrite materials.

The test fixture is built in EIA 7/8 coax. This scaled down version of the coax allows for collecting experimental data on a various ferrites in order to determine the optimum material for the final design.

The coaxial Tee design was analyzed using COMSOL to determine the proper geometry and spacing of the components for the lower power testing [5]. Figures 4 and 5 show the results of the calculated and measured S11 parameter. The frequencies differ because of small variations in positioning of the various components in the experimental set-up. However, comparison of the calculated and experimental results shows good agreement, and indicates both good coupling and a bandwidth of 9%.

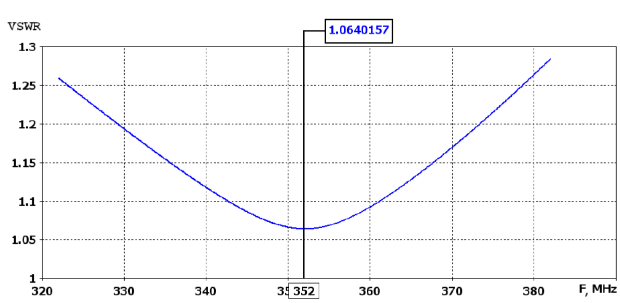


Figure 4: Shows the calculated VSWR at the RF input.

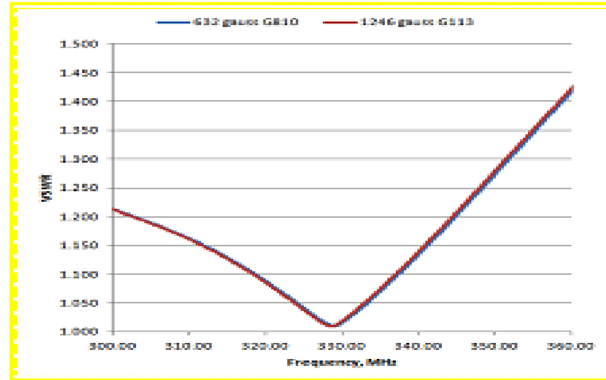


Figure 5: Shows the measured VSWR at the RF input.

Ferrite Loss Measurements and Calculations

Since the tuner design is coaxial, the ferrites are toroidal in shape, and the loss in the ferrites is related to the field intensity of the coaxial structure. Figure 6 shows the loss profile for a 1 cm thick toroid between the inner and outer conductors in EIA $3^1/_8$ coax. The total loss represented is 850 watts.

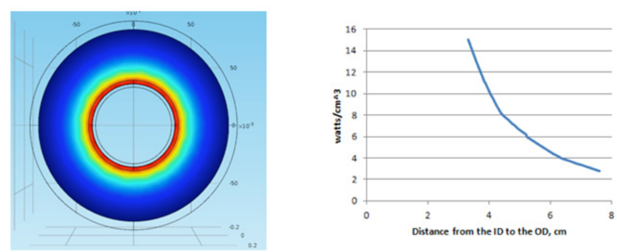


Figure 6: Loss profile for a ferrite toroid between the inner and outer conductor of EIA 3 $^1/_8$ coax.

Figure 7 shows the loss that would occur in the ferrite as a function of the applied magnetic field changing the properties of the ferrite. Shown are curves for Transtech G-810 and G-113, which were the two most promising ferrites material tested.

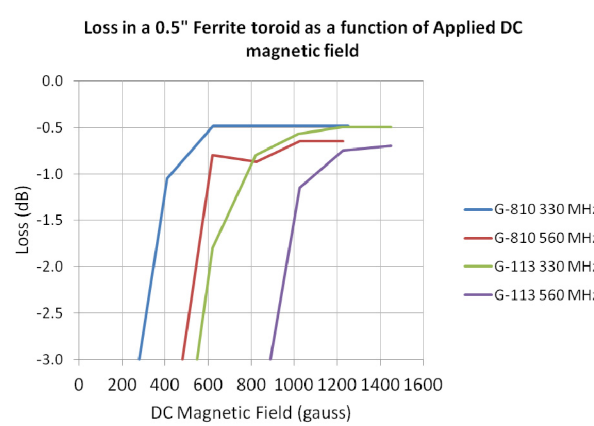
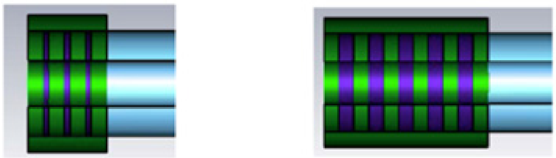


Figure 7: Shows the loss in a 0.5" thick ferrite toroid as a function of the applied DC magnetic field.

A functioning full power design requires balancing the amount (volume) of ferrite material, the ferrite location(s), and heat extraction considerations. Obviously, thinner toroids of ferrite are easier to cool, but produce less of a phase shift. The table in Figure 8 shows the various tradeoffs in this regard.



a) N = 3; FL = 1 mm b) N = 5; FL = 3 mm

Total length of ferrite (FL•N), mm	FL, mm	VSWR at 352 MHz	Losses dP, W/m³	L2, mm	L1, mm
N = 6					
18	3	1.054	5400	40	69
12	2	1.055	8184		109
6	1	1.042	15092		165
N = 5					
15	3	1.054	6870	80	130
10	2	1.052	9835		167
5	1	1.034	14615		218

Figure 8: Sample loss calculations for the full power design of Phase II. L1 and L2 represent positioning information for the ferrites and the output window.

Adjustability

In addition to producing a useable design for a coupler with no moving parts, the goal of the design is a VSWR of better than 1.05:1 and a bandwidth of at least 8% at the at 15:1 VSWR level. Figure 9shows the range of VSWR for a 10% bandwidth as a function of applied magnetic field.

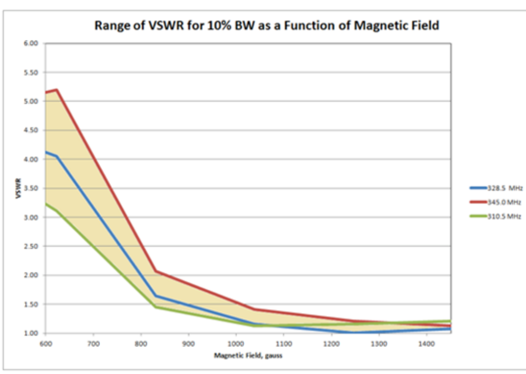


Figure 9: Shows a 10% BW graph as a function of applied magnetic field.

At lower magnetic fields the VSWR is higher and the ferrite losses are greater, necessitating cooling by immersing the ferrite toroids in a dielectric fluid. The fluid will contribute to the losses, but is not affected by the applied magnetic field.

DOUBLE COAX WINDOW

The output arm of the coax coupler will contain two coax windows separated by approximately $\lambda/4$. The dual window design serves not only to isolate the coaxial tuner from the device at port 2, but also to match and reduce reflections at the entrance to the device.

Muons, Inc. is currently working on a Phase II program to develop a double coax window assembly. The windows are designed and fabricated in such a manner that a compression seal exists at the OD (see Fig. 10). This prevents the windows from going into tension as they heat during operation.

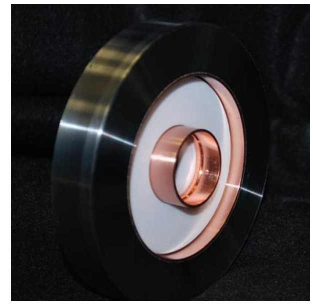


Figure 10: Shows a coaxial window brazed with a compression ring.

Table 1: COMSOL Calculations of power dissipated and the maximum gradient in the EIA 3-1/8 coax line with alumina windows (at room temperature) with tan δ=.0001 at 100 kW input power [6].

Freq (MHz)	Watts in a window at 100kW Pin	Gradient at 100 kW (V/m)
1300	18.6	2.29E+05
805	12.2	2.56E+05
650	10.7	2.72E+05
325	5.14	3.77E+05

In the adjustable high power coax coupler without moving parts, the match through the double windows is dependent upon the spacing between them and the operating frequency of the coupler.

CONCLUSIONS

Phase I low power tests yielded good results of better than 1.05:1 VSWR and 8% bandwidth at less that 1.15:1 VSWR, matching the calculated values. Two useable ferrite materials were determined.

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