NEW RF DESIGN FOR 11.4GHz DIELECTRIC LOADED ACCELERATOR*

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Abstract

In this paper we present a new solution for externally RF coupled dielectric loaded accelerator. In this scheme, a separate TE-TM converter is used for RF coupling and a short tapered section is used for matching the RF into the dielectric accelerating structure. Advantages of this new design are there is no dielectric presented near the coupler, thus less prune to premature breakdowns; and it can be made into separate modules of coupler, matching and accelerating structures, this will simplified the dielectric structure development because only one set of couplers is required for a defined RF frequency but with many different dielectric structures. An example of X-band 11.424 GHz coupler and dielectric accelerating structure is obtained via EM simulations. Based on the simulation results, a set of coupler, matching and dielectric structures were fabricated. We present bench measurement results and its comparison with the design.

INTRODUCTION

Dielectric based accelerating structures were proposed and studied as a practical accelerator in the past decades [1-5]. The advantages and potential problems of using dielectric material are discussed in the above references and summarized in [5]. An implementation is also described in [5]. However, the high power experiments could not demonstrate high power and high field characteristics of dielectric accelerating structures because the RF coupler designed to convert TE-mode from rectangular waveguide to TM-mode in the accelerating structure could not support very high power transmissions. The failure of high power capabilities was suspected due to the presence of dielectrics near the coupling slots [6] that has field enhancement effect, thus causing breakdown near the slot.

In order to eliminate any field enhancement near the coupler due to the presence of dielectrics, we have adopted a new coupling scheme that separate the coupler from the accelerating section as suggested by Tantawi and Nantista[7] and Syratchve[8]. As shown in Figure 1, this new scheme of the dielectric loaded accelerator is consists of 3 modules: 1) Coupler section; 2) Dielectric tapered matching section and 3) Dielectric accelerator section. The coupling section is used to convert the rectangular TE10 mode to circular TM01 mode. The tapered dielectric section is used to provide matching between TM01 modes in coupler and dielectric accelerator. This scheme separates the dielectric loaded accelerator from the coupling structure by a tapered matching section and thus makes the coupler independent of the dielectric properties. Also because the coupling slot is located in a section of circular metallic waveguide, the area of the coupling slots are much bigger than in the previous scheme[5] and this makes the peak value of the EM field much smaller than that of the old scheme under the same input power. Another advantage of this modular scheme is that it simplifies the experimental implementations of high power tests because only one set of input and output coupler needs to be made for different dielectric accelerators. Once the couplers have been proved to have high power capability, we can reuse them in other dielectric loaded accelerators working in the same band provide that we have redesigned and implemented the dielectric taper section accordingly. Because properties of the accelerator section were studied in details previously [1-5], we will concentrate our efforts on coupler and dielectric taper designs. First, we will study the RF

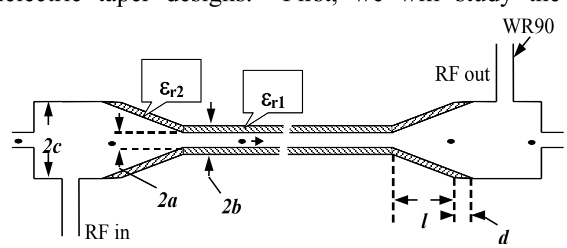

Figure 1: Illustration of the scheme dielectric accelerator, coupler and also the taper section

coupler and, then a tapered matching section is optimized accordingly for a given dielectric structure. For the coupling section, we have multiple choices: symmetric two ports structure and single port structure. By using symmetric two ports structures, one can eliminate field asymmetry in the coupler region and also minimize the beam break up (BBU) effects. By using the single side coupler structure, we can simplify the testing facilities and carry out the experiment easily. Both symmetric two ports structure and single side structure have been designed but only single side structure has been made and used in our tests.

In this paper, we did all the EM simulation by using Microwave Studio[9]. Both simulation results and test results are given and compared.

11.424G RF COUPLING SYSTEM DESIGN AND EM SIMULATIONS

In this section, we have considered designs for coupler and dielectric taper. Due to the availabilities of X-band high power RF sources at SLAC and Naval Research Laboratory, we concentrate our designs at 11.424 GHz center frequency so the modeled structure can be high power tested.

For the coupler, we have designed both symmetric two ports coupler and single side coupler, but only design of

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the single side coupler is presented here because of the space limit. As mentioned before, two ports design can eliminate field asymmetry in the coupler region and also minimize the beam break up (BBU) effects. But it is much more convenient to test a structure with only a single RF coupling port. Although it is difficult to implement single port design for practical high energy linear colliders, but this would satisfy our requirements on high power test of dielectric based accelerators because field asymmetry and wakefield induced instabilities are not concerns here. The scheme of single side coupler is given in figure 2. A set of parameters were found to give maximize the efficiency of mode conversion from rectangular TE10 to circular TM01 mode as illustrated in figure 2. By optimizing these parameters, we obtained the optimized coupling structure. The S parameters of the optimized single side structure are given in figure 3. As shown in figure 3, S21 is almost 0 dB in the region of 11.424GHz, which means that nearly 100% of energy from rectangular TE10 has been converted into circular TM01. Peak electrical fields around the corners

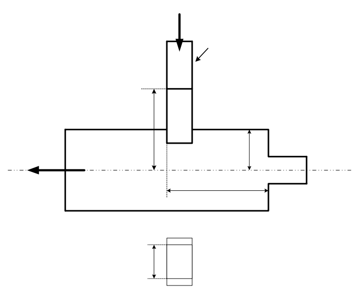

Figure 2: Scheme of the single side coupler

(blended at a radius of 2mm) of the coupling slot are to be less than 40 MV/m for 100 MW RF power, which is well below the copper surface breakdown threshold.

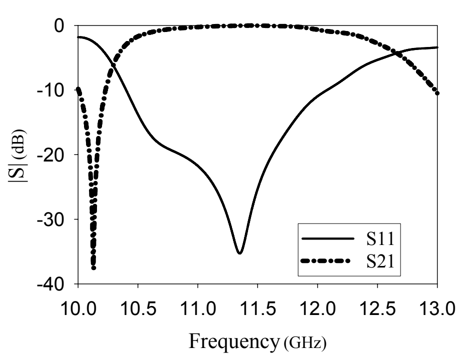

Figure 3: S parameters of optimized single side coupler, optimized for 11.424GHz

So far, we have only discussed the RF coupler that is dielectric material independent. Next we will consider a design of dielectric taper section, which will be determined by the dielectric constant of dielectric accelerating section. Purpose of the dielectric taper section is to match the wave impedance between the dielectric loaded circular waveguide (dielectric loaded accelerator section) and the regular circular waveguide where the RF coupling structure is implemented, thus achieve high transmissions. As shown in figure 1, the geometry of taper section is determined by its length l when the diameters of both dielectric loaded waveguide and the regular waveguide are predetermined. The dielectric constant of the taper can be somewhat different from the dielectric in accelerating section. The parameter d is determined by $d = \frac{b-a}{c-b} l$. The goal of taper section design is to find out a proper length l with acceptable S11, which is a measure of reflection coefficient. The real material we chose for our simulation and experiments are Alumina (εr=9.4) and MCT20 (εr=20). Figure 4 gives the S11 of a taper section for a dielectric accelerating structure with $\varepsilon r1$=9.4 where a=5mm, b=7.185mm and c=12.079mm. Theoretically, every minimum value point in the S11 vs l curve could be selected for our purpose, but a shorter l will results in a tighter tolerance on machine errors because the bandwidth is narrower for shorter l as shown in figure 4. In our final drawing, the length l is chosen to be 40mm with which the expected S11 would be -19dB for alumina material $\varepsilon r2$=9.4.

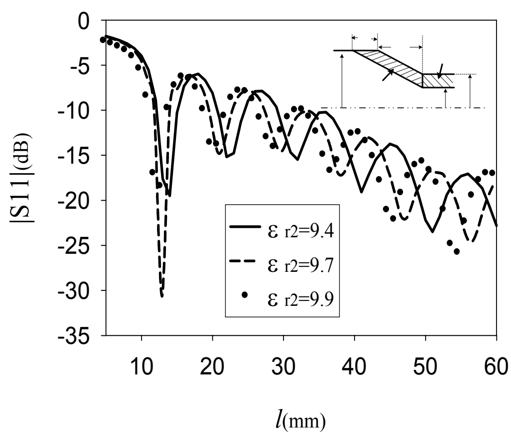

Figure 4: S11 vs l curves of alumina dielectric taper section

Next, we considered MCT 20. This is the same dielectric materials we used in the previous high power test [6]. For MCT20, the geometrical parameters for the dielectric loaded accelerator are determined as a=2.96mm, b=4.53mm. As the taper scheme for alumina does not work well in MCT20 based structure because of the much higher permittivity and much smaller dielectric accelerating tube, an alternative scheme is adopted for designing MCT20 taper section. As shown in figure 5, the alternative scheme has three independent parameters. Changing any one of these 3 parameters could change the properties of the taper section. In our final design for MCT20 taper section, t_1 is chosen to be 39mm and t_3 is chosen to be 5mm. By optimizing t_2 with Microwave studio for minimized S11 at 11.424GHz, t_2 is found out to be 17.8mm. Figure 5 also gives the S11 vs *frequency* for MCT20 taper section with parameters given above. Figure 5 shows that the S11 at the working frequency, 11.424GHz, of this MCT20 taper section is about -25dB and the bandwidth where S11 bellow -10dB is about 200MHz. This MCT20 taper section will be made and tested soon.

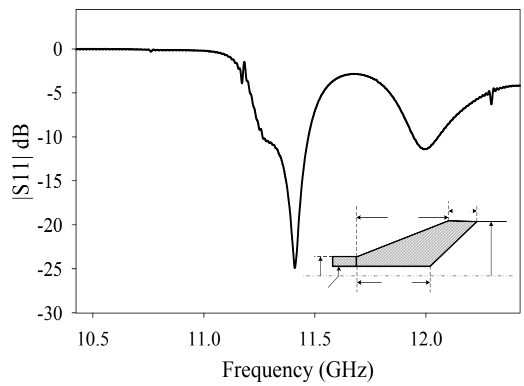

Figure 5: Scheme of the MCT20 taper and it's S11 of structure optimized for 11.424GHz

EXPERIMENTAL VERIFICATIONS

Based on the dimensions obtained from EM simulation via Microwave Studio, two single side couplers and tapered matching section have been made. A set of tests have been carried out using HP8510 network analyzer. Figure 6 is the coupler to coupler tests result comparing with its EM simulation result and shows good agreement between them. Machine errors have been guessed and included in the EM simulation. From figure 6, we could say that the design and implementation of the couplers is a success.

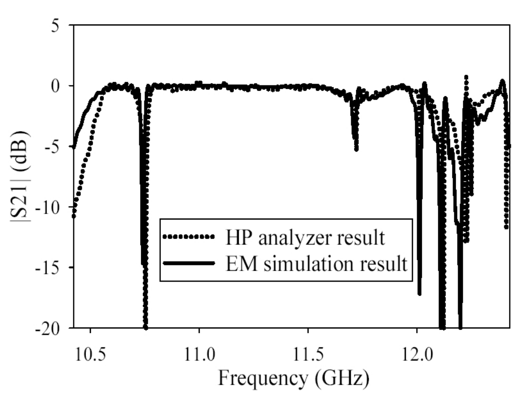

Figure 6: Comparing S21 of Coupler to coupler HP analyzer test result and EM simulation result

Besides the implementation of couplers, several pieces of alumina dielectric taper and a pair of copper jack are also made based on the simulation results given before. The permittivity of alumina used for the taper is 9.7 according to the catalog, which is different from the permittivity of the alumina dielectric accelerator tube, 9.4. By assemble them together with couplers and dielectric accelerating tube, a testing alumina dielectric loaded accelerator is made. The NRL high power test on this testing alumina dielectric loaded accelerator assured that this RF coupling system design has a very good high power capability[10].

SUMMARY

A new RF design for dielectric loaded accelerating structure has been implemented and tested. This new design separates the coupler from the dielectric loaded accelerating structure by a tapered transition section. This has successfully eliminated the arcing problems observed during previous high power tests of our old design. Both symmetric two ports and single port couplers have been investigated. We found that both type are capable of converting the rectangular TE10 mode into circular TM01 mode with efficiency above 99% over a relatively wide bandwidth. For the simplicity of the high power experiments setting at NRL, we used the single side coupler. A testing alumina structure has been made and tested at NRL, and has been proved to have the high power capability.

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