DESIGN OF 2×2 DLDS RF COMPONENTS FOR JLC

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Abstract

We have studied a multi-mode Delay Line Distribution System (DLDS)[1][2] as the RF power distribution system from klystrons to RF structures for linear colliders. In particular, a 2×2 DLDS has been proposed and studied at KEK for Japan Linear Collider(JLC). It has been proved that the 2×2 DLDS is simple, bus has good transmission efficiency. We have designed RF components of a basic unit of a DLDS using the High Frequency Structure Simulator (HFSS) code[3]. They include the TE_{01} extractor, the TE_{11} to TE_{01} converter, and the TE_{11} to TE_{12} converter for TE_{12} mode. HFSS calculation of the system, which consists of TE_{01} extractor and TE_{11} to TE_{01} converter, shows that the transmission efficiency of each mode is better than 95%. A low power test model for the mode stability experiment in 55m long wave guide in DLDS is also being developed. Further study is underway.

1 INTRODUCTION

The Delay Line Distribution System (DLDS) invented by KEK has been considered for the compression and distribution of the RF power from klystrons to accelerator structures in the proposed projects of linear colliders, such as the Japan Linear Collider (JLC)[4] and Next Linear Collider (NLC)[5]. In DLDS, the long pulse of combined klystron output is subdivided into a train of shorter pulses by proper phasing of the sources and each subpulse is delivered to accelerating structures at varying distances from the sources through a delay line distribution system. This system utilizes the delay of the electron beam in the accelerator structure of the linear collider to reduce the length of the waveguide assembly. A conceptual improvement is proposed by SLAC to further reduce the length of waveguide system by multiplexing several low-loss RF modes in a same waveguide. Thus, the subpulse in the distribution waveguide are carried by different waveguide modes so that they can be extracted at designated locations according to their mode patterns. Based on the SLAC multi-mode DLDS, a 2×2 DLDS[6] is proposed in KEK for JLC. The advantage of 2×2 DLDS is that it's simple and easy to be expended to accommodate combinations of more klystrons, and also it has good transmission efficiency.

In this paper, we present the design of the main RF components of a basic unit of 2×2 DLDS. Since the present schemes of multi-mode DLDS have similar feature to handle the over-moded waveguide system, the components may be of common design. The main components include the mode launcher, the TE_{01} extractor, and the TE_{11} to TE_{01} mode converter. The mode launcher converts the power from four rectangular waveguide feeds to separate modes i.e. TE_{01} and TE_{11} modes, in a multi-moded circular guide through coupling slots. The TE_{01} extractor extracts the TE_{01} mode in the circular waveguide but is transparent to other modes. For long distance transmission, the low loss TE_{12} mode is preferred, so a TE_{11} to TE_{12} mode converter is also presented. The High Frequency Structure Simulator (HFSS) code, which evaluates in frequency domain with 3D finite element method, is used to design the above components. A basic system of DLDS that consists of TE_{01} mode extractor and the $TE_{11}$to TE_{01} mode converter is also studied. The results show that the transmission efficiency in the system for both TE_{01} and TE_{11} modes are better than 95%.

2 TE_{01}-TE_{11} MUlTI-MODE LAUNCHER

For TE_{01}-TE_{11} multi-mode launcher, we adopt the same design as that proposed by Zenghai Li, et al[7]. The launcher has four rectangular input ports and one cylindrical output port. The input power is TE_{10} mode of rectangular waveguide, but the output power can be either TE_{01} or TE_{11} mode due to the phase coding of the input signals. Fig. 1 is the HFSS 1/4 geometry solid model.

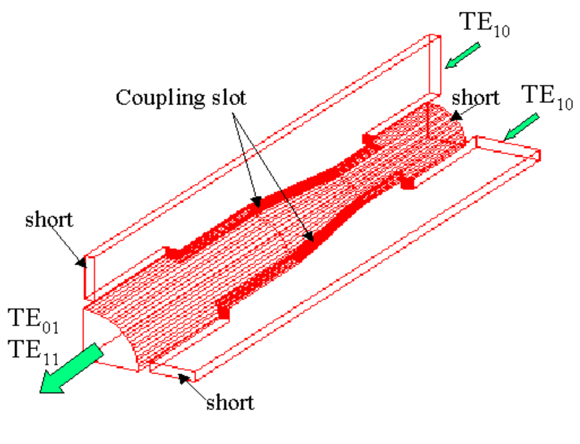

Figure 1: 1/4 geometry solid model of TE_{01}-TE_{11} mode launcher.

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The four rectangular waveguides run parallelly to the cylindrical waveguide and are spaced 90° apart azimuthally around it. Each of the rectangular waveguide is coupled to the cylindrical wavguide through a single coupling slot. The original design is modeled with MAFIA[8], so HFSS is used to check the performance of the same geometry as the MAFIA model. But the result got by HFSS is not so good as that predicted by MAFIA: though the power transmission efficiency from the rectangular waveguide to circular waveguide for TE_{01} mode in the can be 97.4%, the efficiency for TE_{11} mode is only about 90%. We think that the deviation may be caused by the different mesh method between MAFIA and HFSS. By perturbation study [9], we found that it's possible to improve the HFSS result either by increasing the length of the coupling slot on the circular waveguide for 0.35mm or adjusting both short positions in the rectangular and circular waveguide for 0.35mm from the original MAFIA geometry. Then the requirement for high efficiency and low surface field can be satisfied. Table 1 gives the comparison of the results. This confirms that the launcher design has the flexibility to improve the performance practically by adjusting the short position, and suggests that the prototype of the launcher should have the short position tunable. The test result of the prototype will come out soon.

Table 1: Comparison of the transmission efficiency of the mode launcher between MAFIA and HFSS results.

Mode	MAFIA	HFSS		
		Id. M	Sl+0.35	Sh+0.35
TE_{01}	98.5%	97.4%	99.5%	99%
TE_{11}	98.5%	90%	98%	98.7%

Id.M: The identical model as MAFIA
Sl+0.35: Slot length increases 0.35mm
Sh+0.35: Short position adjusts 0.35mm

The present launcher scheme consists of two parts: the TE_{21} extractor and the TE_{01}-TE_{11} launcher, so the MAFIA model of the TE_{21} extractor[7] is also checked with HFSS. The HFSS result coincides with the MAFIA simulation. The TE_{21} extractor extracts 97.2% of the TE_{21} mode power and is transparent to other modes, thus meets the requirement.

3 TE_{01} EXTRACTOR

The TE_{01} extractor design is based on the so called wrap-around converter[2]. When TE_{01} and TE_{11} modes pass through the extractor, the TE_{01} is extracted into another parallel waveguide, while the TE_{11} mode is not affected. The circular waveguide is tapered down to cutoff the TE_{01} mode while allowing the TE_{11} to go through, and the parallel one was shorted at one end to control the direction of TE_{01} mode transmission. Fig. 2 is the HFSS solid model. The rectangular waveguide is warpped around the circular waveguide as shown. There are 6 coupling holes spaced 60° apart in the azimuthal direction around the circular wave guide. The size of the coupling hole is the same as the cross section of the rectangular waveguide. The distance between the center of every two holes is near the wavelength of the TE_{10} mode in the rectangular waveguide, so that the azimuthal resonant coupling between the two waveguides can be achieved. Thus the TE_{01} mode in the circular waveguide can be extracted efficiently into the wrap-around rectangular waveguide. Due to reciprocity, the extracted power in the rectangular waveguide can be converted back to TE_{01} mode in the parallel circular waveguide. The symmetry of the structure prevents the TE_{11} mode in the circular waveguide being affected.

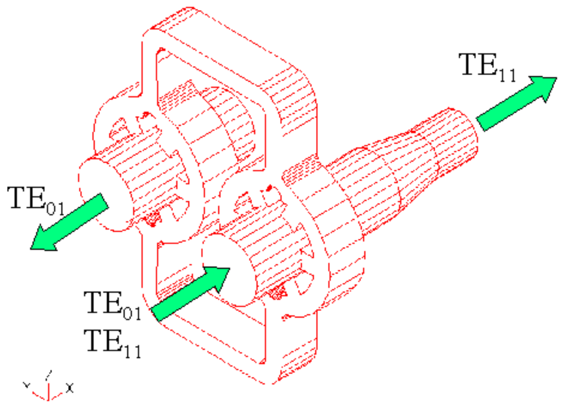
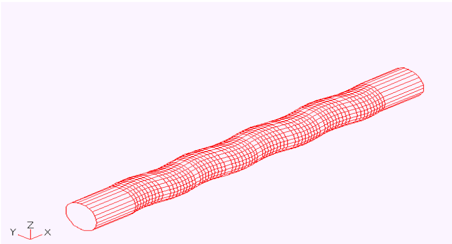


Figure 2: Solid model of TE_{01} extractor.

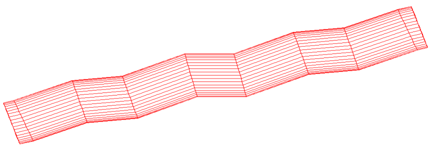
The performance of the extractor is mainly decided by the following geometrical parameters: the distance between the coupling holes in the rectangular waveguide, i.e. the bending radius of the wrap-around rectangular waveguide, the distance beteween the coupling holes on the wall of circular waveguide, i.e. the radius of the circular waveguide, as well as the radius of the round nose at the bifurcation of the rectangular waveguide. The above parameters are optimized with HFSS, and the present geometrical dimensions of the extractor are: the radius of circular waveguide 18.034mm, the tapered down one 12.7mm, the bending radius of rectangular waveguide 26.416mm, and the radius of the nose 4.572mm. The rectangular waveguide is the 22.86mm×10.16mm one. The present results show that about 99.4% of the power of TE_{01} mode can be extracted, 97.2% of TE_{11} mode goes through without perturbation, while 2.3% converted to TM_{01} mode. The peak electric surface field at 600MW is around 80MV/m, which locates in the bifurcation area in the rectangular waveguide. Improvement of the design aiming to decrease the peak electric field at high power, and increase the transparency to TE_{11} mode is underway. In stead of using the cutoff section to extract TE_{01} mode, the option to cascade two extractor together so as to handle much higher power is being studied, too.

4 TE_{11} TO TE_{01} AND TE_{11} TO TE_{12} CONVERTER

In DLDS, the TE_{11} mode has to be converted back to TE_{01} mode so that it can be extracted efficiently. The "Serpentine" style structure is adopted[10]. The radius of the circular waveguide keeps constant, but the axis of the propagation is deformed as a sinusoidal wave shown in Fig. 3(a). The diameter of the waveguide is 20mm, the amplitude of the sinusoidal deformation is 2.33m, and the one periodical length is 80.4mm. The conversion efficiency can be better than 99.5% when four periods cascaded together. Here, We reproduced the SLAC design[11]. An novel idea has been proposed which can simplify the manufacture, that to cut the waveguide slantingly and then weld them in a right way, as shown in Fig. 3(b). With the slant angle chosen properly, the TE_{11} to TE_{01} conversion efficiency can be better than 99%. That can be a hopeful candidate in 2×2 DLDS scheme. A primary design has been confirmed by HFSS. Efforts are still continuing for further improvement in the performance.



(a)



(b)

Figure 3: Solid model of TE_{11} to TE_{01} mode converters.

In order to reduce the resistive loss in long distance transmission, theTE_{11} mode are converted to the low loss TE_{12} mode in the circular waveguide. So TE_{11} to TE_{12} converter is needed. The structure with rippled diameters[12] has adopted. The radius of the waveguide varies longitudinally as sinusoidal wave. To avoid the conversion between TE_{01} and TE_{02}, the diameter of the waveguide is chosen to vary from 50.2mm to 57.8mm. Nine wave periods are needed. The design procedure is as follows: the S-matrix of one period is calculated by HFSS, then the S-matrix of the nine periods structure is got by cascading the S-matrix of single period given by HFSS. Optimization is done on the length for one period. We found that when the length of one period is 64mm, the converter has the highest efficiency. Then, the whole structure is modeled with HFSS, it's confirmed that more than 99.6% of the power of TE_{11} mode will be converted to TE_{12} mode after it goes through the converter. Fig 4. is the HFSS solid model. In HFSS calculation, only 1/4 solid model is needed due to symmetry.

The diameters of waveguides in the above components differ from each other, so tapers are needed to connect them. Tapers are also designed by HFSS. Since the variation of diameter is not very large, the simple linear transition of waveguide diameter is feasible to achieve transmission efficiency better than 99.5%.

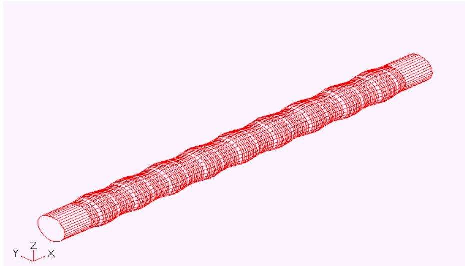


Figure 4: Solid model of the TE_{11} to TE_{12} converter.

5 TEST UNIT OF 2×2 DLDS

To verify the principle of multi-mode 2×2 DLDS, a test unit is proposed and studied. This unit includes the mode launcher, the TE_{01} extractor and the TE_{11} to TE_{01} converter. Fig. 5 is the schematic layout of the unit.

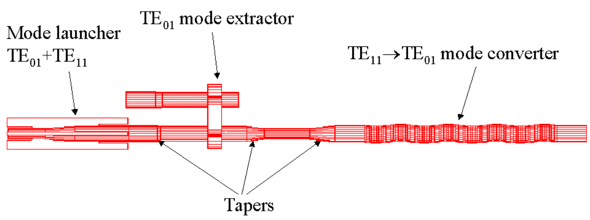


Figure 5: Schematic layout of 2×2 DLDS unit.

Due to the computer memory limit, we only simulate the performance of the system consisting of the TE_{01} extractor, the TE_{11} to TE_{01} converter, as well as the tapers between them. Fig. 6 showes the electric filed pattern propagating in the system.

(a) TE_{01} mode input from left.

(b) TE_{11} mode input from left.

Figure 6: Electrical field patterns in the test unit.

The power of TE_{01} mode is extracted to a parallel waveguide with efficiency better than 96% as shown in Fig. 6(a), while the power of TE_{01} mode goes through the extractor directly and then is converted to again to TE_{01} as shown in Fig. 6(b). The transmission efficiency is better than 95%. With the wall loss taken into account, it's expected that the transmission efficiency in DLDS can be better than 90%. All the above components are being manufactured. The low power test will be done soon. Then the performance of each component, as well as the whole system will be measured.

An absorber is needed at the end of the test unit to absorb the residue power. It's also designed with HFSS. The 1/2 solid model is shown in Fig. 7. A recycled product of SiC is put concentrically in a 20mm circular waveguide. HFSS results show that 99% of incoming power of both TE_{01} and TE_{11} modes can be absorbed. To check its sensitivity of performance to the assembly errors, a 1mm displacement of the SiC from the axis of the waveguide is assumed and then simulated, the efficiency of absorption is still higher than 99%.

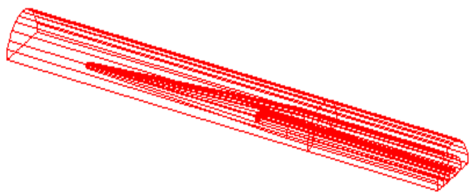


Figure 7: 1/2 solid model of absorber.

The experiment to test the stability of TE_{12} mode transferring for long distance and its sensitivity to all kinds of error is being planed. The main purpose is to measure the purity of TE_{12} mode in a 55m long, diameter equal to 4.75 inches waveguide. The experiment needs an TE_{11} launcher and the TE_{11}-TE_{12} converter. TE_{11} mode in circular waveguide can be converted from TE_{10} mode in rectangular waveguide, the converter, whose main part is the smooth taper from the 22.86×10.16mm rectangular waveguide to the 50.2mm circular waveguide, is designed by HFSS. Fig. 8 is the 1/2 solid model of the launcher. The conersion efficiency is better than 99.2%. The experiment will be done in KEK in near future.

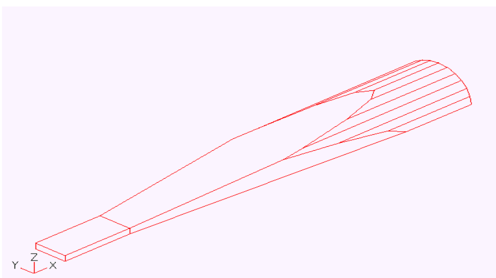


Figure 8: 1/2 solid model of TE_{11} launcher.

6 CONCLUSION

The main components have been designed using HFSS code. According to HFSS result, the power transmission efficiency in the components can at least meet the requirement of DLDS at low power, so the DLDS principle works. A low power test facility will be setup in KEK, and the components will be manufactured according to the HFSS design. The performance of the components as well as the principle of the DLDS will be test experimentally in near future. Meantime, the experiment to study the mode stability after long distance microwave transmission in DLDS is being developed. Improvement on the design of components of DLDS for high power test, or practical use is continuing.

7 ACKNOWLEGEMENT

The author would like to thank Dr. S.G. Tantawi, Dr. Zenghai Li for their kind help.

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