Mode Launcher Design for the Multi-moded DLDS *

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Abstract

The DLDS (Delay Line Distribution System) power delivery system proposed by KEK combines several klystrons to obtain the high peak power required to drive a TeV scale linear collider. In this system the combined klystron output is subdivided into shorter pulses by proper phasing of the sources, and each subpulse is delivered to various accelerator sections via separate waveguides. A cost-saving improvement suggested by SLAC is to use a single multi-moded waveguide to deliver the power of all the subpulses. This scheme requires a mode launcher that can deliver each subpulse by way of a different waveguide mode through selective phasing of the sources when combining their power. We present a compact design for such a mode launcher that converts the power from four rectangular waveguide feeds to separate modes in a multi-moded circular guide through coupling slots. Such a design has been simulated and found to satisfy the requirements for high efficiency and low surface fields.

1 INTRODUCTION

The multi-mode delay line distribution system (DLDS)[1], as proposed by SLAC for the ILC[2, 3], is a power combining and distribution system that combines four or eight klystron outputs to obtain a high power rf to drive the TeV scale linear collider. The combined long pulse is divided into a train of short pulses which are distributed to different parts of the linac by using a single multi-moded cylindrical waveguide. The subpulses in the distribution waveguide are carried by different waveguide modes so that they can be extracted at designated locations according to their mode patterns. These modes are generated by a multi-mode launcher as the klystron powers are being combined. In the current multi-mode DLDS scenario, the launcher takes four rectangular waveguide inputs (in the eight klystron case, klystrons are paired to form four inputs). With four inputs, there are a total of four orthogonal modes that can be generated in the distribution waveguide: "TE_{01}"(++++), "TE_{11}^a"(+–+), "TE_{11}^b"(++–) and "TE_{21}"(+-+-), where "+/-" represents the phase relation. One of the four modes is fed into the local accelerator structures (local mode) and the rest are delivered to other remote accelerator structures (remote mode).

The launching scheme we are proposing in the present paper consists of two parts: a TE_{21} extractor and a TE_{11}-TE_{01} launcher. The TE_{21} extractor extracts the local TE_{21} mode prior to the launching of the remote modes into the distribution waveguide. With the TE_{21} extracted beforehand, the multi-mode launcher now only needs to launch the $TE_{11}^{a,b}$ and TE_{01} modes. The TE_{21} extractor has to be transparent to the modes with the TE_{11} and TE_{01} phase configurations which can then bypass the TE_{21} extractor and be launched by the TE_{11}-TE_{01} mode launcher into the cylindrical waveguide upstream. A schematic drawing of such a launching system is shown in Fig.1. The TE_{21} local mode extractor and the TE_{11}-TE_{01} launcher in this launcher system are separate components that can be designed and tested separately.

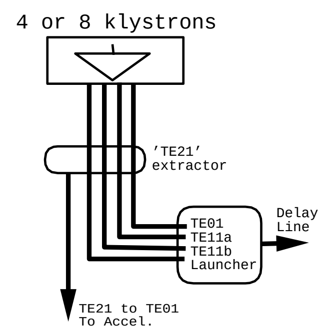

Figure 1: A multi-mode launcher system.

Both the TE_{21} extractor and the TE_{11}-TE_{01} launcher have been designed and simulated, and found to satisfy the requirements for high efficiency and low surface fields. The TE_{21} extractor will not be described here and detailed studies of the design can be found in Ref.[4]. The design of the TE_{11}-TE_{01} launcher has been pursued in various approaches [5]. This paper will present a compact design that is based on a simple longitudinal coupling slot(s) in a tapered-waveguide configuration.

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

The proposed TE_{01}-TE_{11} launcher design has four rectangular input ports and one cylindrical output port. The four rectangular waveguides run parallel to the cylindrical waveguide and are spaced 90^0 apart in the azimuthal direction around it. Fig. 2 shows the solid model and cut plane view of the launcher geometry. The cylindrical waveguide starts out with a 1 inch diameter to cut off the TE_{01} mode but not the TE_{11} modes. It then tapers up to about 1.5 inches as the surrounding rectangular guides taper down, while keeping the distance of the outer wall of the rectangular guides from the axis to be constant. Each of the rectangular waveguides is coupled to the cylindrical waveguide through a single coupling slot, which extends from the 1 inch diameter section through the taper and into the

* This work was supported by the U.S. Department of Energy, under contract No. DE-AC03-76SF00515.

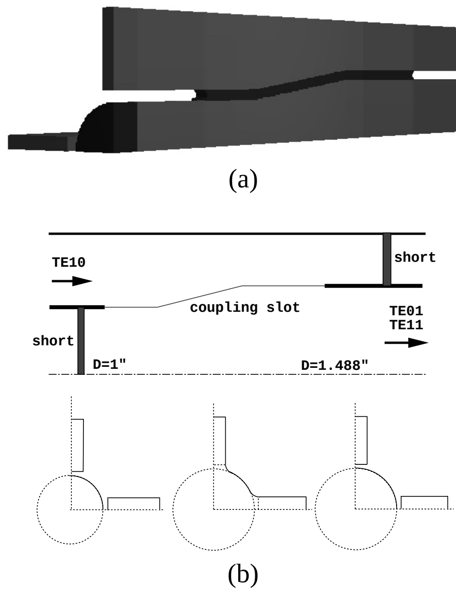

Figure 2: TE_{01}-TE_{11} multi-mode launcher. (a) 1/4 geometry solid model; (b) $r-z$ cut plane and cross sections along the z axis.

1.5 inch diameter section. The slot width is the same as the full width of the rectangular waveguide to avoid localized slot modes.

The design of the launcher is an optimization problem that has to fulfill two mode launching requirements under a surface field constraint. The device has to be able to launch the TE_{01} and the TE_{11} modes with high efficiency and, in addition, to have reasonably low surface fields in either field configuration so that field breakdown at high-power operation will be be an issue.

3 PARAMETER OPTIMIZATION USING S-MATRIX CASCADING

The present mode launcher has its transverse dimensions predetermined as indicated in Fig. 1. Then there are five dimensions left in the axial direction to allow both the TE_{11} and TE_{01} mode impedance to be matched to the four rectangular waveguide inputs. These five parameters are: the short positions in the cylindrical and rectangular waveguides; the length of the slots in the 1 inch diameter section; the length of the slots in the 1.5 inch diameter section; and the length of the taper. The search space for an optimum to these parameters is large and it would be impractical to evaluate the performance of every combination of parameters by full 3D MAFIA [6] simulation of the entire device.

A much more effective way is to divide the geometry into five axial segments each of which contains only one of the five parameters described above. The solution procedure is to find the transmission properties (S matrices) of each segment separately and then to obtain the transmission of the aggregate system by cascading all the S matrices as follows

$$S_{full} = S_1(p1) \otimes S_2(p2) \otimes S_3(p3) \otimes S_4(p4) \otimes S_5(p5) \quad (1)$$

where S_i represents the S matrix of the ith segment.

The $S_1(p1)$ and $S_5(p5)$ are the S matrices of the segments at the two ends of the launcher, which contain smooth waveguides and electric shorts in smooth waveguides. They can be determined analytically once the positions are given. The $S_2(p2)$ is the S matrix of the segment that contains the rectangular guides and the 1 inch cylindrical guide as input ports, and the combined geometry of the 1 inch cylindrical guide and rectangular guides with the coupling slot as one output port. The $S_4(p4)$ is the segment that contains the combined geometry of 1.5 inch cylindrical guide and rectangular guides with the coupling slot as one input port, and the separated rectangular and 1.5 inch cylindrical guides as output ports. The $S_3(p3)$ is the S matrix of the taper that connects the output port of S_2 and the input port of S_4. The S_2, S_3 and S_4 segments are three-dimensional, 3D MAFIA simulations are required to obtain their initial S matrices. The new S matrices of segments S_2 and S_4 with new slot lengths in the 1 inch and 1.5 inch regions can be obtained by adding phase shifting to the MAFIA data S_0

$$S_{new} = [e^{-j\beta_i \times \Delta p}] S_0 [e^{-j\beta_i \times \Delta p}]^T \quad (2)$$

where $[e^{-j\beta_i \times \Delta p}]$ is a $1 \times N$ matrix with N being the number of waveguide modes, β_i the propagating constants, and Δp the length adjustment. For the taper segment, MAFIA simulation is needed to obtain the new S matrix once the taper length is adjusted.

The S matrices of the segments were calculated on a 1/4 launcher geometry with two symmetry conditions for the TE_{11} and TE_{01} modes. A S matrix cascading program has been written to assemble the S matrices of the segments to find the transmission of the whole device. Once a set of optimal parameters is reached to satisfy matching (good transmission) for both modes, one carries out a MAFIA calculation on the full geometry to verify the cascading results. The MAFIA simulations are done in the time domain so that broad-band results are found in the same run. And furthermore, it provides information on the surface fields to ensure that the design is viable at the power level being considered for the DLDS operation.

4 SIMULATION RESULTS

The symmetry condition that corresponds to the TE_{11} mode generation requires mode excitation in one of the input rectangular guides and supports three modes in the output cylindrical guide. The S matrix that describes the launcher is

$$\begin{pmatrix} b_{rec-1} \\ b_{cyl-1} \\ b_{cyl-2} \\ b_{cyl-3} \end{pmatrix} = \left(S_{4\times4,TE11} \right) \begin{pmatrix} a_{rec-1} \\ a_{cyl-1} \\ a_{cyl-2} \\ a_{cyl-3} \end{pmatrix} \qquad \mathrm{TE}_{11} \quad (3)$$

where the first cylindrical mode is the desired TE_{11} mode. The power transmission efficiency to the TE_{11} mode is then determined by the matrix element relating b_{cyl-1} to a_{rec-1} and is given by $|S_{21,TE_{11}}|^2$.

With the other symmetry condition that leads to the TE_{01} mode launching, both input guides are excited and there are two propagating modes in the output cylindrical guide. In this case, the S matrix is

$$\begin{pmatrix} b_{rec-1} \\ b_{rec-2} \\ b_{cyl-1} \\ b_{cyl-2} \end{pmatrix} = \left(S_{4\times4,TE01} \right) \begin{pmatrix} a_{rec-1} \\ a_{rec-2} \\ a_{cyl-1} \\ a_{cyl-2} \end{pmatrix} \qquad \mathrm{TE}_{01} \quad (4)$$

where the second cylindrical mode is the TE_{01} mode. The relevant matrix elements here involve a_{rec-1}, a_{rec-2} and b_{cyl-2} so that the TE_{01} power transmission efficiency is given by $|S_{41,TE_{01}} - S_{42,TE_{01}}|^2$. The S matrix cascading results of the launcher efficiencies for both the TE_{11} and TE_{01} modes are shown in Fig. 3 as functions of the slot lengths and short locations for a taper length of 5 cm. The results in each plot were obtained by holding the remaining parameters fixed at their optimal values. The optimal set of parameters for the launcher at this taper length (5 cm) was found, after examining all the displayed data for both TE_{11} and TE_{01} modes, to be: $L_{slot(D=1'')} = 23$mm, $L_{slot(D=1.5'')} = 42$mm, $L_{leftshort} = 8$mm, $L_{rightshort} = 8$mm. At these values, the power conversion efficiency for either mode is over 98.5%. The performance of the launcher was studied at other taper lengths but the 5 cm length provides the best results.

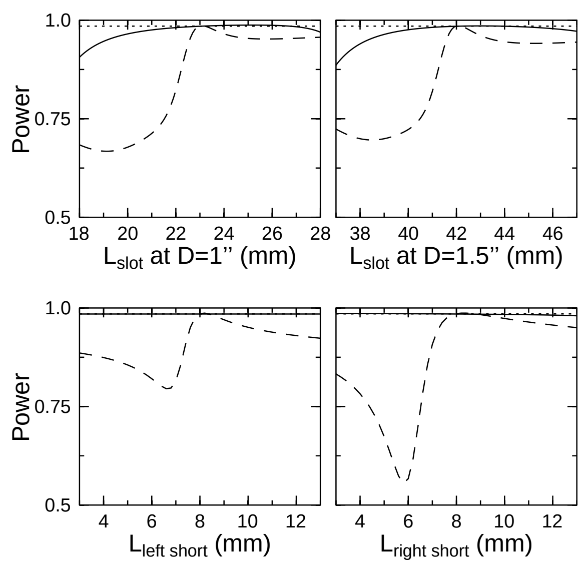

Figure 3: Launcher efficiencies as functions of launcher parameters. Solid: TE_{01}; Dashed: TE_{11}; Dotted: 98.5% efficiency line.

Using the optimal parameters determined above, the full launcher was modeled with MAFIA in the time domain. An input pulse with a realistic rise time of 10 ns was simulated. Fig. 4 shows the transmission for the TE_{01} and TE_{11} modes from the simulation and the efficiencies are similar to the values obtained by S matrix cascading (over 98.5%). The small reflections for both modes were found to be about the same in amplitude(10%) and phase so in practice these can be matched out, at the input ports for example, to further improve the efficiencies.

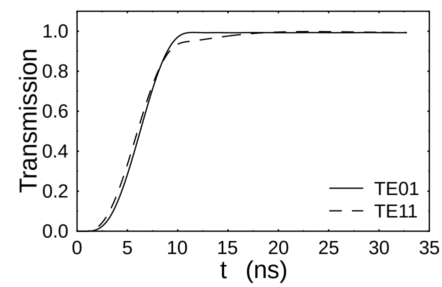

Figure 4: Transmission of TE_{01} and TE_{11} modes. Power conversion for both modes is over 98.5%.

The output pulse shows no distortion in either TE_{11} or TE_{01} operation, thus indicating that the device has adequate bandwidth to transmit pulses with realistic rise times. Scaling the simulated results to 600 MW input power level, the maximum peak surface field for the TE_{01} mode is 68 MV/m and is 54 MV/m for the TE_{11} mode. These are upper-bound values because of the step-stepping in the mesh while the values on the smoothly rounded surface will actually quite a bit lower. Finally, the copper loss was estimated to be about 0.15% and 0.27% for TE_{11} and TE_{01} respectively.

5 SUMMARY

A promising launcher design for the multi-moded DLDS has been presented and shown to meet required standards of efficiency and power handling capability. The optimization of this multi-parameter device was greatly accelerated by an efficient approach that uses S matrix cascading instead of full scale simulation. A prototype of this design will soon be tested while efforts are continuing for further improvement in performance.

6 REFERENCES

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