A FOUR-PORT LAUNCHER FOR A MULTI-MODED DLDS POWER DISTRIBUTION SYSTEM*

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Abstract

We describe a structure for launching the TE_{01} and both polarizations of TE_{12} modes into a highly overmoded low loss circular waveguide providing remote transmission for a multi-moded Delay Line Distribution System (DLDS) [1]. The power from four sources is delivered to four structure ports by rectangular waveguide, and the mode for each pulse subsection is selected by varying the relative phases of the sources. The four ports symmetrically feed a section of waveguide with a fourfold symmetric four-leaf clover-like (or quatrefoil) cross section, dimensioned so as to propagate only four TE modes, characterized as 0, $\pi/2$ (two polarizations), and π modes. The 0 and $\pi/2$ modes are well matched, the π mode only moderately so. A low loss taper transforms the initial cross section to a circular cross section; the 0 mode transforming to TE_{01}, the $\pi/2$ to TE_{11}, the π to TE_{21}, all with negligible mode conversion. A "sausage" type mode transducer then converts TE_{11} to TE_{12} (a lower loss mode), and the diameter is then expanded to the full ~five inch diameter of the delay line. A separate structure to divert power from the last pulse subsection to the local group of accelerator structures is required.

I. INTRODUCTION

The Delay Line Distibution System (DLDS) [2] achieves a high acceleration gradient by combining the power of a number of rf sources for delivery to accelerating structures. It matches the long pulse of the rf sources to the shorter drive time of the accelerating structures by dividing the source pulses into a number of subpulses of duration equal to the structure drive time. The subpulses are phase coded in a manner which allows them to be delivered to accelerating structures at varying distances from the sources through a delay line distribution system designed to deliver the subpulses to the remote

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structures in a timely manner relative to the time of arrival of the particle bunches. In the original version of DLDS a network of 3dB hybrids combines the power of the sources in such a manner that the combined power from different subpulses, directed by the phase coding, emerges from different ports of the network. These are then connected via low loss waveguides to groups of structures at appropriate distances, the first subpulse to the most remote group, the last to a local group. A separate waveguide is used to transport the power from each of the subpulses. The multi-moded DLDS modifies this scheme by transporting the power to the remote structure groups in a single waveguide, utilizing a different mode for each of the remote structure groups. The power is combined in a mode launcher, which replaces the 3dB hybrid network, and makes use of phase coding to associate different modes with each subpulse. In the following we present a design in progress of a particular realization of such a launcher. An alternative design is given in [3].

The launcher discussed here is designed for a four source system with the source pulses divided into four equal subpulses. The relative phase of the sources changes from subpulse to subpulse. The output of the four sources is first transported by four waveguides which pass through an extractor for the local group of accelerator structures. By virtue of the phase coding this extractor is transparent to the rf delivered in the first three subpulses and extracts all of the rf delivered in the last subpulse. Such an extractor is described in [3]. The four waveguides then proceed to the four input ports of the launcher. The launcher itself has two distinct sections: an input section consisting of a waveguide of quatrefoil cross section with four input ports and a tapered section which adiabatically transforms the quatrefoil cross section to a circular one. The three modes which emerge from the circular cross section are the TE_{01} and two orthogonal polarizations of TE_{11}. In order to reduce resistive loss in transmission to the remote structures, the TE_{11} modes are converted to TE_{12}. A section of circular waveguide with undulating diameter, designed by Calabazas Creek Research, Inc., may be used to accomplish the conversion. Subsequently the diameter of the waveguide is tapered up to the 12.7 cm diameter which, to reduce resistive losses, has been selected for remote transmission.

II. THE QUATREFOIL WAVEGUIDE

Two requirements underlie the design of the launcher: mode purity for each of the subpulses and avoidance of excessive electric field. This is facilitated by choosing a structure with fourfold rotational symmetry and with two orthogonal planes of reflection symmetry, and then making use of rounded contours. The cross section of one fourth of the quatrefoil waveguide is shown in Figure 1. The maximum diameter is 3.81 cm, the minimum, 2.74 cm. The modes of a structure with fourfold symmetry may be characterised by the section to section variation of the field phase. The four possibilities may be indicated by the amplitude sequences (1 1 1 1), (1 i -1 -i), (1 -i 1 i), and (1 -1 1 -1) corresponding to 0 modes, degenerate pairs of $\pi/2$ modes, and π modes. We can guarantee mode purity by designing the structure so that there is only one propagating mode of each type. For the quatrefoil waveguide the cutoff frequencies (GHz, MAFIA simulations) of the propagating TE modes are 10.11 for the 0 mode, 4.889 for the $\pi/2$ modes, and 6.615 for the π mode. The cutoff frequencies of the second TE $\pi/2$ mode pair and the TM $\pi/2$ pair are 11.55 and 11.63 respectively. The other potential competitors have cutoff frequencies far above the 11.424 operating frequency. There is, in addition, a propagating TM 0 mode, but its coupling to the only propagating mode of the waveguides connected to the ports is forbidden by reflection symmetry. Any one of the four propagating TE modes may be selected by selecting the relative phase of the sources, and as long as the sources have equal strength, mode purity is guaranteed.
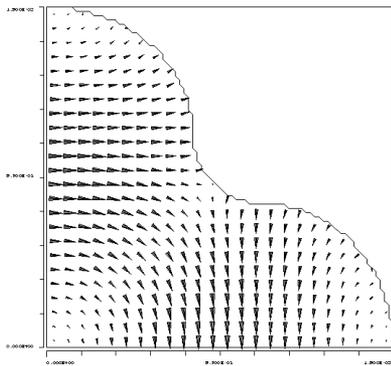
Figure 1. One fourth the quatrefoil waveguide cross section, shown with the electric field of the 0 mode (MAFIA simulation).

The peak surface field for 600 MW in the 0 and $\pi/2$ modes is 37 MV/m, equivalent to 173 MW in WR90. The peak fields are higher for the π mode, but it is not used for power transmission.

III. TAPERING FROM QUATREFOIL TO CIRCULAR WAVEGUIDE

In order to minimize mode conversion and reflection losses, the tapering is carried out adiabatically and in such a manner that the property of having only a single propagating TE mode of each symmetry type is preserved. The principal danger arises from the second $\pi/2$ mode pair. If it is allowed to propagate before the cross section becomes circular, there is a danger of TE_{31} contamination of the TE_{11}. Tapering also couples TE modes to TM modes, so that there is a potential for TM_{11} contamination of the TE_{11}. Unfortunately as the guide becomes circular the TE 0 mode and the TM $\pi/2$ pair cutoffs approach one another, corresponding to the well known degeneracy of the TM_{11} and TE_{01} modes of circular waveguide. Since the TE 0 mode must be propagating throughout the taper, some region in which the TM_{11} also propagates is inevitable.

An example of a MAFIA simulated taper is shown in Figure 2. In order to be able to keep the cutoff of the second $\pi/2$ pair above 11.424, the transition to circular is completed at a diameter of 3.46 cm. Thus the outer diameter of the quatrefoil is tapered down while the inner diameter is tapered up. The taper section of Figure 2 is 16 cm long, has negligible reflection loss, mean resistive loss of 0.19%, and mean mode conversion loss (to TM_{11}) of 0.011%. It is clear that the overall loss figures can be improved by more careful taper design and by reducing the length. In an optimum design, resistive losses should be comparable to other losses rather than dominant. Note that we specify mean losses (i.e. averaged over the three modes) for simplicity. This is appropriate both because the losses are small and because each particle bunch is accelerated by all of the structure groups. Thus the acceleration of each bunch is the result of the accelerating gradient averaged over all of the launcher modes.

IV. LAUNCHING INTO THE QUATREFOIL WAVEGUIDE

The launcher has four WR90 rectangular waveguide ports, aligned so that rf is delivered by waveguides approaching the quatrefoil section perpendicular to the axis of the quatrefoil waveguide, oriented so that the long side of the rectangular cross section is parallel to that axis as shown in Figure 3. As discussed above, mode selection is made by means of the relative phase of the TE_{10} modes in each of the drive waveguides, and mode purity will be preserved by the launcher so long as the basic symmetries are
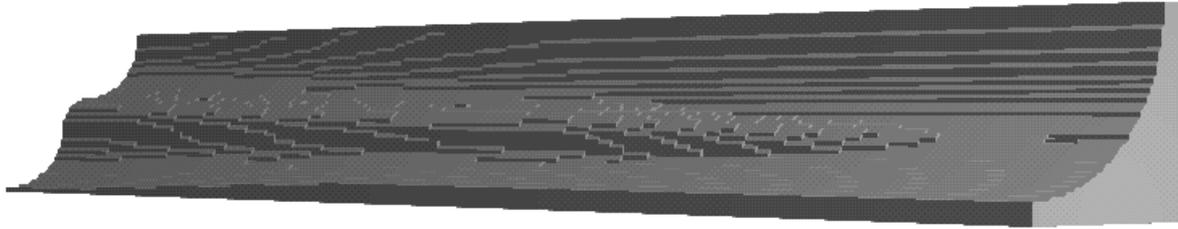
Figure 2. One fourth the quatrefoil to circular taper, shown in perspective (MAFIA simulation).

maintained. The basic design problem is to minimize reflection loss for both the 0 and $\pi/2$ modes. A number of different approaches were explored. The most successful were found to be those conceptually based upon 90° H-plane circular bends. Fitting such bends into the geometry of the quatrefoil obviously involves some modification of the bend geometry. The most successful example obtained so far is that shown in Figure 3. Mean reflection loss is minimized by first minimizing the difference between the complex reflection coefficients of the two modes for the geometry shown. A matching element such as a post or an iris designed to minimize the mean power loss to reflection of the input waves can be inserted at an appropriate position in the WR90 sections of the Figure 3 launcher. For the design shown we find $S_{11}^{(0)}$ = (0.2380, @75.34°) and $S_{11}^{(\pi/2)}$ = (0.3544, @63.87°). After insertion of the corrector, $|S_{11}^{(0)}|$ = 0.0866 and $|S_{11}^{(\pi/2)}|$ = 0.0434, and the mean loss is 0.375%. This large reduction of the loss is possible only because the difference between the not insignificant individual reflection coefficients is fairly small. The length along the axis of the Figure 3 structure is 7.00 cm, 4.75 cm for the bend section and 2.25 cm for the quatrefoil section. The wall losses are approximately 0.07%.

V. CONCLUDING REMARKS

The remaining parts needed for the launcher are a taper to the TE_{11} to TE_{12} mode transducer, the transducer itself, and a taper from the transducer to the large diameter waveguide that will be used for transmission over the longer distances.

A preliminary design by Calabazas Creek Research, Inc. of the mode transducer has the following characteristics. It consists of a circular wave guide with rippled diameter varying from 5.02 cm to 5.78 cm, remaining below the cutoff of TE_{02} to avoid TE_{01} conversion. There are nine ripples and the overall length is 58.5 cm. The residual TE_{11} amplitude, conversion to TM_{11}, and

reflection into all three modes represent a loss of a few tenths of a percent. Wall losses are estimated to also be about 0.3%. The perturbations are essentially transparent to the TE_{01} mode.

This particular transducer requires two diameter tapers, one from 3.46 cm to 5.02 cm and one from 5.02 cm to 12.7 cm. These would be designed after the dimensions of the other elements are more definite. We emphasize that the design described here is highly preliminary and subject to further optimization.
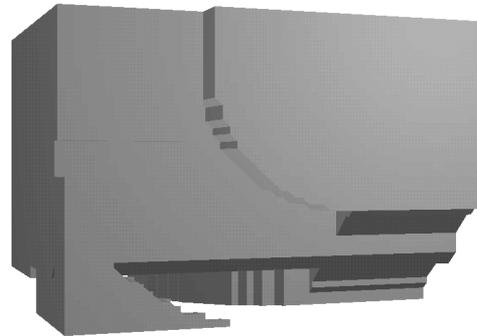
Figure 3. One fourth the launcher shown in perspective (MAFIA simulation).

VI. REFERENCES

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[3] K. Ko, Z. Li, and S. Tantawi, "Mode Launcher Design for the Multi-Moded DLDS," this conference.