MULTIMODED COMPACT DELAY LINES FOR APPLICATIONS IN HIGH POWER RF PULSE COMPRESSION SYSTEMS

Sami G. Tantawi*, SLAC, Menlo Park, CA 94025, USA

Abstract

Pulse compression systems for future linear colliders, such as NLC and JLC, involve hundreds of kilometers of waveguide runs. These waveguides are highly overmoded to reduce the rf losses. Reducing the length of these waveguide by loading them with irises increase the losses of the system. Also, loading makes the waveguide depressive, and rf pulse shapes get distorted. In this paper we present a novel idea for utilizing the waveguides several times by using different modes. All the modes being used have low-loss characteristics. We describe mechanically simple mode transducers that switch the propagation mode from one configuration to another with no observable dispersion. We compare our theoretical designs with experimental data.

1 INTRODUCTION

RF pulse compression for future X-band linear colliders [1] contains very long runs of over moded waveguides. A typical system might contain a few 100 km of vacuum circular waveguide. To reduce these runs multimoded RF structures and transmission lines have been suggested [2]. In these multimoded systems, the transmission lines are used to transmit the rf power in several modes; Hence utilizing the transmission line several times.

Here we suggest a variation on that scheme which is suitable for reflective delay lines. These are used in systems such as the SLED-II pulse compression system [3,4]. The scheme suggested here can reduce the required delay line by factors of more than 4 if one uses more than 4 modes simultaneously. . We present the design for two modes and show an experimental data for that scheme. We also show the design for 4 modes, which indicates the potential for higher number of modes

2 MULTIMODED REFLECTIVE DELAY LINES

Consider the delay line shown in Figure 1.

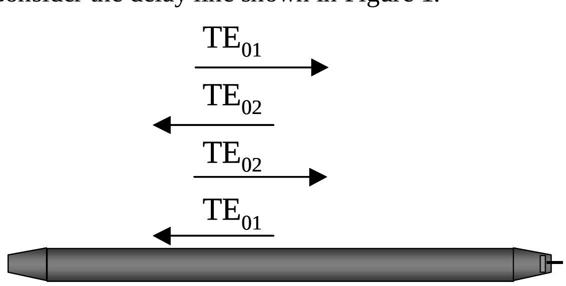


Figure 1: Dual-Moded Delay Line

*Also with the communications and electronics department, Cairo University, Giza, Egypt.

The rf signal is injected from the left into the delay line waveguide in the TE_{01} mode. This is the only azimuthally symmetric TE mode supported at the input port. The waveguide is then tapered up to a diameter that supports several TE_{0n} modes. The TE_{01} mode travels all the way to the end of the delay line and then gets reflected and converted into the TE_{02} mode. The TE_{02} mode travels back to the beginning of this line and, since the input of the line cuts off this mode, it gets reflected. If the input taper is designed carefully, the TE_{02} mode can be reflected perfectly. Then, because of reciprocity, the TE_{02} wave gets converted back to TE_{01} at the end of the line. This mode then travels back and exits the line. The total delay in the delay line is twice that seen by a single-moded line. Hence, one can cut the delay-line length by a factor of two.

This scheme can be repeated for more than two modes. For example one can use TE_{01}, TE_{02}, TE_{03}, and TE_{04} for a factor of four reduction in length. In this case the end taper has to reflect the TE_{01} mode into the TE_{02} mode and reflect the TE_{03} mode into the TE_{04} mode. The input taper has to transmit the TE_{01}, reflect the TE_{02} into the TE_{03} mode and reflect the TE_{04} mode into itself. A design example of such a taper is given below.

3 THE END MODE CONVERTER

The mode converter at the end of the delay line is shown in Figure 2. It is basically a step in the circular waveguide. If the big waveguide supports only the TE_{01} and the TE_{02} modes among all TE_{0n} modes and the small waveguide supports only the TE_{01} mode, one can choose the diameter of the small guide so that the power transmitted from the large guide to the small guide at the step is independent of which mode is incident. Then the junction can be viewed as a symmetrical three-port network.

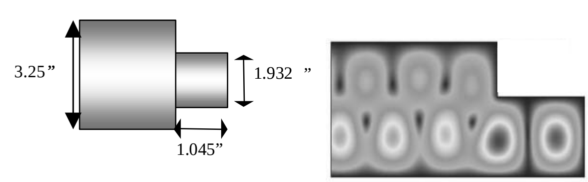


Figure 2: TE_{01}-TE_{02} reflective mode converter. The dimensions shown are for an operating frequency of 11.424 GHz. The field pattern shown from finite element simulations predicts a peak electric field of 26.6 MV/m for 300 MW of input power.

A theory for a three-port network is presented in [4]. It shows that there exists a position for placing a short circuit in the middle arm of this three-port network (the

Contributed to 8th European Particle Accelerator Conference (EPAC 2002), 06/03/2002--6/7/2002, Paris, France

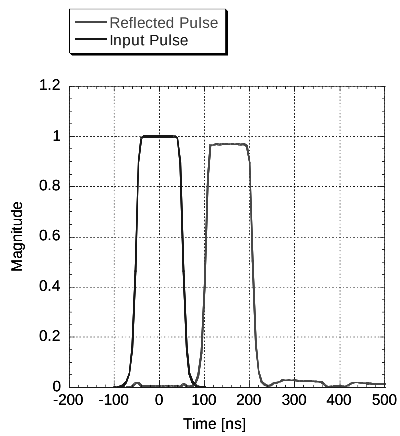
Work supported by Department of Energy contract DE-AC02-76SF00515

small guide in this case) that makes it possible to transfer the power perfectly between the remaining two arms, or in this case between the TE_{01} and the TE_{02} modes in the large guide.

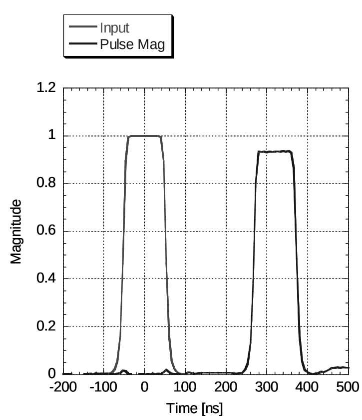
The only step left in the design of this end mode converter is a careful taper design that reduces the diameter of the delay line into the diameter of a waveguide that can support only TE_{01} and TE_{02} modes. The taper needs to transfer both modes perfectly.

4 EXPERIMENTAL RESULTS

Figure 3a shows the delay through a 75-ns delay line with a short circuit at the end for a total delay of 150 ns. Figure 3b shows the delay after placing the mode converter at the end of this line. The delay was doubled at the expense of increased loss. Using larger diameter waveguide for the delay line can reduce the losses.



(a)



(b)

Figure 3: (a) Measured delay through 75 feet of WC475 waveguide terminated with a flat plate. The round trip delay time is 154 ns. (b) Measured delay through 75 feet of WC475 waveguide terminated with the TE_{01}-TE_{02} mode converter. The round trip delay time is 320 ns. The operating frequency is 11.424 GHz.

5 FOUR-MODE TAPER DESIGNS

In order to expand this scheme to more than two modes, the input and end tapers need to perform multiple functions. The design of such tapers is not a trivial task. However, one can intuit the possibility of such designs. Since TE_{0n} modes cutes off at larger diameter as n is increased, one can imagine designing a taper such that the larger diameter portion of the tapers is tailored to operate perfectly with the highest order mode. Then the next part, which does not propagate that highest order mode, deals with the lower order mode and so on.

We also notice that the TE_{0n} mode does not have any axial currents on the walls. This allows the design of these tapers in steps. We divided the tapers into several segments and use a mode matching code to simulate their response. Because of the optimized speed of our mode matching code one can vary the parameters of each section and optimize its performance based on a goal function. The goal function used in this code was the multiplication of all the magnitudes of the scattering parameters of interest.

In figure 4a the design of the input taper for a 4-moded system is shown the frequency of operation is 11.424 GHz. The simulated response of that taper is shown in figure 4b. For the end taper we used the reflective mode converter discussed in the previous section. Hence the taper by it self should need to satisfy the following conditions: reflect the TE_{03} mode into the TE_{04} mode and transmit perfectly the $TE_{01}$and TE_{02} modes. Figure 5a shows the design of such taper and figure 5b shows the simulated response of this taper.

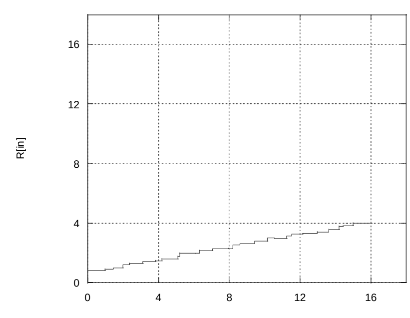


Figure 4a: Input taper design for a 4-mode system. The plot shows the radius versus the axial distance of taper

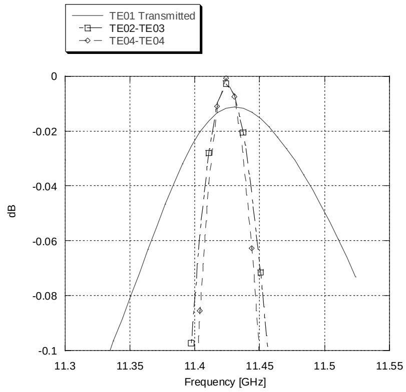


Figure 4:b: Simulated response of input taper for a 4-mode system

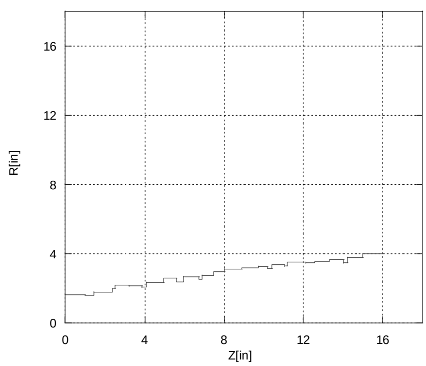


Figure 5a : End taper design for a 4-mode system. The plot shows the radius versus the axial distance of taper.

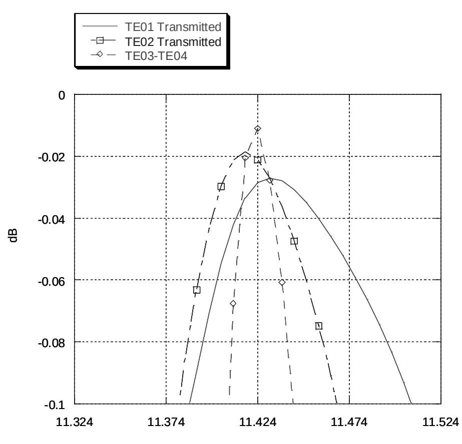


Figure5b: Simulated response of input taper for a 4-mode system

6 SUMMARY

We have demonstrated a new idea for multimoded delay lines. We designed the and built the rf components needed for a dual moded system. Our experimental results agreed well with theory. We also presented designs for components to build a system that can operate with 4 modes. The idea of multiple modes need not stop at 4 modes. The difficulty of designing multiple function tapers can be alleviated with the use of modern optimization tools and fast simulation codes.

7 ACKNOWEDGMENT

The Author wishes to thank C. Nantista for his insight and help in the design of the end mode converters. We would like to also thank, R. Ruth and P. Wilson for many useful discussions.

Work supported by the US Department of Energy

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