

# MULTI-MODED RF COMPONENTS AND THEIR APPLICATION TO HIGH-POWER RF PULSE COMPRESSION SYSTEMS\*

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## Abstract

A new approach to overmoded waveguide taper design allows fast convergence on multifunction component geometries in which several scattering matrix requirements are simultaneously satisfied. Preservation of or conversion between members of a family of waveguide modes of a given type and azimuthal index, such as TE<sub>0n</sub> modes, can be accomplished over minimal distances. Such components can find application in rf pulse compression systems which employ overmoded delay lines, such as SLED-II and Binary Pulse Compression, and in equivalent Delay Line Distribution Systems. By scattering into higher order modes, cut off at the input end of the input taper of a shorted delay line, for multiple reflections before converting back to the input mode and exiting the line, one can effect longer delays in a given length of waveguide. We describe the implementation of such multimode reflective delay lines, even in normally transmissive systems, and their potential impact on rf systems for linear colliders. We also present results of a low-power, double-bounce prototype.

## 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 multiple modes; hence they are utilized more than once during each pulse.

A variation on that multimoding scheme which is suitable for reflective delay lines was introduced in [3]. These are used in systems such as the SLED-II pulse compression system [4]. The scheme suggested here can reduce the required delay line by a factor of four or more, if one uses four or more modes simultaneously. We present recent experimental data showing the operation of the components necessary for two-moded systems. We also summarize how these multimoded reflective delay lines could be utilized to build several novel rf pulse compression systems introduced in [5].

## 2 MULTIMODED REFLECTIVE DELAY LINES

Consider the delay line shown in Figure 1. The rf signal is injected from the left into the delay line waveguide in the TE<sub>01</sub> 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<sub>0n</sub> modes. The TE<sub>01</sub> mode travels all the way to the end of the delay line and then gets reflected and converted into the TE<sub>02</sub> mode. The TE<sub>02</sub> 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<sub>02</sub> mode can be reflected perfectly. Then, because of reciprocity, the TE<sub>02</sub> wave gets converted back to TE<sub>01</sub> 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.

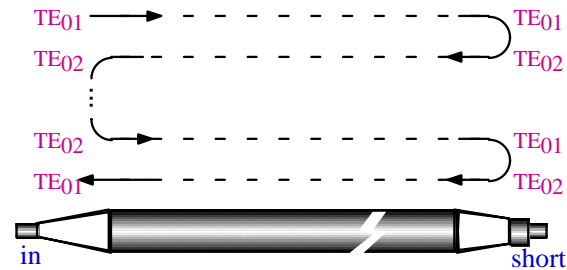


Figure 1: A multi-moded reflective delay line.

This scheme can be repeated for more than two modes. For example one can use TE<sub>01</sub>, TE<sub>02</sub>, TE<sub>03</sub>, and TE<sub>04</sub> for a factor of four reduction in length. In this case the end taper has to reflect the TE<sub>01</sub> mode into the TE<sub>02</sub> mode and reflect the TE<sub>03</sub> mode into the TE<sub>04</sub> mode. The input taper has to transmit the TE<sub>01</sub>, reflect the TE<sub>02</sub> into the TE<sub>03</sub> mode and reflect the TE<sub>04</sub> mode into itself.

## 3 TWO-MODE TAPER DESIGNS

In this scheme 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<sub>0n</sub> modes cut 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 next lower order mode, and so on.

We also notice that TE<sub>0n</sub> modes do not have any axial wall currents. This allows the design of these tapers in steps. We divided each taper into many segments and used a mode matching code to simulate their responses.

\* Work supported by the U.S. Department of Energy under contract DE-AC03-76SF00515.

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Because of the optimized speed of our mode matching code one can vary the dimensions of each section and optimize the 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 2a the design of the input taper for a two-moded system is shown. The frequency of operation is 11.424 GHz. It must efficiently perform the following functions: reflect the  $TE_{02}$  mode into the  $TE_{02}$  mode and transmit the  $TE_{01}$  mode. For the end taper, mode conversion is done in a single step. A preliminary mode-preserving tapered section, shown in Figure 2b, is necessary to cut off all but the lowest two  $TE_{0n}$  modes. Each of these many-stepped tapers is a foot long. The final, mode-converting step is incorporated into a sliding cup, as shown in Figure 2c, to allow for tuning.

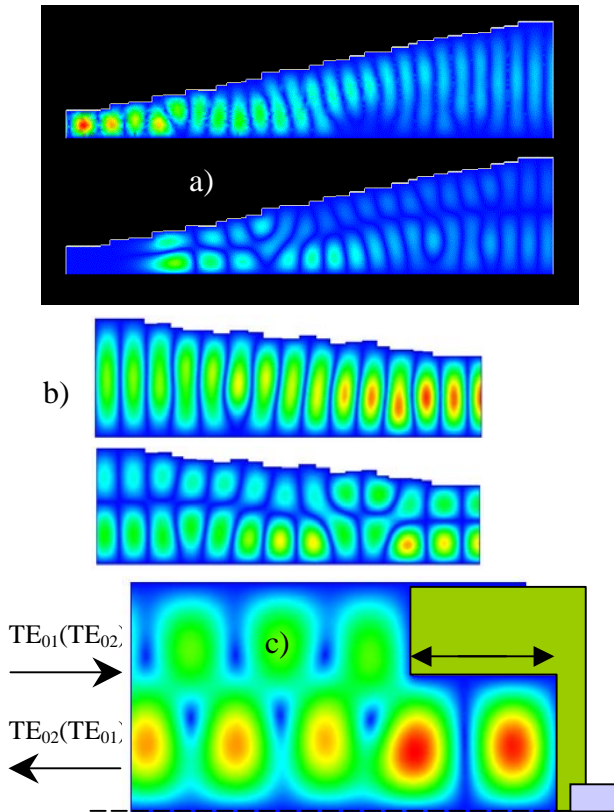


Figure 2: Radial profiles and field patterns of tapers for a highly overmoded, two-mode reflective delay line: a) input taper, b) end taper, c) reflective mode converter.

In figure 3a, we show the measured frequency response of these tapers, connected together without an intervening transmission line. They are fed with a wrap-around mode converter [4]. In figure 3b is shown the time-domain response of the system to a 400 ns square pulse. The total delay is about 15 ns, consistent with two round trips in the assembly. Both the frequency and time domain measurements show an excellent performance by these components, with an extremely low loss level.

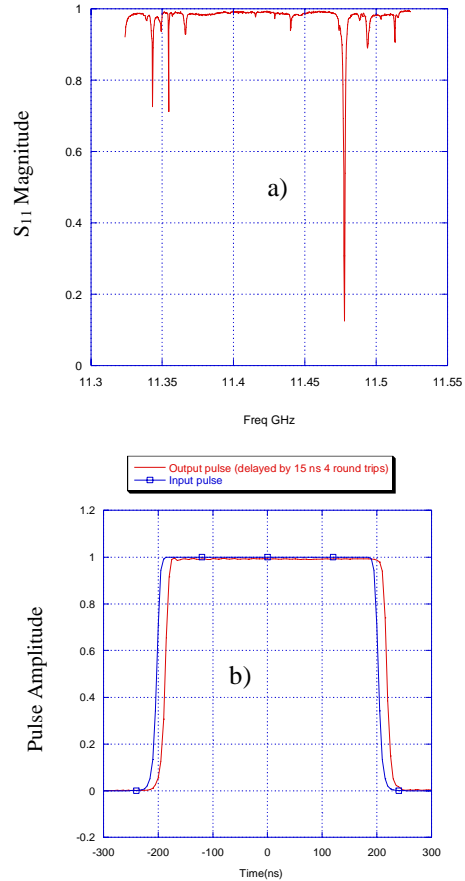


Figure3: a) Measured frequency response and b) constructed time response of the dual-moded taper assembly.

#### 4 APPLICATION TO HIGH-POWER RF PULSE COMPRESSION SYSTEMS

In this section we show how these multimoded delay lines could be applied to different high-power rf pulse compression systems. Our list is not comprehensive. We only aim to illustrate the usage and point to the benefits of this multimoded system.

##### 4.1 MSLED-II

In a SLED-II [6] pulse compressor, a pair of hybrid coupled delay lines is fed through partially reflecting irises for resonant storage. Application of the above multi-moding approach to produce a Multimoded SLED-II (MSLED-II) simply means that the rf makes more than one round trip between each internal impingement on the iris, located where it only sees  $TE_{01}$ . Tuning the overall phase length by means of the mode-converting plunger described in above brings the whole line, with all used modes, into resonance. A dual moded MSLED-II is being constructed this year at SLAC as part of an R&D project to test NLC rf technology.

## 4.2 MR.DLDS

DLDS [7] uses delay lines in a transmissive, rather than reflective, fashion. It also takes advantage of the time-of-flight of the beam along a linac to provide nearly half of the required delays. As a result, it ties together long sectors of the linac through interleaving of modules.

By introducing reflective delays and largely giving up the time-of-flight benefit, one can make each rf module locally power a set of consecutive accelerator feeds and simultaneously facilitate the use of our reflective multimoding scheme. Here, a DLDS network distributes different time bins of a combined source pulse to different upstream feeds, only consecutive rather than distantly spaced, as shown in Figure 4 (with dual-moded distribution as well). At the top of each feed, a pair of hybrid-coupled delay lines provides the remainder of the delay needed for that feed. Only one line of each pair need be tunable, since the overall phase of the rf is tunable through the low-level drive.

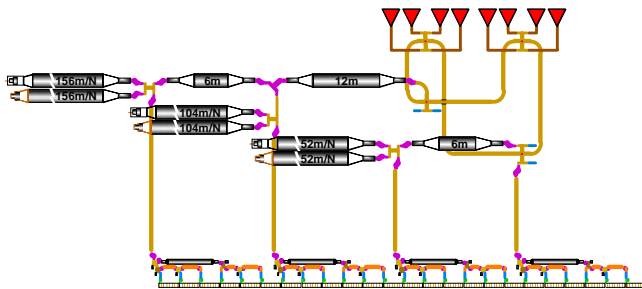


Figure 4: Four-feed Multimoded Reflective Delay Line Distribution System (MR.DLDS).

The result is a Multimoded Reflective DLDS (MR.DLDS). For a four-feed or an eight-feed system, the amount of delay line will be reduced compared to standard DLDS when four or more modes are used. Another benefit over standard DLDS is the flexibility to change the “compressed” rf pulse width by simply changing the delay line lengths or the number of modes used.

## 4.3 MRS.BPC

Binary Pulse Compression (BPC), in which the leading half of a pulse is delayed to coincide with the trailing half in one or more stages, was first suggested in [8]. The length of waveguide required, however, made it an unattractive choice for powering a linear collider. Each factor of two in compression required a folded delay line twice as long as the next stage. It was later realized that one could significantly reduce the total amount of waveguide by combining the upper stages of neighboring BPC systems, then splitting to keep the power level down.

Applying multimoded reflective delay lines to such a split BPC leads to a Multimoded Reflective Split BPC (MRS.BPC), a system which can be reasonably compact.

## 5 CONCLUSIONS

We’ve described designs of novel components for multiple reflection delay lines. Very encouraging cold test measurements of components for high-power, dual-moded SLED-II delay lines have been presented. With automated optimization and fast simulation codes, such multimoding can be extended to four modes and beyond, greatly reducing the length of low-loss waveguide needed for rf pulse compression schemes. We’ve shown how this benefit can be applied not only to SLED-II, but also to systems like DLDS and BPC, by replacing their normally transmissive delay lines with reflective delay lines.

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