AN ALTERNATE DUAL-MODED DLDS UTILIZING THE TE_{01}° AND TE_{02}° MODES*

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Abstract

In recent designs for multi-moded delay line distribution systems, the waveguide modes of choice have been TE_{01}° and one or both polarizations of TE_{12}° [1,2]. For the highly overmoded waveguide diameter of 4.75" (and out to ~7") at X-band, these are the modes with lowest theoretical ohmic loss. Considerable experience with the use of TE_{01}° has been gained in pulse compression development [3] over the past decade, and recent transmission experiments [4] have demonstrated the feasibility of using TE_{12}°. There may, however, be certain advantages to substituting TE_{02}° for TE_{12}°. In the past, this mode has been passed over largely because ideas for selective launching and extracting depended on modes being distinguishable by the azimuthal variation of their fields. The new design approach, however, of manipulating modes in overmoded rectangular waveguide [5] and transitioning to circular waveguide via special tapers, suggests that we could work instead with the rectangular TE_{20} and TE_{40} modes. We present reasons to consider a TE_{01}°/TE_{02}° system and describe waveguide circuits for launching and directing the above rectangular modes.

1 INTRODUCTION

In the proposed Next Linear Collider (NLC), electron and positron beams will be accelerated through copper structures powered with hundreds of megawatts of 11.424 GHz rf. The plan for delivering this power from groups of klystrons to the accelerating structures, with effective pulse compression, through a Delay Line Distribution System (DLDS) [6] has evolved over the past few years. In each rf module, by means of phase switching, the combined power from eight klystrons is directed in sequential time bins to four feeds, each driving a set of three structures. To allow for the fill time of the structures, the feeds of each module are approximately 55 m apart, and the modules are therefore interleaved. The desire to reduce the amount of low-loss, overmoded, circular-waveguide delay line required for such a scheme has led to the combining of different operating modes in the same pipe [1,2], each to be extracted into an accelerator feed at the proper location.

Recent design efforts have focused on developing such a Multi-moded Delay Line Distribution System (MDLDS) carrying two modes in a delay line. For low loss, the focus has been on the TE_{01}° and TE_{12}° modes in highly overmoded circular waveguide. We will briefly consider here the potential benefits of substituting for the latter mode, in a dual-moded system, the TE_{02}° mode.

Current plans call for performing such functions as power combining, bending, mode launching, and mode extraction, in oversized rectangular waveguide, and to this end special components have been developed [2,5]. Along with simplicity of design, these provide greater power handling potential than previous components employing circular waveguide with coupling slots and irises. H-plane symmetry is exploited to allow the use of overheight waveguide, thus reducing surface fields. The interface between the circular delay line waveguide and these components is to be accomplished through special cross-section tapering mode converters [7].

The two key components needed in an MDLDS are a multi-mode launcher, through which to combine the power, and a mode-selective extractor, with which to direct the power. Designs have been presented for a TE_{01}°/TE_{12}° system [5]. We will describe here ideas for similar over-moded H-planar rectangular waveguide components for a TE_{01}°/TE_{02}° dual-moded MDLDS.

2 REASONS TO CONSIDER TE_{02}

Above cutoff in overmoded circular waveguide, TE_{01}° quickly becomes the lowest loss mode. At large radius, its attenuation falls off inversely with the cube of the radius. It is therefore the ideal choice for efficient transmission and delay of high-power rf pulses. It has been a mainstay of X-band rf pulse compression work at SLAC for the past decade [3].

For a multi-moded system, the TE_{12}° mode was an obvious addition. From a diameter of about 2.4 inches to 7.2 inches, where TE_{02}° overtakes it, it has the second lowest attenuation. The 4.75 inch delay line diameter that has been carried over from the NLC Test Accelerator's SLED-II system [8] falls well within this range. Furthermore, we'd hoped to use both polarizations of TE_{12}° in our original goal of a three-mode MDLDS. We could thus, in a sense, get two for the price of one.

Recent designs, however, have focused on a more modest two-mode system. The polarized nature of TE_{12}° thus ceases to be a benefit. Degeneracy with its cross polarization might, in fact, be considered a liability. Any extended perturbation in the circular waveguide cross-section which couples the two could lead to coherent power loss. For example, a continuous wall deformation of 0.010 inchs with a cos2ϕ dependence at 45º could

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completely transfer the power between polarizations in less than twenty feet of our delay line waveguide.

Of course, the above is a worst-case scenario. Recent transmission experiments [4] with a 55 m run of carefully fabricated 4.75 inch circular waveguide, assembled from several sections, surprisingly revealed no noticeable coupling between TE_{12}° polarizations. Nevertheless, the danger is there, and, if nothing else, a polarized mode complicates installation, as launchers and extractors must be precisely level or identically angled.

The same experiments did show a 0.4% power loss to the near-degenerate TE_{41}^{o} mode and an overall attenuation 46% higher than the theoretical ohmic loss. Similar excess loss was not seen for the TE_{01}° mode, and thus one might reasonably expect to see none for TE_{02}°. A future experiment at KEK will measure TE_{02}° transmission in the same waveguide. In practice then, TE_{02}° could be a more efficient carrier than TE_{12}° in our delay lines, particularly if the waveguide diameter is increased.

Another argument for changing modes is the longitudinal currents required by TE_{12}°. TE_{0n}° modes, having only azimuthal wall currents, are unaffected by small longitudinal gaps such as those that occur at flange joints. In the above-mentioned experiments, special choked flanges [4] were used, with a groove in the flange face to radially confine the n=1 azimuthal gap mode. Such choked flanges are designed for a fixed gap width. In the high-power NLC systems, however, expansion joints with bellows will be required to allow for thermal changes, and gap widths will need to vary on the order of a millimeter.

3 H-PLANAR COMPONENTS

The overmoded rectangular waveguide components designed for our $TE_{01}^{\circ}/TE_{12}^{\circ}$ system depend on a taper which converts the rectangular modes to the corresponding circular modes [7]. The TE_{01}° mode is matched into the rectangular TE_{20} mode. The corresponding mode for TE_{02}° would be TE_{40}. A carefully designed taper might accomplish both conversions in a reasonable length. Even if the taper converter needs to be more adiabatic than that for our current system (a few inches in length), it will have a larger cross-section to accommodate TE_{40} and therefore smaller attenuation constants.

3.1 Launcher

Thus, if we take this same approach, we need a way to launch and then separate TE_{20} and TE_{40}. Since we already have a dual-moded launcher for TE_{10} and TE_{20}, we might seek a way to convert the latter pair into the former, that is, to double the first indeces.

This is nontrivial. Converting TE_{10} to TE_{20} requires a change of symmetry with respect to the center line, while converting TE_{20} to TE_{40} doesn't. Thus we can't simply wiggle the walls. Note that the "jog converter" described in [5] accomplishes the first conversion but also changes TE_{20} to TE_{10}, thus leaving us where we started.

Using matched splitters and jog converters, we can design a launcher as sketched in Figure 1 which goes to four waveguides and then back to one. However, to work for both modes, it requires one waveguide to cross over the other three.

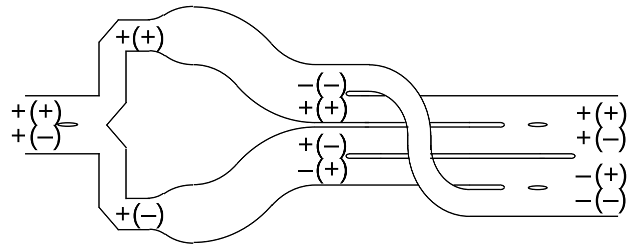

Figure 1: Schematic of a $TE_{10/20}$ to $TE_{20/40}$ converter with three waveguide crossings. Signs indicate field direction.

If we eliminate the jogs, matching the second splits for TE_{10}, and break the symmetry by introducing, after recombination to two double-moded guides a π relative phase length difference between the two paths for one mode but 2π for the other, as indicated in Figure 2, we can get away with only one cross-over.

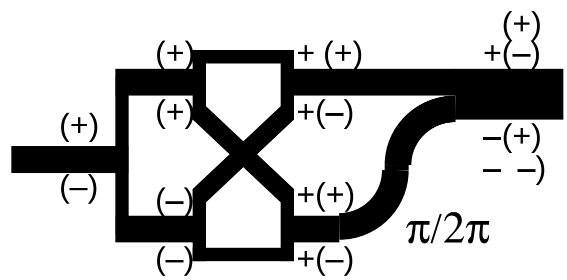

Figure 2: Schematic of revised $TE_{10/20}$ to $TE_{20/40}$ converter with one waveguide crossing or "pass-through". Signs indicate field direction.

An important motivation, however, for working with rectangular waveguide is our ability to exploit planar symmetry to increase the height and thus the power-handling capacity. We would prefer not to have to leave the plane for any waveguide to cross another. We can, in fact, replace the cross-over with a "pass through". Our design for such a device is a modification to a novel "H"–shaped planar hybrid design [9] that yields, in effect, a 0 dB directional coupler.

We can also incorporate the "magic H" hybrid on which the pass-through is based in each arm after the first split to simultaneously transition to wider waveguide and match the second splits. Finally, a properly spaced pair of the above-mentioned jog converters in series can give the phase length difference and bring the guides together before the final rejoining. The resulting planar waveguide circuit for simultaneously converting TE_{10} to TE_{20} and TE_{20} to TE_{40} is shown in Figure 3 with field plots from an HP HFSS [10] simulation.

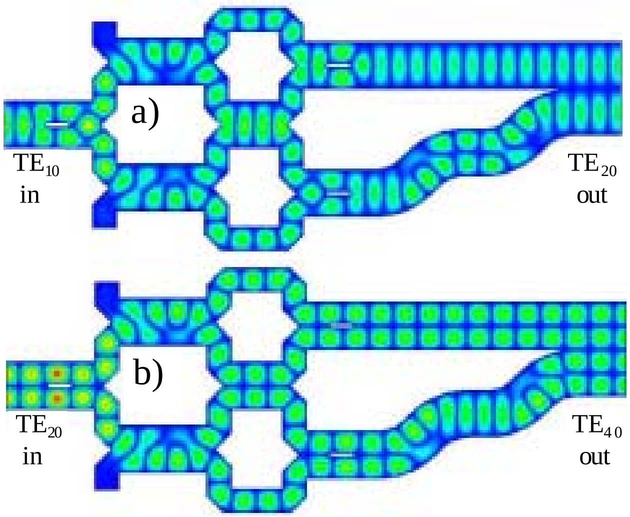

Figure 3: Geometry of H-planar $TE_{10/20}$ to $TE_{20/40}$ converter illustrated with HFSS field plots showing conversion from a) TE_{10} to TE_{20} and from b) TE_{20} to TE_{40}.

3.2 Extractor

As a companion component, a system using the above launcher extender would require a TE_{02}^{o} extractor which passes TE_{01}^{o}, or, assuming the same transition to and from rectangular waveguide, a TE_{40} extractor which passes TE_{20}. One way to accomplish this latter function is illustrated in Figure 4.

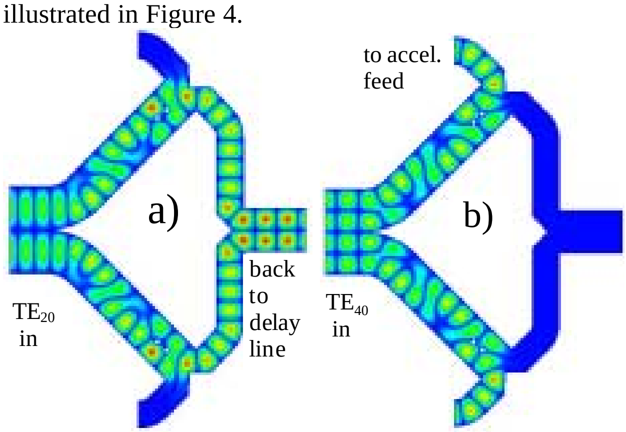

Figure 4: Geometry of H-planar TE_{40} extractor illustrated with HFSS field plots showing a) passing of TE_{20} and b) extraction of TE_{40}.

Taking advantage of the common symmetry of our two modes, this extractor incorporates a version of the $TE_{01}^{\circ}/TE_{12}^{\circ}$ system extractor [5] extended to extract the other mode. The waveguide is bisected into two guides supporting only the first two TE_{n0} modes. 45º bends accommodate this separation and provide in each arm an equal mixture of TE_{10} to TE_{20}. The interference of the latter at properly placed T splits causes all the power each arm to be directed one way or the other, depending on the original mode incident at the bisection.

The inner split ports are joined through a T identical to one side of the magic H hybrid, and TE_{20} is relaunched to be converted to TE_{01}° in the delay line. The outer split ports can be similarly joined, after E-plane and H-plane bends, below the extractor into an accelerator feed.

4 CONCLUSION

We have presented reasons for keeping open the option of changing the second mode of the NLC MDLDS from TE_{12}^{o} to TE_{02}^{o}. These include considerations of parasitic mode loss, symmetry implications for installation, and the need to accommodate thermal expansion. As a proof of existence exercise, we've devised components to allow use of TE_{01}^{o} and TE_{02}^{o} in the same delay line. Like similar components in our present design, these are based on conversion to corresponding modes in rectangular waveguide.

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