A PLANAR, RECTANGULAR WAVEGUIDE LAUNCHER AND EXTRACTOR FOR A DUAL-MODED RF POWER DISTRIBUTION SYSTEM*

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Abstract

The desire to reduce the amount of low-loss, circular-waveguide delay line required in a pulse-compressing power distribution system for the Next Linear Collider has led to the pursuit of multi-moded schemes [1]. In such a system, power is delivered to different destinations through the same waveguide via different propagating modes. Current plans [2] utilize two modes, with manipulations done primarily in overmoded rectangular guide. We describe two key components of the system, a four-input/four-output, dual-mode launcher and an extractor for diverting one mode from the delay line to an accelerator feed while allowing the other to pass on to an upstream feed. These novel passive waveguide devices utilize the rectangular TE_{10} and TE_{20} modes. Because they must carry up to 600 MW pulsed rf power, H-planar symmetry is maintained in their designs to allow the use of overheight waveguide, and features that invite breakdown, such as coupling slots, irises, and septa, are avoided. Special rectangular-to-circular tapers [3] will be used to convert between the above modes and the circular TE_{11}° (TE_{12}°) and TE_{01}° delay line modes, respectively.

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 distribution system for delivering this power from groups of klystrons to the accelerating structures 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 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], each to be extracted into an accelerator feed at the proper location.

A modest realization of such a Multi-moded Delay Line Distribution System (MDLDS) is one carrying two modes in a delay line. For low loss, the TE_{01}° and TE_{12}° modes in highly overmoded circular waveguide are used. Manipulations such as power combining, bending, mode launching, and mode extraction, will be done in oversized rectangular waveguide for relative ease of handling. Mode converters, including special cross-section tapers [3] will be used to transform between the above circular waveguide modes and the TE_{20} and TE_{10} rectangular waveguide modes, respectively.

The two key components needed in an MDLDS are a multi-mode launcher and a mode-selective extractor. The former is a passive waveguide circuit with several matched and mutually isolated inputs and an equal number of outputs, two or more of which are distinct modes in the same waveguide. Orthogonal phase combinations for equal rf power sources at each input allow the total power to be combined in any single output port/mode. To translate multiple modes into multiple destinations, a companion component is required that will extract one mode from a waveguide while efficiently passing other operating modes. The extractor is thus a three–port insertion device with at least the input port overmoded.

Our dual-moded, rectangular waveguide launcher and extractor, to be described below, have relatively open interiors. In the hope of being able to reliably pass 600 MW pulses without rf breakdown, we have avoided the use of small irises or resonant slot-coupling. We have also avoided field enhancing E-plane bends, matching buttons, and anything that breaks the H-plane symmetry.

An overmoded waveguide width is used which allows TE_{10} and TE_{20} propagation while remaining below cutoff for TE_{30}. Since the launcher and extractor geometries are translationally symmetric in the direction of the electric fields—that is, since they are entirely H-plane devices—, the height is a free parameter. Because surface electric field amplitudes are inversely proportional to the square root of waveguide height, this feature of our designs allows them, in theory, to be built to handle arbitrary power levels. Although they may thus be overmoded in height as well, they contain no features to couple in the other propagating modes, including any TM modes, which have a non-zero second index. Thus, we are effectively dealing with dual-moded devices. The height will be chosen to accomodate the rectangular-to-circular taper / mode converters to which they will be joined.

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2 CROSS POTENT DUAL-MODE COMBINER/LAUNCHER

2.1 Magic H Hybrid

The focus in our rf system development on rectangular waveguide components with planar symmetry began with the design of planar hybrids [4] to replace magic T's which had been exhibiting rf breakdown above 200 MW at the mouth of the E-plane port. A novel hybrid design with an "H" geometry has a central guide wide enough to support two TE modes. At its junctions, triangular wall protrusions essentially present opposite, matched, mitred bends to the two lobes of TE_{20} into half-width ports. The width and length of this connecting guide are chosen to simultaneously provide a match for the other mode, TE_{10}, and yield a phase difference through the hybrid of 90° for the corresponding odd and even input port combinations. The two three-port (with one carrying two modes) junctions of this "magic H" thus form a simple quadrature hybrid. Prototypes have been successfully operated at peak power levels approaching 500 MW.

2.2 Cross Potent Superhybrid

If two such "magic H" hybrids, with ports half the width of the central guide, are placed side-by-side and their common wall removed, the resulting oversized ports have the same cross-section as the central guide. If these are split again with T's at the proper distance, the symmetry is completed, and a compact eight port device in the shape of a cross potent (cross with a bar at each extremity) results. This "cross potent superhybrid" [5], equivalent to a network of four hybrids, can be used to combine power from four input ports into any one of four output ports, by proper phasing. The ports on opposite pairs of cross arms are isolated.

Figure 1: Cross potent superhybrid prototype with 90° bends tapering to standard 0.900 inch wide ports. It is shown without cover plate and flanged port stubs.

A 0.400 inch-high prototype, pictured in Figure 1, has been built and its scattering parameters measured with a network analyzer. All isolations were better than –38.8 dB at the design frequency and below –20 dB over a bandwidth of ~200 MHz. All couplings were within 0.06 dB of an average of –6.07 dB, adjusted for added bends. The insertion loss of ~0.05 dB would be reduced in an overheight version.

2.3 Cross Potent Launcher

One can eliminate the T split from one or more of the cross arms, substituting in each case a central oblong post or pair of posts to provide matching for TE_{10} while preserving the TE_{20} match. The TE_{10} and TE_{20} modes are then the orthogonal outputs (or inputs) at the resulting overmoded ports. This concludes the evolution of the cross potent dual-mode launcher, whose configuration and function are illustrated, with electric field plots from an HP HFSS [6] simulation, in Figure 2. The overmoded waveguide width is 1.442 inches. Combined with a taper converter and Marié converter, it will allow us to launch the desired modes into our circular waveguide delay lines from four independently phased sources.

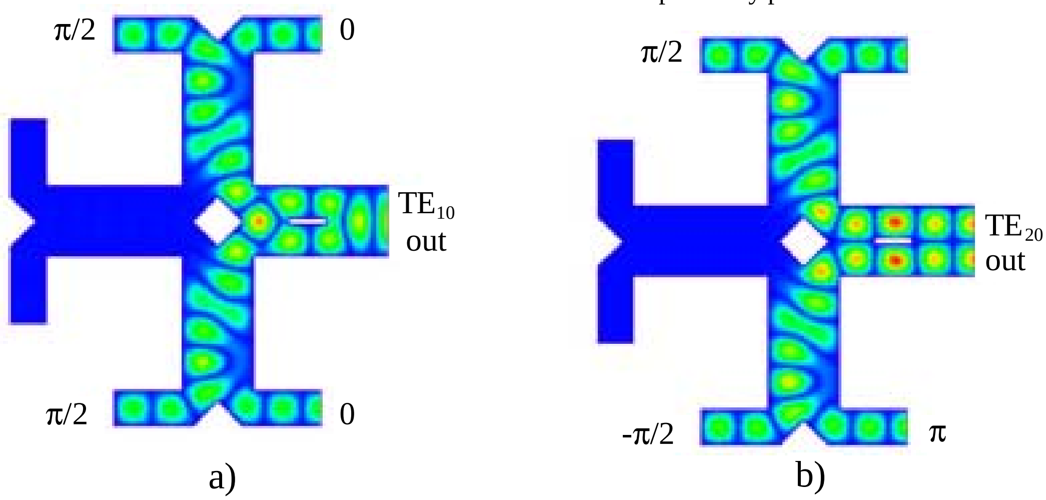

Figure 2: Example Cross Potent Launcher with simulated electric field plots illustrating launching a) TE_{10} and b) TE_{20} in the right overmoded rectangular port with the indicated relative phases for four equal amplitude inputs. Alternate phasings of the inputs send the power to either of the left ports.

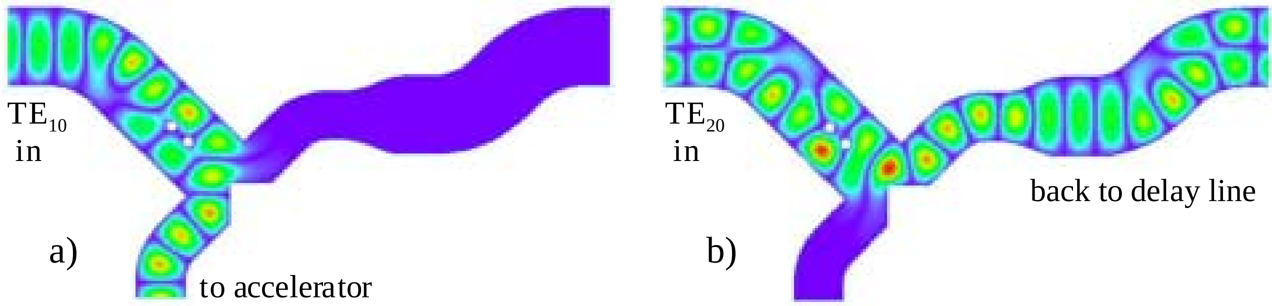

Figure 3: Extractor with simulated electric field plots illustrating a) extraction of the TE_{10} mode and b) passing the TE_{20} mode. For the latter, a "jog converter" attached to the through port after a width taper restores the mode and brings the port back in line with the delay line. Power flow is from the left port.

3 EXTRACTOR

Flanked by the proper tapers and converters, our dual-mode extractor begins and ends in the same rectangular dimensions as the launcher output. Its geometry and function are illustrated in Figure 3. It consists of three main sections.

3.1 Bend Mixer

Bending our overmoded waveguide in the H-plane with an inner-wall radius-of-curvature of 1.055 inches couples our two opoerating modes in such a way that at 45º either input has been converted into an equal combination of TE_{10} and TE_{20}. The different wave numbers then allow us to achieve the desired relative phase with a short straight section.

3.2 Doubly Matched Splitter

A mitred T split follows, preceded by central posts to give a good match for both modes. Here the TE_{10} field adds constructively to one lobe of TE_{20} and destructively to the other, sending all the power one way for a given extractor input mode and all the power the other way for the other input mode. Since the two extractor input modes result in combinations with relative phases differing by π, they excite opposite ports at the split.

Because it corresponds to the circular delay line mode with the greater attenuation, the TE_{10} mode is selected for extraction. Single-moded 45º H-plane bends orient the extraction port waveguide perpendicular to the delay line and the through port waveguide parallel to it, albeit offset.

3.3 Jog Converter

The through port is then tapered to full width and finally sent through a dogleg or "jog converter". The jog converter is a compact mode transducer. It consists of two oppositely oriented 45º bends, like that at the beginning of the extractor, separated by a very short phasing section. The result is complete conversion between TE_{10} and TE_{20}. It works in either direction, for either input mode. This simple device is used at several points in our rf system plans. It can be combined with a rectangular waveguide taper and a rectangular-to-circular taper converter of the type mentioned above to form a novel TE_{10} to circular $TE_{01}{}^{o}$ launcher.

As part of our extractor, it simultaneously brings the through port back in line with the delay line axis and restores the TE_{20} mode. An identical mode converter can be appended to the extraction port, so that, through taper converters, the power will be relaunched in either the delay line or the accelerator feed in the more efficient circular $TE_{01}{}^{o}$ mode.

4 CONCLUSION

We have designed novel passive rectangular waveguide components, with H-planar symmetry, for launching and selectively extracting power from the delay lines of a dual-moded MDLDS. These are expected to handle 600 MW, 1.5–3 µs X-band pulses in the NLC. Prototypes will soon be built for high-power testing.

REFERENCES

[1] S.G.Tantawi, et al., "A Multi-Moded RF Delay Line Distribution System for the Next Linear Collider," proc. of the Advanced Accelerator Concepts Workshop, Baltimore, MD, July 5-11, 1998, pp. 967-974.

[2] S.G.Tantawi, et al., "New Developments in RF Pulse Compression," invited talk, these proceedings.

[3] S.G. Tantawi, et al., "RF Components Using Over-Moded Rectangular Waveguides for the Next Linear Collider Multi-Moded Delay Line RF Distribution System," presented at the 18th Particle Accelerator Conference, New York City, NY, March 29-April 2,1999.

[4] C.D. Nantista, *et al.*, "Planar Waveguide Hybrids for Very High Power RF," presented at the 1999 Particle Accelerator Conference, New York, NY, March 29—April 2, 1999; SLAC-PUB-8142.

[5] C.D. Nantista and S.G. Tantawi, "A Compact, Planar, Eight-Port Waveguide Power Divider/Combiner: The Cross Potent Superhybrid," submitted to IEEE Microwave and Guided Wave Letters.

[6] HP High Frequency Structure Simulator, Version 5.4, Copyright 1996-1999 Hewlett-Packard Co.