SLAC-PUB-8500
July 2000

OVERMODED RECTANGULAR WAVEGUIDE COMPONENTS FOR A MULTI-MODED RF POWER DISTRIBUTION SYSTEM[1]

Christopher D. Nantista and Sami G. Tantawi[2], SLAC, Stanford, CA94309, USA

Abstract

We describe the design of several novel, passive waveguide devices being developed for the high-power rf distribution system of the Next Linear Collider [1]. This system allows the combined power of several klystrons to be directed, by means of drive phase manipulation, to different accelerator feeds at different times during each pulse. The desire to reduce the amount of required low-loss, circular-waveguide delay line has led to the present multi-moded scheme, in which different modes travel through the same waveguide to different destinations. Components are needed for combining, launching, splitting, and directing hundreds of megawatts at X-band. For simplicity, manipulations are done primarily in overmoded rectangular guide, with the height increased to improve power-handling capacity. Features that invite breakdown, such as coupling slots and h-plane septa, are avoided. The components described here utilize TE_{10} and TE_{20} as operating modes. They include a four-input superhybrid, a mode-selective extractor, mode–preserving bends, a rectangular mode converter, and a rectangular-to-circular taper [2], which converts between the above modes and the circular TE_{11} and TE_{01} modes, respectively.

1 INTRODUCTION

High-gradient linear accelerators use rf pulse compression to match source capabilities (longer pulses) to accelerator structure requirements (higher peak power). For the Next Linear Collider (NLC) design, an effective pulse compression technique called DLDS (Delay Line Distribution System) [3] replaced the less efficient method involving resonant energy storage. This newer technique uses phase patterns to send the combined power from a group of sources to different accelerator feeds during different time bins of their common rf pulse duration. The rf is shipped upstream, and the time-of-flight of the beam combines with the waveguide delay to allow time for successive sets of structures fed by a given rf station to be filled. To reduce the resulting number of large low-loss waveguides in a given cross-section of the accelerator tunnel, it is desirable to use more than one mode per waveguide [1]. This requires specially designed components, most obviously a combiner which launches the different modes according to the relative phases of its inputs and an extractor which efficiently diverts one mode into an accelerator feed while passing other utilized modes unperturbed.

The current design uses the two lowest loss modes, TE_{01} and TE_{12}, in highly overmoded circular waveguide in the bulk of the system. Wherever coupling to the delay lines is required, diameter tapers are used to transition to more moderately overmoded guide and, if necessary, a wall-undulation mode converter exchanges TE_{12} for TE_{11} without affecting TE_{01}. Original plans for getting power in and out of these modes and negotiating bends involved components with coupling slots and irises [1]. Since the system must carry a peak power of 600 MW, rf breakdown is a serious concern. Recent development efforts have led to a set of components with which these functions can be accomplished in relatively open overmoded rectangular waveguide.

2 TAPER CONVERTER

What enables us to utilize such components without giving up our low-loss circular waveguide transmission modes is a mode converter which transitions between the smaller, 3.81 cm diameter circular waveguide and a 3.66 cm × 3.07 cm rectangular cross-section. This efficiently converts the circular TE_{01} and TE_{11} modes respectively to the rectangular TE_{20} and TE_{10} modes.

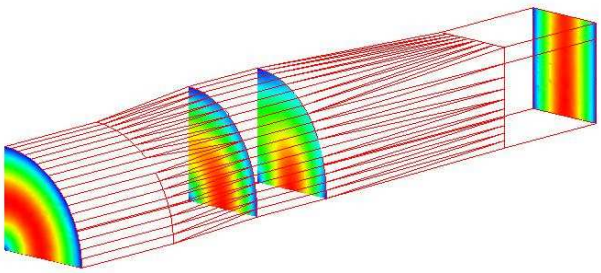

Figure 1: Taper Converter ¼ geometry converting circular TE_{01} to rectangular TE_{20}. An incident circular TE_{11} wave would be converted to rectangular TE_{10}.

An adiabatic taper from a circular cross-section to a square one would map the circular TE_{11} mode into the rectangular TE_{10} mode and the circular TE_{01} mode into a combination of the rectangular modes TE_{20} and TE_{02} (the orthogonal combination corresponding to the circular TE_{21} mode). To obtain a pure TE_{20} wave from TE_{01}, the degeneracy is first broken by choosing a non-square

[1] Work supported by Department of Energy contract DE-AC03-76SF00515.
[2] Also with the Communications and Electronics Department, Cairo University, Giza, Egypt.

rectangular ending cross-section. From the circular end, a cos 2ϕ wall perturbation is first tapered in. A short straight section then allows an appropriate phase slip between the two resulting modes, so that in a second taper section, to fully rectangular waveguide, the TE_{02} mode is suppressed (see [2]). This is accomplished, while preserving the TE_{10} conversion, in under 10 cm in the design shown in Figure 1. Simulated field plots were generated using HP HFSS [4] simulation.

3 LAUNCHER

The move in our pulse compression work toward rectangular waveguide components in which planar symmetry is exploited to allow arbitrary height began with the design of planar hybrids [5], motivated by power handling problems in magic T's. One design has an "H" geometry, with the connecting guide supporting two modes.

If two "H"-shaped 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 an eight port device in the shape of a cross potent (cross with a cross bar at each extremity) results [6]. This "cross potent superhybrid" can be used to combine power from four input ports into any one of four output ports, by proper phasing.

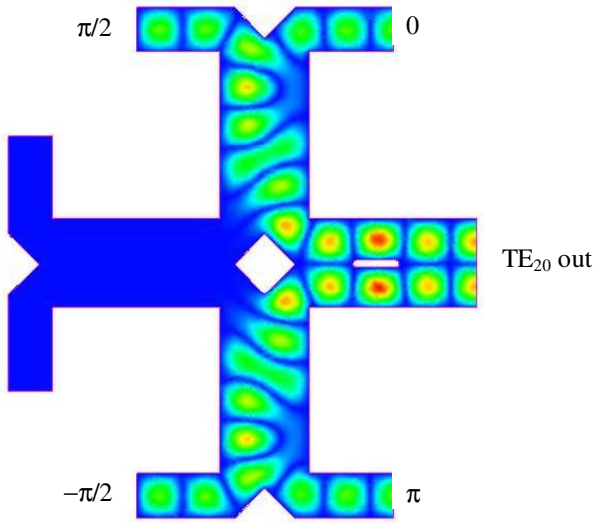

Figure 2: Cross Potent Launcher launching TE_{20} in the right port. Alternate phasings of the inputs send power into TE_{10} or to either of the left ports

Of course, one can leave off the T split on one or both of the output arms, substituting posts for matching, and consider the TE_{10} and TE_{20} modes as the orthogonal outputs. This configuration and its function are illustrated with an electric field plot in Figure 2. Combined with a taper converter, it will allow us to launch the desired modes into our circular waveguide delay lines from four independently phased sources.

4 EXTRACTOR

At the midpoint of a dual-moded delay line, one mode is extracted and fed into the accelerator. The extractor begins in the same rectangular dimensions as the launcher output and the taper converter. A 45º H-plane bend mixes the two rectangular guide modes, converting either input into an equal combination of TE_{10} and TE_{20}. After a short straight section to achieve the proper relative phase, a post-matched T split sends all the power one way for a given extractor input mode and all the power the other way for the other input mode. This works because the TE_{10} field adds constructively to one lobe of TE_{20} and destructively to the other. Since the two input modes excite combinations with opposite relative phases, they excite opposite ports at the split. Again, we illustrate the geometry and function with field plots in Figure 3. The TE_{10} mode is extracted, since it corresponds to the circular guide mode with the greater attenuation.

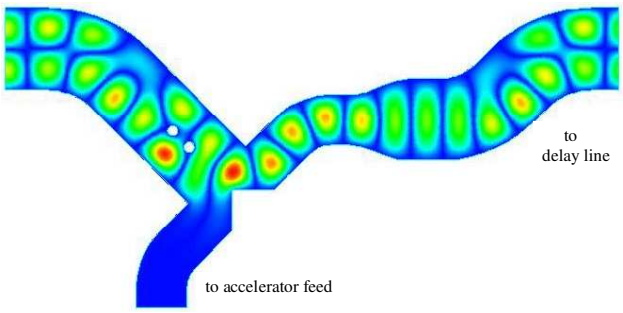

Figure 3: Extractor with jog converter passing TE_{20}. A TE_{10} wave incident from the left would be extracted to the lower port.

The single-moded output waveguides are bent through simple 45º H-plane bends, leaving one perpendicular to the delay line and the other parallel to it, albeit offset. The latter is tapered to full width and sent through a jog converter, described in the next section, which brings it back in line with the delay line. The same can be done to the other port, resulting in both carrying TE_{20}, so that, through taper converters, the power can be relaunched in either the delay line or the accelerator feed in the more efficient circular TE_{01} mode.

5 BENDS, ETC.

Bends will inevitably be required in an rf system layout. We now describe plans for negotiating these and otherwise manipulating the waveguide modes.

5.1 Overmoded H-Plane Bend

We have designed a 90º H-plane bend in the overmoded rectangular guide described above. We find

that, for this cross-section and our 11.424 GHz operating frequency, a bend with a radius-of-curvature from the inner wall of 3.58 cm transmits the two operating modes purely from input to output, as shown in Figure 4.

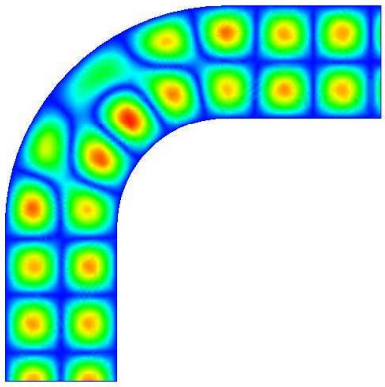

Figure 4: Dual-moded H-plane bend. TE_{10} and TE_{20} pass from input to output unmixed.

5.2 Jog (Bend) Converter

An inner-wall radius-of-curvature of 2.68 cm couples exactly half the power from either mode into the other at 45º. This is used at the extractor input above. A straight section of about 0.74 cm is enough to adjust the relative phase so that a second such bend in the opposite direction completes the mode conversion. Such a "jog converter" is shown attached to the extractor through port in Figure 3.

By extending the straight section by 5.56 cm, half a beat wavelength, and keeping the bends in the same direction, one can change this design into a 90º "bend converter" if both these functions are desired.

5.3 Height Taper

It has been assumed that the rectangular guide components described above will be built with an overmoded height (propagate modes with non-zero second index) in order to reduce surface fields and match the taper converter. At points in the rf system such as the klystron outputs and the structure inputs, it is necessary to transition to single moded waveguide. We have a double-stepped height taper design that goes from WR90 (height=1.016 cm) to our design height in less than 2.5 cm.

5.4 Overmoded E-Plane Bend

Our power combining layout requires some E-plane bends for which it is convenient to be in full height guide. Bending, again in WR90 width, with an inner wall radius-of-curvature of 5.84 cm couples strongly to the TM_{11} mode but returns to pure TE_{10} at 90º, as seen in Figure 5. The field enhancement is strong, but we only need it to carry ¼ of the total power.

6 CONCLUSION AND PLANS

We have described a number of overmoded passive microwave components in rectangular waveguide designed for very-high-power, narrow-band operation at x–band. These allow us to manipulate, in various ways, rf in a dual-moded, pulse compressing power distribution system for the NLC. We have exploited planar symmetry in designs independent of height to increase the power carrying capacity of our system. Our goal has been surface fields < 40 MV/m at full power. The absence of small apertures in our designs is beneficial from the standpoints of both rf breakdown and vacuum conductance.

We have built a low-power cross potent superhybrid and characterized it, with very satisfactory results. High-power components are scheduled to be built soon and tested above 600 MW in the coming year.

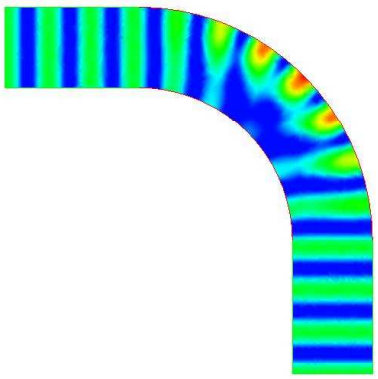

Figure 5: Overheight E-plane bend. No power is left in the coupled TM_{11} mode at the end.

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., “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, NY, March 29-April 2,1999.

[3] H. Mizuno and Y. Otake, “A New Rf Power Distribution System for X Band Linac Equivalent to an Rf Pulse Compression Scheme of Factor 2^N,” presented at the 17th International Linac Conference (LINAC 94), Tsukuba Japan, August 21-26, 1994.

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

[5] 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.

[6] 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.