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HIGH-POWER RF DISTRIBUTION SYSTEM FOR THE 8-PACK PROJECT*

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Abstract

The 8-Pack Project at SLAC is a prototype rf system whose goal is to demonstrate the high-power X-band technology developed in the NLC/GLC (Next/Global Linear Collider) program. In its first phase, it has reliably produced a 400 ns rf pulse of over 500 MW using a solid-state modulator, four 11.424 GHz klystrons and a dual-moded SLED-II pulse compressor [1]. In Phase 2, the output power of our system has been delivered into the bunker of the NLCTA (Next Linear Collider Test Accelerator) and divided between several accelerator structures for beam acceleration. We describe here the design, cold-test measurements, and processing of this power distribution system. Due to the high power levels and the need for efficiency, overmoded waveguide and components are used. For power transport, the TE_{01} mode is used in 7.44 cm and 4.064 cm diameter circular waveguide. Only near the structures is standard WR90 rectangular waveguide employed. Components used to manipulate the rf power include transitional tapers, mode converters, overmoded bends, fractional directional couplers, and hybrids.

INTRODUCTION

As part of the research and development for the future linear collider, SLAC has undertaken the 8-Pack Project, its goal being the realization of a working prototype rf system of the type envisioned for a machine powered by warm X-band technology, as in the NLC/GLC (Next/Global Linear Collider) designs. Employing a state-of-the-art solid-state modulator, four 50 MW klystrons, dual-moded transmission waveguides, and a novel dual-moded SLED-II pulse compression system, this project has had remarkable success in reliably generating 400 ns flat compressed pulses of 500 MW and above. This phase of the project is reported on elsewhere [1,2].

In this paper, we describe Phase 2 of the 8 Pack Project, in which the power produced in Phase 1 is used to conduct gradient tests and accelerate beam in accelerator structures. To this end, we have designed and constructed an rf distribution system to transport the high power pulses into the NLCTA (Next Linear Collider Test Accelerator) bunker and distribute them between several structures. As the use of overmoded waveguide and components is dictated by the need for high power-handling capacity and reasonable efficiency, such a system is non-trivial. Indeed, the interface between power sources and the accelerator represents an important part of an rf module, increasingly so as the design has moved toward higher peak-power pulses and shorter structures, requiring more division.

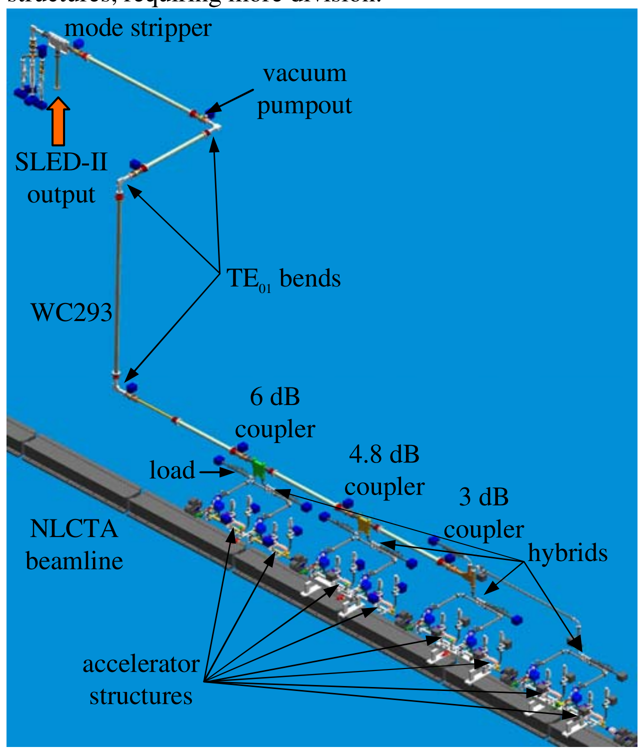

Figure 1: Physical layout of the distribution system from the 8-Pack pulse compressor to the accelerator structures.

SYSTEM LAYOUT

A scaled graphical representation of the distribution waveguide system, picking up from the output of the SLED-II system, is shown in Figure 1. The dual-moded nature of the Phase 1 system [3], along with the project title, is a vestige of the originally conceived configuration (retained for power source versatility and to test components capable of accommodating either option). The distribution system uses only the TE_{01} mode in circular waveguide. A “mode stripper” thus replaces the splitter that previously divided the output power into a series of eight loads. It directs any TE_{11} power due to source mismatch/misphasing into a smaller four-load tree while bending the desired power horizontally.

Due to the position and orientation of our pulse compression system, three more overmoded 90° bends are required to bring the power parallel and in close proximity to the NLCTA beamline. The vertical run penetrates the roof of the concrete bunker housing the accelerator.

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While components are fitted with circular flanges of 1.6 inches (4.064 cm), transmission runs of significant length are made in 2.93 inch (7.442 cm) guide, for which the attenuation is reduced by a factor of nine. Short tapers connect these diameters.

Directional coupler power dividers are shown to split off first one fourth, then one third, and finally one half of the power flowing along the main transmission line. The power can thus be split equally between four pairs of structures. Directional couplers are used, rather than three-port tap-offs, so that the structures will be uncoupled in case of breakdown reflections. High-power loads are installed on the fourth ports.

A second level of power division, between each structure pair, is accomplished with hybrids of the "magic H" type [4]. Although the hybrids have double height interiors, this part of the distribution system, including bends and diagnostic directional couplers, uses standard WR90 waveguide. The power is low enough and this provides mechanical flexibility needed at the accelerator structure inputs.

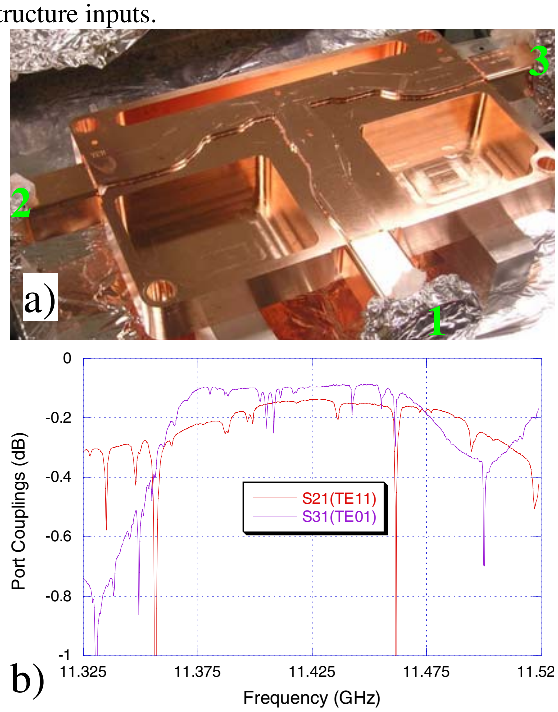

Figure 2: a) Mode stripper with brazed circular-to-rectangular tapers. TE_{11} power at the bottom input port is directed to the left port (as TE_{01}) and TE_{01} power is directed to the right port. b) network analyzer measurements of TE_{11} (red) and TE_{01} (purple) transmission. Losses and bandwidths are dominated by the mode launchers used for cold tests.

OVERMODED COMPONENTS

While circular flanges are used at all overmoded joints in the distribution system, the interiors of several components manipulate power in the TE_{10} and TE_{20} modes of over-height (1.435 inch) rectangular waveguide, as in the Phase 1 components. This facilitates the design of such components without unduly limiting their power-handling capacity. The transition from and to circular TE_{01} at the ports is accomplished with mode converting tapers described in [5].

Mode Stripper

The "mode stripper" removes TE_{11} power propagated past the pulse compressor by the Phase 1 system. In a final rf system, such power would never be launched, but rather dumped directly into a high-power load through the combining hybrid. It is in essence the same as the input of the SLED-II head which directs the modes through or past SLED-II.

After conversion of circular TE_{01} and TE_{11} into rectangular TE_{20} and TE_{10} respectively, a slight jog couples the latter two modes, creating a 50/50 mix from either. A T-junction follows, matched for both modes and precisely spaced so that the orthogonal mixes resulting from either input add in one port and cancel in the other. After a width taper and mode-converting jog, more pronounced than the mixing jog, the power sent either way enters a rectangular-to-circular converter as TE_{20} to emerge at the port as TE_{01}. Figure 2 shows the actual device and cold test measurements. TE_{11} leakage to the TE_{01} port was -39 dB.

Bends

The system uses three compact, high-power 90° TE_{01} bends. The 1.600 inch diameter ports give an effective bend radius of less than ten inches. This component is composed of two circular-to-rectangular tapers and a simple overmoded rectangular H-Plane bend. The latter is designed such that TE_{10} and TE_{20} are allowed to mix in the interior but the input mode is restored at the end. Although we use the bend here only for TE_{01}, it is actually a dual-mode bend, working equally for TE_{11}, albeit restricted to the H-plane. Figure 3 shows a drawing of the component and a field simulation of the interior.. Losses measured through these bends were on the order of one percent.

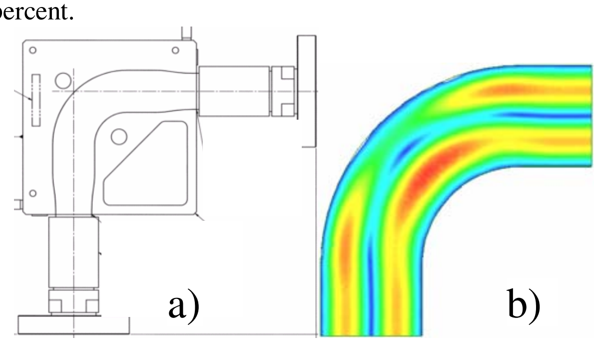

Figure 3: a) High-power TE_{01} bend with converters and b) electric field plot of interior overmoded rectangular H-plane bend.

Fractional Directional Couplers

To divide power between eight structures, one could use three levels of binary hybrid splitting. To provide more flexibility (e.g. to be able to feed six structures) we chose rather to use hybrids only for the lowest level of splitting between pairs of structures and fractional power dividers in series in the main transfer line to extract the appropriate power for each pair – first 1/4, then 1/3 of what remains, and finally 1/2. The interior of the latter is identical, except in height, to the lower level hybrids. The former two have modified designs of the same geometry [6], for which the phase length difference of the interior waveguide for the two modes it supports is appropriately adjusted. The planar design of the 1/4, or 6 dB, directional coupler, along with an electric field plot, is shown in Figure 4a.

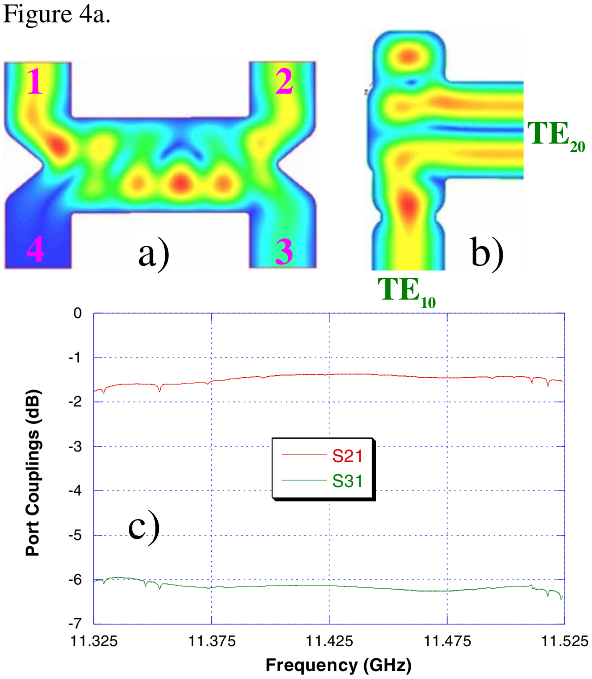

Figure 4: a) 6 dB directional coupler geometry with electric field plot, b) TE_{10}-TE_{20} mode converter attached to upper ports with field plot, and c) network analyzer measurement of power split through the device.

A new feature incorporated into two of these directional couplers is a compact right-angle TE_{10}-TE_{20} converter [5] at each port connected to the TE_{01} transfer line. It connects the 0.900 inch wide rectangular port to the rectangular-to-circular taper, replacing a mitred bend, width taper, and jog converter used in the previously fabricated 3 dB coupler. Its shape and function are shown in Figure 4b. To the lower coupler ports are brazed smooth height tapers down to WR90, through which the forward port is connected to a hybrid and the reverse port to a load.

Figure 4c is a plot of the coupling S parameters of the 6 dB coupler. The measured loss, correcting for the cold test mode launchers, is ~2%, and the split 66.3%/33.7%. For the 4.8 dB coupler, these numbers were ~0.6% and 75.1%/24.9%. For the 3 dB coupler, they were 1.3% and 49.5%/50.5%. Port matches and isolations measured from -34–-59 dB. Cold tests of the four WR90 hybrids (with double height interior) showed losses ranging from 0.8%–1.7%, largely attributable to the measurement flange adaptors, and split ratios differing from unity by 0.67% on average, 1.6% maximum.

PERFORMANCE

The rf distribution system described here has not yet been fully installed. As an intermediate step, we have powered only the last four structures with the 8-Pack by omitting the 6 dB and 4.8 dB directional couplers. The WR90 run to the final structure pair shown in the main transfer line was replaced with 1.6 inch circular waveguide to reduce losses and the risk of rf breakdown. As with any overmoded system, care had to be taken during installation to avoid resonances.

In this configuration, we have successfully performed months of high-gradient accelerator structure testing, running at the 300 MW level. Processing of the system was quick and painless, driven by the structures, although the upstream components see only about half their intended power. From the output of SLED-II to the diagnostic directional couplers at the inputs of the structures, the average efficiency of the system was measured to be ~85%, without noticeable distortion of the tailored pulse shape. An anomalously large difference (on the order of 10%) between powers measured at structures 7 and 8 may be due to a calibration error (At tens of megawatts, measurements must be made through ~95 dB of attenuation.). This will be further investigated when the structure installation schedule allows.

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