EXPERIMENTAL DEMONSTRATION OF AN RF SYSTEM FOR THE X-BAND LINEAR COLLIDER *

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Abstract

Designs for a future X-band linear collider (NLC/GLC) require an rf unit that can produce 450 MW to feed eight 60 cm accelerator structures. The implementation of this rf unit is envisioned to include a dual-moded SLED-II pulse compression system, with a gain of approximately three at a compression ratio of four, followed by an overmoded transmission and distribution system. We describe the tunnel layout plan for these rf systems. The design, construction, and operation of a prototype system are a focus of the 8-Pack project at SLAC. In its initial phase last fall, powered by four 50 MW X-band klystrons sharing a common 400 kV solid-state modulator, the SLED-II system delivered to a set of loads 400 ns pulses of up to 580 MW. In the next phase, this power will be delivered to the NLCTA beamline and distributed between several structures, through which a bunch train will be accelerated. We describe the layout of this system and the functionality of various overmoded, high-power components which comprise it. We also present data on the cold testing, processing and initial operation of the system, which is setting high-power records in pulsed rf.

1 INTRODUCTION

The high-energy physics community desires an electron-positron linear collider with an energy reach of 0.5—1 TeV. A leading contender for the design of such a collider uses X-band rf at a frequency of 11.424 GHz to power copper accelerating structures. Development of an X-band design and the technology required by it has represented for the past several years an area of strong research in the United States and Japan.

In addition to high-power modulators, klystrons and accelerating structures that can reliably sustain gradients of 65 MV/m (unloaded), the X-band design requires a waveguide system to compress, transmit, and distribute the rf pulses to the structures. The demonstration of such an rf system, capable of handling peak power levels on the order of half a gigawatt, has been a focus of the so-called 8-Pack Project at SLAC. The name derives from the original plan to demonstrate an eight-source DLDS system [1]. Ultimately the project was recast to include a dual-moded SLED-II pulse compressor [2,3], in line with the evolved baseline linear collider design (see Fig.1). In the following sections, we will describe the layout and functionality of the 8-Pack rf system. We will then briefly consider component design and performance. Finally, we will present results of high-power operation.

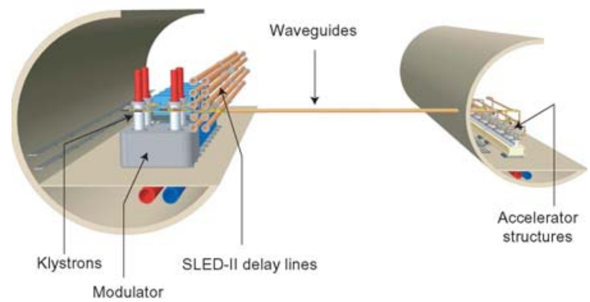

Figure 1: X-band linear collider two-tunnel layout, showing overlapping SLED-II delay lines, klystrons sharing a modulator, and a waveguide system transporting and distributing power to a set of accelerating structures.

2 THE RF SYSTEM

The prototype rf system which we've built and demonstrated is illustrated in Fig. 2. Four 50 MW XL-4 X-band klystrons are powered by a state-of-the-art 400 kV solid-state modulator. Their 1.6 microsecond outputs are combined in pairs, providing two sources to the combiner at the bottom of the upright overmoded circuit.

Depending on the phase of the inputs, this combiner can launch the circular TE_{01} mode, which emerges compressed at the top of the system, or the TE_{11} mode, which bypasses the pulse compressor. This dual-mode feature, a vestige of former plans, could be used, in a slightly modified configuration, for binary pulse compression. Dual-mode directional couplers before and after the SLED head provide diagnostics. With powers balanced and phase adjusted by manual attenuators and phase shifters in the waveguides driving the klystrons from TWT's, we launch TE_{01}.

The SLED head divides the power through a hybrid between two iris-coupled resonant delay lines. The combined reflected power is directed forward through the fourth port. The delay lines themselves are dual-moded, in a way that allows them to be about half as long as would otherwise be required. With a 17 cm diameter, they can support six TE_{0n} modes. Two are used. TE_{01} is converted

* Work supported by U.S. Department of Energy contracts DE-AC03-76SF00515 and W-7405-ENG-48.

upon reflection at the end of the lines to TE_{02}. As the wavefront returns to the input end, it is reflected by the input taper, which passes only TE_{01}. After a second round trip, during which it is reconverted to TE_{01}, it again sees the iris. Thus a 400 ns delay is accomplished in ~29 m.

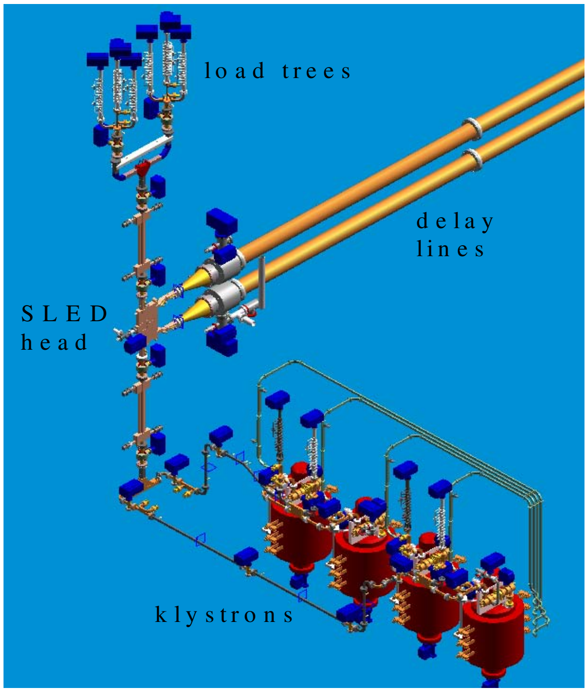

Figure 2: Phase 1 layout showing klystrons and the dual-moded SLED-II pulse compressor.

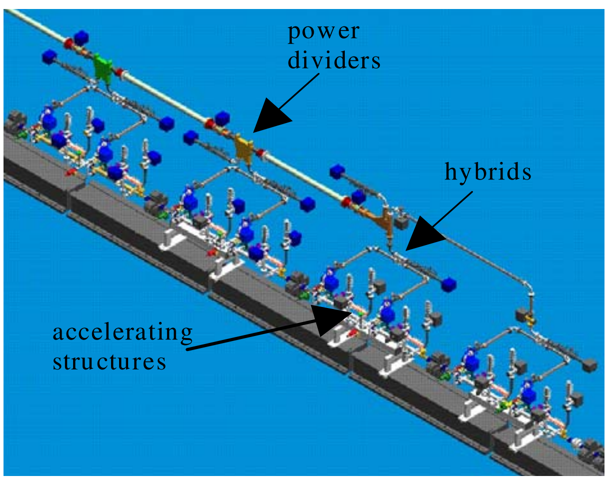

Figure 3: Phase 2 distribution circuit.

In the Phase 1 layout of Fig.1, the circuit is terminated by a dual-mode splitter, matched for both TE_{01} and TE_{11}, and two load trees, each of which further divides the power between four high-power loads [4]. For Phase 2, the splitter is being replaced by a mode stripper, which provides a single load tree termination for any TE_{11} power, while directing TE_{01} to a transport waveguide. This overmoded waveguide incorporating three bends, will deliver the compressed power through the roof of the Next Linear Collider Test Accelerator (NLCTA) bunker. There it will be passed through a series of power dividing directional couplers of approximately 1:3, 1:2, and 1:1 ratios, as shown in Fig. 3. Thus will the power be roughly divided between four pairs of structures. The final division for each of these outputs is done with a "Magic H" hybrid [5], and the connecting plumbing with WR90. A Phase 2a arrangement during which only four structures will be fed by this system is being installed this month.

3 RF COMPONENTS

The 8-Pack rf system includes many novel overmoded waveguide components which perform various functions. Most are described elsewhere [3,5,6]. Special circular-to-rectangular cross section tapers allowed us to use oversized rectangular waveguide modes in the interior of some components for simpler manipulation. Fig. 4a) shows a photo of one such component, the mode stripper, with three 4.06 cm circular ports. TE_{11} power entering the lower port (1) is directed to the left port (2), while TE_{01} power is directed to the right port (3). Both output ports use the TE_{01} mode. Cold test results are shown in Fig. 4b). The 2-3% loss shown includes the loss in the mode converters used for cold testing, which is of the same order. All port matches and isolations for this device measured better than –30 dB.

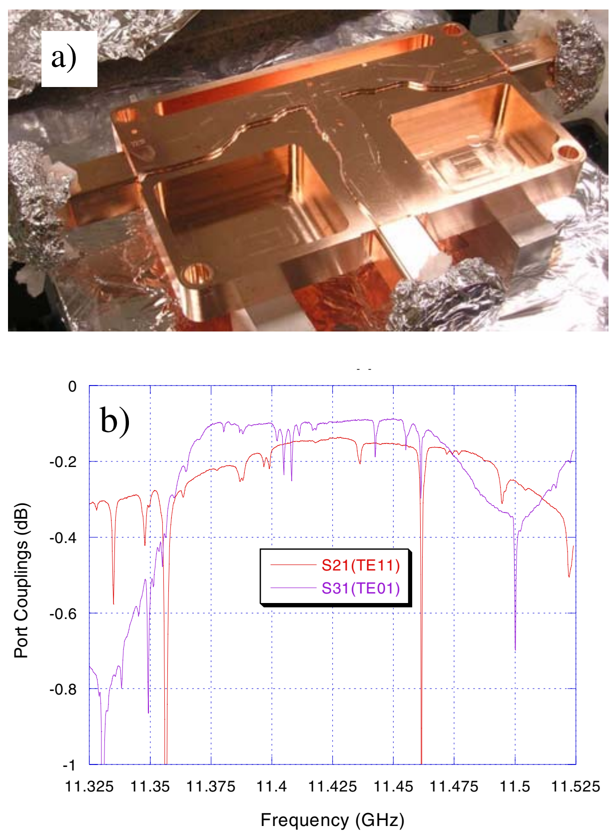

Figure 4: a) Mode stripper and b) cold test measurements.

4 EXPERIMENTAL RESULTS

Phase 1 of the 8-Pack project, concluded in February, successfully demonstrated the basic system, as well as the power handling capacity of the components. There were some obstacles to be overcome.

The SLED-II iris flanges were custom made to correct a small phase length difference on the SLED head side that affected directivity. The delay line tapers were tested in different combinations and the optimal resonant positions of the shorting plunger mode converters (three lie within the range of each) were determined. This allowed us to eliminate small mid-bin steps in the output pulse caused by mode impurities at the –30 dB level. A spacer had to be removed to avoid a parasitic resonance in the overmoded input line between the combiner and SLED head. A period of processing was required to outgas the large surface area of the delay lines. A breakdown bottleneck in ramping up the power turned out to be a bad length of WR90 connecting the further two klystrons to the combiner. It had been badly oxidized by a vacuum leak during in-situ baking and was replaced.

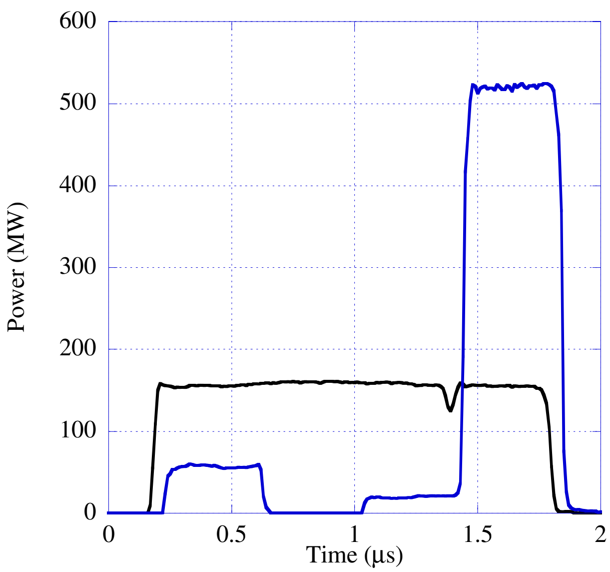

Figure 5: Peak power meter measurements of high power waveforms. The black trace is the input power and the blue trace is the output of the pulse compressor

Eventually, the goal of 475 MW was surpassed, as was 500 MW. A remaining problem with the pulse shape was solved by changing the low-level rf drive system. The four channels were replaced by a single, shared signal, and each pair of klystrons was driven by a single TWT. Two arbitrary waveform generators driving an I/Q modulator were incorporated. A PC controlled the arbitrary waveform generators, and the phase and amplitude of the SLED-II input pulse were measured and acquired by the PC through a digital oscilloscope. A feedback code was written to correct amplitude and phase in small time steps across the combined SLED input pulse.

The final result was a 400 ns flat compressed pulse of X-band rf with peak power exceeding half a gigawatt. The calibrated peak power meter waveforms can be seen in Fig. 5. Calorimetric power measurements were used to confirm the rf calibration. The gain through the dual-moded SLED-II for a compression ratio of four was approximately 3.1 out of an ideal lossless gain of 3.44.

An extended run of round-the-clock 500 MW operation was undertaken to demonstrate the reliability of the system, accumulating 357 hours at a repetition rate of 30 Hz and 99 hours at 60 Hz. While more frequent faults occurred due to causes such as klystron pulse tearing, WR90 breakdown, and human interference (the latter minimized by implementation of automated SLED tuning), the rate of faults attributed to breakdowns in the overmoded rf system fell comfortably below the goal limit of 0.083 per hour (one in 1.3 million pulses).

5 CONCLUSION

We have successfully designed, constructed, and demonstrated an rf station capable of reliably providing pulsed rf power at pulse width and power levels required for driving a set of eight 0.6 m accelerating structures at the design gradient of 65 MV/m. This satisfies the current design envisioned for an X-band, warm linear collider. The pulses of 400 ns and 500 MW (200 J), represent a major achievement in pulsed rf power. Years of overmoded component development have born fruit in this pulse compression system which has finally tested their power-handling capability.

6 REFERENCES

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