TRC R1 # 2

> The other critical element of the rf system is the dual-moded SLED-II pulse compression system. Tests of its rf power and energy handling capability at JLC-X/NLC design levels are planned in 2003. As far as the 75 MW X-band PPM klystron is concerned, the Working Group considers the JLC-X PPM-2 klystron a proof of existence (although tested only at half the repetition rate). A similar comment can be made regarding the solid-state modulator tested at SLAC.

Summary:

This TRC R1 requirement has been satisfied. The high power rf test station in NLCTA reached the goal of 475 MW at 400 ns pulse width on December 4, 2003, and has been run since for about 100 hours. It later reached a peak output power of 580 MW at 400 ns – the highest X-band peak power that has been generated at SLAC (or likely anywhere else), and over 20% higher than design.

Recent results:

The 8-Pack Project at SLAC is a joint effort with KEK, FNAL, LLNL and Bechtel Nevada. It is a feasibility demonstration of the rf system proposed for GLC/NLC. A state-of-the-art solid state modulator provides 400 kV pulsed power to a set of four 50 MW solenoid-focused X-band klystrons feeding a Multimoded SLED-II [1,2] pulse compression system. Phase I has achieved its design goal by producing 400 ns compressed rf pulses with greater than 475 MW peak power. Figure 1 shows the input and output pulses during high power operation. In Phase II of the project, the compressed power will be brought into the NLCTA tunnel and distributed to 8 accelerator structures. This will complete a demonstration of an X-band rf sub-unit as specified in TRC R2 #2.

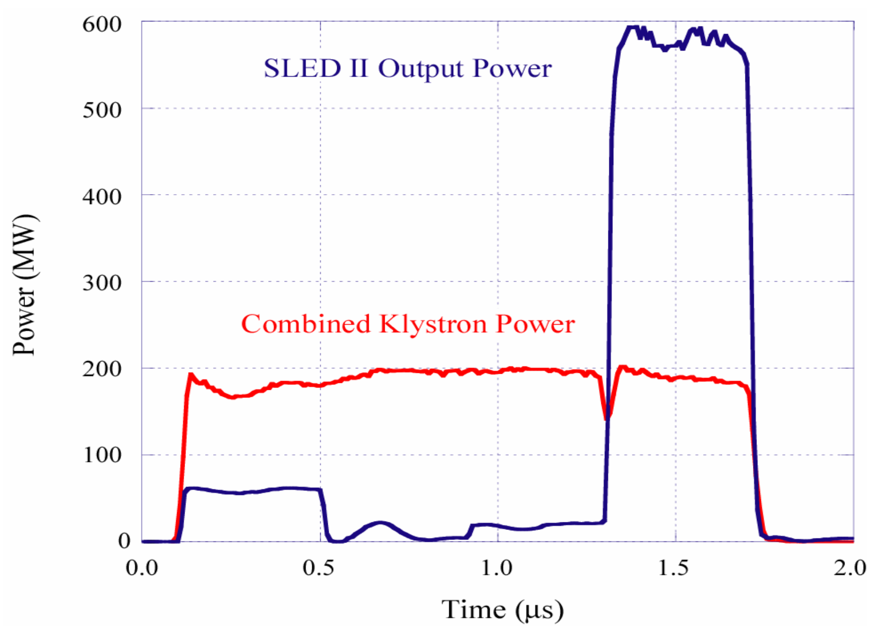

Fig. 1. Power meter measurements of input and output pulses during high power operation. The 500 MW level was reached and soon significantly surpassed.

Overview of the system:

The layout of the system is pictured in Figure 2. The four klystrons are powered from a common solid state modulator and driven through TWT's, providing a nominal 200 MW input at a pulse width of 1.6 μs. The outputs of these klystrons are combined in pairs through planar hybrids [3]. WR90 waveguide carries the combined rf from each of these klystron pairs to a port of the dual-mode combiner. This combiner is a three-port device, whose third port launches power from the single-moded inputs into overmoded circular waveguide in either the TE_{11} or TE_{01} mode, depending on the relative phase of the inputs.

The total combined power is fed into the SLED Head [4] which, depending on the klystron relative phasing, directs the power to the dual-moded SLED-II pulse compressor or bypasses it. Thus, the system can be run in compressed (TE_{01}) or uncompressed (TE_{11}) mode. Before and after the SLED Head are dual-mode directional couplers in circular waveguide for monitoring the power in each operating mode. A series of splitters divides the output power so that it can be sent into eight high-power loads.

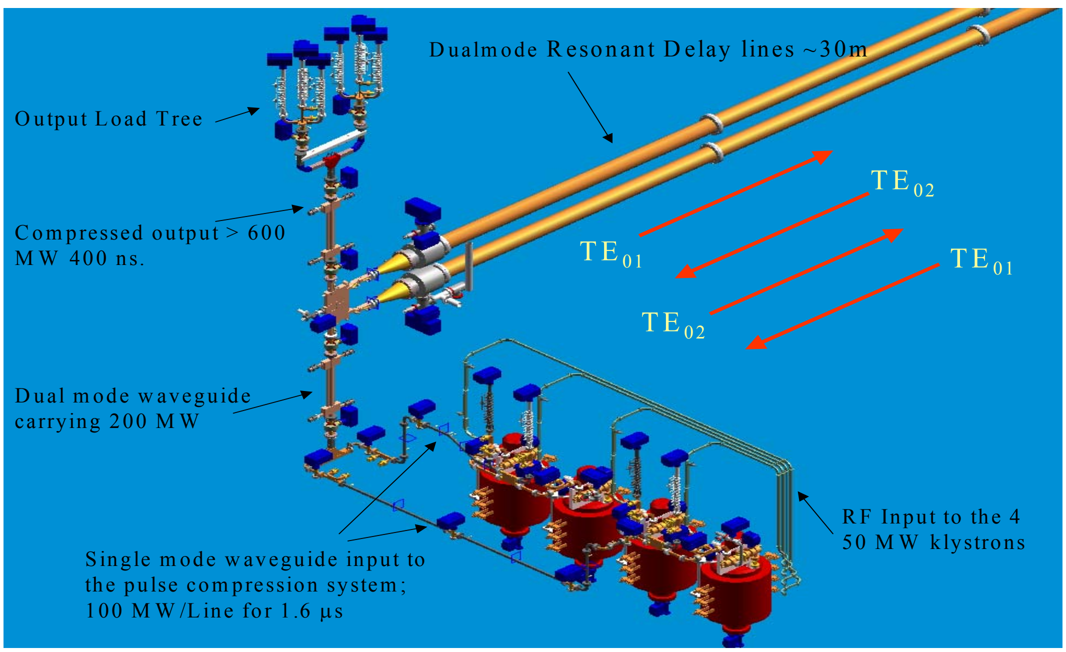

Fig. 2. Isometric layout of the 8-Pack RF system with dual-moded SLED II pulse compressor.

The pulse compressor consists of two highly-overmoded, iris-coupled, resonant delay lines, attached to two additional ports on a hybrid section of the SLED Head. These delay lines, roughly 30 m long in 17 cm circular waveguide, are also dual-moded. Here dual moding refers to the fact that they are designed to operate in both the TE_{01} mode and the TE_{02} mode, simultaneously. A mode converting reflector at the end of each line transfers power between these two modes. Since TE_{02} is cut off at the input taper of each line, it takes two round trips between each time the wave can impinge on the coupling iris. This effectively doubles the delay time for a line of given length, allowing the system to be considerably more compact than would be a standard SLED-II for the desired compressed pulse width. The reflectors are mounted on accurately centered, steppingmotor driven vacuum feed-throughs for resonant tuning of the lines. With a 400 ns double-bounce delay, we get a compression ratio of four from our 1.6 μs input and a gain, in the phase-flipped last time bin, of approximately 3.

In the development of this rf system, power handling capacity was a chief concern and the use of overmoded components was a necessity. The designs and functionality of the passive waveguide components are described in more detail elsewhere [5]. Many components, including the combiner, SLED Head, splitter, mode-converting and mode-mixing jogs, and bends, manipulate the rectangular TE_{10} and TE_{20} modes in oversize waveguide rather than the circular TE_{11} and TE_{01} modes. This reduces the fields in the components to be less than ~40 MV/m at full power.

Before and during installation, components were individually cold tested with a network analyzer and results were quite satisfactory, with reflections typically well below -30 dB. Gains from measurements on each SLED line were in the range of 2.9 to 3.2, out of an ideal 3.25. Both lines together, with the SLED Head and directional coupler in the circuit produced gains of approximately three. After completion of installation, the system was pumped down and carefully baked, after which vacuum levels on the order of 10^{-9} Torr could be reached. Then high power operation commenced, and after correcting a few minor problems, the goal of more than 475 MW at full 400 ns pulse width was rapidly reached. Work is still needed to improve the low-level rf system to better flatten the pulse in amplitude and phase and to identify and correct the additional losses.

References:

[1] P.B. Wilson, Z.D. Farkas, and R.D. Ruth, "SLED-II: A New Method of RF Pulse Compression," presented at the Linear Accelerator Conf., Albuquerque, NM, September 10-14, 1990.

[2] S.G. Tantawi and C.D. Nantista, "Multimoded RF Components and Their Application to High-Power RF Pulse Compression Systems," presented at the XXI International LINAC Conference, Gyeongju, Korea, August 19-23, 2002; SLAC-PUB-9502.

[3] 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.

[4] C. D. Nantista and S. G. Tantawi, "A Compact, Planar, Eight-Port Waveguide Power Divider/Combiner: The Cross Potent Superhybrid," IEEE Microwave Guided Wave Lett., vol. 10, no. 12, pp. 520-522, December 2000; SLAC-PUB-8771.

[5] S. G. Tantawi and C. D. Nantista, "Recent Advances in RF Pulse Compressor Systems at SLAC," invited talk at the 6th Workshop on High Energy Density and High Power RF (RF 2003), Berkeley Springs, West Virginia, June 22-26, 2003.