HIGH POWER RF COMPONENT TESTING FOR THE NLC*

A.E. Vlieks, W.R. Fowkes, R.J. Loewen, S.G. Tantawi
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309, USA

Abstract

In the Next Linear Collider (NLC), the high power rf components must be capable of handling peak rf power levels in excess of 600 MW. In the current view of the NLC, even the rectangular waveguide components must transmit at least 300 MW rf power. At this power level, peak rf fields can greatly exceed 100 MV/m. We present recent results of high power tests performed at the Accelerator Structure Test Area (ASTA) at SLAC. These tests are designed to investigate the rf breakdown limits of several new components potentially useful for the NLC. In particular, we tested a new TE_{01}–TE_{10} circular to rectangular 'wrap-around' mode converter, a modified (internal fin) Magic Tee hybrid, and an upgraded 'flower petal' mode converter.

1 INTRODUCTION

In SLAC's version of the NLC, sources, such as klystrons, transport rf power to accelerator structures primarily in circular overmoded waveguide. Various rf components—such as mode converters, 90° bends, and 3-dB hybrids (each consisting in part of single-moded rectangular waveguide)—route rf power from one circular guide to another.

In order to verify that these components can handle the required power levels of up to 300 MW, we conducted a series of tests to establish breakdown limits and to investigate mechanisms of breakdown. We present the results of experiments, which led to the identification of components capable of operating reliably at rf power levels in excess of 300 MW. In earlier tests [1], two key components of SLED-II—a $TE_{01}^{(circ.)}$–$TE_{10}^{(rect.)}$ flower petal mode converter and the Magic Tee hybrid—failed at a power level of 220–250 MW [2]. These components were modified and subsequently retested along with the newly designed wrap-around mode converter.

2 EXPERIMENT

2.1 General Layout

The general setup is shown in Figure 1. The experimental setup consists of an rf source, a SLED-II pulse compressor, and a high power load assembly. Two 50 MW klystrons operating at 11.424 GHz supply the rf power. The pulse width of each klystron is 1.05 μs running at a repetition rate of 60 Hz. Each klystron is driven by its own TWT driver which in turn is driven by a common signal generator. The power from these klystrons combine through a Magic Tee 3-dB hybrid and feed the input to the SLED-II system. The combiner was previously conditioned to full klystron power by being connected to the load assembly.

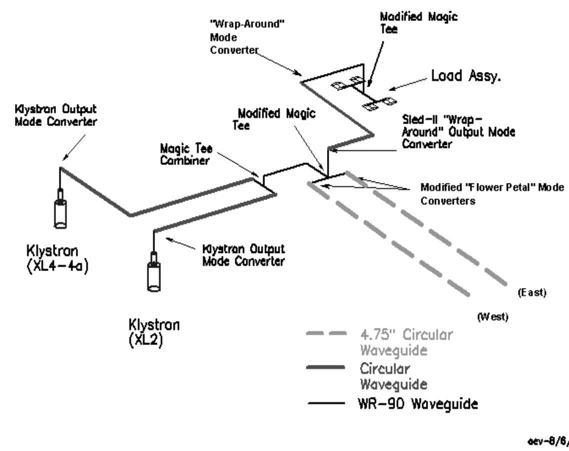

Figure 1. Schematic of the initial experimental setup.

The SLED-II pulse compression system operates with a compression ratio of 7 and a peak power gain of ≈4. Hence, this configuration can potentially yield up to 400 MW of peak power with a flat top of 150 ns. The primary components under test are the 3-dB hybrid, the two delay line mode converters, and the output mode converters.

The load assembly consists of four choked, stainless steel 'dry' loads [3] arranged in parallel. (A Magic Tee first splits the incoming power and then two additional Magic Tees divide each of the split power levels again.) In earlier tests, an individual load of this type was successfully tested to ≥100 MW at a pulse width of 150 ns.

2.2 Preparation

During all phases of the experiment, the vacuum system is baked out to approximately 150°C for at least 24 hours (plus a ramp-up/cool-down of 24 hours each). At the end of this cycle, the vacuum in the system is $\leq 1\times10^{-9}$ Torr. In addition, any new components added to the system during the course of the experiment are first high temperature baked to 400°C before installation in order to remove residual hydrogen and other contaminants.

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2.3 Initial Experiment

In the first phase of the experiment, two modified flower petal mode converters were installed in the SLED-II delay lines. As described in [1], these components are modified from an earlier design to alleviate the rf erosion at the bifurcation in the rectangular waveguide section. The 3-dB hybrid is a modified Magic Tee configured with the H-arm as input and the E-arm as output. The modification consists of replacing the matching post in the throat of the Tee by a broad fin with fully rounded corners and rounding the edges at the E-arm throat. (This was motivated from witnessing significant erosion of the post during previous testing). A newly designed wrap-around mode converter was placed at the output of SLED-II.[4]

Results of the initial phase of the experiment show that all components work well up to ≈240 MW. Above this power level, there were significant rf breakdown events at the SLED-II Magic Tee as well as enhanced, steady state X-ray emission. One of the two delay line mode converters—labeled the 'West' mode converter—also exhibited enhanced X-ray emission albeit far less than the Magic Tee. The wrap-around mode converter was essentially breakdown-free and radiation levels at this mode converter were about the same level as the nearby rectangular WR90 waveguide.

Figure 2 shows typical radiation levels measured at the waveguide surface of the Magic Tee by an X-ray survey meter. One curve shows a typical dose rate when the system is well conditioned. The other curve shows the effects of conditioning. Initially, at low power levels, the dose rate is anomalously high. Then, after an rf breakdown event occurs and testing is resumed, the radiation levels reduce to the typical values. These typical values did not improve or deteriorate with time.

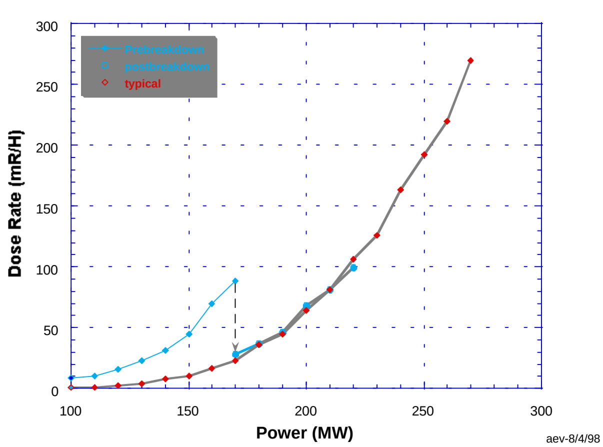

Figure 2. Radiation Intensity at the SLED-II Magic Tee.

An interesting result from radiation measurements is that the Magic Tee at the entrance of the load had much lower radiation levels than the SLED-II Magic Tee even though the peak power levels are approximately the same. It appears that the standing wave set up between the delay line iris and the SLED-II Magic Tee enhances the peak fields. Simulation verifies that the increased fields from this standing wave pattern can greatly enhance the peak fields in critical regions of the Magic Tee. It also became clear that reversing the input and output ports of this Magic Tee would significantly reduce these peak fields.

2.4 Phase Two

At the conclusion of the initial experiment, the SLED-II and load entrance Magic Tees were removed and cold tested. Their RF properties were found to be unchanged from their pre-test values although some erosion was observed in the SLED-II Magic Tee along the fin. The West delay line mode converter was also checked and found unchanged. It was decided that the positions of the two Magic Tees would be exchanged and that the new SLED-II Magic Tee would be installed with the roles of the input and output ports interchanged, i.e. now the E-arm is input and the H-arm is output. It was also decided to coat the problematic West flower petal mode converter with Titanium Nitride to try to reduce the X-ray radiation by decreasing the electron secondary emission yield.

The interchange of input and output ports of the SLED-II Magic Tee had a marked improvement on system performance. The steady state radiation level at the Magic Tee was reduced by a factor of 18. Unfortunately, the radiation levels at the West delay line mode converter remained the same with no effect due to the TiN coating. As the peak power levels approached 270 MW, it became clear that the limiting component was this mode converter. Figure 3 compares the radiation levels from the East and West mode converters and Magic Tee. It is remarkable that the radiation levels of the East mode converter are 150 times smaller than the West even though the system is apparently symmetric.

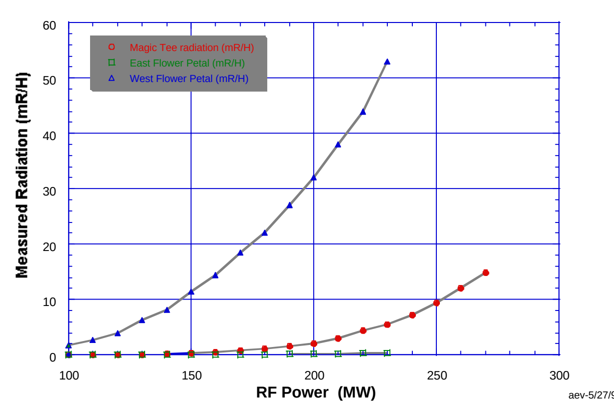

Figure 3. SLED-II Radiation levels.

To further pinpoint the location of this radiation, measurements were made through a 0.64-cm aperture of a lead-shielded survey meter in 1-cm intervals along the centerline of the mode converter (see Figure 4). The results, as shown in Figure 5, indicate that the radiation is emanating at or behind the coupling irises (or 'flower petals').

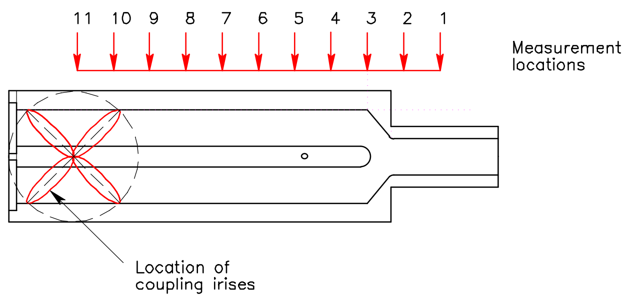

Figure 4. Location of measurement points along the rectangular portion of the mode converter. Additional measurement points are located out of the paper along the circular portion of the converter.

To estimate the energy of these X-rays, aluminum and copper absorbers of various thicknesses were used to measure the X-ray attenuation coefficient at a power level of 200 MW. Since the slope of the attenuation is quite linear (on a semi-log plot) with absorber thickness, we may assume that the walls of the mode converter selectively removed the low energy portion of the X-ray spectrum leaving only X-rays with the highest energies. Under these assumptions, we find the peak X-ray energy to be near 150 KV as shown in Table 1. For electrons accelerated from rest across the petal gap, this corresponds to a peak gradient of 510 KV/cm. This value is in excellent agreement with earlier computer simulations of 523 KV/cm at 200MW [6].

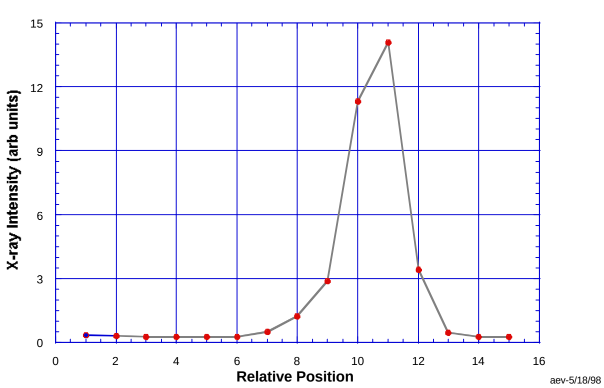

Figure 5. X-ray radiation intensity at the West flower petal mode converter at 130 MW power.

2.5 Phase Three

At the conclusion of the second phase of this experiment, both delay line mode converters were replaced with wrap-around mode converters and testing resumed.

This time we were able to drive the SLED-II system to a power level of 320 MW with no evidence that a power limit had been reached. The X-ray intensity at the Magic Tee was similar to previous measurements, and the wrap-around mode converters showed no evidence of excessive radiation (i.e. no greater than WR90 waveguide).

Table 1. Comparison of measured attenuation coefficient with tabulated values near 150 KV.

Absorber	**Measured attenuation (cm^2/g)**	**Tabulated attenuation[5]**
Copper	0.136	0.134@ 150KV
Aluminum	0.191	0.203@ 150KV 0.148@ 200KV

3 SUMMARY AND CONCLUSION

A series of experiments were performed to determine the peak power performance of various rf components. The mode converters of the modified flower petal type are adequate up to peak power levels of approximately 225 MW. Wrap-around mode converters perform well at least up to 320 MW and in all likelihood much higher. The modified Magic Tee 3-dB hybrid transmits 320 MW without difficulty but when used in applications where standing waves can enhance peak fields (such as SLED-II), the details of the installation becomes important.

At the moment, the exact reason for the heightened X-ray emission in the West mode converter is unclear. However, the measured energy of the X-rays corresponds to the expected peak field levels based on simulation.

4 REFERENCES

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