

# HIGH POWER TEST OF NEW SLED SYSTEM WITH BIPLANAR 3 DB POWER DIVIDER AND DUAL SIDE-WALL COUPLING IRISES FOR PAL XFEL

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## Abstract

The Stanford Linear Accelerator Energy Doubler (SLED) system for the PAL (Pohang Accelerator Laboratory) XFEL (X-ray Free Electron Laser) is requested to operate with an RF input power of 80 MW and a pulse width of 4  $\mu$ s. We designed a new SLED system with a biplanar 3 dB power divider and dual side-wall coupling irises by using the finite-difference time-domain (FDTD) simulation. The new SLED system proved to be a good solution that reduces the probability of RF breakdown in high powered operations. We fabricated the prototype of the new SLED system and carried out the high power RF test.

## INTRODUCTION

Since the accelerator energy is determined as an RF input peak power to the accelerating section, increasing the accelerating energy by enhancing the peak RF power at the expense of pulse time width may be a solution that does not require an increase in the average input power consumption. Based on this concept, the RF pulse compression system, called SLED (Stanford Linear Accelerator Energy Doubler), was first developed in the 1970's [1]. The SLED is a method of achieving RF pulse-compression through the use of high-Q resonant cavities. A 3 dB sidewall waveguide power divider is inserted into a waveguide between the klystron and the accelerating section as shown in Fig. 1. Two identical over-coupled cavities, resonant at the SLAC RF frequency, are connected to the remaining power divider ports. A fast-acting triggered PIN diode  $\pi$ -phase-shifter which reverses the phase of the klystron output power is inserted into the klystron drive line. At first, the cavities store klystron

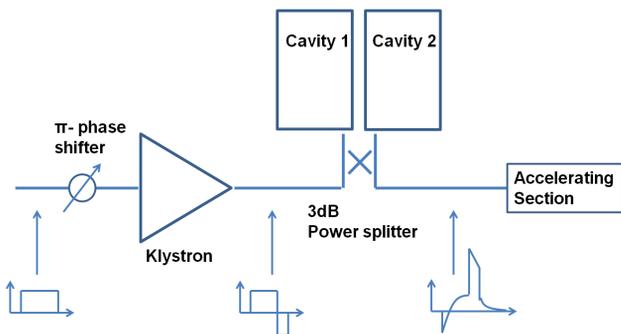


Figure 1: A schematic diagram of the SLED system in the accelerator.

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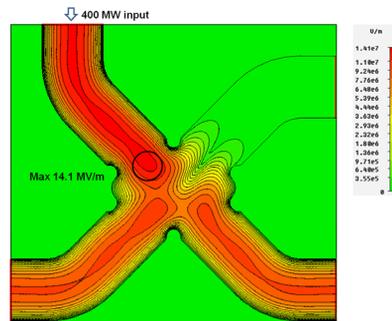


Figure 2: The simulated distribution of electric field of the new 3 dB power divider.

output power during a large fraction of each pulse. Then the phase of the klystron output is reversed, and the cavities emit stored power rapidly into the accelerating section adding to the given klystron output power during the remaining of the pulse. By this means, peak power is enhanced at the expense of pulse width without increasing the average input power consumption simultaneously.

The RF system of PAL (Pohang Accelerator Laboratory) XFEL (X-ray Free Electron Laser) project provisionally requires the klystron RF output peak power of about 80 MW and the repetition rate of 120 Hz. Consequently, it is important to design the new SLED system with low electric field and low surface current even in the high power operation.

In this study, we designed a new SLED system which consists of a biplanar 3 dB power divider and the dual side-wall coupling irises using a finite-difference time-domain (FDTD) simulation. The prototype is fabricated and tested with RF pulse power.

## BIPLANAR 3 DB POWER DIVIDER

The new 3 dB power splitter which can minimize the field gradient enhancement is designed by modifying the biplanar coupler structure [2,3]. The size of the waveguide is set to that of conventional WR284 waveguide for the S-band operation. The other structural parameters are determined by the FDTD simulation code, CST MWS [4] in order that the power split ratio is 1:1. The simulated distribution of electric field with the RF input power of 400 MW is shown in Fig.2. The maximum peak electric field is about 14.1 MV/m, which means the field gradient enhancement over the normal WR284 waveguide is only 1.05.

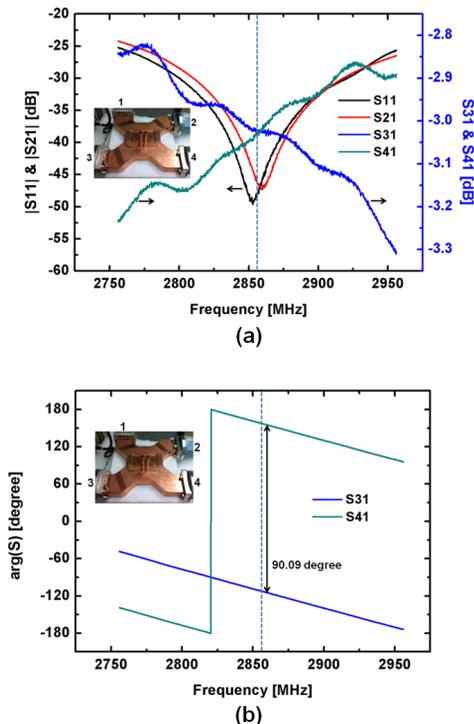


Figure 3: (a) The measured amplitude of S parameters and (b) the phase of S parameters for the prototype of the new 3 dB power splitter.

The prototype of the new 3 dB power divider is fabricated and then RF performance test is carried out using WR284 to N-type transition, matched loads, and the vector network analyzer. The experimental result of the

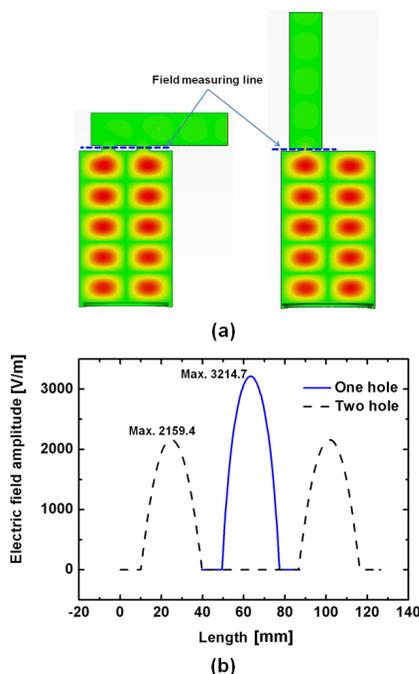


Figure 4: (a) The simulated electric field distribution of dual side-wall coupling irises and single iris waveguide-cavity and (b) The electric field amplitude along the line crossing the center of coupling iris.

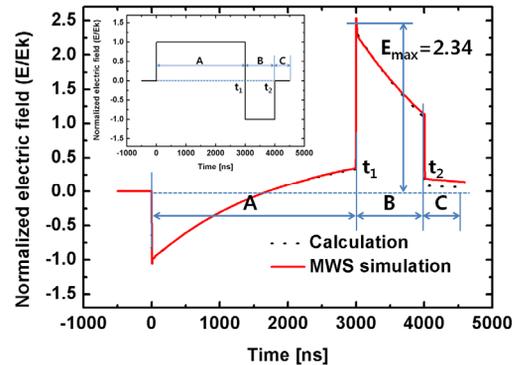


Figure 5: The SLED output waveform from the analytical calculation and MWS simulation. The input waveform is in the inset.

magnitude of S parameter is shown in Fig. 3(a), and the phase of S parameter is shown in Fig. 3(b). The prototype of the power splitter on the RF test bench is shown in the inset. The  $|S11|$  and  $|S21|$  are about -48.87 dB and -46.48 dB at the frequency of 2856 MHz, respectively. This reflection coefficient is 15 dB lower than that of the original one. That means that the field enhancement in the power divider is low because of the low standing wave ratio. The magnitudes of divided waves ( $|S31|$  and  $|S41|$ ) are -3.02 dB and -3.03 dB, respectively. In addition, the phase of the divided wave crossing the power splitter ( $\arg(S41)$ ) is delayed by 90.09 degrees from that of the other divided wave ( $\arg(S31)$ ).

### DESIGN OF DUAL SIDE-WALL COUPLING IRISES STRUCTURE

The over coupled cavity with dual side wall coupling irises is designed to relieve the serious breakdown and radiation safety hazards. The electric field at the coupling iris is decreased by making two irises for RF coupling.

The distribution of electric field of the cavity with the dual side-wall coupling irises is compared with that of the cavity with the single-iris coupling iris as shown in Fig. 4(a). The input power is normalized to 1 W. Here, the dimension of the dual side-wall coupling structure is determined so that the coupling coefficient would be the same as that of single-iris coupling structure. In order to compare the electric field amplitude at coupling iris in the cases of different coupling structures, the electric field along the line crossing the center of the coupling iris is plotted in Fig. 4(b). The maximum electric field strength

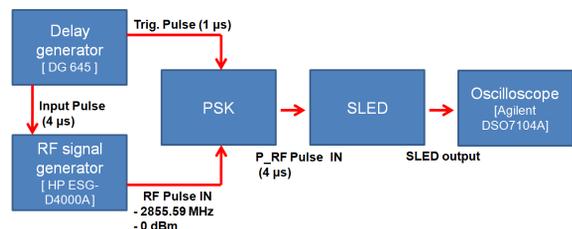


Figure 6: The pulse test setup of the new SLED system.

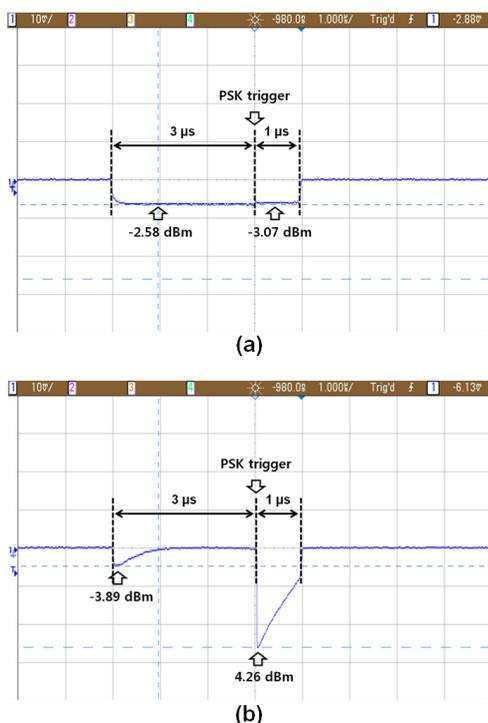


Figure 7: (a) The input pulse of the SLED and (b) the output pulse.

of the dual side-wall coupling irises is just two thirds of that of the single-iris cavity. This result is well matched with the experience that the electric field is reduced by 20-30 % when the dual side-wall irises are adopted [5].

The dimension of the cavity is determined as the length of 335.9 mm and diameter of 205.1 mm by MWS simulation. It is also found that the coupling coefficient is calculated as about 4.93 and ohmic Q factor is about 106000.

### ESTIMATION OF SLED PERFORMANCE

From the well-known SLED operation theory [1], the waveform at output of the SLED is calculated and compared with that numerically simulated using CST MWS time domain solver as shown in Fig. 5. The input wave normalized to klystron output power is shown in the inset. The MWS simulation result is well matched with that of analytical calculation. The maximum amplitude of wave reaches 2.34 times of that of the initial input wave. Therefore, the power gain of the SLED is estimated as 7.384 dB.

### LOW POWER TEST

The low power test setup is shown in Fig. 6. The input waveform is shown in Fig. 7(a). The output pulse waveform is also shown in Fig. 7(b). The power gain is calculated as 6.84 dB from the input power level (-2.58 dBm) and the output peak power level (4.26 dBm). Finally, the SLED gain becomes to 7.33 dB, because the input power level after the PSK trigger is reduced as 0.49 dB. It is similar to the estimated value.

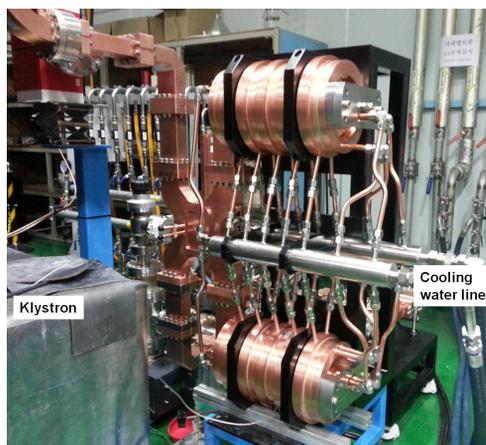


Figure 8: High power test setup for the new SLED system.

### HIGH POWER TEST

The prototype of the new SLED system is mounted on the high power test bench as shown in Fig. 8. Now the increasing of RF peak power is undergoing.

### CONCLUSION

We designed a new SLED system with the biplanar 3 dB power coupler and the dual side-wall coupling irises using FDTD simulation. The prototype is fabricated in domestic factory. The RF performance of the new SLED system is well matched with the analytic and numerical estimation. The high power test is undergoing.

### REFERENCES

- [1] P. B. Wilson, SLAC-TN-73-15 (1973).
- [2] C. G. Montgomery, R. H. Dicke and E. M. Purcell, Principles of Microwave Circuits, New York, McGraw-Hill, 1948.
- [3] J. Neilson, S. Tantawi and V. Dolgashev, Proceedings of Linear Accelerator Conference, MOP077 (2010).
- [4] CST Microwave Studio User's Manual.
- [5] H. Matsumoto, H. Baba and S. Yamaguchi, Nucl. Inst. Meth. Phys. A, A330, 1 (1993).