# High Power Operation Results of the X-Band SLED System

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*Abstract*

This report describes the results of high power operations of the X-band (11.424 GHz) SLED system. After 32 hours of 5 pps processing, the peak output reached to 59 MW with the RF input pulse of 15 MW with 470 ns duration. Up to this power level the processing had been carried out smoothly, and no serious discharge was observed. Later this system was utilized as an RF pulse compression method for the high power test of an accelerating structure.

## I. INTRODUCTION

Supplying RF pulses with high peak power of over 100 MW with 100 ns duration, it will be possible to produce very high accelerating gradient of 100 MV/m in the X-band (11.424 GHz) main linac of JLC. For realizing this plan, a lot of R&D works on microwave tubes with high output power of 100-150 MW have been carried out at KEK [1]. Recently, high output power of 80 MW with 50 ns duration was provided by the newest klystron. Side by side with these efforts, development of some RF components for high power use has been also carried out. It becomes necessary to test critical components by using high RF power of around 100 MW. The RF pulse compression is very useful as well as traveling wave resonator to generate such a high power for testing a critical component [2]. Using these it is possible to boost a relatively low power pulse with relatively long pulse length to a shorter pulse with higher peak power. The principle of operation of the RF pulse compression is reported elsewhere [3,4,5]. As a first step, the SLED system was chosen for high power test bench where the RF windows, the waveguide system including power monitor and matched load would be examined with very high peak power enhanced an output of klystron.

The SLED system was originally developed in S-band to increase the beam energy of the SLAC linac [3].

The advantage of the SLED are:

1) the assembly comprising a 3-dB hybrid and a couple of pillbox cavities were simple and compact made, so as expected to sustain high electric stress.

2) it is easy to reinstall itself in any high power RF circuit.

At the high power test-bench, in the first place, an output power of 0.5-15 MW from 30 MW class klystron (XB-50K) was supplied into the SLED assembly so as to examine its performance under high electric stress.

Maximum amplitude and decay time are depend on the Q-value and the coupling coefficient $\beta$ of the cavity. The peak voltage is obtained at time $t_1$, that is the charging time before the phase was reversed, and the theoretically calculated value for the case $t_1$=400 ns with using measured value by low level RF $\beta$=4.5, $Q_0$=52000, is 2.28 times as high as the klystron output voltage (5.2 times as high in the power). As already reported [6], the experiment with low level RF has been successfully carried out and the obtained result showed good agreement with the one calculated theoretically. Here, we report on fabrication and high power test result of the X-band SLED system.

## II. COMPONENTS

### A. *The TE-015 cavities*

Room temperature cavities made of copper (O.F.H.C.) were used as pillbox cavities for the assembly. The TE015 mode was chosen as the S-band SLED system of the SLAC. The Q-value of the each cavity were measured as 52000 and 52300, respectively. To lower the resonant frequency of the TM115 mode, a groove was circularly cut in one end-plate, also following the model of the SLAC. This groove, which was width of 1.5 mm and depth of 1.5 mm, shifted the center frequency of the TM115 mode nearly 45 MHz with no influence on the TE015 mode. A coupling aperture was drilled through the other end-plate. That was a hole, 8.2 mm in diameter with 1.5 mm thick, and finished in a round shape to avoid the breakdown. The measured coupling coefficient $\beta$ of the each cavity were 4.55 and 4.57, respectively.

### B *The 3-dB coupler*

As the 3-dB hybrid of the assembly, the Riblet short-slot coupler made with wire-cutting method was employed. Through this coupler an output of the klystron is guided to a couple of cavities, and waves from the each cavity are combined so as to add and transmitted to the load as well known. The value of coupling depends on the width and the length of the coupling region. For 3-dB coupling, they were designed 36.0 mm and 26.6 mm, respectively. A couple of posts made of copper, called as capacitive dome, were attached for fine tuning at the center of top and bottom walls of coupling region. Measured characteristics of the coupler are listed in Table 1.



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Table 1
Measured characteristics of the 3-dB coupler

| | | |
|---|---|---|
| COUPLING | (MAIN LINE) | -3.16 DB |
| | (SUB LINE) | -3.14 DB |
| PHASE DIFFERENCE | | 96.1 DEG |
| ISOLATION | | -25.0 DB |
| INPUT VSWR | | 1.09 |
| OUTPUT VSWR | | 1.15 |

This type of 3-dB coupler has relatively simple structure enough to sustain high electric stress, but actual fabrication of the model for high power use is not so easy. In this time, the microwave transmission line including the coupling region was made by cutting away the shape accurately by wire from a copper block (300 l x 70 w x 10.15 h) as shown in Fig.1, and then a couple of copper plates were brazed in a hydrogen furnace on each side of that block. Finally, four connecting flanges were attached on each port.

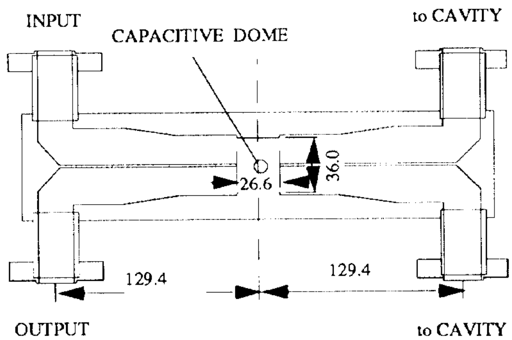


Figure 1. A cross section view of the 3-dB hybrid.

The wire-cut surface was finished within 6 microns enough to avoid serious breakdown under high electric field. A sample of measured roughness after wire-cutting on the test piece is illustrated in Fig.2.

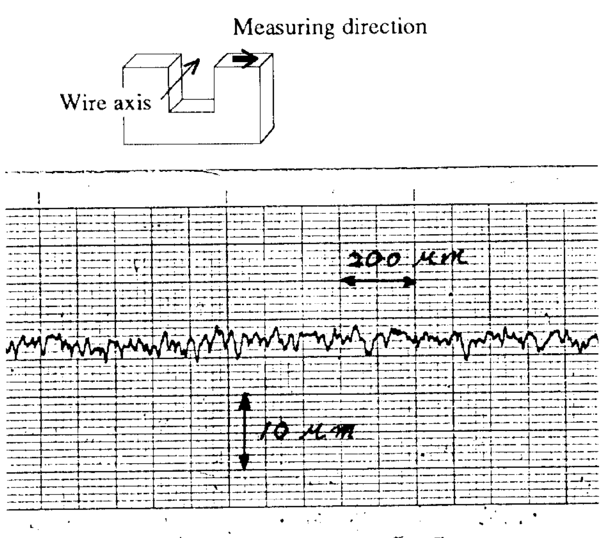


Figure 2. Measured roughness of surface after wire-cutting.

## III. TEST RESULTS

An experiment with low level RF has been successfully carried out as already reported. Peak RF power enhanced by the SLED reached almost five times as high as input RF power of which pulse width was 500 ns with the phase reversed in the rear of 100 ns. That was nearly 90% of the calculated value, so it was found that the assembly was well fabricated for practical use at the test-bench. The phase control system of the klystron input pulse was also successfully made for use. The measured time for reversing phase of input pulse was less than 3 ns. The design and fabrication of this circuit are described in detail in reference [7].

In the first aging run, high RF output of 0.5-15 MW with repetition rate 5 pps of the 30 MW class klystron (XB-50K) was supplied to the SLED system. This klystron had been operated for long time and was expected to generate relatively long pulse with high RF power. The pulse width of the klystron output was adjusted 470 ns with keeping flatness of the pulse including reversal phase time of 70 ns in the rear. Some interlock systems were prepared for protect the assembly from serious damage caused by discharge around the coupling iris of the cavities or inside of the 3-dB coupler. When reflected pulse with high peak power or abrupt out-gassing were detected, they worked so as to stop the operation. The output power of the klystron was raised step by step with careful observation on the RF ceramic window set at an output port of the klystron and on the vacuum pressure in the RF transmission line including the SLED assembly. In thirty-two hours operation, an output of the SLED was reached to 59 MW smoothly which was 4 times as high as klystron output of 15 MW. The peak power obtained in high power operation was, however, slightly lower than that expected from the test result with low level RF. This was influenced by following phenomena that the time of reversing the phase of the klystron output was longer (more than 10 ns) and reflected wave from SLED was added to the output of the klystron. Observed output signals are shown in Fig.3 and Fig.4.

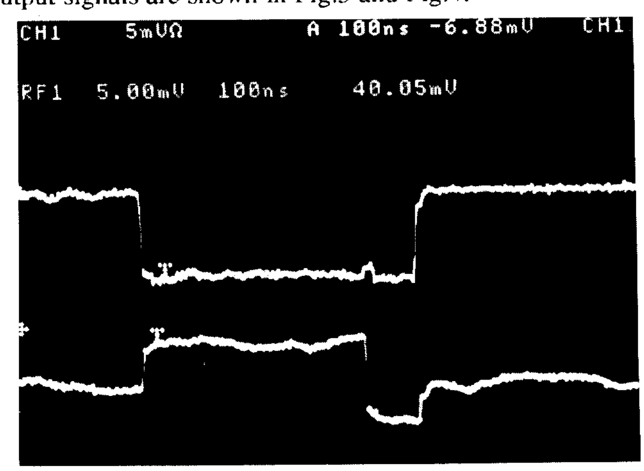


Figure 3. Observed output signals of the 1 kW preamplifier.
Top: Output of the 1 kW preamplifier.
Bottom: Observed phase signal of the pulse.

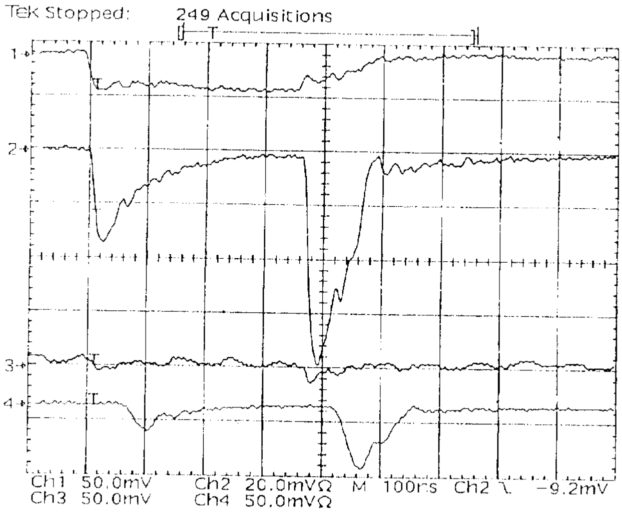


Figure 4. Observed signals at high gradient experiment.
1: Output power of 10 MW of the klystron.
2: Output power of 37 MW of the SLED.
3: Reflected power from the test structure.
4: Transmitted power through the test structure.

To the output power level of almost 60 MW, the aging run had been carried out smoothly as shown in Fig.5.

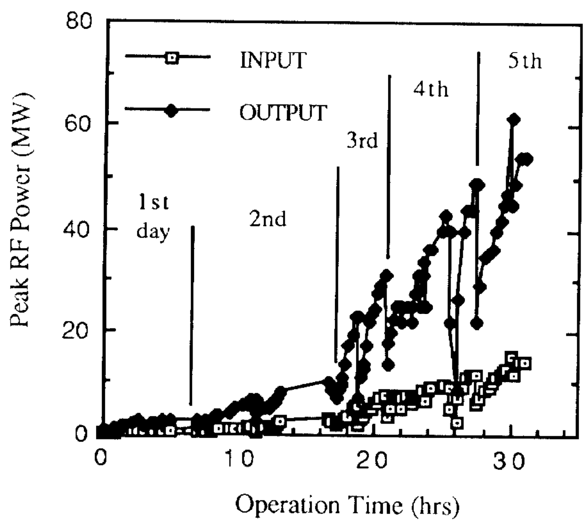


Figure 5. An aging result of the X-band SLED

The SLED system was pumped by ion pumps in the high power RF test-bench. Without RF input, the vacuum pressure reached down to $10^{-6}$ Pa range in three days and stay under this range. In the high power aging run, due to RF discharge, the vacuum pressure frequently rose up to $3\times10^{-5}$ Pa which was previously set as the threshold value to stop the klystron output. With proceeding the conditioning of the SLED, the vacuum pressure at the same RF input decreased.

After this aging process, the SLED assembly was installed in the high gradient test system for accelerating structures. The same klystron was used as an RF source. The accelerating structure had been operated with high RF power of less than 15 MW in the previous aging run. Finally, an output pulse of the SLED system was successfully introduced into the structure without serious breakdown up to 50 MW peak power. At that time, the power enhancement by the SLED looked lower as well as the rear part of the klystron output pulse during 70 ns, when the phase of input pulse was reversed. These might be caused by the reflected RF power from the structure and the noise around power measuring system. Further investigation is necessary for these problems.

## IV. CONCLUSION

Construction of the X-band SLED for high power use was successfully completed. The result of the SLED operation with low level RF gave good agreement with the value which had been obtained by theoretical calculation in the case of $\beta$=4.5,Q0=52000, $t_1$=400 ns and $t_2$=500 ns. That shows the cavities and the 3-dB coupler has been well fabricated for practical use.

In high power aging process of 32 hours, peak output of 59 MW became available without any serious problems. The results of high gradient experiment show that the SLED is useful for high power experiment of critical RF components.

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