

## RF MODULATION STUDIES ON THE S BAND PULSE COMPRESSOR

G. Shu<sup>#</sup>, F. Zhao, S. Pei, Key Laboratory of Particle Acceleration Physics and Technology, Institute of High Energy Physics, Chinese Academy of Science, Beijing, China

### Abstract

An S band SLED-type pulse compressor has been manufactured by IHEP to challenge the 100 MW maximum input power, which means the peak power around the coupling irises is about 500 MW at the phase reversal time. In order to deal with the breakdown problem, the dual side-wall coupling irises model was used. To further improve the reliability at very high power, RF phase modulation (PM) with flat-top output is considered. By using the CST Microwave Studio (MWS) transient solver, a new method was developed to simulate the time response of the pulse compressor. In addition, the theoretical and experimental results of the PM theory are also presented in this paper.

### INTRODUCTION

The SLED-type pulse compressors play an important role in the linear accelerators to increase the efficiency of the klystron RF power. An S band SLED-type pulse compressor has been manufactured by IHEP to challenge 100 MW input peak power. At just one compressed pulse time (usually equal to the filling time of the travelling wave accelerating structure) from the incident RF pulse end, the incoming pulse phase is reversed 180° by the PSK (phase shift keying) switcher, the output peak power will reach 500 MW. The extreme high power leads to the sparking phenomena around the SLED coupling irises and the first several accelerating cells.

A significant reduction of the electric fields near the irises had been achieved by adopting dual side-wall coupling irises model. High power test results show that the maximum input power can reach 85 MW. To further improve the high power reliability, the amplitude modulation (AM) and phase modulation (PM) of the SLED was considered to obtain the flat-top output. For AM, the input power is slowly increased to compensate the damped radiation power of the storage cavities during the pulse compressed interval. Due to the non-linear input/output characteristics of the klystron at high power, AM can't be implemented in the saturation regime [1]. For PM, the incoming RF pulse phase can be manipulated with a constant amplitude, thus the PM is a more feasible option.

### THEORY AND SIMULATIONS

Figure 1 shows the equivalent circuit model of the SLED. The energy storage cavity can be regarded as an oscillating circuit. The voltage source refers to the RF generator.

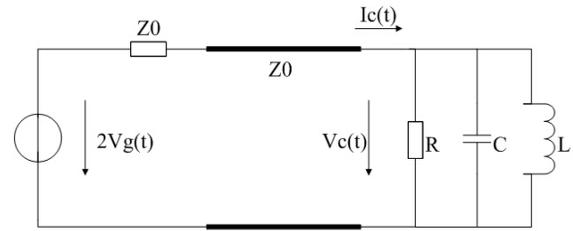


Figure 1: Equivalent circuit model of the SLED.

According to the Kirchhoff's law, the following differential equation can be obtained (dots mean derivatives with respect to time) [2][3].

$$V_r + \tau \dot{V}_r = \Gamma V_g - \tau \dot{V}_g, \quad (1)$$

where  $V_g$  is the equivalent complex voltage of the SLED input while  $V_r$  is the output.  $\tau = 2Q_l/\omega_c$  is the filling time of the storage cavity,  $Q_l$  and  $\omega_c$  are the loaded Q and the resonant angular frequency.  $\Gamma$  is the reflection coefficient and can be defined as  $(\beta - 1)/(\beta + 1)$  with  $\beta$  the coupling factor.

The RF power is fed into the SLED at time  $t_0$ , the input has a phase jump with a step  $\phi_0$  (generally much less than 180°) at time  $t_1$ , then the phase is increased continuously until the RF pulse ends at  $t_2$ . The phase modulation based upon the differential Eq. (1) is carried out during  $t_1 \leq t < t_2$ , then a compressed pulse with constant amplitude can be acquired.

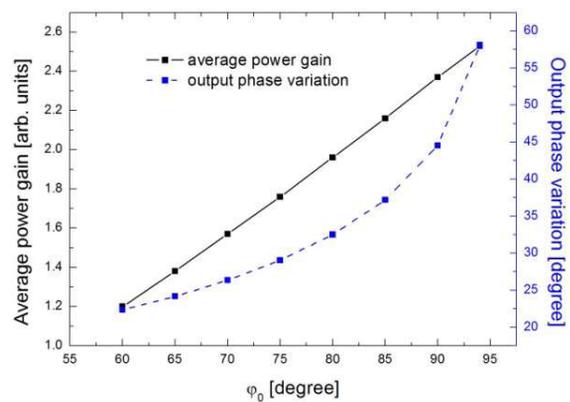


Figure 2: Dependence of the average power gain and the output phase variation on the phase jump step  $\phi_0$ .

Figure 2 shows the dependence of the average power gain and the output phase variation on the phase jump step  $\phi_0$ . The average power gain is proportional to  $\phi_0$ , while the output phase variation increases with  $\phi_0$  as well. For the time duration  $t_1 \leq t < t_2$ , the output phase experiences a large variation. As we all know, the

<sup>#</sup>shug@ihep.ac.cn

compressed pulse will be fed into the accelerator structure, the large phase variation will have a negative influence on the beam quality.

In order to reduce the output phase variation, the RF generator frequency can be set at a relatively higher value (e.g. 150 kHz) than the cavity resonant frequency. For this scenario, Eq. (1) can now be modified as follows

$$Vr(1 + j2\pi\tau\Delta f) + \tau\dot{V}r = (\Gamma - j2\pi\tau\Delta f)Vg - \tau\dot{V}g, \quad (2)$$

where  $\Delta f = f_0 - f_c$  is the frequency shift,  $f_0$  the driven frequency,  $f_c$  the resonant frequency of the cavity.

The input and output amplitude and phase variations can be calculated by solving the Eq. (2). In our case, the specifications of the phase modulated SLED are listed in Table 1.

Table 1: Main Parameters of the Phase Modulated SLED

Frequency	2998	MHz
Resonant mode	TE <sub>0,1,5</sub>	
Coupling coefficient	3.6	
Unload Q factor	~100,000	
Input pulse length	4	μs
Output pulse length	0.83	μs
Frequency shift (Δf)	150	KHz
Phase step at t <sub>1</sub> (φ <sub>0</sub> )	94	degree

Figure 3 and 4 show the input and output amplitude and phase shapes. The maximum power gain with constant output is 2.36. At the time point of 3.17 μs, a input RF phase jump of 94° is introduced, by comparing Figure 2 and Figure 4, the output phase variation decreases from several tens of degree to several degree.

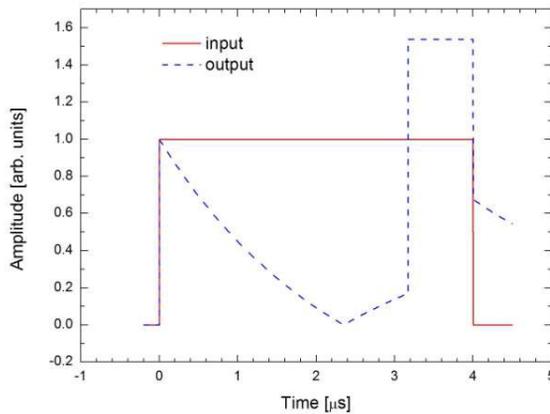


Figure 3: Input and output pulse amplitude.

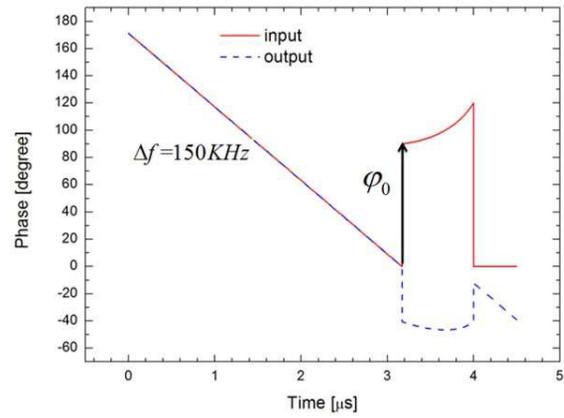


Figure 4: Input and output pulse phase.

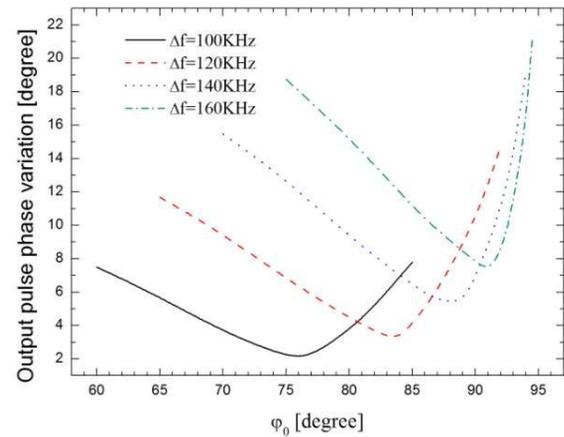


Figure 5: Relationship between the output phase variation and the phase jump  $\phi_0$ .

The average power gain is proportional to  $\phi_0$ , once the  $\phi_0$  is determined, an optimal value of the frequency shift can be found to minimize the output phase variation. Figure 5 shows the relationship between the output phase variation and the phase jump  $\phi_0$ .

By using the MWS transient solver, the SLED response in time domain can be studied qualitatively, then the theoretical study results of the PM can be confirmed. In Figure 6(a), the input pulse is expressed by  $\sin(2\pi f(t) + \phi(t))$ , and  $\phi(t)$  is the incoming phase function in Figure 4. By importing the driven signal shown in Figure 6(a) into MWS, the SLED response can be simulated, which is shown in Figure 6(b). The flat-top output is acquired, so this proves the correctness of the theoretical calculations.

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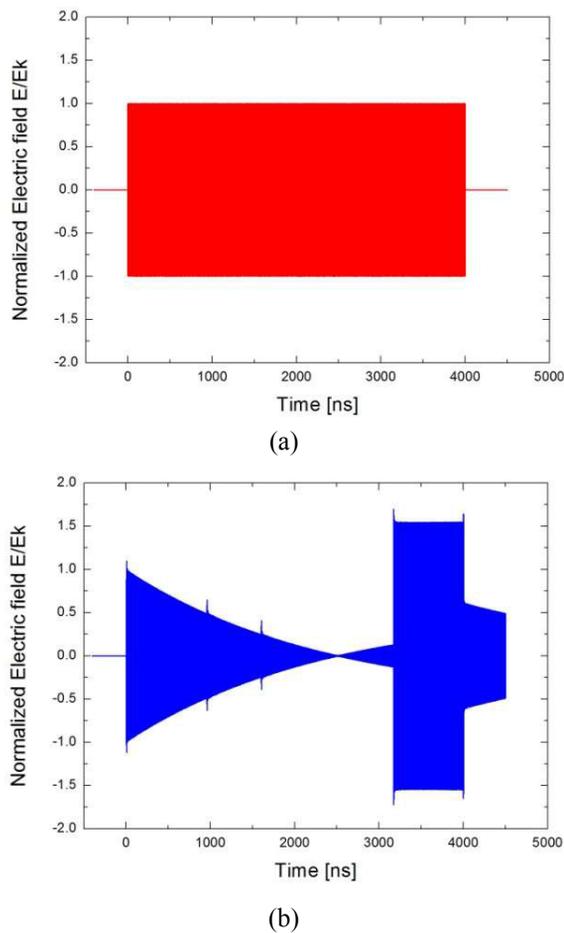


Figure 6: (a) and (b) correspond to the input and the output signals of SLED simulated by MWS transient solver.

### THEORY AND SIMULATIONS

To further confirm our PM study, the low power experimental setup was constructed shown in Figure 7. The carrier wave coming from the RF signal generator is modulated by I and Q control levels which are generated by two arbitrary waveform generators. Then the modulated pulse is fed into the SLED cavities. The peak power meter is used to monitor the output.

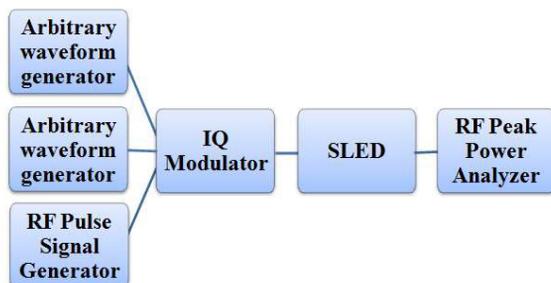


Figure 7: The schematic layout of the test.

The parameters of the SLED used in the experiment are listed in Table 1. At first, the frequency of the SLED

cavities were tuned to  $f_0 = 2998$  MHz. Then, the RF generator frequency was set 150 kHz higher than  $f_0$ , finally the PM process was implemented, and the flat-top output was obtained. Figure 8 shows the results. The output power was 2.3 times the input and the flatness was better than 95%.

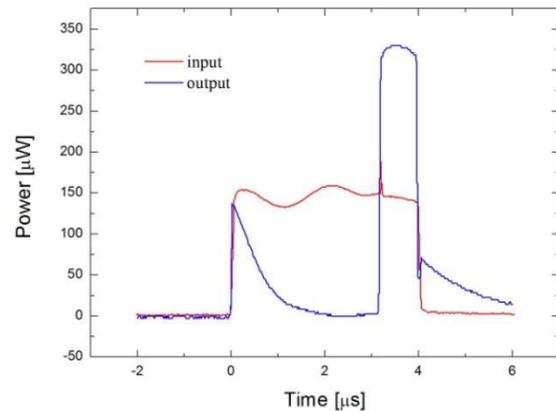


Figure 8: Input and output waveforms measurement of the SLED.

### CONCLUSIONS

The maximum RF input power of the SLED-type pulse compressors can be enhanced by introducing the PM method. We perform the PM theoretical analysis, the flat-top output was obtained both in the MWS simulation and the low power test.

### REFERENCES

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