THE RF DESIGN OF A COMPACT, HIGH POWER PULSE COMPRESSOR WITH A FLAT OUTPUT PULSE*

Ping Wang*[1,2,3], Igor Syratchev[3], Hao Zha[3], Jiaru Shi*[1,2], Walter Wuensch[3], Huaibi Chen[1,2]
[1]Department of Engineering Physics, Tsinghua University, Beijing 100084, PR China
[2]Key Laboratory of Particle and Radiation Imaging of Ministry of Education, Tsinghua University, Beijing 100084, PR China
[3]CERN, Geneva, Switzerland

Abstract

An X-band, high-power pulse compressor, which can produce a flat pulse and a power gain of 4.3, has been designed. The device is compact, with the dimensions of within 1m, and is designed for CLIC first energy stage based on klystrons. We also discuss about a two stage pulse compressor with power gain of 9.18, which may be a candidate of the X-FEL using CLIC X-band linacs and klystrons with low peak power.

INTRODUCTION

The klystron-based option for the CLIC 380 GeV linac and X-band X-FEL linac have many similarities. Both use accelerator units that contain several accelerating structures, an RF distribution network and an RF pulse compressor [1, 2]. In both cases a flat top input pulse is required for accelerating the electron beams with constant energy. A SLED II RF pulse compressor naturally provides such a pulse. In SLED II the RF energy is stored in delay lines, the length of which depends on the pulse duration after compression. For example, the length of a delay line should be 17.7m for an output pulse length of 244ns, which means the system requires a lot of space. Another drawback is the rather large vacuum volume of the complete system and need to provide temperature compensation and stabilization.

Another method which can produce flat top pulse was proposed in 1992[3]. Its principles are as follows [3, 4]:

1. The frequency spectrum of a long delay line can be approximated by a limited number of individual correction cavities.
2. Only the main storage cavity needs to have high Q-factor.
3. The output pulse length is inversely proportional to the frequency separation between the nearby peaks of the spectrum.
4. Loaded Q-factor for all the cavities should be equal (flat top)

In such a system the individual cavities fall into two categories: a single storage cavity and several correction cavities. Due to the limited number of spectral lines generated by the correction cavities, the compressed pulse is not entirely flat and contains some ripples whose amplitude and frequency depends on the number of correction cavities being used. This effect can be mitigated by applying phase special modulation to the driving klystron pair [5]. As a result, the overall efficiency will be slightly reduced, but the great flexibility of such approach is very important to control the compressed pulse shape.

*shij@tsinghua.edu.cn
*ping-wang13@mails.tsinghua.edu.cn

SINGLE STAGE PULSE COMPRESSOR

An alternative to the original two beam CLIC concept, the klystron-based CLIC option is being considered for the 380GeV initial energy stage. In the current baseline version of this scheme, klystrons provide RF power to feed the accelerator structures and a SLED II RF pulse compressor with length of 17.7m compresses the microwave pulse from 2us to 244ns. A new pulse compressor with correction cavities has been designed to take the place of the SLED II RF pulse compressor, which dramatically reduces the size and the cost of the system.

Storage Cavity

The SLED-type X-band pulse compressor (SLEDX) is the core element of the system. Such a pulse compressor was developed at CERN [4] and has been in operation in the CLIC high gradient test facility (Xbox2) since 2014, see Fig.1. SLEDX design follows the requirements given by the CLIC accelerating structures and was optimised to provide optimal compression for 250ns long RF pulses, when powered by 1.5 μsec pulses delivered from klystron. The storage cavities operate in the H_{01} mode. They are 45 cm long and have unloaded Q-factor of 1.8×10^5.

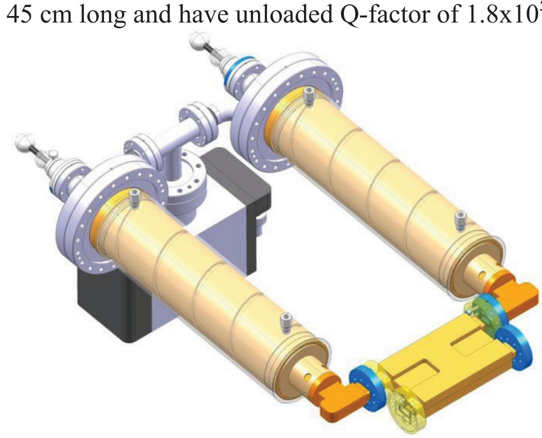

Figure 1: General view of the X-band SLED-type RF pulse compressor.

Correction Cavity

For the practical reasons, we have decided to use only 8 additional spectra lines to the cavity-based system. These lines are generated by an ensemble of four individual

ISBN 978-3-95450-147-2

cavities pairs and each of them is operated in the '0' and 'π' modes. The correction cavities unit comprises a dual-mode polarizer, two spherical cavities and a small coupling cavity in-between, see Fig. 2. The dual-mode polarizer is an RF component with 3 ports and has the function to convert the input TE_{01} mode in the rectangular waveguide into two TE_{11} modes polarized in quadrature in the circular waveguide [7]. In this device, the signal reflected from the cavities pair is directed to the output port, like in the standard 3dB hybrid. The frequency difference between the two modes in this system can be adjusted by modifying the dimension of the coupling cavity. The height of a correction cavities unit is about 25 cm

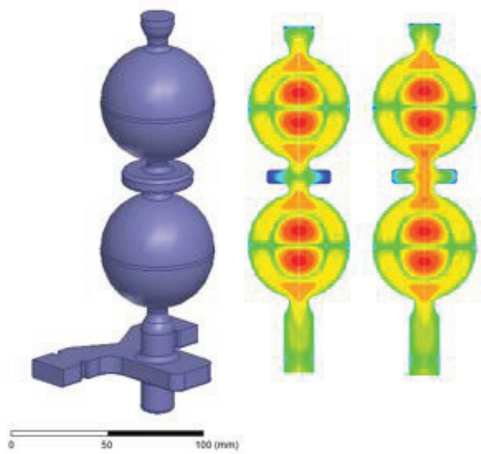

Figure 2: Correction cavity and two field patterns of 0-mode and pi-mode. The unload quality factors of the two modes are all around $4.5x10^4$.

Spectrum and Waveforms

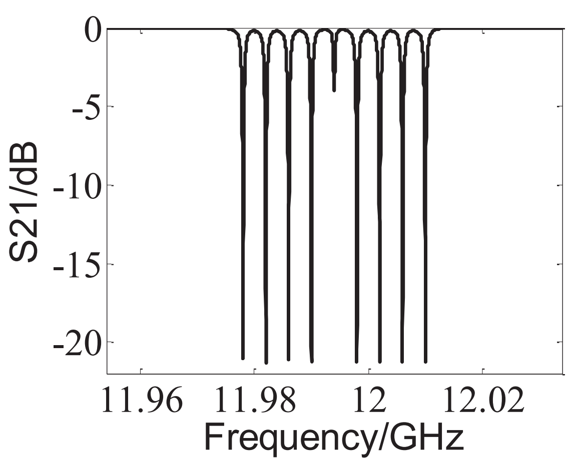

Figure 3: The transmission spectrum of the new RF pulse compressor with correction cavities. The central frequency of the spectrum is 11.994GHz and the frequency difference between two nearby peaks is 4MHz.

When connected, the SLEDX and correction cavities units in series generate the required spectrum, see Fig.3. The small peak in the middle of the spectrum is produced by the SLEDX and the others are produced by the correction cavities.

The resulting CLIC-type output pulse, with a ramp during accelerating structure filling time and a flat top, is shown in Fig. 4. The compression ratio is 10 and the peak power gain is 4.3.

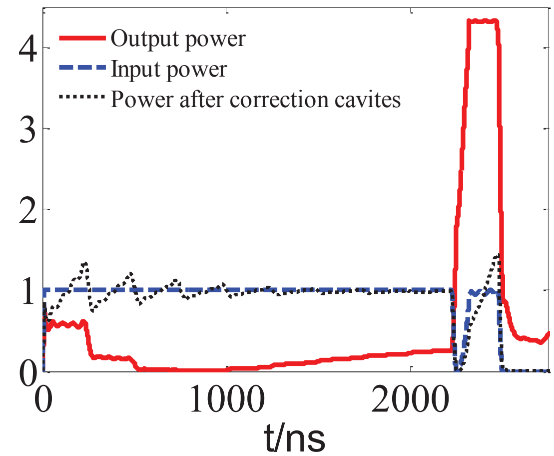

Figure 4: Calculated input and output power of the new pulse compressor. The blue and dashed curve is the input power. The black dotted curve is the power after the correction cavity and the red solid curve is the output power of the new pulse compressor. As CLIC need a ramp during the filling time for the compensation of the transient beam loading, we modulate the amplitude of the second part of the pulse [6].

TWO STAGE PULSE COMPRESSOR

A pulse compressor with two stages has higher RF power gain than one with a single stage [8]. That makes it well adapted to RF power sources which can provide long pulses (large compression ratio) but at modest peak RF power. Such klystrons tend to be less expensive than those with high peak power. Thus by using two stage pulse compressor the cost of the total RF power production can be reduced. Another significate advantage of klystrons with modest peak power is that they can be operated at high (0.5 kHz) repetition rate. For example, this could be of a great importance for the future X-FEL linac based on the CLIC X-band high gradient technology.

Spectra and Waveforms for the Two Stages

In this approach, the two stages have a similar layout, but the correction cavities frequencies are optimised to provide different lengths of the intermediate and fully compressed pulses. Examples of spectra lines for the first and second stages are shown in the Fig.5 and Fig.6. In this example, the unload quality factor of the storage cavities for both stages is $2x10^5$, and $1x10^5$ for the correction cavities. The coupling coefficients of all the cavities at each stage are optimised for the highest power gain in the compressed pulse. In this exercise, a compression ratio of 30 and the peak power gain of 9.18 has been achieved, see Fig.7

ISBN 978-3-95450-147-2

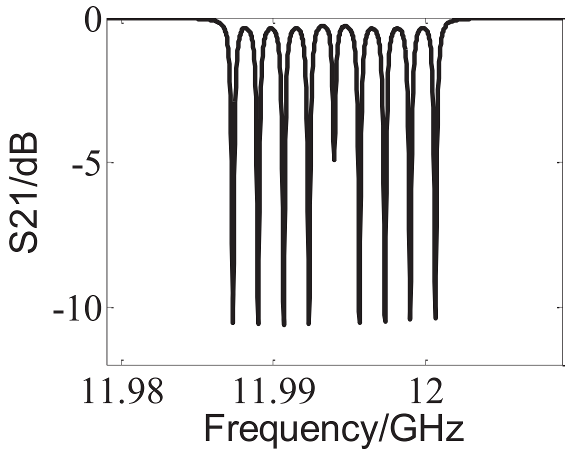

Figure 5: The spectrum of the first stage. The output pulse length is 600ns and the frequency difference between the two nearby peaks is 1.7MHz.

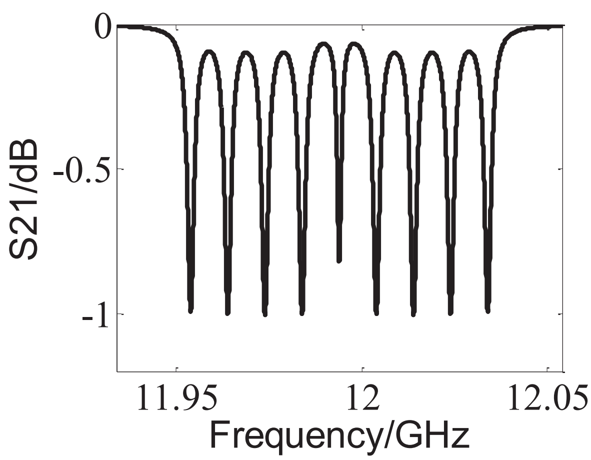

Figure 6: The spectrum of the second stage. The output pulse length is 100ns and the frequency difference between the two nearby peaks is 10MHz.

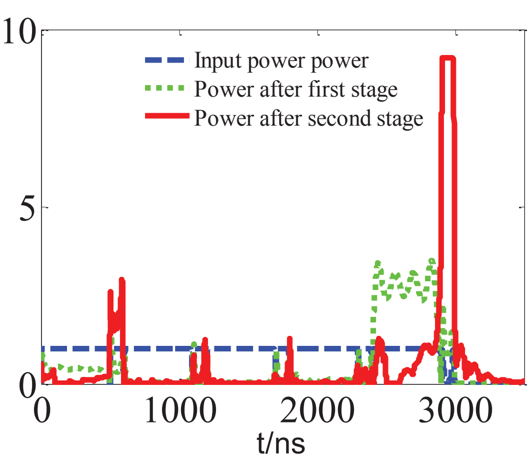

Figure 7: The input and output power of the two stage pulse compressor. The blue and dashed curve is the input power with amplitude modulation of the last part. The green dotted curve is the power after the first stage and the red solid curve is the output power of the second stage. The pulse length is 100ns with rising and falling time of 10ns.

CONCLUSION

A compact RF pulse compressor with correction cavities, which can produce the flat top pulses, has been designed and evaluated. The pulse compressor consists of a SLED-type pulse compressor (SLEDX) and four sets of the correction cavities units. We have shown that a two stage pulse compressor can provide large a power gain, almost 10. This makes it possible for the klystrons with low peak power to be potential candidates for the high gradient accelerators like an X-FEL. A detailed RF design of the two stage pulse compressor will be made in the future.

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ISBN 978-3-95450-147-2