RF POWER COMPRESSION WITH CHIRPED PULSE

Y. Iwashita†
Accelerator Laboratory, NSRF, ICR, Kyoto University
Gokanosho, Uji, Kyoto 611, Japan

Abstract

Chirped Pulse Amplification technique has been used for boosting the laser power to TW level. Similar technique may be used to compress a long chirped high-power RF pulse from Klystron. Some basic ideas on this subject will be discussed

1 INTRODUCTION

Lasers have achieved terawatt levels with so-called Chirped Pulse Amplification [1,2]. This technique keeps the peak power in the amplifiers to reduce the damage caused by the high power on devices. Because klystrons also have upper limit on the peak power, some pulse compression techniques have been devised[3,4,5].

Although the resulted frequency band width from CPA is somewhat broad, such pulse compression technique may be useful for some applications. The CPA used in lasers is explained in the next section. Subsequent sections describe a possible use of the concept in microwave regime.

2 CHIRPED PULSE AMPLIFICATION

The CPA is schematically described in Fig. 1, which is used in Table Top Terawatt (T^3) lasers. It stretches the time structure of a short laser pulse by a dispersive element such as a grating to reduce the peak power. The stretched long pulse with less peak power is amplified, while the time-spectral structure is kept. With a similar dispersive element that has an inverse effect against the former dispersive one, the pulse is compressed and recovers the original short pulse width, where a very high peak power is achieved. It makes use of the optical path difference in the spectra to compress the pulse length.

Because the initial laser pulse is generated and mode locked in an optical cavity, it consists of discrete eigenmodes in the cavity. From the uncertainty relationship;

$$\Delta t\ \Delta\omega \geq 1\,,$$

a pulse of 100 fs width for wave length of 1 μm has a bandwidth of 0.5%;

$$\Delta\omega/\omega \sim 1/(\omega\,\Delta t)\,.$$

The mode separation $\Delta\omega$ in a cavity with length L of the order of 10^5 times longer than its wavelength λ is calculated as

$$\Delta\omega = \omega\lambda/L\,.$$

Thus, the number of modes in the pulse for the case is of the order of 500. These modes are superposed to produce high energy density. If such mode superposition is achieved in an RF cavity, we also can generate very high gradient field [6,7].

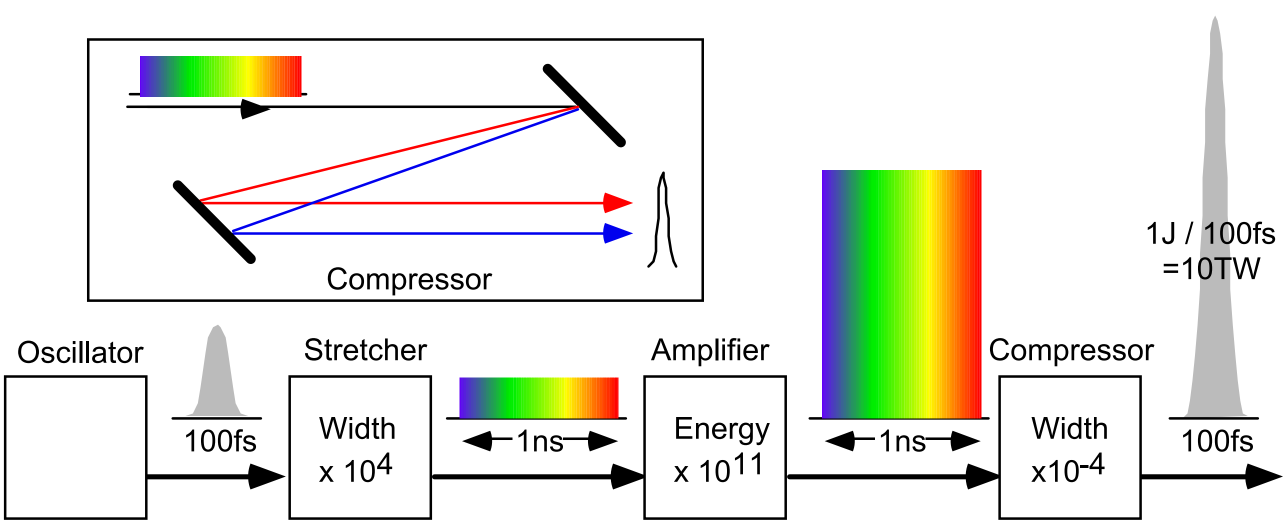

Fig. 1 Chirped Pulse Amplification of Laser

3 CHIRPED RF PULSE COMPRESSION

In a high power RF world, klystrons can directly generate the chirped high power RF with such as 1% band width. The frequency modulated output from a klystron should look like as shown in Fig. 2.

The FM slope may be flipped depending on the dispersive element. The frequency range and the period of the FM modulation depend on the dispersive elements. A configuration for a chirped RF pulse compression is schematically shown in Fig. 3.

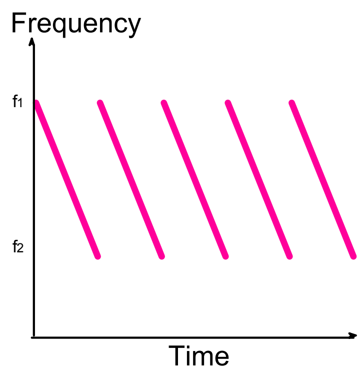

Fig. 2 Frequency modulation for a CPA.

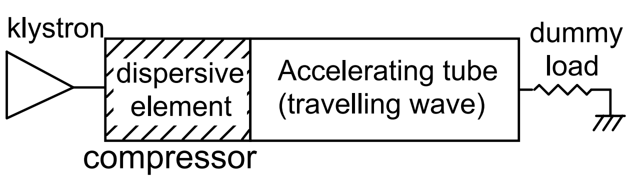

Fig. 3 Schematic layout for a RF-CPA.

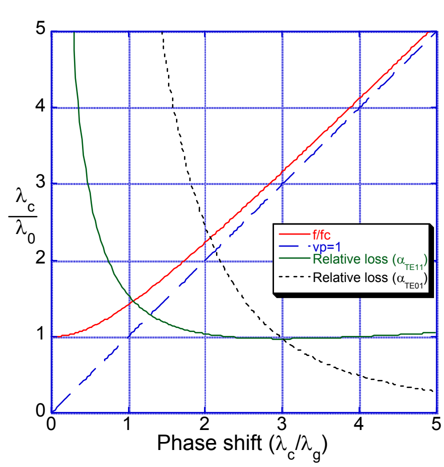

Fig. 4 Brillouin diagram of a plain wave guide.

4 CANDIDATES FOR THE COMPRESSOR

Waveguides have usually large dispersion at their cut off frequency, but the attenuation becomes large in the vicinity of the cutoff frequency(see Fig. 4).

For a periodically loaded waveguide such as a disc-loaded accelerating tube, the group velocity changes rapidly at the end of the pass-band(see Fig. 5). For example, in a disc-loaded waveguide with a 5% passband, the maximum group velocity is up to 4% of speed of light c at the phase shift of $\pi/2$ (rough estimation). Fig. 6 shows the group velocity change as a function of the frequency. If we use 1% of the frequency range, the difference is about 2%. Propagation time τ in a waveguide if length L with group velocity of v_g is;

$$\tau = \frac{L}{v_g}.$$

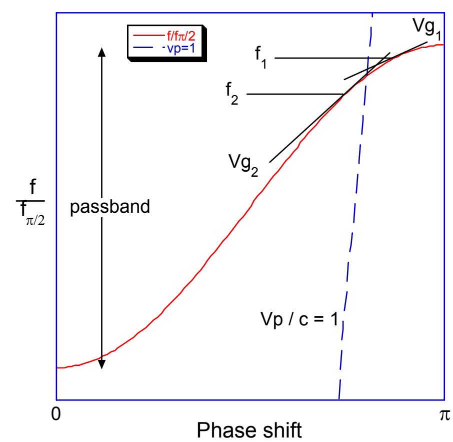

Fig. 5 Brillouin diagram of a disc-loaded wave guide.

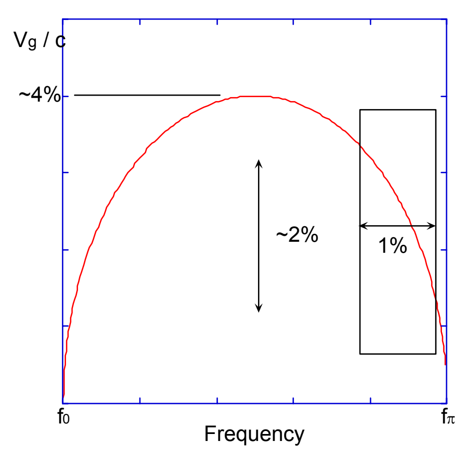

Fig. 6 Group velocity of a disc-loaded waveguide as a function of frequency.

Then the time difference $\Delta\tau$ can be expressed as;

$$\Delta\tau = L\left(\frac{1}{v_{g1}} - \frac{1}{v_{g2}}\right).$$

Finally the waveguide length required to compress the pulse duration of $\Delta\tau$ can be written as;

$$L = \frac{c\Delta\tau}{\frac{c}{v_{g1}} - \frac{c}{v_{g2}}}.$$

Suppose that the FM period is 100 ns and we use the group velocity range of 1%~3%; then waveguide of 0.45m length can compress the pulse width. The possible pulse width is;

$$\Delta\tau \geq \frac{1}{\Delta\omega}.$$

For a 1% width of 10GHz, the width can be of the order of 1ns and the compression ratio would be 100. This corresponds to wave packet of 100 cycles. Although the dispersion relationship is not linear to the frequency, a nonlinear FM modulation may be able to compensate the nonlinearity(see Fig. 7).

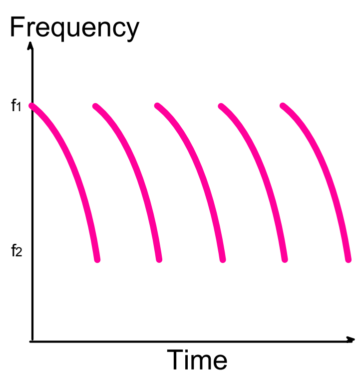

Fig. 7 Nonlinear FM compensation.

5 DISCUSSION

Because the assumed compressor element is a disc-loaded waveguide, it also have a spark limit as in accelerating tubes. Although the surface field gradient may be very high in the compressor, the pulse width becomes very short and may prevent the initial discharge from developing to a spark.

Design of an accelerating tube needs special care to make use of such a wide spectrum or short wave packet.

6 REFERENCES

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