NEW CONCEPT OF SMALL DELAY LINE TYPE RF PULSE COMPRESSOR USING COUPLED CAVITIES

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Abstract

I propose a new concept for the RF pulse compressor using the coupled cavities to make a small delay line. This new concept is a hybrid scheme of a cavity type and a delay line type of the RF pulse compressor. The delay line produces the pulse compression outputs through resultant RF beat between two inputs connected both ports of the coupled cavities. The time constant of the beat is matched to the time constant of the power flow of the coupled cavities. Further the special test stand for the coupled cavities was developed to easily adjust the resonant frequency of such high-Q coupled cavities.

CONCEPT

Beam Loading Compensation for Multi-bunch Acceleration

The multi-bunch beam acceleration will be adopted to accelerate the high current beam in the linac. One way to accelerate the multi-bunch beam uniformly is the beam loading compensation. When the high current beam exists, the accelerating voltage will drop due to the beam loading effect. The way to compensate for the beam loading effect is that the electric field shape considering the beam loading is made in the accelerating structure before the beam is coming. The electric field shape is the same field shape as in the steady state having the fixed beam current. This electric field shape means that the input RF power must be modulated like a trapezoid shape. Figure 1 shows the steady state of the electric field in the accelerating structure (left) and the input RF power to compensate for the beam loading effect (right).

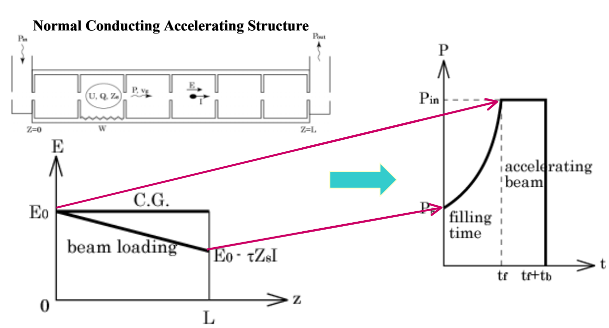

Figure 1: The steady state of the electric field in the accelerating structure (left) and the input RF power to compensate for the beam loading effect (right).

This beam loading compensation method was planned to be used in the normal conducting linear collider project such as the Global Linear Collider (GLC) [1]. However it is possible to accelerate small number of bunches using this method even for the present linac. For example, such a multi-bunch beam acceleration method was recently demonstrated in the KEK linac [2].

New Concept of RF Pulse Compression

The RF pulse compression is used to obtain the higher gradient because of the peak power of the klystron is limited. The modulated waveform like a trapezoid shape is required to compensate for the beam loading effect. However, when a conventional SLED is used for the RF pulse compression, the efficiency to make such an output waveform is much reduced because the modulation of the klystron output is too big.

Therefore, this study aims to demonstrate the new effective method of the RF pulse compression. This new method consists of the coupled cavities which produce the delay corresponding to the group velocity. And the input RF is modulated periodically like a beat wave whose time constant is same as the delay time of the coupled cavities. Figure 2 shows the schematic view of the new concept of the RF pulse compression in case of the three coupled cavities.

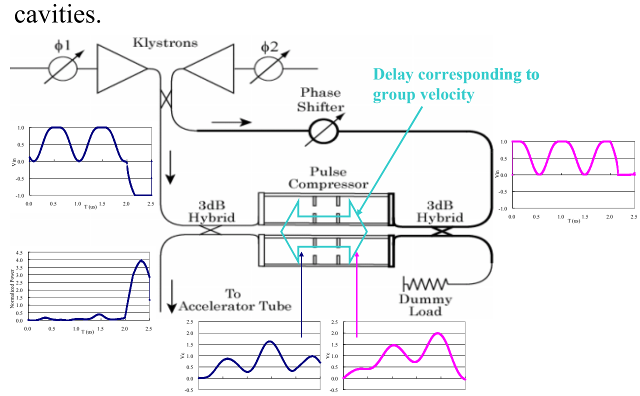

Figure 2: The schematic view of the RF pulse compression.

Comparison

The comparison of the RF pulse compression schemes including a cavity type and a delay line type is shown in Figure 3. This new concept shown in Figure 3 (d) is a hybrid scheme of a cavity type and a delay line type of the RF pulse compressor. Thus it is principally different from the coupled cavity type [3] shown in Figure 3 (c), its components are very similar to the coupled cavity type. And Table 1 shows the advantage and the disadvantage of each RF pulse compression scheme.

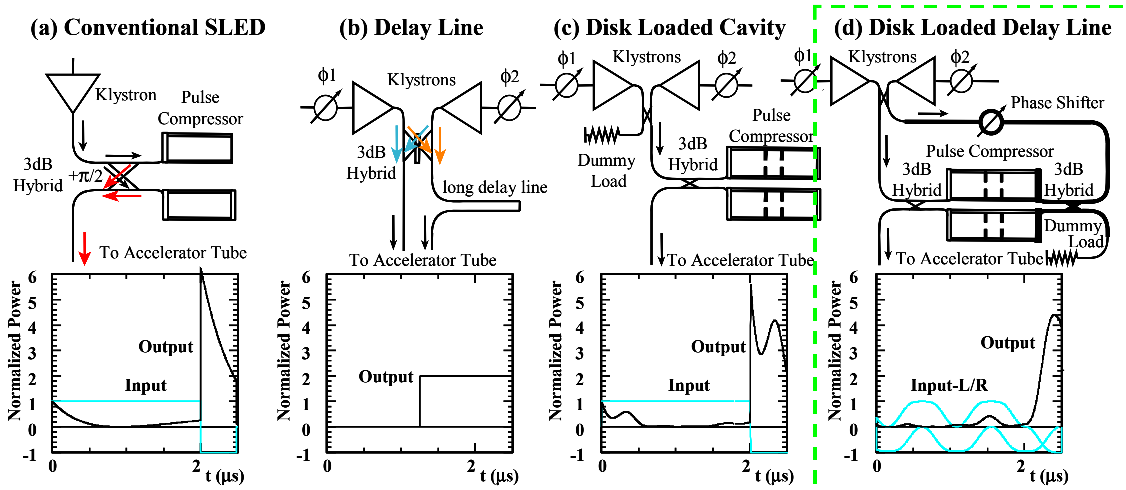

Figure 3: The comparison of the RF pulse compression schemes.

Table 1: The Advantage and the Disadvantage of Each RF Pulse Compression Scheme

	Advantage	Disadvantage
SLED	Simple structure	Gain decreases to make flat top
Delay Line	High efficiency	Too long structure for delay line Many klystrons must be combined for higher gain
Disk Loaded Cavity	Higher gain than SLED	Remained Energy in the third cavity
Disk Loaded Delay Line	Higher gain than Disk Loaded Cavity	Some additional components required

SIMULATION

The equivalent circuit simulation of the coupled cavities were developed [4]. Figure 4 shows the equivalent circuit model of the coupled cavities.

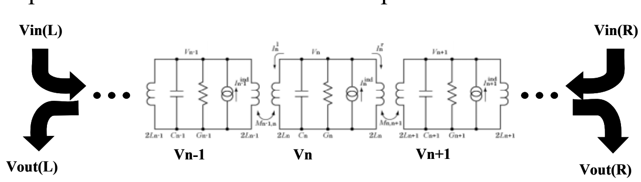

Figure 4: The equivalent circuit model of the coupled cavities.

In this experiment, the 3-cell cavities are adopted for the demonstration of the principle. Figure 3 (d) shows the simulated waveform of this new scheme for the C-band (5712 MHz). This waveform can be modified by the small input modulation to make a flat top corresponding to the GLC configuration. Figure 5 shows the simulated waveform of this scheme for the X-band (11.424 GHz) corresponding to the available time structure of the present X-band klystron.

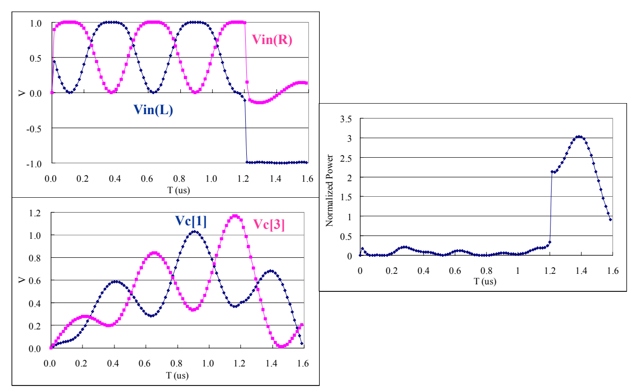

Figure 5: The simulated waveform.

TEST CAVITIES AND TEST STAND

X-band Test Cavities

The cold model of the X-band RF pulse compressor as shown in Figure 6 is developed to demonstrate the principle of this scheme.

Figure 6: The cold model of the X-band RF pulse compressor.

It consists of three cavities. The first and third cavities are designed for energy storage used $TE_{01,15}$ mode, and the second cavity is designed for coupled section between two energy storage cavities used $TE_{01,5}$ mode.

Fine Alignment for Cold Test

For such a cavity type RF pulse compressor, the required quality factor of the cavity is over 100,000, and even the external quality factor becomes over 30,000. Thus the special alignment stand for the coupled cavities as shown in Figure 7 was developed to easily adjust the resonant frequency of such high-Q coupled cavities.

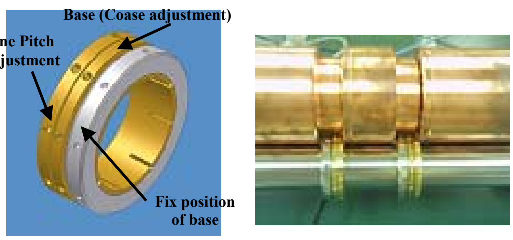

Figure 7: The special alignment stand for the coupled cavities.

MEASUREMENT

Parameter Measurement

The transmission coefficient (S21) and the reflection coefficient (S11) measured using the network analyzer are shown in Figure 8.

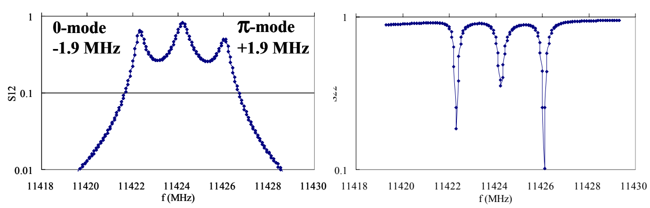

Figure 8: The transmission coefficient (left) and the reflection coefficient (right).

The external coupling coefficient (β) is calculated from the loaded Q factor and the coupling coefficient (k) between cavities is calculated from the frequency difference between the 0 and π mode. Table 2 shows the designed and measured parameters of the external coupling coefficient (β) and the coupling coefficient between cavities (k).

Table 2: The Designed and Measured Parameters

	Designed	Measured
k	0.0005	0.00047
β	4.0	3.9

Transient Response

The transient response of the RF pulse compression is measured using the fast phase modulation circuit as shown in Figure 9.

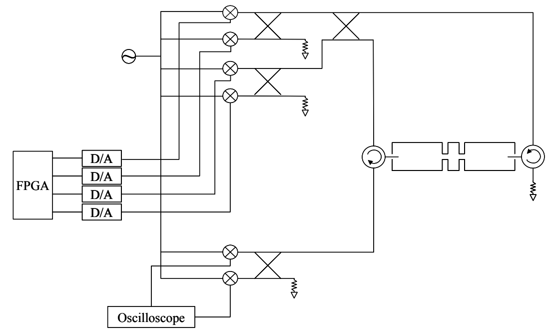

Figure 9: The fast phase modulation circuit.

Figure 10 (left) shows the experimental transient response of new pulse compression scheme. And the comparison of the normalized power between the simulation and the experiment is shown in Figure 10 (right).

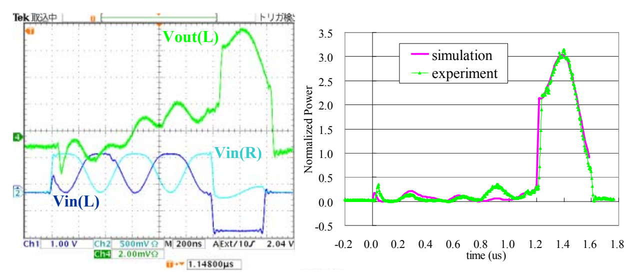

Figure 10: The experimental transient response of new pulse compression scheme (left) and the normalized power between the simulation and the experiment (right).

SUMMARY

The new concept of the RF pulse compression was demonstrated to be successful using the X-band cold model. The experimental transient response is agreed with the simulation very well. More multi-cell cavities will be considered to optimize such a RF pulse compression scheme.

REFERENCES

[1] "GLC Project Report", 2003.

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