A Radiofrequency Pulse Compressor for Square Output Pulses in the Microsecond Range

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Abstract

For high-power klystrons driving electron linacs, SLED-(LIPS-) type pulse compressors have aroused widespread interest, [1]. To overcome their inherent disadvantage, the peaked output pulse which makes them not very suitable for driving constant-gradient accelerating structures, various other schemes have been proposed. Reflective (SLED-type) or transmissive (binary) schemes are, without resorting to superconducting or highly overmoded waveguides for energy storage, limited to pulses well below one microsecond. Therefore, a system using serveral mutually coupled resonators rather then one (on each side of a SLED scheme) is proposed. According to calculations, two resonators already yield a much flatter top of the output pulse. Low-power measurements on a 1 : 1 scale set-up show, for a 5 μsec input pulse, phase switched after 4 μsec a power gain of about 5.6 dB. A comprehensive theory as well as results of a comparison with other schemes will be presented.

1 THEORY

If two or more cavities are coupled together, the stored energy starts to oscillate between them. As a consequence the output signal is modulated by this oscillation. The amplitude and frequency of the oscillation depends on the coupling coefficient between the cavities. Providing the proper value for the coupling coefficient, the exponential decay of the output signal of a single cavity can be compensated to some extent by the ascending portion of the additional oscillation. In the following we will investigate a system with two coupled cavities. The two cavities are of the same type.

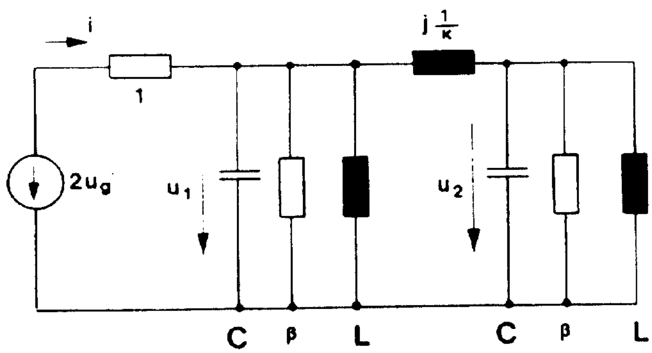

Figure 1: Equivalent circuit for two coupled cavities

1.1 Equivalent Circuit

For the calculation of the output pulse the arrangement is transformed into an equivalent circuit, fig. 1. All impedances are normalized with respect to the characteristic impedance of the feeding waveguide. The coefficient κ describes the coupling between the two cavities and β is the coupling coefficient to the generator. The elements L and C representing the cavities can be calculated from the quality factor and the resonance frequency of the cavities.

1.2 Equations

The relation between the voltage and current in the equivalent circuit and the wave amplitudes is given by

$$a = \frac{1}{2}(u_1 + i), \quad (1)$$

$$b = \frac{1}{2}(u_1 - i), \quad (2)$$

where a is the amplitude of the foward and b of the backward running wave. From fig. 1 this results in

$$a = u_g \quad (3)$$

$$b = u_1 - u_g. \quad (4)$$

We assume the voltages to be of the form

$$u_g = \underline{U}_g e^{j\omega t}, \; u_1 = \underline{U}_1 e^{j\omega t}, \; u_2 = \underline{U}_2 e^{j\omega t}, \quad (5)$$

where $\underline{U}_g$, $\underline{U}_1$ and $\underline{U}_2$ are complex amplitude factors. Deriving the differential equations for the voltage from fig. 1 and substituting u_g, u_1 and u_2 by the expressions in eq. 5 one arrives at

$$\frac{d}{dt}\underline{U}_1 + \frac{1+\beta-j\kappa}{\tau}\underline{U}_1 = \frac{2\beta}{\tau}\underline{U}_g - j\frac{\kappa}{\tau}\underline{U}_2, \quad (6)$$

$$\frac{d}{dt}\underline{U}_2 + \frac{1-j\kappa}{\tau}\underline{U}_2 = -j\frac{\kappa}{\tau}\underline{U}_1. \quad (7)$$

The time constant τ is given by

$$\tau = \frac{2Q}{\omega(1+\beta)}, \quad (8)$$

with the quality factor Q of the cavities.

1.3 Numerical Results

The eqs. 6 and 7 were solved for cavities with a Q factor of 170 000 and a generator frequency of 3 GHz which

Figure 6: Result of measurement, input pulse 5 μsec, output $\approx$ 1 μsec, gain 5.4...5.6 dB

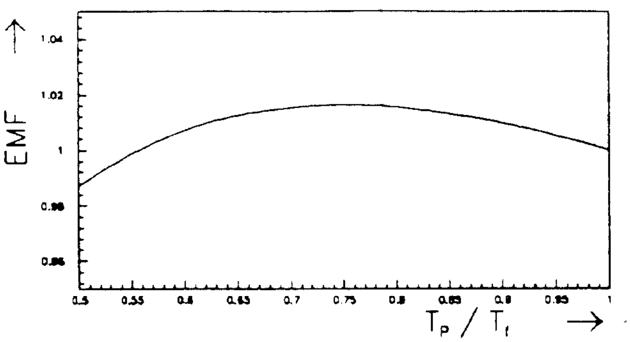

Figure 7: EMF versus (square) input pulse length

suming an input pulse of unit amplitude and duration T_k the maximum EMF is given by

$$EMF_{ideal} = \sqrt{\frac{T_k}{T_p}}, \qquad (9)$$

where T_p is the duration of the output pulse. But using cavities as a storage device a part of the input signal is reflected and therefore not all of the delivered energy is deposited in the cavities. We have calculated the energy W_p available for acceleration by substracting the reflected and dissipated energy from the energy provided by the input pulse. Assuming a rectangular output pulse the EMF is then given by

$$EMF_{max} = \sqrt{\frac{W_p}{T_p}}, \qquad (10)$$

With the above mentioned system parameters this gives an EMF of 1.667. The calculated EMF of the single LIPS system reaches 93 % of that value. Further investigation of the accelerating section showed that the design is not optimum. Even for a square pulse of a given energy, the EMF shows an overshoot of about 1.6 % at a pulse length which is about 75 % of the filling time of the section, fig. 7. Optimizing the pulse length for the existing section for a single and a double LIPS yields an EMF of 1.605 and 1.638, respectively. The attainable EMF can be improved by increasing the ratio of the input pulse length to the length of the output pulse. For example an output pulse of 0.7 μsec will increase the EMF to 1.911 which is 94.7 % of the maximum of 2.017 according to eq. 10. To match the filling time of the section the group velocity gradient must be reduced to $g_a = 0.6237$, leaving geometrical length and Q unchanged.

4 CONCLUSIONS

The presented two-resonator scheme yields an output pulse which is considerably flatter than that of the original SLED/LIPS setup. Because of the influence of bandwidth limitations the high peak at the beginning of the measured output pulse is missing. This will also be the case for a high-power device. A practical reduction of the highest field in the section of about 30 % seems realistic (double to single LIPS). However, the gain of this scheme compared to the original, single-resonator one, expressed as its Energy Multiplication Factor, is limited to a few percent. This is not surprising since the original scheme is already close to the attainable optimum.

An alternative possibility, which was presented in [6] yields a somewhat inferior EMF, but needs only one resonator (on each side of a practical installation). Either scheme seems to be interesting for driving electron linacs to a very high gradient, where breakdown due to the high peak of the SLED output pulse becomes a problem. The decision on which of the two schemes to implement will depend on the availability of hardware (resonators vs. phase modulators).

5 REFERENCES

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