MULTI-MODE SLED-II PULSE COMPRESSORS

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Abstract

Compact SLED-II pulse compressors are considered. The primary idea to use a set of the cylindrical multi-mode cavities, to be free of high-Q resonances around the 11.4 GHz, is analyzed [2]. This idea is developed, in order to provide more delaying time per miter of the line. Another idea to provide compactness is to avoid two-channel scheme with 3dB coupler usually used for SLED-II pulse compressors. A reflectionless delay line is built in this case, using coupling in a form of the non-symmetrical mode converter. SLED-II pulse compressors of higher frequency bands also are considered. It is suggested to shape these compressors on a base of the multi-mirror transmission lines. The operating mode in this case is a Gaussian wavebeam traveling between mirrors.

PULSE COMPRESSORS BASED ON A SET OF CYLINDRICAL MULTI-MODE CAVITIES

The SLED-II pulse compressor consists of two delaying lines, operated with TE_{01} modes, which are coupled by means of 3 dB coupler [1].

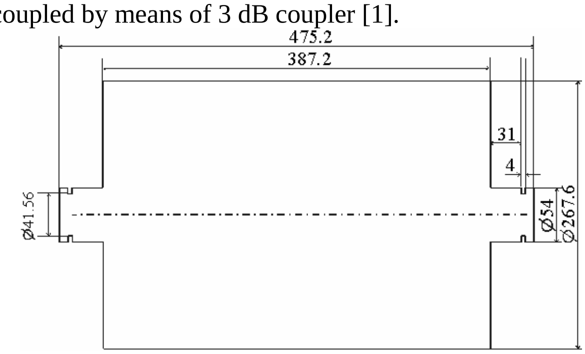

Figure 1: The 11.4 GHz elementary delaying cell.

In order to reduce the total length of delay waveguides, the idea to use a set of cavities, which are to be an equivalent of delaying line, was suggested [2]. One of cells of the mentioned type, which was calculated for 11.424 GHz, is shown in Fig. 1. Near the operating frequency the cavity does not have any high-Q resonances. The incident power in a form of TE_{01} mode passes many times inside the cavity. This provides several times larger delay time comparing to the straight waveguide of the same length as the cavity's length. Several cavities, connected in a chain, can provide delaying time up to hundreds of nanoseconds.

The necessary condition for the mentioned solution is to avoid spurious high-Q resonances in the frequency band which at least wider than spectrum width of the output compressor's pulse:

$$|f - f_0| >> \Delta f, \qquad (1)$$

where f – is a real part of the eigen frequency of the nearest eigen mode, f_0 – is an operating frequency, and Δf – is a width of spectrum of the output pulse. The low-Q resonances are not dangerous if Q-factors are much less than:

$$Q^* = f_0 / \Delta f. \qquad (2)$$

The conditions (1-2) are satisfied, in particular, if the cavity has spectrum of eigen modes consisted of the quasi-degenerated modes. This situation takes place in the solution presented in [2].

In order to test at low power level the idea of compact pulse compressor, the cavity with the shape, shown in Fig. 1, was chosen. The transmission and reflection characteristics of the delay line consisted of this chain are plotted in Fig. 2. Near the operating frequency the reflection is less than 1% on power. The dependence of the phase on frequency is practically linear one (Fig. 3). This means that the incident pulse has delaying only (23 ns/m) without distortions on amplitude and phase.

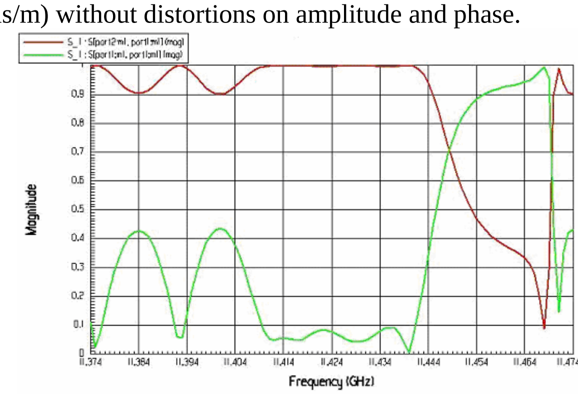

Figure 2: Reflection and transmission for the 4-cell chain (the cell shape is shown in Fig. 1).

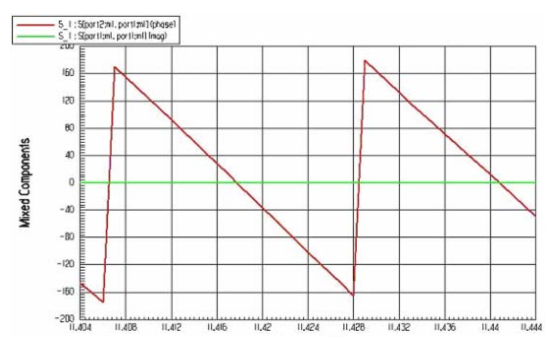

Figure 3: Phase of the reflected (red curve) wave for the 4-cell chain.

The low power tests were carried out at 34.27 GHz with the one-channel prototype (Fig. 4), where the last cell was closed by means of movable cut off reflector. This reflector was used for precise frequency tuning. The design of each cavity with scaling to 34.27 GHz corresponded the Fig. 1. The coupling diaphragm before the first cavity was calculated separately in order to provide maximal efficiency under compression ratio 5.

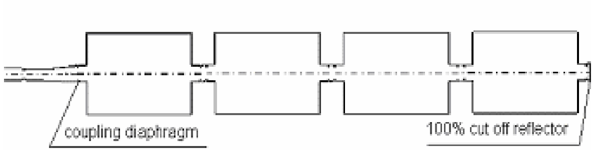

Figure 4: Scheme of the tested 4-cell pulse compressor.

The observed compression of 200 ns pulse without phase modulation (Fig. 5) as well as compression with the switched step-type phase modulation on (Fig. 6) is in good agreement with the theory. The power gain is ~2.2 without phase modulation, the power gain is about 4.5 with the π step-type phase modulation.

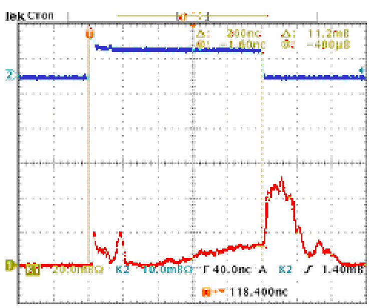

Figure 5: Experimental plot of the input (blue) and output (red) pulses formed by the compressor (no phase reverse).

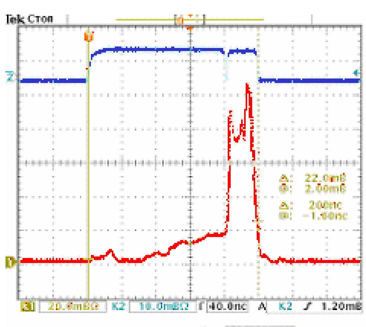

Figure 6: Experimental plot of the input (blue) and output (red) pulses formed by the compressor (with phase reverse).

In order to provide maximal compactness, it is natural to increase the diameter of delaying cavity and simultaneously to reduce the length. A compressor assembled of cavities of such design usually requires more cells, but total length is reduced dramatically. The results of such calculations are summarized at Table 1. Designations of sizes are plotted in Fig. 7.

Table 1: Parameters of the calculated cavities scaled to 34.27 GHz

Name	L1, mm	L2, mm	D1, mm	D2, mm	Delay time, ns/m	Ohmic Loss / delay time, %/ns
Kazakov cavity	14.7	129	18	89.2	22.9	0.13
"Long" cavity	5	100	14	69.3	52.8	0.16
"Short" cavity	5	25.1	11.3	171	152.3	0.21

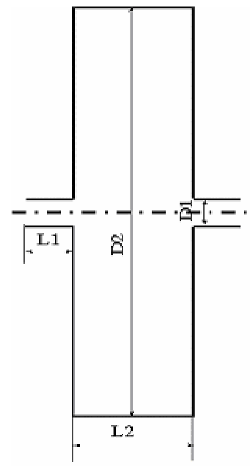

Figure 7: Sizes of the calculated cavities.

Obviously, in order to obtain most compact design, it is necessary to expand the volume of cavity. However, volume expansion means an appearance of additional eigen modes which can spoil delaying without distortion of the pulse shape. Nevertheless, the mentioned problem is solvable. There are cavities, which have the pure degenerated eigen modes only. Any frequencies between groups of these degenerated modes are free of undesirable eigen modes and could be used for compression. These are so-called two-mirror confocal cavities. In geometry-optical approach all eigen modes of them are strictly degenerated.

ONE-CHANNEL SLED-II PULSE COMPRESSOR

The principal idea of the one-channel SLED-II pulse compressor, based on a ring-like cavity, is illustrated by means of the Fig. 8. The operating mode of the axis-symmetrical cavity consists of mode *B* and mode *C*, which propagate toward each other. In particular, let us consider the compressor with B=TE_{01} and C=TE_{02}. These modes are transformed each to other in the ends of the delay line by means of special reflecting converters (Fig. 9). The feeding wave *A* is to be the TE_{11} mode, which propagates through the mentioned converters without conversion into other modes. This is reached due smooth converter's profile, which is not resonant for the TE_{11} mode.

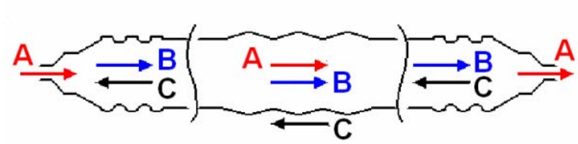

Figure 8: General scheme of one-channel SLED-II pulse compressor.

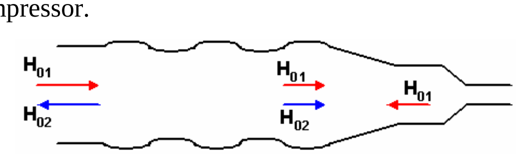

Figure 9: TE_{01}-TE_{02} mode reflector which does not perturb TE_{11} mode propagated through the compressor.

The transmitting TE_{11} mode is coupled selectively with the forward TE_{01} mode only by means of the serpent-like periodic mode converter placed in the delay line (Fig. 10). This converter should provide optimal mutual TE_{11}-TE_{01} conversion in order to obtain high compression efficiency. Note that the backward TE_{02} mode should be not perturbed by the coupling converter. The mentioned conditions are achievable due to relatively small periodic deformation of walls.

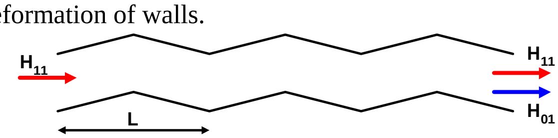

Figure 10 : TE_{11}-TE_{01} (forward modes) mode coupler.

The Figs 11-12 describe results of calculation of the 34.27 GHz pulse compressor. The first figure shows mode behavior at the TE_{01}-TE_{02} mode reflector. At the operating frequency of the compressor the mutual conversion is about 99%. The TE_{11} mode is transmitted through this reflector with efficiency 99%. For the compression ratio 4, the optimal coupling is 50% on power. That is why, in Fig. 12 mutual conversion of TE_{11} and TE_{01} modes reaches this value at the operating frequency.

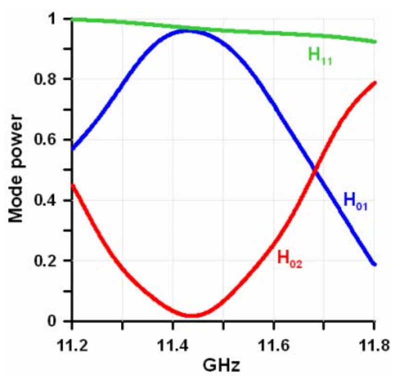

Figure 11: Calculation of modes at the TE_{01}-TE_{02} mode reflector.

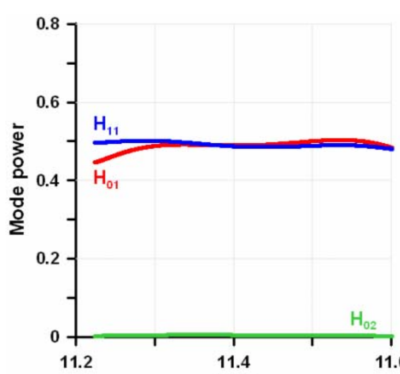

Figure 12: Calculation of the mode coupler with coupling coefficient 0.5 on power.

The mentioned modes *A*, *B*, and *C* could be arbitrary. For example, scheme with pure axisymmetrical modes (*A*=TE_{01}, *B*=TE_{02}, *C*=TE_{03}) seems attractive.

COMPRESSORS BASED ON MULTI-MIRROR DELAY LINES

At high frequencies the use of mirror lines becomes more natural in comparison with the closed waveguide delay lines. The mirror lines are capable to provide low-loss transmission and good compactness. The suppression of the reflected power, propagating in backward direction to the incident RF source, is achieved by means of diffraction grating (Fig. 13).

In Fig. 13 the 30 GHz pulse compressor is shown which was calculated to provide 25 ns duration of the output pulse. The total height of the compressor in vertical direction is ~1800 mm ($2a$=520 mm, b=426 mm, φ=55°). The sizes of the used mirrors are 174×143 mm^2. Each of two neighbor mirrors represents a so-called confocal pair.

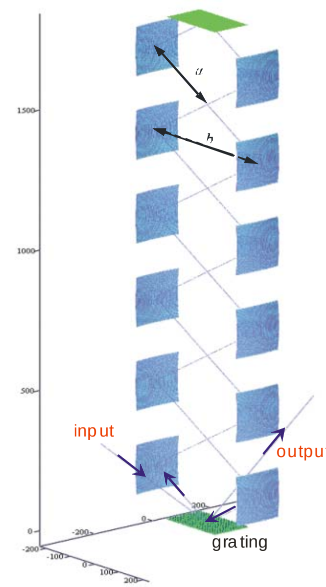

Figure 13: SLED-II pulse compressor based on multi-mirror delaying line.

CONCLUSION

The SLED-II pulse compressor, based on TE_{0n} mode cavity chains allow to reduce up to 50 times the length of delaying lines in comparison with usual delay lines.

The one-channel TE_{01}-TE_{02} SLED-II pulse compressor is suggested. It does not require the 3 dB coupler.

SLED-II pulse compressors, based on multi-mirror delaying lines, are suggested for frequencies 30-100 GHz. They allow to provide high efficiency and excellent compactness, really flat output pulse shape.

REFERENCES

[1] Farkas Z.D. et al, SLED: A Method of Doubling SLAC's Energy, Proc. 9th Conf. On High Energy Accelerator, SLAC, Stanford, CA, USA, May 2-7, 1974, p. 576, SLAC-PUB-1453.

[2] S. Kazakov, Multi-mode delay lines, ISG-XI, KEK, December 2003.