COMPACT ONE-CHANNEL K-a BAND SLED-II PULSE COMPRESSOR

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Abstract

A compact, one-channel RF pulse compressor that does not require a high power 3-dB hybrid is described for producing high-power flat-top 100 ns wide RF pulses at 34.272 GHz, with peak power in the range of 100 MW. This pulse compressor, operating akin to SLED-II, is intended to multiply peak power by over 3:1 and compress in time by 5-6:1 600 ns output pulses produced by the Yale/Omega-P magnicon amplifier.

INTRODUCTION

Development of warm high-gradient accelerator structures requires testing at frequencies at and above 11.4 GHz, including 30 GHz as in the CLIC concept now under study at CERN. Typical required powers for such tests falls in the range of 100-200 MW, with a pulse width of up to 150 ns. This power can be achieved by creation of a longer pulse RF source and then employing an RF pulse compressor that transforms the long pulse into a shorter pulse but with higher power. Multi-mode SLED-II pulse compressors were considered as prospective systems for NLC and JLC [1-2]. One of the indisputable advantages of these is the flat-top output pulse that is desirable for a traveling-wave structure tests. The flat-top pulse is formed through use of waveguide delay lines that use oversized waveguides operating with the low-loss breakdown-proof TE_{01} mode or TE_{01}-TE_{02} mode combination. A 3-dB hybrid coupler is required, and may be considered a serious challenge for a millimeter-wave SLED-II pulse compressor, because of the impossibility at the high power levels required of using WR-28 rectangular waveguide, and thus the need for an elaborate quasi-optical design. Work at 34 GHz is particularly propitious at this time, since the Yale/Omega-P 34-GHz magnicon has come into operation, with performance approaching its design ratings of 35-40 MW peak power output in 1.0 μs pulses, at a 10 Hz repetition rate. An array of components have been developed and built by Omega-P for high-power use at 34 GHz, and other components are in development, or are being proposed. Existing components include a four-way combiner, to allow power from four WR-28 waveguide outputs of the magnicon with windows to be summed and transmitted along a TE_{01} mode cylindrical waveguide to a test load of choice. The single-channel pulse compressor described in the present paper will be configured with one end to connect to the power combiner output; the compressed pulse is to emerge from a TE_{01} mode waveguide at the opposite end. This novel pulse compressor that provides the flat-top pulse has the advantage of not requiring a high-power millimeter-wave hybrid, and of having separate input and output ports. A schematic drawing of the device is shown in Fig. 1. It is an axisymmetric multi-mode cavity [3-4] operating in the TE_{02} mode propagating one way (left-to right in Fig. 1—the blue arrow) and a TE_{03} mode propagating the other way (right-to-left in Fig. 1—the green arrow). Mutual mode converters (elements **1** in Fig. 1) at each end of the cavity convert one of these modes into the other by means of selective reflecting converters. The input (output) wave is in the TE_{01} mode, and enters (leaves) at the left (right). The left-to-right traveling TE_{01} mode (red arrow) is coupled only with the left-to-right traveling TE_{02} mode by means of a selective mode converter (element **2**) placed in the middle of the cavity. This converter plays the role of an input coupler and must provide the optimal level of conversion $TE_{01} \rightarrow TE_{02}$ in order to obtain high compression efficiency. The left-traveling TE_{03} mode must not be perturbed by the $TE_{01} \rightarrow TE_{02}$ coupling converter at all. As shall be described, only a small amount of radiation exits the cavity until a critically-timed 180 degree phase flip of the TE_{01} mode input signal causes an intense compressed pulse to emerge in the TE_{01} mode from the right-hand end of the structure.

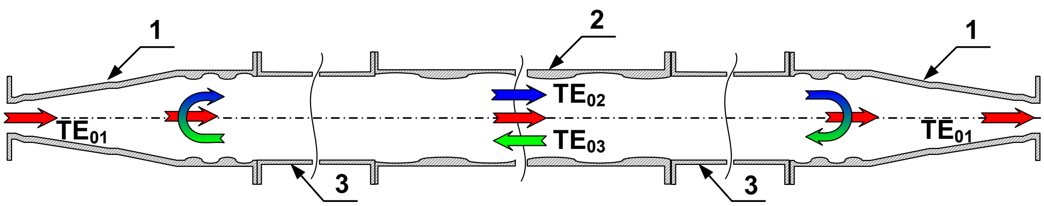

Figure 1: One-channel SLED-II pulse compressor. **1** - $TE_{02} \leftrightarrow TE_{03}$ reflective mode converter; **2** - $TE_{01} \rightarrow TE_{02}$ transmission mode converter; **3** – waveguide delay lines.

DETAILED ANALYSIS

Among eigemodes of the cavity there of course exists a degenerate mode that consists of the same mixture of TE_{02} and TE_{03} modes, but with directions of propagation opposite to those of the operating eigenmode. The two degenerate modes are depicted in Figs. 2 and 3. The spurious eigenmode has the potential to be excited from imperfect design of the mode converters, for example if one wave is converted into another desired mode with less than full 100% efficiency. This leads in this case to reflection of some RF power and splitting of eigenfrequencies. In order to avoid this,

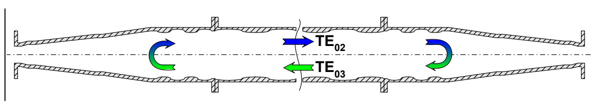

Figure 2: $TE_{02\ (forward)} - TE_{03\ (backwaerd)}$, the operating eigenmode.

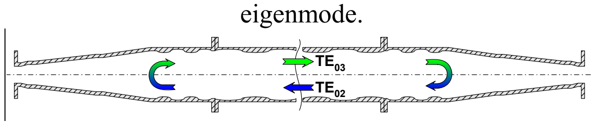

Figure 3: Spurious $TE_{03\ (forward)}$ - $TE_{02\ (backward)}$, the degenerate eigenmode.

spurious coupling between the operating eigenmode and the degenerate spurious mode should be much less than $R^2 = (kL/Q_c)^2$, where Q_c is the coupling quality factor of the cavity, and $k = \omega/c$.

$TE_{02} \leftrightarrow TE_{03}$ reflective mode converter. This mode converter consists of several sections, as shown in Fig. 4. The TE_{02} mode is incident from the left. In the first corrugated section the incident mode is converted into a mixture of 50% TE_{03} and 50% TE_{02}. To achieve this, a corrugation period $p = 2\pi/(h_2 - h_3)$ is chosen, where h_2 and h_3 are propagation constants of the TE_{02} and TE_{03} modes respectively. The next part is a narrowed section which totally reflects the TE_{03} mode because the following cylindrical section is cut off for the TE_{03} mode. The TE_{02} mode propagates through this section while accumulating a phase shift. This TE_{02} mode is reflected by the next down taper. Therefore, in the corrugated section the returning 50% TE_{02} mode is converted into TE_{03} mode, and merges completely with the first 50% TE_{03} mode due to proper phase differences provided by choice of a proper length for the aforementioned cylindrical section. A conversion efficiency of 99.9% is achievable, as shown in Fig. 5.

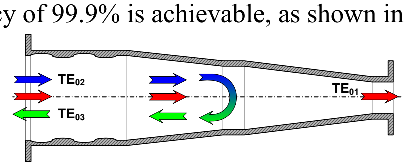

Figure 4: $TE_{02} \leftrightarrow TE_{03}$ mode converter-reflector.

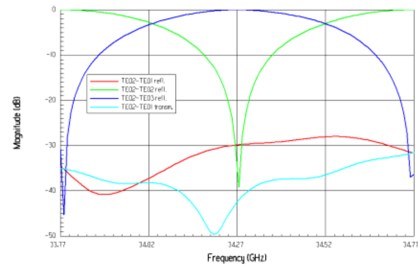

Figure 5: Results of calculation of mode conversions in the $TE_{01} \leftrightarrow TE_{02}$ mode reflecting converter with the TE_{02} mode incident.

$TE_{01} \rightarrow TE_{02}$ mode converter. This element is depicted in Figure 6. It plays the role of a directional coupler, satisfying three conditions simultaneously, namely (*i*) the forward TE_{01} mode should provide necessary coupling with the forward TE_{02} mode (for example for $s = 5$ the conversion must be 50%) without losses into other modes; (*ii*) the backward TE_{03} mode should propagate without diffraction losses; and (*iii*) the forward TE_{02} mode should not have significant scattering into other modes except the forward TE_{01} mode. Note that condition (*iii*) is satisfied automatically when conditions (*i*) and (*ii*) are satisfied. In order to satisfy all three conditions the profile $r(z)$ was examined which is given by

$$r(z) = r_1 \sin[(h_1 - h_2)z + \varphi_1] + r_2 \sin[(h_2 - h_3)z + \varphi_2] + \\ + r_3 \sin[(h_1 - h_3)z + \varphi_3],$$

as a function of coordinate z, where h_1, h_2, and h_3 are propagation constants of the TE_{01}, TE_{02}, and TE_{03} modes respectively. The corrugation period of the main profile space harmonic with amplitude r_1 and period $p_1 = 2\pi/(h_1 - h_2)$ is responsible for transformation of the input TE_{01} mode into the TE_{02} mode. Magnitudes of other space harmonics with amplitudes r_2 and r_3 are optimized in order to suppress scattering into other undesirable modes. As seen in Figures 7-8 mutual conversion of the TE_{01} and TE_{02} modes is very close to the desired level of 50%. Spurious scattering is negligibly small.

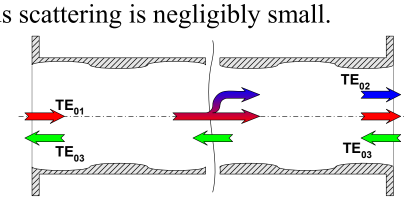

Figure 6: TE_{01}-TE_{02} selective directional coupler.

As an illustrative example, Table 1 gives parameters of a one-channel SLED-II pulse compressor suitable for operation at 34 GHz. The output pulse envelope is shown in Fig. 9 with phase reverse during 50 ns that corresponds to the magnicon bandwidth [6].

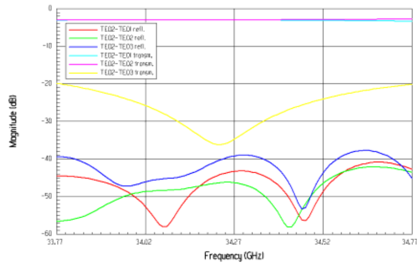

Figure 7: Conversion of the forward TE_{02} mode into other modes.

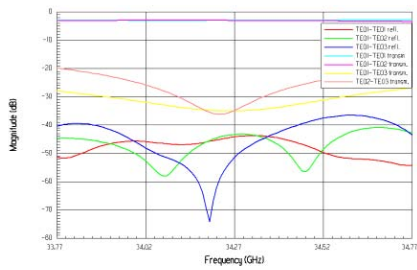

Figure 8: Conversion of the forward TE_{01} mode into other modes.

Table 1: Design parameters of the 34 GHz one channel SLED-II pulse compressor.

operating mode	$TE_{01}/TE_{02}/TE_{03}$
compression ratio	5
power gain	3.3
length of delay lines	1×11.5 m
one-trip losses	15%
reflection	<0.5%
input pulse	30 MW×500 ns
output pulse	100 MW×100 ns
efficiency	66%

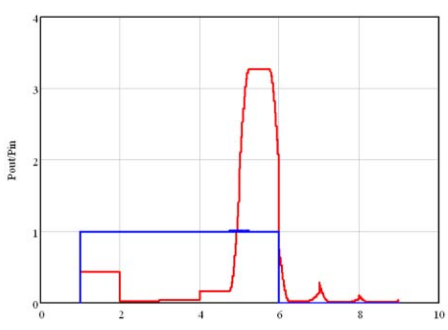

Figure 9: Calculated envelope of the input (blue) and output (red) pulses for the one-channel SLED-II with phase reversal switch time of 50 ns. Td = 100 ns.

FIRST LOW POWER TEST

A 30-GHz prototype of the one-channel compressor was built to demonstrate key principles of operation. This compressor included two $TE_{02}\leftrightarrow TE_{03}$ reflectors and a $TE_{01}\rightarrow TE_{02}$ mode converter (Fig. 10). To

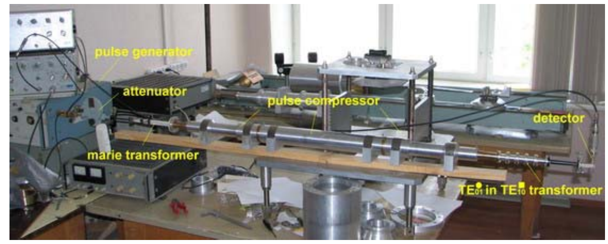

Figure 10. Photograph of the 30 GHz prototype.

simplify the first test, delay line waveguides were excluded, thus resulting in a round trip delay time of only 12 ns. The compressor was operated as a SLED-I pulse compressor, because the incident pulse was much longer than the round trip delay time. Results are shown in Fig. 11. A 180° phase flip was not used for the first test reported here, so power gain was observed at the trailing edge of the input pulse. The measured power gain ~2.4 agrees well with theoretical predictions, taking into account the actual compression ratio s≈33 which was far from the mentioned optimal value. From the experiment, round trip losses were estimated to be 4.5%, which could be due to the brass movable plungers in the end reflectors. The measured reflection from the whole compressor at the operating frequency did not exceed 3%.

Results confirm the serviceability of the three-mode compressor circuit and good agreement of the measured and calculated parameters. Full-scale experiment with the optimal compression ratio, the 180° phase flip, and the declared efficiency are planned soon.

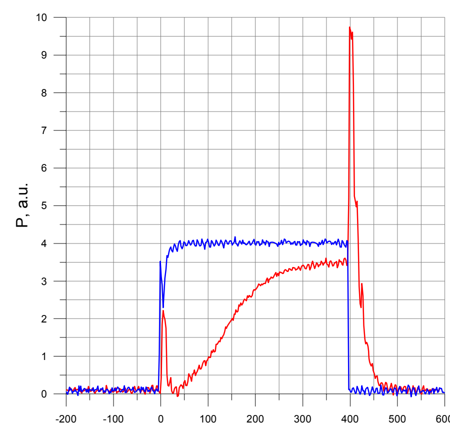

Figure 11: Oscillograms of the incident and compressed output pulses.

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