Helically corrugated waveguides for compression of microwave pulses

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***Abstract*—Waveguide with a helical corrugation of the inner surface has the desirable properties of optimised dispersion, operation far from cut-off and high breakdown field strength which make it an excellent medium for passive pulse compression. New compression measurements at both milli-watt and kilowatt powers using an optimised frequency modulation of the input pulse will be presented and discussed.**

I. INTRODUCTION

Research into ultrahigh power, short duration microwave pulses for a range of applications including radars and plasma chemistry[1] is an active field. The use of an overmoded circular metal waveguide with appropriate helical corrugations on its inner surface as a dispersive medium enables effective compression of frequency modulated microwave pulses [2, 3]. Furthermore, the use of such a compressor can enhance the power of frequency-modulated nanosecond pulses up to the gigawatt (GW) level.

II. THEORY

Consider a waveguide with the helical profile, **Figure 1** of its inner surface represented in a cylindrical coordinate system (r, φ, z) as follows:

$$r(\varphi, z) = r_0 + l\cos(m_B\varphi + k_B z) \qquad \text{Equation 1}$$

Here r_0 is the mean radius of the waveguide, l is the amplitude of corrugation and m_B and $k_B = 2\pi/d$ define the azimuthal number and axial component of the Bragg periodicity vector, respectively, and d is the corrugation period.

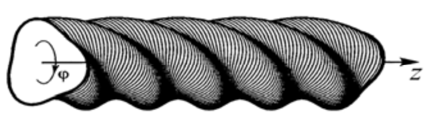

Figure 1 Schematic view of a waveguide with a three-fold right-handed helical corrugation.

In a periodically corrugated waveguide, the electromagnetic field can be represented as a superposition of the spatial harmonics, which, at negligibly small corrugation amplitude, possess dispersion characteristics of the smooth waveguide modes (partial modes) shifted along the axial wavenumber axis by an integer number of the Bragg periodicity vector k_B.

At nonzero amplitude of corrugation, resonant (strong) coupling between the circularly polarised modes occurs when their axial and azimuthal wavenumbers satisfy the Bragg conditions

$$k_{z1} - k_{z2} = k_B; \quad m_1 - m_2 = m_B \qquad \text{Equation 2}$$

Where m_1 and m_2 are the azimuthal numbers of modes 1 and 2, respectively (positive value of m is defined for right-handed modes), and k_{z1} and k_{z2} are the axial wavenumbers. This coupling results in the appearance of eigenwaves whose dispersion can be represented by the splitting of the partial mode dispersions near the frequencies of their intersections with dispersions of the spatial harmonics.

The structure used in the compressor experiments had a three-fold right-handed corrugation, $m_B = -3$ which in the lowest frequency region resonantly coupled a forward propagating left-handed $TE_{-1,1}$ mode $(m_1 = -1)$ and a near-cutoff right-handed $TE_{2,1}$ mode $(m_2 = 2)$.

In a dispersive medium, the group velocity of any wave propagating through it is dependent on the frequency of the wave as shown in **Figure 2**. Therefore, in the case of the helically corrugated waveguide, if a microwave pulse is produced in which the wave is swept from a high frequency with a low-group velocity to a low frequency with a high-group velocity, the tail of the pulse will move to overtake the front of the pulse, resulting in pulse shortening and a corresponding growth in amplitude if the losses are sufficiently small.

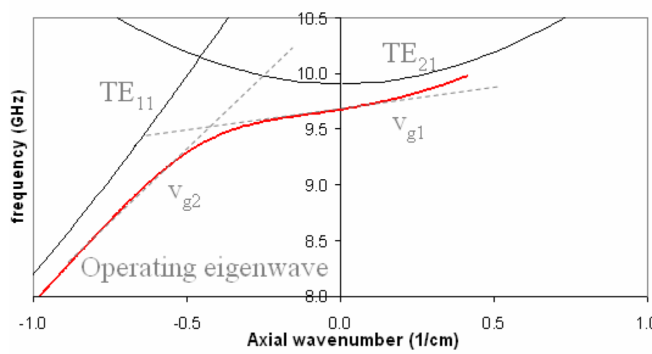

Figure 2 Operating eigenwave for helically corrugated waveguide.

The modes of the helically corrugated waveguide can be found using the method of perturbation and coupled mode theory, leading to the resultant operating eigenwave, **Figure 2** dispersion equation:

$$\left(k^2 - k_z^2 - k_{\perp 1}^2\right)\left(k^2 - (k_z - k_B)^2 - k_{\perp 2}^2\right) = 4\kappa^2 k_0^4 \qquad \text{Equation 3}$$

And

$$\kappa = \frac{l}{2 r_0^3 k_0^2}\frac{\nu_1^2\nu_2^2 - m_1 m_2 r_0^2\left(k_0^2 + k_{z1}k_{z2}\right)}{\sqrt{\left(\nu_1^2 - m_1^2\right)\left(\nu_2^2 - m_2^2\right)}} \qquad \text{Equation 4}$$

III. RESULTS OF STUDIES

The experiment comprises an arbitrary waveform generator (AWG) to generate an input signal to the Input-Output function of a

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vector signal generator (VSG) with optimum parameters as well as a 12GHz single-shot digitizing oscilloscope used to monitor the input and output radiation to-and-from the compressor respectively, **Figure 3.**

Low power results

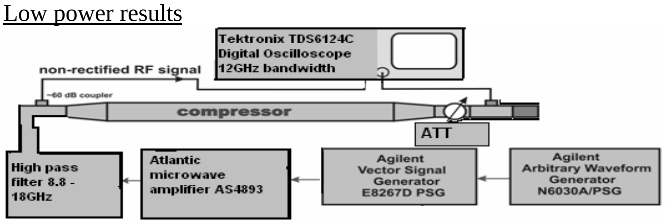


Figure 3 Low power compressor experimental set up.

The low power tests included an Atlantic microwave pre-amplifier (AS4893) with a 25dB gain and high pass filter, 8.8 - 18GHz .

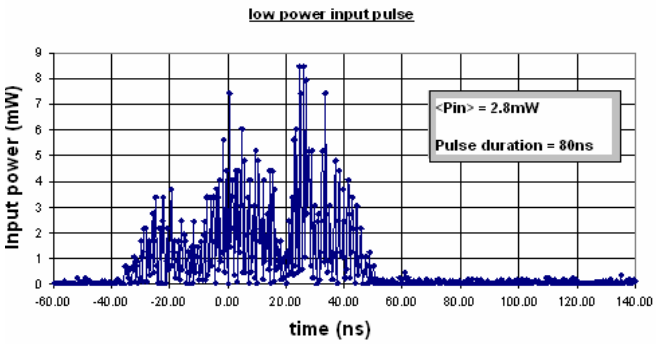


Figure 4 Measured input pulse.

The average value for the input power of pulse, $\langle P_{in} \rangle$ is 2.8mW with a pulse duration of 80ns and the corresponding peak value, P_{peak} of the compressed pulse is 68mW with pulse duration of 1.5ns, therefore power compression ratio of 25 was measured.

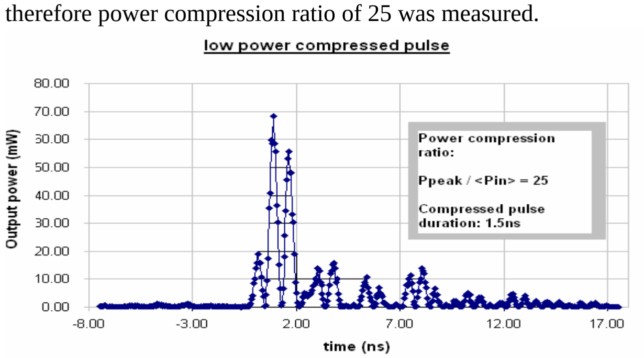


Figure 5 Measured compressed pulse.

High power results

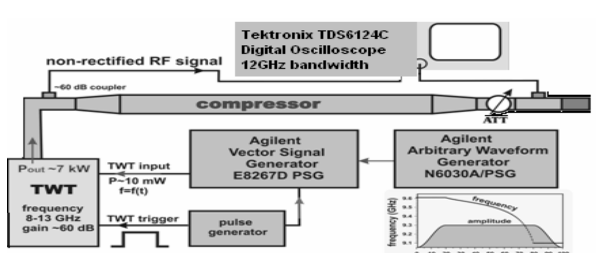
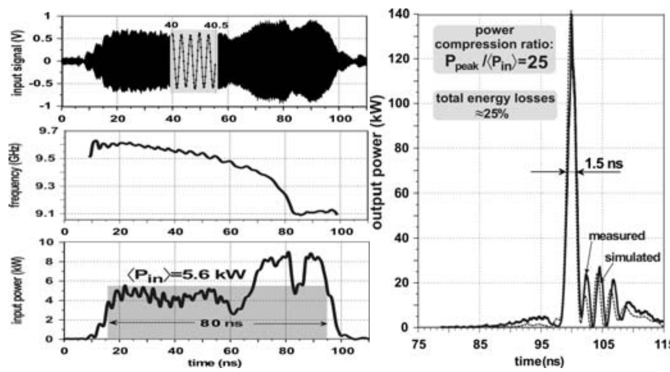


Figure 6 High power compressor experimental set up.

A conventional X-band travelling wave tube (TWT) was used to amplify the RF radiation generated by the VSG up to powers of 5-7kW, **Figure 6**. The optimum frequency modulation of a quasi-rectangular input pulse was found from analysis of the measured helical waveguide dispersion[4]. The sweep started from the frequency corresponding to the minimum value of the group velocity sweeping to a frequency of higher group velocity in such a manner that the inverse group velocity was a linearly decreasing function of time over the input pulse duration determined by the length of the waveguide. This pulse was produced using a Matlab program to generate a 1 GHz bandwidth swept pulse from the AWG which fed into the input/output function of the VSG which up-mixed the signal to produce a microwave pulse with a frequency sweep from 9.6 to 9.1 GHz in 80 ns at a maximum sweep rate of up to 20 MHz/ns. The measured frequency modulation coincided with the predicted optimum frequency sweep, **Figure 7**a predicted by theory.



(a) (b)

Figure 7 Experimental results for the pulse compression: a) input pulse details; b) measured (solid line) and simulated (dashed line) compressed pulse.

Measurements showed that the maximum available (for this compressor) power compression ratio was 25. A 5.6 kW (averaged over the pulse), 80 ns duration microwave pulse was compressed to 1.5 ns duration, with a peak power of 140 kW as shown in **Figure 7**b. The measured output pulse shape was in very good agreement with the simulations shown in **Figure 7**b using a Fourier optics approach, which included the measured compressor[3] and input pulse characteristics shown in Figure 7a.

Future work incorporating the amplifier and filter in high power tests along with new instrumentation such as a pin switch diode and a low pass filter will be conducted. The operating parameters (frequency range, input pulse duration-shape, sweep interval) of non-resonant electron devices such as backward wave oscillators (BWOs) [5] and TWTs to increase the peak power to the GW and multi-MW power level respectively will be investigated.

Acknowledgements

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Reference

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