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Helically corrugated waveguides for compression of frequency swept microwave pulses

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Introduction

Short pulse high power microwave radiation can be used for time of flight diagnostic measurements in plasmas, e.g. density profiles by reflectometry. A three-fold helical corrugation of the inner surface of a waveguide synthesises eigenwaves having useful dispersive properties by combining two distinct counter-rotating modes of a corresponding circular waveguide. The dispersion may be tailored to the requirements of an application by adjusting the amplitude and period of the corrugations. Such dispersive properties have proven useful in broadband radiation amplifiers, or to achieve passive compression of smoothly frequency modulated microwave pulses. The paper presents results of experiments using a solid state source to produce an optimised frequency-chirped input pulse and amplified by a high power Travelling Wave Tube Amplifier (TWTA). The waveforms of the input and output microwave signals were captured on a UHF Digital Storage Oscilloscope. The results demonstrated at 5.7kW input power levels that X-band radiation pulses of 67ns duration with 5% frequency modulation can be compressed into a 2.8ns pulse having 12 times higher peak power, whilst retaining 50% of the energy in the input signal. The technique offers great potential for scaling to higher frequencies and power levels.

Helically corrugated waveguides for passive pulse compression

One method of pulse compression, commonly used for electromagnetic radiation (from radio to optical frequencies), exploits the frequency sensitive dispersion offered by many types of propagation media or transmission lines. An attractive passive pulse compressor at microwave frequencies, due to high power capability and convenient sizes, is the hollow waveguide with its hyperbolic dispersion above some limiting cut-off frequency. Unfortunately such waveguides exhibit strongly dispersive behaviour only in the region close to cut-off. In practice when using such a device at the output of a high power frequency agile oscillator or broadband amplifier, some part of the

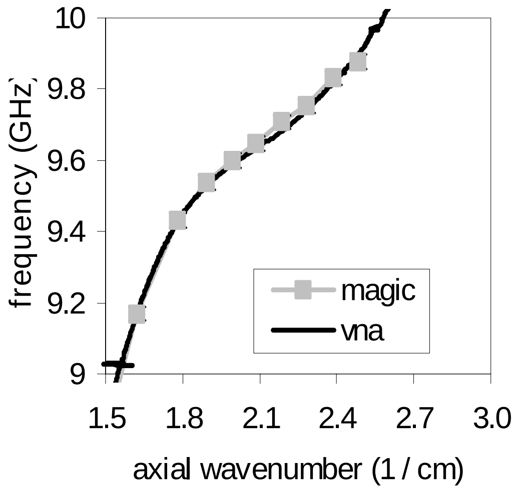


Figure 1: *Measured and computed dispersion of the corrugated waveguide*

oscillator or amplifiers spectral range will be below the cut-off of the output line, resulting in strong feedback. This will disrupt the proper operation of an oscillator, causing it to change its frequency from the required value whilst spoiling its efficiency, and will cause an amplifier to oscillate at some uncontrolled frequency. This may be resolved through the use of a helically corrugated waveguide, coupling together two circularly polarised modes of a smooth circular waveguide [1-5], to form a hybrid operating eigenmode having a smooth but strong variation in its dispersion in regions far above cut-off. The length and dispersion of the waveguide may then be synthesised in conjunction with the realisable tuning rate of the source to provide an optimised pulse compression system. To demonstrate this method in the X-band (8.2-12.4GHz), a three fold helical structure [1,2,5] was fabricated having a mean radius of 14.7mm, an axial period of 28.9mm, a length of 208cm and a corrugation depth of 1.4mm. The dispersion of this waveguide was accurately predicted using perturbation theory [3,5], then checked using the 3D PiC code Magic and direct measurement using a Vector Network Analyser [4,5]. The dispersion produced by this structure is illustrated in Figure 1.

Pulse Compression Experiments

Given the waveguide dispersion, confirmed by two calculations and an experimental measurement, an optimum frequency chirped microwave input pulse was devised to experimentally test the behaviour of the pulse compressor. The experimental configuration is illustrated in Figure 2. This signal was provided by a fast tuning microwave voltage controlled oscillator (VCO) tuneable through the X-band. The oscillator was driven by both a DC power supply and a fast pulse applied to the frequency control. The shape of the ramp

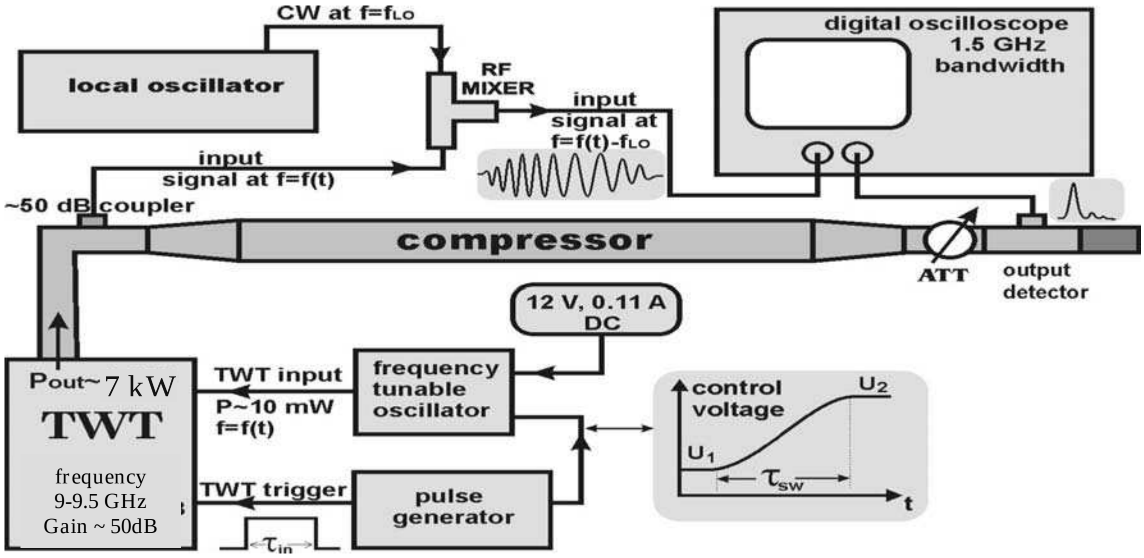
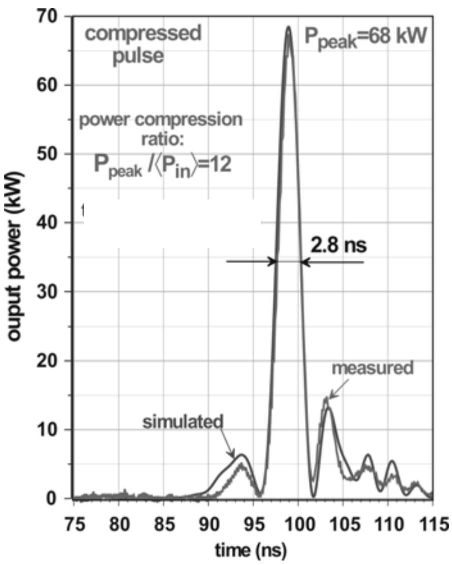


Figure 2: *Experimental apparatus to investigate the pulse compression technique*

was adjusted using a highly configurable pulse generator to yield close to the ideal frequency sweep for the compressor's known dispersion. This was in turn used to drive a pulsed X-band TWT amplifier capable of delivering up to 8kW of peak power. The input pulse was sampled using a calibrated directional coupler, with additional attenuation, and the rectified output signal was compared to that achieved at the output of the compressor using special high speed microwave rectifying diodes with reduced video buffer capacitance. A sample of the input signal was mixed down to the UHF range for display on a deep memory digital oscilloscope for dynamic monitoring/adjustment of the spectral



COMPRESSION PARAMETERS	
Power compression ratio	*=12*
Compression efficiency	=50%
Initial pulse duration	*=67ns*
Compressed pulse duration	*=2.8ns*
Frequency sweep	*=9.6–9.2GHz*
Compressor length	*=2.08m*

Figure 3: *Comparison of measured and calculated output pulses from the compression apparatus*

sweep of the input pulse. Figure 3 illustrates the behaviour observed, showing that for the actual pulse chirp produced by the oscillator and confirmed by the measurements of input signal, a compression of 12 in amplitude and 24 in duration were obtained, in very close agreement with calculations for the measured frequency sweep. Calculations indicated that with increased optimisation of the chirp rate and chirp profile a factor of two improvement was attainable, but this was impossible to realise with the resonant VCO and therefore new experiments are underway using the latest high bandwidth arbitrary waveform generators to provide true optimisation of the input chirp profile. Preliminary results will be presented in the poster.

Conclusions

A passive microwave pulse compression system, based on the special dispersive properties of a helically corrugated waveguide, capable of being used at the output of high power oscillators and amplifiers has been demonstrated at a frequency of 9GHz. A pulse chirped by 400MHz from 9.6 to 9.2GHz in a period of 67ns by a VCO and amplified to a power of 5.7kW by a TWTA was compressed into a 2.8ns pulse of 68kW amplitude by the dispersive medium. Excellent agreement was achieved between the compression experiment and numerical predictions based on the calculations and measurements of the dispersive properties of the waveguide and the input pulse. New research aims to attain a factor of two further improvement by enhanced optimisation of the pulse chirp.

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