MICROWAVE PULSE COMPRESSION USING A HELICALLY CORRUGATED WAVEGUIDE

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ABSTRACT

One interesting method of microwave pulse compression is passive–frequency based microwave pulse compression where a dispersive medium is used to compress a frequency swept pulse. Oversized circular waveguide having helical corrugation supports eigenmodes that are suitable for pulse compression for frequency modulated input pulse is as shown by Brat et.al. [IEEE Trans. Plasma Sci., vol. 33, no.2, pp. 661–667, 2005.]. In this paper, theoretical studies on microwave pulse compression in helically corrugated waveguide is presented. The numerical results show peak power compression for Gaussian and rectangular pulse.

INTRODUCTION

Ultra high-power short microwave pulses have been produced in recent years due to its wide range of applications **[1].** These high-power pulses can be produced by microwave pulse compression. One of the common methods to achieve necessary power levels is to use electron beam –wave interaction to amplify the microwave pulse to higher powers. To further increase the peak output power, an economically viable method is to compress a long duration lower power pulse into short duration higher power pulse. The principles and method of pulse compression vary depending on their application **[2]**.

Compression of smoothly frequency modulated electromagnetic pulses in dispersive medium is well known and actively used in microwave electronics and laser physics**.** Hollow metal waveguides representing dispersive media are attractive for the microwave pulse compression because of their capabilities of handling very high power, relative compactness and simplicity. In a dispersive medium, the group velocity of any wave propagating through it is dependent on the frequency of the wave. Therefore, if a microwave pulse is produced in which the wave is swept from a frequency with a low-group velocity to a 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. If a cylindrical waveguide is used as the dispersive medium, the optimum region of operation is where the largest change in-group velocity with frequency occurs, which is near cutoff for a smooth waveguide.

One of the solutions is to use a helically corrugated waveguide **,** which was previously studied intensively for use as an interaction region for a gyro-TWA **[3].** The helical wall perturbation can provide selective coupling between a higher and a lower circularly polarized mode avoiding the Bragg reflection zones, which would inevitably appear in the case of an axisymmetric corrugation because of coupling between forward and backward propagating spatial harmonics. This coupling results in an eigenmode where the dispersion characteristics of one mode gradually transform into the other. If the parameters of the corrugation are chosen correctly, this can give the eigenwave a group velocity that decreases with frequency, and avoids regions with zero or negative group velocity, in its operating bandwidth, which is far from cutoff.

As the helically corrugated waveguide operates far from cutoff, the compressor provides much lower reflections at its input than the smooth circular waveguide. This allows the compressor to be used at the output of a high-power Cherenkov TWT. The second advantage is that the optimum frequency sweep in a helical compressor is from a high frequency to a lower frequency, and can be controlled by the corrugation parameters. This makes the helically corrugated waveguide compressor attractive for use at the output of a powerful relativistic BWO as this would require a beam voltage that decays with time for compression to take place **[4].**

This paper deals with the theoretical study to obtain a multigigawatt radiation power, which is based on passive compression of the microwave pulse compression generated in helically corrugated waveguide. Section 2 presents the general principles and relationships determining compression of frequency modulated pulses and considers the features of a dispersive medium in the form of a helically corrugated waveguide. Section 3 discusses the analytical results and also compared to experimental results.

DISPERSION RELATION AND PULSE COMPRESSION

In this section, the dispersion characteristics of helically corrugated waveguides are presented. Considered the waveguide with the helical profile of its inner surface is represented in a cylindrical coordinate system (*r, ɵ, z)* as follows:

Inner wall radius

$$R(z,\theta) = R_0 + h\cos(k_o z + q_0\theta)$$

(1)

Where $k_0 = 2\pi/z_0$ and $q_0 = 2\pi/\phi_1$. Periodicity in axial direction is z_0, while periodicity in azimuthal direction is ϕ_1.

Here R_0 is the mean radius of the waveguide, h is the amplitude of the corrugation, and z_0 is the corrugation period**.**

In a periodically corrugated waveguide, the electromagnetic field can be represented as a superposition of the spatial harmonics. Using the boundary conditions that the tangential component of electric field must vanish on the helical boundary, we get a dispersion relation, to be published elsewhere, whose solution is:

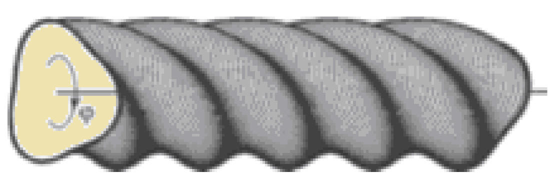


Figure. 1 Schematic view of a waveguide with a three-fold right-handed (q=3) helical corrugation

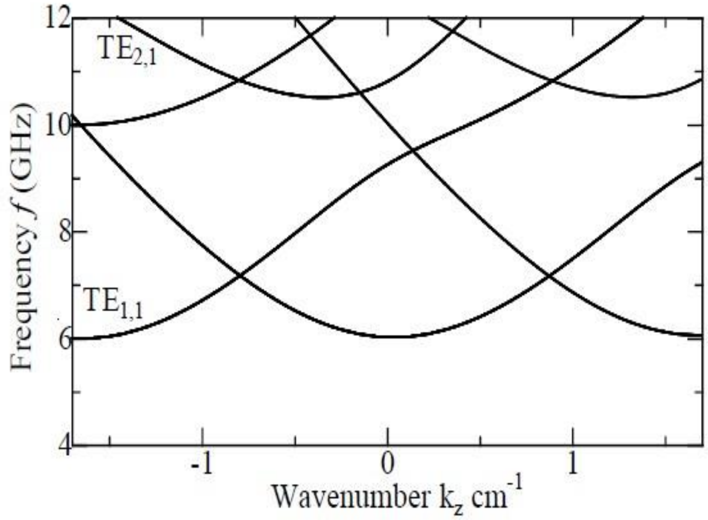


Figure. 2 Dispersion diagram for three-fold helically corrugated waveguide: Mean radius R_0=1.47cm, corrugation period z_0=2.89, and amplitude h=0.19cm.

To compress microwave pulses, the modulation of the oscillation frequency in the wave package and the dispersion of the medium should be chosen such as to ensure that the leading edge of the pulse propagates at a lower group velocity than its trailing edge. Moreover, an increase in the pulse amplitude due to the compression should exceed its damping in the medium due to evitable losses. [5]

Here we consider a specific model for the dependence of frequency on wavenumber and calculate the propagation of pulse in helical corrugated waveguide with certain parameters to estimate the maximum compression ratio. We assume that a quasi-monochromatic pulse $u(z,t)$ at the input of the waveguide compressor is

$$u(z,t)=e^{-\alpha t^2}\sin\left[\left(\omega_0-\frac{\omega_0 t}{500}\right)t-k(t)z\right] \qquad (2)$$

Where $\omega=f(k)$ or $k=g(\omega)$

Thus if ω is time dependent then k is also time dependent.

The pulse travel in both positive and negative direction of z therefore equation (2) can be written as

$$u(z,t)=\frac{1}{2}e^{-\alpha t^2}\sin\left[\left(\omega_0-\frac{\omega_0 t}{500}\right)t-k(t)z\right]+\frac{1}{2}e^{-\alpha t^2}\sin\left[\left(\omega_0-\frac{\omega_0 t}{500}\right)t+k(t)z\right] \qquad (3)$$

Differentiating above equation w.r.t z and $\frac{\partial u(0,t)}{\partial z}=0$ we get

$$u(0,t)=e^{-\alpha t^2}\sin\left(\omega_0-\frac{\omega_0 t}{500}\right)t \qquad (4)$$

$$u(z,t)=\sqrt{\frac{2}{\pi}}\int_{0}^{\infty}A(\omega)\sin(\omega t-kz)d\omega \tag{5}$$

$$u(0,t)=\sqrt{\frac{2}{\pi}}\int_{0}^{\infty}A(\omega)\sin(\omega t)d\omega$$

The amplitude $A(\omega)$ describes properties of the linear superposition of the different waves. It is given by the transform of the spatial amplitude $u(z,t)$,evaluated at z=0 therefore initial value problems for the wave equation demand the initial value of both function $u(0,t)$ and the space derivative $\frac{\partial u}{\partial z}(0,t)$. Then it is easy to show that $A(\omega)$ is given in terms of the initial value.

$$u(0,t)=\sqrt{\frac{2}{\pi}}\int_{0}^{\infty}A(\omega)\sin(\omega t)d\omega \tag{6}$$

To find out the $A(\omega)$ multiply above equation by $\sin(\omega' t)$ and integrating it w.r.t t

We get

$$\int_{0}^{\infty}\sin(\omega' t)u(0,t)dt=\sqrt{\frac{2}{\pi}}\int_{0}^{\infty}\int_{0}^{\infty}A(\omega)\sin(\omega' t)\sin(\omega t)d\omega dt \tag{7}$$

$$\int_{0}^{\infty}\sin(\omega' t)\int_{0}^{\infty}A(\omega)\sin(\omega t)d\omega dt=\sqrt{\frac{\pi}{2}}\int_{0}^{\infty}\sin(\omega' t)u(0,t)dt \tag{8}$$

Solving L.H.S of equation (8)

$$\int_{0}^{\infty}A(\omega)d\omega\int_{0}^{\infty}\sin(\omega' t)\sin(\omega t)dt=\frac{\pi}{2}\int_{0}^{\infty}A(\omega)[\delta(\omega-\omega')]d\omega \tag{9}$$

On equating (8) and (9) we get

$$A(\omega')=\sqrt{\frac{2}{\pi}}\int_{0}^{\infty}\sin(\omega' t)u(0,t)dt \tag{10}$$

At $\omega=\omega'$

$$A(\omega)=\sqrt{\frac{2}{\pi}}\int_{0}^{\infty}u(0,t)\sin(\omega t)dt \tag{11}$$

we have already assumed $u(0,t)=e^{-\alpha t^2}\sin\left(\omega_0-\frac{\omega_0 t}{100}\right)t$ as the initial shape of the pulse for which $A(\omega)=\sqrt{\frac{2}{\pi}}\int_{0}^{\infty}u(0,t)\sin(\omega t)dt$.

Substituting the value of $u(0,t)$ as initial pulse in $A(\omega)$ we get

$$A(\omega)=\sqrt{\frac{2}{\pi}}\int_{0}^{\infty}e^{-\alpha t^2}\sin\left(\omega_0-\frac{\omega_0 t}{500}\right)t\sin(\omega t)dt \tag{12}$$

Substituting the value of $A(\omega)$ in $u(z,t)$ equation (6) will give the expression for the frequency swept compressed pulse at the other end of the helically corrugated waveguide.

A similar case is also discussed taking initial pulse of rectangular shaped

$$u(z,t) = \sin(\omega - 0.002\,\omega(t-20))(t-20)(heaviside(t-5.0) - heaviside(35.5-t)) \quad (13)$$

Numerical results are obtained for both the two shapes of pulses that are discussed in the next section of results

RESULTS AND DISCUSSION

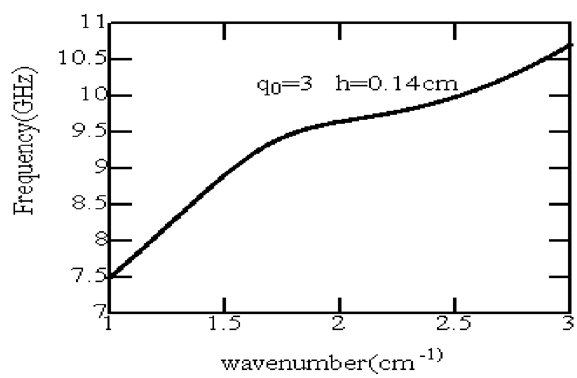
In this section we examine the operation of helically corrugated waveguide for given set of parameters. We have used the operating mode from cold dispersion diagram of helically corrugated waveguide obtained in the previous chapter1 for pulse compression.

The results are obtained for the following set of eigenwave of $q_{0=} = 3$ and for corrugation depth 0.14cm

Figure 3(a) is operating mode for corrugation amplitude 0.14cm. The compression of Gaussian pulse is four-fold and three-fold power at 0.01 and 0.02 value of alpha respectively. Fig. (b, c).

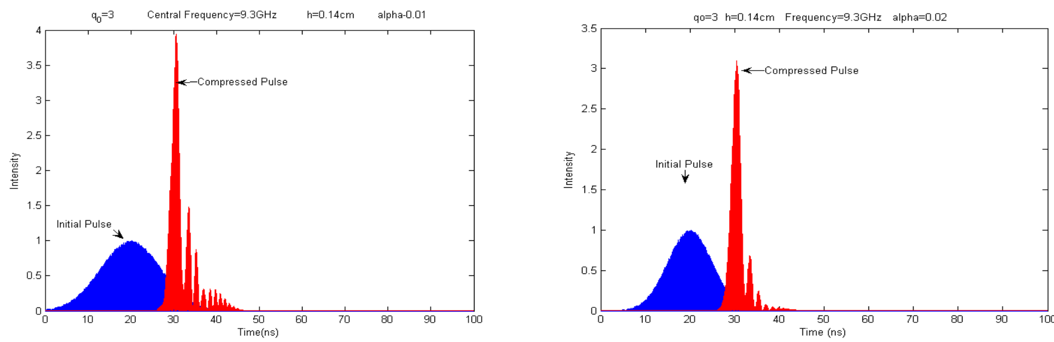
The rectangular pulse gives compression of seven and eleven-fold for 9.3GHz and 9.5GHz of central frequencies as shown if Figs. 4 d and e, respectively.

It is observed that the compression ratio for rectangular pulse is more than the compression ratio for Gaussian pulse for all the values of corrugation amplitude.



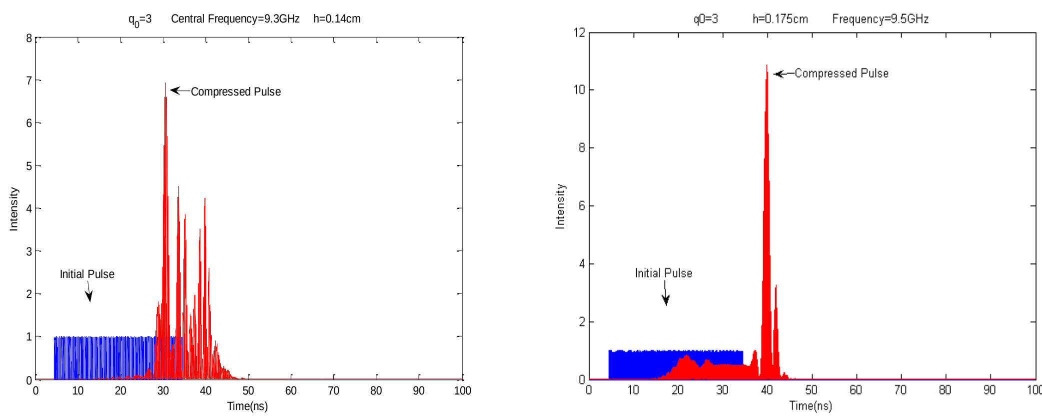
(a)

Fig 3(a) Dispersion characteristics for the compressor waveguide



(b) (c)

Fig. 3 (b) $\alpha = 0.01$ and 3 (c) $\alpha = 0.02$ Pulse compression in the helically corrugated waveguide with Gaussian shaped pulse.



(d) (e)

Figure. 3 (d) and 5 (e) Pulse compression of rectangular shaped pulse at different central Frequencies.

Highest compression is found for helical structure having corrugation amplitude of 0.14 cm for given mean radius 1.47 cm and periodicity 2.89 cm. The rectangular pulse chosen is having central frequency 9.5 GHz. The pulse having width of 30 ns compresses to 5 ns with eleven-fold compression.

CONCLUSION

Helically corrugated waveguide dispersion relation is solved. Pulse compression studied for Gaussian as well as rectangular pulse. Seven fold in former and eleven fold power increase in latter case, and also more in comparison to earlier results obtained for higher corrugation depth [5]. The numerical results are in agreement with the experimental results of G. Burt et. al.[4].

REFERENCES

1. Gaponov-Grekhov A V and Granatstein V L, Eds., *Applications of High-Power Microwaves*.Boston, MA: Artech House, 1994.
2. Denisov G H, Bratman V L, Cross A W, He W, Phelps A D R, Ronald K, Samsonov S V and Whyte C G 1998 *Phys. Rev. Lett.* **25**, 5680
3. Burt G, Samsonov S V, Phelps A D R, Bratman V L, Ronald K, Denisov G G, He W, Young A R, Cross A W and Konoplev I V 2005 *IEEE Trans. Plasma Sci.* **33** 661

4. Burt G, Samsonov S V, Ronald K, Denisov G G, Young A R, Bratman V L, Phelps A D R, Cross A W, Konoplev I V, He W, Thompson J and Whyte C G 2004 *Phys. Rev. E*. 70046402

5. Vasudha Rajput,N.Parmar, K.S.Bhat, K.P.Maheswari, Y.Choyal ,Journal of Physics: Conference Series 365(2012)012056