A Novel Co-Harmonic Gyrotron

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A novel interaction cavity has been designed for a gyrotron, allowing co-harmonic generation at the 2nd and 4th resonances of the electron cyclotron frequency, ω_c. The output aperture of the cavity has been designed to trap the lower harmonic, allowing pure output of the upper harmonic. Results from recent numerical simulations, conducted in the PiC code, MAGIC 3-D, and the electromagnetic code, CST Microwave Studio, are presented.

The Gyrotron

The gyrotron [1, 2] is a fast wave device, capable of generating high average power in the mm-band, by exciting the Cyclotron Resonance Maser (CRM) [3] instability. In order to obtain excitation, a beam-wave resonance condition must be satisfied.

$$\omega = s\omega_c + k_z v_z$$

$$\omega_c = \frac{eB_z}{\gamma m_0}$$

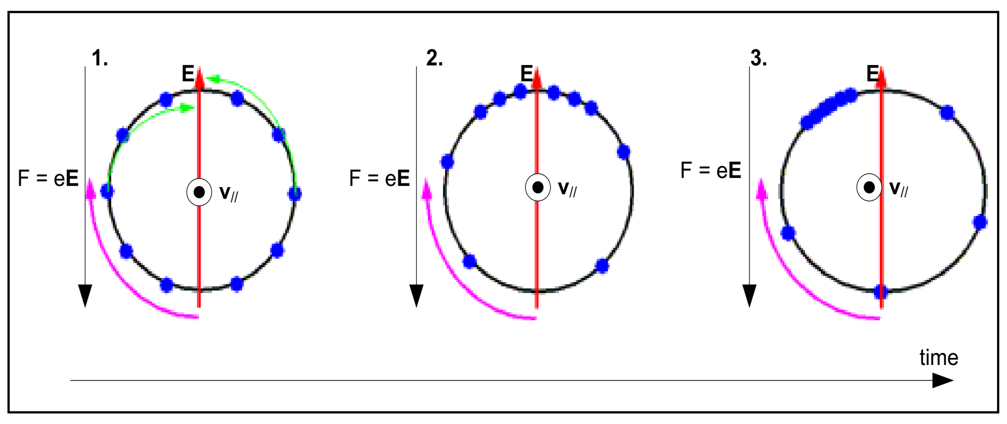

Figure 1 – The cyclotron resonance maser instability

However, few devices are capable of delivering output in the sub-mm region, where several attractive potential applications lie. This is a result of the costly and bulky magnetic systems required. To mitigate this, it is necessary to operate at a harmonic, s, of the cyclotron frequency; however, direct excitation of a high harmonic is problematic.

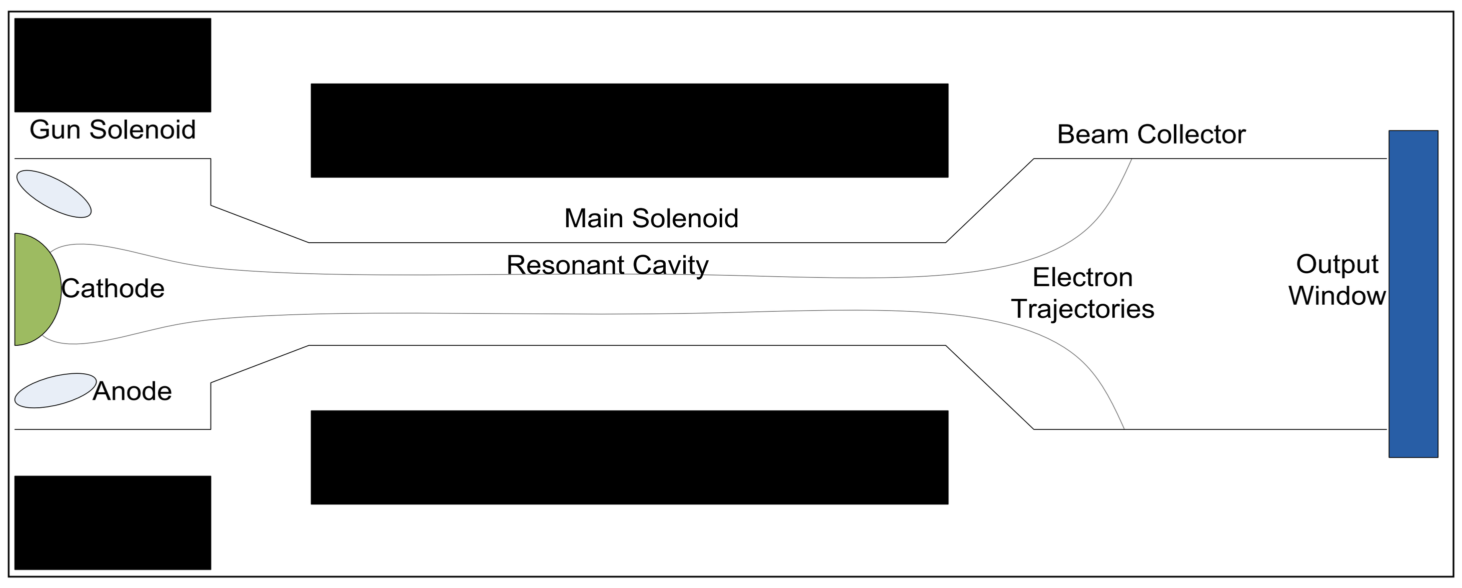

Figure 2 – Schematic of the gyrotron

The Corrugated Cavity

A co-harmonic [4] type scheme allows generation of a high harmonic as a "parasite" resonance in a lower harmonic oscillator. In order to achieve this, the cut-off frequencies, f_{cut}, of the modes being generated must be in an integer ratio – a feature not possible in a cylindrical geometry, where f_{cut} is given by the roots of the Bessel function of the first kind. This can be realised through an azimuthal corrugation of the cavity, given by the equation below, where r_0 is the mean cavity radius, 8 mm, and l_0 is the corrugation depth, 0.7 mm.

$$r(\varphi) = r_0 + l_0 \sin(8\varphi)$$

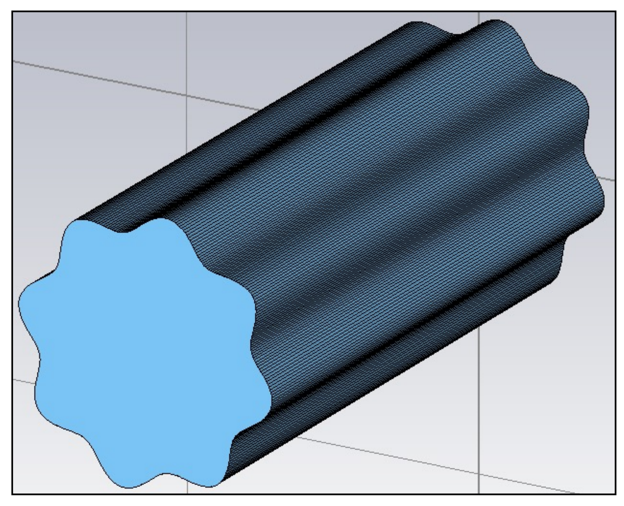

Figure 3 – The corrugated cavity

The modes of interest are the $TE_{2,2}$ at 37.5 GHz, excited at the 2nd harmonic, and two non-degenerate polarisations of the $TE_{4,3}$ at 69 GHz and 75 GHz, respectively, excited at the 4th harmonic. The output waveguide of the system is cut-off to the 2nd harmonic and the lower $TE_{4,3}$ mode, through the use of an output taper, of length 6 mm, which should result in a pure output of the 75 GHz signal. The axis-encircling electron beam used has a current of 5 Amps, voltage of 60 kV, and pitch alpha of 1. The efficiency of the resulting 4th harmonic is expected to be ~ 2%.

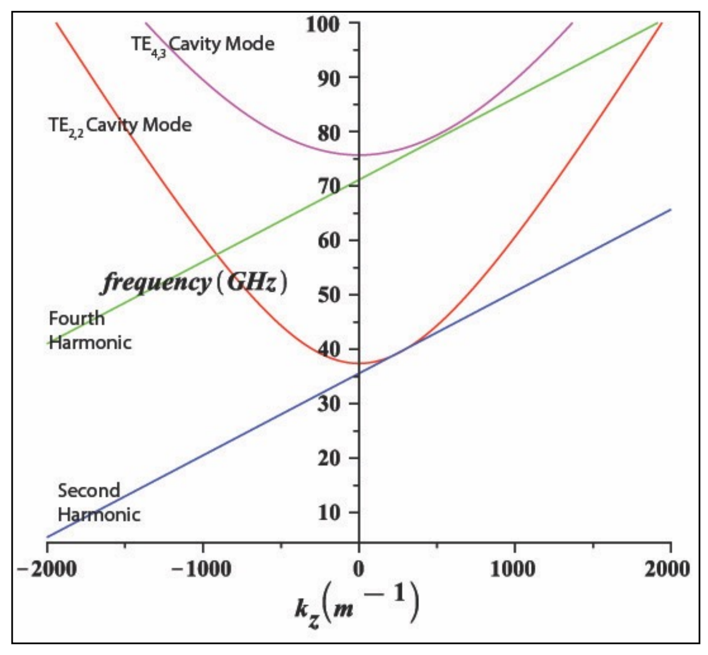

Figure 4 – Dispersion diagram of system

Hot Simulations

"Hot" calculations are performed in Magic 3-D to observe the beam-wave interaction. Within the cavity, a $TE_{2,2}$ was observed as predicted; however, at the output a $TM_{2,1}$ mode is witnessed, at the expected 2nd harmonic frequency of 36.73 GHz. The intended co-harmonic behaviour is witnessed, with a 4th harmonic signal at 73.46 GHz; however it is dominated by the 2nd harmonic.

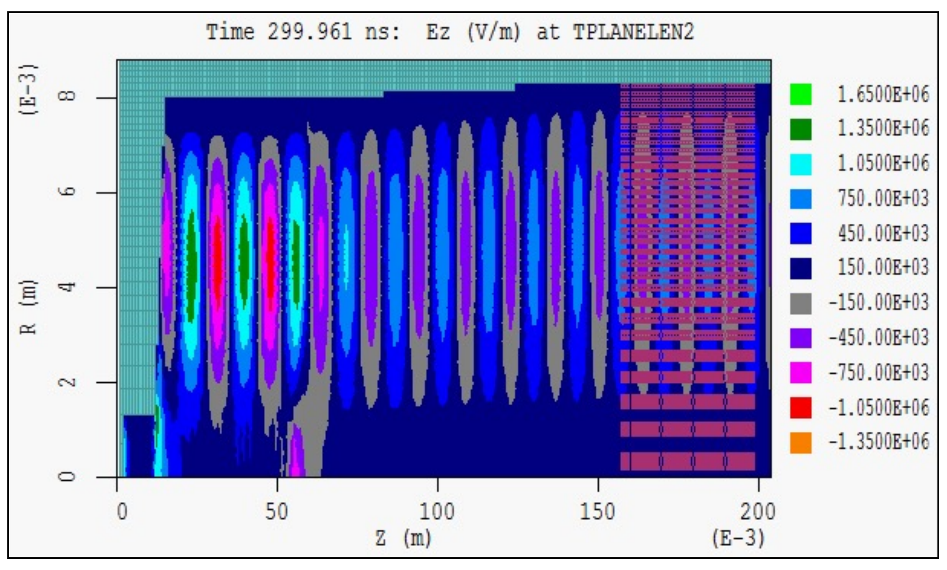

Figure 5 – Simulated geometry, as generated by MAGIC 3-D, showing Ez field component

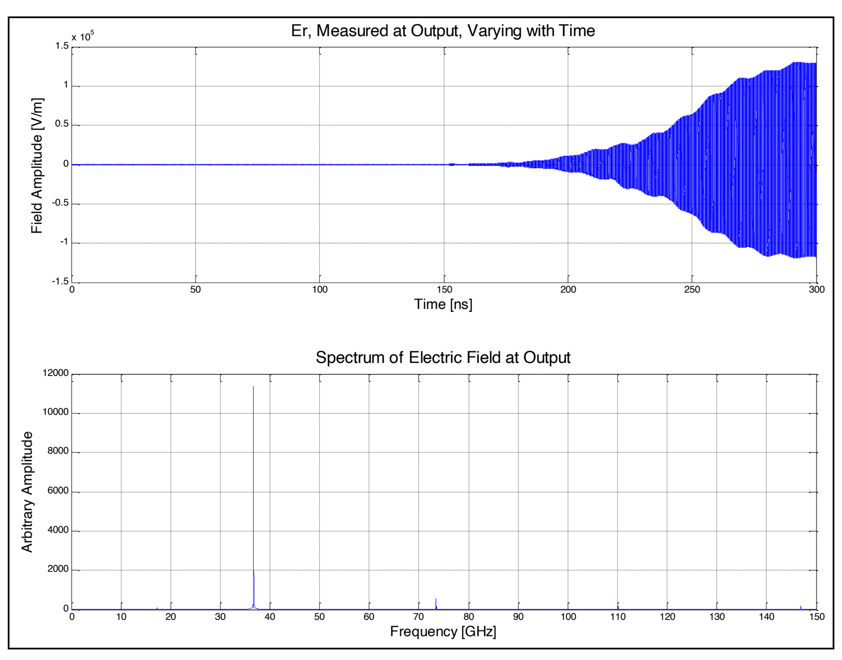

Figure 6 – Er component measured at the output

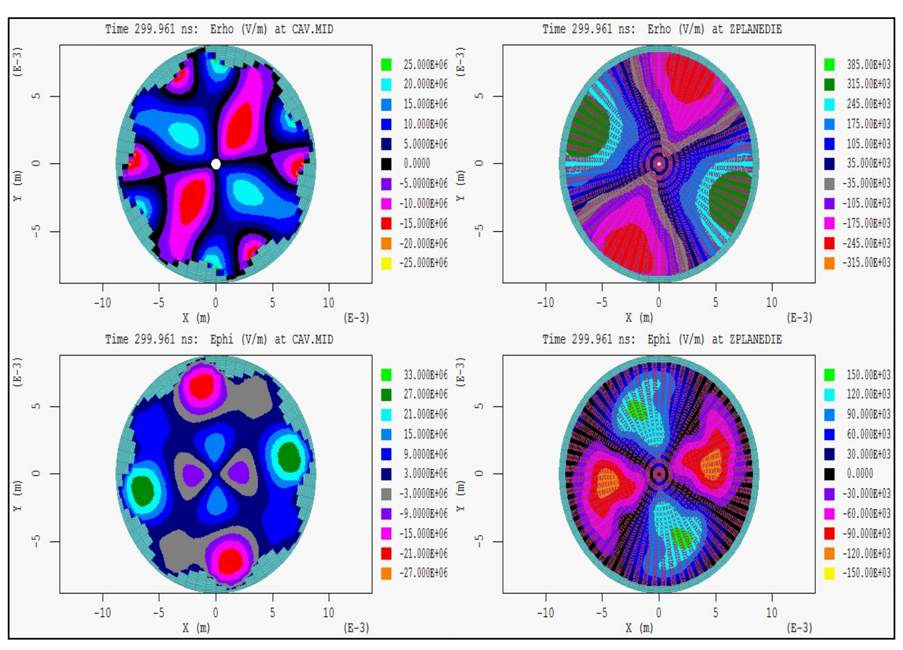

Figure 7 – Er and Ephi field profiles, within the cavity and at the output

Cold Simulations

Simulations are conducted in CST Microwave Studio, in an attempt to confirm the mode conversion problem witnessed in Magic 3-D. A $TE_{2,2}$ signal is injected into the simulated structure, across a frequency band of 35 GHz – 40 GHz. Mode conversion is observed to both the $TE_{2,1}$ and $TM_{2,1}$ modes across the entire band. By extending the length of the output taper to 40 mm, the mode conversion is seen to reduce dramatically. However, when used in Magic, the 2nd harmonic continues to dominate the output.

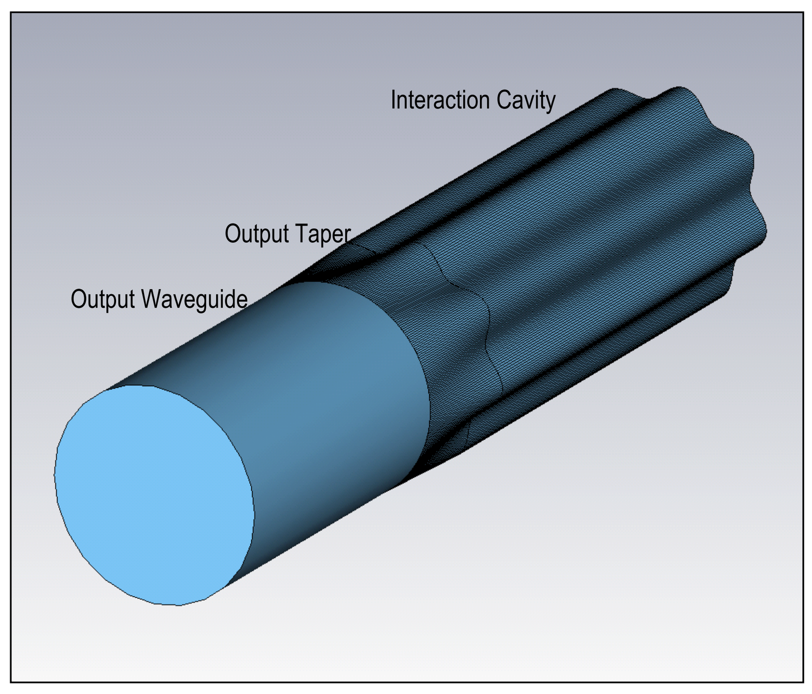

Figure 8 – System geometry simulated in CST Microwave Studio

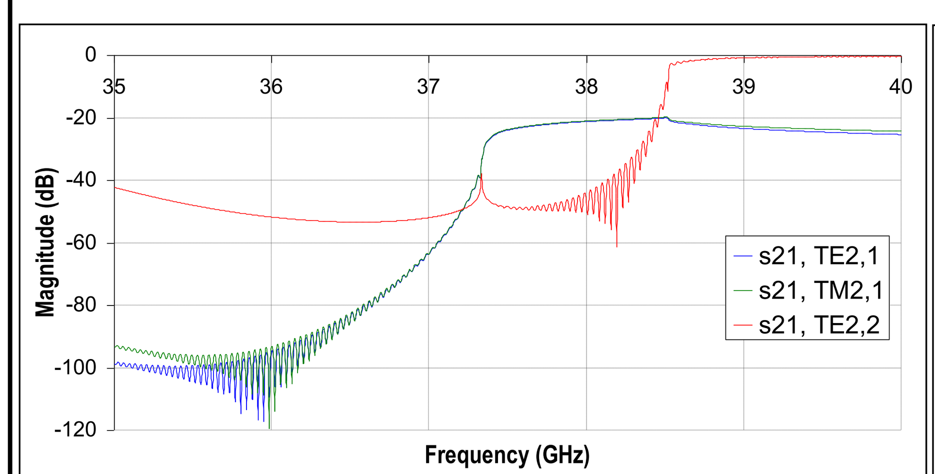

Figure 9 – S21 parameters for the experimental system

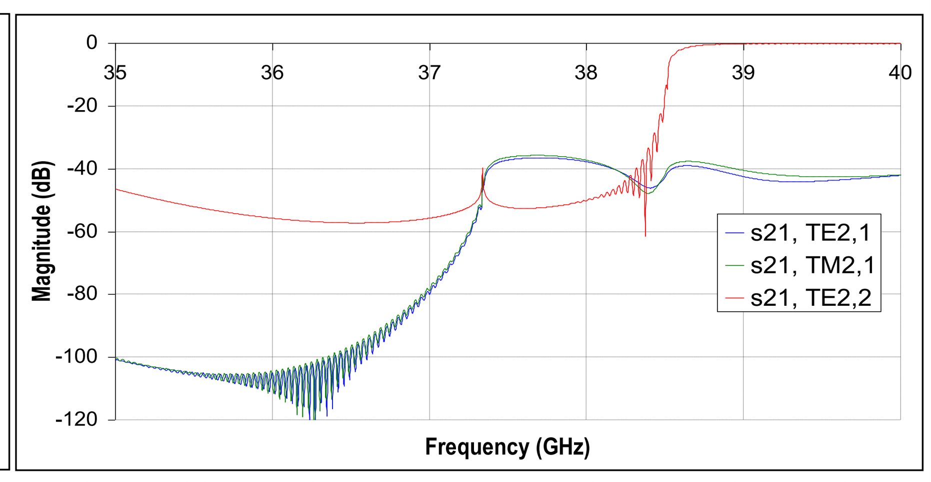

Figure 10 – S21 parameters for the experimental system with an extended taper

Future Work

Attempts have been made to separate the 4th harmonic and the mode converted 2nd harmonic using a Bragg reflector. While an isolation of better than -20 dB was obtained for the $TM_{2,1}$ mode, the $TE_{4,3}$ suffered a similar rejection. A potential solution lies with a quasi-optical mode converter [5], the design of which is ongoing.

Construction and subsequent cold experimental testing of the system will be conducted within the near future.

Acknowledgments

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