A High-Efficiency Four-Frequency Mode Converter Design With Small Output Angle Variation for a Step-Tunable Gyrotron

Shaolin Liao[a], Ronald J. Vernon[a], and Jeffrey Neilson[b]
[a] University of Wisconsin, Madison, WI 35706, USA
[b]Calabazas Creek Research, Inc., San Mateo, CA 94404, USA

***Abstract*—A new multi-frequency quasi-optical mode converter design for four frequency/mode pairs for a step-tunable gyrotron is discussed. The design frequency/mode pairs are 110 GHz/TE$_{22,6}$, 124.5 GHz/TE$_{24,7}$, 127.5 GHz/TE$_{25,7}$ and 107.5 GH/TE$_{21,6}$. The design is for an 88 mm diameter variable-spacing double-disk vacuum window.**

I. Introduction And Background

THE design of a mirror system for a quasi-optical mode converter for a four-frequency step-tunable gyrotron is discussed. The mirror system uses four beam-shaping reflectors to obtain a Gaussian beam output at the window. (See Fig. 1.) The input to the mirror system is the output from a launcher designed using LOT [1]. The mirror system is designed to produce a Gaussian beam output through an 88 mm diameter variable-spacing double-disk vacuum window. The mirror system design was optimized for four frequencies: 110 GHz, 124.5 GHz, 127.5 GHz, and 107.5 GHz. The frequencies are chosen for possible use on DIII-D at General Atomics. Associated with each frequency is a gyrotron cavity mode: 110 GHz →TE$_{22,6}$, 124.5 GHz →TE$_{24,7}$, 127.5 GHz →TE$_{25,7}$, and 107.5 GHz →TE$_{21,6}$.

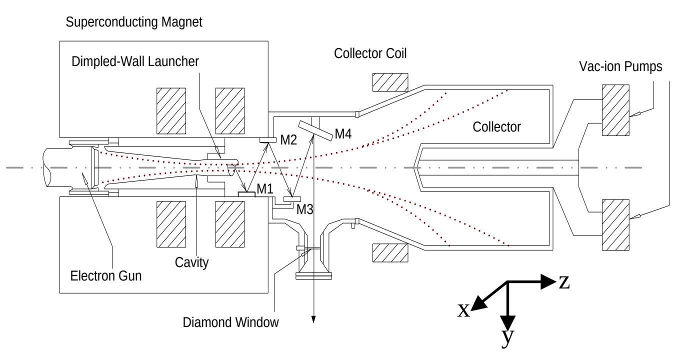

Fig. 1. Schematic diagram of a CPI-type gyrotron with a 4-mirror internal mode converter.

II. System Design

The launcher was optimized for two frequency-mode pairs, 110 GHz-TE$_{22,6}$ and 124.5 GHz-TE$_{24,7}$, but it functioned reasonably well for some other frequency-mode pairs also. It was designed using LOT [1].

The mirror system consists of four mirrors each of which has beam-shaping perturbations. Mirrors 1 and 2 are cylinder-based and mirrors 3 and 4 are planar-based. For example, the starting mathematical form of mirror 1 is

$$y_1 = y_{1,o} + (x_1 - x_{1,o})\, tan(\theta_{1,x}) + (z_1 - z_{1,o})\, tan(\theta_{1,z}) - \left[R_{1,x} + R_{1,z} - \sqrt{R_{1,x}^2 - [x_1 - x_{1,o}]^2} - \sqrt{R_{1,z}^2 - [z_1 - z_{1,o}]^2}\right] \quad (1)$$

where the subscript "1" denotes mirror 1; the center of mirror 1 (offsets) is at $(x_{1,o}, y_{1,o}, z_{1,o}) = (0.5,\ 5.7, 18)$ cm; the tilt angles $(\theta_{1,x}, \theta_{1,z})$ are used to adjust the beam's center position to coincide with the center of mirror 2 and are usually set to 0 or very small values. The radii are estimated through paraxial Gaussian optics using the q-parameter,

$$\frac{1}{q_{1,in}} - \frac{1}{q_{1,out}} = \frac{2}{R_{1,x/z}} \quad (2)$$

which gives the radii values of roughly $(R_{1,x}, R_{1,z}) = (6, 100)$ cm. Similarly, for mirror 2, $(R_{2,x}, R_{2,z}) = (6.5, 100)$ cm.

The mirror design was done using a new method developed at the UW we call the Taylor-FFT algorithm [2]. The Gaussian beam is polarized in the $\vec{x}$ direction and has a beam waist radius of $w_0 = 2.63$ cm, located at the window plane ($y = 25.4$ cm),

$$E_x \propto \exp\left(-\frac{x^2 + z^2}{w_0^2}\right). \quad (3)$$

The multi-frequency design began with independent single-frequency mirror system designs for each frequency. A multi-frequency least mean square optimization approach was then used to finish the mirror surface corrections for all four frequency-mode pairs.

All four design modes have output propagation direction angles from the window axis of 0.4º or less and complex coupled power to an ideal Gaussian beam greater than 99.45% over the window aperture. Comparison of design results were made to independent simulations based on the method of moments available from commercial software, Surf3d [3]. The simulated output radiation patterns for both amplitude and phase at the window plane for 110 GHz and 124.5 GHz are shown in Figs. 2 through 5 below. The dark circle is the 88 mm diameter window perimeter circle in all four figures. The converter design is for a double-disk variable-separation window. The results for 127.5 GHz and 107.5 GHz are of similar quality. The design goal was for the -24 dB contour to be at the window edge.

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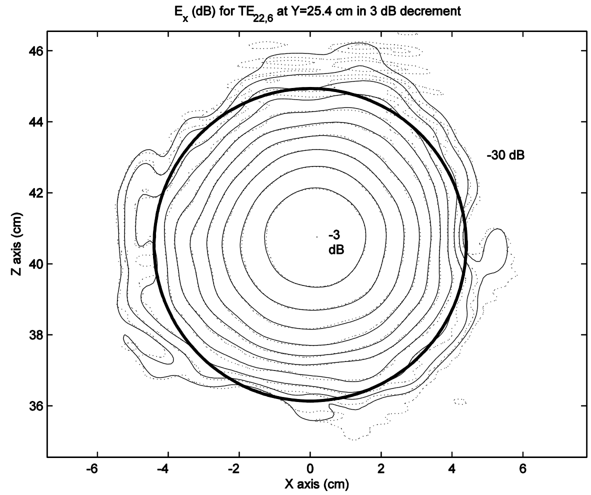

Fig. 2. Comparison of amplitude of UW simulation (solid contours) and CCR Surf3d simulation (dotted contours) at the window plane for 110 GHz/$TE_{22,6}$ frequency/mode pair. Contours are in 3 dB decrements from -3 to -30 dB.

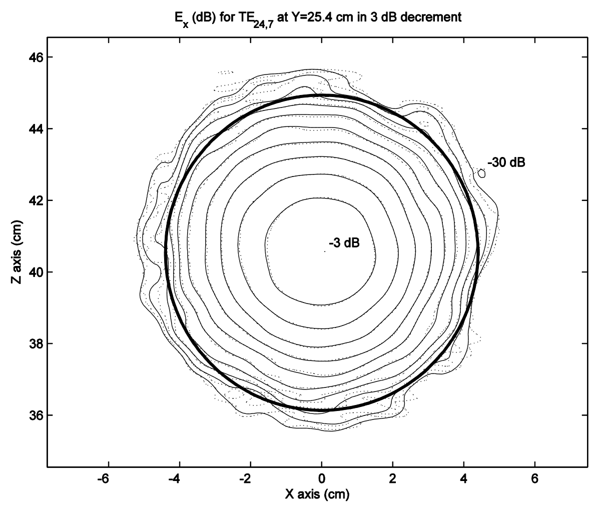

Fig. 3. Comparison of amplitude of UW simulation (solid contours) and CCR Surf3d simulation (dotted contours) at the window plane for 124.5 GHz. Contours are in 3 dB decrements from -3 to -30 dB.

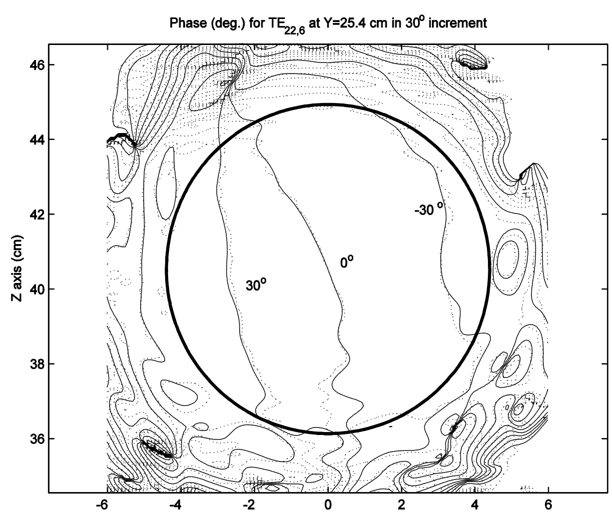

Fig. 4. Comparison of phase of UW simulation (solid contours) and CCR Surf3d simulation (dotted contours) at the window plane for 110 GHz.

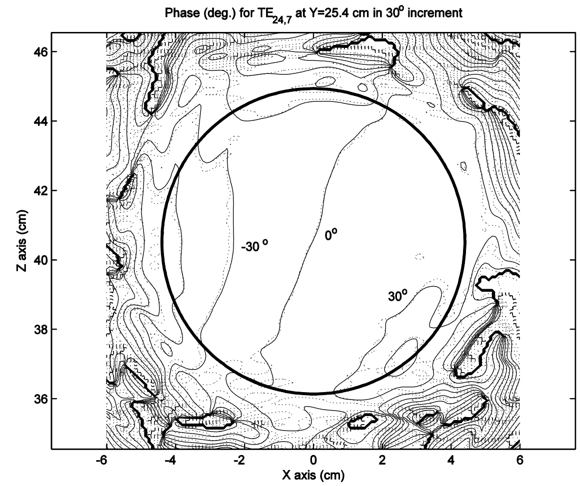

Fig. 5. Comparison of phase of UW simulation (solid contours) and CCR Surf3d simulation (dotted contours) at the window plane for 124.5 GHz.

Table I shows the simulated power loss at various stages in the mode converter for the four design frequencies. The tilts in the beam exit angles are given in the last two rows and are very small. For the three most important frequencies (110 GHz, 124.5 GHz, and 127.5 GHz) the overall converter efficiency is greater than 96.6 %, a result better than for most single frequency converters.

Table I. Power Efficiency along the Beam Path

Frequency f (GHz)	110.0	124.5	127.5	107.5
Corresponding Mode	$TE_{22,6}$	$TE_{24,7}$	$TE_{25,7}$	$TE_{21,6}$
Launcher to M1 (%)	99.49	99.67	99.65	98.43
M1 to M2 (%)	99.23	99.04	99.02	98.71
M2 to M3 (%)	99.61	99.88	99.72	99.53
M3 to M4 (%)	99.49	99.57	99.56	99.79
M4 to window plane (%)	99.57	99.59	99.60	99.72
Coupling to Gaussian (%)	99.39	99.34	99.40	99.27
Coupled power (%)	96.83	97.12	96.98	95.53
Power within 88mm-diameter aperture (%)	97.10	97.31	97.08	95.37
Coupling to Gaussian within 88mm-diameter aperture (%)	99.55	99.53	99.56	99.47
Coupled power within 88mm-diameter aperture (%)	96.66	96.85	96.65	94.87
Tilt angle x-direction	0.4°	-0.4°	0	0
Tilt angle z-direction	0.15°	0.15°	0.15°	-0.15°

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy under contract DE-FG02-85ER52122 and US DOE SBIR Grant DE-FG02-05ER84181.

REFERENCES

[1] J. Neilson, “Optimization of Quasi-Optical Launchers for Multi-Frequency Gyrotrons,” *IEEE Trans. Plasma Sci.*, Vol. 35, No. 6, 2007.

[2] S. Liao and R. J. Vernon, “A Fast Algorithm for Wave Propagation from a Plane or a Cylindrical Surface,” *Int. Journal of Infrared and Millimeter Waves*, Vol. 28, No. 6, 2007.

[3] J. Neilson and R. Bunger, “Surface Integral Equation Analysis of Quasi-Optical Launchers,” *IEEE Trans. Plasma Sci.*, Vol. 30, No. 3, June 2002.