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A MAGICTRAC DESIGN FOR THE MTX TRANSPORT SYSTEM*

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ABSTRACT

A design of a MAGICTRAC (Microwave Antenna for Whispering-Gallery-Mode Conversion using a Twist Reflector Antenna Converter) device is presented for use on the MTX (Microwave Tokamak Experiment) transport system. The MAGICTRAC device, consisting of a mode converting waveguide taper and three metal reflectors, transforms the $TE_{15,2}$ circular waveguide mode output of a VARIAN Associates 140 GHz gyrotron into a free-space Gaussian-like beam with $> 95\%$ efficiency. Dimensions of the MAGICTRAC are chosen to produce a beam matched to the MTX quasi-optical transport system.

MAGICTRAC DEVICE

The MAGICTRAC device (Fig. 1) is a quasi-optical mode converter which transforms a whispering-gallery mode into a free-space Gaussian beam with high efficiency ($> 95\%$). The converter is front ended with a conventional waveguide mode converting taper which transforms the input rotating TE_{mn} mode(s) into a linear combination of rotating $TE_{mn'}$ modes having a radiation pattern with both low sidelobe power and a predominantly azimuthal component of field. For the $TE_{15,2}$ mode several such amplitude combinations are possible: $0.4438TE_{15,1} + 0.8961TE_{15,2}$, $0.3206TE_{15,1} + 0.8913TE_{15,2} + 0.3206TE_{15,3}$, and $0.6058TE_{15,2} + 0.7956TE_{15,3}$. Similar linear combinations of modes exist for other whispering gallery modes. This fact seems to have been first pointed out by Thumm[1]. A $TE_{15,2}/TE_{15,3}$ mode combination exiting a 5.08 cm diameter waveguide was used as the input to the MAGICTRAC device.

The azimuthal component of field has a $\exp(im\theta)$ variation, where θ is the azimuthal angle, which is removed by the "counterbore" cut (Fig. 2.) in the first annular reflective optic, MT_1 . Upon reflection from the counterbore the azimuthal variation is removed leaving a field structure analogous to a circular electric TE_{0n} mode, but one in which the power is concentrated in a single primary lobe.

A twist reflecting annular surface, MT_2 , is used to transform the azimuthal component of the field into one which is linearly polarized. The grooves comprising the twist reflector, shown in Fig. 3, are incorporated in a second reflective optic which is also used to focus the annular shaped beam through the hole in the center of the first optic, MT_1 . Rotating the twist reflector rotates the polarization of the reflected wave so that the polarization can be oriented along an arbitrary axis transverse to the direction of propagation.

A third optic, MT_3 , is used to transform the linearly polarized annular beam into a Gaussian-like beam. This optic is positioned in a region where the beam interference is strong. A simple phase correction is applied to the beam by adjusting the surface profile of the MT_3 optic. The functional form used was $a_{lin}r + a_{sq}r^2$ where a_{lin} and a_{sq} were adjusted empirically to obtain the flattest possible phase profile after reflection from the surface.

The final result is a linearly polarized ($> 99\%$) Gaussian-like beam. Conversion efficiency from the initial $TE_{15,2}$ waveguide mode to the free-space beam is calculated to be 96%.

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MTX TRANSPORT SYSTEM

The Microwave Tokamak Experiment (MTX) presently is using a VARIAN Associates 140 GHz, 400 kW CW tube operating in the $TE_{15,2}$ mode as a source of millimeter waves. A conventional Vlasov launcher is currently used to convert the $TE_{15,2}$ mode from the gyrotron into a free-space beam for propagation through the quasi-optical transmission system and ultimate injection into MTX for the purpose of electron cyclotron heating. The MAGICTRAC design presented above is an alternative method under consideration as a replacement for the Vlasov launcher.

In the past an intense (> 100 MW) millimeter wave pulse from a FEL driven by an induction linac was used as the source. Future experiments will use the gyrotron as the master oscillator for the FEL under high average power conditions (1 GW peak, 1 MW average). The possible system configurations are shown in Fig. 4.

With the gyrotron as the millimeter wave source, the quasi-optical transport system is configured with 4 reflectic optics (2 flats and 2 focussing) in a 30 m long evacuated beamline 50 cm in diameter. The final optic focusses the beam through a 4 by 30 cm port on the tokamak resulting in an illuminated spot on the plasma of between 2 by 3 cm and 2 by 6 cm ($1/e$ points), depending of the choice of focal lengths on the final transport optic. Dimensions of the transport optics are 43 by 58 cm.

OVERALL SYSTEM

The overall system from gyrotron to tokamak is depicted in Fig. 4. The polarization at the tokamak is that for O-mode heating and is adjusted on the MAGICTRAC device by the orientation of the twist reflector optic, MT_2 . Table I. lists the focal lengths of the optics, the spot sizes on them, and the net transport efficiency to that optic. The efficiency of the transport system alone is about 99% and that of the MAGICTRAC device alone is 96%, making the net calculated transport efficiency from gyrotron to tokamak 95%.

Table I. Transport System Parameters

Optic	Focal Length (m)	Spot Size (cm)	Integrated Path Length (m)	Transmitted Power
MT_1	0.375	—	0.50	99.0%
MT_2	∞	—	1.00	97.0%
MT_3	—	—	1.70	96.0%
G_2	∞	12.0	4.23	96.0%
M_2	10.0	12.0	11.50	96.0%
M_3	∞	12.0	32.03	95.2%
M_4	2.16	12.0	34.32	95.2%
MTX Port	—	2.20	36.48	95.0%

The conversion efficiency of the MAGICTRAC device is significantly greater than the 75% calculated for the simplest possible Vlasov converter and is comparable to the conversion efficiencies of advanced versions of Vlasov transducers[2].

CONCLUSIONS

The MAGICTRAC device is a colinear quasi-optical mode transducer which efficiently converts the rotating whispering-gallery mode output of current generation high power gyrotrons into free-space Gaussian-like beams. Calculations yield a conversion efficiency of 96% from a $TE_{15,2}$ mode to a free-space beam and 99% transport efficiency from converter to tokamak for an overall system efficiency of 95%.

Conversion efficiencies may be further increased by incorporating all but the final optic, MT_3 , of the

MAGICTRAC device in the gyrotron itself. Its colinear geometry complements that of the tube and provides a convenient region for beam extraction between optics MT_1 and MT_2 . Also the field structure of the exiting beam is nearly ideal for existing output window designs.

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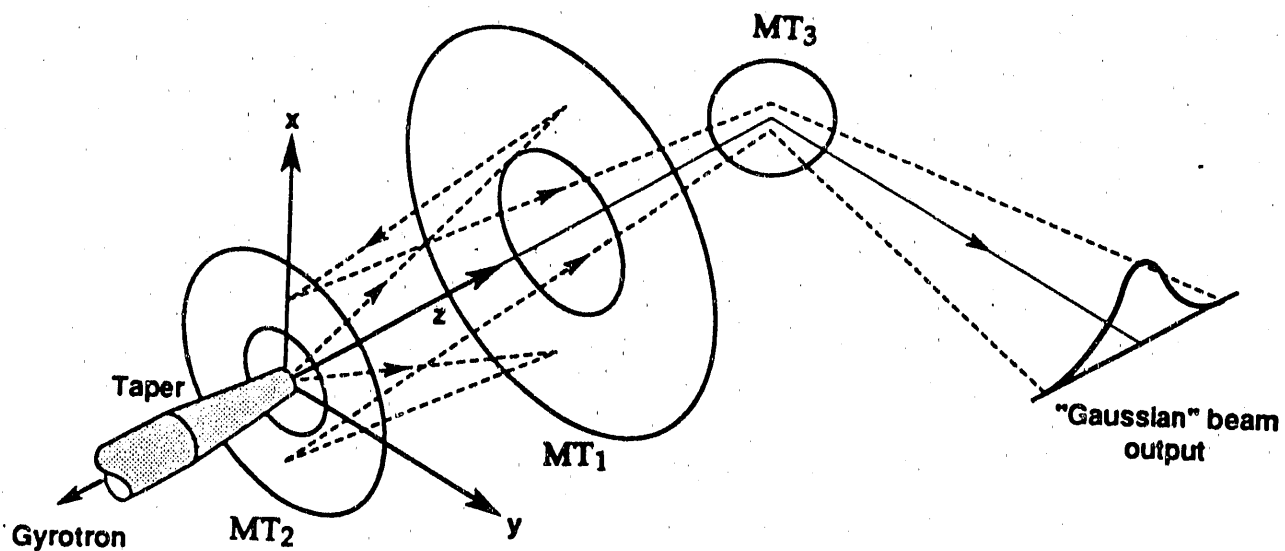


Figure 1. Configuration of the MAGICTRAC optics showing the waveguide taper, the optic MT₁ with counterbore reflector, the mirror MT₂ with twist reflector, and a final phase-correcting optic MT₃.

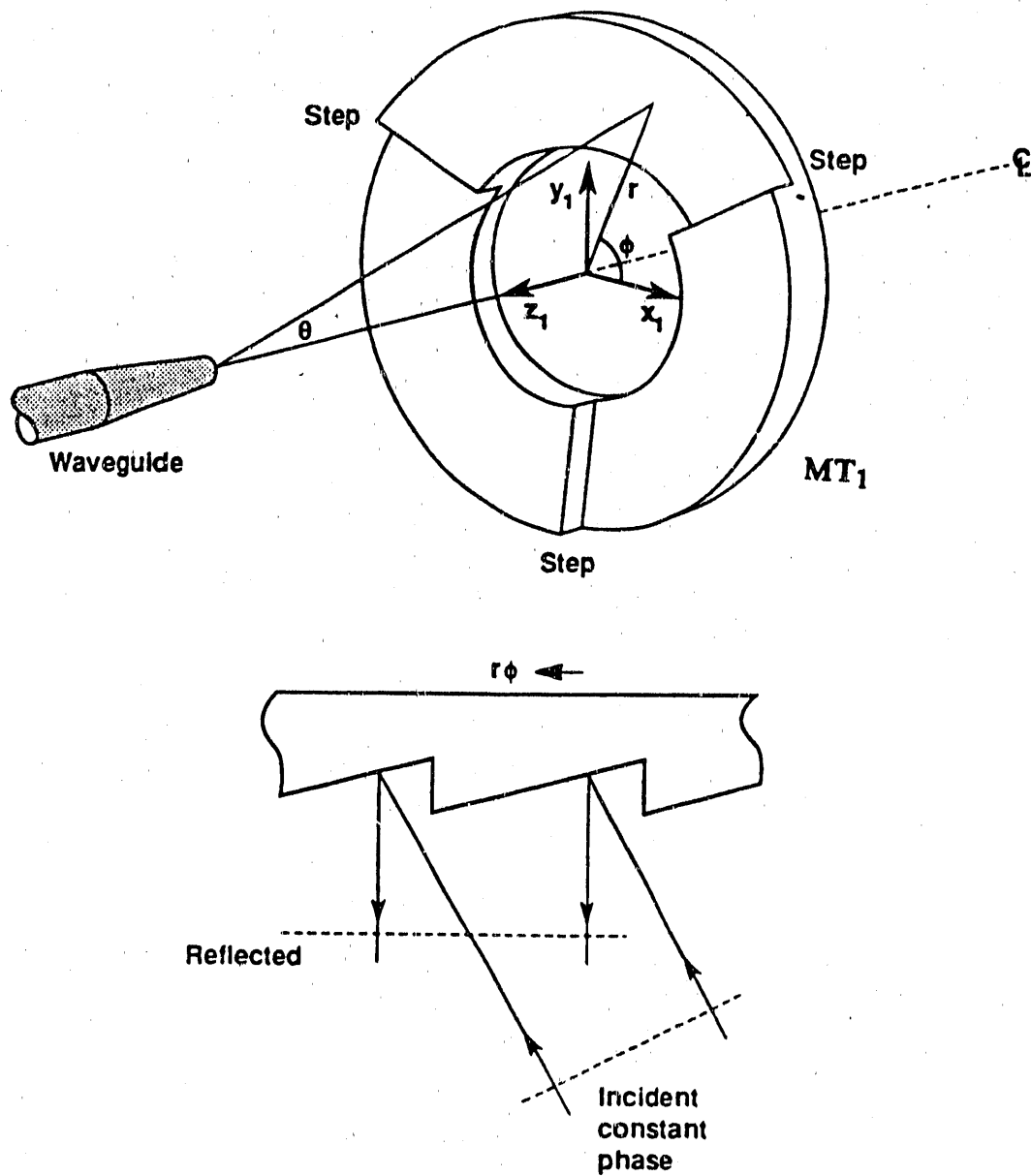


Figure 2. Details of a counterbore reflector with three steps, showing the incident and the reflected constant-phase surfaces for an "unrolled" reflector.

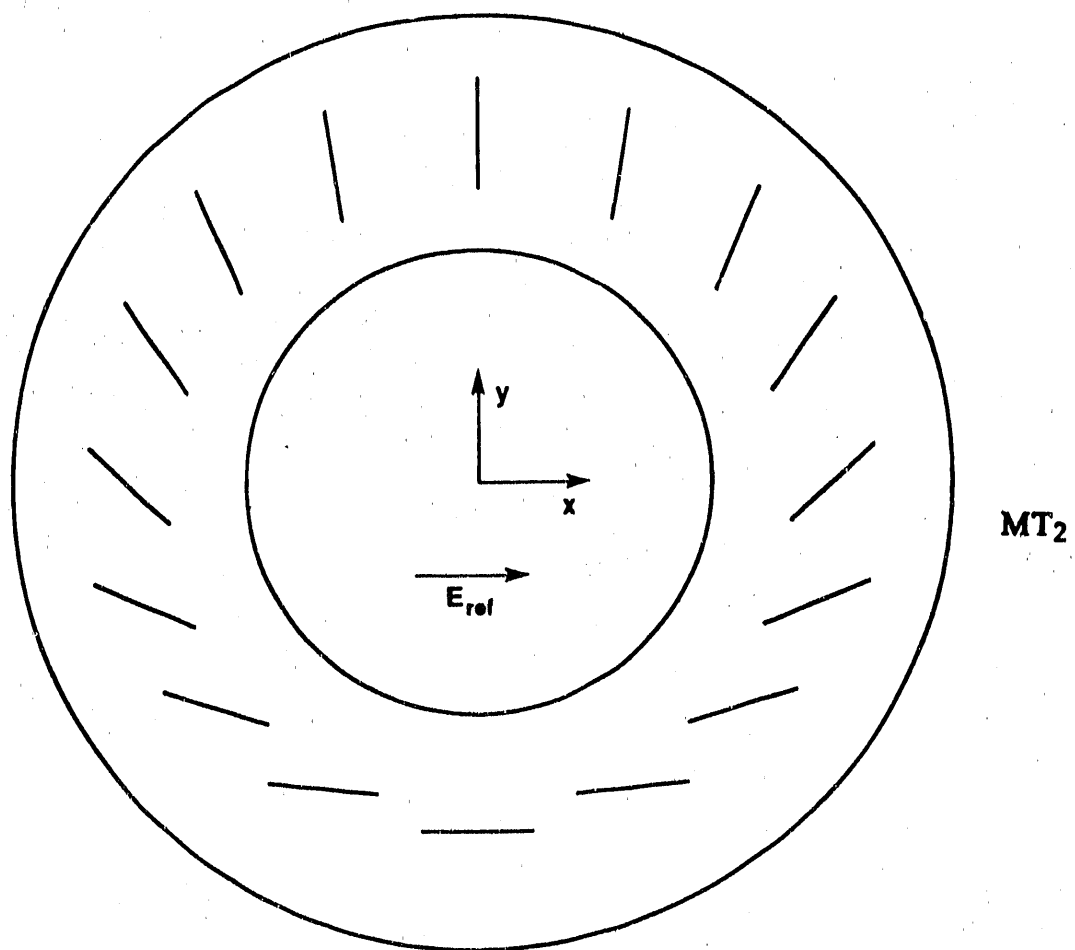


Figure 3. A sketch of the direction of the polarizing grooves for the twist reflector on mirror MT_2 for a pure azimuthal incident electric field.

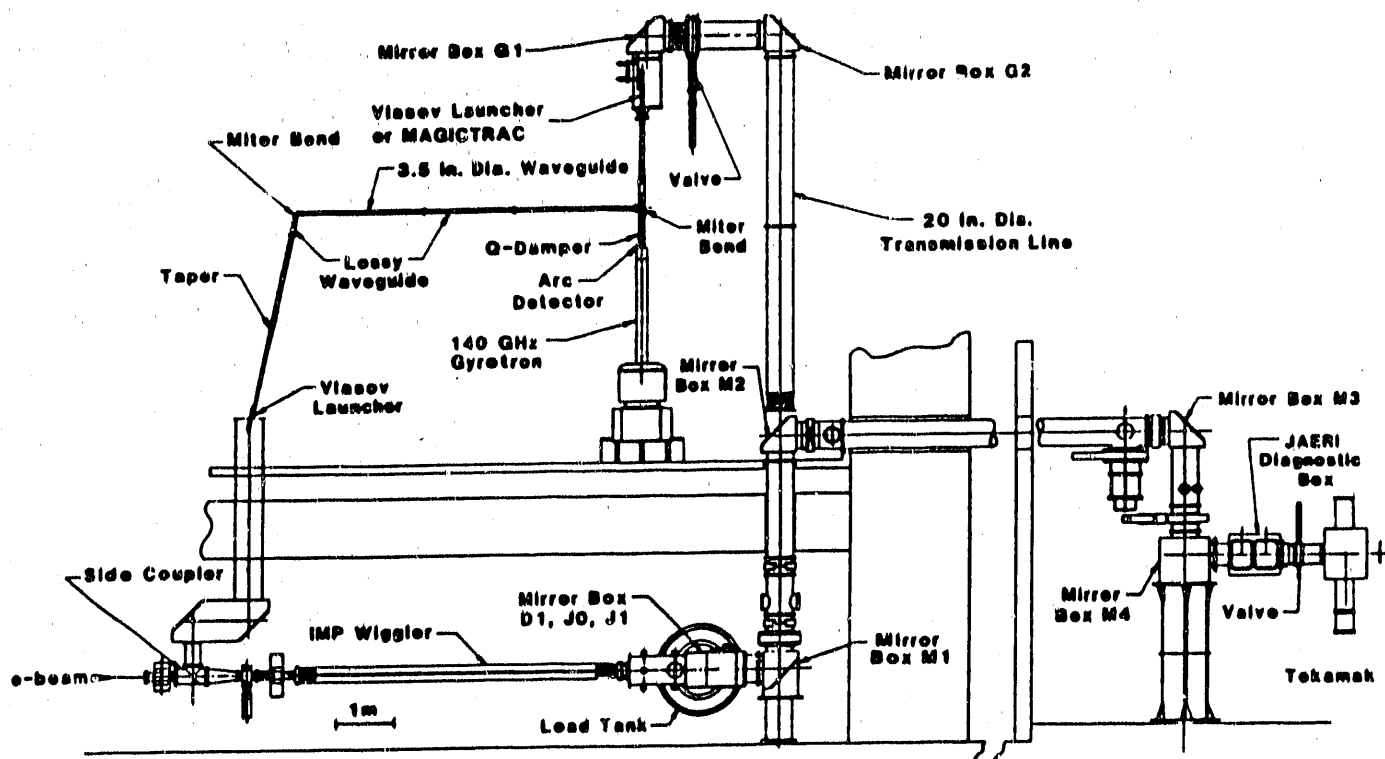


Figure 4. A schematic of the possible MTX transport system configurations.

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