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A GYROTRON OUTPUT TRANSMISSION CIRCUIT*

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ABSTRACT

The chief virtue of gyrotrons, their capability of producing high average power efficiently at millimeter wavelengths, places special demands on separating high power microwaves in oversized waveguides from high power electron beams. It is possible to transmit the microwave power across a region bounded by a large diameter cylindrical collector through the use of two spherical mirrors. The optimization at low power levels of such an arrangement at 28 GHz is discussed along with the presentation of measurements of transmission and mode purity at the output. In a specific case, for the TE_{01}^o mode using 12-in.-diam spherical mirrors with a 2.5-in.-diam output waveguide, the optimum entrance diameter is 2.5 in. for a 16-in. focal separation. This yields a maximum TE_{01}^o mode transmission of 94%. Adding a 12-in.-diam cylinder between the mirrors to simulate the collector surface produces a transmission ripple of only ± 0.2 dB provided that a 0.5-in. gap is present at one mirror to load spurious modes.

INTRODUCTION

This work is part of a larger ORNL microwave development program aimed at producing high power cw microwave tubes for plasma heating, initially at 28 GHz with later scaling to 120 GHz (1). The gyrotron device has been identified as the preferred approach for this application where efficient high power cw sources are considered essential. Gyrotrons typically operate in the TE_{0n}^o (circular electric) modes since these modes give the highest ratio of electric field strength to power losses in the gyrotron output cavity. Removing the high power electron beam from the TE_{0n}^o modes in an oversized waveguide, while maintaining mode purity, places special demands on the output transmission circuit. This paper deals with the design and low power microwave testing of one possible approach to this problem, namely, the use of a two-mirror output transmission circuit.

DESIGN

The two-mirror system is shown schematically in Fig. 1 and consists of two identical spherical mirrors of diameter D separated by a focal length f , with both mirrors fed by an oversized circular waveguide of diameter d . The length of the electron beam collector is given by L and θ_M is the maximum half-angle subtended by the mirrors. Microwave fields in the TE_{0n}^o modes generated by the gyrotron output cavity are radiated from the oversized waveguide and converted to a plane wave by the first spherical mirror. The second spherical mirror refocuses the plane wave back down to the output waveguide with nearly the same incident mode content.

Figure 2 shows the oversized waveguide power radiation pattern (normalized) for both the TE_{01}^o and TE_{02}^o modes in the far field (2). Also shown are the integrated power patterns normalized to the total radiated power for each of the two modes. Both sets of curves are plotted vs the dimensionless parameter $(\pi d/\lambda) \sin \theta$, where λ is the free space wavelength and θ is the polar angle in spherical coordinates. The arrows on the horizontal axis mark the zeroes of $J_n'(P_n') = 0$ where $P_{0n}' = 3.83, 7.02, 0.17$, etc. The integrated power curves show that for the TE_{0n}^o most of the power is intercepted by the first mirror if θ_M is given by

$$\theta_M = \sin^{-1} \left(\frac{\lambda P_{0n}'}{\pi d} \right) \quad (1)$$

For the TE_{01}^o and TE_{02}^o modes, the total power intercepted amounts to 98% and 97%, respectively. From the geometry of Fig. 1, we have

$$\frac{D}{2f} = \sin \theta_M \left(\sqrt{4 - \sin^2 \theta_M} - \cos \theta_M \right) \quad (2)$$

and the total beam collecting area is

$$A = \pi D L = 2\pi D f \left[\sqrt{4 - (D/2f)^2} - 1.5 \right] \quad (3)$$

for $D/2f \leq 1.33$.

The maximum path difference, Δr , measured from focus to focus between spherical and parabolic mirror systems, is equal to

$$\Delta r = 4f \left\{ \sqrt{1 + [\tan^4 (\theta_M/2)/4]} - 1 \right\} \quad (4)$$

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and must be much less than a half-wavelength if spherical mirrors are to perform as well as parabolic mirrors in this application. Results of the design calculation are summarized in the following table.

Mode	TE_{01}^o ($n = 1$)
d	2.5 in.
λ	0.422 in. (28 GHz)
θ_M	22.1°
$D/2f$	0.390
A	557 in. ² (fixed)
$2\Delta r/\lambda$	0.055

The collecting area was fixed to allow for the same power density (1 kW/cm²) as exists in present high power collectors. Also, a 12-in. diameter and a 16-in. focus were chosen, giving a design close to that in the table.

MEASUREMENTS

For the TE_{01}^o mode measurements the test circuit consists of a $TE_{01}^o \rightarrow TE_{01}^o$ mode transducer (3) followed by a TE_{01}^o mode filter and a two-section linear taper (4) to flare from the 0.688-in. to the 2.5-in. diam. An identical system is used to get back down to the TE_{01}^o mode in WR-28 waveguide. The insertion loss measurements were done by direct substitution of the two-mirror system between tapers. Figure 3 shows the TE_{01}^o insertion loss vs frequency for the two-mirror system with and without a beam collector surface. The absorption dips in the calibration curves are due to trapped higher order circular electric modes between the tapers. The maximum insertion loss is -0.25 dB at 28 GHz without a collector surface. Adding a collector gave sharp frequency sensitive spikes indicative of trapped modes; therefore a 0.5-in. circumferential air gap was added to the collector to reduce the overall ripple to ± 0.2 dB by loading trapped modes in the two-mirror system. In a real tube the air gap would be a water-backed ceramic gap.

The effect of varying the axial separation of the two mirrors at 28 GHz is shown in Fig. 4. The maxima are separated by a half wavelength and the smallest insertion loss occurs at about 15.5 in. and not at 16 in. because the effective phase centers are located somewhat inside the waveguide apertures. Also shown is the direct path transmission for two 2.5-in.-diam waveguides multiplied by +20 dB. This shows that the direct path transmission is much less than the doubly reflected path.

CONCLUSIONS

By using the design equations, a two-mirror collector system can be built with very high transmission characteristics for the TE_{01}^o mode. The best theoretical performance may be approached by careful selection of waveguide tapers to reduce higher order circular electric modes that radiate beyond θ_M . Tests are now under way for evaluating the TE_{02}^o mode design. Implementation of these designs will depend on the details of the fabrication of these systems.

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FIGURE CAPTIONS

- Fig. 1. Schematic diagram of the two-mirror collector system.
- Fig. 2. TE_{01}^o and TE_{02}^o radiated and integrated power patterns.
- Fig. 3. Frequency response of the two-mirror system with a 16-in. focal separation.
- Fig. 4. Axial variation of the TE_{01}^o insertion loss at 28 GHz.

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Fig. 1. Schematic diagram of the two-mirror collector system.

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Fig. 2. TE₀₁ and TE₀₂ radiated and integrated power patterns.

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Fig. 3. Frequency response of the two-mirror system with a 16-in. focal separation.

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Fig. 4. Axial variation of the TE_{01} insertion loss at 28 GHz.