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THE MEASURED PERFORMANCE OF A MILLIMETER WAVE BEAM SPLITTER

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The Measured Performance of a Millimeter Wave Beam Splitter

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An essential component of any high power transmission system is a directional coupler that provides a sample of the forward and reflected power when this power is being delivered to the intended load. In the case of millimeter power delivered through a highly oversized corrugated waveguide, there is the much more complex issue of mode purity.

It is possible to design an effective mode selective branch guide directional coupler in smooth wall overmoded waveguide. In the typical highly overmoded corrugated waveguide propagating the HE_{11} mode, however, obtaining an adequate coupling factor can be difficult, and branch guide attenuation and phase velocity matching over several meters become concerns.

A more practical approach for large diameter corrugated waveguide is to obtain a sample of the propagating beam at a miter bend mirror. At low power, the mirror could be a thin metal screen. At the megawatt level, however, heat removal must be considered. For example, at 110 GHz at 1 MW, taking the surface resistance of copper to be 0.10 Ω, the dissipation on a 45° copper mirror would be 750 W or 1500 W for H or E plane reflection, respectively. With a peak to average power ratio of 3.7 for the circular HE_{11} mode, in 31.75 cm diameter corrugated waveguide the peak dissipation can be as high as 500 W/cm^2 at the center of the mirror.

An edge cooled thin metal screen is not therefore practical, but a thick plate containing a single narrow channel, at the bottom of which is a row of holes in the remaining thin wall, can be adequately water-cooled on its face. To maintain vacuum and focus the radiation from the holes, the narrow channel is filled by a fused quartz plate, the shape of which is a 45° sector of a circle having a truncated apex at the coupling holes. These are being used as power monitors on the DIII–D ECH system and on other systems. Since this single row of holes samples only part of the wave field, however, interference among higher order modes, even when they are of low amplitude, can produce noticeable variations in received power, depending on the exact gyrotron frequency and temperature of the waveguides.

The only certain way to avoid this problem is to use a true beam splitter that provides a sample of the fields in the entire cross section of the waveguide. Our proposed means of overcoming the heat removal problem is to make the mirror an edge cooled CVD diamond disk having a very thin copper coating on the high power side of the mirror. A two dimensional array of holes is etched through the copper. An image of the incident wave free of aliasing is launched on the opposite side of the copper film. This process is easily scaled to frequencies greater than 170 GHz.

We have analyzed the thermal response of such a plate bonded to water-cooled heat sinks on the periphery of both faces. In our case, the heat sinks have 32 mm by 45 mm apertures. The gray diamond we are using is 60 mm diameter with two flats 48 mm apart. For a diamond 1.1 mm thick having an assumed thermal conductivity of 1300 W/m-K and heated with a total of 1500 W (times a correction for the resistivity increase with temperature) on one face with the circular HE_{11} distribution, the steady state temperature at the center is 210°C, starting at 35°C. The temperature reaches steady state by 1 s, while the 1/e time is about 160 ms. This temperature is slightly higher than the steady state gyrotron window temperature. If necessary we can reduce the peak temperature, at greater cost, by using a thicker gray diamond, say 1.5 mm, or by using a white diamond 1.1 mm thick having 1800 W/m-K conductivity. Either would bring the final central temperature down to <160°C. Since we are using edge cooling, this result is independent of waveguide diameter, so this device can be made for any diameter.

A prototype, using only inertial cooling, was built and operated with single pulses as long as 550 ms at powers as high as 600 kW. The coupling factor measured at low power was –40.5 dB and –41.47 dB for the E and H polarizations, respectively.

There are several ways the output of this coupler can be used:

- The sampled output power is high enough to permit a calorimetric measurement of the total sampled power.
- The output could be passed through a corrugated taper which cuts off all but the HE_{11} mode, and that could be measured calorimetrically as well as detected on a fast time scale.
- If the output is tapered to a reduced diameter, individual modes could be measured using phase velocity directional couplers or a K-spectrometer.
- The output could be used to illuminate an absorber, the temperature distribution of which is recorded with a IR camera.

New versions of the beam splitter incorporating water-cooling have been built and testing has begun.

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