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Millimetric FSS Waveguide Beamsplitter

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ABSTRACT

A frequency selective surface consisting of an array of concentric rings has been developed for use as a beamsplitter in an oversized S-band waveguide system. Good agreement is shown between measured and predicted transmission coefficients in the range 73-127 GHz.

INTRODUCTION

Extensive use is made of millimetre wave systems for measuring the parameters of the plasmas produced in modern day thermonuclear fusion devices. At the joint European Torus (JET) project [1] a heterodyne radiometer, which operates in the range 73-139GHz, is used to measure the cyclotron emission (ECE) spectrum from which the plasma electron temperature profile is obtained [2]. Radiation from the plasma is transmitted through a single long oversized (S band/WG10) waveguide. The radiometer uses five waveguide beamsplitters to divide the incident power six ways between six broadband mixers, which provide simultaneous measurements over the wide RF bandwidth from the single waveguide input. The current system employs simple crosswound wire grid diplexers which have a weakly frequency dependent transmission response, giving a typical loss of 45% in both the reflection band and the passband. Potentially the signal-to-noise ratio of measurements could be increased by improving the frequency selectivity of the waveguide beamsplitters, to direct to each mixer more of the power in the frequency range for which it is sensitive.

Previously Cahill et. al. [3], [4] have shown that in quasi optical systems, efficient demultiplexing in the millimetric and submillimetric bands can be achieved by employing arrays of self resonant conducting elements which are supported on a dielectric substrate. In this letter we demonstrate that this technology can also be applied to waveguide beamsplitters. Although the electromagnetic environment in the waveguide differs from that in free-space, the modelling technique is shown to give good agreement with measurements.

DESIGN AND FABRICATION

An FSS beamsplitter has been developed to replace one of the existing inductive grids in the JET heterodyne radiometer. At 45° incidence the diplexer is required to generate a high pass filter response with a single reflection band between 73-79GHz and two transmission bands in the range 91-103GHz and 115-127GHz in two orthogonal polarisations. A multilayer FSS [5] could be designed to give the sharp roll off rate which is generally required to separate closely spaced frequency bands. However, the predicted improvement in performance that can be achieved from a single layer array of concentric ring elements was considered to be adequate for this application. The array was designed using a rigorous modal analysis technique which assumes that the FSS is infinite in extent and illuminated by an incident plane wave [6]. Fig.1a

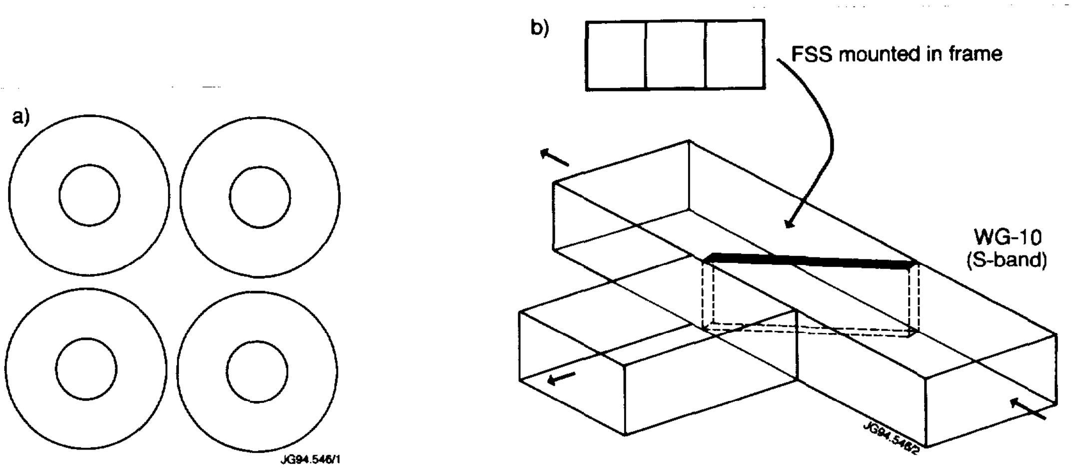

Fig.1: (a) Geometry of concentric ring array
Mean diameter of outer ring=0.88mm
Mean diameter of inner ring=0.32mm
Element periodicity=0.97mm

(b) Schematic of waveguide beamsplitter assembly.

shows the geometry and nominal dimensions of the optimum design. The close packed outer rings generate the reflection resonance which is insensitive to the angle and plane of incidence, and the smaller inner rings are used to control the width and position of the broad passband. The FSS was fabricated by patterning three 60mm diameter optical quality fused silica (e~3.78) wafers of thickness 0.24mm. Precision etching of the 2μm sputtered aluminium film enabled the element geometry to be printed with an accuracy of ±1μm over the whole surface. Each wafer was then sawed, aligned and bonded in a frame with an a perture of 104mm×34mm. The frame was designed to fit snugly into a groove in the waveguide wall as shown in fig.1b.

RESULTS AND DISCUSSIONS

The transmission response of the FSS beamsplitter was measured at 45° incidence in the oversized waveguide over the frequency range 73-127GHz. Fig.2 shows a comparison between the predicted and experimental transmission coefficients in the TE and TM planes. The reflection bands in the orthogonal planes are correctly predicted to be coincident because of the choice of lattice periodicity. In the TE plane the upper reflection band (not shown) which is generated by the inner rings is very sensitive to the angle of incidence and this causes the passband width to narrow. The shape of the TE response curve is predicted accurately, however a small frequency shift occurs above the upper edge of the rejection band. Conversely in the TM plane excellent agreement is demonstrated over the entire frequency range. In the oversized waveguide, mode conversion occurs at mitre bends and tapered sections, the amplitude and phase varies spatially across the beamsplitter surface and the edges are highly illuminated. Nevertheless the predictions are satisfactory considering that the electromagnetic environment differs from the assumptions that are employed in the numerical model.

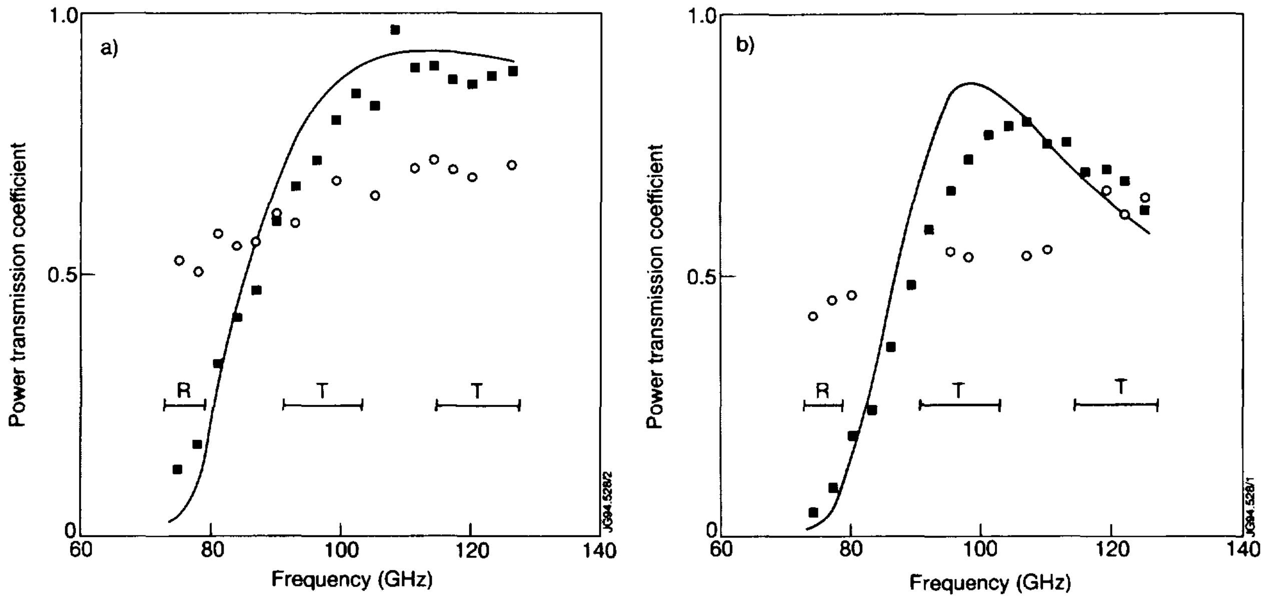

Fig.2: Computed and measured frequency response at 45° incidence
(a) TE plane
(b) TM plane

——— *predicted (FSS)*
■■■■ *measured (FSS)*
OOOO *measured (GRID)*
├R┤ *Reflection band*
├T┤ *Transmission band*

To compare the performance of the FSS with the existing crosswound inductive grid, measured results for the latter are superimposed in fig.2a and b. The monotonically varying transmission coefficients of the grid contrasts with the highly shaped FSS response. Over the upper passband (115-127GHz) the average transmissivity of the two beamsplitters in the TE plane is similar, however in the TM plane the FSS is 20% higher. A further significant improvement in the performance occurs in the lower passband (91-103GHz) where the increase in transmitted power varies between 5%-20% in the TE and TM planes. The FSS response curve rolls off rapidly to generate a measured reflection band (73-79GHz) which reduces the average loss by 37% in both planes.

CONCLUSIONS

A millimetre wave FSS beamsplitter has been shown to perform well in an oversized waveguide assembly. The results have been used to confirm that in waveguide measurement systems, an improvement in the signal to noise ratio can be achieved by employing self resonant element FSS diplexers in preference to simple wire grids.

REFERENCES

[1] The JET Team: 'Fusion energy production from a deuterium-tritium plasma in the JET tokamak', Nuclear Fusion, 1992, **32**, pp.187-203.

[2] Porte, L., Bartlett, D.V., Campbell, D.J.and Costley, A.E.: 'First results with the upgraded ECE heterodyne radiometer on JET', Proc., 18th European Conference on Controlled Fusion and Plasma Physics, 1991, **iv**, pp.357-360.

[3] Cahill, R., and Parker, E.A.: 'Performance of millimetre-wave frequency selective surfaces in large incident angle quasi optical systems', Electron. Lett., 1992 **28**, (8), pp.,788-789.

[4] Cahill, R. and Parker, E.A.: 'Frequency selective surface design for submillimetric demultiplexing', Microwave and Optical Technology Letters, 1994, **7**, (13), pp.595-597.

[5] Cahill, R., Parker, E.A. and Antonopoulos, C.: 'Design of multilayer frequency selective surface for diplexing two closely spaced channels', Microwave and Optical Technology Letters (submitted for publication).

[6] Parker, E.A., Hamdy, S.M.A., and Langley, R.J.: 'Arrays of concentric rings as frequency selective surfaces', Electron. Lett., 1981, **17**, (23), pp.880-881.