CHARACTERISTICS OF OPTIMIZED DIPLEXERS BASED ON THE SPATIAL AND ANGULAR TALBOT EFFECTS

B. Plaum[1], *E. Holzhauer*[1], *U. Niethammer*[1]

[1] Institut für Plasmaforschung, Pfaffenwaldring 31, D-70569 Stuttgart, Germany

email: plaum@ipf.uni-stuttgart.de

Two types of diplexers, which combine microwaves at two different frequencies for transmission in a single waveguide, are presented. They are based on the spatial and angular Talbot effects respectively. Theoretical and experimental results for both types of diplexers are shown.

Introduction

The diplexers are based on the Talbot effect[1]. This effect, which originally describes the periodical reconstruction of interference patterns at particular distances from a grating, can also be applied for rectangular waveguides [2]. The diffraction orders in free space become TE_{m0}-modes with the same dispersion characteristics. The mathematical proof of the original Talbot effect requires a paraxial approximation, the Talbot effect in rectangular waveguides appears only if an oversized waveguide is assumed. Both approximations are mathematically identical.

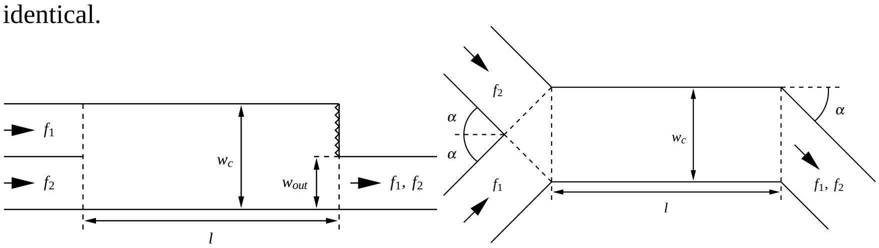

Fig. 1: Principles of the spatial (left) and angular (right) diplexer.

The diplexers work by injecting 2 frequencies into a main waveguide (See Fig. 1). The incoming TE_{10}-Modes excite mode spectra in the main waveguide, which propagate with different phase constants. If the field corresponding to f_1 is reproduced antisymmetrically after the length l, while the field of f_2 is reproduced symmetrically, both microwaves will excite pure TE_{10}-modes in the output waveguide. The goal is to find dimensions, where the TE_{10} output power becomes maximal for both frequencies.

Calculation of the fields

The calculation of the mode spectra inside the main waveguide is done by a mode matching technique, where reflected waves are neglected [3]. The reflections due to the impedance step at the input were calculated with an FDTD code and measured. Both calculated and measured values remained below 0.1 % for the center frequencies. For the spatial diplexer, the mode spectra in the output waveguide can be calculated the same way as at the input. For the angular diplexer, issues arise because the boundary of the main- and output waveguide, at which the fields of the main- and output-waveguide are matched, is not perpendicular to the axis of the output waveguide. In this case, it is not possible to use an orthogonality relation to derive the amplitudes of the output modes.

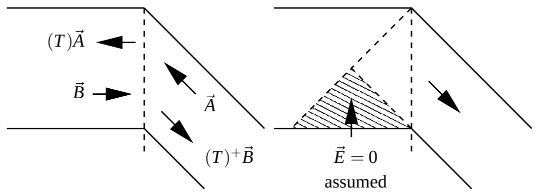

Fig. 2: Mode matching at the output of the angular diplexer.

One solution is to calculate a complete transmission matrix (T) for the case that the waves propagate in the opposite direction (See Fig. 2 left). By assuming a reciprocal system, the output modes can then be calculated from the modes in the main waveguide by using the pseudoinverse $(T)^+$ of the (in general nonsquare) transmission matrix. Another approach is to do the mode matching along a line, which is completely inside the main waveguide and perpendicular to the output waveguide axes. This method implicitly assumes, that the field is zero inside a triangle located at the lower right corner of the main waveguide (See Fig. 2 right). This assumption is, however, valid if the output mode is a pure TE_{10} mode. Errors due to nonzero fields in the triangle will show up mainly in the amplitudes of higher order modes. Fig. 2 shows a relativley large angle of 45°. The optimizations normally result in much smaller angles, which means, that the area, in which a zero field is assumed, will also be smaller.

Analytical solutions

Assuming an oversized waveguide with the transversal dimension a, the propagation constant β_m of a TE_{m0}-mode can be approximated by:

$$\beta_m \approx k_0 \left[1 - \frac{1}{2}\left(\frac{m\pi}{ak_0}\right)^2\right] \tag{1}$$

where k_0 is the free space wavelength. After a distance of

$$l = 4na^2/\lambda, \tag{2}$$

the phase shifts between the modes lead to a symmetrical reproduction of the total field for even n and an antisymmetrical reproduction for odd n. For a frequency ratio of e.g. $f_1/f_2 = 2:3$, the length can be chosen as $l = 12a^2/\lambda_1 = 8a^2/\lambda_2$ to fulfill the phase requirements.

Optimization

The analytical solutions usually result in unaccpetably large dimensions. In addition, it is desirable to use frequencies of arbitrary ratios. Therefore, a hybrid *Simulated Annealing/Downhill Simplex* method from [4] was implemented to optimize the dimensions of the diplexers. It should be noted, that the solutions found by the optimization algorithm have the described phase properties of the modes at the end of the main waveguide required for the field reproduction. But generally, neither the condition of an oversized waveguide nor equation (2) need to be fulfilled. This means, that optimized diplexers no longer utilize the Talbot effect in the strict sense.

Result: Spatial diplexer

A diplexer for the 45 GHz and 70 GHz was optimized, and manufactured. Fig. 3 shows calculated Poynting energy flow for 70 GHz (top) and 45 GHz (bottom). One can see that the mode purity is better than 96 % for both frequencies. It should, however, be noted, that ohmic losses are not taken into account for the calculation.

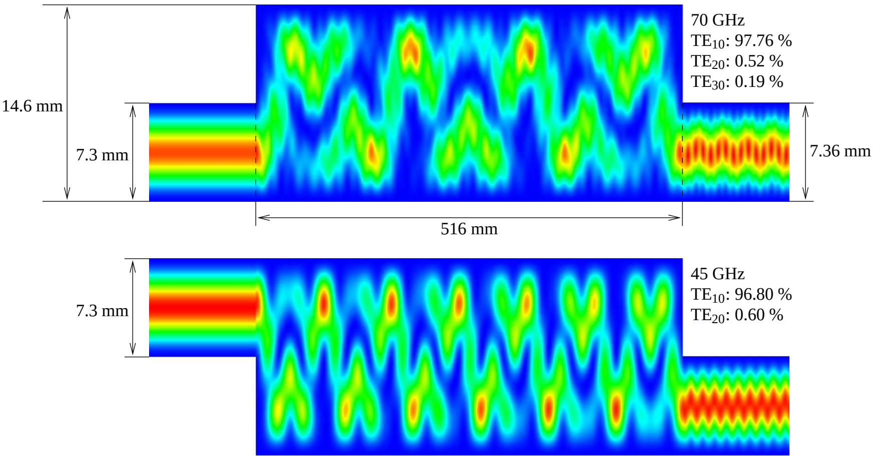

Fig. 3: Power flow in an optimized spatial diplexer for 70 GHz (top) and 45 GHz (bottom)

The diplexer was manufactured and tested using a vector network analyzer. Fig. 4 shows the transmitted power. One can see, that the transmission loss is below 1 dB at the center frequencies of both inputs.

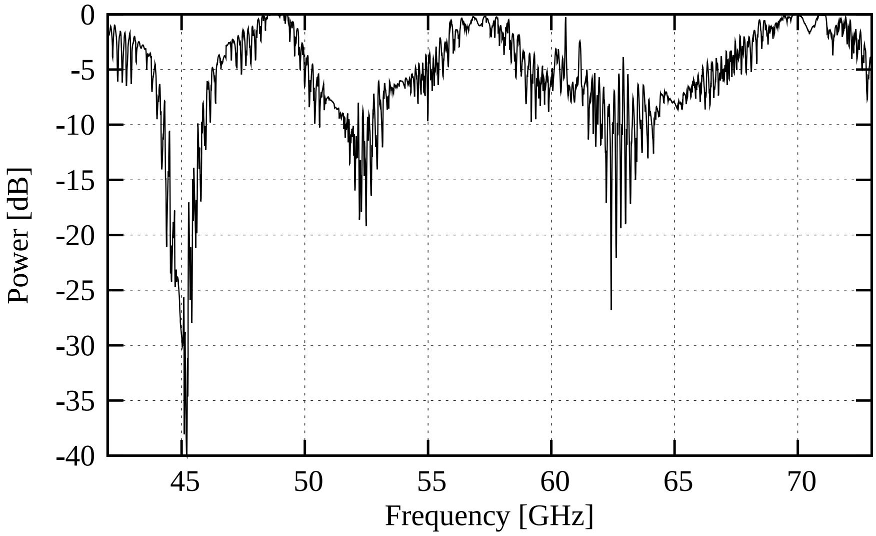

Fig. 4: Transmitted power for the 70 GHz input.

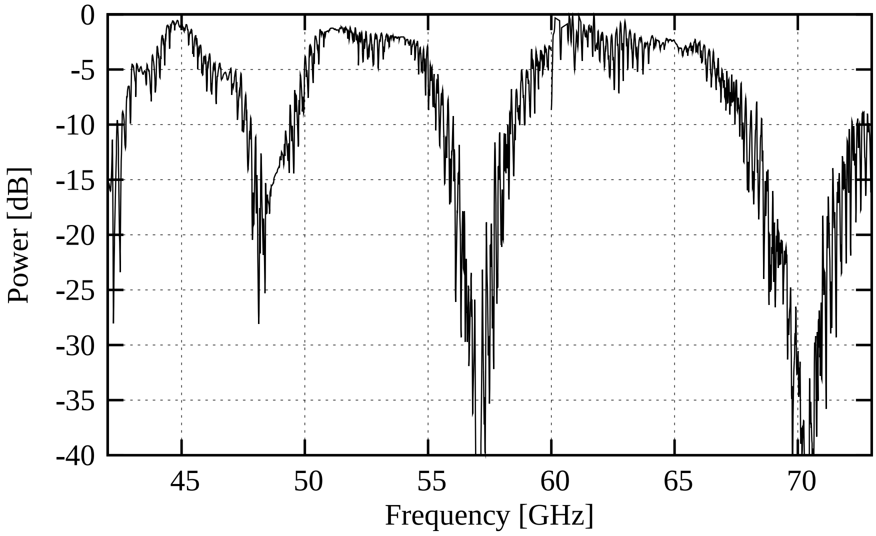

Fig. 5: Transmitted power for the 45 GHz input.

Result: Angular diplexer

An angular diplexer was also optimized and manufactured. The frequencies (150 and 160 GHz) are close together. Using the analytical approach, the resulting diplexer would be very long. The optimizer however, found a solution, which has a mode purity of more than 95 % at sufficiently small dimensions. Fig. 6 shows the Poynting flow in the diplexer. Note, that the distortions of the field pattern in the output waveguide are due to different scaling factors in the *x* and *y*-directions.

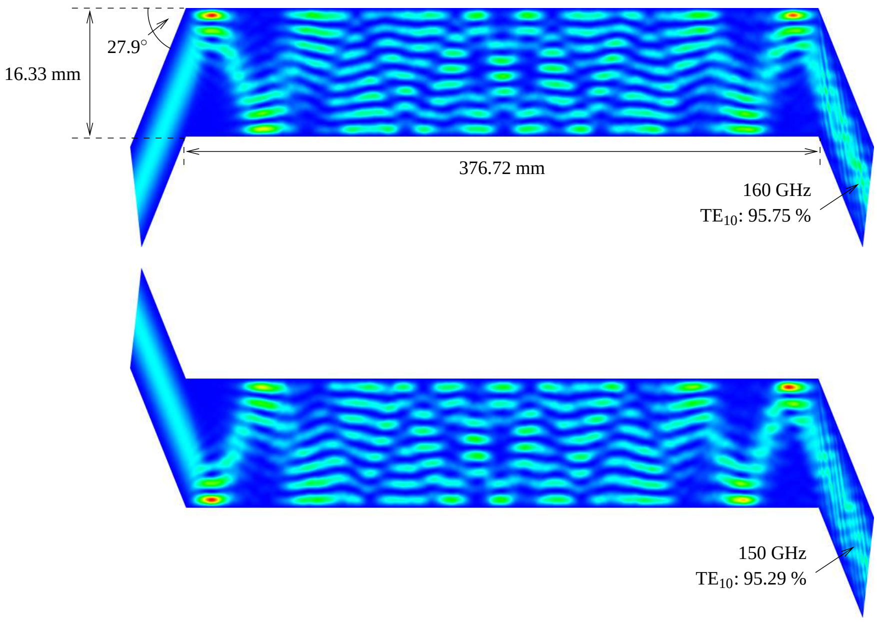

Fig. 6: Power flow in an optimized angular diplexers for 160 GHz (top) and 150 GHz (bottom)

Fig. 7 shows the measured transmission for both inputs over the frequency. While the principal characteristics of the curves are as expected, very high transmission losses are observed (-8 dB for 150 GHz, -7.5 dB for 160 GHz). The reason could be, that the waveguide has a height of only 0.83 mm. This results in attenuation coefficients at 160 GHz of 3.94 dB/m for the TE_{10} mode and 19.55 dB for the $TE_{17,0}$ mode, which is the highest order TE_{m0}-mode in this waveguide. It is therefore planned to improve the design by increasing the waveguide height. The Ohmic losses and the sensitivity to manufacturing tolerances should become lower then.

Conclusion

Two types of diplexers have been designed, manufactured and tested. While the *proof of principle* was successful for both designs, the angular diplexer has unacceptable transmission losses. Currently, investigations are being carried out in order to reduce these losses.

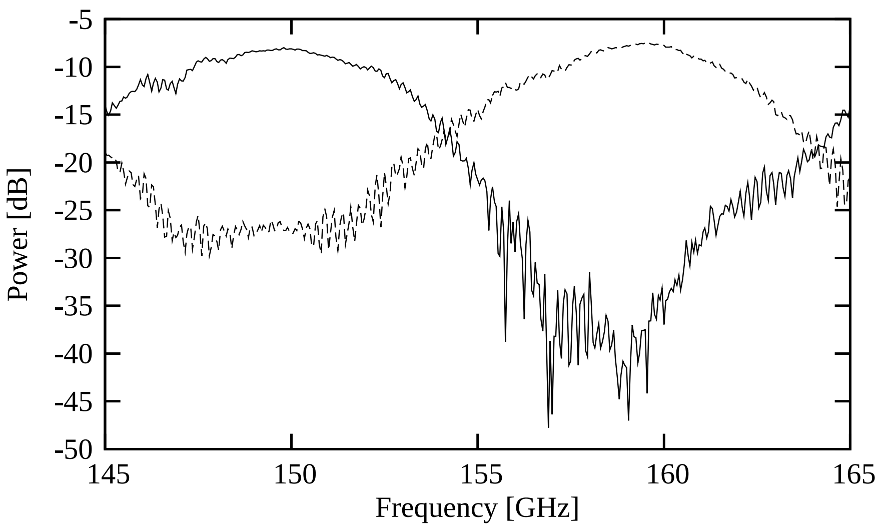

Fig. 7: Transmission of an optimized angular diplexer for 150 GHz (solid line) and 160 GHz (dashed line).

A comparison of Fig. 3 and Fig. 6 shows, that the peak field strength in the main waveguide of the angular diplexer is much higher than in the input waveguide. This is not the case in the spatial diplexer. The reason is, that the indices of the dominant modes in the angular diplexer, which strongly depend on the angle α, are usually higher, than in the spatial diplexer. The appearance of high mode indices could be a principal weakness of the angular diplexer. On the other hand, the spatial diplexer requires an absorber, as well as a waveguide wall with (theoretically) zero thickness. The realization was done by using tapers at the input and output side, which introduce sharp edges. These could lead to arcing problems in high power applications.

Up to now, neither of the two designs can be shown to be principally superior to the other. This is especially the case for low power applications, where the potential problems described above are not important.

References

[1] W. Talbot, *Facts related to optical sciences*, No. IV, Philos. Mag. 9 (Third Series) (1836), 401

[2] L. Semenov, A. Rivlin, Transmission of images through optical waveguides, Laser Focus (Feb 1981), 82 - 84

[3] B. Plaum, , E. Holzhauer, W. Kasparek: *Optimization of a frequeny diplexer based on the Talbot effect in oversized rectangular waveguides*, International Journal of Infrared and Millimeter Waves, Vol. 24, No. 3, 311-326, 2003

[4] W. H. Press, S. A. Teukolsky, W. T. Vetterling, B. P. Flannery, *Numerical Recipes in C*, Cambridge University Press, 1992