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DEVELOPMENT OF A COUPLER IN FINLINE TECHNIQUE

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Abstract

Among other components directional couplers are employed in millimeterwave finline circuits. The method presented here allows a simple calculation of all modes which can exist on such couplers under consideration of the thickness of the metallization. In this way a 3-dB coupler has been developed for the Ka-band. Numerical and experimental results illustrate the applicability of this method.

Introduction

Since finlines permit a simple integration of semiconductor elements, their use as waveguides has considerably gained in importance during the last years. Today many components such as e.g. oscillators, electronically controlled attenuators and isolators can be realized in this technique and it will be possible in the future to integrate complete circuits in this way. For this purpose directional couplers are needed and, in order to design them, the propagation properties of waves on coupled finlines must be known. Therefore a field analysis of symmetrical coupled finlines must be developed first.

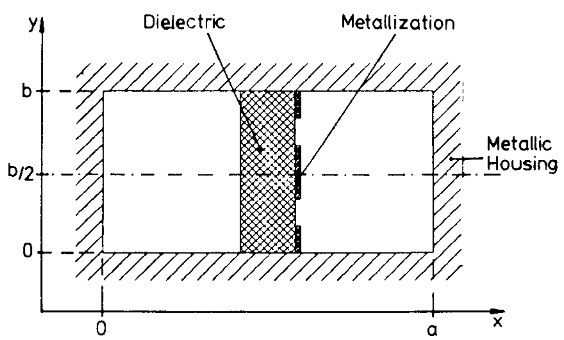

Fig.1: Cross-section of a finline coupler with two symmetrical slots.

The method presented here takes into account the finite thickness of the metallization and moreover it permits a complete solution of the boundary value problem shown in Fig.1. The methods published up to now either are approximate calculations /2/ or they did not consider the finite thickness of the metallizaton /3,4/.

Solution of the Boundary Value Problem

Making use of the symmetry, the finline coupler presented in in Fig.1 can be analysed by superposing the two fundamental modes (even and odd modes, as shown in Fig.2) which are solutions of the boundary value problem.

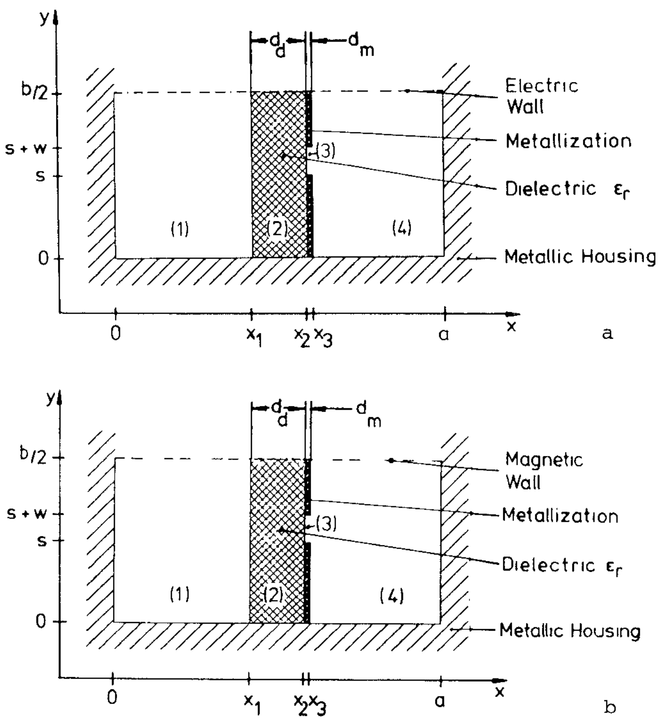

Fig.2: Geometry of the lower half of the symmetrical finline coupler,
a) for the odd mode,
b) for the even mode.

The cross sectional structures shown in Fig.2 are divided into four homogeneous subregions (1)-(4). The potential functions in the individual subregions can be described by superposing the solutions of the boundary value problems shown in Fig.3.

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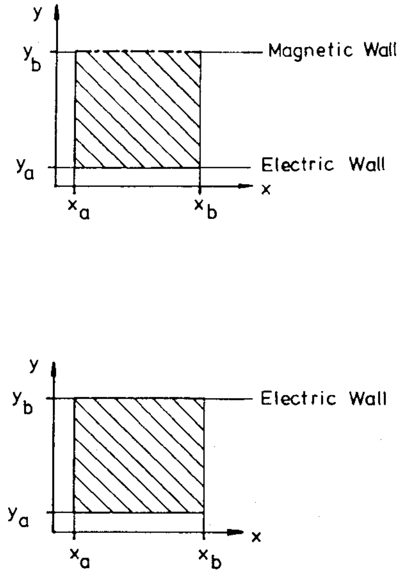


a

b

Fig.3: Geometry of the fundamental rectangular subregions which are used for solving the boundary value problem.

For a rectangular region with two electric walls, one magnetic wall and one open boundary (Fig.3a)) the potential functions are:

LSE mode:

$$\Psi_m = A_m \sin(k_{xm}(x-x_a))\cos((m-\frac{1}{2})\pi\frac{y-y_a}{y_b-y_a}) , \quad (1)$$

LSM mode:

$$\Phi_m = B_m \cos(k_{xm}(x-x_a))\sin((m-\frac{1}{2})\pi\frac{y-y_a}{y_b-y_a}) . \quad (2)$$

Analogously, for a rectangular region with three electric walls and one open boundary (Fig.3b)) the following potential functions can be found:

LSE mode:

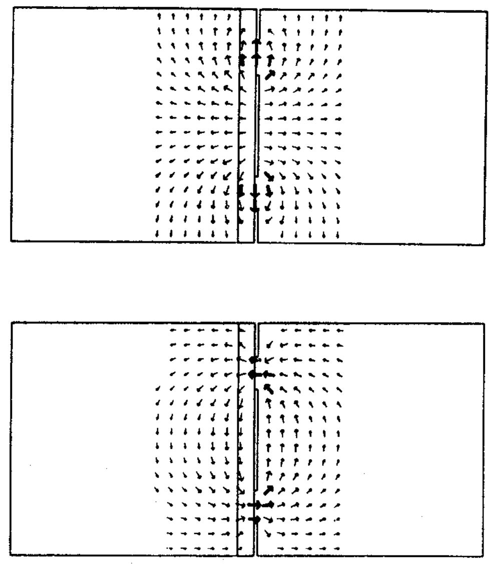
$$\Psi_m = A_m \sin(k_{xm}(x-x_a))\cos(m\pi\frac{y-y_a}{y_b-y_a}) , \quad (3)$$

LSM mode:

$$\Phi_m = B_m \cos(k_{xm}(x-x_a))\sin(m\pi\frac{y-y_a}{y_b-y_a}) . \quad (4)$$

A coupling of the amplitude coefficients A_m, B_m results from the continuity conditions and the boundary conditions which have to be satisfied. Making use of the orthogonality of the expansion functions, a homogeneous equation system can be obtained as a function of the phase constant β, from which the phase constant can be computed by searching the zeros of the system determinant.

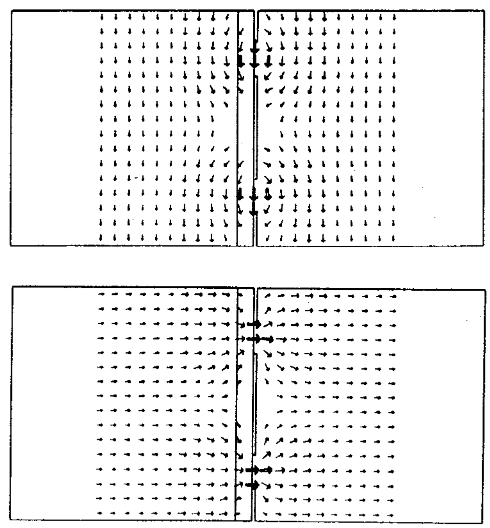
The employed field theoretical method has the advantage that it can be used to determine the electromagnetic field and its components directly. Fig.4 and Fig.5 show the field distributions of the even and the odd fundamental modes on two coupled finlines.



a

b

Fig.4: The field distribution of the even mode on two coupled finlines: The electric field (a) and the magnetic field (b).



a

b

Fig.5: Field distribution of the odd mode on two coupled finlines: The electric field (a) and the magnetic field (b).

Design of a Finline Coupler

On a finline with two symmetrical slots (Fig.1), the even mode and the odd mode have different phase constants und thus a periodical coupling is obtained. The 0-dB coupling length L of such a structure is defined as /5/:

$$L = \frac{\pi}{\beta_{even}-\beta_{odd}} \quad (5)$$

For the realization of a finline coupler in the Ka-band the 0-dB coupling length L has been callated in dependence on the frequency for different spacings s between the slot and the mount (Fig.6) and for different slot widths w (Fig.7).

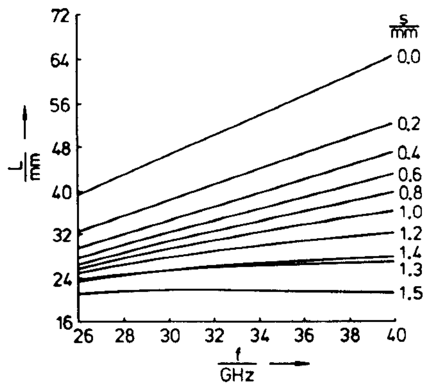


Fig.6: The 0-dB coupling length L versus the frequency f with the spacing s between the slot and the mount as a parameter. (w=0.2 mm).

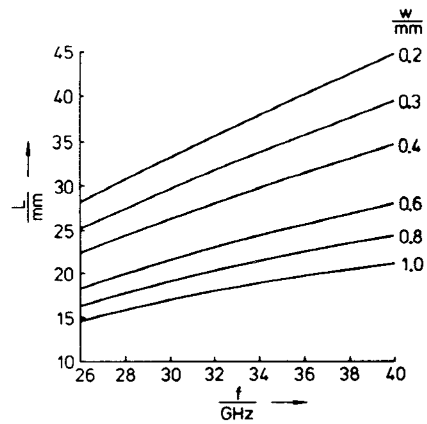


Fig.7: The 0-dB coupling length L versus the frequency f with the slot width w as a parameter. (s=0.5 mm).

For the realization of a finline coupler in the Ka-band the 0-dB coupling length L in dependence on the frequency has been calculated for different spacings s between the slot and the mount (Fig.6) and for different slot widths w (Fig.7).

From Fig.6 and Fig.7 it can be recognized that in the considered cases the frequency dependence of L is smallest for s=1.5 mm and w=0.2 mm. However, the metallic strip between the two parallel slots for technological reasons should not be too narrow; therefore in the actual coupler design s was chosen to be s=1.475 mm. In this case the slot width again is 0.2 mm. The phase constants β_{even} and β_{odd} of this configuration are shown in Fig.8.

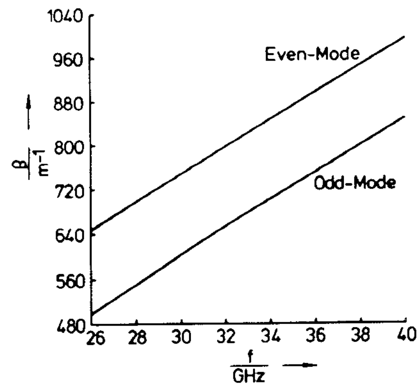


Fig.8: The phase constants of the even and the odd mode versus the frequency (s=1.475 mm, w= 0.2 mm).

The tapers which connect the coupler to the homogeneous waveguides (Fig.9) cause frequency dependent overcouplings which must be taken into account when the homogeneous coupling length L shall be determined. In order to keep this effect as small as possible, the tapers must be short. However, they should not be too steep as to avoid high reflections. In order to prevent waveguide resonances, short-circuit pins have been introduced into the two T-junction regions.

Due to the geometrical symmetry only 8 of the 16 scattering parameters are needed to describe the coupler completely. They are shown in Fig.10 for the designed coupler in the frequency range between 26 GHz and 40 GHz.

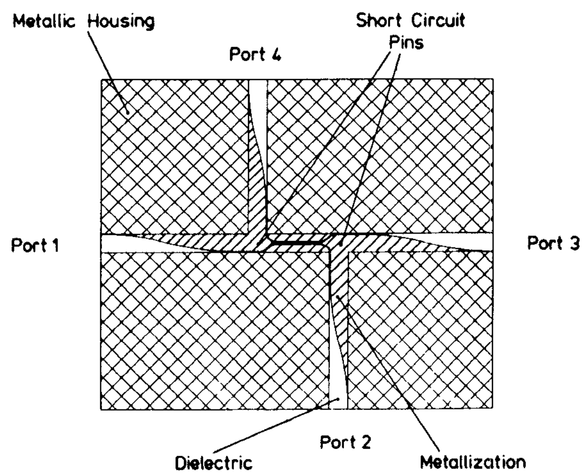


Fig 9: Top view of a four port finline coupler.

Fig.10a) and Fig.10b) show the coupling coefficients S_{31}, S_{21}, S_{12} and S_{42}. As can be recognized from these figures, the designed coupler does not posses the specified 3-dB coupling but the coupling coefficients is somewhere between 4 dB and 6 dB. There are several reasons for this deviations:

1) In the design process the bent finlines which make the connection to the tapers are not taken into account. As is known from similar couplers

in dielectric image line technique /6/ these interconnection lines have a notable influence on the coupler properties. The theoretical consideration of these lines is very difficult because they are inhomogeneously coupled finlines.
2) There is another critical aspect of the coupler shown in Fig.9. The asymmetrical tapers which are in the prototype coupler use the metal walls of the housing as one electrode of the taper finline. This construction cannot be produced with the required accuracy so that the tapers also could have an influence on the deviation of the coupling coefficients. This effect of course can be avoided by designing tapers which have a metallization on both sides of the finline slot.

The coupler has been designed for an operating frequency of 32 GHz. As Fig.10c) and Fig.10d) show, the minimum of the return loss (Fig.10d)) and the best isolation between ports 3 and 2 as well as ports 4 and 1 is reached at nearly 32.6 GHz. The deviation from the original design frequency has the same reasons as described above for the deviations of the coupling coefficients. At the frequency of 32.6 GHz a return loss of -40 dB and an isolation of 40 dB is measured for the coupler.

If a -20 dB return loss and a 20 dB isolation are required for defining the operating frequency band of the coupler, a bandwidth of about 3.5 GHz can be found for the finline coupler. Outside this band the return loss as well as the coupling between ports 3 and 2 and ports 4 and 1 are in the order of -15 dB.

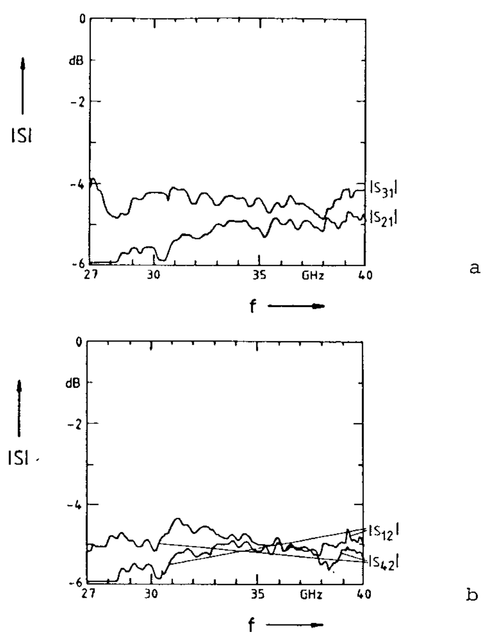


Fig.10: Measured scattering parameters of the designed finline coupler versus the frequency.

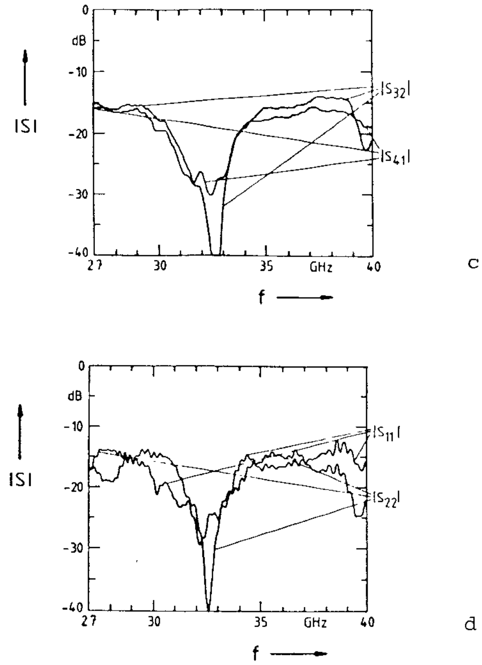


Fig.10 (cont.): Measured scattering parameters of the designed finline coupler versus the frequency.

Conclusions

The design of a finline coupler has been described. The properties of the produced coupler have to be improved e.g. by using Y-junctions instead of T-junctions in the waveguide housing. For a better understanding of the coupler, more detailed field pattern must be computed by means of the method presented here. Moreover, the problem of the inhomogeneous coupling regions and the taper between the rectangular waveguide and the finline must be considered in more detail. The described method can easily be modified for bilateral finlines or similar problems such like strip line couplers. Even isotropic magnetic materials and losses in the media could be taken into account.

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