FINLINE TAPER DESIGN MADE EASY

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Abstract

In this paper a method is presented which permits the quick and exact fabrication of tapers in finline technique. This method uses tapers in the form of circular arcs which are matched to the slotwidth as a function of the characteristic impedance. For the application of the described method the field distributions and the characteristic impedances of finlines must be known.

Introduction

In finline technique optimized bent structures are used in many components and systems. Examples of such structures are tapers which match different geometrical and electrical parameters of two waveguide sections or bent coupling sections which realize the desired coupling ratios of two slot structures.

For an easy fabrication of millimeter wave circuits a computer aided production of the layout masks is needed. The complexity of the circuit structures and especially the arbitrarily bent contours of e.g. tapers on the one hand render the fabrication difficult, on the other hand they effect the accuracy of the desired layouts. In the following a method is presented which allows to fabricate the layouts faster and with a higher degree of accuracy.

Circular Arc Finline Tapers

Some papers have presented calculation methods for inhomogeneous finlines /1,4/. The optimization of the inhomogeneous sections of finlines yields arbitrary contour functions which for practical applications are approximated by polynomials. Plotters and mask cutters normally can produce circular arcs quickly and with a high degree of accuracy. For this reason the optimized tapers instead of using polynomials are approximated by means of circular arc sections in this paper.

Fig.1 shows the slotwidth s of a finline taper (2) which is used to match a rectangular waveguide (1) and a homogeneous finline (3). This taper is approximated by means of two circular arcs (Fig.2); its taper function is not only continuous but it is also characterized by a taper function which is continuously differentiable in the interconnection points P_H and P_F to the homogeneous waveguides (1) and (3). From these conditions of the taper function it follows that at the points P_H, P_S, P_F:

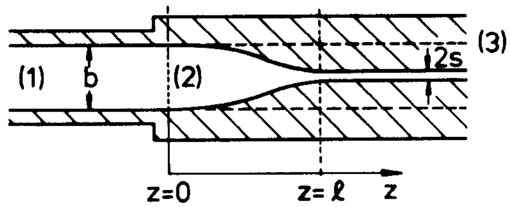

Fig.1: Finline taper.

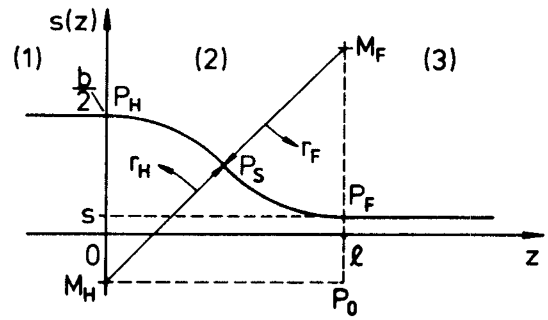

Fig.2: Geometry of a finline taper composed by two circular arcs.

- the center M_H of the circular arc which issues into the waveguide section is a point of the line z=0,
- the center M_F of the circular arc which issues into the finline section is a point of the line z=l
- the intersection point of the circular arcs lies on the connecting line between M_H and M_F.

The Pythagorean theorem can be applied to the triangle (M_H,M_F,P_0) and the sum r_F+r_H can be determined to:

$$r_F + r_H = \frac{l^2+(b/2-s)^2}{2(b/2-s)} \quad . \tag{1}$$

The geometry of the taper (l,s,b) defines a quantity of circle radii which permit to find an overall continuous and continuously differentiable taper function. Moreover (1) still contains a degree of freedom which can be used with regard to other than geometrical aspects. Two cases shall be considered which a) use equal radii and b) unequal radii of the two circular arcs.

a) Equal radii:

$$r = r_F = r_H = \frac{l^2+(b/2-s)^2}{4(b/2-s)} \quad . \tag{2}$$

The solution given in (2) is the easiest and most obvious one. In this case only one adjustment of the radii is needed so that the structural function can be produced with a high degree of accuracy (only the intersection point P_S is critical in this context).

Fig.3 shows the qualitative dependences of the slot widths s(z) and of the characteristic impedances $Z_L(z)$ for the cases a) and b). The

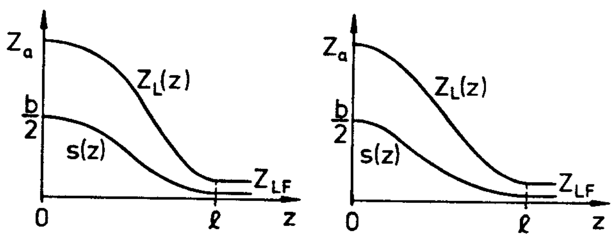

Fig.3: Plot of the functions $Z_L(z)$ and s(z)
a) for identical radii $r_H=r_F$,
b) for different radii $r_H \neq r_F$.

field theoretical background for the determination of these quantities is described in /1/.

b) Unequal radii:

The structural function according to a) implies that

$$s(z=l/2) = \frac{b/2+s}{2} \quad , \tag{3}$$

i.e. at z=l/2 the slotwidth s is the mean value between the height of the waveguide and the slot width of the homogeneous finline. It clearly can be seen that the structural function s(z) in case a) and $Z_L(z)$ in case b) have more smooth taper functions. However, the reflection properties of the tapers are largely determined by the dependence $Z_L(z)$. Consequently, it is more reasonable to match the dependences of the characteristic impedances at z=l/2:

$$Z_L(z=l/2) = \frac{Z_{LF}+Z_a}{2} = Z_M \tag{4}$$

and to require:

$$s(z=l/2) = s(Z_M), \tag{5}$$

where $s(Z_M)$ is the slotwidth which is adjoint to the impedance Z_M.

The slotwidth at z=l/2 (half taper length) must be determined so that it is the algebraic mean value of the characteristic impedances Z_{LF} and Z_a at the ends of the taper (i.e. at z=0 and z=l). The function $Z_L(z)$ is known from a taper analysis program, e.g. /1/. Equ.(4) then directly can be determined from $Z_L(z)$ and (5) from its inverse function. Thus from the pairs of circular arcs which fit (1) that pair which fulfills the condition (5) can be found.

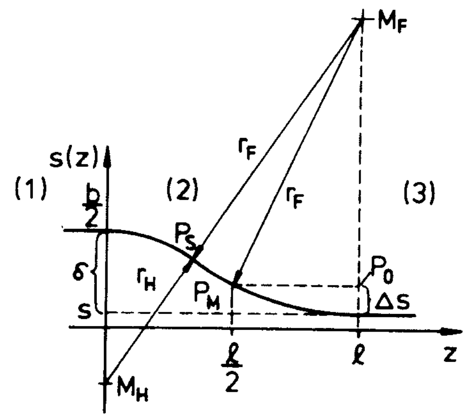

Fig.4: Geometry of the matched radii of a circular arc taper.

If Δs is the extension of the slot width s at z=l/2 compared to the slotwidth of the homogeneous finline, in the case a) of equal radii this value is: $\Delta s=\delta/2$. For all practical applications of the structural function which is defined by the characteristic impedance up to now only cases with $\Delta s<\delta/2$ have been found. Then it follows from Fig.4 that $r_F \rightarrow r_H$, i.e. that the circular arc around M_F with the radius r_F intersects the point P_M. The radius r_F can be calculated from the triangle (M_F, P_M, P_0):

$$r_F = \frac{(l/2)^2+\Delta s^2}{2\Delta s} \tag{6}$$

If (considering Fig.4) the case $\Delta s \rightarrow 0$ is regarded, it becomes clear that below a lower bound of Δs no pair of circles can be found, because for such values of Δs negative radii r_H result. From (6) it follows that in the limiting case $r_H \rightarrow 0$ the condition

$$\frac{l^2+\delta^2}{2\delta} - r_F > 0 \tag{7}$$

results for the existence of the structural function. If (7) is inserted into (6) and solved with respect to Δs, the following condition for Δs must be fullfilled:

$$\Delta s > \frac{\delta}{2}\{1+(l/\delta)^2(1 \underset{(+)}{-} \sqrt{1+(\delta/l)^2+(\delta/l)^4})\} \ . \quad (8)$$

In the case of $r_H \to 0$ the negative sign of the root has to be used. The positive sign of the root holds for analogous considerations in the case $r_F \to 0$. For a K-band finline mount the following geometrical dimensions are used: $b/2=2.159$ mm, $s=100...200$um and $l > 15$ mm or $l/\delta > 7$. Under the condition $l/\delta \gg 1$ the fourth power of δ/l is neglected and because

$$\sqrt{1+x} \cong 1 + 0.5x \ , \ |x| \ll 1 \ , \quad (9)$$

the following condition results from (8):

$$\Delta s > \frac{\delta}{4} \ . \quad (10)$$

For all substrate materials for which the characteristic impedance fulfills the following conditions:

$$Z_L(s+\frac{\delta}{4}) < \frac{Z_a+Z_{LF}}{2} < Z_L(s+\frac{\delta}{2}) \quad (11)$$

(with Z_{LF} the characteristic impedance of the homogeneous finline and Z_a the characteristic impedance of the waveguide) a matched circular arc taper can be found using equs. (6) and (7).

A similar condition can be found for the slotwidth $s(z)$:

$$s + \frac{\delta}{4} < s(z=l/2) < s + \frac{\delta}{2} \ . \quad (12)$$

All tapers discussed in this paper meet these conditions.

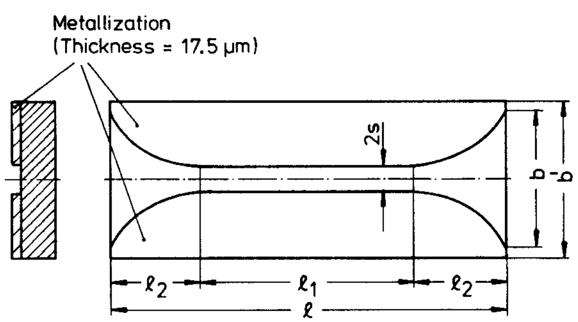

Fig.5: Geometry of a two-taper section. Material: RT/Duroid 5880, height 125 um, $\varepsilon_r=2.22$.

Experimental Verification

In order to examine the efficiency of this method a double circular arc taper designed for the K-band (18 GHz - 26.5 GHz) is compared to a linear and a polynomial taper. The structure of each taper corresponds to that shown in Fig.5, which also specifies the common geometrical dimensions and electrical parameters. Fig.6a) shows the return loss of the linear two-taper section.

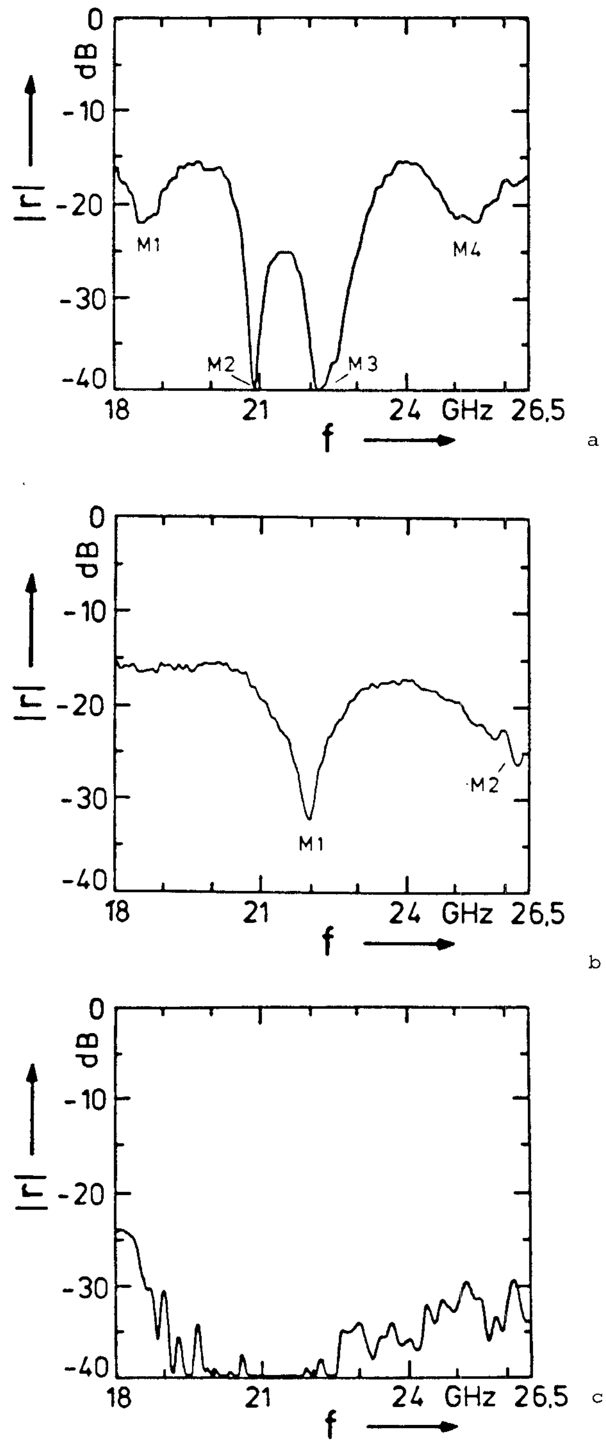

Fig.6: Return loss of two-taper sections versus the frequency at K-band:
a) for a linear taper,
b) for a near optimum taper,
c) for a circular arc taper.

This figure shows four minima M_1, M_2, M_3 and M_4; two of them are in the order of -40 dB and the other two only nearly -20 dB. The four minima result from reflexions at the beginnings and the ends of the tapers. The frequency spacing between the minima is inversely proportional to the geometrical spacing between these reflecting planes (consider: The phase constant β varies along the taper). In the case shown in Fig.6a) the frequency spacings between the minima are relatively small because the geometrical spacing l_1 is large. From the figure it can be concluded that the reflexion at the taper input where the empty waveguide changes into the the finline section is large (-20 dB) compared to the reflexion at the end of the taper and the beginning of the homogeneous finline.

Fig.6b) shows the return loss of an optimized two-taper section with a polynomial slot function. The bent contour sections have been produced using a plotter and thus they surely do not exhibit the desired smooth curve. In the case of this taper M_1 and M_2 indicate the reflection minima. A comparison with the preceding structure shows that the frequency spacing between the minima is more than three times larger as in the case of the linear taper (Fig.6a)) because the geometrical spacing between the reflecting planes is about one third compared to that of the linear taper.

It should be mentioned that the tolerances for producing the slot at the taper end, where the taper changes into the homogeneous finline, are much more critical than at the interconnection between the empty waveguide and the taper, because at the end of the taper the slotwidth is 15 times smaller than the waveguide height.

The best results for the return loss have been measured for the circular arc two-section taper (Fig.6c)). No dominant reflection can be observed in this case. The minimum return loss is improved by -8 dB; the mean value of the return loss is even -14 dB lower in the case of the circlar arc taper compared to the other tapers.

Conclusions

From the results presented in this paper it can be concluded that in a practical finline taper design it is much more efficient to realize a smooth taper function than to put high effort into a numerical optimization of other structural functions. This conclusion is made under the assumption that the layout masks of the tapers are produced with a plotter of low accuracy as it often is done in the laboratory. The results presented here do not mean that the theoretically optimized taper functions could not deliver even better properties if they can be produced with a very high accuracy. So the arguments given in this paper could be a little bit debilibitated if a high accuracy mask cutter is used. In any case the production of the circular arc tapers is much simpler than that of the other tapers.

References

/1/ A.Beyer and I.Wolff: Calculation of the transmission properties of inhomogeneous finlines. Proc. 10th European Microwave Conference, Warsaw (Poland), 1980, pp. 322 -326.

/2/ R.P.Hecken: A near-optimum taper matching section without discontinuities. IEEE Trans. MTT-20, No. 11, pp. 734-739, Nov. 1972.

/3/ J.R.W.Hoefer: Fin line design made easy. 1978 IEEE MTT-S Internat. Microwave Symp. Digest, Ottawa (Canada), pp. 471-474.

/4/ A.M.Saad, K.Schünemann: Design of fin-line tapers, transistions, and couplers. Proc. 11th European Microwave Conference, Amsterdam (Netherlands), (1981), pp. 305-308.

/5/ L.Solymar: Spurious modes in nonuniform waveguides. IRE Trans. MTT-7, No.7, pp. 379-383, 1959.

/6/ Ch.P.Womack: The use of exponential transmission lines in microwave components. IRE Trans. MTT-10, No.3, pp. 124-132, 1962.