Spurious Resonances in Asymmetrical Fin-Line Junctions

KLAUS SOLBACH, MEMBER, IEEE HEINRICH CALLSEN, AND WOLFGANG MENZEL

Abstract—**Spurious resonances which occur in asymmetrical fin-line junctions are investigated. The field distribution and the resonant frequency are computed using a field matching technique. Looking at the field distribution, methods for resonance suppression are discussed.**

I. Introduction

In the last years, the fin-line has emerged as an effective medium for millimeter-wave integrated circuits. Several fin-line components have been reported, from passive components to oscillator, mixer, and p-i-n devices [1]–[5].

In the course of the investigation of coupled fin-line directional couplers serious difficulties arose due to resonance effects in the fin-line junctions.

These resonances were identified as the quasi-TM_{010} mode, the dominant mode for a short fat cavity. This mode has its electric field perpendicular to the plane of the fin-line substrate; the boundaries of the effective cavity are formed by the meeting open-waveguide arms, which, for the considered polarization of the resonance mode, are operated below cutoff. In the following, a field expansion is used to verify the assumptions concerning the nature of the resonances. Finally, methods are discussed to avoid the resonance effects.

II. The Field Expansion

For the analytical treatment of the resonance modes in fin-line junctions, a four-port junction in a symmetrical mount, Fig. 1, was chosen. Other configurations, like the three-port T-junction or the Y-junction may be analyzed in a similar manner, employing different sets of field expansion functions [6].

In the central portion of the junction, a quasi-TM_{010} mode is assumed with its electric field perpendicular to the plane of the fin-line and terminated by the four joining waveguide channels in the fin-line mount.

Since usually standard waveguide dimensions for the channels are used in fin-line mounts, in the fundamental mode region of the fin-line, the width, a, of the channels does not allow propagation of a mode polarized perpendicularly to the fin-line plane. Thus for the resonance mode, the channels represent a purely imaginary impedance (below-cutoff waveguide).

The field-theoretical solution of the resonator problem is basically a mode-matching technique [7]. The fields of the undisturbed resonance mode can be described by an eigenmode expansion in a junction with an electric wall in the plane of the fin-line (zero-slot-width fin-lines). Due to the symmetry of both the junction and the investigated resonance mode, magnetic walls may be assumed along the planes of symmetry as shown in Fig. 2.

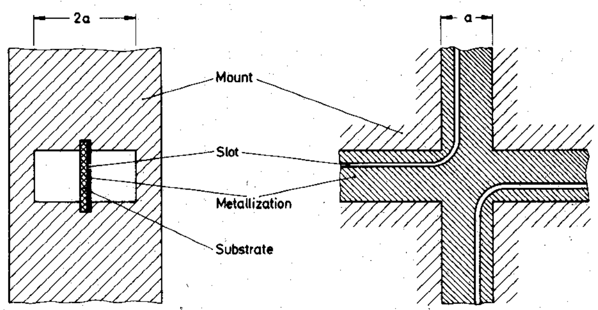


Fig. 1. Cross-sectional view of a four-port fin-line junction.

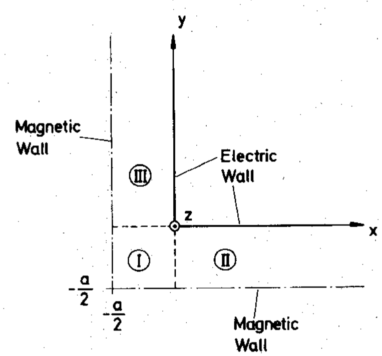


Fig. 2. Structure adapted for the calculation of the resonance-mode fields.

In region I, a standing-wave type potential is assumed; while in region II, only outgoing waves (exponentially decaying) are assumed. Due to the symmetry of the structure, the potentials in regions II and III are identical.

Since no variation of the fields perpendicular to the plane of the junction (z direction) is assumed, only TE_{m0} modes are allowed in the expansion ($E_X = E_Y = 0$)

$$\psi^{I} = \sum_{m=1}^{\infty} A_m \left[\cos\left(\frac{m\pi}{a} y\right) \cos\left(k_{xm}^{I}\left(x+\frac{a}{2}\right)\right) + \frac{1}{j\omega\mu_0} \cos\left(\frac{m\pi}{a} x\right) \cos\left(k_{ym}^{I}\left(y+\frac{a}{2}\right)\right)\right], \quad m = 1,3,5,\cdots \tag{1}$$

Manuscript received April 22, 1981; revised July 13, 1981.

The authors are with AEG-Telefunken, Hochfrequenztechnik, D 7900 Ulm, Federal Republic of Germany.

0018-9480/81/1100-1193$00.75 ©1981 IEEE

$$\psi^{\mathrm{II}} = \sum_{n=1}^{\infty} B_n \cos\left(\frac{n\pi}{a}y\right) e^{-jk_{xn}^{\mathrm{II}}x}, \qquad n=1,3,5,\cdots \tag{2}$$

with

$$k_0^2 = \left(\frac{m\pi}{a}\right)^2 + \left(k_{xm}^{\mathrm{I}}\right)^2 = \left(\frac{m\pi}{a}\right)^2 + \left(k_{ym}^{\mathrm{I}}\right)^2$$
$$= \left(\frac{n\pi}{a}\right)^2 + \left(k_{xn}^{\mathrm{II}}\right)^2, \qquad \begin{Bmatrix} n \\ m \end{Bmatrix} = 1,3,5,\cdots \tag{3}$$

and k_0 is the free-space wavenumber.

The electric and magnetic field components can be calculated from the potentials using standard methods.

The continuity conditions

$$\left.\begin{matrix} E_z^{\mathrm{II}} = E_z^{\mathrm{III}} \\ H_x^{\mathrm{II}} = H_x^{\mathrm{III}} \end{matrix}\right\}, \qquad \left\{\begin{matrix} x=0 \\ -a \leqslant y \leqslant 0 \end{matrix}\right. \tag{4}$$

yield

$$A_i \cosh\left(|k_{xi}^{\mathrm{I}}|\frac{a}{2}\right) = C_i, \qquad i=1,3,5,\cdots \tag{5}$$

where

$$|k_{xi}^{\mathrm{I}}| = \sqrt{\left(\frac{i}{a}\right)^2 - k_0^2}.$$

The continuity condition

$$H_y^{\mathrm{II}} = H_y^{\mathrm{III}}, \qquad \left\{\begin{matrix} x=0 \\ -a \leqslant y \leqslant 0 \end{matrix}\right. \tag{6}$$

can be satisfied employing, e.g., a least squares fit condition to yield a system of homogeneous equations for the field amplitudes.

This system of equations is cast into a matrix form

$$\vec{C} \cdot \vec{A} = 0 \tag{7}$$

with A the amplitude vector and the elements of the coefficient matrix

$$c_{mp} = \left(\frac{m\pi}{a}\right)^2 \cdot \frac{2}{a} \cdot \frac{\cosh\left(|k_{ym}^{\mathrm{I}}|\frac{a}{2}\right)}{\left(\frac{p\pi}{a}\right)^2 + |k_{ym}^{\mathrm{I}}|^2} - \delta \frac{|k_{xp}^{\mathrm{II}}|}{2} e^{|k_{xp}^{\mathrm{II}}| \cdot (a/2)},$$
$$m, p = 1,3,5,\cdots \tag{8}$$

with

$$\delta = \begin{cases} 1, & \text{for } m=p \\ 0, & \text{for } m \neq p. \end{cases}$$

Equation (7) is the eigenvalue equation of the resonator defined by the structure in Fig. 2. The eigenvalue, i.e., the resonance frequency is found, if the eigenvalue equation

$$\det(\vec{C}) = 0 \tag{9}$$

is satisfied, i.e., if the zero of the system determinant is found.

The infinite system of equations may be truncated to a finite number N of equations. Due to the high degree of symmetry in the investigated resonator it turns out that the convergence of the calculated resonance frequency with the number N of the modes assumed is very rapid. In fact, using only the fundamental mode, $N=1$, yields a very good approximation to the exact eigenvalue equation with an error of only 1–2 percent in the calculated resonance frequency.

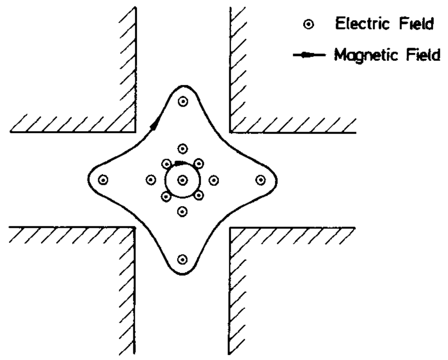


Fig. 3. Sketch of the field distribution of the quasi-TM_{010} mode in a fin-line mount (symmetrical cross junction).

The results of calculation show that the resonance frequency of the quasi-TM_{010} mode can be approximated by

$$f_0 = \frac{123.7 \text{ GHz}}{a/\text{mm}} \tag{10}$$

which means that for a *KA*-band (26.5–40 GHz) fin-line mount the resonance is calculated at 34.75 GHz.

For the resonance frequency, the field distribution in the junction was calculated and is sketched in Fig. 3. As can be seen, the resonance mode has a strong similarity to the TM_{010} mode in a closed metallic cavity with an effective radius $r \approx a$.

It has to be noted here that in other junction configurations, like Y- and T-junction, the quasi-TM_{010} mode exhibits slightly higher resonance frequencies.

III. Suppression of Spurious Resonances

The simplest method for the suppression of the resonance mode in fin-line junctions is not to excite the modes, i.e., to design the fin-line structure in the junction area strictly symmetrical with respect to the resonance field distribution in the junction.

In the case of the four-port junction discussed here, this means that the slot would only be allowed along the magnetic walls $x=-a/2$ and $y=-a/2$, Fig. 2. The fields of such fin-lines are completely orthogonal to the resonance-mode fields and thus no excitation is possible for the resonance mode, e.g., in Y-junction fin-line p-i-n switches [3], resonances were totally avoided since the fin-line was centered along the symmetry planes of the junction.

Since, e.g., in junctions for coupled fin-line directional couplers, a completely symmetrical design of the fin-line structure is not possible, the existence of the resonance modes has to the prevented. Several techniques have been examined.

The first method was to reduce the width a of the fin-line mounts in order to shift the resonance frequency up across the upper band limit of the fin-line device. Unfortunately, this technique may lead to high costs for the fabrication of the fin-line mounts, due to the complicated contours to be milled.

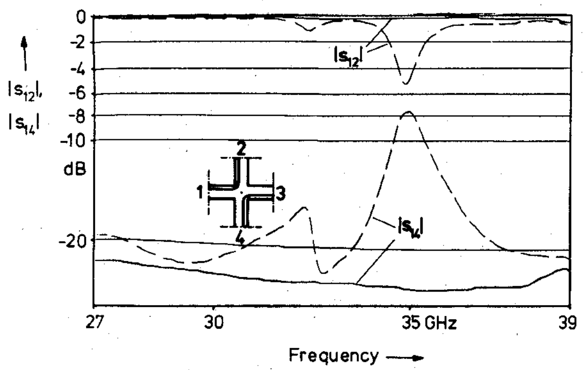


Fig. 4. The measured transmission of a four-port fin-line junction as a function of frequency. ---: without suppression of resonance mode; —: resonance mode short circuited. Substrate thickness $t=0.25$ mm, $\epsilon_r=2.2$, mount dimensions equivalent to WR-28 standard waveguide.

Methods using absorbing material or high-permittivity dielectric material placed in the fin-line mount in order to attenuate the resonance mode or to shift the resonance frequency down across the lower band limit of the fin-line device have shown to be useless, since in both cases the guided fin-line wave is strongly affected too.

The only suppression technique capable of useful discrimination between the resonance mode and the fin-line mode was found to be a conducting wire mounted in the center of the junction in order to short-circuit the electric field of the resonance mode, while the fin-line mode has its main electric field components perpendicular to the direction of the wire and thus is only slightly affected.

As a practical example of a fin-line junction with suppression of resonance effects, in Fig. 4, the measured transmission of the four-port junction depicted in Fig. 1 is plotted versus the frequency. It can be seen that in the junction without suppression of resonance modes there are two resonances near 35 and 32 GHz, respectively. The higher resonance frequency is due to the quasi-TM_{010} mode in the space above the metallization layer. The latter mode is loaded by the dielectric substrate and thus its frequency is shifted from that of the other mode. Since the modes suffer a field distortion due to the fin-line slots, the upper frequency differs slightly from the calculated resonance frequency of the undisturbed mode ($f_0=34.75$ GHz).

As can be seen from Fig. 4, the resonance effects are completely removed through the insertion of a wire. The silver plated wire of 0.8-mm diameter is inserted through a hole in the fin-line mount, placed in the center of the junction, and is threaded through a hole in the fin-line substrate to terminate in the other side of the mount.

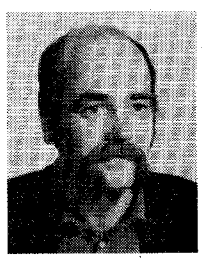
IV. Conclusions

It has been shown, both theoretically and experimentally, that quasi-TM_{010} resonance modes may be excited in fin-line junctions. These spurious resonances can be suppressed by a conducting wire placed perpendicular to the plane of the fin-line.

References

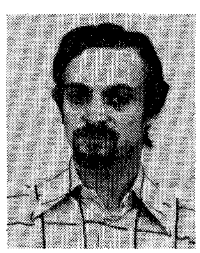
[1] P. J. Meier, "Millimeter integrated circuits suspended in the *E*-plane of rectangular waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-26, pp. 726–733, 1978.
[2] H. Hofmann, H. Meinel, and B. Adelseck, "New integrated mm-wave components using fin-lines," in *1978 IEEE MTT-S Symp. Dig.*, pp. 21–23.
[3] H. Meinel and B. Rembold, "New mm-wave fin-line attenuators and switches," in *1979 IEEE MTT-S Symp. Dig.*, pp. 75–78.
[4] H. Hofmann, "MM-wave Gunn oscillator with distributed feedback fin-line circuit," in *1980 IEEE MTT-S Symp. Dig.*, pp. 59–61.
[5] R. N. Bates and M. D. Coleman, "Millimeter wave 'E'-plane MIC's for use up to 100 GHz," in *Military Microwaves*, London, England, 1980.
[6] M. Kirschning and E.-J. Roebbers, "Transmission properties of symmetrical waveguide Y-junctions and 120°-bends," *Arch. Elektron. Uebertragung*, (Germany), vol. 35, pp. 51–53, 1981.
[7] E. Kühn, "A mode-matching method for solving field problems in waveguide and resonator circuits," *Arch. Elektron. Uebertragung*, (Germany), vol. 27, pp. 511–518, 1973.

Klaus Solbach (M'80) for a photograph and biography please see page 957 of the September 1981 issue of this Transactions.



Heinrich Callsen was born in Söby near Kiel, West Germany, on April 6, 1948. He began his professional education on a shipyard serving his apprenticeship as an electrician. After a period as a sailor on a freighter he studied electrical engineering. He received the Ing.-Grad. degree in 1971 from the Fachhochschule Lübeck, Lübeck, West Germany, and the Dipl.-Ing. degree in 1978 from the Technische Universität Berlin, Berlin, West Germany.

In 1979 he joined AEG-Telefunken in Ulm, West Germany, where he is engaged in the development of integrated millimeter-wave components and subsystems on the basis of planar and quasi-planar waveguide structures.



Wolfgang Menzel was born in Brilon-Wald, West Germany, on December 10, 1948. He received the Dipl.-Ing. degree from the Technical University of Aachen, Aachen, Germany, in 1974, and the Dr.-Ing. degree from the University of Duisburg, Duisburg, Germany, in 1977.

From 1974 to 1979, he was working at the University Duisburg on microstrip circuit problems. In 1979, he joined AEG-Telefunken in Ulm, Germany, working on integrated millimeter-wave components and planar antennas.