POWER DENSITY DISTRIBUTION ANALYSIS OF FERRITE LOADED FINLINES FOR THE DEVELOPMENT OF INTEGRATED NONRECIPROCAL MILLIMETER WAVE ELEMENTS

Adalbert Beyer and Ingo Wolff

Duisburg University, Department of Electrical Engineering, Bismarckstr. 81, D-4100 Duisburg
Fed. Rep. of Germany

Abstract

A hybrid mode field analysis for a finline loaded with a ferrite- and additionally a dielectric speciem is presented.

Using this theory the power density distribution of forward and backward waves is calculated and demostrated.

The results are used to design a finline isolator for the 28.5 GHz range with a bandwidth of 2 GHz, an insertion loss smaller than 1.2 dB and an isolation higher than 39 dB.

Introduction

The development of integrated nonreciprocal millimeter wave elements in finline technique requires the use of an efficient theory, which besides the properities of a realistic finline model, takes into account the nonreciprocal behaviour of the necessary ferrite sample, too. In earlier papers /1-3/ preliminary numerical and experimental results were obtained for the development of such elements. There were also obtained /3/ preliminary results for the power density distribution at the cross-section of a field displacement isolator in finline technique.

Following, a ferrite loaded finline-structure which serves as the basis for the realization of an isolator in finline technique, is analised using a hybrid mode field analysis technique, which also provides the calculation of second order effects as e.g. the influence of the metallization thickness and substrate holding grooves.

The Field Theoretical Method

For the calculation of the electromagnetic fields which can propagate on a combined line as shown in Fig. 1, the cross-section is subdivided into five field regions (1)-(5), and a complete set of field solutions is derived for each subarea. The x and y dependences of the electromagnetic fields in subregions (1), (3)-(5) are formulated using harmonic functions, so that the boundary conditions are fulfilled on the metallic wall or metallization of the dielectric substrate. As an example, the scalar potentials in subregion (1) are given by

$$\Phi^{(1)} = \sum_{m=1}^{\infty} \{\bar{A}_m^{(1)} \sin(\bar{k}_{xm}^{(1)} x) + \bar{B}_m^{(1)} \cos(\bar{k}_{xm}^{(1)} x)\} \sin\{\bar{k}_{ym}^{(1)}(y - \frac{b}{2})\} \quad (1)$$

$$\bar{k}_{ym}^{(1)} = \frac{m\pi}{b} \quad (2)$$

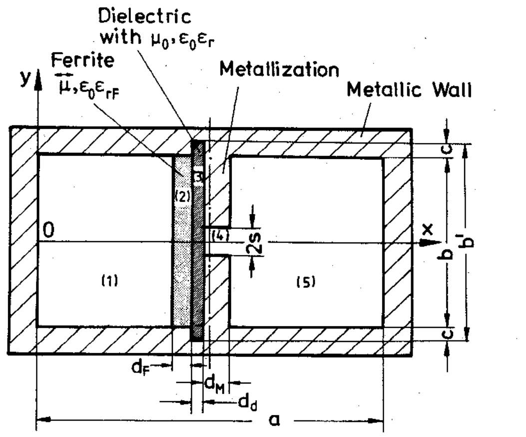

Fig. 1: Cross-section of the ferrite loaded unilateral grounded finline. (The dimensions for Ka-band are: a=7.112mm, b=3.556mm, b'=4.55mm, d_M=17.5μm, d_d=125mm, ε_{rd}=2.22, d_f=1.5mm, H_0=7.96kAcm^{-1}; ferrite material: TT2-111; the frequency: 28.5GHz.)

and

$$\Psi^{(1)} = \sum_{n=0}^{\infty} \{A_n^{(1)} \cos(k_{xn}^{(1)} x) + B_n^{(1)} \sin(k_{xn}^{(1)} x)\} \cos\{k_{yn}^{(1)}(y - \frac{b}{2})\} \quad (3)$$

$$k_{yn}^{(1)} = \frac{n\pi}{b} . \quad (4)$$

In region (2) the fields are expanded in following terms /4/:

$$E_{xm}^{(2)} = C_{xm}^{(2)}(x)\sin(k_{ym}^{(2)} y), \quad H_{xm}^{(2)} = K_{xm}^{(2)}(x)\cos(k_{ym}^{(2)} y), \quad (5,6)$$

$$E_{ym}^{(2)} = C_{ym}^{(2)}(x)\cos(k_{ym}^{(2)} y), \quad H_{ym}^{(2)} = K_{ym}^{(2)}(x)\sin(k_{ym}^{(2)} y), \quad (7,8)$$

$$E_{zm}^{(2)} = C_{zm}^{(2)}(x)\sin(k_{ym}^{(2)} y), \quad H_{zm}^{(2)} = K_{zm}^{(2)}(x)\cos(k_{ym}^{(2)} y) \quad (9,10)$$

with

$$k_{ym}^{(2)} = \frac{m\pi}{b} . \quad (11)$$

From the coupled differential equations

$$\{\frac{\partial}{\partial x^2} + (k^2 - \frac{1}{\mu_1} k_{ym}^{(2)2} - \beta^2)\} K_{ym}^{(2)} + jk k_{ym}^{(2)} \frac{\mu_2}{\mu_1} C_{ym}^{(2)} = 0 \quad (12)$$

and

$$\{\frac{\partial}{\partial x^2} + (k^2 \mu_{eff1} - k_{ym}^{(2)} - \beta^2)\} C_{ym}^{(2)} + jk k_{ym}^{(2)} (\mu_2/\mu_1) K_{ym}^{(2)} = 0, \quad (13)$$

the unknown function $C_{ym}^{(2)}(x)$ and $K_{ym}^{(2)}(x)$ can be de-

0149-645X/84/0000-0187 $01.00 © 1984 IEEE

termined. The effective permittivity μ_{eff1} of the lossless ferrite is calculated from the permittivity tensor $\overleftrightarrow{\mu}$ as

$$\mu_{eff1} = \frac{\mu_1^2 - \mu_2^2}{\mu_1} \qquad (14)$$

with

$$\overleftrightarrow{\mu} = \mu_0 \begin{bmatrix} \mu_1 & 0 & j\mu_2 \\ 0 & 1 & 0 \\ -j\mu_2 & 0 & \mu_1 \end{bmatrix} \qquad (15)$$

$$\mu_1 = 1 + \frac{\omega_M \omega_L}{\omega_L^2 - \omega^2} \qquad (16)$$

$$\mu_2 = \frac{\omega \omega_M}{\omega_L^2 - \omega^2} . \qquad (17)$$

The quantities ω_M and ω_L are related to the gyromagnetic ratio γ, the saturation magnetization M_s, and the bias magnetic field H_0 as

$$\omega_M = \gamma \dot{M}_s \qquad (18)$$

$$\omega_L = \gamma H_0 . \qquad (19)$$

With the help of the solutions for $C_{ym}^{(2)}(x)$ and $K_{ym}^{(2)}(x)$, the other functions $C_{xm}^{(2)}(x)$, $K_{xm}^{(2)}(x)$, $C_{zm}^{(2)}(x)$ and $K_{zm}^{(2)}(x)$ - after many mathematical operations - can also be determined.

Using the given field equations, the field components of the electromagnetic field can be derived using well-known methods. The continuity conditions for the field at the boundaries between the subareas (1) - (2), (2) - (3), (3) - (4), (4) -(5) lead to a system of integral eigenvalue equations, which, using the Ritz-Galerkin method as described for unloaded finlines in /1/, is converted into a system of homogeneous equations

$$\overleftrightarrow{F} \cdot \vec{A} = \vec{0} \qquad (20)$$

with $\overleftrightarrow{F}$ the system matrix and $\vec{A}$ the amplitude vector. This eigenvalue equation can be solved determining the system determinant

$$\det(\overleftrightarrow{F}) = 0 \qquad (21)$$

thus yielding the phase constant and the field distributions of the waves propagating on the ferrite loaded finline. For practical calculations the size of the system was truncated to a number of about 30 equations to achieve satisfactory convergence of the results.

Numerical and Experimental Results

Using the results for the fields, the power density in a cross-section of ferrite loaded fin-

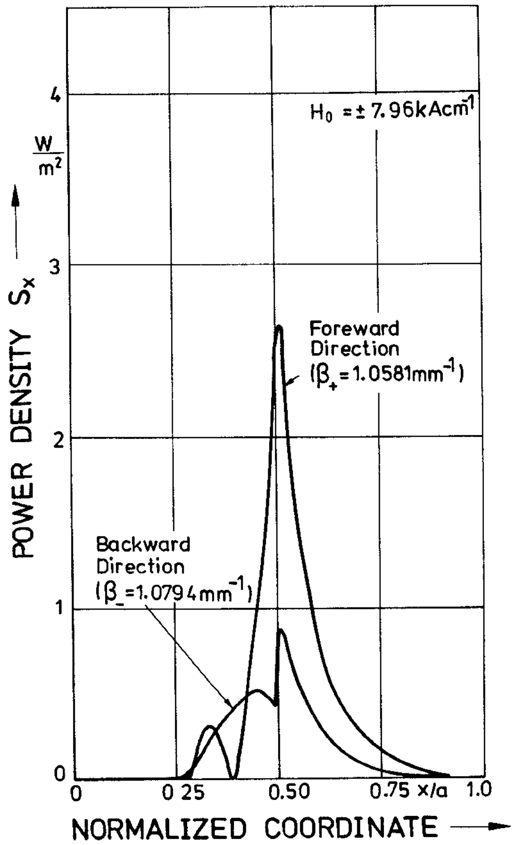

Fig. 2: Power density distribution for the finline given in Fig. 1 in x-direction versus the x-coordinate at y=0.

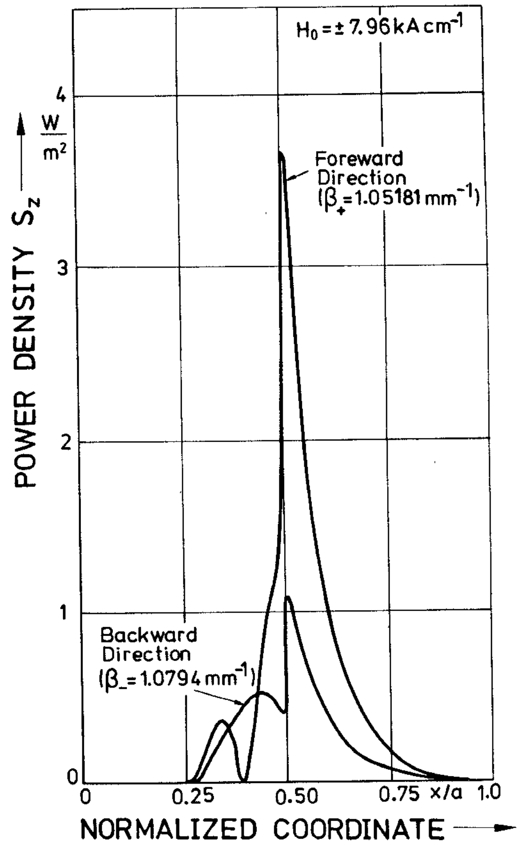

Fig. 3: Power density distribution for the finline given in Fig. 1 in z-direction versus the x-coordinate at y=0.

line can also be calculated. In Fig. 2, 3 and 4 the power density distributions are plotted at y = 0. It is seen that the ferrite sample displaces the fields of the guided waves similar to the field displacement arrangements in metal waveguide isolators.

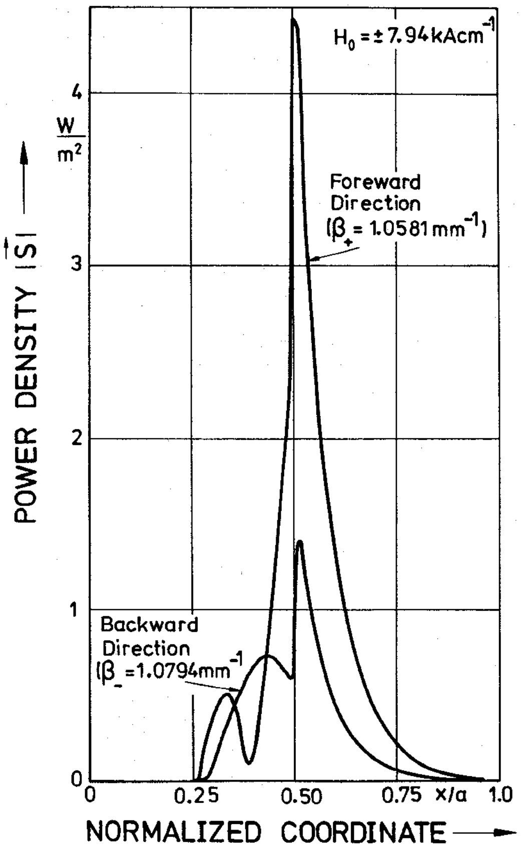

Fig. 4: Absolute values of power density for the finline given in Fig. 1 versus the x-coordinate at y=0.

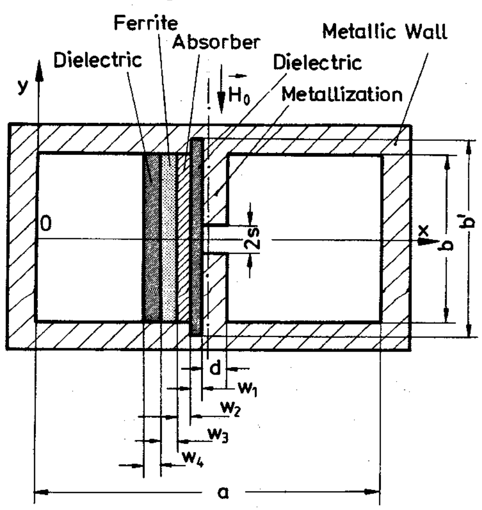

Fig. 5: Cross-section of the designed isolator in finline technique

Fig. 5 shows a composite ferrite slab-loaded finline structure designed to realize a field displacement isolator in finline technique at 28.5GHz. From the above-mentioned results, the ferrite slab was placed in the plane of circular polarization ($|H_x| = |H_z|$); its thickness was optimized, so that the backward/forward ratio is an optimum. Since so far no theoretical investigation of this structure, which is still more complicate than the structures in Fig. 1, were carried out, the determination of the optimum permittivity of the dielectric spacer and the optimum position of the absorber, were found experimentally.

In Fig. 6 the measured isolator characteristics are plotted for this isolator.

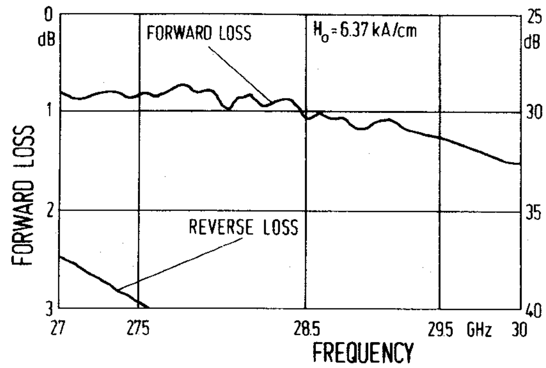

Fig. 6: The characteristics of the realized isolator in finline technique at 28.5 GHz. (w_2=0, w_3=1.6mm, w_4=1.9mm. Thin resistive sheets are placed on the left side of the ferrite sample and of the dielectric, respectively.)

It is seen that the transmission loss is better than 1.2 dB,while over the required 2 GHz bandwidth the minimum reverse loss is 39 dB. The isolator exhibits virtually the same VSWR for both forward and reverse direction, with VSWR < 1.37.

Conclusions

A rigorous expansion method for the analysis of a ferrite loaded finline has been obtained, which can be considered as a basis for the development of a field desplacement isolator in finline technique. Theoretical results fof the power density distribution show the possibilities of the method to help in the optimization of a field displacement isolator in finline technique.

This work was done in connection with a cooperation with British Telecom Research Laboratories, England.

References

/1/ Beyer, A. and Solbach, K.: 1981 IEEE MTT-S International MW Symposium Digest, 296-298

/2/ Beyer, A. and Wolff, I.: 11th Eu.M.C., Amsterdam, 321-325 (1981)

/3/ Beyer, A. and Solbach, K.: IEEE Trans. MTT-29, No. 12, 1344-1348 (1981)

/4/ Wolff, I.: Fields and waves in gyrotropic microwave structures. F. Braunschweig, Germany: Vieweg & Sohn, 1973 (In German)