# COPLANAR WAVEGUIDE SHORT CIRCUIT WITH FINITE METALLIZATION THICKNESS

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## ABSTRACT

Coplanar waveguide is an interesting transmission line alternative for integrated circuits, especially MMICs, as there is no need for substrate thinning and for via holes. For high frequencies and high integration density, the circuit dimensions are becoming very small; therefore metallization thickness may play an increasing role. In this contribution, the end effect of a coplanar waveguide short circuit is investigated using the transverse resonance technique, taking into account the influence of finite metallization thickness.

## INTRODUCTION

Coplanar waveguides show advantages compared to conventional microstrip lines. They are less dispersive and therefore favorable in broadband applications. Substrate thinning is not necessary, and there is no need for via hole techniques.
In connection with high frequencies and increasing circuit density, which becomes usual for modern MMIC design, small strip/slot dimensions create the need to account for the effects caused by the influence of finite metallization thickness. In this contribution, the end effect of a short-circuited coplanar line is computed including the influence of a finite metallization thickness.

## THEORETICAL DESCRIPTION

The structure under investigation is shown in Fig. 1. In an equivalent circuit, the end effect of the short circuit can be described by an additional piece of line of length $\Delta l$ (Fig. 1). In the case of small line dimensions and substrate thickness compared to wavelength, radiation and the generation of surface waves can be neglected. For the following analysis, the structure is enclosed by a perfectly conducting shielding. As only the excitation with the basic quasi-TEM mode is of interest, a magnetic wall is introduced in the symmetry plane of the structure.

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For configurations of this type, the transverse resonance method has proven as an effective calculation procedure. With this method, the relatively complicated planar circuit discontinuity problem is transferred into a waveguide iris problem which can be solved much easier [1]. The price to pay for is the fact that this now results in an eigenvalue problem with a homogenous system of equations; its solution requires the multiple calculation of the system determinant. The final configuration of the problem modified for the transverse resonance procedure is shown in Fig. 2.

This structure now can be decomposed into 4 sections I, II, III, and IV. A cartesian coordinate system as shown in Fig. 2 has been chosen. In each section a complete set of waveguide-type modes travelling in the z-direction is assumed.
For a complete analysis, forward and backward travelling TE and TM (H and E) waves have to be considered in each of the regions.

For example the $E_y$-components in the regions I, III, and IV result as

$$E_y^i = -\sum_{m=0}^{\infty}\sum_{n=1}^{\infty}(A_{mn}^{H^i}e^{-j\beta_{mn}^i(z-z_i)} + B_{mn}^{H^i}e^{+j\beta_{mn}^i(z-z_i)})\sqrt{\frac{\varepsilon_H}{2ab}}\frac{k_x}{\sqrt{k_x^2+k_y^2}}\sin k_x x\cos k_y y$$

$$+\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}(A_{mn}^{E^i}e^{-j\beta_{mn}^i(z-z_i)} + B_{mn}^{E^i}e^{+j\beta_{mn}^i(z-z_i)})\sqrt{\frac{2}{ab}}\frac{k_y}{\sqrt{k_x^2+k_y^2}}\sin k_x x\cos k_y y$$

$$z_I = 0,\ z_{III} = t,\ z_{IV} = t+h\ , \qquad \varepsilon_H = \begin{cases} 2 & \text{for } m=0,\ n\neq 0 \\ 4 & \text{for } m\neq 0,\ n\neq 0 \end{cases}$$

$$\varepsilon_{r_I} = \varepsilon_{r_{IV}} = 1,\ \varepsilon_{r_{III}} = \varepsilon_r$$

$$k_x = \frac{m\pi}{a},\ k_y = \frac{(2n-1)\pi}{2b},\ \beta_{mn}^i = -j\sqrt{k_x^2+k_y^2-\omega^2\varepsilon_0\varepsilon_{r_i}\mu}$$

Due to the electric walls at $z=-l_1$ and $z=l_2$, the fields in region I and IV can be represented as standing waves.

A complete field representation in region II has to account for TE and TM modes as well; thus $E_y$ takes the following form:

$$E_y^{II} = -\sum_{m=0}^{\infty}\sum_{n=1}^{\infty}(A_{mn}^{H^{II}} e^{-j\beta_{mn}^{II} z} + B_{mn}^{H^{II}} e^{+j\beta_{mn}^{II} z})\sqrt{\frac{\varepsilon_H}{x_0 w}}\frac{k_x^{II}}{\sqrt{k_x^{II^2}+k_y^{II^2}}}\sin k_x^{II} x \cos k_y^{II}(y-u)$$

$$+\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}(A_{mn}^{E^{II}} e^{-j\beta_{mn}^{II} z} + B_{mn}^{E^{II}} e^{+j\beta_{mn}^{II} z})\frac{2}{\sqrt{x_0 w}}\frac{k_y^{II}}{\sqrt{k_x^{II^2}+k_y^{II^2}}}\sin k_x^{II} x \cos k_y^{II}(y-u)$$

$$0 \le x \le x_0$$
$$u \le y \le h-s$$

$$k_x^{II} = \frac{m\pi}{x_0},\ k_y^{II} = \frac{n\pi}{w},\ \beta_{mn}^{II} = -j\sqrt{k_x^{II^2}+k_y^{II^2}-\omega^2\varepsilon_0\mu_0}$$

The slotwidth w is very small compared to the wavelength, and the end effect of the short circuit is an integral quantity due to stray fields mainly outside the slots. Therefore, for a first approach, in the slot no field depending in the y-direction is taken into account. This means that for a good approximation only $H_{mo}$-waves are assumed in region II, leading to a considerable reduction in computing time.

$$E_y^{II} = -\sum_{m=1}^{\infty}(A_m^{II} e^{-j\beta^{II} z} + B_m^{II} e^{+j\beta^{II} z})\sqrt{\frac{2}{x_0 w}}\sin k_x^{II} x$$

$$H_x^{II} = +\sum_{m=1}^{\infty}(A_m^{II} e^{-j\beta^{II} z} - B_m^{II} e^{+j\beta^{II} z})\frac{1}{Z_m^{II}}\sqrt{\frac{2}{x_0 w}}\sin k_x^{II} x$$

$$k_x^{II} = \frac{m\pi}{x_0},\ \beta_m^{II} = -j\sqrt{k_x^{II^2}-\omega^2\mu\varepsilon},\ Z_m^{II} = \frac{\omega\mu}{\beta_{mn}^{II}}$$

Using mode-matching methods at the interfaces between the regions and eliminating the amplitude coefficients of regions I, III and IV, the following homogeneous system of equations results:

$$\vec{\vec{C}} \cdot \begin{pmatrix} \vec{A} \\ \vec{B} \end{pmatrix} = 0$$

$$\vec{A} = (A_1, A_2, \ldots, A_M),\ \vec{B} = (B_1, B_2, \ldots, B_M)$$

Basically, an infinite number of modes is necessary; for numerical calculations, the number of modes is truncated.
M gives the number of modes which have to be taken into account in region II. A considerably higher number of modes have to be considered in regions I, III, and IV.
Solving this eigenvalue problem requires the solution of det(C)=0 as a function of the length of the coplanar line section $x_0$ (see Fig. 2). Physically, this corresponds to resonances of multiples of $\lambda/2$ on the coplanar line.
As the resulting length $x_0$ depends on both end effect and propagation constant of the coplanar line, another calculation of this type has to be performed. If the coplanar line is extended up to the left side shielding (i.e. $x_0=a$, Fig. 2), a considerable reduction in computing time is achieved, as in x-direction, only modes with $k_x=\pi/a$ have to be considered in this case.
This calculation directly gives the propagation constant, and the end effect can be extracted easily from the first result.
To ensure accurate results, convergence investigations have been made in relation to the mode numbers in the different regions and to the dimensions of the shielding.

## NUMERICAL RESULTS

A number of calculations have been made, evaluating both propagation constant and end effect.
For the propagation constant, these agree with data published in [2], [3]; in these references, metallization thickness was included as well. For the end effect, results exist only for infinitely thin metallization [4].
Fig. 3 shows the dispersion of the normalized guide wavelength for different metallization thickness for a coplanar line on GaAs.
The dependence of the end effect on metallization thickness is shown in Figs. 4 and 5 for two examples, one for GaAs, the other for RT-Duroid substrate material.
For very small values of t, the end effect $\Delta l$ is nearly constant, whereas for $t>1\mu m$, $\Delta l$ is decreasing rapidly. A typical metallization thickness for circuits on GaAs is a few $\mu m$ and $17\mu m$ or even more on RT-Duroid, respectively. In these cases, therefore the effect of metallization thickness can no longer be neglected.
For smaller line dimensions, this is even shifted to smaller values of t.

### REFERENCES


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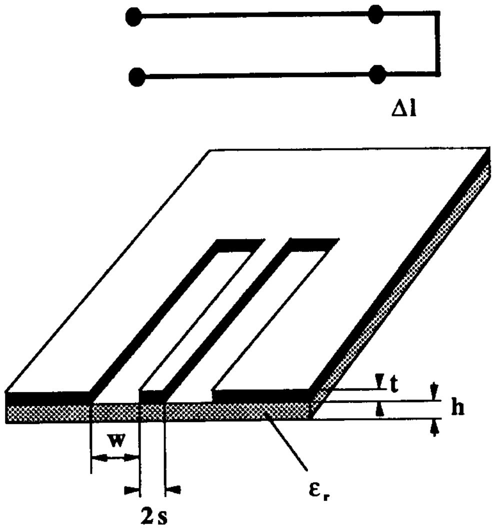


Fig. 1: Coplanar waveguide short circuit

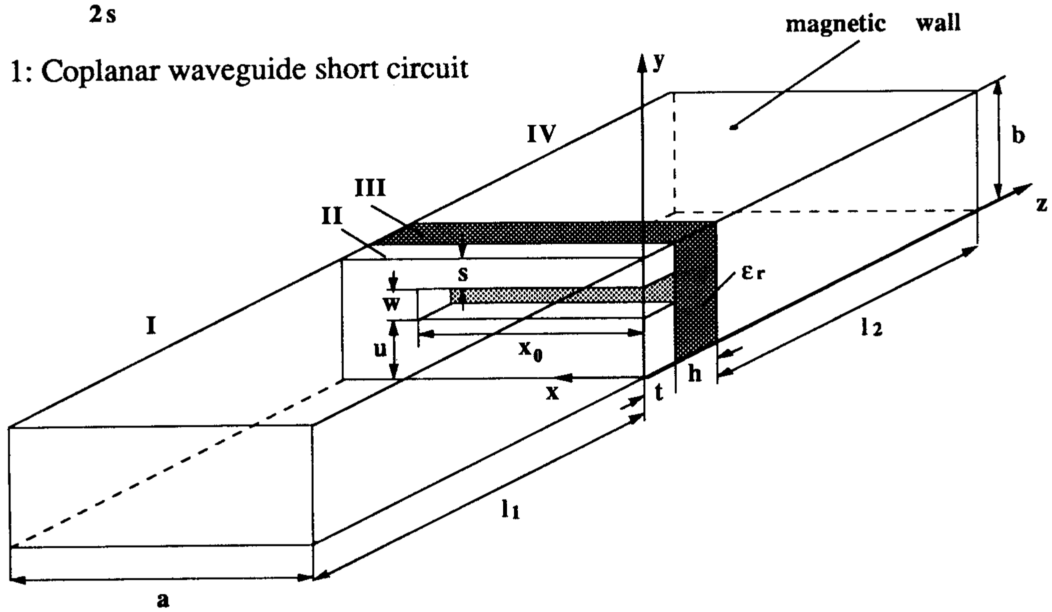


Fig. 2: Modified configuration for analysis

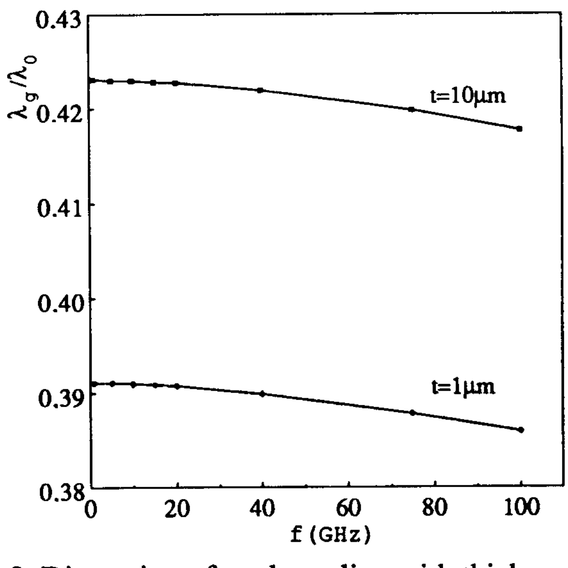


Fig. 3: Dispersion of coplanar line with thick metallization

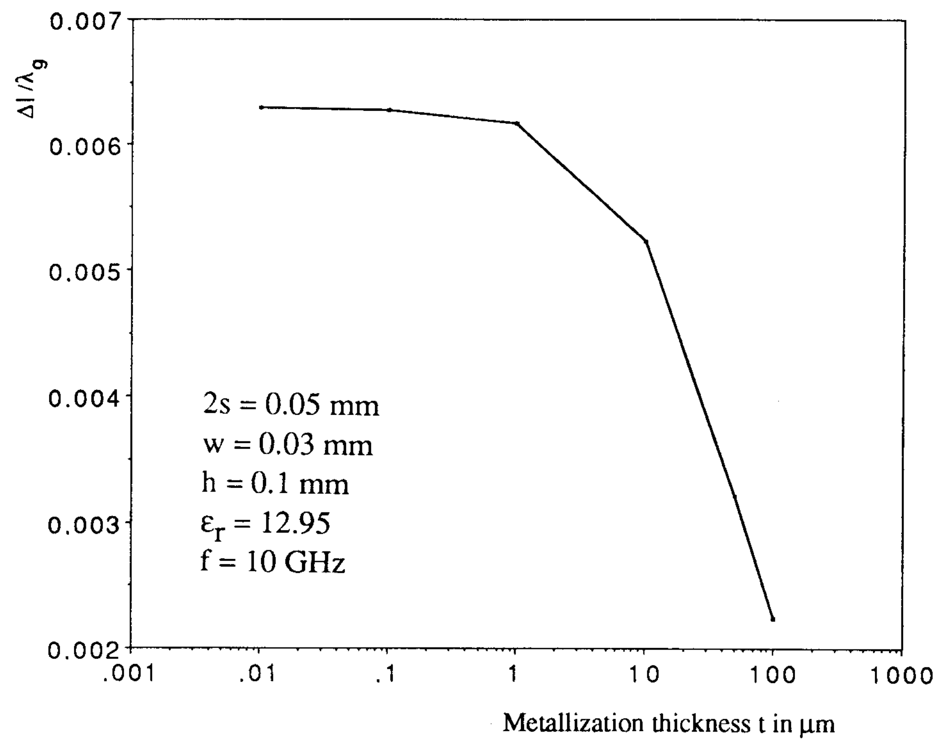


Fig. 4: End effect of short-circuited coplanar line (RT-Duroid)

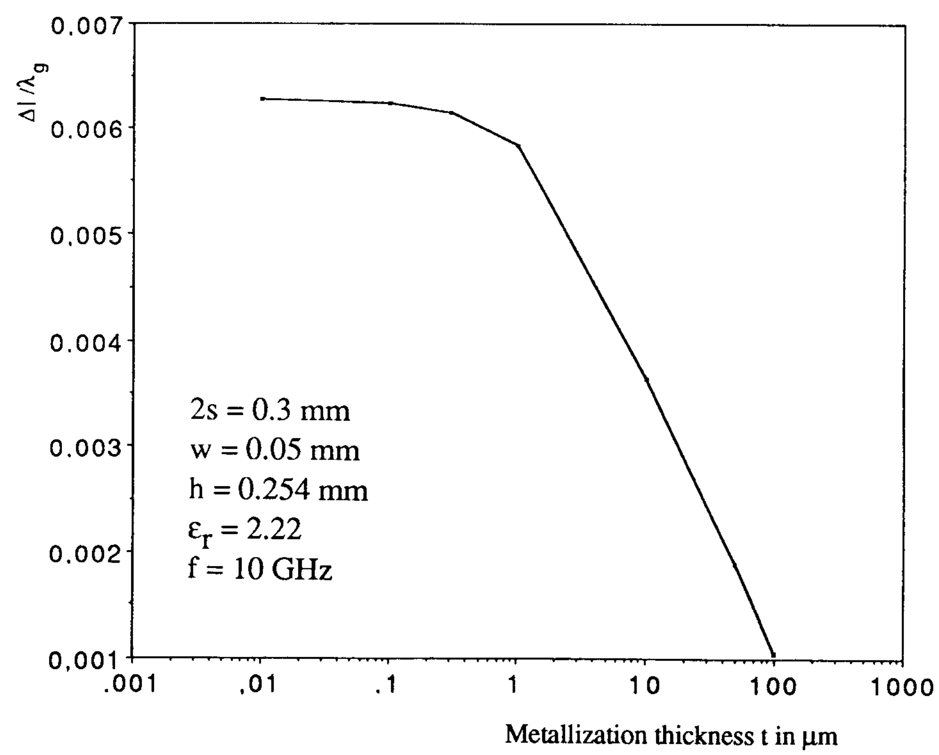


Fig. 5: End effect of short-circuited coplanar line (GaAs)