Propagation Characteristics of Schottky Contact Suspended Slow-Wave Microstrip Line

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***Abstract*—The single-layer reduction (SLR) model computes the normalized phase constant (β/β_0), dielectric loss (α_d), and conductor loss (α_c) for the Schottky contact slow-wave microstrip (SCSM) line with accuracy about 2.0% for β/β_0 and within 0.01 dB/mm for the total loss ($\alpha_t = \alpha_d + \alpha_c$) as compared against the experimental results. The SLR model has been further used to analyze the normal and abnormal characteristics of a proposed Schottky contact suspended slow-wave microstrip (SCSSM) line with 22% increase in β/β_0 over the normal SCSM line. The SCSSM line could be useful in the lower range of RF for the development of compact components.**

***Index Terms*—MICs, Schottky contact, suspended Schottky contact microstrip line.**

I. Introduction

In the present work, propagation characteristic parameters, i.e., the normalized phase constant (β/β_0) and the total loss (α_t) of the Schottky contact slow-wave microstrip (SCSM) line, have been computed by the single-layer reduction (SLR) formulation [1], [2]. The theoretical investigators of SCSM line have compared their computed results against the experimental results of Jager and Rabus [3] only for the normalized phase constant. The experimental results for the total loss of such lines present by Jager *et al.* [4] have not been compared against any theoretical model. However, we compare the computed results for both the normalized phase constant and the total loss against the experimental results of Jager *et al.* with good agreement.

Further, the voltage-dependent SCSM line has been extended to a new Schottky contact suspended slow-wave microstrip (SCSSM) line, as shown in Fig. 1(a). Normally, for a standard suspended microstrip line, both the normalized phase constant and the dielectric loss decrease with increase in the air gap and the line becomes less dispersive with extended bandwidth of nondispersive part of normalized phase constant. However, we also report in this work that, in the case of the proposed SCSSM line, the propagation behavior is opposite that of the standard suspended microstrip line, i.e., for the SCSSM line, the normalized phase constant, and the dielectric loss increase, whereas the bandwidth decreases with increase in the air gap.

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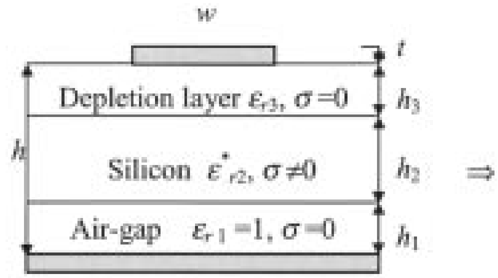
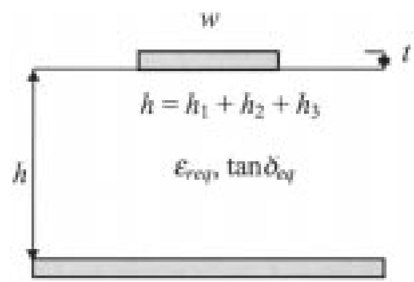


(a)



(b)

Fig. 1. Schottky contact suspended microstrip line. (a) Schottky contact suspended microstrip slow-wave line and (b) equivalent single-layer microstrip line.

II. SLR Model

The multilayer structure shown in Fig. 1(a) can be reduced to the equivalent single-layer structure shown in Fig. 1(b) by using the concept of SLR formulation [1], [2]. The quasistatic complex relative effective permittivity $\varepsilon^*_{\rm eff}$ of the structure shown in Fig. 1(a) can be obtained from

$$\varepsilon^*_{\rm eff} = \frac{C^*}{C_0} = \varepsilon'_{\rm eff} - j\varepsilon''_{\rm eff} \tag{1}$$

where C_0 is the line capacitance of the same structure on the air substrate. The complex line capacitance C^* of SCSSM line is determined by the following variational expression

$$\frac{1}{C^*} = \frac{1}{\pi\,\varepsilon_0}\int_0^\infty \frac{\left[\frac{f(\tilde{\beta})}{Q}\right]^2}{\beta Y^*}d\beta. \tag{2}$$

In (2), $f(\tilde{\beta})$ is the cubic charge distribution function in the Fourier domain [1], Q is the total charge on the strip conductor, and β is the Fourier variable. Y^* showing the Green's function of the three layer structure is given by (3), shown at the bottom of the next page.

In (3), h_1 is the air gap, h_2+h_3 is the doped silicon substrate, and h_3 is the voltage-dependent depletion depth of the SCSSM line given by

$$h_3 = \left[\frac{2\,(V+\nu_d)\,\varepsilon_r\,\varepsilon_0}{n\,e}\right]^{1/2} \tag{4}$$

where

- V applied reverse dc bias voltage;
- ν_d diffusion potential of the Schottky barrier;
- e charge on electron [$1.602\,19 \times 10^{-19}$ C];
- ε_r relative permittivity of substrate [For silicon $\varepsilon_r = 12.0$];
- ε_0 permittivity of free space [8.854×10^{-14} F/cm];
- n doping concentration of the carrier per cubic cm.

The SLR-formulation reduces the original three layer SCSSM line shown in Fig. 1(a) into an equivalent single-layer microstrip structure as shown in Fig. 1(b) with equivalent relative permittivity and equivalent loss-tangent given by [1]

$$\varepsilon'_{\text{req}} = \frac{[\varepsilon'_{\text{eff}}-1]}{q}+1 \tag{5}$$

$$\tan\delta_{\text{eq}} = \frac{\varepsilon''_{\text{eff}}}{\varepsilon'_{\text{eff}}+q-1}. \tag{6}$$

The filling factor q is obtained from the Wheeler's formula. The dielectric loss (α_d) for the equivalent single-layer microstrip line can be computed by using the standard expression [1]. Likewise, the conductor loss (α_c) of SCSSM line can also be computed by the SLR formulation [2]. The total loss α_t is summation of dielectric and conductor losses.

III. Results and Discussion

The structure shown in Fig. 1(a) can be reduced to the SCSM line by taking $h_1 \to 0$. The line has $\varepsilon_{r2} = \varepsilon_{r3} = 12.0$, $h_2 + h_3 = 200$ μm, $w = 100$ μm, $\rho = 0.1$ and 1.0 Ω-cm, thickness of strip conductor and ground plane, $(t) = 0.003$ mm, $\nu_d = 0.5$ V, and bias voltage $V = 0$. Fig. 2 shows deviation of about 2% for the normalized phase constant (β/β_0) computed by the SLR formulation against the experimental results of Jager and Rabus [3]. They have further provided the experimental results [4] for the total loss (α_t) on SCSM line for $(h_2+h_3) = 40$ μm, $w = 170$ μm, $\rho = 10$ Ω-cm, $\nu_d = 0.5$ V, and the reverse bias voltage $V = 0, 1, 2, 4$ and 12 volts. For $V = 0$, Fig. 3 compares the total loss (α_t) computed by the SLR formation within 0.01 dB/mm against the experimental results of Jager *et al.* We have also carried out such comparisons for other bias voltages with even better agreement with their experimental results.

Figs. 2 and 3 also present results on the normalized phase constant (β/β_0) for SCSSM line with several air gaps (h_1). Both the figures clearly show a transition point for the normal and

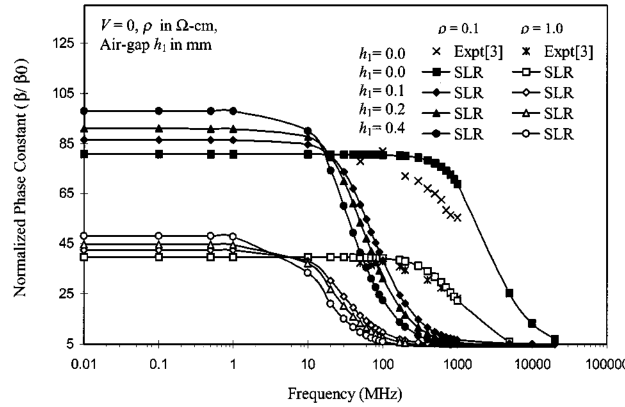


Fig. 2. Normalized phase constant with frequency.

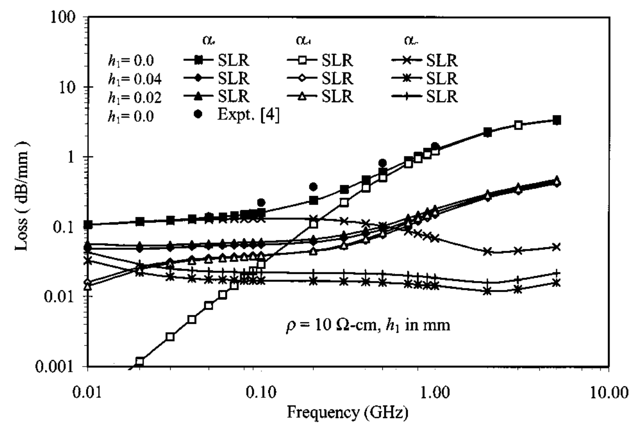


Fig. 3. Loss with frequency of the Schottky contact suspended slow-wave microstrip line.

abnormal behavior of the SCSSM line. Fig. 2 shows that in the slow-wave region, there is a significant increase (22%) in β/β_0 with increase in air gap, whereas in the transition and dielectric mode region, β/β_0 decreases with increase in air gap that is the normal behavior of a suspended microstrip line. The 22% increase in β/β_0 is not the optimum one. It can be optimized for the given substrate. We have further observed that in the slow-wave region, for a fixed air gap, β/β_0 for the SCSSM line decreases with increase in the reverse bias voltage. This is like normal behavior of SCSM line. This clearly shows the presence of two Maxwell-Wagner type interfacial polarization, one at the interface of the depletion layer (h_3) and doped silicon substrate (h_2) and another at the interface of doped silicon substrate (h_2) and air gap layer (h_1). Interestingly, in the first case, increase in depletion depth with reverse bias voltage decreases β/β_0, whereas in the second case, increase in air gap increases β/β_0.

$$Y^* = \varepsilon^*_{r3}\left[\frac{\varepsilon^*_{r2}\left\{\dfrac{\varepsilon^*_{r1}+\varepsilon^*_{r2}\tanh(\beta h_1)\,\tanh(\beta h_2)}{\varepsilon^*_{r1}\,\tanh(\beta\,h_2)+\varepsilon^*_{r2}\,\tanh(\beta\,h_1)}\right\}+\varepsilon^*_{r3}\,\tanh(\beta\,h_3)}{\varepsilon^*_{r3}+\varepsilon^*_{r2}\left\{\dfrac{\varepsilon^*_{r1}+\varepsilon^*_{r2}\tanh(\beta h_1)\,\tanh(\beta h_2)}{\varepsilon^*_{r1}\,\tanh(\beta\,h_2)+\varepsilon^*_{r2}\,\tanh(\beta\,h_1)}\right\}\,\tanh(\beta\,h_3)}\right]+1 \tag{3}$$

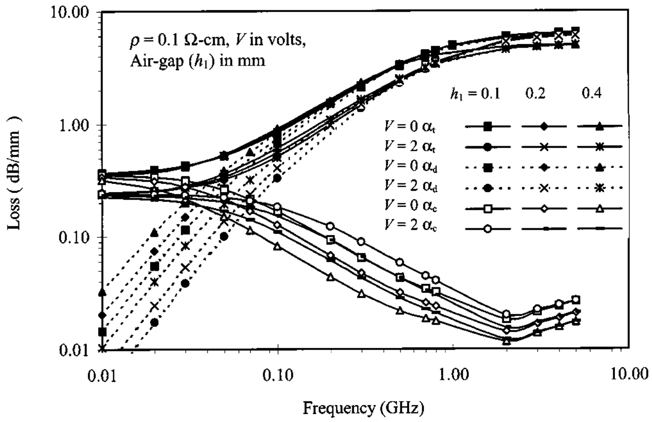


Fig. 4. Loss with frequency of the Schottky contact suspended slow-wave microstrip line.

Figs. 3 and 4 show such normal and abnormal behaviors in the case of dielectric loss and total loss. The conductor loss does not show significant change in behavior with air gap. The transition point separating the abnormal-normal behavior of the SCSSM line is determined by the resistivity of substrate, reverse bias voltage, air gap, and frequency.

IV. Conclusion

The quasistatic SLR model can compute accurately the normalized phase constant (β/β_0) and total loss of the Schottky contact and MIS microstrip line. The model can also handle more dielectric layers. We have further presented a new SCSSM line with higher value of phase constant. This structure could be useful in designing compact components at the lower end of RF-frequency band.

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References

[1] A. K. Verma and A. Bhupal, “Dielectric loss of multilayer microstrip lines,” *Microwave Opt. Tech. Lett.*, vol. 17, pp. 368–370, Apr. 1998.

[2] ——, “Conductor loss of multilayer microstrip line using the single-layer reduction formulation,” *Microwave Opt. Tech. Lett.*, vol. 19, pp. 20–24, Sept. 1998.

[3] D. Jager and W. Rabus, “Bias-dependent phase delay of Schottky contact microstrip line,” *Electron. Lett.*, vol. 9, pp. 201–202, May 1973.

[4] D. Jager, W. Rabus, and W. Eickhoff, “Bias-dependent small-signal parameters of Schottky contact microstrip lines,” *Solid-State Electron.*, vol. SSE–17, pp. 777–783, Aug. 1974.