A Coplanar Millimeterwave Resonator on Silicon

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Abstract

A CPW resonator in completely coplanar technique is built on grounded silicon substrate and the input impedance is investigated experimentally and numerically. The passive planar structure is extensively studied using a space-domain full-wave analysis method. The resonator is fed by a coplanar transisson line through a capacitive gap and shows a marked resonance at the fundamental coplanar waveguide mode. Calculated data and measured data agree better than 5%.

Introduction

Future applications of silicon monolithic millimeterwave integrated circuits (SIMMWICs) demand the integration of complete millimeter transmitters and receivers on a single chip [1,2]. The very narrow placement of active devices as well as passive devices results in a strong coupling of the electromagnetic fields and requires in the case of planar resonators a straight and economical oscillator design. In the state-of-the-art monolithic millimeterwave integrated circuits (M^3ICs) the coplanar waveguide (CPW) offers several advantages over the conventional microstrip line [3,4]. It affords the attractive features of reducing interline coupling and being usable on thick substrates without via holes. To calculate these structures electromagnetic full wave models are required in order to include effects such as dispersion, radiation and coupling.

Model

A dynamical radiation model based on the surface current $\mathbf{J}_s$ is used to analyse passive planar structures embedded into stratified media [5]. A so-called mixed-potential form is derived, in which the induced charge density q_s is explicitly accounted for. This is accomplished by introducing fictious vector and scalar potentials which, in general, do not belong to the Lorentz gauge [6].

$$\mathbf{e}_z \times \mathbf{E}^e = Z_s \mathbf{J}_s + \mathbf{e}_z \times \left(j\omega \int_{S_0} \overline{\overline{G}}_{\mathbf{A}} \mathbf{J}_s \, dS' + \nabla \int_{S_0} G_V q_s \, dS' \right). \tag{1}$$

Eq.(1) is the Mixed Potential Integral Equation (MPIE) with the electric surface current to be the sole unknown. Because there is no analytical solution available, the functional must be treated with numerical methods. The MPIE is an integral equation method that matches the surface current distribution to a field distribution fulfilling the boundary conditions by means of dyadic Green's functions in the space domain. The model takes ohmic and dielectric losses as well as radiation and surface-wave losses into account.

Calculation

The Method of Moments (MoM) is applied to convert the integral equation into a matrix algebraic equation [7]. Using the subsectional basis function approach rooftop-type basis functions for the current distribution are defined above equivalent spaced subdomains and uni-dimensional rectangular pulses are chosen as test functions for the method of moments procedure. The resulting system matrix of the linear equation system

$$\left(\begin{array}{c|c} \overline{\overline{C}}^{xx} & \overline{\overline{C}}^{xy} \\ \hline \overline{\overline{C}}^{yx} & \overline{\overline{C}}^{yy} \end{array} \right) \left(\begin{array}{c} \mathbf{I}_x \\ \hline \mathbf{I}_y \end{array} \right) = \frac{1}{jZ_0} \left(\begin{array}{c} \mathbf{V}_x^{(e)} \\ \hline \mathbf{V}_y^{(e)} \end{array} \right) \tag{2}$$

is complex and symmetric and exhibits the rotational and

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translational symmetries of the Sommerfeld-type Green's functions. Taking advantage of these relations one can map the whole MoM matrix onto the first row of the matrix. This yields a simple algorithm which reduces the computational storage of the MoM-matrix to a minimum [8]. The computation time for the solution of this type of matrices can be kept within applicable limits by the implementation of a highly vectorized conjugate gradient algorithm on a Cray computer [9]. Hence the calculation of arbitrary shaped geometries discretized by ten thousand and more equivalent subsections is possible.

Design, Fabrication, Measurement

At the very beginning the parameters for the design of the coplanar waveguide resonator were taken from [10]. Assuming that the length of the waveguides is of the same order of magnitude compared with the wavelength of the transmitted signal, these waveguides are electrically long and transmission line theory can be applied. The reactance of the resonator seen by the coplanar feeding line is made up by the reactance of two shunt-connected shorted coplanar lines. But if, in addition, the line is lossy, it attenuates the signal and the approximate transmission line solution fails. The amplitude of which decreases while travelling along the line. Because attenuation is frequency dependent, the shape of the signal is modified or distorted. Therefore propagation characteristics of higher-order modes and hybrid modes have to be included into the analysis and the required design parameters have to be taken from new models. Such passive planar distributed resonator structures can't be successfully simulated before one proceeds to a more sophisticated analysis method, for example an integral equation method.

Fig.1 shows the schematic of a gap-coupled CPW resonator with its dimensions. The required resonance frequency of 30.5 GHz is produced by a $\lambda/2$-CPW resonator of the dimensions l=1.83mm, w=0.10mm and s=0.14mm. The resonator is fed by a tapered CPW transmission line l'=0.34mm, w'=0.05mm and s'=0.07mm, designed to be compatible with common used wafer probes. The reference plane of the calculation and measurement is at the beginning of this line. The coupling takes place through a gap that models

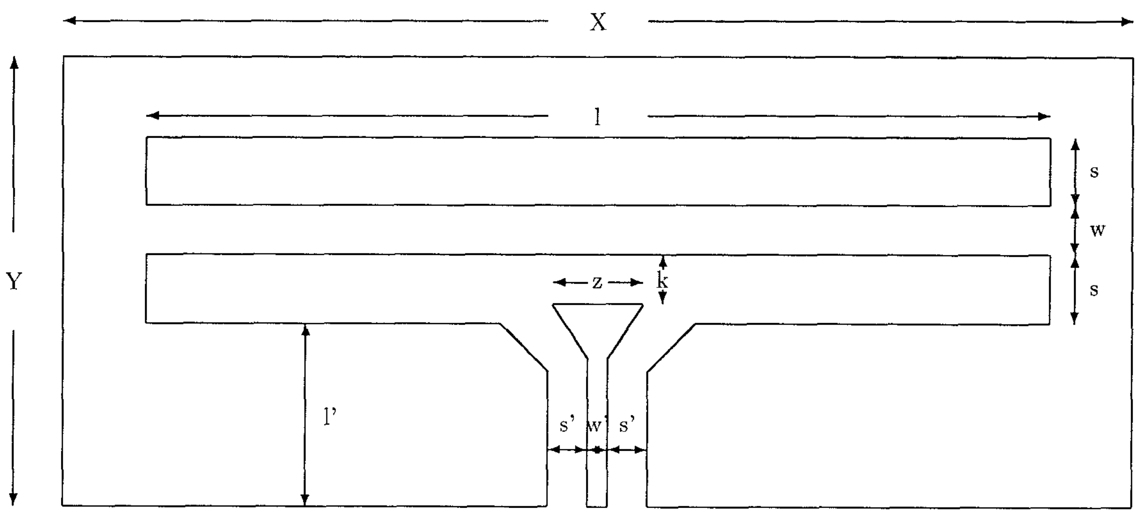

Figure 1: Geometry of the coplanar resonator

a capacity strongly dependend on the length z=0.17mm of the coupling zone and the coupling gap spacing k=0.08mm. The circuit is fabricated on 500μm thick grounded high-resistivity ($\rho > 5 \cdot 10^3$) silicon substrate (ϵ_r=11.67) and is located within a rectangular patch of the size X=2.17mm and Y=0.94mm. The conductor thickness is of 4μm.

To evaluate the input impedance of the CPW resonator numerically the planar structure has to be discretized. The patch of Fig.1 is inscribed in a rectangle of the sides X,Y and is again divided by a grid of straight lines into $N_x \times N_y$ equivalent rectangular subsections. The real geometry of the passive planar structure is then replaced by a staircase-approximation. A problem to deal with is to match the dimensions of the real structure geometry to the simulated one. Within the limits of fabrication of printed circuits, the technological resolution of a edge or a gap for example, one has to find the suitable discretization. Thus the CPW resonator was simulated by an equally spaced grid and a staircase-approximation, by a total of 2916 grid cells, 2818 basis functions in x-direction and 2684 basis functions in y-

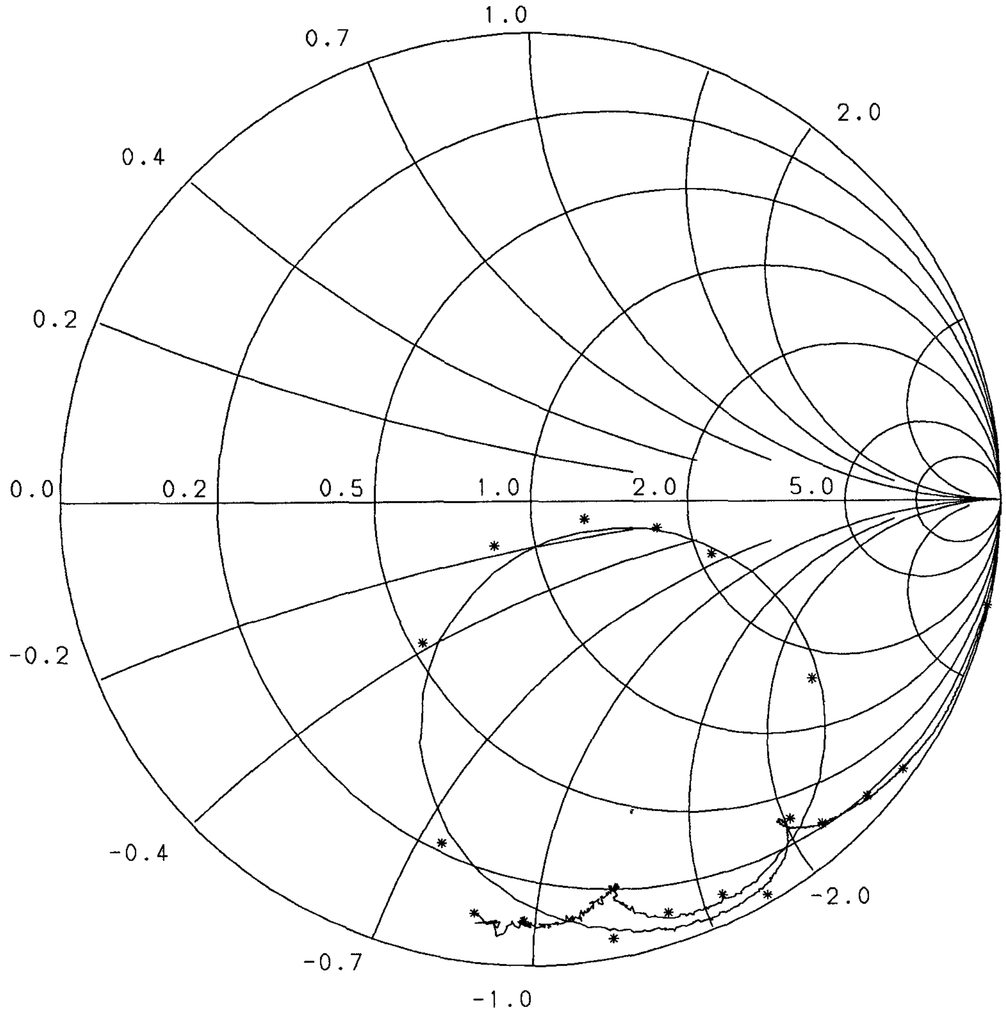

Figure 2: Results (Z_w=50Ω): - measurement (6GHz-40GHz), * simulated data

direction respectively.

The fabricated resonator was on wafer measured in the frequency range from 6 to 40 GHz using an HP8510 and LRM Calibration. In Fig.2 the measured and simulated resonator structure shows three resonances in the frequency range up to 40 GHz. The most sensitive coupled resonance is causedby the coplanar mode. The one below the coplanar resonance is due to the coupling into the slotline mode. This one can be suppressed successfully by using airbriges or bondwires connecting the grounded planes at the resonator feeding coplanar line. The parasitic resonance with the higher resonance frequency is supposed to be excited by the measurement setup. The simulated data show excellent agreement to the measured data.

Conclusion

An integral equation technique is used in the space domain to analyse a complex $\lambda/2$-CPW resonator on silicon substrate. The planar resonator is coplanar fed through a capacitive gap and shows a marked resonance at the basic coplanar waveguide mode. With the usage of a equally spaced discretization grid one not only saves the maximum of computational storage for the numerical simulation but also can implement highly vectorized algorithms. This way there are no more limits to analyze planar structures with five thousand and more basisfunctions. The almost ever occuring additional resonances, the slotline modes, as well as higher order modes can be verified now.

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