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Proposal of a Simple MEMS Phase Shifter Based on Effective Dielectric Constant Modulation

Daisuke Nakano[1], Masayuki Mori[1], Koichi Maezawa[1], Hiromu Ishii[2], and Hiroya Andoh[3]

[1]University of Toyama
3190, Gofuku, Toyama 930-8555, Japan
Phone: +81-76-445-6725 E-mail: maezawa@ieee.org
[2] Toyohashi University of Technology
1-1 Hibarigaoka, Tempaku-cho, Toyohashi, Aichi, 441-8580, Japan
[3] National Institute of Technology, Toyota College
2-1 Eiseicho, Toyota, Aichi, Japan, 471-8525, Japan

Abstract

A simple MEMS phase shifter consisting of a coplanar wave guide and a movable ground plane was proposed. The operating principle is based on the effective dielectric constant modulation. The operating principle was first confirmed by electromagnetic analysis. Then, it is demonstrated by a simple experiment using fixed ground planes.

1. Introduction

A phase shifter is an important component in micro and millimeter wave systems. It is especially used in phased array antenna. Among various types of phase shifters, distributed MEMS transmission line (DMTL) phase shifters offer lower insertion loss, high linearity over a large bandwidth [1]. The DMTL phase shifter is based on the transmission line periodically loaded with movable MEMS bridges to vary the line capacitance. The propagation velocity of the line and thus the signal phase between the input and the output are controlled by the bridge position. The cutoff frequency of the DMTL is determined by the Bragg frequency, which is in inverse proportion to the propagation time of the unit cell. Higher density and smaller bridges are required for increasing the cutoff frequency. In this paper, we propose a phase shifter based on a novel operating principle, which is promising for higher frequency applications.

2. Device Structure and Operating Principle

Figure 1 illustrates the configuration of the novel phase shifter. This phase shifter consists of a coplanar waveguide (CPW) and a movable ground plane on it. The distance from the CPW and the ground plane determines the signal propagation velocity.

The operating principle is explained by two different points of view. First, it is explained by the change of the effective dielectric constant. When the ground plane is far from the substrate surface, the effective dielectric constant of the CPW is approximately a half of that of the substrate, because a half of the electric field is in the substrate, and the other half is in the air. When the ground plane is approaching the CPW, the electric field between the signal line and the ground plane is increasing, which reduces the effective dielectric constant. Consequently, the signal propagation velocity ($v = 1/\sqrt{\varepsilon_{\mathrm{eff}}\mu}$) is increasing when the ground plane is approaching. On the other hand, this velocity change is explained by the inductance reduction when the ground plane is approaching to the CPW. The magnetic field around the signal line of the CPW is blocked by the ground plane, which decreases the inductance. Again, this leads to higher signal propagation velocity. These two explanations are identical, and view same physics from the different sides. It should be noted that the dependence of the signal propagation velocity on the ground plane position is opposite to that on the bridge position in the DMTL, where the velocity decreases when the bridge is approaching to the signal line.

This type of the phase shifter has various advantages beyond the DMTL phase shifter. First, this is made of a very simple structure, and its operation frequency is not limited by the Bragg frequency. Next, this can handle large induced current densities at high RF power, which has been a significant problem in the DMTL using thin and narrow metal bridges [2]. Moreover, analog phase control is possible, if the ground plane position can be controlled continuously. It is possible, for example, by using a comb drive actuator.

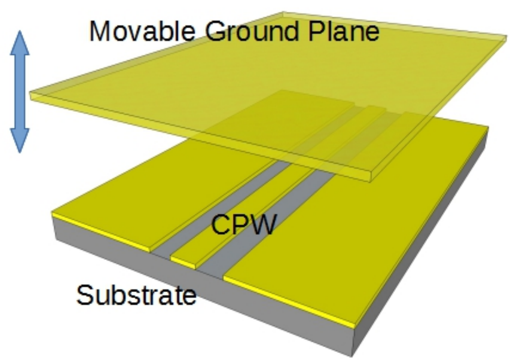

Fig. 1. Basic concept of the novel phase shifter.

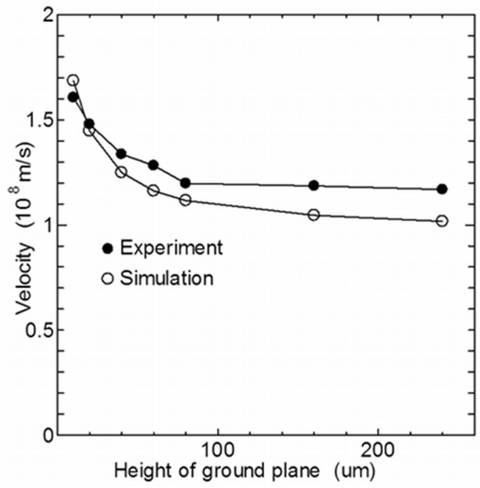

Fig. 2. Signal propagation velocity as a function of the ground plane height.

3. Simulation Results

We carried out electromagnetic analysis using EMPro (Keysight Technology) to demonstrate the operating principle. Figure 2 shows the signal propagation velocity dependence on the ground plane height. The substrate is GaAs, and the CPW has 90 μm wide signal line and 60 μm gaps. The simulation result demonstrates that the velocity increases when decreasing the ground plane height. This dependence is in contrast to the bridge height in the DMTL phase shifter. A large change of about factor 2 was obtained from 100 μm to 5 μm.

To analyze the operating principle, the electric field around the CPW is calculated and shown in Fig. 3. The electric field concentrates between the signal line and the ground plane, when the ground plane is approaching the CPW. This indicates the reduction of the effective dielectric constant.

On the other hand, Fig. 4 shows the magnetic field around the CPW. The magnetic field is blocked by the ground plane, and it is weaken when the ground plane is close to the CPW. This indicates the lower inductance, and thus higher velocity. Consequently, the simulation results confirm the proposed operation.

4. Experiments

Next, we tested the operating principle by a simple experiment. We used a GaAs substrate having a CPW pattern. The ground planes were fabricated with Si substrate coated with evaporated Au. Then the ground planes were set on the CPW substrate with spacers having various thicknesses. S-parameters were measured up to 40 GHz, and the propagation velocity was calculated. The experimental results are also plotted in Fig.2. The propagation velocity increases when decreasing the ground plane height, and it agrees well with the simulation result.

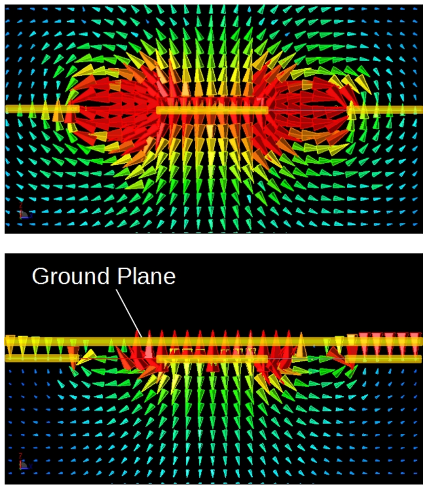

Fig. 3. Electric field obtained by the simulation. The ground plane heights are 240 um and 10 um for the upper and lower figures, respectively.

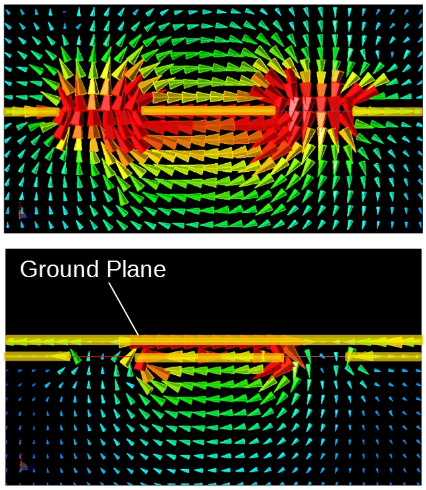

Fig. 4. Magnetic field obtained by the simulation. The ground plane heights are 240 um and 10 um for the upper and lower figures, respectively.

4. Conclusions

We have proposed a novel phase shifter based on effective dielectric constant modulation. The basic operation has been demonstrated by the electromagnetic simulation and the simple experiment.

Acknowledgements

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