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COMMUNICATIONS

MICROSTRIP RESONATOR WITH SLOTTED GROUND PLANE FOR DETECTING LATERAL POSITION

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A new type of microwave position sensor is introduced. It is a microstrip stub resonator with slotted ground plane under the stub. It produces frequency-modulated signal with frequency corresponding to covering of the slot in the ground plane. The sensing is performed by sliding the metal plate over the slot. The structure is simple, low fabrication cost and compact. It is without multilayers, coupling, via holes, air bridges, active or discrete components.

Keywords: microwave, lateral position sensor, microstrip, slotted ground plane

1 INTRODUCTION

In recent times, microwave sensors are becoming common and important sensors in application [1, 2]. Microwave resonator sensors are one type of them. They are sensitive, able to survive overdrives and their signal can be directly transmitted over a distance to be evaluated at a safe location [2]. In question of technology, planar printed microwave structures are easy for fabrication, cheap and have compact design. Microstrip is the most common type of planar printed microwave structure. They are, also, widely applied in sensor technology [3–13].

Microstrip resonator sensors are founded on tuning capability of a microstrip resonator. Such resonant sensors are based on: defect in a periodic structure [3, 4, 12], coupled resonators [5, 6, 9], defected ground structure (DGS) [9–13] and shunt stub resonators [7, 8, 13].

As revealed in the previous text, one type of microstrip resonator is shunt stub. Frequency of stop-band minimum depends on electrical length of the stub. To control the frequency of stop-band one need to control the electrical length of the stub. In [7, 8, 13] the electrical length depends on dielectric properties of the measured fluid.

One way to control microstrip structure is etching in the ground plane, known as defected ground structure — DGS. Mentioned technique consists of etching pattern in metallization of the ground plane of a microstrip structure. It is useful and common for producing microwave filters [14]. Controlling (modifying) DGS one can control characteristics of a microstrip transmission line. That feature is applied in number microwave sensors [9–13]. Papers in [10, 11] represent microstrip with etched ground plane in the shape of complementary split-ring resonator and applied for material and crack characterization. Periodic DGS in the shape of circles [12] is also used for material characterization. In [9] moving ground metallization layer located under the substrate is used for controlling microstrip resonators. In [13] a slot, the simples type of DGS, is used for material characterization.

Unfortunately, only DGS structure in [9] can be characterized as a position sensor. Thickness of a narrow air gap between ground electrode and substrate is controlled by piezo-actuator. Maximum of air gap, $100\,\mu$, is very small. Other position sensors are without DGS. Periodic structures with defect in [3, 4] can also be characterized as position sensors but only for vertical distance below 1 mm. Microstrip displacement sensors are presented in [5, 6]. They are based on coupling influence on microstrip line split ring resonator. It is important to say that the operation principle of the sensors [3–5, 9] is based on resonance frequency, rather than variation in the depth like in [6]. In that way, the sensors are generally immune to the environmental noise, which is very important and will be applied in this paper.

In this paper a microstrip stub resonator with slotted ground plane under the stub is introduced. Advantage of the stub solution against the case with only one microstrip line is that the sharp bandstop always exists in the stub solution. It is based on resonance frequency generally immune to the environmental noise, which is very important. Slot is the simplest type of the DGS. Controlling (modifying) slot one can control the frequency of stop-band minimum. In this paper, it is modification of the slot by covering part of the slot with a metal plate. The covering of the slot induces frequency shift of the stop-band minimum. It produces frequency-modulated signal with frequency corresponding to position of the metal plate. The sensing is performed by sliding the metal plate over the slot. Proposed structure is simple, low fabrication cost and compact. It is without multilayers, coupling, via holes, air bridges, active or discrete compo-

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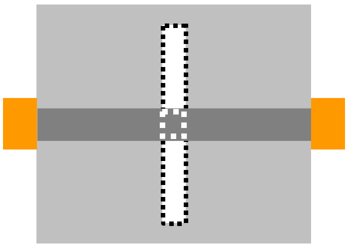

Fig. 1. Microstrip line (black) with a slot in the ground plane (gray). White dots represent the slot beneath microstrip line. Slot is 0.7 mm wide and 31.6 mm long. Microstrip is a 1.6 mm wide 50 Ω line.

nents. It is useful for high range of the measured distance ($\sim$ 10 mm) and practically linear in the lower distance range. Microstrip T-junction is separated with the metalized ground plane and the outer influence can be obtained only through the slot.

2 SLOW–WAVE EFFECT INDUCED WITH A SLOT ETCHED IN A GROUND PLANE

For example, microstrip with a slot in the ground plane is presented in Fig. 1. It is simulated on substrate $\varepsilon_r = 2.17$ and $h = 0.508$ mm. The slot is symmetrical in respect to the microstrip line.

As a circuit, it can be presented as an equivalent parallel LC circuit [14]. For certain frequency, it blocks transmission and forms bandstop. In that case, low frequency passband exhibits slow-wave effect [14]. Slow-wave effect can be presented as a ratio of group delays with and without slot. Calculation of the group delay t_d is as in [15]

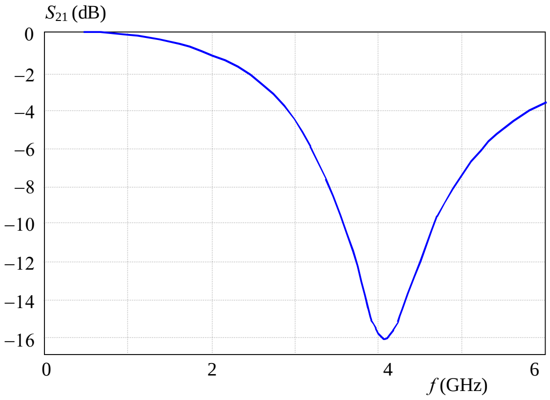

Fig. 2. Bandstop created by the slot

$$t_\mathrm{d} = -\frac{\partial(phase_{21})}{\partial\omega}\,. \tag{1}$$

As can be seen from (1) steeper phase-frequency relation exhibits higher value of group delay and higher slow-wave effect in the low frequency passband. Simulated bandstop created by the slot is presented in Fig. 2. Simulated phase-frequency relation in the case of lonely 50 Ω microstrip line and in the case of incorporated slot in the ground plane is presented in Fig. 3. Simulation was performed with IE3D Zeland program package 10.0.

As can be seen, phase-frequency graph is much steeper for the case with the slot, Fig. 3, and it means higher group delay. According to that, slow-wave effect can be used for phase shifting in the lower passband region. Longer group delay means longer electrical length seen by the incident wave. It means longer electrical length of the test microstrip line in the lower passband frequency range. Shortening slot length one can decrease the slow-wave effect in the lower passband region which means shortening of the electrical length.

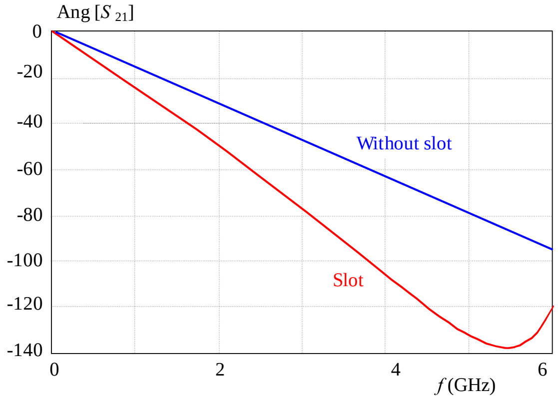

Fig. 3. Phase-frequency relation in the case without and with the slot (steeper line)

3 SHUNT STUB WITH A SLOT IN THE GROUND PLANE AS A TUNABLE MICROSTRIP RESONATOR

One common type of microstrip resonator is the shunt stub. The first resonant frequency of a shunt stub is for wavelength

$$\lambda_{\mathrm{g}0} = L_\mathrm{g}/4\,. \tag{2}$$

Incorporation of a slot in the ground plane is presented in Fig. 4.

The slot induces slow-wave effect on the stub line and increases effective length of the stub which is now longer than L_g ($L_\mathrm{geff} > L_\mathrm{g}$) in (2). According to that, appropriate guided wavelength λ_g is longer in the case of incorporated slot and the resonant frequency is shifted to lower frequencies. The result is that the stop-band central frequency can be controlled by a slot in the ground plane.

Influence of the slot can be reduced by covering part of the slot. Reducing the influence of the slot reduces the influence of the slow-wave effect and decrease the effective length of the stub. The result is shifting of the resonant to higher frequencies. It produces frequency-modulated signal with frequency corresponding to the length of the slot.

4 FABRICATION

As an example of the T-junction structure in Fig. 4 is realized on substrate $\varepsilon_r = 2.17$ and $h = 0.508$ mm.

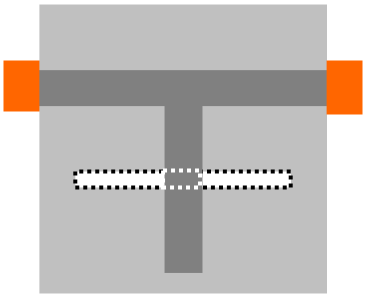

Fig. 4. Microstrip stub resonator (black) with slotted ground plane (gray), white dots represent slot beneath microstrip line

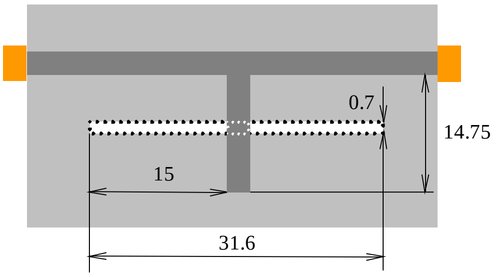

Fig. 5. Upper side of the realized microstrip stub resonator (black) with slotted ground plane (gray). All microstrip lines are 1.6 mm wide 50 Ω lines. White dots represent part of slot beneath microstrip line.

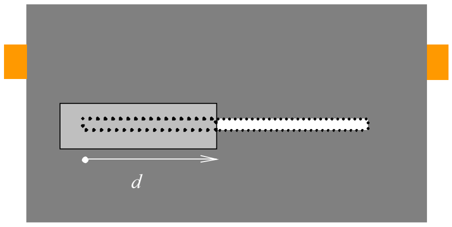

Fig. 6. Ground plane of the realized microstrip stub resonator with a slot. Metal plate (gray) is sliding over the slot and covers distance d from the left edge of the slot (black dots)

Dimension are in Fig. 5. Microstrip lines are 1.6 mm wide and slot width is 0.7 mm. Down side (ground plane) is presented in Fig. 6. and in photo in Fig. 7. Photo of the upper side is presented in Fig. 8.

In our case, a metal plate, gray in Fig. 6, is sliding on the ground plane covering the slot. The covered length of the slot (black dots) is d. It induces frequency shift of the resonator (frequency of the minimum of the bandstop). It produces frequency-modulated signal with frequency corresponding to position d of the front edge of the metal plate covering the slot.

5 SIMULATION, MEASUREMENT AND DISCUSSION

Simulation was performed with IE3D Zeland program package 10.0 and measurement was performed on Agilent Technologies Network Analyzer N5227A. Transmission characteristics were first investigated for boundary cases: full slot, position $d = 15$ mm (edge of the microstrip line, according to Figs. 5 and 6) and without slot (or covered slot). Simulation and measurement of relation S_{21} *vs* frequency for the boundary cases are presented in Fig. 9. As can be seen, stopband always exists and has a clearly measureable minimum at the resonant frequency. Simulation and measurement are in an excellent agreement. Without slot the resonant frequency of the stub is 3.67 GHz. With the full slot the resonant frequency of the stub is 2.24 GHz.

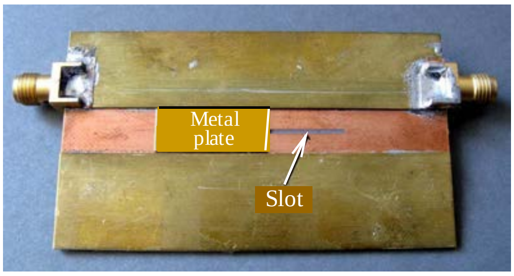

Fig. 7. Photo of the down side of the fabricated microstrip sensor: Metal plate is sliding over the slot in a track made of two brass plates

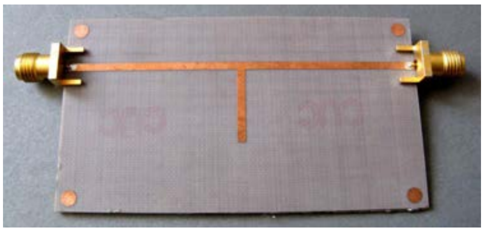

Fig. 8. Photo of the upper side of the fabricated microstrip sensor

Simulation and measured results for resonant frequency vs. position d are presented in Fig. 10. As can be seen, results enter saturation for $d > 15$ mm. As mentioned, position $d = 15$ mm (3.473 GHz) is position of the edge of the microstrip line as in Fig. 5. According to that, the results are logical. For further measurement on can use non-saturated range from $d = 0$ to $d = 15$ mm. Dependence is practically linear in the range up to 6 mm, as presented in Fig. 11.

In discussing the width of the slot it is important to present that, for example, slot width of 2.0 mm, according to simulation, has frequency shift from 2.077 GHz to 3.403 GHz for position shift from 0 to 15 mm. Frequency shift increases only around 0.1 GHz in comparison with the slot width of 0.7 mm. On other side, narrow slot width, below 0.7 mm, decreases frequency shift which is not acceptable.

6 CONCLUSION

In this paper a new type of position microwave sensor is introduced. It is a microstrip stub resonator with slotted ground plane under the stub. It produces frequency-modulated signal with frequency corresponding to covering of the slot with a metal plate. It is useful for high

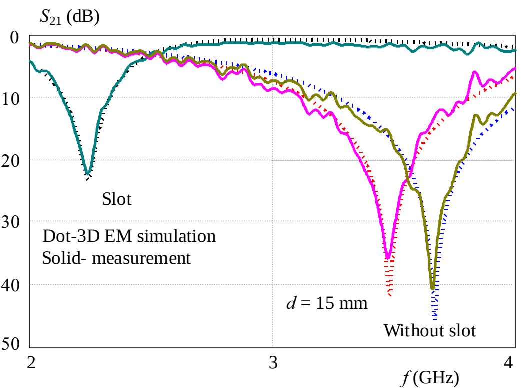

Fig. 9. Simulated (dot) and measured (solid) relation S_{21} *vs* frequency for boundary cases: full slot, $d = 15$ mm and without slot (totally covered)

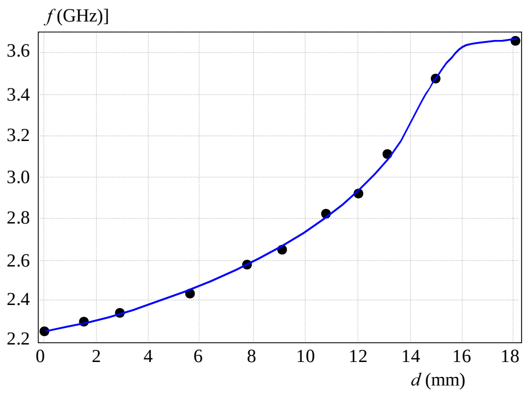

Fig. 10. Simulation (solid) and measured results (circles) for resonant frequency *vs* position d

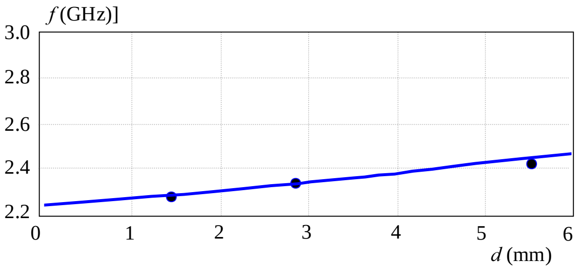

Fig. 11. Result from Fig. 10 is practically linear (≈ 38 MHz/mm) up to 6 mm

range of the measured distance (in our case up to 15 mm), and it is practically linear in the lower distance range (in our case up to 6 mm). One of the advantages is that the sharp stopband always exists and the resonant frequency can be clearly measured. Overall, the resonance frequency is generally immune to the environmental noise.

The proposed structure is simple, low fabrication cost and compact. It is without multilayer, coupling, via holes, air bridges, active or discrete components. The outer influence can be obtained only through the slot and the rest of the metalized ground plane protects microstrip T-junction from non-desired influence.

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