Microwave Position Microstrip Sensor with a Resonant Open Stub and a Slot

Dusan Nesic, *Member, IEEE*

***Abstract*—This paper introduces an investigation of one type of position sensors. It is a resonant microstrip sensor with a resonator as an open stub controlled by a simple slot. It produces signal with frequency variation corresponding to covering of the slot in the ground plane. The sensing is performed by sliding the metal or dielectric plate over the slot. The structure is in planar technology, simple, low fabrication cost and compact. It is without multilayers, coupling, via holes, air bridges, discrete or active components.**

***Index Terms*—Microwave position sensor; Microstrip; Slot.**

I. Introduction

IN recent times, microwave sensors are becoming common and important sensors in application [1-3]. Microwave resonant 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. Microstrip is one of the most common type of microwave structures. Microstrip is also widely applied in sensor structures [4-14]. It is planar printed technology easy for fabrication, cheap and have compact design.

Position (displacement) sensor is an important type of sensors [4-8,12-14]. Moving object is controlling characteristics of the microstrip resonant structures. Resonators can be: a defect in the a periodic structure [4, 5, 12], a coupled resonator [5-8] or an open stub [13,14]. There are some disadvantages for [4-6, 12]. In the cases of [4-6] it is only for vertical distances below 1 mm. In technological aspect using defect in the periodic structure produces a too long structure and complicates fabrication.

Structures in [7, 8, 12-14] are applied for lateral position sensors. It is important to say that the operation principle of the sensors [7, 12-14] is based on variation of the resonant frequency, rather than variation in the depth like in [8]. In that way, the sensors are generally immune to the environmental noise, which is very important. Main advantage of sensors in [7, 8] is two-dimensional sensing. In the other hand, disadvantage of the same sensors is importance of air gap (distance) between the microstrip structure and the moving object. There is also one problem for all sensors in [7, 8, 13, 14]. There is no difference between left and right position of the moving object against the middle position.

Slot in the ground plane of the microstrip can be used to eliminate need for air gap. Moving object can slide over the ground plane and control the length of the slot. Slot and similar defected ground structures (DGS) are common in microwave technology. In fact, slotted ground plane has now a wide application in microwave sensors [4-6, 9-14].

Sensor with microstrip T-junction incorporating stub resonator with slotted ground plane under the stub is introduced in [13, 14]. Advantage of the open stub solution against the case with only one microstrip line is that the sharp bandstop always exists in the open 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) the slot length one can control the frequency of the stopband minimum. It is modification of the slot by covering part of the slot with a metal or dielectric plate. The covering of the slot induces frequency shift of the stop-band minimum. It produces variation of frequency with frequency corresponding to position of the plate. The sensing is performed by sliding the plate over the slot. Proposed structure is simple, low fabrication cost and compact. It is without multilayers, coupling, via holes, air bridges, discrete or active components. Microstrip T-junction is separated with the metalized ground plane and the outer influence can be obtained only through the slot. In that way, the sensors are generally immune to the environmental noise, which is very important. It is useful for high range of the measured distance (~10mm) and practically linear in the lower distance range. Basic scheme of the introduced open stub with a slot in the ground plane is presented in Fig. 1.

Introducing dielectric instead of metal plate shifts resonant frequency minimum in opposite direction, to lower instead to higher frequency. It can be used to distinguish left and right displacement and improve the position sensing.

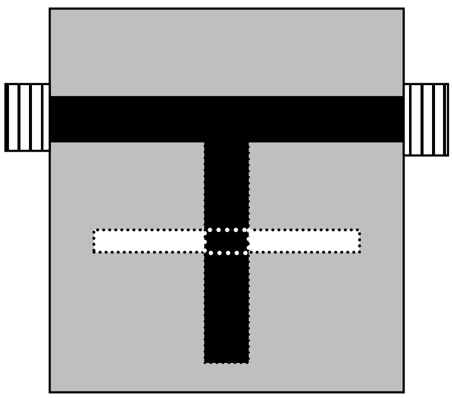

Fig. 1. Basic scheme of the microstrip T-junction with an open stub and a slot in the ground plane beneath the open stub.

Dušan Nešić is with the Centre of Microelectronic Technologies, Institute of Chemistry, Technology and Metallurgy, University of Belgrade, Njegoseva 12, Belgrade, Serbia (e-mail: nesicad@nanosys.ihtm.bg.ac.rs).

Proceedings of 4th International Conference on Electrical, Electronics and Computing Engineering, IcETRAN 2017, Kladovo, Serbia, June 05-08, ISBN 978-86-7466-692-0 pp. MTI1.5.1-3

II. Slow-Wave Effect Introduced with a Slot Etched in the Ground Plane

The slot etched in the ground plane of a microstrip induces bandstop and slow-wave effect in the lowpass region. Sliding a plate (metal or dielectric) over the slot one can control the slow-wave effect on the line. Covering of the slot with a metal plate decreases the slow-wave effect. In opposite, covering of the slot with a dielectric plate increase the slow-wave effect. Applied to an open stub equation for the resonance (1) it means that effective permittivity ε_{reff} can be changed according to the sliding of the plate over the slot. L is the length of the open stub, λ_0 is vacuum wavelength (ε_{reff} =1) and λ_{res} is the resonant wavelength

$$\frac{\lambda_{res}}{4} = \frac{\lambda_0}{4 \times \sqrt{\varepsilon_{reff}}} = L \qquad (1)$$

Covering of the slot with a metal plate decreases ε_{reff}. In opposite, covering of the slot with a dielectric plate increase ε_{reff}.

III. Realization and Results

The upper and the ground plane of the fabricated structure are shown in Fig. 2 and Fig. 3. Substrate characteristics are ε_r = 2.1 and h =0.508 mm. Photo of the slot side (down side) is presented in Fig. 4. SMA connectors are on the both ports. Metal or dielectric plate is sliding over the slot in a track made of two brass walls as shown in Fig. 4. Brass walls are brass plates bonded on the ground plane with silver epoxy.

Measuring position of the moving object (plate) is presented in Fig. 3 as a distance d. In the case of the metal plate the shapes of the bandstops are presented in Fig. 5. It can be seen that sharp stopbands always exist. Relation between distance and the measured resonant frequency is presented in Fig. 6. In the case of the dielectric plate relation between distance and measured resonant frequency is presented in Fig. 7. As can be seen, metal plate is increasing the resonant frequency and dielectric plate is decreasing the resonant frequency.

Practically, opposite effect can be used to distinguish left and right displacement of the moving object. Start with one metal plate and one dielectric plate on the opposite sides of the slot length. Suppose that the both plats are connected on the same moving object. Moving right from the middle position, for example, metal plate is covering the slot and the resonant frequency is increased. Moving left from the middle position dielectric plate is covering the slot and the resonant frequency is decreased. The main problem can be disproportional shifting of the resonant frequency for metal and dielectric plate. In the presented case, shown in Fig. 6, dielectric plate is ε_r = 10.2 and h =0.635 mm with one and two layers of the mentioned substrate. Solution can be a higher permittivity dielectric.

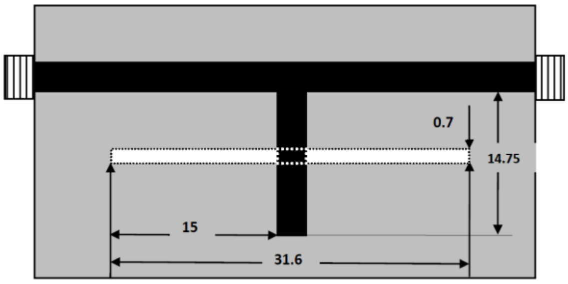

Fig. 2. Upper side of the realized microstrip stub resonator (black) with slotted ground plane (gray). All microstrip lines are 1.6 mm wide 50 Ω lines. White dots represent part of slot beneath microstrip line.

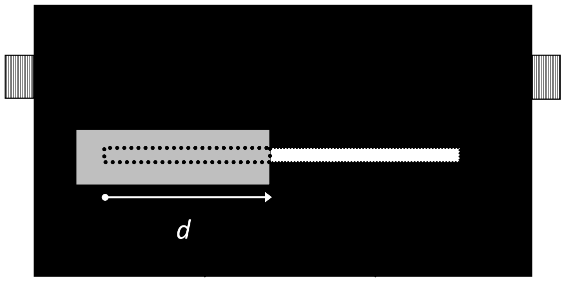

Fig. 3. Down side (ground plane) of the realized microstrip stub resonator with a slot. Metal or dielectric plate (gray) is sliding over the slot and covers distance d from the left edge of the slot (black dots).

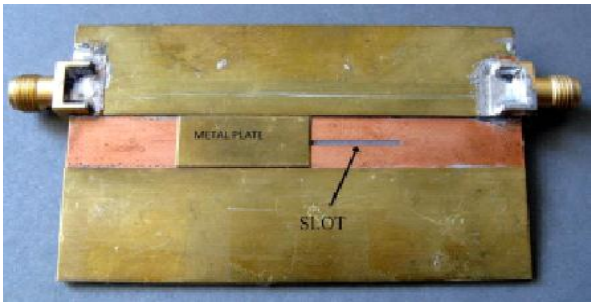

Fig. 4. Photo of the slot side (down side) of the fabricated microstrip sensor: Metal or dielectric plate is sliding over the slot in a track made of two brass walls.

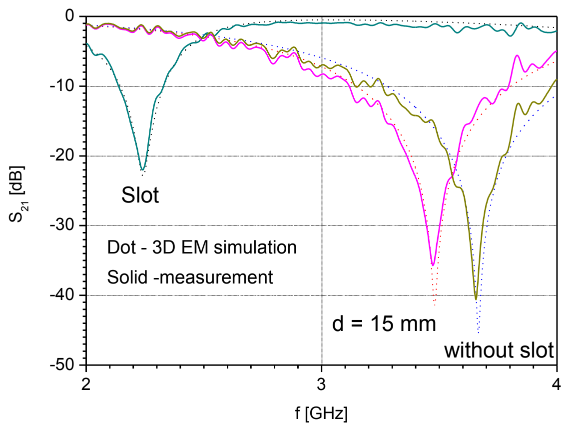

Fig. 5. Simulated (dot) and measured (solid) relation S_{21} vs. frequency in the case of the metal plate for boundary cases: full slot, d = 15 mm and without slot (totally covered). Stopband always exists.

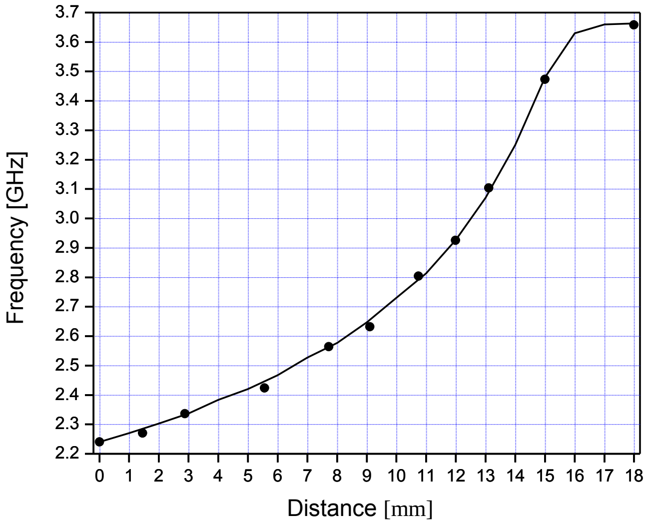

Fig. 6. Simulation (solid) and measured results (circles) in the case of a metal plate for resonant frequency vs. position distance *d*.

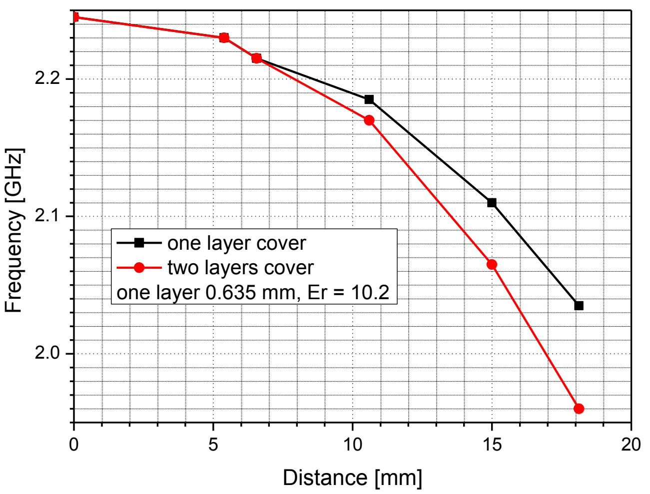

Fig. 7. Measured results in the case of a dielectric plate for resonant frequency vs. position distance *d*.

IV. Conclusion

In this paper one position microwave sensor is introduced. It is a microstrip stub resonator with slotted ground plane under the stub. Covering of the slot with a metal or dielectric plate produces frequency variation of the resonant frequency of the open stub. One of the advantages is that the sharp stopband always exists and the resonant frequency can be clearly measured. One advantage in investigation is possibility of distinguishing right and left movement. Covering of the slot with a metal plate increases the resonant frequency. In opposite, covering of the slot with a dielectric plate decreases the resonant frequency.

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.

Acknowledgment

This work was funded by Serbian Ministry of Education and Science, project TR 32008. The author would like to thank colleagues, I. Radnovic, M. Pesic, N. Tasic, Lj. Radovic, N. Popovic and P. Manojlovic, from Institute IMTEL for their help in realization and to professor M. Potrebic from University of Belgrade, School of Electrical Engineering, for help in measurement.

References

[1] S. Dey, J.K. Saha, and N.C. Karmakar, “Smart Sensing,” *IEEE Microwave Magazine*, November 2015, pp. 26-39

[2] J. Polivka, “An Overview of Microwave Sensor Technology,” April 2007, *High Frequency Electronic*, pp.32-42

[3] L. Su, J. Mata- Contreras, P. Vélez, and F. Martín, “A Review of Sensing Strategies for Microwave Sensors based on Metamaterial-Inspired Resonators: Dielectric Characterization, Displacement and Angular Velocity Measurements for Health Diagnosis, Telecommunication and Space Applications,” *International Journal of Antennas and Propagation*, Article in press

[4] T.-Y. Yun and K. Chang, “An Electronically Tunable Photonic Bandgap Resonator Controlled by Piezoelectric Transducer,” Proceedings of the 30th European Microwave Conference, 2000, pp.1145-1147

[5] T.-Y. Yun and K. Chang, “Piezoelectric-Transducer-Controlled Tunable Microwave Circuits,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 50, no. 5, 2002, pp.1303-1310

[6] Y. Poplavko, D. Schmigin, V. Pashkov, M. Jeong and S. Baik, “Tunable Microstrip Filter with Piezo-moved Ground Electrode,” Proceedings of the 35th European Microwave Conference, 2005, pp.1291-1293

[7] A.K. Horestani, J. Naqui, Z. Shaterian, D. Abbott, C. Fumeaux, F. Martín, “Two-dimensional alignment and displacement sensor based on movable broadside-coupled split ring resonators,” *Sensors and Actuators A*, 210 (2014) 18–24

[8] A.K. Horestani, J. Naqui, D. Abbott, C. Fumeaux and F. Martín, “Two-dimensional displacement and alignment sensor based on reflection coefficients of open microstrip lines loaded with split ring resonators,” *Electronics Letters*, 2014, Vol. 50 No. 8 pp. 620–622

[9] A.M. Albishi, M.S. Boybay, and O.M. Ramahi, “Complementary Split-Ring Resonator for Crack Detection in Metallic Surfaces,” *IEEE Microwave and Wireless Components Letters*, vol. 22, no. 6, 2012, 330-332

[10] B. García-Baños, F. Cuesta-Soto, A. Griol, J. M. Catalá-Civera, and J. Pitarch, “Enhancement of Sensitivity of Microwave Planar Sensors With EBG Structures,” *IEEE Sensors Journal*, vol. 6, no. 6, 2006. 1518-1522

[11] C. Liu and Y. Pu, “A Microstrip Resonator With Slotted Ground Plane for Complex Permittivity Measurements of Liquids,” *IEEE Microwave and Wireless Components Letters*, vol. 18, no. 4, 2008 257-259

[12] D. Nešić, "Position Sensor Based on Irregularity in Periodic Structure and Defected Ground Structure", Proceedings of 2nd International Conference on Electrical, Electronic and Computing Engineering, IcETRAN 2015, Silver Lake, Serbia, pp. MTI2.6.1-3, June 8 – 11, 2015

[13] D. Nešić, "New Type of Microwave Position Sensors", 12th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services - TELSIKS 2015, Nis 14-17 Oct., Proceedings of Papers, pp.197-199

[14] D. Nesic, “Microstrip Resonator with Slotted Ground Plane for Detecting Lateral Position,” *Journal of electrical engineering*, Vol. 67, No.5, pp. 383-386, 2016