COMMUNICATIONS

Resonant coaxial SMA microwave permittivity sensor

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Resonant coaxial SMA microwave permittivity sensor is introduced. It is constructed using only commercially available SMA connectors. The sensor is tested in two different frequency ranges for two different dielectric constant ranges, from 1 to 10 and from 10 to 80. Presented sensor is designed, fabricated, simulated, and tested. Good agreement between simulations and measurements is shown. The sensor is also applicable for differential permittivity measurements.

K e y w o r d s: microwave sensor, resonant coaxial SMA sensor, differential permittivity measurement.

1 Introduction

Microwave sensors become a widespread type of sensors [1–3]. Among them permittivity sensors are important in characterization of microwave substrates and materials such gasses, fluids, and solids [2–4]. The resonant method, as a type of permittivity sensing, has some advantages over the other methods. The resonant method enables the lowest uncertainty for the permittivity determination [2] while the permittivity is determined from measurements of the resonance frequency.

Application of coaxial structures in sensing represents foundation for one of the most convenient and frequently used techniques to measure lossy materials at high frequencies (*ie* radio and microwave frequencies). The most common method relying on coaxial structures is coaxial probe method which detects reflected signal (phase and magnitude) from the tested material [3]. The method is applicable to fluid measurements. However, it has some disadvantages. The disadvantages are: repetitive calibrations required, the reflections for the low permittivity materials and required stability of cables [3, 4].

Another coaxial method used to measure the dielectric properties of fluids is a method based on usage of coaxial open stub $\lambda_g/4$ (or coaxial shorted $\lambda_g/2$) resonator [5–8]. This technique is less sensitive to errors, especially for the errors produced by electromagnetic interference.

In all cases found in [5–8] the measurement systems are used with relatively high amount of fluids, mainly for water monitoring. In these cases, diameter of open stub is around 25 mm while length over 250 mm.

A general drawback of resonance-based sensors is that permittivity depends on environmental conditions such is temperature or moisture and thus the resonance frequency can be shifted by spurious effects. Typical solution to beat the environmental factors is through differential measurements *eg* through usage of differential sensor. Also, the differential permittivity sensors are not rare for planar sensors [9]. As far as the authors of this paper know, there is no differential coaxial sensor described in the literature.

SMA coaxial resonant open stub $\lambda_g/4$ permittivity sensor presented in this paper is intended for testing a small amount of material. It is constructed using only commercially available SMA connectors. The applied SMA connectors are two SMA jack-to-jack-to-jack Tee adapters and two plug-to-jack adapters. The sensor is fabricated, simulated, and preliminary measured in a wide range of relative dielectric constant. The structure is also obtained for the differential permittivity measurement.

2 Sensor construction

The presented sensor in Fig. 1 is constructed using two SMA jack-to-jack-to-jack Tee adapters (A) and two SMA plug-to-jack adapters (B) connected with one SMA plug-to-plug adapter (C). A copper wire which is 12.3 mm long is mounted on each Tee adapter as a central conductor of the open stub. It is shown in Fig. 1(a). The inner content of the both SMA plug-to-jack adapter (B) is removed and one hollow metal cylinder is mounted on each Tee adapter with the wire, Fig. 1(a), forming the final structure shown in Fig. 1(b). Now, both open stubs are formed in such manner that they contain the wire (the central conductor shown in Fig. 1a) and the hollow SMA plug-to-jack adapter which represents the outer conductor, Fig. 1(b). The hollow SMA plug-to-jack adapter marked with (B) in Fig. 1(b), is filled with fluid which represents material under test (MUT).

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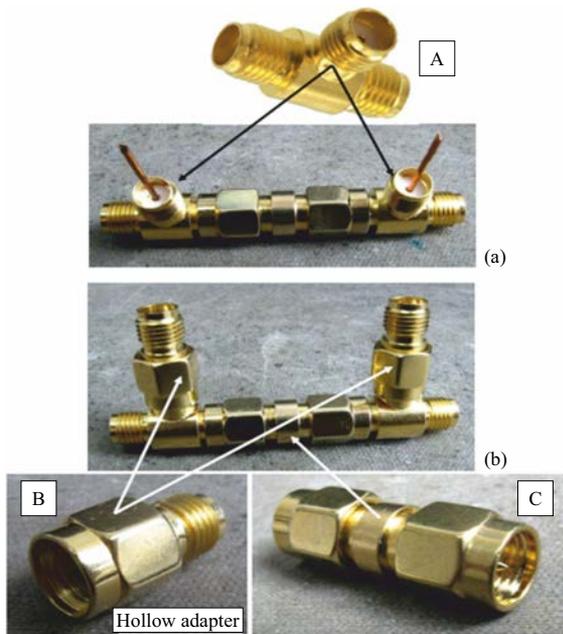
Fig. 1. (a) – structure without the hollow adapter, (b) – with the hollow adapter: A-SMA jack-to-jack-to-jack tee adapter; B-SMA plug-to-jack adapter; C-SMA plug-to-plug adapter
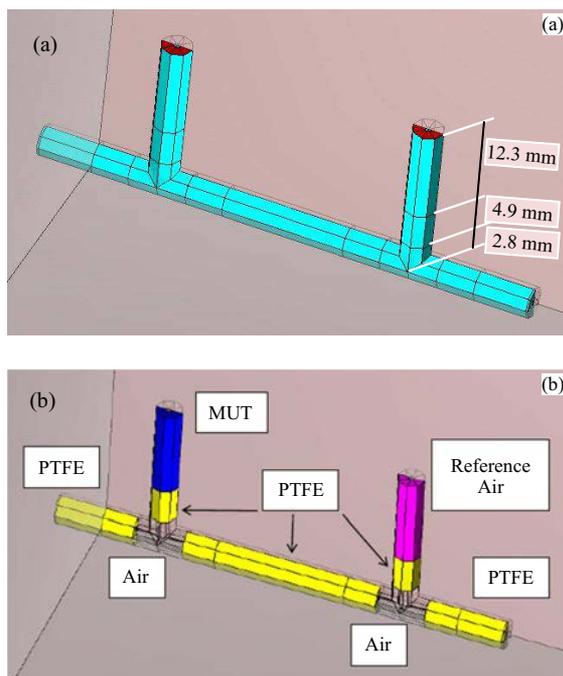

Fig. 2. Preview of the sensor modeled in WIPL-D pro software suite

3 Simulation and measurement

Simulation is performed in WIPL-D Pro software suite [10]. The WIPL-D Pro model of the sensor is presented in Fig. 2 in two ways: showing outer coaxial metal conductor and dimensions of two $\lambda_g/4$ resonators, Fig. 2(a) and dielectric materials filling the SMA

adapters: MUT-material under test, reference air, air-hollow area inside SMA jack-to-jack-to-jack tee adapter, Fig. 2(b).
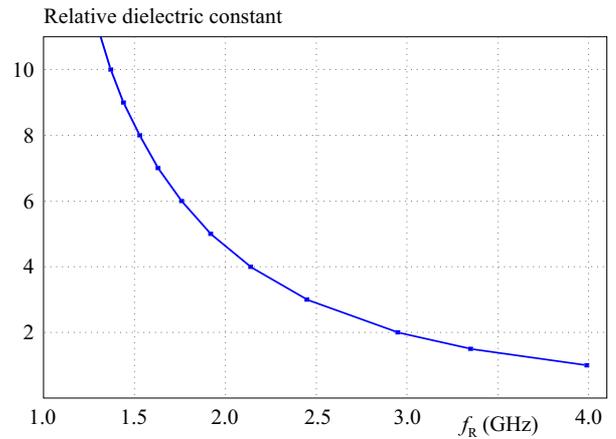

Fig. 3. Calibration ε_R-f_r curve for the lower range of relative dielectric constant(ε_R is between 1 and 10)

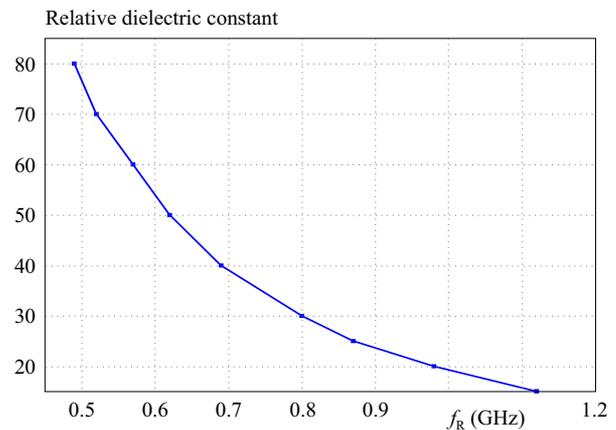**Fig. 4.** Calibration ε_R-fr curve for the higher range of relative dielectric constant(ε_R is between 10 to 80)

Table 1. Measured and referent values of ε_R for simulated MUTs

MUT	Measured ± 5 MHz		Ref	ε_R	error (%)
	ε_R	f_R (GHz)			
Gasoline	1.96 ± 0.01	2.98	[12]	2.0	2
Paraffin oil	2.1 ± 0.01	2.88	[13]	2.2	5
Water *	80.0 ± 2	0.49	[11]	80.0	1
Ethanol 70%	43.0 ± 1	0.66	[14]	40.0	7.5

* water from the regular water supply, near $20\,^\circ$C

The resonant frequencies (calibration curves) for the given MUT ε_R according to simulation are presented in Fig. 3 and Fig. 4. Figure 3 assumes lower real dielectric constant ε_R (1 to 10) while Fig. 4 assumes higher ε_R (10 to 80). The air ε_R is considered to be 1 while PTFE ε_R equal to 2.1 is used. In real life measurements, materials under test with lower ε_R values are usually gasoline and oils. Materials under test with higher ε_R values include ethanol, water, and their mixture.
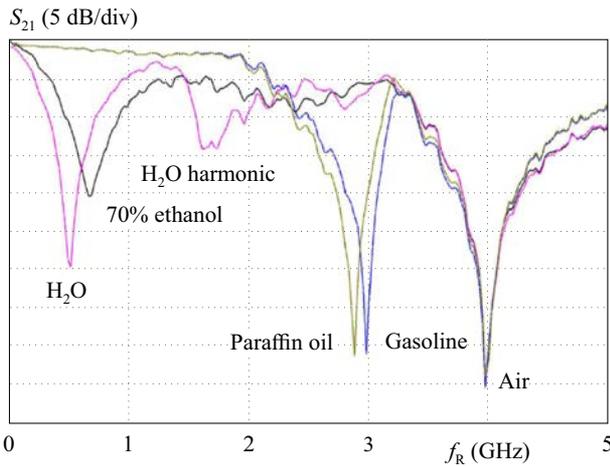
Fig. 5. Measured S_{21} parameters for air, gasoline, paraffin oil, 70 % ethanol-water mixture and tap water
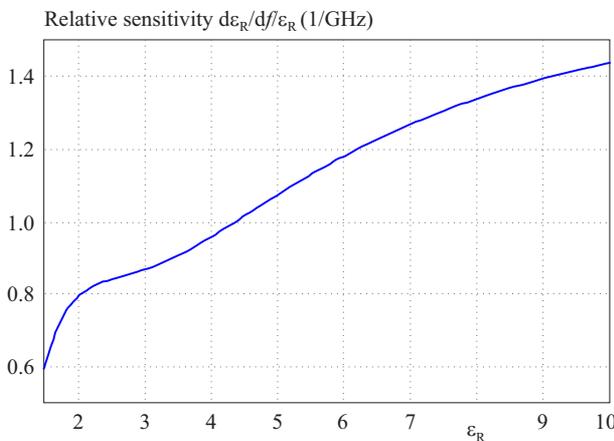

Fig. 6. Relative sensitivity in the lower range of relative dielectric constant (ε_R is between 1 to 10)
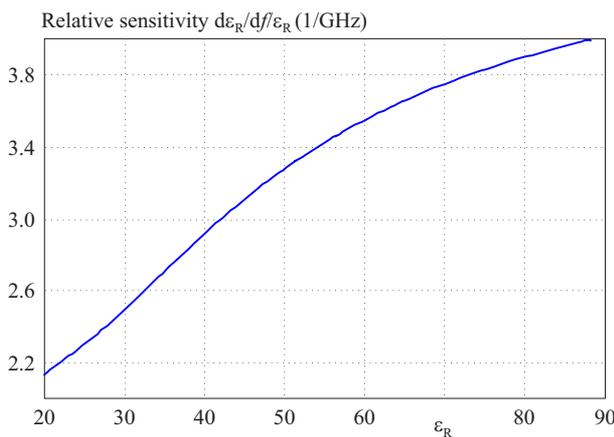

Fig. 7. Relative sensitivity in the higher range of relative dielectric constant (ε_R is between 20 to 80)

Preliminary measured results are presented for air, gasoline, paraffin oil, 70% ethanol-water mixture, and tap water in Fig. 5, the resonant frequencies f_R are clearly visible. Higher harmonic resonances can be recognized if water is used as MUT. The second resonance is somewhat shifted from $3f_R$ and have a wider bandgap. The reason

is lower dielectric constant and higher losses for higher frequencies in the case of water [11].

Relative sensitivity $-(d\varepsilon_R/df)/\varepsilon_R]$ is calculated from the fitting curves and presented in Fig. 6 and Fig. 7.

Calculated values of ε_R for MUTs obtained from the calibration curves and the referent values for ε_R are presented in Table 1. Only the first resonant frequencies are listed. The resolution depends on the frequency step (± 5 MHz) and on the dielectric constant range.

4 Conclusion

This paper represented a new type of coaxial resonant sensor. The presented coaxial resonant sensor was constructed using only SMA connectors (adapters): SMA jack-to-jack-to-jack Tee adapter and SMA plug-to-jack adapter. It offers good protection from electromagnetic interference since the outer coaxial conductor enables very good shielding. Also, it is easy for construction since it consists of commercial SMA adapters and it is very useful for smaller amount of fluid under test. The coaxial resonant sensor can also be used both as a differential sensor.

The sensor is simulated and measured for lower values of real dielectric constant (ε_R between 1 and 10) and for higher values of dielectric constant (ε_R between 10 and 80). All results well match values found in the available references.

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