Open-Loop Stub-Loaded Dual-Band Resonator for Solution Sensing

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Abstract

In this paper, a dual band resonator using open-loop stub-loaded resonator is studied. By the characteristics of even/odd modes, the two resonant frequencies can be designed independently. Based on the capacitive loading effect in the even mode operation, the solution sensing is implemented. For verification, a dual-band 1.8/2.4 GHz resonator is used as a probe to sense the volume of 0.9 wt% NaCl solution ranged from 0 µl to 20 µl. It is observed that the lower operating frequency is unaltered but 100 MHz frequency variation around the upper resonant frequency is recorded.

1. Introduction

Dual-band bandpass filter (BPF) has become one of the most important circuit components in modern wireless communication system. Manufacturers are in great demand of BPF for these types of filters can be easily embedded into RF/Microwave devices. To meet the demand, many studies have been carried out and a variety of design methods are proposed [1]-[5]. However, the study in biological material characterization using such dual-band BPF is still lacking [6]-[8], where the permittivity characterization is focused and the saline solution modelling is commonly used. Considering this practical issue, a novel probe is proposed based on the dual-band resonator in the paper. Capacitive loading effect as demonstrated in [9] and [10] will be used to influence resonant frequency of the filter. In order to be used as a sensor, an additional layer of economic Low-Density Polyethylene (LDP) is used to implement the capacitive loading effect due to the saline solution. This LDP layer allows contact measurement of liquid samples without diminishing the probe's performance. A prototype probe is also designed and fabricated to demonstrate the proposed structure performance. Besides this introductory section, a dual-band resonator is designed based on the open-loop stub-loaded resonator (SLR) in Section 2 and the simulation and measurement results are shown in Section 3. Followed Section 4, some tested saline solution is experimentally characterized by the new probe and discussed. Finally, a conclusion is then drawn in Section 5.

2. Design of Dual-Band Open-Loop Stub-Loaded Resonator

As shown in Figure 1, the proposed SLR consists of a conventional microstrip half-wavelength resonator and open stub, where Y_1, L_1, Y_2, L_2 denote the characteristic admittances and lengths of the microstrip line and open stub, separately. The open stub resonator is shunted at the mid-point of main resonator, owing to the filter geometry is symmetrical, and so the odd- and even- mode analyses can be applied to this structure. Moreover, compared with the conventional open-loop resonator, the filter structure can obtain a dual-band operation. Referred to [4], the odd-mode and even-mode resonant frequencies can be derived as

$$f_{odd} = \frac{(2n-1)c}{2L_1\sqrt{\varepsilon_{\text{eff}}}} \tag{1}$$

$$f_{\text{even}} = \frac{nc}{(L_1+2L_2)\sqrt{\varepsilon_{\text{eff}}}} \tag{2}$$

where L_1 is half-wavelength resonator length, L_2 is the length of the open-stub, c is the speed of light, $n = 1, 2, 3\ldots$, and ε_{eff} denotes the effective dielectric constant of the substrate. In addition, the equations here should be deduced in the case of $Y_1 = Y_2$.

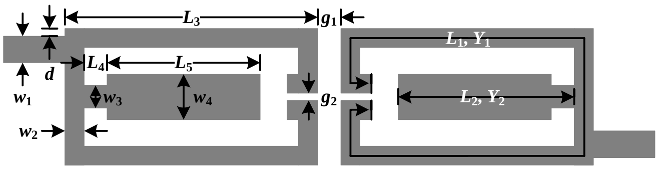
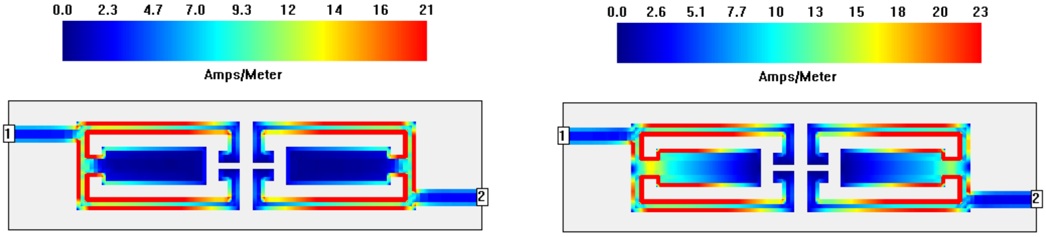


Figure 1: The dual-band BPF using open loop SLR geometry.

Based on (1) and (2), it concludes that the passband frequencies are mainly determined by the entire length of open loop L_1 and the length of open stub L_2. For a fixed open loop resonator length, the fundamental odd-mode resonant frequency can be fixed correspondingly. The fundamental even-mode resonant frequency is able to be shifted within a limited range by changing the stub length, whereas the fundamental odd-mode resonant frequency is preserved.

3. Design Verification

According to previous discussion, a prototype filter is designed. The filter is designed at 1.8 GHz and 2.4 GHz respectively (as shown in Figure 1), with a substrate Roger RO4003 (the relative dielectric co0nstant is 3.38 and the thickness is 1.524 mm). The corresponding filter dimensions are calculated as follows (all in mm): $w_1 = 2$, $w_2 = 1.5$, $w_3 = 2.5$, $w_4 = 4.5$, $L_3 = 19.5$, $L_4 = 1.5$, $L_5 = 12.5$, $d = 0.5$, $g_1 = 1.5$, $g_2 = 0.5$. As shown in the figure, stepped impedance technique is applied to the open-stub. As such, the adjustability of even-mode passband can be extended without further increasing the length L_2 relaxing the geometry limitation on the length of the open-stub.



(a) (b)

Figure 2: Current distributions of the filter at (a) 1.8 GHz and (b) 2.4 GHz.

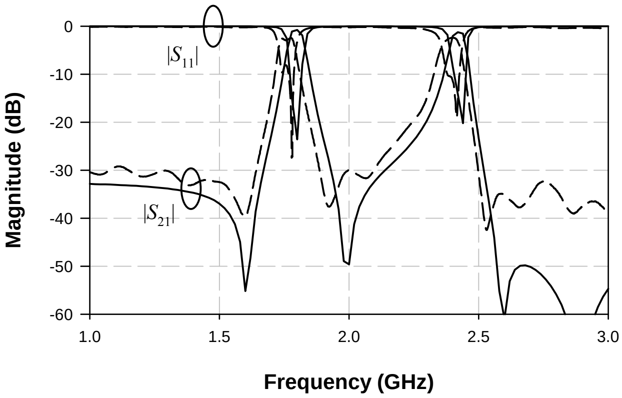


Figure 3: Comparison of simulation (——) and measurement (– – –) results.

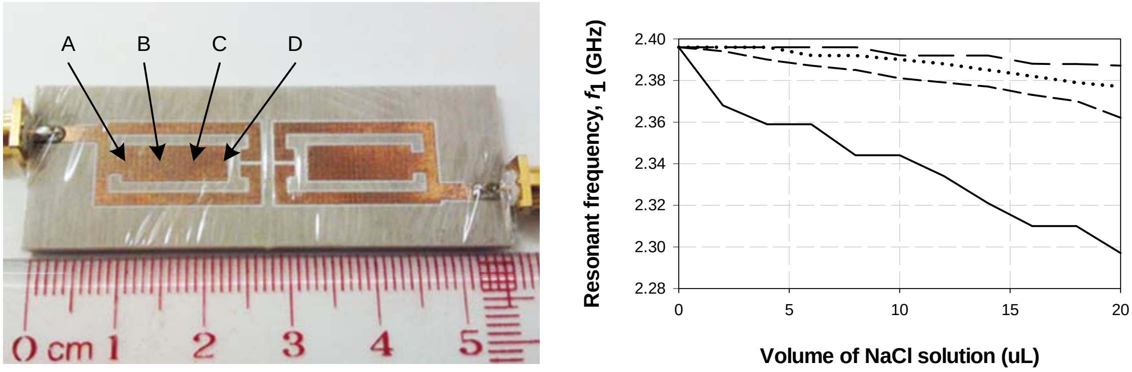
To demonstrate the correctness of the filter design, the current distributions at the resonant frequencies are depicted in Figure 2. In the odd-mode operation (as shown in Figure 2a), no current flows into the open-stub. This results a longer wavelength and hence the odd-mode is at 1.8 GHz. In contrast, current flows into the open-stub during the even-mode operation (as shown in Figure 2b). This results a shorter wavelength and hence the resonant frequency is at 2.4 GHz.

Furthermore, the simulated and measured frequency responses of the dual-band filter are presented in Figure 3. It can be observed that simulation result matches the analysis; two frequencies are centred at 1.8 GHz and 2.42 GHz with insertion loss of 0.8 dB and 1.2 dB, respectively. Measured passbands are at 1.77 GHz and 2.41 GHz with insertion loss at 2.7 dB and 2.9 dB, respectively. The lower and upper passbands have the fractional bandwidths of 3.9% and 3.7%. The stopband rejection is better than 30 dB till 3 GHz.

4. Saline Solution Characterisation

Water has a high dielectric constant and exhibits losses in the microwave frequency regime and so the measured signals from many biological samples are dominated by the water contents of the samples. A simple sensor for liquid volume is thus highly desired. As illustrated in previous sections, the prototyped filter's reflection coefficient $|S_{11}|$ of the second passband could be easily altered by the capacitive loading effect, which is equivalent as changing the stub length L_2 in principle. If this loading effect is due to the concerned liquid sample, it is thus possible to help investigate material electrical property. In order to quantitatively study the sensing capability of water solution by the designed filter, the volume of 0.9 wt% NaCl solution is tested. As the illustrated in Figure 4, sample will be placed at different points (A to D) of the filter and this causes the change of second resonant frequency. It can be observed that the filter resonant frequency change due to NaCl solution which contribute as the most abundant ionic fluid in biological samples at a 0.9 wt% (molecular weight of NaCl is 58.45 gram) concentration.

In order to isolate the physical contact of the filter's top metal with the NaCl solution, the filter is layered with Low-Density Polyethylene (LDP). The LDP is inexpensive, has good chemical resistance, is ultra low permeability to water, and has an adopted thin film thickness of 12.7 µm. The addition of this thin layer will not affect the filter performance. But on the other hand, it allows the filter to act as a probe. For example, the filter performance (in terms of frequency responses) may change differently if the saline solution is dropped on different positions on the filter. In this case, the saline solution acts as the capacitive loading to the filter via this LDP.



(a) (b)

Figure 4: (a) Experimental Setup for NaCl solution sensing; (b) Measurement results with different amounts and positions (Point A — —, Point B ……, Point C – – – and Point D ——).

According to Figure 3, the measured $|S_{11}|$ reports -29 dB at the first resonant frequency f_0 of 1.76 GHz, along with -19 dB at 2.39 GHz for the second resonant frequency f_1. As shown in Figure 4a, the open-stub is marked with four positions (Point A to Point D), and different amount of saline solution is dropped at the position and the return loss is observed. As expected, the first resonant frequency remains unchanged as in the odd-mode operation. In comparison, Figure 4b shows the measured values of second resonant frequency, which is in the even-mode operation, as a function of saline volume ranged from 0 µl to 20 µl. Obviously, it is noticed that the frequency shifts to the lower sideband as the amount of solution increases. Nevertheless, point D is most sensitive point of the filter, which presents the second passband frequency change from 2.3 GHz to 2.4 GHz with $|S_{11}|$ at about -15 dB. Saline sample creating capacitive loading effect internally makes even-mode resonator longer so that passband shifts to a lower frequency like extending the stub length. This new probe provides a dynamic measurement range of around 100 MHz for the above trace volume of NaCl.

5. Conclusion

This paper represents a dual-band open-loop resonator with stub-load. To implement liquid sample sensing, a filter with LDP layered is used to allow the sample analysis. A prototype is designed and tested for different volume of NaCl, measurement results demonstrate the sensing feasibility by the proposed simple resonator structure. In the experiment, it is found that the open end of the stub is most sensitive to the saline solution. When 20 μl of NaCl is dropped to this end, the resonant frequency of the second passband shifts from 2.4 GHz to 2.3 GHz, whilst the first resonant frequency remains unchanged at 1.8 GHz.

Acknowledgments

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