# Crack Sensoring Devices Construction by Means of Microwave Resonant Circuit Design

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***Abstract*— Microwave engineering applications related to crack sensoring may have some implications and obstacles; for instance, high cost, adaptive design and external circuitry coupling. This paper presents simulated and practical results of a band-pass filter, constituted of two quarter-wavelength spaced open circuit stubs, connected in shunt along a transmission line, which acts as a series resonant circuit. The device is used as a crack sensor, using flexible substrates. Comparison is made to check which substrate fits best this application.**

**Keywords—microwave resonant circuits, chipless tag, RFID, crack detection.**

## I. Introduction

Ultra-wideband antenna applications have increased on a massive scale since the discovery of microstrip antenna technology. Although it is not a new process, an application that has been received more credit in the last recent years is the RFID (Radio-Frequency Identification). Such systems have a similar working principle of the radar system [1], since it detects the presence of an object through electromagnetic waves reflection, specifically, through wave backscattering. In this case, however, the signal reflected consists of encoded data that contains specific information.

A RFID system consists of a transponder, which is a transmitter-receiver that is stimulated once it receives the desired signal (tag), a reader that emits a signal in order to activate or not the tag and a software where specifications are made for the tag to respond accordingly [2]. For that reason, RFID technology has been called “the barcode of the future”, operating as a sensor/identifier. Since tags with chip are more expensive [2], chipless tags have been selected in order to decode this information through analogical parameters, e.g. amplitude, frequency and phase [2].

Another structure of relevance is the microwave filter, that is a two-port network capable of transmitting or attenuating a signal at a given frequency. These components are widely used in applications such as radars, test and measurement systems [3]. They are structures of simple construction, lightweight, inexpensive and compact. The latter characteristic can be helpful when it comes to crack sensoring in areas of difficult access and exposed to disturbances. In this work, a parametric study of planar resonators on flexible substrates for wireless crack sensor in the frequency domain is made.

This paper is organized in the following topics: section II introduces a theoretical approach on resonator circuits and microwave filters, section III shows simulated, fabricated and measured results of band stop filters with different substrates and section IV gives theory corroboration and a prospective insight on future works based on the results achieved by the experiments made on this work.

## II. Methodology

### *A. MICROWAVE RESONANT CIRCUIT THEORY*

A resonant circuit has a purely real (resistive) input impedance at a desired frequency, denominated resonant frequency. The structure of a resonant circuit can assume various shapes. In this paper, is used a transmission line with two open circuit stubs, spaced by a quarter-wave length. The input impedances of the stubs are purely reactive, acting either as a capacitor or an inductor. Given that, the stub is a specified length of transmission line often used in resonant circuits and distributed element filters.

In this paper there is a particular interest on quarter-wave open circuit stubs, acting as a band-stop filter as [3] suggests. An open circuit stub has an input impedance given by [4]

$$Z_0 = -jZ_0 cot(\beta l) \qquad (1)$$

where $Z_0$ is the line characteristic impedance, $\beta$ is the phase constant and $l$is the real, or physical, line length. From Equation (1) it is possible to see that, according to different values of $cot(\beta l)$, the stub will have either capacitive or inductive behaviour.

In this work, a microstrip line device is going to be used. Such device is designed according to the structure in Figure 1.

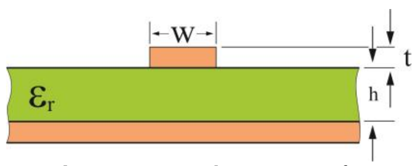



Fig. 1. Microstrip line prototype with parameters of interest

In Figure 1, the parameter *t* stands for feed line thickness, *W* feed line width, *h* substrate thickness and $\varepsilon_r$ relative dielectric permittivity. Such parameters are of relevance to this study, since it is necessary to know the feed line width and thickness in order to achieve impedance matching along with the open circuit stubs.

The structure used as a band-stop filter will be made with a microstrip line, along with two quarter-wave open circuit stubs in shunt with the transmission line. It was made according to the layout presented in Figure 2.

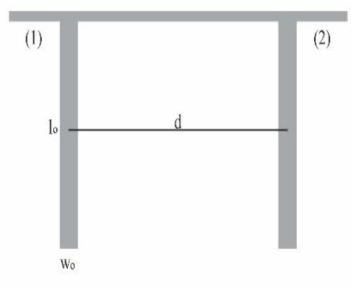



Fig. 2. Band-stop filter layout

Given the layout and the desired resonant frequency, it is possible to evaluate the stubs characteristic impedance, according to [3]

$$Z_{0n} = \frac{4Z_0}{\Delta \pi g_n}, n = 1,2 \quad (2)$$

where $Z_0$ is the characteristic impedance of the line, $g_n$ is the impedance-scaled prototype elements and $\Delta$ is the fractional bandwidth. Picking $g_n$ and $\Delta$ values according to design requirements, a stub characteristic was found to be of 22.5 Ω. Therefore, the matching techniques used were evaluated with this value of characteristic impedance. A more profound study can be found in [5], where it is shown that stub length determines the resonant frequency and stub width is changeable in order to evaluate its characteristic impedance.

## III. SIMULATED AND MEASURED RESULTS

Given the proper design and optimization of the resonator circuit, an analysis was made on CST® Microwave Studio. Based on simulated and real structure performance, through scattering parameters analysis, it was possible to analyse the filter behaviour before and after being broken.

The methodology used was made with similar procedures found in [6] and [7], where scattering parameters analysis is made to validate the proposed theory, with electromagnetic software simulations and prototype manufacturing. In this particular work, however, scattering parameters are measured in order to assess sensor performance due to a significant change in these data, reporting different behaviours before and after a physical crack is made.

Given the structure depicted in Figure 2, different substrates were used, thus varying the relative permittivity and loss tangent. This alteration leads to different quarter-wave distances. Therefore, an analysis can be made through the structure size and cost of fabrication according to the substrate used. The structure simulated on CST® Microwave Studio is presented in Figure.

The reflection coefficient is analysed to see the filter response to a signal in the 2.5 GHz frequency band, region in the electromagnetic spectrum used in wireless communication applications. The parametric analysis was made through structure assembling, and fed by an external signal with two ports located at the feed line extremities. The substrates in Table I were used.

TABLE I. FLEXIBLE SUBSTRATES AND PROPERTIES OF RELEVANCE

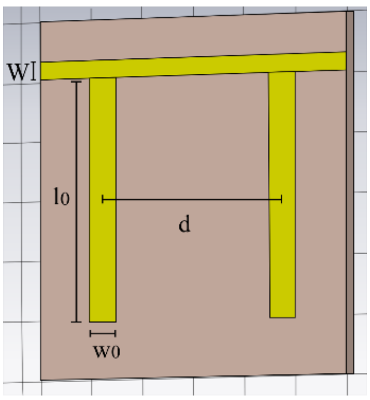
| **Substrate** | **Properties** | | |
|---|---|---|---|
| | ***Thickness (mm)*** | $\varepsilon_R$ | **Loss tangent *(δ)*** |
| Ultralam® Rogers 3850 | 1 | 2.9 | 0.0025 |
| Melinex 339 | 0.1 | 3.48 | 0.0056 |
| Melinex 339 | 0.05 | 3.53 | 0.005 |

### 1. *Rogers substrate*

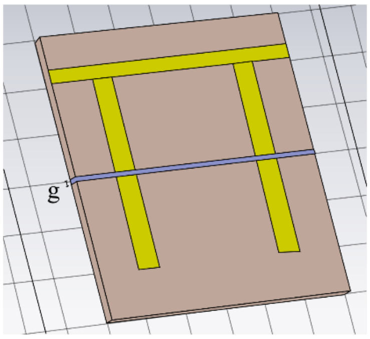
The first substrate was Ultralam® Rogers. This material shows great performance in high frequency applications, besides of good mechanical properties and great electric stability [5]. The filter dimensions were the same used in [3], except for the fact that the parameters *W* and *h* are affected directly in microwave filter design. Such parameters were calculated through macro calculators in CST® Microwave Studio, along with the quarter-wave length distance using the 2.5 GHz frequency band.

For Ultralam® Rogers 3850 (lossy material), the quarter-wave distance found was of 17.6 mm. The feed line width used was of 1.5 mm and the substrate thickness *h* was specified according to the available material which will be presented shortly, which was of 1 mm.

There were then performed, in electromagnetic simulation software, situations of the band-stop filters in whether it is physically intact or broken in its midpoint, in case of cracking.




(a)




(b)

Fig. 3. Band-stop filter simulated on CST® Microwave Studio (a) before and (b) after cracking.

After structure assembling, a frequency domain analysis was made in order to check if the filter was acting accordingly. Figure 4 presents the obtained results.

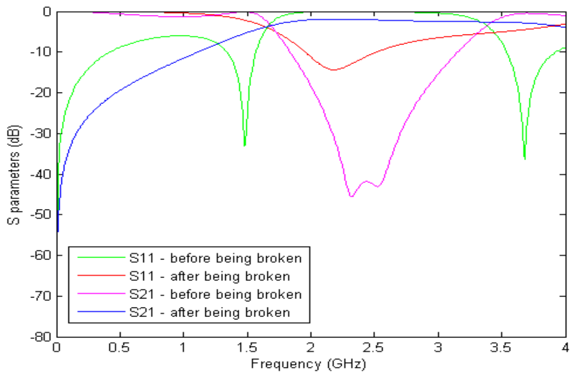
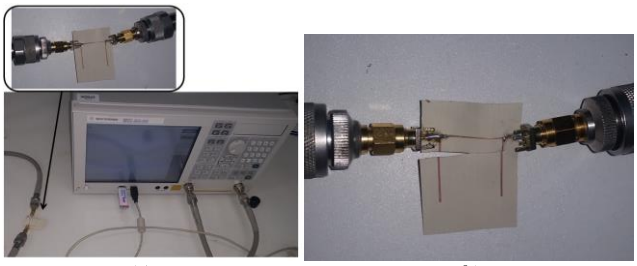



Fig. 4. Scattering parameters for a band stop filter acting as a crack sensor prototype with Ultralam® Rogers 3850 (lossy) substrate simulated on CST® Microwave Studio.

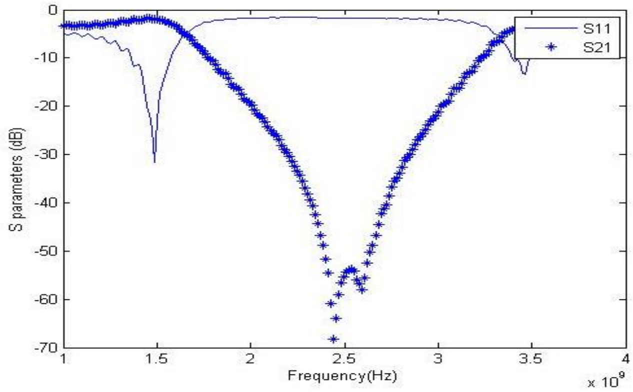
For this substrate, a prototype was manufactured and put to test in order to corroborate the theory previously quoted. To create a band-stop filter, a disposable quarter-wave open circuit stub was implemented and connected with a vector network analyser (VNA), as shown in Figure 5.



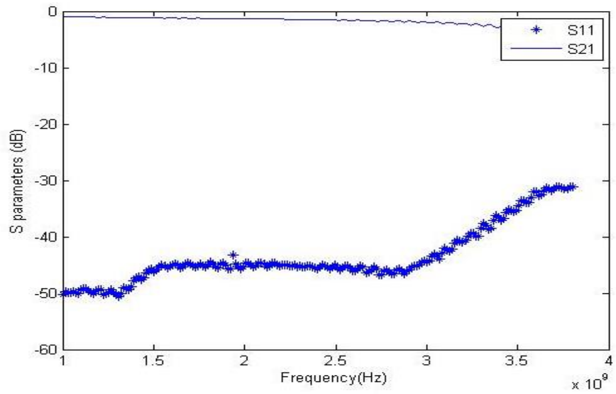
(a) (b)

Fig. 5. Resonator prototype manufactured on flexible substrate: (a) before with the network analyzer and (b) after being broken.

The scattering parameters for this prototype were then measured and shown on a frequency range from 1 to 4 GHz, as Fig. 6 (a) and (b).




(a)




(b)

Fig. 6. Scattering parameters for a band stop filter prototype acting as a crack sensor prototype with Ultralam® Rogers 3850 (lossy) substrate (a) before and (b) after being broken.

In Fig. 6 the measured transmission and reflection coefficients are reported for the filter prototype before and after being broken. It is demonstrated that the breaking does significantly affect the stub resonator performance, causing a variation in the received signal at 2.5 GHz.

2. *Melinex 339 Substrate – 0.05 mm thickness*

The same procedure was made for this substrate. Such material offers many convenient high frequencies performances for this application, such as high mechanical flexibility [6]. For this material, the parameters were of d = 15.96 mm, h = 0.05 mm and l = 26.4 mm. The other values remained the same from the previous substrate. The parameters of the microstrip line were again changed in order to achieve maximum power transfer and matching circuitry.

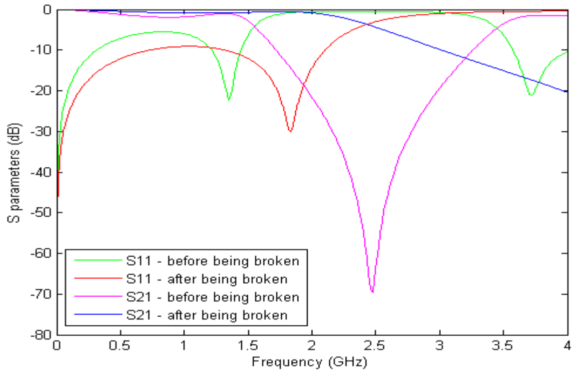



Fig. 7. Scattering parameters for a band stop filter acting as a crack sensor prototype with Melinex® 339 (lossy) substrate simulated on CST® Microwave Studio.

In Figure 7, it is clearly seen that, in the desired frequency band (2.5 GHz), the filter's performance is significantly altered, proving that it is possible to manufacture a prototype working as a crack sensor using this type of material.

### 3. *Melinex 339 Substrate – 0.1 mm thickness*

Similarly, the crack sensor substrate was altered, leading to different dimensions for the feed line width and stub length due to a different $\varepsilon_r$. Hence, Figure 8 shows the resonator's behaviour before and after being broken. Again, for this substrate, in order to maximize power transfer, the parameters were found to be of d = 16.07 mm, h = 0.1 mm and l = 16.4, with the remaining parameters left unaltered.

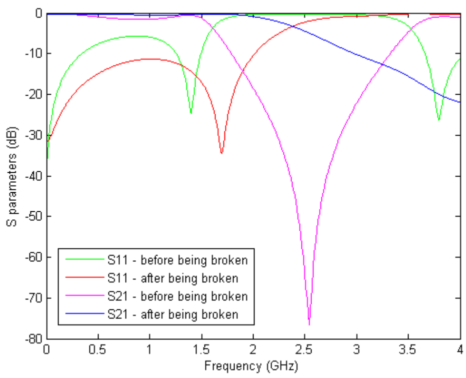



Fig. 8. Scattering parameters for a band stop filter acting as a crack sensor prototype with Melinex® 339 (lossy) substrate simulated on CST® Microwave Studio.

Comparing this filter with the former one, it is visible from graphical analysis that is has a greater magnitude decrease in the refflection coefficient, depiciting a better resonance. However, it is not significantly changed, indicating that, for the same material, thickness, while having minor variations, is not a leading parameter on filter performance.

## IV. CONCLUSIONS

In this paper, a parametric study of a band rejection filter on flexible substrate, operating in the 2.5GHz band was performed. It has been proved the idea of using this structure in chipless tags working as sensor, since it was observed that the breaking does significantly affect the structure's response. When a crack occurs in a RFID chipless tag, it sends the reflected signal with such modifications which generates an alarm. This type of tag can be also used in a scenario where there are multiple tags connected to a desired communication circuit, and if a problem appears it would be easily detected, given that each tag is provided with a crack sensor.

This study has opened new perspectives of resonant microwave filter design with different substrates, since their dimensions and costs are significantly altered while these materials are changed. Another field of research can be found in whether the substrate characteristics can impair or improve filter performance, and new materials design specifically for crack sensoring in this approach, using different types of distributed elements.

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