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Metal crack size recognizing used circular patch antenna

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Abstract. Metal crack size recognition based on a circular patch antenna is presented in this article. The material under investigation is positioned onto the microstrip antenna's ground plane. Subsequently, antenna parameters such as return loss, VSWR, and resonance frequency shift are analyzed to ascertain their correlation with the length of cracks occurring within the metal. This study seeks to establish relationships between these antenna parameters and crack length, ultimately aiming to develop a crack detection methodology using the microstrip antenna. The testing results have revealed a significant correlation between the microstrip antenna parameters and the length of cracks within the metal material. Notably, the VSWR parameter of the antenna exhibits a correlation coefficient of 0.9881, while the resonance frequency shift displays a correlation coefficient of 0.9891.

1 Introduction

Monitoring building health during its implementation pertains to detecting damages and characterization strategies for structural components. Crack refers to alterations in the structural system's material composition or geometric attributes in this context, encompassing changes in the system's connectivity that influence its overall performance. In construction projects, during and after the construction phase, issues with iron plates are frequently encountered, such as corrosion, voids, and cracks induced by external loads and physical processes. There is a need for instruments capable of assessing such suitability, thereby preventing material defects[1].

The microstrip antenna is one of the distinctive types of antennas, characterized by its diminutive dimensions and wireless conduction capabilities[2]. This antenna structure encompasses a dielectric substrate affixed to a fundamental plane, the ground plane, housing the radiation elements within[3]. The microstrip antenna design is significant in modern wireless communication systems due to its compact form factor and efficient radiation properties. Its integration with dielectric materials and ground plane configuration enables effective signal propagation and reception, contributing to its prominence in various research and practical applications within wireless communication technology[4].

Microstrip antennas have been extensively researched and developed as a means of detecting cracks in metal structures[5]. The intricate interplay of electromagnetic interactions within these antennas offers a promising avenue for non-destructive testing and structural health assessment[6]. The ability to exploit the changes in antenna parameters, such as return loss, VSWR, and resonance frequency shift, in response to cracks in the material has garnered significant attention within the scientific community[7]. This attention is driven by the potential to establish accurate and efficient crack detection methodologies, which in turn contribute to the safety and reliability of various industries relying on structural integrity[8].

In this study, a microstrip antenna is designed, utilizing a circular radiating element with a microstrip line feed, operating at a central frequency of 2450 MHz. This antenna employs a varying crack size technique by modifying the crack dimensions based on their respective positions and angles. This research investigates the impact of crack dimensions on antenna performance and resonant behaviour. The circular radiating element allows for precise adjustments in crack dimensions, enabling the exploration of different crack geometries. By systematically altering the crack sizes about their positions and angles, the study seeks to comprehend the intricate interplay between crack characteristics and antenna response. The findings of this research contribute to the advancement of crack detection methodologies in microstrip antennas and enhance the understanding of how varying crack parameters influence the antenna's operational effectiveness.

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2 Method

The microstrip antenna employed in this research forms a circular patch, resonating at a frequency of 2450 MHz. Mathematical computations were used in the initial design, subsequently optimized to achieve an antenna configuration with minimal return loss precisely at the 2450 MHz frequency. The microstrip antenna's dimensional parameters are illustrated in Fig. 1, serving as a reference for the antenna's physical structure and geometry. This design approach blends theoretical calculations with empirical optimization, resulting in an antenna configuration tailored to exhibit optimal performance characteristics at the specified frequency of operation.

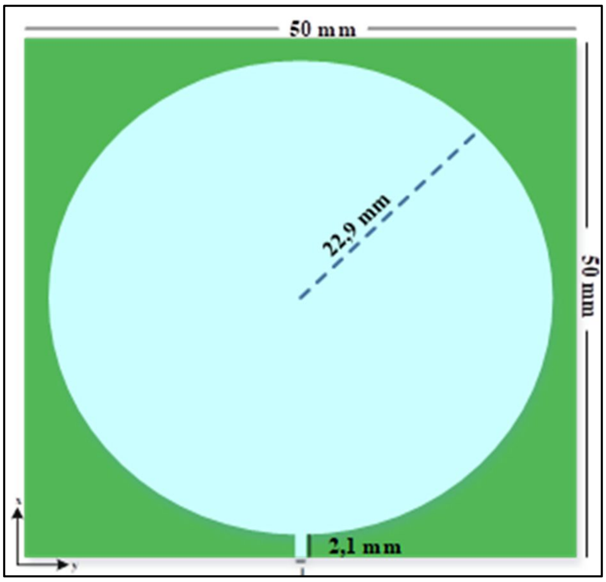

Fig. 1. Antenna design.

The antenna employs a Substrate (RO3210) with a relative permittivity value of 10.2 and a substrate thickness of 1.28 mm. The antenna's simulation process is conducted utilizing finite element method computations. This advanced numerical technique enables the accurate modelling and analysis of the antenna's electromagnetic behaviour, considering the complex interactions between various components and the surrounding environment. The choice of Substrate (RO3210) material, characterized by its relative permittivity and specific thickness, is pivotal in determining the antenna's impedance matching and radiation characteristics.

The simulation results of the antenna are presented in Figure 2. Based on the simulation outcomes, the antenna exhibits a minimum return loss value of -20.2837 dB at the frequency of 2450 MHz. This distinctive point on the return loss curve signifies the frequency at which the antenna resonates most effectively, leading to optimized energy transmission and reception characteristics. The achieved minimum return loss value at the specified frequency underscores the antenna's resonance behaviour and corroborates the accuracy of the design and optimization process. This resonance phenomenon is vital for ensuring efficient signal transmission and reception, critical aspects of the antenna's overall performance.

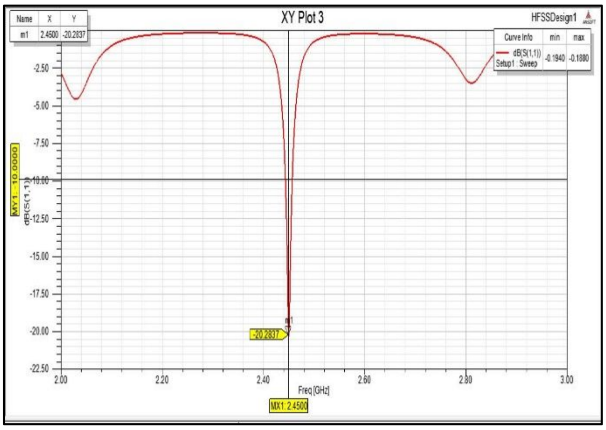

Fig. 2. Return loss simulation result.

2.1 Crack sensor

Upon obtaining the designed patch layout, feed channel configuration, and antenna substrate dimensions by the specified parameters, the subsequent step involves characterizing the antenna's capabilities as a crack detection sensor. This is accomplished by inducing cracks in the ground plane of the antenna. For this testing phase, cracks are simulated using rectangular slots. The ground plane in this study is assumed to be metal as the testing material. The dimensions of the testing metal specimen are 150 mm x 400 mm, as illustrated in Figure 3.

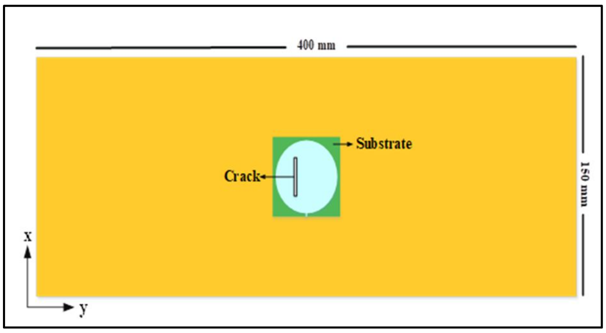

Fig. 3. Crack sensor method.

3 Result and discussion

The microstrip antenna sensor that has been meticulously designed is subsequently subjected to testing to detect cracks in metal specimens. These cracks possess a standardized width of 1 mm, while the length of the cracks is systematically varied. This experimental phase evaluates the antenna sensor's effectiveness in accurately identifying and characterizing cracks within metal specimens of varying lengths.

The antenna parameters under analysis for crack detection include return loss, VSWR (Voltage Standing Wave Ratio), and resonance frequency shift. These parameters are pivotal in assessing the antenna sensor's efficacy in identifying and quantifying cracks within the material. Return loss quantifies the discrepancy between incident and reflected signals, highlighting the antenna's impedance match. VSWR offers insights into the impedance mismatch, indicating energy reflection efficiency. Resonance frequency shift, on the other hand, portrays alterations in the frequency at which the antenna resonates optimally. These parameters collectively facilitate a comprehensive evaluation of the antenna's response to different crack dimensions, aiding in determining its proficiency as a crack detection sensor.

The simulation results for the antenna's return loss at its initial resonant frequency can be observed in Figure 4. This graphical representation illustrates the extent of signal reflection at the antenna's resonant point, thereby indicating the level of impedance match between the antenna and its surroundings.

Based on the provided data, it is evident that variations in crack length exert a linear influence on the return loss values. The observed relationship underscores the consistent and proportional change in return loss with alterations in crack dimensions. This linear correlation signifies that as the crack length is modified, the resultant impact on the antenna's impedance matching is predictable and proportionate. This empirical observation reinforces the understanding of how cracks in the material affect the antenna's performance, particularly in impedance behaviour, which is a crucial indicator of the structural changes occurring within the metal specimen.

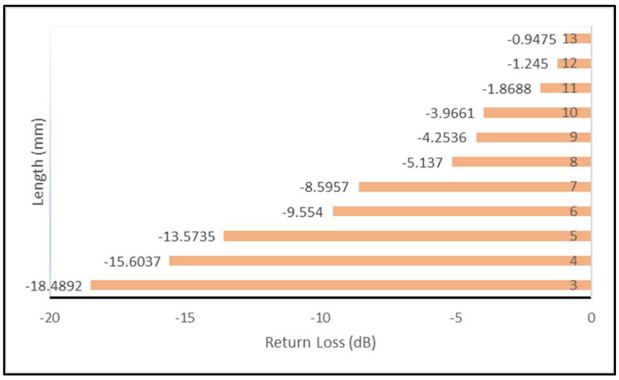

Fig 4. Return loss for various length crack.

Another antenna parameter analyzed for crack detection is VSWR (Voltage Standing Wave Ratio). As depicted in Figure 5, the VSWR values of the antenna exhibit a notable correlation with the length of cracks within the metal specimen. The trend approximation demonstrates a substantial correlation coefficient of 0.9881, achieved through a third-order polynomial fit. This substantial correlation underscores the strong relationship between variations in crack length and changes in the VSWR values observed in the antenna's response.

The length of the crack introduced onto the microstrip antenna's ground plane significantly impacts the antenna's impedance, resulting in a resonance frequency shift, as illustrated in Figure 6. This graphical representation visually portrays the relationship between crack length and the resultant antenna's resonant frequency alterations. The observed frequency shift is a direct consequence of the impedance changes induced by the crack's presence and dimensions. This shift in resonance frequency directly indicates the crack's influence on the antenna's performance characteristics, providing valuable insights into the crack-detection capabilities of the antenna sensor.

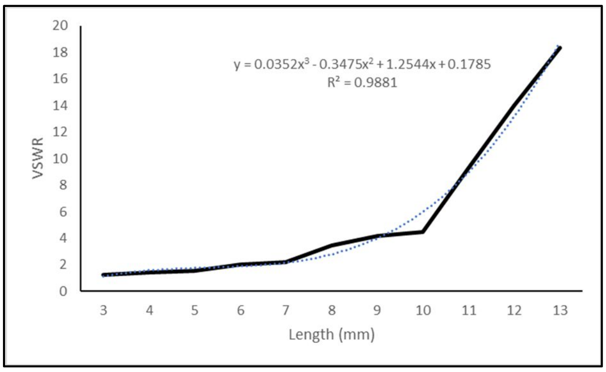

Fig 5. VSWR for various length crack.

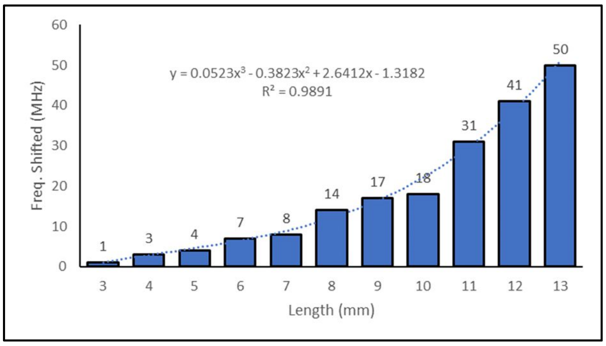

Fig 6. Frequency shifted for various length cracks.

The correlation between the resonance frequency shift of the antenna and the crack length yields a coefficient of 0.9891. The trend employed for this analysis is a third-order polynomial fit. This correlation coefficient slightly surpasses the correlation coefficient obtained from the VSWR parameter analysis. This robust correlation underscores the closely linked relationship between changes in the antenna's resonant frequency and variations in the length of the crack. The higher correlation coefficient emphasizes the antenna's resonant frequency sensitivity as a reliable indicator of crack presence and length. This finding reinforces the antenna's efficacy as a crack detection sensor, providing a nuanced perspective into its capacity to identify and quantify structural changes within the metal specimen.

4 Conclusion

The microstrip circular patch antenna operating at 2450 MHz frequency can effectively serve as a sensor for crack detection in metals. The testing results have revealed a significant correlation between the microstrip antenna parameters and the length of cracks within the metal material. Notably, the VSWR parameter of the antenna exhibits a correlation coefficient of 0.9881, while the resonance frequency shift displays a correlation coefficient of 0.9891. Both of these correlations were established using a third-order polynomial approximation. These findings highlight the strong relationships between the antenna's performance parameters and crack dimensions. The obtained correlation coefficients further underscore the robustness of the antenna's response in detecting changes within the metal structure. The antenna's sensitivity to VSWR and resonance frequency shifts amplifies its potential as a reliable crack detection sensor. In conclusion, the microstrip circular patch antenna demonstrates its capacity to discern and quantify metal crack lengths, substantiating its feasibility as an efficient crack detection tool for structural health assessment.

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