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Crack Detection using Chipless RFID Based Split Box Resonator

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Abstract: *The notion of a chipless radio-frequency identification-based ubiquitous crack sensing technique for structural health monitoring is presented in this article. This plan includes the creation of a new sensor that can detect structural deformations at any point on its surface in a continuous or nondiscretized manner. The suggested sensor can detect the growth and spread of fractures in a building structure's region. A sensitive microwave structure consisting of cascaded innovative split box resonators is connected to a coplanar waveguide (CPW)-based transmission line in the smart skin sensor. This enables it to provide continuous fracture detection as well as the capacity to identify several structural disturbances at the same time.*

Keywords: Radio-Frequency Identification

I. INTRODUCTION

Due to the low cost and simplicity of sensor nodes, chipless radio-frequency identification based wireless sensor networks are developing as an unavoidable technology in our society to come.Due to its durability in operation and cost-effectiveness, as well as specific characteristics that can endure difficult environments such as extreme humid and dry conditions, temperatures exceeding 80°C, and cryogenic temperatures near to absolute 0°K, the chipless RFID sensor has significant promise. It also offers a variety of unique qualities, including the ability to be totally printable, passive, disposable, and ecologically friendly. The potential benefits of these unique properties allow chipless RFID sensor nodes to be used in applications that were previously impossible to achieve with regular RFID tags and sensors [1].

The development of low-cost chipless RFID sensor nodes has been facilitated by advancements in wireless communications, micro/nanofabrication, printed electronics, and integrated circuit technologies. As these technologies advance, the possibility of mass manufacturing and development of sensor nodes becomes more apparent. These innovative and ubiquitous sensor nodes are being used to investigate new application areas. Smart cities, food safety, military,disaster management, health, home and security ,agriculture, and environmental monitoring are just some of the applications for the chipless RFID sensor [2]. There are distinct technological difficulties that researchers are presently overcoming for each application area. However, many of them are attempting to solve the technological obstacle that is unique to their application. The suggested sensor can detect the growth and spread of fractures in a building structure's region. A sensitive microwave structure constructed of cascaded unique split box resonators connected to a coplanar waveguide (CPW) based transmission line is used in this sensor. This enables it to provide continuous fracture detection as well as the capacity to identify several structural disturbances at the same time.The design and analysis of a new chipless RFID-based sensor for non-discretized crack monitoring and moisture intrusion detection is proposed in this study. The sensor, which is made up of cascaded splitbox resonators, can provide continuous crack detection thanks to its particular microwave structure, which is very sensitive to any external deformation. The suggested sensor can also detect several structural deformations at the same time, making it an excellent alternative for the SHM sector [3].

RFID is a contactless ID technology that uses radio frequency signals to automatically identify target devices and retrieve pertinent data without the need for human participation. However, as compared to barcodes, the greater production cost of chip-based RFID tags prevents them from being extensively employed. Chipless RFID, which refers to RFID tags that do not contain silicon chips, is a recent innovation in RFID technology [4]. It has been combined with pressure, humidity, temperature, gas, and strain sensors for various practical applications, lowering the manufacturing cost. The chipless RFID tag has the inherent capacity to resist the tough operational environment without the need of a silicon chip It helps detect the malfunctioning asset with high confidence by connecting the open-ended microstrip line output of each chipless RFID tag to a sensing coil and putting it directly on a suitable place of an electrical asset [3]. Low-frequency,ultrahigh frequency, and ultra-wideband chipless RFIDs have been researched in recent years for defect detection on metallic constructions, notably fracture detection. Chipless RFID has a number of benefits over existing standards in terms of cost, sensing capabilities, and the ability to perform in difficult settings. By using a circular patch antenna as the crack sensor, it was revealed that a chipless RFID sensor tag may have a multi-parameter sensing capacity, allowing characterization of fracture direction as well as crack breadth. Because the technology operates in a wide bandwidth, frequency signature based chipless RFID may enable multi-parameter sensing [5] Cross-polarization reading and temporal separation detection have recently been proposed in the literature to address the readability and robustness issues in general chipless RFID systems. The chipless RFID tag response may be isolated from undesired reflections using cross-polarization reading, and the temporal separation detection utilising the short-time Fourier transform (STFT) can further separate the tag response from clutters. These approaches have not yet been deployed and researched for chipless RFID-based SHM systems, and in particular for crack characterisation [1].

II. BACKGROUND

A. Chipless RFID Sensors : Working Principle

Chipless RFID tags are linked to a specific RF reader, which interrogates the tag and extracts the data it contains. The reader's operation is based on the transmission of a particular electromagnetic (EM) signal to the tag, followed by the collection of the signal reflected by the tag. The information included in the tag can be recovered by processing the signal received—most commonly via a decoding stage. Chipless RFID tags, on the other hand, are fundamentally different from RFID tags. In the latter, the reader sends a specific frame to the tag using a traditional binary modulation scheme. The tag demodulates this signal, evaluates the request, perhaps stores data to memory, and modulates its burden by sending back a response.Chipless RFID tags, on the other hand, don't need a communication protocol to work. They make use of a grid of dipole antennas tuned to various frequencies. The interrogator sends out a frequency sweep signal while scanning for signal dips. One bit can be encoded by each dipole antenna. The antenna length will decide the frequency scanned. They can be thought of as radar targets with a distinct, stationary temporal or frequency signature. The remote reading of an identifier using this technique entails assessing the tag's radar signal.

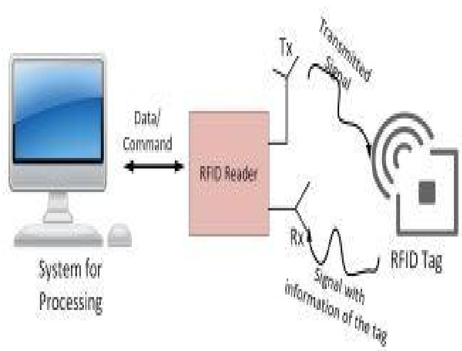

Fig. 1. A chipless RFID and generic RFID system

A scanning antenna, a transceiver, and a transponder are the three components of every RFID system. An RFID reader or interrogator is created when the scanning antenna and transceiver are coupled. Fixed readers and mobile readers are the two types of RFID readers. The RFID reader is a networkconnected device that can be either portable or fixed [6].

Real World Applications of Chipless RFID as Crack Sensor

Chipless RFID is widely utilised for data collection and object characterisation in the commercial and industrial sectors.For fracture detection on metal surfaces, chipless RFID is utilised as a crack sensor.The proposed sensor combines a gap coupled split box resonator array with a Coplanar resonator. The creation and propagation of fatigue fractures on the metallic surface is caused by cyclic stress of mechanical components. Hidden flaws in structural components cause fracture and cause the structure to deteriorate. As a result, fatigue crack examination is becoming increasingly important, particularly in aircraft fuselage, wire ropes,and railway tracks. For detecting surface cracks in metallic surfaces, several electromagnetic nondestructive testing techniques had been used [1], [6].

III. CRACK SENSOR

An array of gap coupled split box resonators is merged with a Coplanar Waveguide(CPW) transmission line that is deployed on a structural surface in the suggested sensor. In the frequency domain, the conductive surface of the CPW line becomes extremely sensitive, and its response varies even with minor perturbations. This one-of-a-kind characteristic is used here to enable unbroken and continuous fracture detection over the whole surface. It detects the existence of a fracture even when none of its detecting (split box) resonators are physically disturbed.Because the resonators on a sensing tag are engineered to work at different frequencies, they can help identify several cracks or ruptures on different parts of the sensing surface at the same time.

The suggested technology is a sensor since it can detect disruption across its entire surface, exactly like human skin. Due to the development of cracks and the distribution of moisture across the surface, this sensor can produce a noticeably altered signal response. As a result, not only can the sensor identify cracks, but it can also monitor moisture infiltration or dampening in a structural material. This sensor can be used to monitor key zones of beams and columns in buildings and bridges, especially those that are prone to unexpected, catastrophic breakdowns.

IV. RESONATOR SELECTION AND SENSOR DESIGN

The cascaded split box resonator-based sensing tag is introduced in this section of the study. The developed tag is utilised to detect structural cracks in a non-discriminatory manner, as shown in the following sections. The generalised diagram of a single split box resonator coupled to a CPW transmission line is shown in Fig. 3. The resonator is etched out of the CPW line's copper layer here. The ground plane is visible on both sides of the CPW line, indicating that it contains a one-sided metallization layer.

4.1 Benefits of Split Box Resonators

Split box resonators have a construction and features that are comparable to spiral resonators, which are more commonly employed in chipless RFID. Split box resonators feature a box-shaped construction with one of its corners split, as the name implies. Compared to their spiral counterparts, they have a number of benefits. They can improve the spacing between consecutive harmonics while increasing the quality factor.When a structure has a high-quality factor, it suggests it can store more energy, making it easier to detect wirelessly while being probed with a reader. In this case, the resonators are coupled to a CPW transmission line with two corresponding replicators on both sides of the ground. The split box resonator, on the other hand, is useful for resolving problems such as mutual coupling with neighbouring frequency notches and a low Q factor. This split box resonance guarantees that the tag is easier to read and eliminates the possibility of interference or mutual coupling. The split box resonator is a better choice for the sensing tag presented here because of these features.

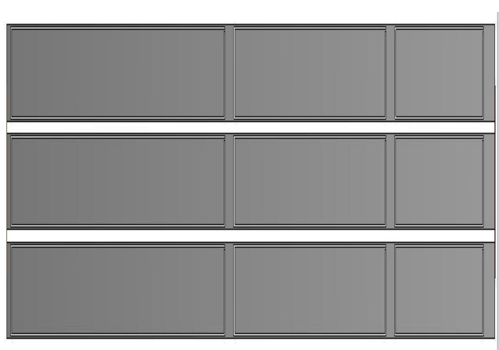

Fig. 2. Split Box Resonator

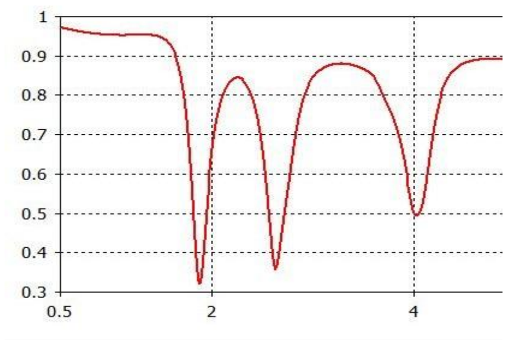

Fig. 3. Split Box Resonator Frequency Response

4.2 The Frequency Response of a Customized Sensing Tag

The existence and opening of cracks in a building structure are detected using a sensor tag. s the created tag, which is made up of three split box resonators connected by a CPW transmission line. Two replicators are also installed on both sides of the ground plane to improve the minimum detection/resonance depth of the resonances. Three frequency signatures are generated by the resonators and their replicators. There is a notable variation in RF performance if a fracture develops anywhere on the sensor structure. The FR-4 substrate material was used to create this tag. The copper coating on the substrate is just 35 um thick, hence this material is only
0.5 mm thick.

4.3 Insights that have been simulated

Through simulated analysis, various generalised situations of the sensor's RF performance variation owing to crack propagation are described in this section. CST microwave studio's Boolean subtraction function is used to represent the fracture on the sensor structure. Between the resonators, there is a vertical fracture. Due to the presence of a fracture across the sensing structure, the sensor signal amplitude has dropped. Because the resonators are not physically disrupted, each of the frequency notches corresponding to 3 resonators is still present. However, as seen, the existence of a fracture generated amplitude level fluctuation or damaged resonators are completely removed [6].

V. CRACKS IN SPLIT BOX RESONATORS

The sensor tag is developed in the split box resonator to detect the presence and opening of cracks in a building structure. The created tag, which is made up of three split box resonators connected by a CPW transmission line, Two replicators are also installed on both sides of the ground plane to improve the minimum detection/resonance depth of the resonances. If a fracture develops anywhere on the sensor structure, the RF performance suffers noticeably. Taconic TLX-9 substrate material was used to create this tag. The copper coating on the substrate is only 35 um thick, hence this material is only
0.5 mm thick. As can be seen, the sensor signal amplitude has dthe presence of crack caused the amplitude level variation or the resonance notches for the fractured resonators have been completely eradicated

1 *Vertical Crack:* As observed, the existence of a vertical crack in resonator produced amplitude level fluctuation and resonance notches for cracked resonators were completely removed. icated.
2 *Horizontal Crack:* The impacts of horizontal fractures are examined in this section of the research. Because these fractures do not completely impede the signal flow on the transmission lines or ground planes, they have a lower influence on the sensing structure. As a result, it'll be fascinating to see if they can get the sensor to produce enough signal deviation.

5.1 Vertical Crack

Vertical Crack in First Resonator: The effect of a thin vertical fracture on the sensor's surface is the starting point for the sensor's experimental study. In this situation, a crack with a width of 0.2mm appears on various regions of the sensor. The results of the following investigation show how such fractures respond on distinct cutting zones of the sensor and

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how they differ from the reaction of a healthy structure.Resonant frequency shifts towards left like from 4.03GHz to 2.3GHz and amplitude level fluctuation due to the existence of a vertical crack in the first resonator.

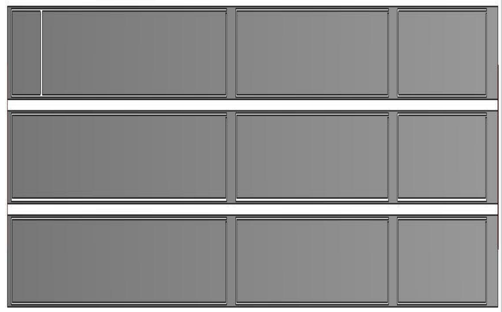


Fig. 4. Split Box Resonator with vertical crack in first resonator

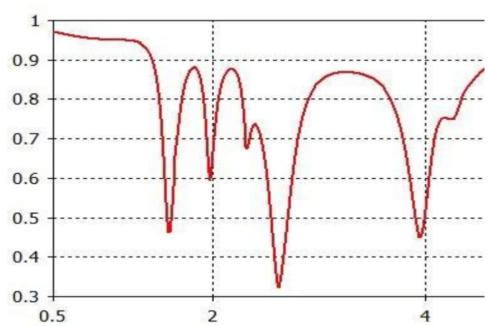


Fig. 5. Freqency Response of Split Box Resonator with vertical crack in first resonator

5.2 Vertical Crack in Second Resonator

Due to the presence of a vertical fracture in the second resonator, the resonant frequency changes to the left and the amplitude level fluctuates.In this situation, a 0.2 mm wide fracture appears on the sensor causes frequency shift and amplitude variation

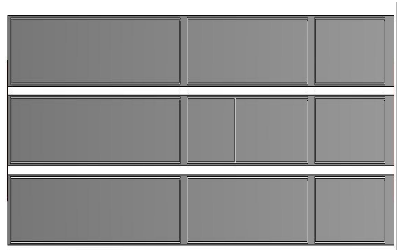


Fig. 6. Split Box Resonator with vertical crack in second resonator

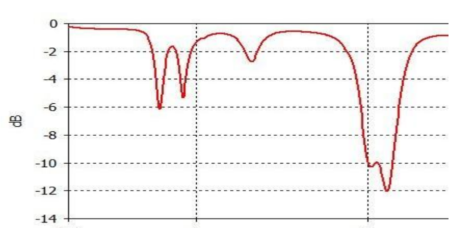


Fig. 7. Freqency Response of Split Box Resonator with vertical crack in second resonator

5.3 Vertical Crack in Third Resonator

Frequency shift and amplitude level change are also caused by a crack in this resonator.

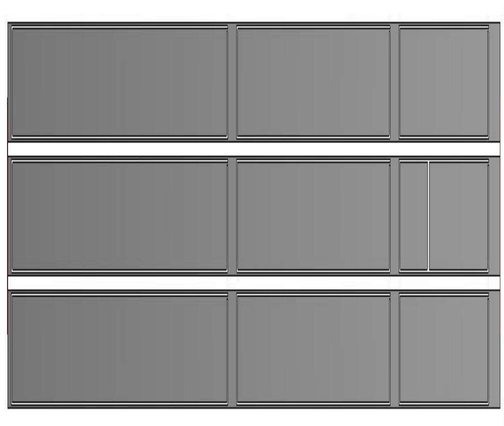


Fig. 8. Split Box Resonator with vertical crack in third resonator

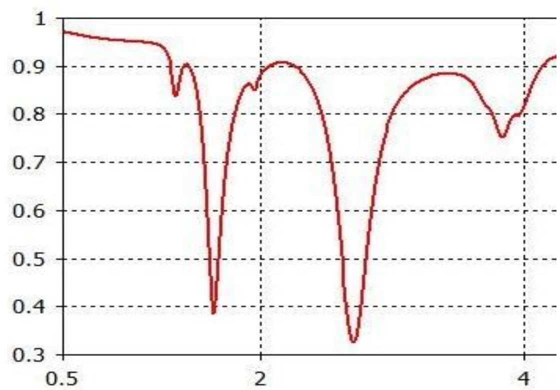


Fig. 9. Freqency Response of Split Box Resonator with vertical crack in third resonator

5.4 Horizontal Crack

Horizontal Crack in First Resonator: The impacts of horizontal fractures are examined in this section of the research. Because these fractures There was a shift in frequency response and amplitude

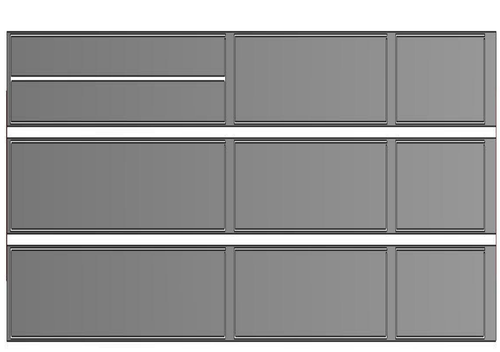


Fig. 10. Split Box Resonator with horizontal crack in first resonator

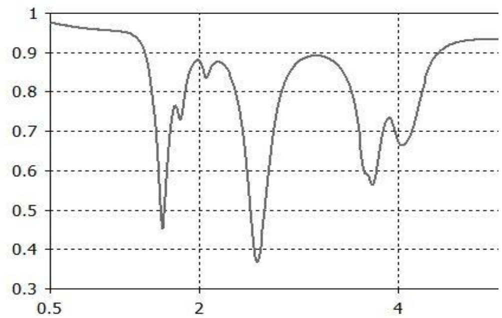


Fig. 11. Freqency Response of Split Box Resonator with horizontal crack in first resonator

Horizontal Crack in second Resonator

There is a slight frequency shift and amplitude change due to the presence of a horizontal fracture in the resonator.

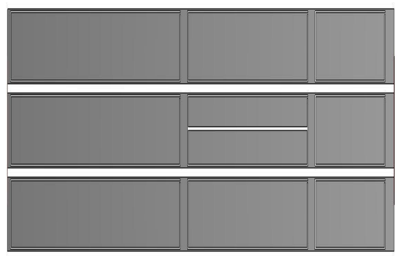


Fig. 12. Split Box Resonator with horizontal crack in second resonator

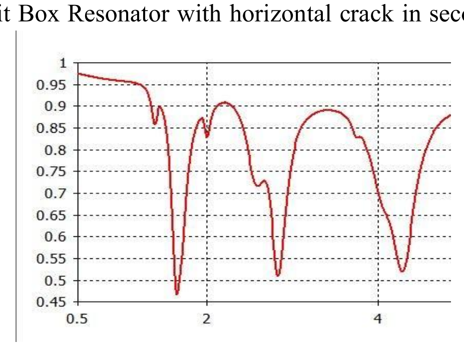
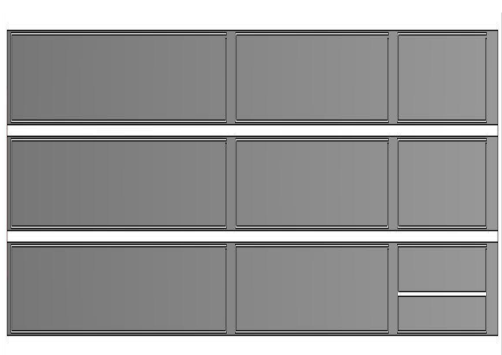


Fig. 13. Frequency Response of Split Box Resonator with horizontal crack in second resonator

Horizontal Crack in third Resonator



There is also a shift in frequency response and a change in frequency response.

Fig. 14. Split Box Resonator with horizontal crack in third resonator

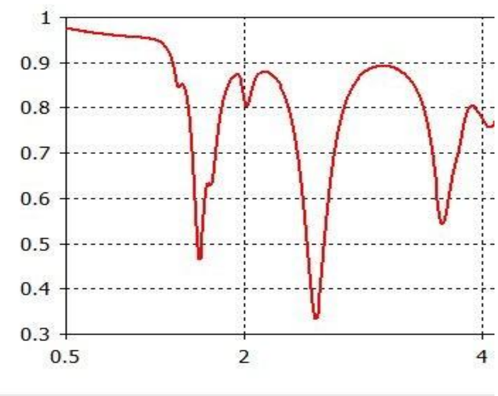


Fig. 15. Freqency Response of Split Box Resonator with horizontal crack in third resonator

VI. BENDING OF RESONATORS

We can demonstrate that resonators are flexible by bending them. Bending produces the same outcome as not bending. The frequency response of resonators with bend cracks can be found by altering the amplitude or by vanishing the frequency response.The bending of resonators and their frequency response are depicted in the diagrams below.

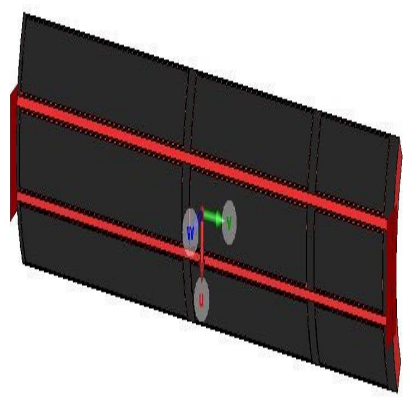


Fig. 16. Split Box Resonator with Bend

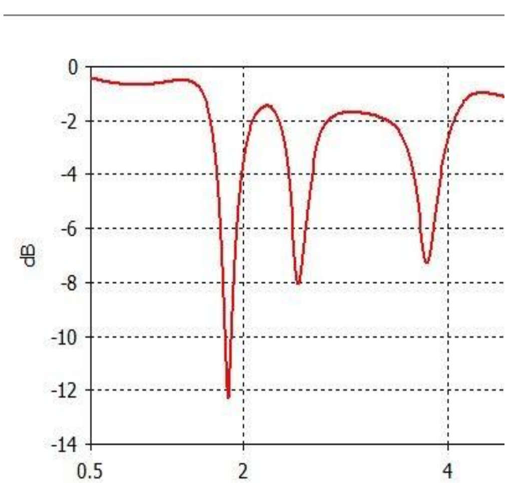


Fig. 17. Frequency response of split Box Resonator with Bend

Bending of Resonators with horizontal crack in resonator

Changes in amplitude and frequency can be used to investigate the horizontal fracture in the resonator.The outcome of vertical bending is seen in the diagram below

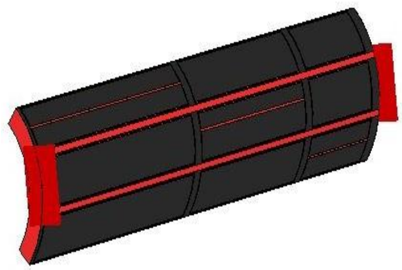


Fig. 18. Horizontal crack in resonator of split Box with Bend

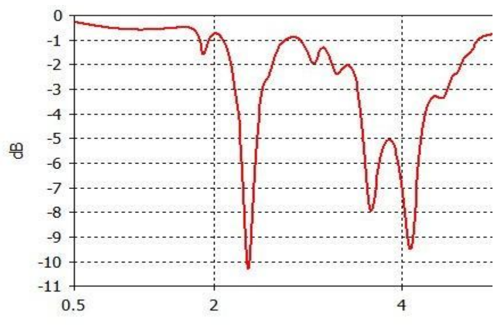


Fig. 19. Frequency response of Horizontal crack in resonator of split Box with Bend

Bending of Resonators with vertical crack in resonator

Changes in amplitude and variance in frequency response can also indicate vertical bending.The outcome of vertical bending is seen in the diagram below.

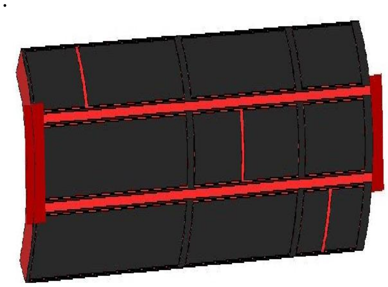


Fig. 20. Frequency response of vertical crack in resonator of split Box with Bend

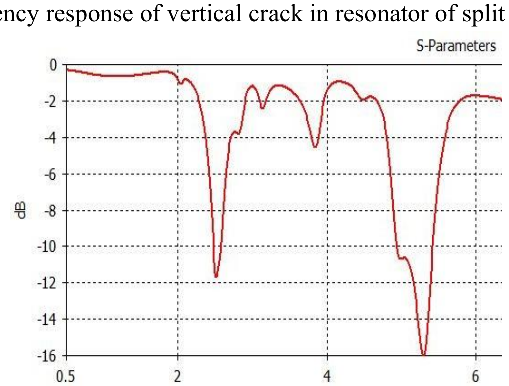


Fig. 21. Frequency response of vertical crack in resonator of split Box with Bend

VIII. CONCLUSION

The accompanying study depicts the innovative crack sensor in great detail. Due to its unique attribute of responding to a minor disruption on its surface, this novel non-discretized crack sensor." This gadget can also detect several ruptures on the same structure at the same time. The shown analysis delineates a few simulated generalised scenarios that are later confirmed by an in-depth examination of empirically observed data.

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