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# Highly sensitive frequency selective surface for structural health monitoring system

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**ABSTRACT**

This paper is introduced a passive sensor to detect the performance of the structure using three-dimensional (3D) Frequency Selective Surfaces (FSS). The proposed 3D Circular FSS results are proved behave as passive sensor with changing of sensitivity incident angles to be apply in Structural Health Monitoring (SHM) system. Moreover, this 3D Circular FSS capable to operate without stand to any (DC/AC) power and very low cost in term of installation and maintenance.



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## 1. INTRODUCTION

Following the tragic earthquake in Sabah, there are concerns that the earthquake could also hit others place such as national capital and most residents global city of Malaysia which is Kuala Lumpur. According to a geologist, Kuala Lumpur is located near the centers of the ancient fault line zone and most of our buildings are unfortunately not designed for it. Therefore, structural health monitoring (SHM) technologies for civil structures are becoming important. It is used to monitor structural changes such as tension and stress [1-3].

Structural Health Monitoring (SHM) is defined as an integrated procedure for the detection and characterization of damage to the structure or building. The systems are installed on bridges, building and highways in order to improve the capacity of damage detection. Over the past decade, the field of Structural Health Monitoring (SHM) has begun to attract the interest of researchers [4].

Nowadays, SHM system has been offered a huge beneficial for building structure safety and performance. By developing SHM system, it is proved that the percentage of safety increased. SHM is commonly applied to tracking and detect any poor structure performance such as tilting, crack and movement of structure with using various sensors [5-7]. There are many type of sensors have been proposed and applied in SHM system which are wired and wireless sensors. Besides that, mostly researchers are more concentrating to wireless sensor compared to wired sensor due to their higher active element needed and difficulties in installation [8-10].Characteristic of passive sensor has been overcome the active sensor problem in term of easier installation and maintenance, less power consumption and long term of endurance element [11-12].

Although there are a lot of works and researches that has been done in wireless sensors and their application in structural health monitoring, all these technologies still have room for improvement. These disadvantages include all these systems require a battery which has a restricted life time, require sensors which are independent from each other and also require antenna that increases the complexity, size of the sensor unit, and weight. It is also costly because they require special skills to fabricate the sensor, and finally require for a wireless sensor network which need complex software and data acquisition units (DAQ). Mostly, all the methods mentioned above is a wired sensors. These sensors have many disadvantages such as the need for installation during building. Wires also limit the structures' functionality, add more complexity to it and increase the heaviness of the structure. Therefore, a new design of technologies is becoming necessary for civil structural health monitoring (SHM)

Regarding to SHM system, wireless sensors for Structural Health Monitoring (SHM) are an emerging new technology that promises to overcome many disadvantages pertinent to conventional, wired sensors. Active wireless sensors network is one of the methods where it is used a combination system of RF communication module, microprocessor, sensing module and battery. It can broadcast the sensing signal up to 100 meter range hence give early indicator for society. Moreover, passive sensors have been developed for tracking abnormalities building structure without pertinent to power supply on itself.

## 2. 3D FREQUENCY SELECTIVE SURFACES FOR SHM DEVELOPMENT

The 3D Frequency Selective Surfaces with circular shaped was introduced here to act as a passive sensor. A good performance in term of sensitivity angular response for this circular shaped was chosen [13-14]. A new technique of 3D FSS was proposed in this paper to tracking abnormalities structure performance for SHM system. The electromagnetic wave characteristic will varies by changing the angle of FSS due to the building tilting as shown in Figure 1 (b). The changing (frequency shifting) of different electromagnetic wave characteristics were presenting in two polarizations which is TE- and TM- incident angle. For this case, the TE- and TM- incident angle required to obtain in two different characteristic frequency responses TE and TM angle such sensitive and insensitive angular response respectively. See Figure 1 (c), sensitivity of angular response indicating that the frequency response (band stop) shifting from 3.8GHz to 3.86 GHz with the angle 0° to 20° respectively. Meanwhile, insensitive frequency response (band stop) is maintained in one location of frequency response with various angles up to 60 degrees. Therefore, the building tilting is monitored by a different of sensitivity angular response changing.

The 3D Circular FSS design is shown in Figure 1(c), where behaves as a passive sensor and attached on the building structure. See Figure 2, by increasing the conducting element will render the frequency characteristic. The geometry FSS play an important role towards the frequency behavior [15]. Therefore the frequency response of FSS can be control in two different polarizations by alter the geometry size.

The FSS shape was designed in circular geometry. FSS structure was modified by elevating the height of conducting element. Besides that, 3D Circular FSS has shown the different S21 band stop results in two polarization TE and TM incident angle. Controllable FSS performance and characteristic made the two polarization results become sensitive and insensitive in various angle. Simulation on 3D FSS has been done from 0° up to 60°.

The dependence of the frequency selective surfaces response on the element height is studied as shown in Figure 2. Based on the results, shows a significant improvement in term of stability angles after increasing the height of elements 3D square FSS. See Figure 3 to 5, the height of the 3D square FSS was optimized from 10 mm to 25 mm while keeping its side length and unit cell size constant. TM-incident polarized becomes more stable while TE-incident polarized becomes sensitive toward incident angle as the height increasing. An increase of the element height causes a shift to higher resonant frequencies of the transmission stop band. In Figure 6 indicate that two different polarization TE-and TM- incident angle have been simulated. Result in Figure 2 (b) looks sensitive in various angles and will be used for monitoring in SHM system. Table 1 and Table 2 indicated the percentage different center frequencies in each angle as the FSS (building) changed.

Table 1. Values Center Frequencies of the 3D Circular FSS with Different Angle at TE Incident Angle

| Degree (°) | Frequency (GHz) | Deviation (%) |
|---|---|---|
| 0 | 3.81 | 0 |
| 20 | 3.816 | 0.15 |
| 40 | 3.816 | 0.15 |
| 60 | 3.815 | 0.13 |

Table 2.Values Center Frequencies of the 3D Circular FSS with Different Angle at TM Incident Angle

| Degree (°) | Frequency (GHz) | Deviation (%) |
|---|---|---|
| 0 | 3.81 | 0 |
| 20 | 3.893 | 2.17 |
| 40 | 4.12 | 8.13 |
| 60 | 4.38 | 14.9 |

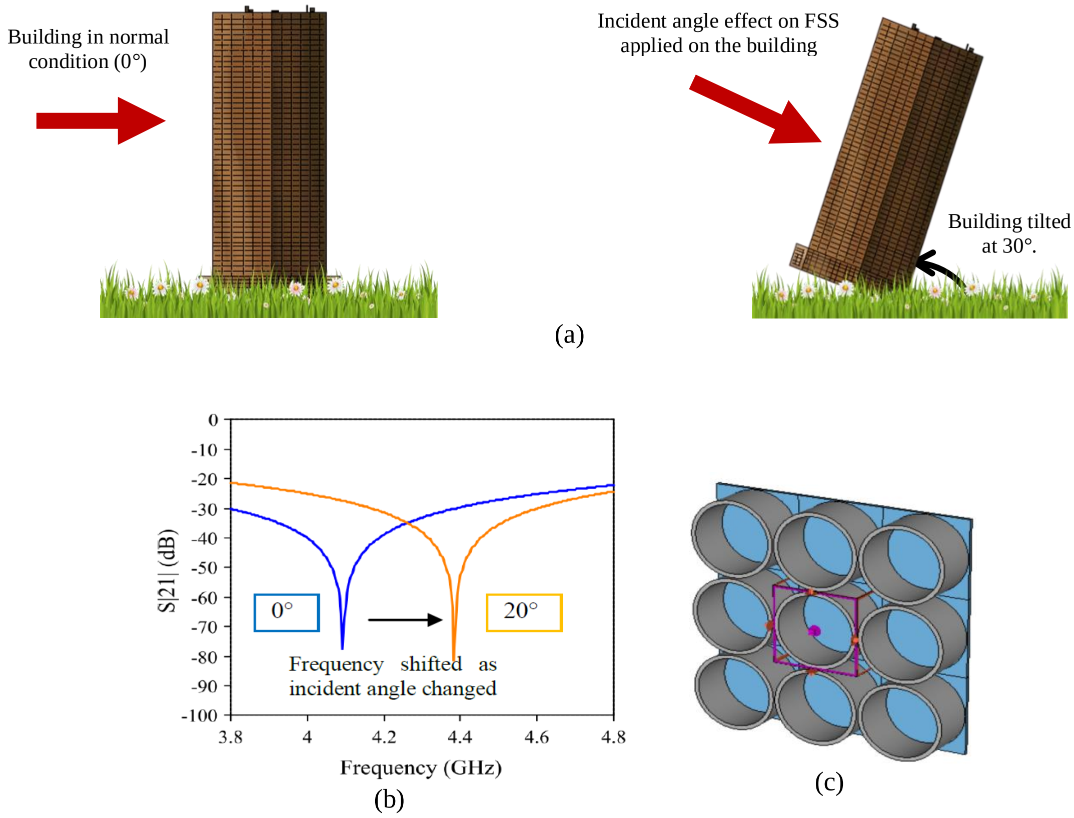



Figure 1. (a) Incident angle effect as building tilting (b) Frequency response shifting as incident angle changed (from 0° to 20°) (c) 3D Circular FSS design with unit cells

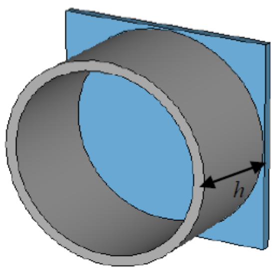



Figure 2. Elevating the height of conducting element

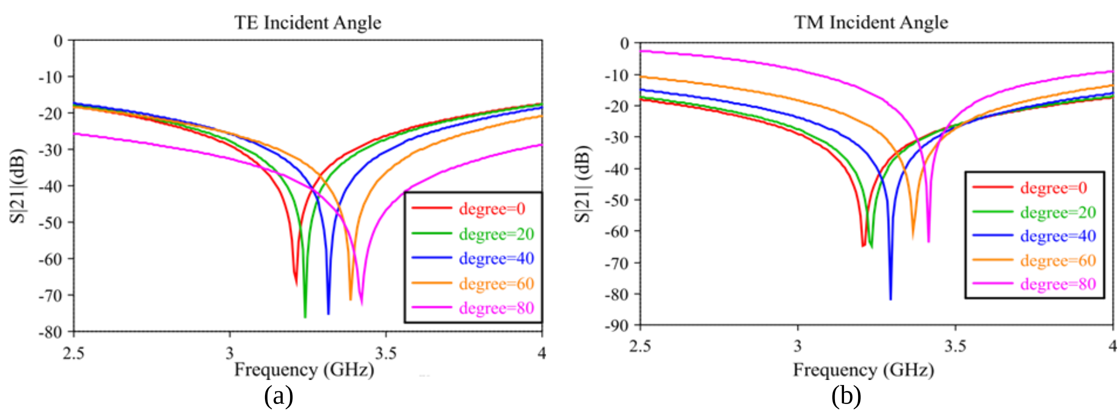
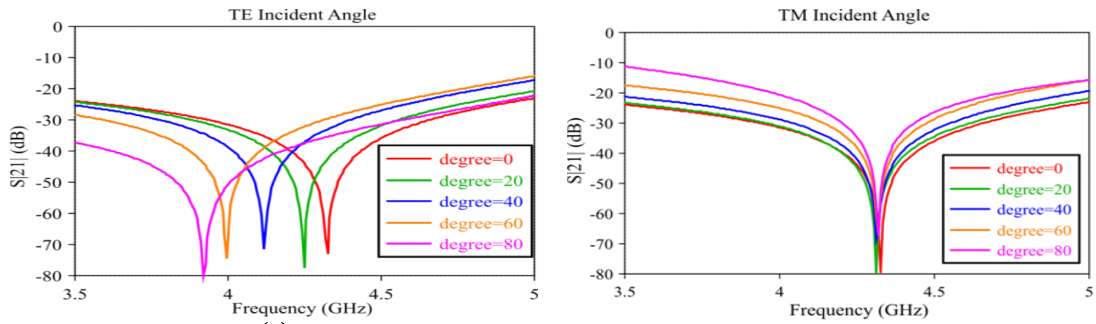
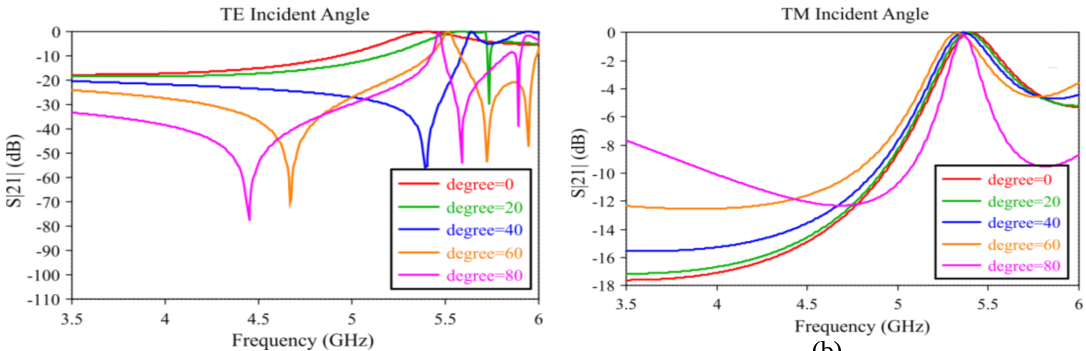



Figure 3. TE- and TM-polarized incidence at a height of 10 mm



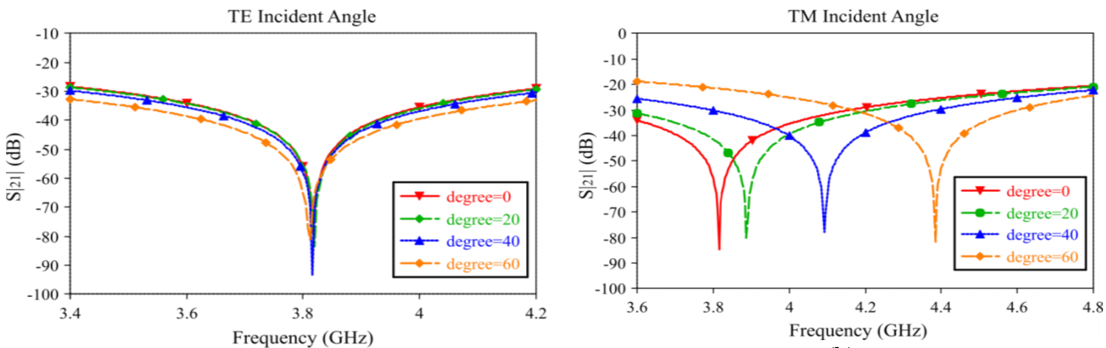

(a) (b)

Figure 4. TE- and TM-polarized incidence at a height of 18 mm




(a) (b)

Figure 5. TE- and TM-polarized incidence at a height of 25 mm




(a) (b)

Figure 6. Frequency response results up to 60° (a) TE incident angle, insensitive
(b) TM incident angle, sensitive

By changing the height of the unit elements to 10 mm, 18 mm, and 25 mm, the center of the band-stop (at 0 degree) shifted to 3.2 GHz, 4.3 GHz, and 5.3 GHz respectively. Significant rate of change can be observed in resonance upon incident angle variations and upon the height increment of the FSS conducting elements. This behavior indicates that the height of the conductor elements influenced the characteristic of the 3D FSS.

## 3. CONCLUSION

The proposed of 3D Circular FSS was introduced to perform as a passive sensor in SHM system. 3D Circular FSS able to utilize without depends on the power supply on it. Moreover, various angles S21 results shown a sensitivity incident angle (TM-polarized), meanwhile insensitivity (stable) incident angle at TE-polarized. 3D Circular FSS proved that can controlled the sensitivity incident angle in both polarizations instead of 2D FSS structure. A result in Figure 2 (b) has shown a terrific sensitivities frequency shifting as the incident angle of building changed. Therefore, a result will be used as monitoring building performance due to sensitive on different building condition

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