# DUAL-BAND MIMO ANTENNA USING GRADIENT ARCS FOR CONSTRUCTION MONITORING AND INSPECTION SYSTEMS BASED ON IIOT

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***Abstract***— Industrial Internet of Things (IIoT) is an evolution that bring great advantages of real-time monitoring and inspection in construction through the sensors as well as wireless equipment. One of the important elements of these equipment is antenna which decides the quality and performance of device over various communication standards. In this paper, a design of dual-band MIMO antenna is proposed. The antenna operates at 1.8 GHz and 2.6 GHz which cover No 3 and No7 of LTE-A bands and No.2, No.3, No.7 and No.38 of 5G NR bands of IoT communication. Basing on FR4 substrate with height of 1.6mm, the antenna get compact in size with radiating patch dimension of 25mm x 21.5mm and very thin which compared to conventional PIFA structure. Using novel adjacent arcs on the surface plane, mutual coupling between radiation elements of MIMO antenna has decreased at both operating bands with narrow distance of 0.13λ at 1.8GHz from edge to edge. A good agreement between simulations and measurements are shown in this context.

***Keywords***—IIoT, MIMO, PIFA, DGS, mutual coupling.

## I. INTRODUCTION

The present construction industry is being developed to make construction process more efficient and consequently, more profitable. One of current trends to improve productivity and decision making is smart construction or construction basing on Industrial Internet of thing (IIoT) **[1]**. IIoT cover domains of machine to machine and industrial communication technologies with automation applications through industrial standards of WirelessHART and ISA.100.11a and/ or advanced cellular technologies such as 4G/ 5G **[2]**. The IIoT components that provide the interaction for smart construction monitoring and inspection are sensors.

Different IIoT communication technologies operate at different bands. This has led to the requirement of IIoT antennas operating at multiband or wideband. Besides, Multiple Input Multiple Output (MIMO) system can increase channel capacity at both transmitting and receiving sides without bandwidth addition or transmission power increasing. Thus this technology has attracted attention in the terminal of modern wireless communication systems, especially for monitoring applications. However, has been well known, with compact size for application in sensors and wireless devices, MIMO systems have a huge challenge of high mutual coupling between antenna elements that can degrade significantly data rate of wireless system as well as total efficiency of antennas [3].

There are many methods which decrease mutual coupling between antenna elements such as grooving dielectric, covering the patch by additional dielectric layers, using shorting pins for cancellation of capacitive polarization currents of the substrate or using metamaterial structures such as defected ground structure (DGS) and Electromagnetic Band Gap (EBG). However, most of these methods are useful for single band antenna. Recently, there are a number of proposed dual band MIMO antennas with high isolation for mobile equipment but most of them use method of distance isolation [4], [5] that the distance between radiation elements in MIMO antenna rather long (higher than 0.5λ). By using neutralizing line [6], MIMO antenna gets narrow distance of 0.1225λ but the mutual coupling between radiation elements is not well, S12 parameter is -15dB at high band. These are the same for study in [7] which uses DGS method and in [8] which uses capacitive loaded loops.

In this paper, we present a novel 1x2 MIMO antenna which operates at 5G bands and is applied for smart construction system in IIoT area. The proposed antenna uses a combination of a shorting pin like Planar Inverted F Antenna (PIFA), a triple rectangular DGS [9] and novel adjacent arcs on the surface plane is proposed. Based on FR4 substrate with the height of 1.6mm, the antenna has got compact radiating elements with size of 25x21.5mm$^2$ and operates at 1.8GHz and 2.6GHz which are two main 4G-LTE bands as well as 5G NR bands that is able to apply for construction monitoring and inspection systems based on IIoT [2]. Besides, the MIMO antenna gets low mutual coupling of under -20dB at both operating bands with narrow distance of 0.13λ at 1.8GHz.

Next section presents the brief description of construction monitoring and inspection systems on IIoT. The geometry of the proposed MIMO antenna and its

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detailed dimensions is shown in Section III. Section IV discusses simulated results of the proposed antenna. Discussion of measurement results is presented in Section V.

## II. CONSTRUCTION MONITORING SYSTEM ON IIoT

IoT, IIoT and Industry 4.0 are closely related concepts that bring the smart operation and automation to manufacturing technologies. The intersections of IoT, IIoT and Industry 4.0 are shown in Fig.1 where CPS is Cyber-Physical System. It can be seen that IIoT is a subset of IoT which is precise about industrial applications. Thus the IoT communication technologies such as 3G/4G/5G are useful for IIoT connectivity, especial 5G communication [2].

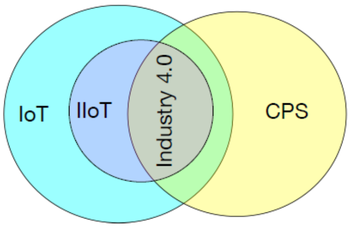



Fig. 1. IoT, CPS, IIoT and Industry 4.0 in Venn Diagram [2]

Construction monitoring and inspection system on IIoT is a part of smart construction which is illustrated in Fig.2.

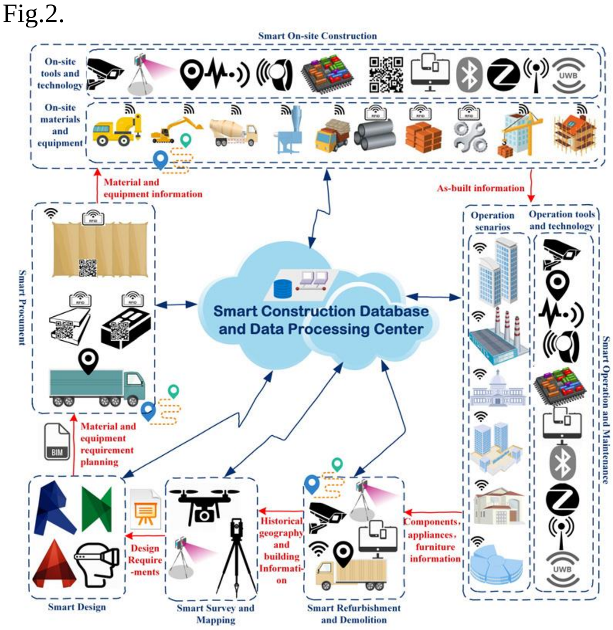



Fig.2. Landscape of the smart construction based on IIoT [10]

From this figure, it is seen that the IIoT can give many benefits in smart construction monitoring and inspection as following:

– Enables real-time inspection of construction sites for easier control of operation even in the unexpected weather condition and construction conditions.
– The sensors used on construction equipment and vehicles help to locate and monitor them round the clock.
– Enable effective resource asset management, which reduce the cost due to the wastage the resource.
– Locating and tracking materials and other resources to improve scheduling and coordination with other teams.

In the construction monitoring systems, the proposed dual-band MIMO antenna is both applied for sensors of construction equipment to collect quality-related information from construction objects such as monitoring building, locating and tracking construction objects and applied for wireless access points to gather data from sensors to IIoT Gateways.

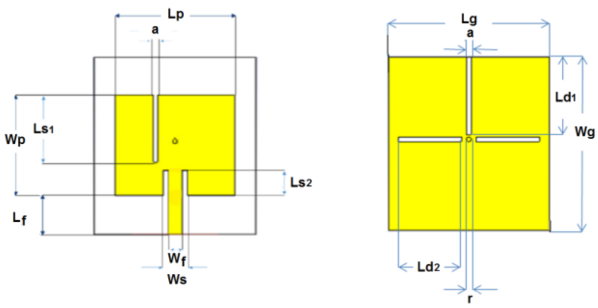
## III. ANTENNA DESIGN

In this work, the design of antenna is divided into two sections. Firstly, a dual-band single antenna is designed using a triple rectangular DGS and a shorting pin which makes the proposed antenna to be like a PIFA structure and decrease antenna size. Then, MIMO PIFA antennas using novel adjacent arcs on the surface plane is proposed to ensure low mutual coupling at both operating bands.

### *A. Design of Single Antenna*

Figure 3 shows the proposed single antenna element structure. The antenna is built on FR4 substrate of 1.6mm thickness with relative permittivity of 4.4, loss tangent of 0.02. Dimension and efficiency of each microstrip antenna depend on operating frequency or wavelength [11]. Thus, a 1.8 GHz antenna design with FR4 substrate has patch size of 51 x 40 x 1.6 mm$^3$. To reduce the size of antenna, combination a triple rectangular Defected Ground Structure (DGS) [9] and a shorting pin which is like a PIFA structure is proposed. Thus, size of PIFA antenna is decreased by 74% compared with theoretical antenna (from 51 x 40 mm$^2$ down to 25 x 21.5 mm$^2$). In addition, the height of the proposed antenna is reduced to a great extent if compared with traditional PIFA that gets further results in reducing thickness of mobile phones as well as complexity of antenna fabrication.

The tradition PIFA structures usually use coaxial feeding method so that they make the inverted F shape which call PIFA. However, using DGS in the ground with coaxial feeding has a little trouble if it is fabricated [9]. Because the position of coaxial line feeding point is so close to the position of DGS serial slot, the surface current distribution on the antenna ground may be effected by the SMA connector welding. To solve this problem, our like-PIFA antenna use microstrip line feeding but still ensure the same patch dimensions as coaxial line feeding antenna. The detail dimensions of proposed antenna are optimized by using CST software and presented in Table 1.




(a) (b)

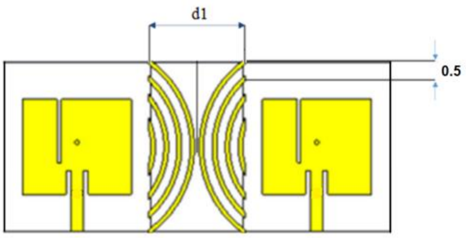
Fig.3. Proposed like-PIFA antenna (a) top view and (b) back view

TABLE 1. DIMENSION VALUES OF SINGLE ANTENNA

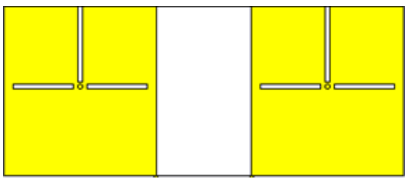
| Parameter | Value (mm) | Parameter | Value (mm) |
|---|---|---|---|
| $L_g$ | 34 | $L_f$ | 7 |
| $W_g$ | 38 | $W_f$ | 2.5 |
| $L_p$ | 25 | $L_{d1}$ | 16.5 |
| $W_p$ | 21.5 | $L_{d2}$ | 13 |
| $L_{s1}$ | 14 | $d_1$ | 22 |
| $L_{s2}$ | 5 | a | 0.7 |
| $W_s$ | 4 | r | 0.3 |

### *B. Design of MIMO antenna*

A MIMO PIFA antenna is constructed by placing two single antennas side by side at narrow distance of 22mm (0.13λ at 1.8GHz or 0.2λ at 2.6GHz) from feeding point to feeding point. The total size of antenna is 90 x 38 x 1.6 mm$^3$. To decrease mutual coupling between two closed antenna elements at both operating bands, a novel structure of adjacent arcs on the surface plane is proposed as illustrated in Figure 4.




(a)



(b)

Fig.4. Proposed MIMO PIFA antenna with adjacent arcs (a) top view and (b) back view

Here, radius of adjacent arcs is fallen steadily with the distance between arcs of 0.5mm. The equivalent circuit of the proposed structure of adjacent arcs is shown in Figure 5 where C is sum of $C_i$ (i is from 1 to n) which is the gap capacitance between adjacent arcs; $C_1$ capacitor is formed by metal line of surface and ground plane. L is equivalent inductance that is made of metal arc in the surface plane.

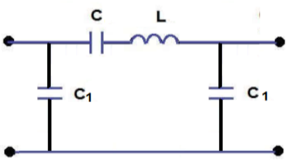



Fig. 5. Equivalent circuit of the proposed decoupling structure

Transfer function of equivalent circuit of adjacent arcs is calculated by Equation (1) and shown in Fig.6. It is clearly seen that, this structure likes a band-pass filter at low frequency and a stop band at high frequency. At $f > f_c$ where $f_c$ is determined by Equation (2), there is no wave which can through the structure of adjacent arcs. That is why this structure can reduce mutual coupling between two antenna elements at high frequency.

$$H(jw) = \frac{U_{out}}{U_{in}} = \frac{1}{\left(1+\frac{C_1}{C}\right)\left(1-w^2\frac{LCC_1}{C+C_1}\right)} \quad (1)$$

$$f_c = \frac{1}{2\pi}\sqrt{\frac{C+C_1}{LCC_1}} \quad (2)$$

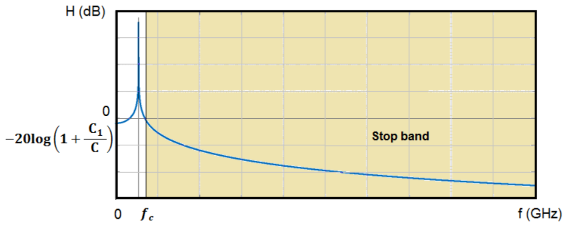



Fig. 6. Magnitude of frequency response of the proposed decoupling structure

## IV. SIMULATION RESULTS

### *A. Single Antenna*

The simulation of prototype antenna using CST software is presented in this part. The S parameter of single like-PIFA antenna is shown in Figure 7.

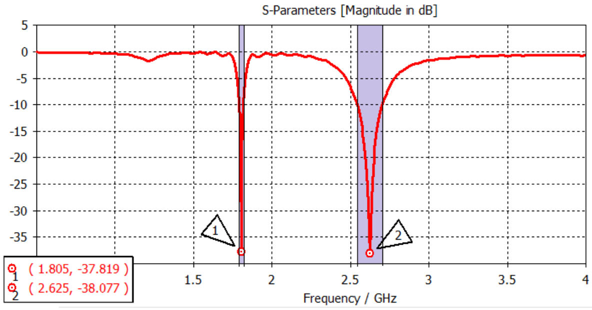
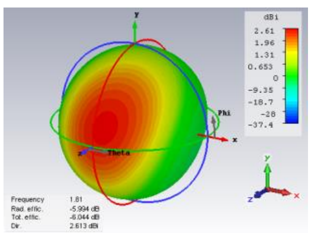


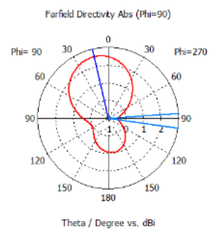

Fig. 7. S11 parameter of single PIFA antenna

It is clear to see that the antenna operates at two resonant frequencies: 1.8 GHz and 2.6GHz for No3 and No7 of LTE bands respectively as well as No.2, No.3, No.7 and No.38 of 5G NR bands. At low frequency, antenna reflection coefficient is -27 dB and antenna bandwidth is 60 MHz. At high frequency, antenna reflection coefficient is -35dB and antenna bandwidth is 273MHz.

The 2D and 3D radiation patterns of the proposed antenna are illustrated in Figure 8 and Figure 9 that are acceptable for terminals with smooth radiation.

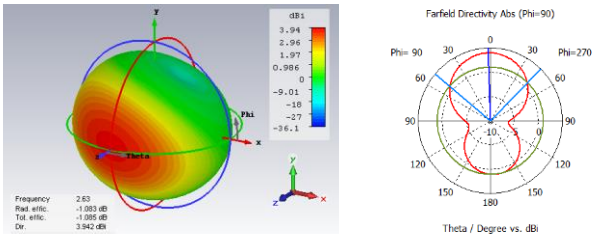


(a) 3D




(b) 2D

Fig. 8. The antenna radiation pattern at 1.8 GHz resonant frequency



(a) 3D (b) 2D

Fig. 9. The antenna radiation pattern at 2.6 GHz resonant frequency

## B. *MIMO antenna*

The simulated results of reflection coefficients of the initial MIMO antenna (without adjacent arcs) are shown in Figure 10. From this figure, it is observed that the S11 parameter seems unchanged compared with single like-PIFA antenna. At low band, the S12 parameter is below -20dB thanks to rectangular DGS. However, this value is raised and gets nearly -18dB at high band. Thus, it cannot meet the isolation demand of good MIMO antenna [12]. To decrease mutual coupling at both operating bands, adjacent arcs the on the surface plane is proposed. Thus, the S12 is below -20dB all over the wide band as illustrated in Figure 11.

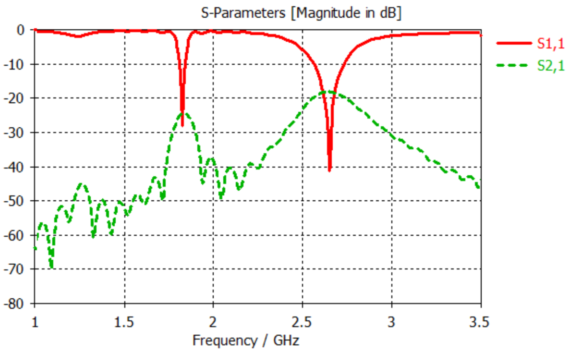


Fig. 10. Simulation S parameters of initial MIMO antenna

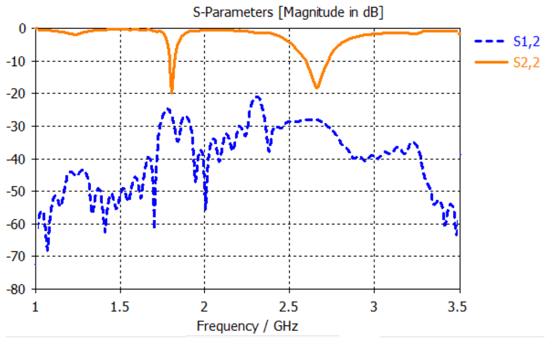
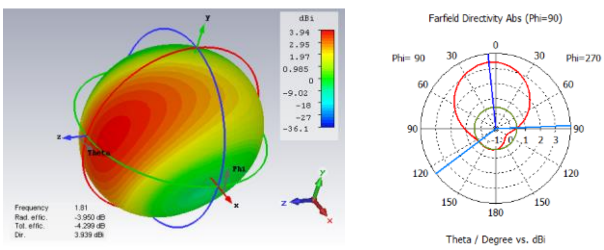
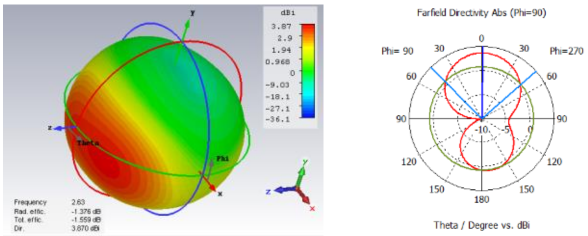


Fig. 11. Simulation S parameters of MIMO antenna with adjacent arcs



(a) 3D (b) 2D

Fig. 12. The MIMO antenna radiation pattern at 1.8 GHz resonant



(a) 3D (b) 2D

Fig. 13. The MIMO antenna radiation pattern at 2.6 GHz

The 3D and 2D radiation pattern of MIMO antenna using adjacent arcs structures are shown in Figure 12 and Figure 13 at 1.8GHz and 2.6 GHz resonant frequencies, respectively. Comparison with single antenna, the MIMO antenna gets higher directivity at both resonant frequencies that are increased from 2.61dBi to 3.94dBi at 1.8GHz, from 3.94dBi to 4.36 at 2.6GHz. Besides, the MIMO antenna gets acceptable radiation efficiencies of 40% and 73% at 1.8GHz and 2.6 GHz resonant frequencies respectively while gets high miniaturization rate.

In MIMO antenna system, correlation factor, which is so-called enveloped correlation coefficient (ECC), will be significantly degraded with higher coupling levels. The factor can be calculated from radiation patterns or scattering parameters. For a simple two-port network, assuming uniform multipath environment, the enveloped correlation ($\rho_e$), simply square of the correlation coefficient ($\rho$), can be calculated conveniently and quickly from S-parameters, as follows [13]:

$$\rho_e = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)} \quad (3)$$

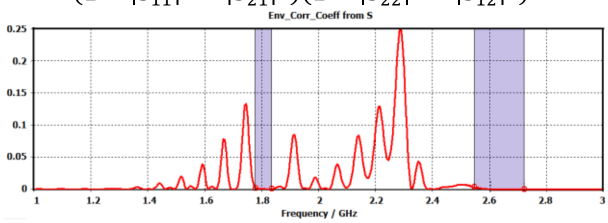
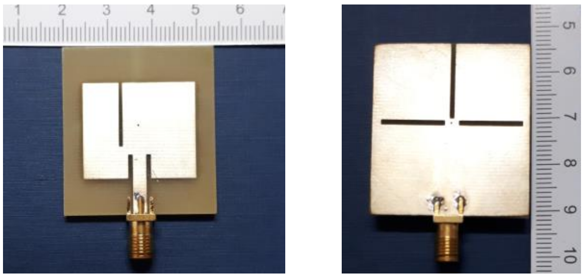


Fig. 14. Correlation Factor |ρ12| curve for the proposed MIMO antenna

The correlation factor curve of proposed MIMO antenna is shown in Figure 14. From this figure, the MIMO like-PIFA antenna using combination DGS and adjacent arcs has simulated ECC lower than 0.3 for all operation band, especially it is nearly zero at both operating bands. Therefore, it is quite suitable for LTE equipment with value of |ρ| ≤ 0.3 for the bands of interest [14].

# V. MEASUREMENT RESULTS

To verify the performance of the proposed antenna, the antennas are fabricated with single and MIMO model on FR4 substrate. The permittivity of the substrate is 4.4 and the substrate thickness is 1.6 mm. Figure 15 shows a photograph of the fabricated single antenna. It is clearly seen that the antenna patch decreased of nearly 74% in size in case of microstrip line feeding antenna. The total size of single antenna is 38 x 34 x 1.6 mm$^3$.



(a) top view (b) back view

Fig.15. Fabricated single PIFA antenna

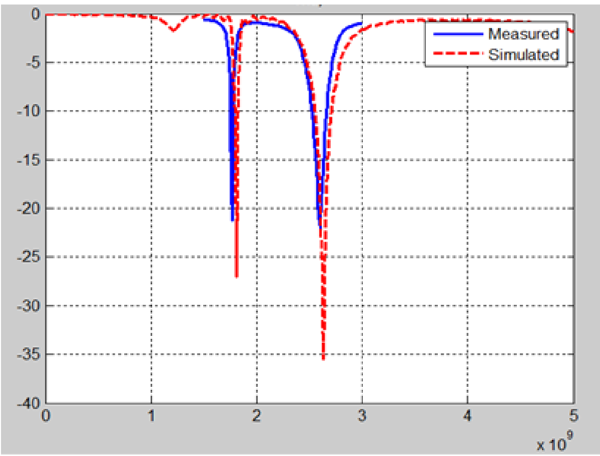
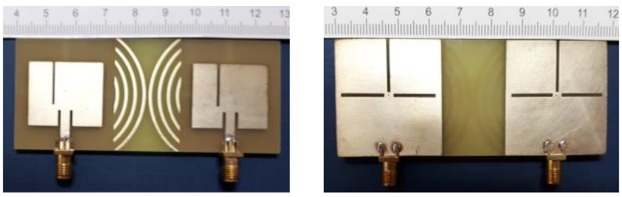



Fig. 16. Comparison between measured result and simulated one of S11 parameter of single antenna

The S11 parameter of fabricated single antenna which is compared with the simulation single antenna is presented in Figure 16. It should be noted that the measured result is in good agreement with simulated result.



(a) top view (b) back view

Fig.17. Fabricated MIMO PIFA antenna

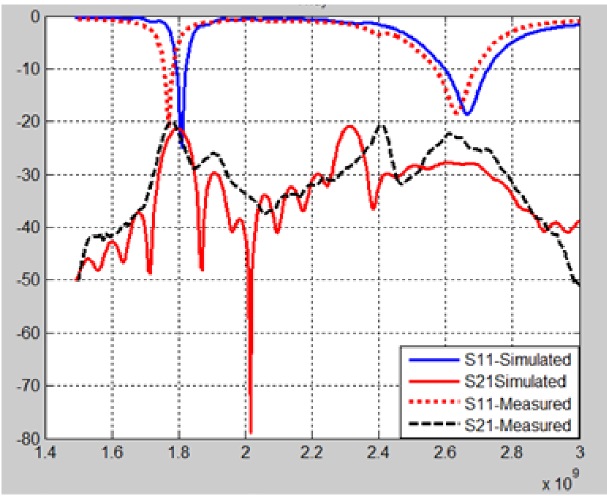



Fig. 18. Comparison between measured result and simulated one of S11 parameter of MIMO antenna

The MIMO antenna is also fabricated on the FR4 substrate as shown in Figure 17 with total size is 90 x 38 x 1.6 mm$^3$. In Figure 18, the measured results of S11 and S12 are compared with simulated results. This result agrees well with the simulated results.

From this experimental demonstration, it can be concluded that using combination double rectangular Defected Ground Structure and adjacent arcs on the surface plane, the MIMO antenna can get high isolation between MIMO elements for both of operating bands.

## VI. CONCLUSION

In this paper, a dual-band MIMO antenna is proposed. Using combination a triple rectangular Defected Ground Structure and adjacent arcs on the surface plane, the MIMO PIFA antenna can get high isolation between MIMO elements for both of operating bands. Operating at 1.8GHz and 2.6GHz with compact size, the MIMO antenna can be able for sensors and/or wireless access points of monitoring and inspection application in smart construction systems based on IIoT.

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## ANTEN MIMO HAI BĂNG SỬ DỤNG CẤU TRÚC ĐƯỜNG CONG BIẾN ĐỔI ĐỀU CHO HỆ THỐNG GIÁM SÁT XÂY DỰNG TRONG KỶ NGUYÊN IIOT

*Tóm tắt*— Vạn vật kết nối internet cho các ứng dụng trong nghiệp (IIoT) là một bước phát triển mới của kỷ nguyên công nghiệp 4.0. Thông qua hệ thống cảm biến của truyền thông không dây, IIoT đã mang đến bước phát triển mới cho hệ thống quản lý, giám sát thông minh theo thời gian thực của ngành công nghiệp nói chung và công nghiệp xây dựng nói riêng. Sự thành công này không thể không kể đến vai trò của anten, một phần tử không thể thiếu trong các hệ thống thu phát vô tuyến, có vai trò quyết định đến chất lượng và hiệu năng của thiết bị qua các chuẩn truyền thông vô tuyến khác nhau. Trong bài báo này, chúng tôi đề xuất một cấu trúc anten MIMO hai băng cho hệ thống giám sát công trình xây dựng trong kỷ nguyên IIoT sử dụng truyền thông 4G/ 5G. Anten hoạt động tại hai băng tần 1.8 GHz và 2.6 GHz truyền thông LTE-A băng 3 và 7, truyền thông 5G NR băng 2; 3; 7 và 38. Thiết kế trên vật liệu điện môi FR4 có chiều dày 1.6mm, anten có kích thước nhỏ gọn với diện tích tích bức xạ đạt 25mm x 21.5mm và mỏng hơn nhiều khi so với kiến trúc anten PIFA truyền thống. Bên cạnh đó, chúng tôi cũng đề xuất một cấu trúc giảm tương hỗ sử dụng các đường cong biến đổi đều. Với cấu trúc này, ảnh hưởng tương hỗ của anten giảm sâu dưới -25dB trên cả hai băng tần hoạt động trong khi hai anten được đặt rất gần nhau với khoảng cách 0.13λ tại tần số cộng hưởng 1.8GHz. Anten đề xuất được chứng minh trên mô phỏng và thực nghiệm cho kết quả tương đồng nhau.

*Keywords*—IIoT, MIMO, PIFA, DGS, ảnh hưởng tương hỗ.

## AUTHORS' BIOGRAPHIES

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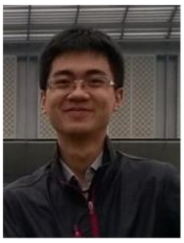

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