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Hexagonal open loop resonators employing frequency shift coding for Chipless RFID tag applications

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***Abstract*—A novel, high surface encoding capacity compact planar multiresonator tailored for Chipless RFID tag applications is discussed in this article. The tag consists of three hexagonal open loop resonators that are etched on the ground plane of a 50Ω microstrip transmission line. It operates within the frequency range of 2.12 GHz to 5.45 GHz, with a bandwidth of 3.33 GHz. Frequency Shift Coding is employed to record the tag's identification in the spectral domain. A maximum of 343 distinct code words can be generated utilizing three resonators. A notable feature of this tag is its capability to achieve distinct resonating frequencies by adjusting the overall dimensions of the slot. The tag prototype is designed and fabricated on an RT5880 lossy substrate, characterized by loss tangent of 0.0009 and dielectric constant of 2.2. Experimental data from actual prototypes are presented to verify the dependability of the suggested design.**

***Keywords*—Chipless radio frequency identification tag; Frequency Shift Coding; Internet of Things; Hexagonal open loop resonator**

I. Introduction

RFID technology, an established form of automatic identification technology, utilises low power radio waves to effortlessly recognise tagged things and get data from them. The RFID technology is utilised in several sectors such as healthcare [1], control and automation [2], and signal tracing and monitoring [3]. Chipless RFIDs [4] are being utilised without the need for an Application-Specific Integrated Circuit (ASIC) implementation, resulting in a system that is resilient, cost-effective, and simple. Chipless RFID tags have a completely distinct method for encoding data in contrast to traditional tags. Every chipless RFID tag consists of a planar passive circuit that reveals the its identity to the reader by reflecting a unique electromagnetic signal back. It utilises multiresonating structures to store data in the frequency spectrum, resulting in a distinct spectral signature. The identification of the tag is recorded in the frequency domain, either through the reduction of amplitude or the variation in group delay. References [5]-[11] provide documentation on different approaches used to create chipless tags that rely on spectral signatures.

A chipless RFID tag utilising eight-bit open-loop resonators has been mentioned in reference [5]. The multiresonator is specifically engineered to function within the frequency spectrum spanning from 3.3 to 5.8 GHz, with the purpose of encoding a total of eight bits. In [6], a chipless RFID tag composed of multi-resonating structures based on rectangles to encode 6-bit data within the frequency range of 3.4 to 4.6 GHz is proposed. The cascaded rectangular resonators are positioned adjacent to the microstrip line. Each resonating dip represents the logical state '1', whereas the absence of a resonating dip indicates the logical state '0'. A chipless RFID working in the 1.3–2.8 GHz band is presented in [7]. This RFID system employs a 12-bit technology that relies on retransmission. The construction consists of a transmission line that has been changed and shaped into a square loop. It also includes strips of different lengths arranged in a clear manner, as well as additional strips that enable the operation of changeable frequencies. A parallel microstrip quarter-circled multi-resonator (PQMR) utilising absence or presence coding (APC) is used to encode tag in the 3.30–6.53 GHz frequency range is proposed in [8]. A quarter wave open stub resonator based eight-bit chipless RFID, encoding identification code in 2.08 GHz to 4.03 GHz tag is described in [9]. An integrated chipless RFID temperature sensor is proposed in reference [10]. The resonator is composed of a connected line section and three lines containing parts of varying lengths. The longest element, which remains always attached, is specifically built for temperature monitoring, while the other two arms are utilised for encoding four distinct codes. Chipless RFID tag by V-shaped Multi-resonator for Partial Discharge-affected Equipment Identification is discussed in [11]. The tag is designed by using V-shaped multi-resonators on a one-eighth- wave transmission line that is reciprocally bent by a V-shape. The multiresonator operates in a frequency range 2.86 to 5.27 GHz.

The majority of the reported works utilise the APC approach to encode the identity of the tag; wherein the number of resonators decides the maximum number of bits that an RFID tag can represent. Through the utilisation of the Frequency Shift Coding (FSC) technique, the tag's ability to encode bits can be significantly improved by recording multiple bits per resonator[12,13]. This approach is particularly suitable when there is a need for encoding huge amounts of data using a smaller quantity of resonators. Another benefit is in the creation of high-security tags, where the tags may have a similar appearance, but their identification codes will be different. The purpose of this study is to use the FSC technique for chipless RFID tag. The paper is structured as follows. Section II introduces the fundamental principles of multiresonator design utilising hexagonal open loop resonators. Section III offers a thorough elucidation of FSC. Section IV gives the empirical results, whereas Section V offers the derived conclusions.

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II. Design of Hexagonal Open Loop Resonator

The resonator structure has developed from a single hexagonal open loop resonator. An open loop with a length of half a wavelength (λg/2) is etched onto the bottom plane of a 50Ω microstrip line, as depicted in Fig.1(a) and Fig.1(b).

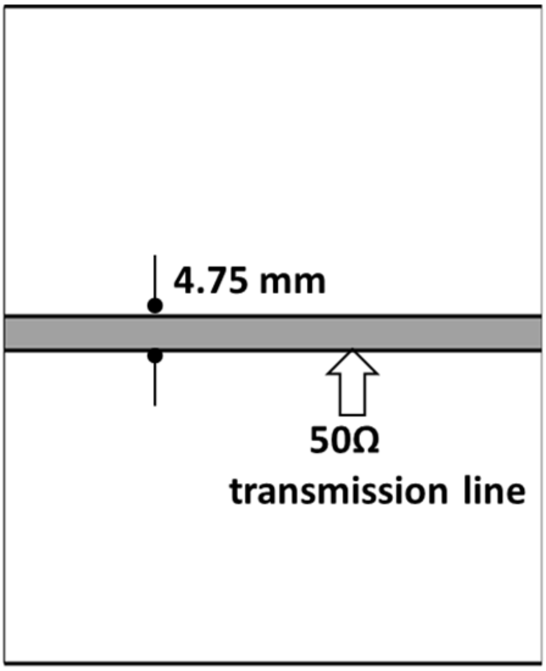


Fig. 1a. Top Layer

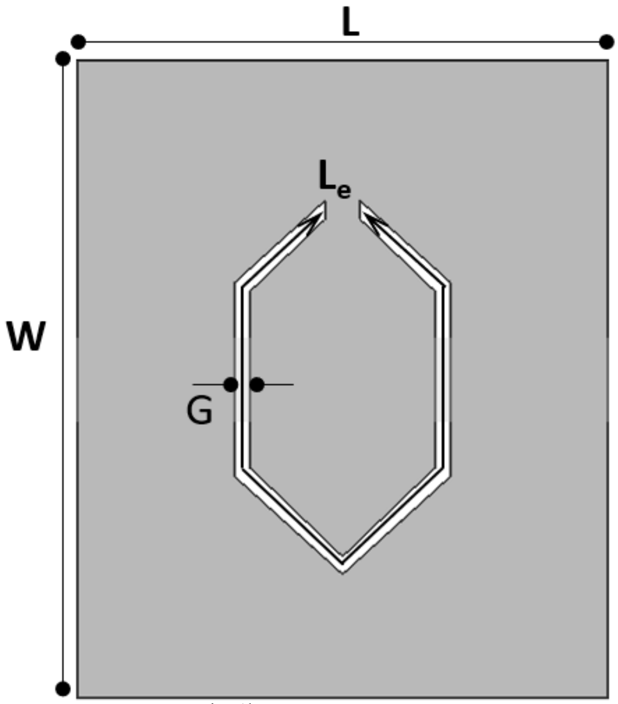


Fig. 1b. Bottom Layer

Fig.1 (a) Top Layer (b) Bottom Layer [Hexagonal open slot resonator L = 30 mm, W = 36 mm, G = 0.3 mm, L_e = 51.69 mm], Substrate: height = 1.57 mm, ε_r = 2.2, loss tangent = 0.0009.

The transmission line is designed using standard design equations [14]. Fig.2 shows the simulated transmission characteristics of the hexagonal open loop resonator. The resonant frequency is approximated as in (1)

$$f_r \cong \frac{c}{2*Le*\sqrt{\varepsilon_{eff}}} \quad (1)$$

The mean circumference, L_e, which is the average of its inner and outer circumferences, is half of the wavelength at the resonance frequency. The substrate's effective permittivity, abbreviated as ε_{eff}, is determined by (2)

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} \quad (2)$$

and the guide wavelength (λ_g) is

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}$$

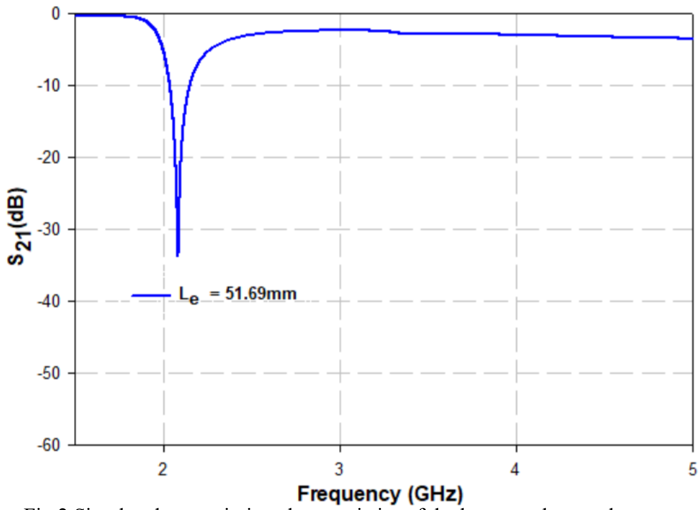
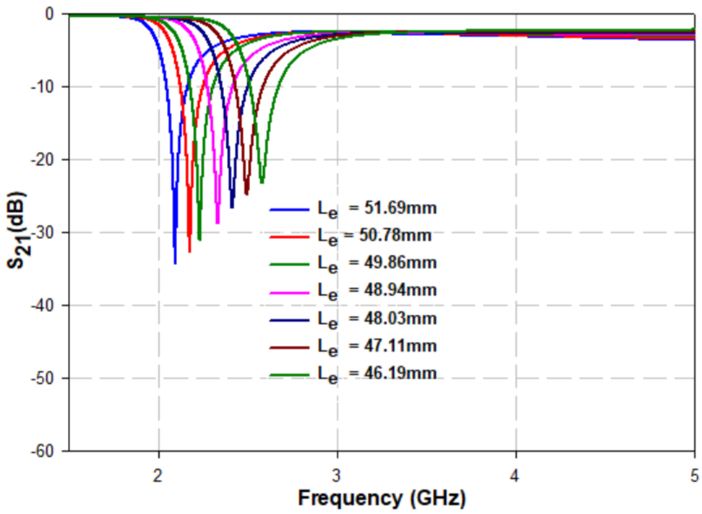


Fig.2 Simulated transmission characteristics of the hexagonal open slot resonator

Modifying the mean circumference of the loop can affect the resonance frequency. The transmission characteristics shown in Fig. 3 demonstrate a variation in resonating frequency ranging from 2.27 to 3.10 GHz when the average circumference is tuned from 48.26 to 36.12 mm. The multiresonator takes advantage of this ability to produce many resonances by altering the total length of the slot.

Fig. 3. Simulated transmission characteristics for various values of Le (mm)



of hexagonal open slot resonator shown in Fig.1(b)

III. FSC APPLIED TO MULTIRESONATOR WITH THREE HEXAGONAL OPEN LOOP RESONATORS

Two potential methodologies for encoding tag identification include the absence or presence of resonance-based coding and frequency shift coding technology. In the APC technique, each resonator represents a distinct bit of data. The absence of resonance at a particular frequency signifies logic 0, whereas resonance at a designated frequency indicates logic 1. The total number of viable combinations with n resonators is exactly 2^n. The FSC technique enhances coding capacity by encoding multiple bits per resonator. Resonators are designated specific frequency ranges (Δf), within which distinct resolution bandwidths (δf) are clearly defined. The selection of Δf can be determined by considering the available spectrum of frequencies and the quantity of resonators. The value δf denotes the spectral range required by each resonator to precisely depict its resonant frequency. Thus, an individual resonator has the capacity to represent an increased number of states. This approach enables an improvement in coding efficiency by encoding multiple bits per resonator. Furthermore, the tags exhibit a resemblance, since the only discernible difference lies in the tiny variation in the length of the slot from one tag to another. The identifying code, though, will be unique. This aids in the creation of highly secure identification tags.

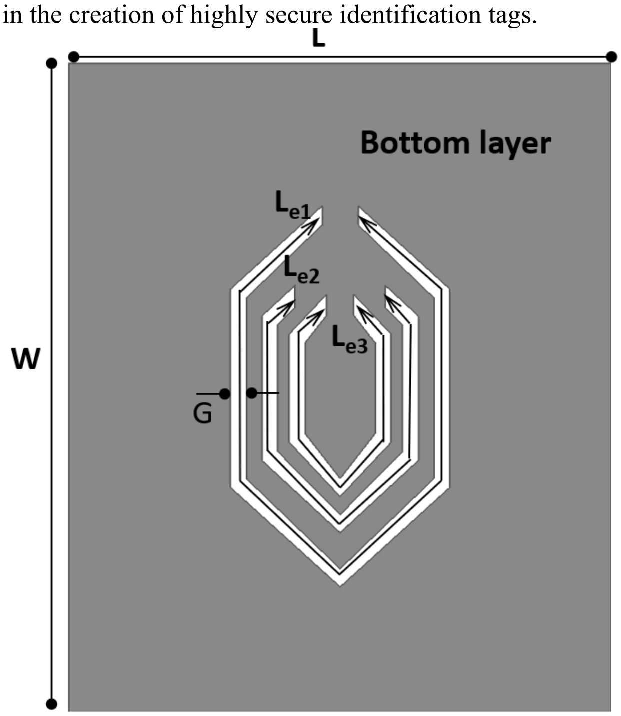


Fig. 4 Layout of multiresonator with three hexagonal open loop resonators [Hexagonal open slot resonator L = 30 mm, W = 36 mm, G = 0.3 mm, L_{e1} = 50.98 mm, L_{e2} = 31.68 mm, L_{e3} = 25.19 mm] Substrate: εr = 2.2, height = 1.57 mm, loss tangent = 0.0009.

Fig.4 depicts the layout of multiresonator with three hexagonal open loop resonator whose dimension (L_e) is individually varied for FSC. The position of transmission line (top layer) is optimised for maximum coupling to all the resonators. Microstrip version of the multiresonator is shown in Fig.5a. Fig. 5b depicts the surface current distributions for each resonator. Every resonator is triggered at the resonance frequency that corresponds to a length of λg/2

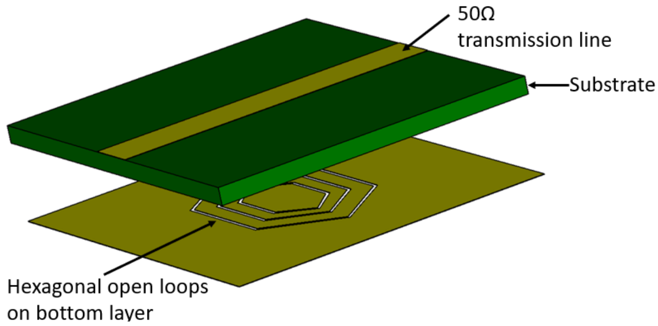


Fig.5a Microstrip version of the hexagonal open loop multiresonator

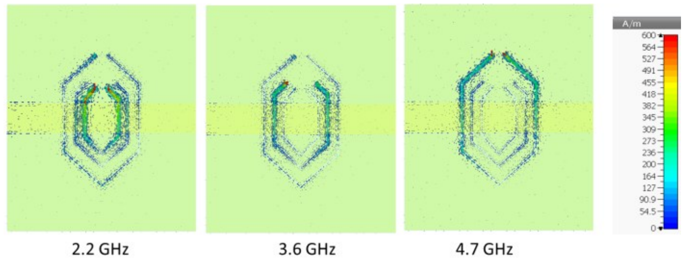


Fig.5b Surface current distribution of individual resonators in the hexagonal open slot multiresonator shown in Fig.4

The frequency band (Δf) and resonant frequency (f) of each resonator are provided in Table 1. Seven distinct resonant frequencies can be observed by adjusting the dimension of the outer hexagonal loop while maintaining the dimensions of the other two, as illustrated in Fig. 6(a). Similarly, altering the length of the second loop while maintaining the size of the first and third loop constant leads to the emergence of seven distinct resonant frequencies, as illustrated in Fig. 6(b). Similarly for the third hexagonal loop also[Fig.6(c)].

TABLE I
RESONANT FREQUENCY (f), FREQUENCY BAND (Δf) OF MULTIRESONATOR WITH THREE HEXAGONAL OPEN LOOP RESONATORS (ALL VALUES IN GHZ)

f	Δf_1 (2.12-2.58)	Δf_2 (3.62-4.18)	Δf_3 (4.43-5.42)
f_1	2.12	3.62	4.43
f_2	2.20	3.71	4.60
f_3	2.27	3.80	4.76
f_4	2.35	3.89	4.91
f_5	2.41	3.97	5.09
f_6	2.51	4.08	5.26
f_7	2.58	4.18	5.42

It is critical to guarantee that the resonance produced by other resonators is not affected by changing the size of one particular resonator. Using FSC for bit encoding requires meticulous deterrence of the merging of resonant bands (Δf) with the interference of harmonics from lower frequency resonators with the fundamental resonance of high frequency resonators. One can assign a different identification code for every set of resonant frequencies. Combining the four resonators generates a total of 343 possible codes since every resonator shows seven different resonant frequencies. As shown in Fig. 6(a), varying the dimension of the outer hexagonal loop results in seven different resonant frequencies while preserving the dimensions of the other two.These codes range from [000 0000 0000] to [101 0101 1110]. Therefore, the surface encoding capacity is 73. With the addition of a greater number of resonators, the surface encoding capacity rises to 7^n, where 'n' is the number of resonators

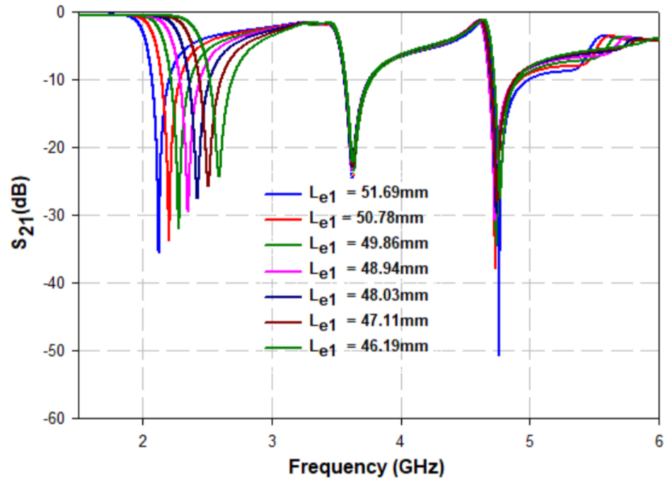


Fig. 6(a) Simulated transmission characteristics of varying the dimension of first hexagonal open loop in the multiresonator, keeping L_{e2} at 31.30 mm and L_{e3} at 24.20 mm

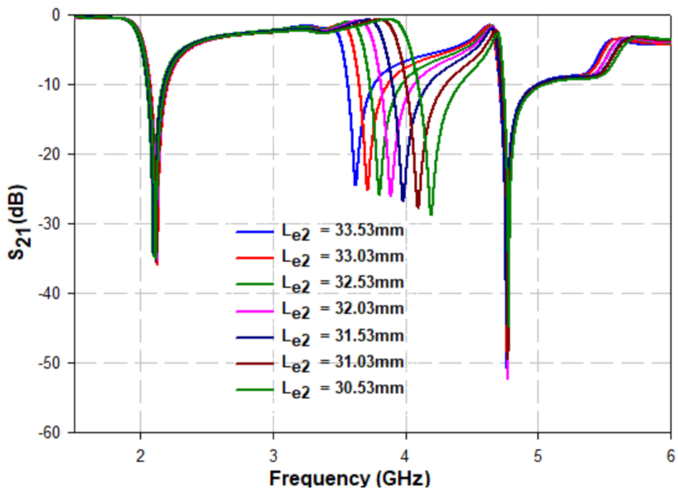


Fig. 6(b) Simulated transmission characteristics of varying the dimension of second hexagonal open loop in the multiresonator, keeping L_{e1} at 50.80 mm and L_{e3} at 24.20 mm

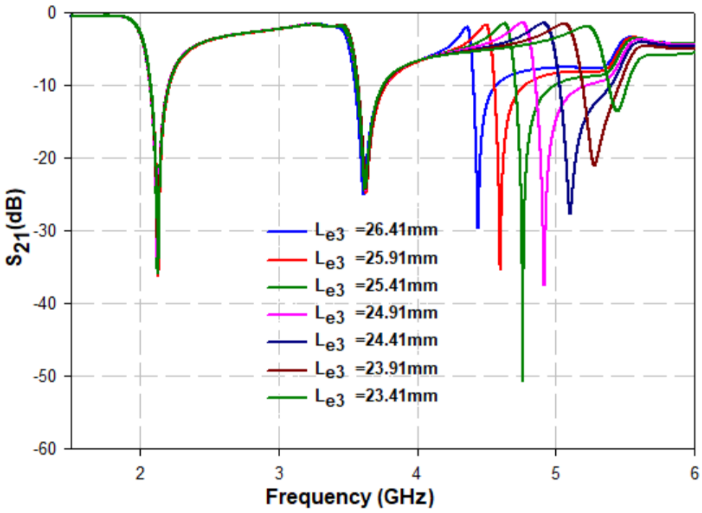
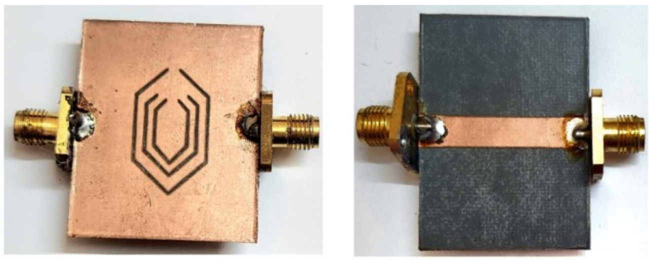


Fig. 6(c) Simulated transmission characteristics of varying the dimension of third hexagonal open loop in the multiresonator, keeping L_{e1} at 50.80 mm and L_{e2} at 31.30 mm

IV. EXPERIMENTAL RESULTS OF HEXAGONAL OPEN LOOP MULTIRESONATOR

Fig.7 displays an image of a developed multiresonator featuring three hexagonal open loop resonators. The Anritsu VNA MS2038C vector network analyser is employed for doing measurements. The multiresonator device is connected between the vector network analyzer's two ports, as depicted in Fig. 8. The transmission characteristics were measured by altering the dimensions L_{e1}, L_{e2}, and L_{e3}. The results are displayed in Fig.9(a) to Fig. 9(c) accordingly.



(a) (b)

Fig. 7 Image of the hexagonal open slot multi-resonator
(a) Bottom layer (b) Top layer

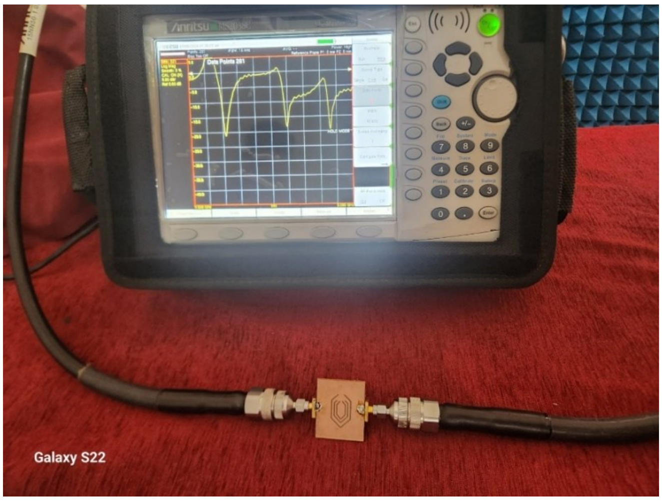


Fig.8 Network analyser with device under test

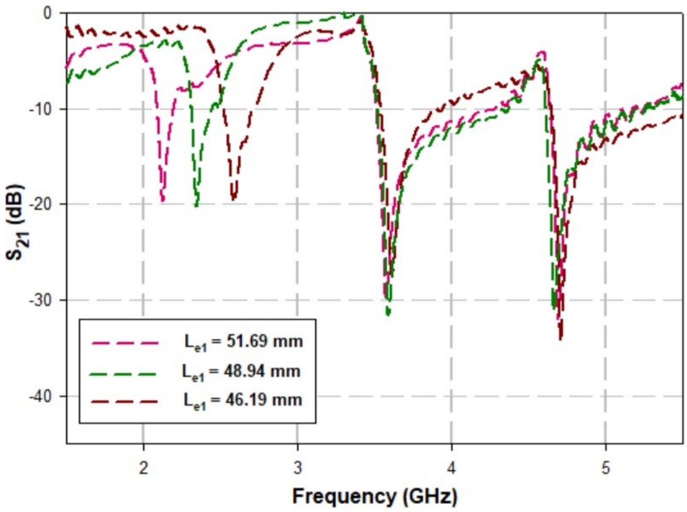


Fig. 9a Measured transmission characteristics of varying the dimension of first hexagonal open loop in the multiresonator, keeping L_{e2} at 31.53 mm and L_{e3} at 24.91 mm

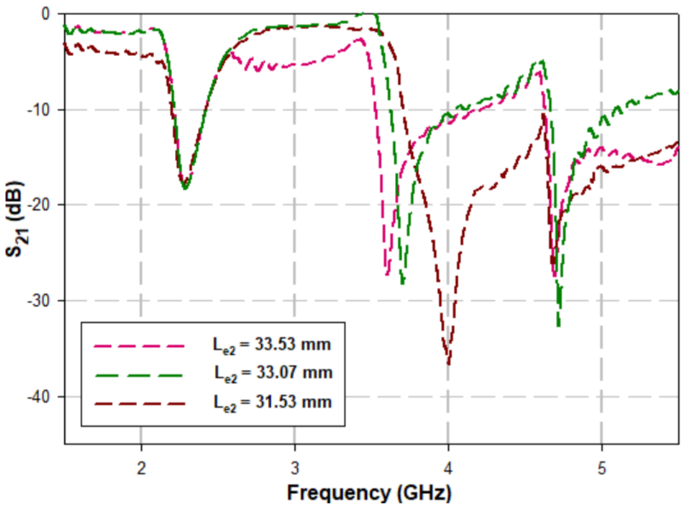


Fig. 9b Measured transmission characteristics of varying the dimension of second hexagonal open loop in the multiresonator, keeping L_{e1} at 48.94 mm and L_{e3} at 24.91 mm

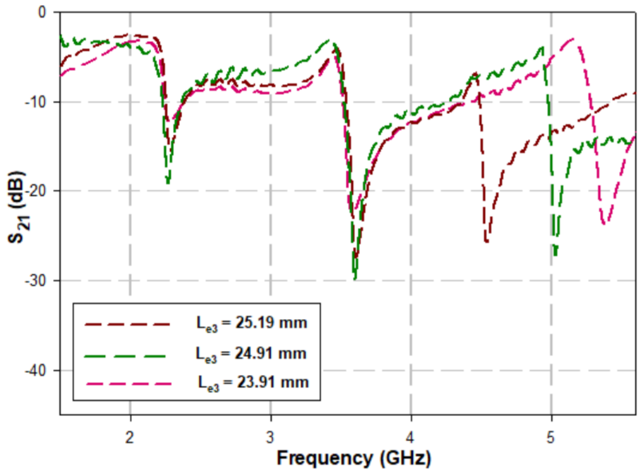


Fig. 9c Measured transmission characteristics of varying the dimension of first hexagonal open loop in the multiresonator, keeping L_{e1} at 48.94 mm and L_{e2} at 31.53 mm

CONCLUSION

This article discusses a compact planar multiresonator that utilises three hexagonal open loop resonators that are etched on the ground plane of a 50Ω microstrip line. The purpose of this multiresonator is to facilitate chipless RFID tag application. A technique known as frequency shift coding is utilised in order to encode the identity of the tag. Within the frequency range of 2.12 GHz to 5.45 GHz, it is possible to generate a total of 343 different identification codes that are entirely unique. The addition of a greater quantity of resonators results in an increase in the surface encoding capacity to 7^n, where 'n' constitutes the total number of resonators.

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REFERENCES

[1] S. K. Behera and N. C. Karmakar, "Wearable Chipless Radio-Frequency Identification Tags for Biomedical Applications: A Review [Antenna Applications Corner]," in IEEE Antennas and Propagation Magazine, vol. 62, no.3, pp. 94-104, June 2020. https://doi.org/10.1109/MAP.2020.2983978

[2] F. Liu and Z. Miao, "The Application of RFID Technology in Production Control in the Discrete Manufacturing Industry," 2006 IEEE International Conference on Video and Signal Based Surveillance, Sydney, NSW, Australia, 2006, pp. 68-68.https://doi.org/10.1109/AVSS.2006.111

[3] L. M. Ni, D. Zhang and M. R. Souryal, "RFID-based localization and tracking technologies," in IEEE Wireless Communications, vol. 18, no. 2, pp. 45-51https://doi.org /10.1109/MWC.2011.5751295

[4] V. Sharma and M. Hashmi, "Advances in the Design Techniques and Applications of Chipless RFIDs," in IEEE Access, vol. 9, pp. 79264-79277, 2021. https://doi.org /10.1109/ACCESS.2021.3084056.

[5] V. Sharma and M. Hashmi, "Chipless RFID tag based on open-loop resonator," 2017 IEEE Asia Pacific Microwave Conference (APMC), Kuala Lumpur, Malaysia, 2017, pp. 543-546. https://doi.org /10.1109/APMC.2017.8251502

[6] A. Habib and M. Nadeem, "Multi-resonator Based Passive Chipless RFID Tag for Tracking Applications," 2023 International Conference on Communication Technologies (ComTech), Rawalpindi, Pakistan, 2023, pp. 69-72. https://doi.org /10.1109/ComTech57708.2023.10165189

[7] P. Prabavathi and S. Subha Rani, "Modified microstrip transmission line based chipless RFID tag with high bit encoding," Measurement (Lond.), vol. 190, no. 110684, p. 110684, February 2022. https://doi.org/10.1016/j.measurement.2021.110684

[8] G. B. W. Mohamed, A. K. M. Z. Hossain, M. Z. A. B. A. Aziz, and S. M. K. Azam, “A Quarter-Circled Multi-Resonator for UWB Re-transmission Based Chipless RFID,” J. Phys. Conf. Ser., vol. 2550, no. 1, p. 012026, August 2023. https://doi.org /10.1088/1742-6596/2550/1/012026

[9] C. M. Nijas et al., "Chipless RFID Tag Using Multiple Microstrip Open Stub Resonators," in IEEE Transactions on Antennas and Propagation, vol. 60, no. 9, pp. 4429-4432, Sept 2012. https://doi.org/10.1109/TAP.2012.2207081

[10] W. M. Abdulkawi and A.-F. A. Sheta, “Chipless RFID sensors based on multistate coupled line resonators,” Sens. Actuators A Phys., vol. 309, no. 112025, p. 112025, July 2020. https://doi.org/10.1016/j.sna.2020.112025.

[11] S. M. Kayser Azam, M. Othman, T. A. Latef, H. A. Illias, A. K. M. Z. Hossain and A. A. Ababneh, "Chipless RFID Tag by V-shaped Multi-resonator for Partial Discharge-affected Equipment Identification," 2023 Innovations in Power and Advanced Computing Technologies (i-PACT), Kuala Lumpur, Malaysia, 2023, pp 1-5. https://doi.org /10.1109/i-PACT58649.2023.10434634.

[12] M. Polivka and M. Svanda, "High Encoding Capacity Chipless RFID Tag," 2023 17th European Conference on Antennas and Propagation (EuCAP), Florence, Italy, 2023, pp. 1-4. https://doi.org /10.23919/EuCAP57121.2023.10133353.

[13] M. Sumi, S. Mridula, A. Pradeep and B. Paul, "Frequency Shift Coded microstrip shorted stub resonators for Chipless RFID tag applications," 2019 URSI Asia-Pacific Radio Science Conference (AP-RASC), New Delhi, India, 2019, pp. 1-4. https://doi.org /10.23919/URSIAP-RASC.2019.8738461

[14] J. A. G. Malherbe, Microwave Transmission Line Filters. Norwood, MA, USA: Artech House, 1979.