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Design of A 20-Bit Chipless RFID Tag Utilizing Multiple Resonators in UWB Frequency Range

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ABSTRACT

Radio frequency identification (RFID) is a growing technology for monitoring and recognizing objects, persons, or animals via wireless communications. Precisely, RFID can operate longer range and has an ability to be automated without human control. Chipless RFID tag basically is a RFID tag that does not require a microchip in the transponder. The major impediments in designing chipless RFID tag are data encoding and transmission. The passive chipless RFID tag can be fabricated on any substrate material without external operating circuit, which is different compared to a conventional chipped RFID tag. In this paper, 20 resonators are used to design a 20-bit chipless RFID tag, which operates at the ultra-wideband (UWB) frequency range between 3.00 and 10.00 GHz. It is found that the additional resonators can encode data and increase the chipless RFID tag's encoding capacity significantly. In sum, multiple resonators enable the chipless RFID tag to encode data at different operating frequencies.

1. Introduction

In this modern age of advanced technologies, radio frequency identification, also known as RFID, is a growing technology for monitoring security system [1–2] and recognizing objects, persons, or animals in wireless communications [3]. Basically, RFID technology has various sensing, object identification, product tracking, and logistics applications using digital communications [2], which have gained interest by technologies [4]. The RFID technology has gained much attention for Internet of Things (IoT)-based applications, which require RFID tags embedded with sensors [5–6]. RFID technology is intended to replace barcodes because of its low capacity for data, and it is complicated to reprogramming the information. The RFID tag and RFID reader are the two main elements of this emerging technology. The RFID tag encodes and transmits the data; the RFID reader will receive the

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data and extracts the coded information. Due to higher costs than barcodes, the RFID technology is relatively slow in implementation in applications [7].

RFID tags are classified into three types: active RFID tag, semi-passive RFID tag, and passive RFID tag. The active RFID tag has its microchip embed and an internal power source. Compared to the active RFID tag, the passive RFID tag has no internal power supply. The passive tag relies on the antenna electric current caused by the incoming radio frequency (RF) signal and is rectified to power the integrated circuit (IC) tag to transmit the response signal. The semi-passive RFID tag is comparable to the passive RFID tag with the addition of a battery, which helps to achieve a comparatively longer lifetime than the passive RFID tag [5].

Microchips play a significant role in RFID technology. However, the industry also has a growing interest in developing a tag with no active electronics, like an utterly passive RFID tag. Chipless RFID tag basically requires neither battery nor power source or a silicon chip to capture information wirelessly [8]. Chipless RFID tag is fundamentally a simple passive antenna or resonator. In contrast, chip-based RFID tag passive sensors require power source for activation from the reader through wireless power transfer (WPT) [9]. The nonexistence of a battery and a silicon chip in the chipless RFID tag may decrease the cost of the sensor and achieve a theoretically infinite lifetime. Moreover, the lack of any electronic circuit, chipless RFID sensors are possibly applicable for tough environments [10–13].

The working principle of the chipless RFID tag works as shown in Figure 1. The particular signature of the chipless RFID tag is communicated with the RFID reader antenna by the backscattering principle and electromagnetic waves [7]. Previous studies have been done in designing various unique shapes of chipless tags, such as butterfly-shaped slots in tag [14], circularly shaped tag, and multi-resonator-based chipless tag holding capacity of 3-bits [15–16].

Due to the passivity of the chipless RFID tag, this technology opens doors for low-cost chipless RFID applications. For example, it will be difficult for the existing chipped RFID tag to sensing a water bottle package in a refrigerator at a cold temperature because IC functionality may fail in sub-zero or cold temperatures [5]. Moreover, a broader range of possibilities also is opened up with the chipless RFID technology. For instance, the chipless RFID tag can be fabricated on any substrate such as thin paper material to hard metal, challenging to accomplish with the chipped RFID tag [7].

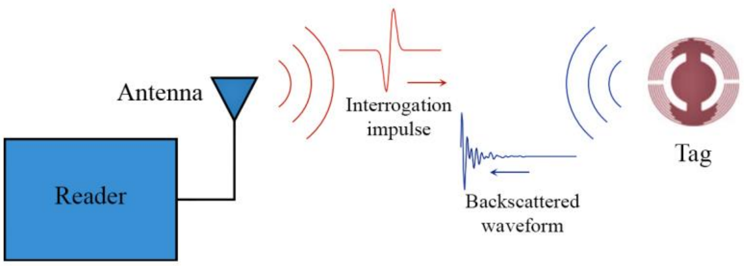


Fig. 1. Principles of Chipless RFID [7]

Many applications use integrated sensors and encoding of data sensing such as moisture sensing, temperature sensing, human surveillance, stress sensing, light sensing, humidity, and gas detection [4]. The main drawback to adopting the RFID technology because the cost is relativity higher compared to current technologies, such as barcodes. The chipless RFID tag does not require an external circuit to operate compared to chipped RFID tags [5]. Two general types of chipless RFID tags can be designed and developed, which are the time domain-based and spectral or frequency domain-based, respectively [9]. Generally, the time domain-based chipless RFID tags need a large printed circuit board (PCB) manufacturing technology and are unable to encode a high number of bits [17]. Due to this limitation, the frequency domain-based chipless RFID tag using multiple resonators will be designed instead to encode data in this paper. In this case, the chipless tag will encode data into the spectrum using resonant structures [18]. Theoretically, additional resonators may increase the frequency domain-based chipless RFID tag's encoding capacity.

In contrast, the limitation in the number of bits is critical in tracking and identification applications, where the chipless RFID tag competes with the barcode technology for commercial product labelling [19].

2. Design of 20-Bit Chipless RFID Tag

A 20-bit chipless RFID tag design starts with determining the dielectric material where a proper material will enhance the performance of the chipless RFID tag. Then, approximation parameters for the dimension of the design and resonator layout pattern will be done. After that, a simulation and a full-wave analysis are done using the CST Studio Suite software. The *S*-parameters result then will be examined to identify whenever the frequency response is acceptable or not. There is a need to change the dimensions if the frequency response is not acceptable and re-check the frequency response is acceptable or not for the 20-bit chipless RFID tag. Figure 2 shows the flowchart process in determining the 20-bit chipless RFID tag frequency response.

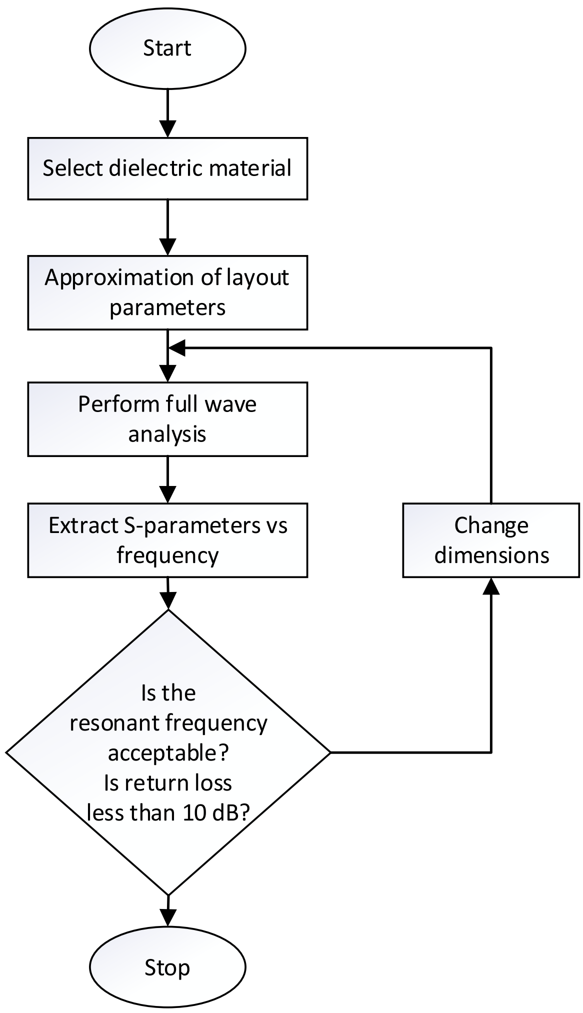


Fig. 2. Flowchart of Determining the Frequency Response

As shown in Figure 3, the substrate material (in cyan colour) is the polyethylene terephthalate (PET) whereas the conductor material (in yellow colour) is the copper foil in the chipless RFID tag design.

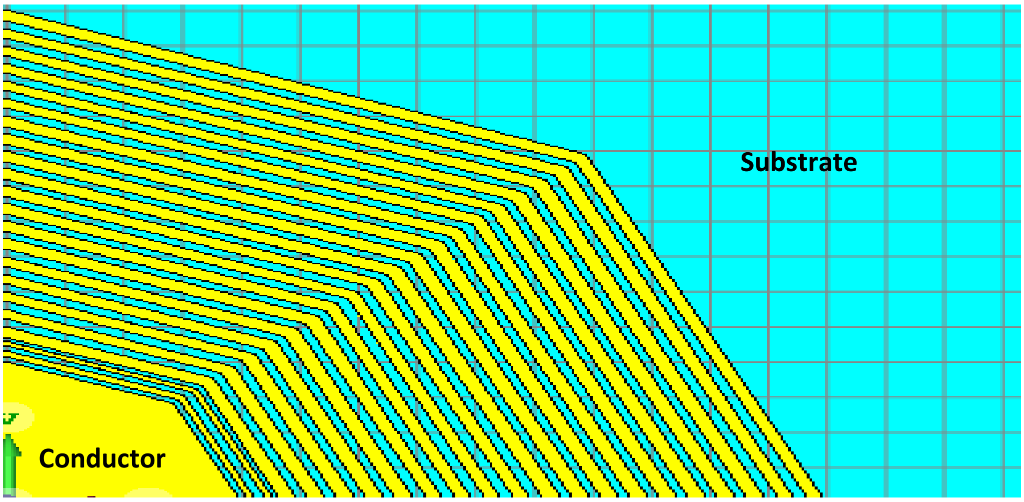


Fig. 3. Chipless RFID Tag Materials

The PET substrate, as shown in Figure 4 provides an additional feature of flexibility [8]. The PET substrate thickness is 0.1 mm, its dielectric constant, ε_r is 2.9 and its loss tangent value, δ is 0.0025. The copper foil thickness is 0.025 mm and its conductivity is 5.96×10^7 S/m, respectively.

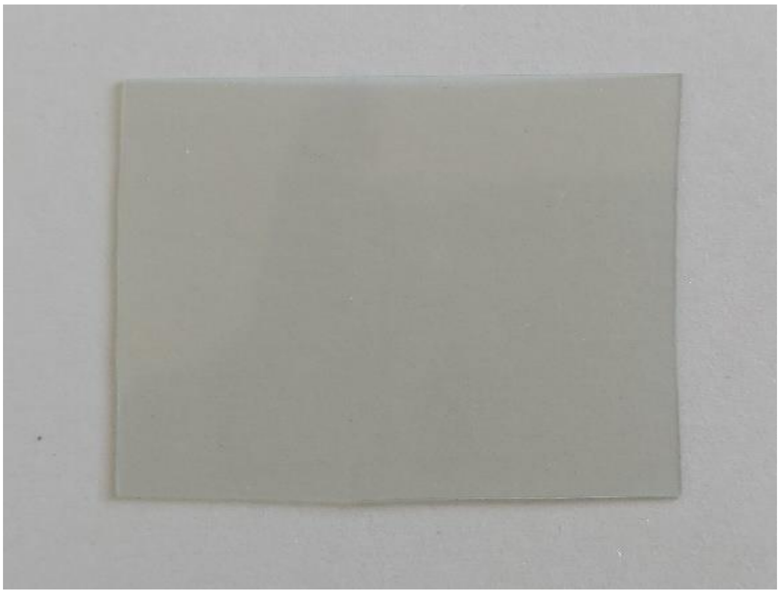


Fig. 4. Polyethylene Terephthalate (PET)

In this paper, the octagonal slot resonator chipless RFID tag consists of 1 patch and 21 octagonal slot resonators is designed. Hence, the chipless RFID tag has 8 segments. In this case, resonant frequency for each bit at each gap between octagonal slot resonators is generated.

The 20-bit chipless RFID design has its parameter of the slot gap, inner slot and outer slot to achieve 20 bit of data for its dimensional or material used for the substrate. There are two different 20-bit chipless RFID tag designs for radar cross-section (RCS) and S_{11} parameter, respectively. This is because the chipless RFID tag design for RCS can backscatter the information from certain predefined angle. The RCS of the tag is designed where each resonator is treated as a separate scatterer completely characterized by a specific reflection coefficient [20]. In contrast, the chipless RFID tag design for S_{11} parameter can backscatter the information to front only not from different angle.

Table 1 enlists the parameter values of slot gap for the 20-bit RFID chipless design. As shown in Figure 5, the chipless RFID tag design 1 consisting of copper foil and PET for RCS has resonators separated by gaps to produce a bandpass filter (BPF). The gap of each slot increases as the number of resonators increases, as shown in Table 1. The wider or narrow the gap will result in different resonant frequencies.

Table 1
Parameter Value of Slot Gap for Design 1

Parameter		Value (mm)
Gap of each slot	Gap no. 1 to no. 2	0.15
	Gap no. 3 to no. 20	0.20
	Gap no. 21	0.40

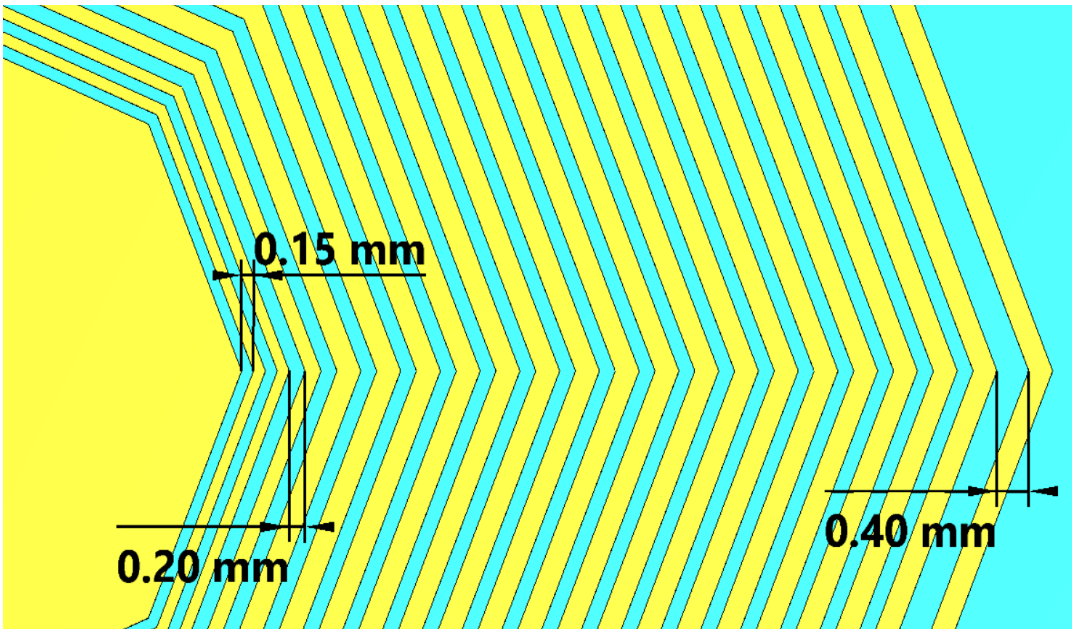


Fig. 5. Polyethylene Terephthalate (PET)

Each resonator consisting of copper foil in the chipless RFID tag design 1 with a substrate of PET for RCS has a different radius to ensure resonant frequency does not collide with a neighbouring resonant frequency. As shown in Table 2, the inner and outer parameters create a suitable slot for each resonator for the chipless RFID tag design 1.

As shown in Figure 6, the gap of chipless RFID tag design 2 consisting of copper foil and PET for S_{11} has resonators separated by gaps to produce a bandpass filter (BPF). The gap of each slot increases as the number of resonators increases, as shown in Table 3. The wider or narrow the gap will result in different resonant frequencies.

Table 2
Dimensions of the Chipless RFID Tag Design 1 for Slot

Radius of each slot	Inner slot (mm)	Outer slot (mm)
Patch	0	8
1st slot	8.30	8.6
2nd slot	8.90	9.2
3rd slot	9.6	10
4th slot	10.4	11
5th slot	11.4	12
6th slot	12.4	13
7th slot	13.4	14
8th slot	14.4	15
9th slot	15.4	16
10th slot	16.4	17
11th slot	17.4	18
12th slot	18.4	19
13th slot	19.4	20
14th slot	20.4	21
15th slot	21.4	22
16th slot	22.4	23
17th slot	23.4	24
18th slot	24.4	25
19th slot	25.4	26
20th slot	26.4	27
21st slot	27.8	28.4

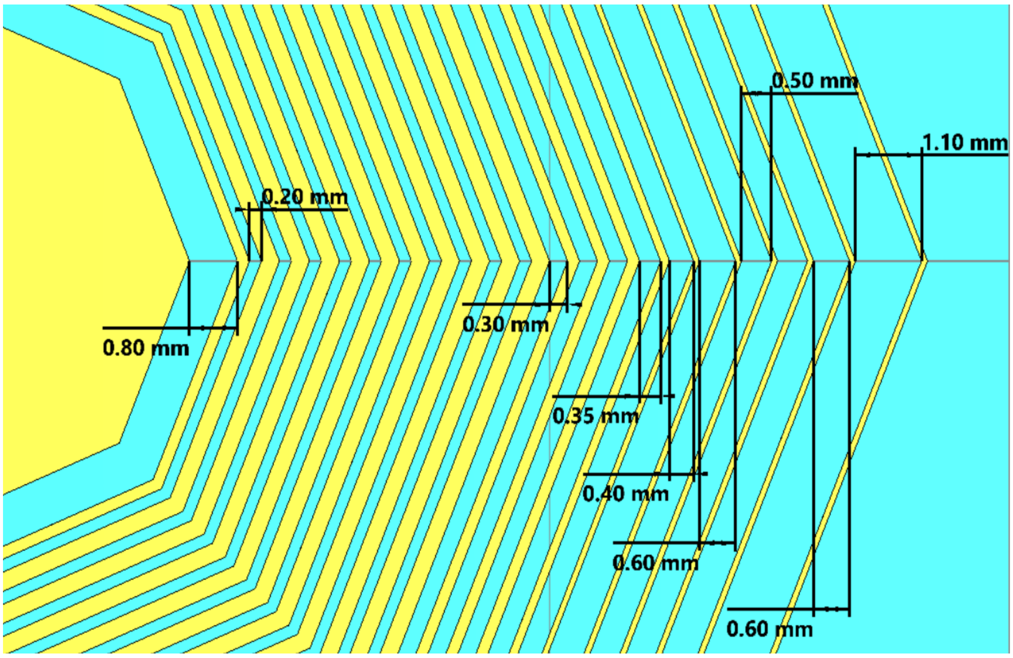


Fig. 6. Parameter of Slot Gap for Design 2

Table 3
Parameter of Slot Gap for Design 2

Parameter		Value (mm)
Gap of each slot	Gap no. 1	0.80
	Gap no. 2 to no. 11	0.20
	Gap no. 12 to no. 14	0.30
	Gap no. 15	0.35
	Gap no. 16	0.40
	Gap no. 17	0.60
	Gap no. 18 to no. 19	0.50
	Gap no. 20	0.60
	Gap no. 21	1.10

Each resonator consisting of copper foil in the chipless RFID tag design 2 with a substrate of PET for S_{11} has a different radius to ensure resonant frequency does not collide with a neighbouring resonant frequency. As shown in Table 4, the inner and outer parameters create a suitable slot for each resonator for the chipless RFID tag design 2.

Table 4
Dimensions of the Chipless RFID Tag Design 2 for Slot

Radius of each slot	Inner slot (mm)	Outer slot (mm)
Patch	0	8
1st slot	9.6	10
2nd slot	10.4	11
3rd slot	11.4	12
4th slot	12.4	13
5th slot	13.4	14
6th slot	14.4	15
7th slot	15.4	16
8th slot	16.4	17
9th slot	17.4	18
10th slot	18.4	19
11th slot	19.4	20
12th slot	20.6	21
13th slot	21.6	22
14th slot	22.6	23
15th slot	23.7	24
16th slot	24.8	25
17th slot	26.2	26.4
18th slot	27.4	27.6
19th slot	28.6	28.8
20th slot	30	30.2
21st slot	32.4	32.6

3. Results and Discussion

The chipless RFID tag design with the design 1 parameter values as in Table 1 and Table 2, can achieve 20 bits in the frequency range from 3.00 to 10.00 GHz. As shown in Figure 7, the resonant frequency for each bit can be viewed in the RCS probe. The RCS curve is relatively high of -20 dBm^2 notched across all bits. The narrow resonant dips represent the individual octagonal resonances. In this case, the RCS level has the resonance dips between 8 and 13 dB deep. The use of PET as the substrate material has enabled the chipless RFID to operate between 3.00 and 10.00 GHz. Therefore, PET is a suitable material for RCS of the chipless RFID tag in tracking/identification.

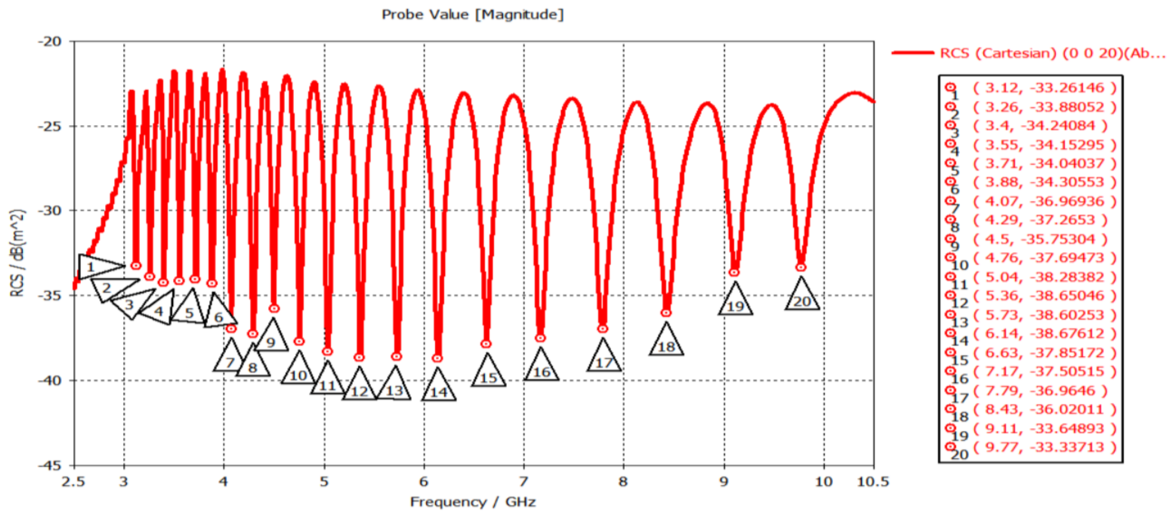


Fig. 7. RCS of the PET as 20-bit Chipless RFID Tag Substrate

The RCS curve is relatively high of -20 dBm^2 notched across all bits. The narrow resonant dips represent the individual octagonal resonances. In this case, the RCS level has the resonance dips between 8 and 13 dB deep. The use of PET as the substrate material has enabled the chipless RFID to operate between 3.00 and 10.00 GHz. Therefore, PET is a suitable material for RCS of the chipless RFID tag in tracking/identification.

Moreover, the PET-based chipless RFID tag is tested also on the ability to operate different bits or set of identifications (IDs) while maintaining 20-bit capacity information in the RCS probe result. The first design of a chipless RFID tag contains its unique identification of 01010101111010101010, which is obtained by removing resonator no. 1, 3, 5, 7, 9, 14, 16, 18, and 20, as shown in Figure 8. The RCS graph curve shows the new ID of the PET-based chipless RFID tag after removing the resonators, and the resonant frequency has changed, as shown in Figure 9.

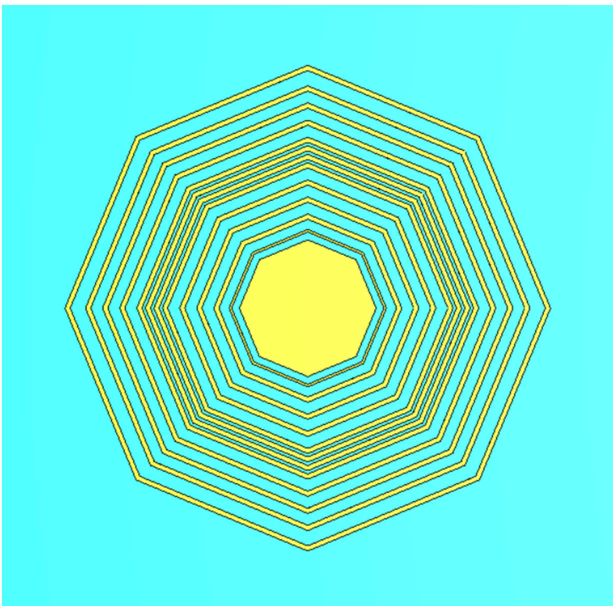


Fig. 8. PET-Based Chipless RFID Tag of ID = 01010101111010101010

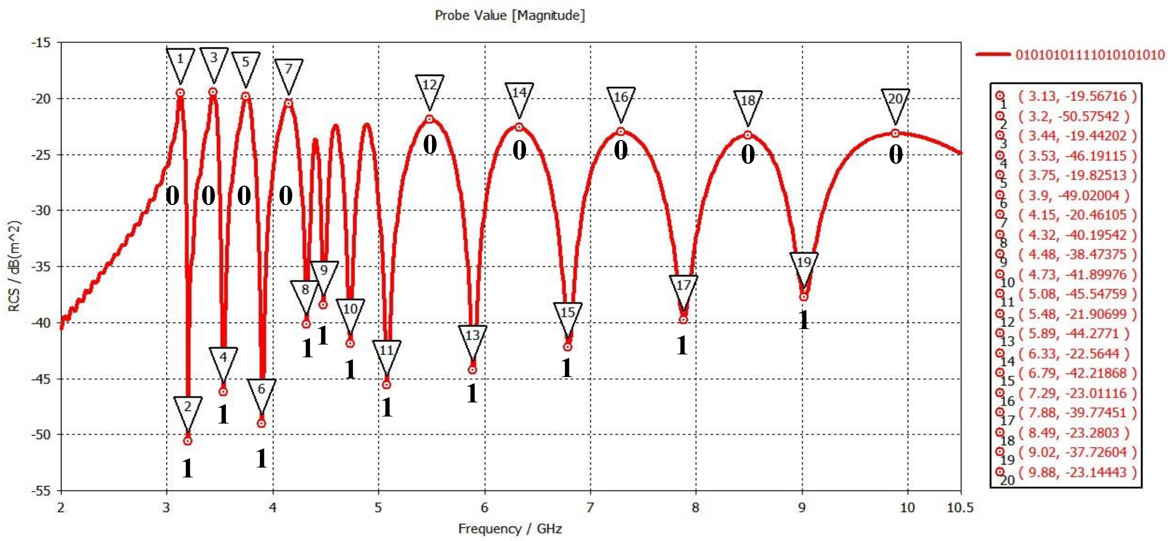


Fig. 9. PET-Based Chipless RFID Tag RCS of ID = 01010101111010101010

Moreover, there is an analysis on the performance of S_{11} parameter at different distances, such as 100, 150, 200, and 300 meters between the PET-based chipless RFID tag structure and the transceiver device. Figure 10 shows the three distance setups for testing whereas Figure 11 shows that the simulation results are similar for those three distance setups.

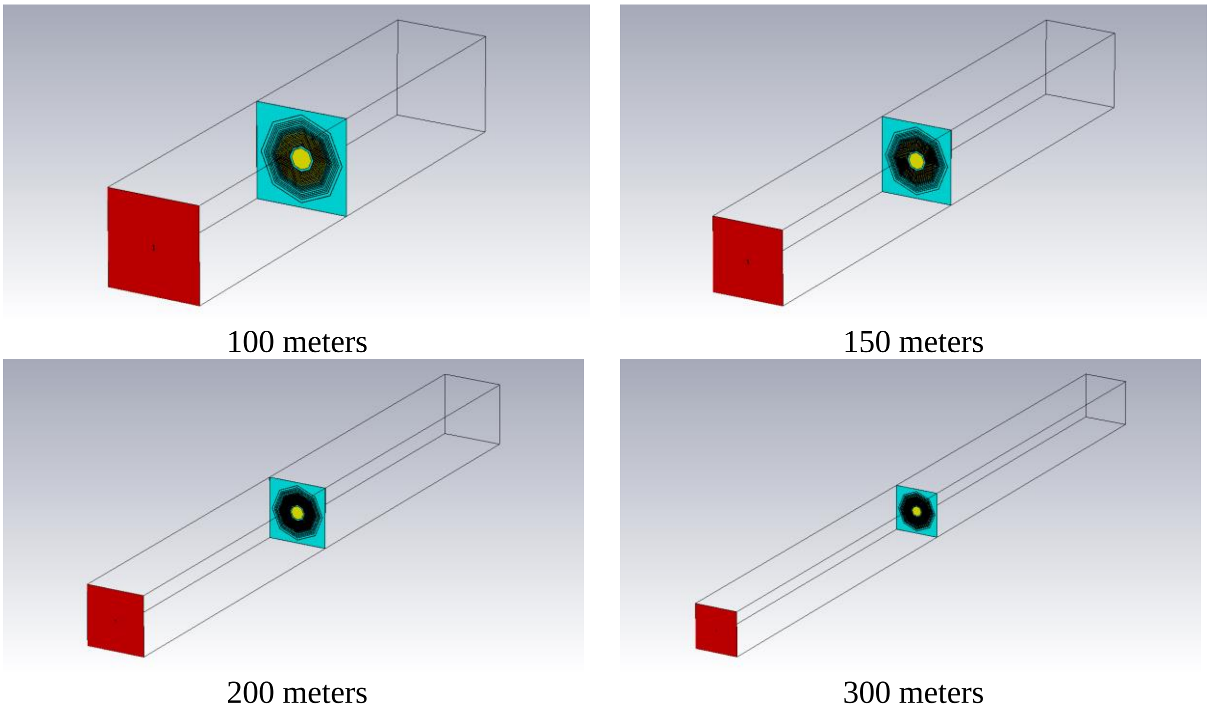


Fig. 10. PET-based Chipless RFID Tag Distance Visual Testing

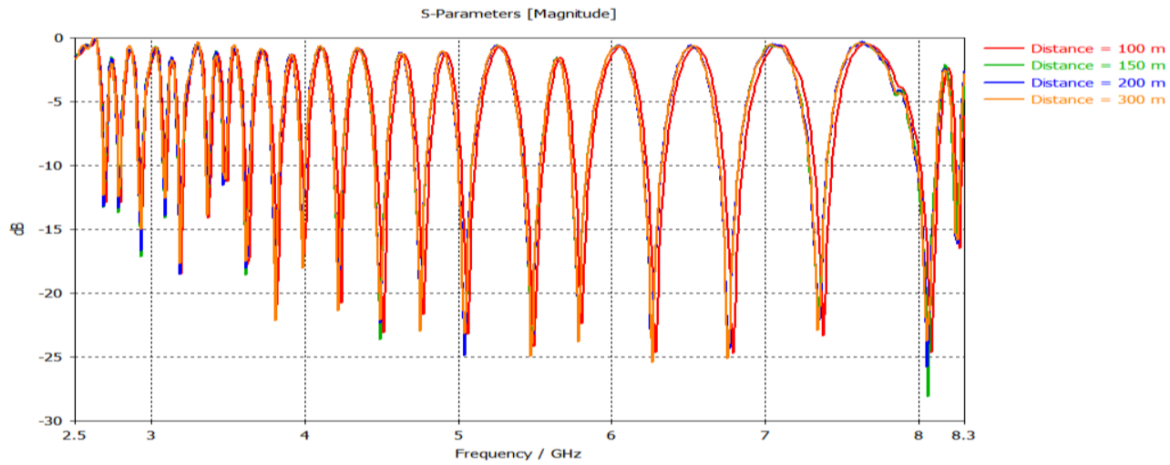
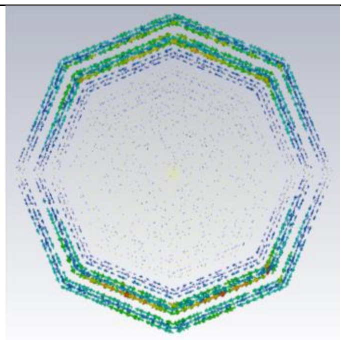
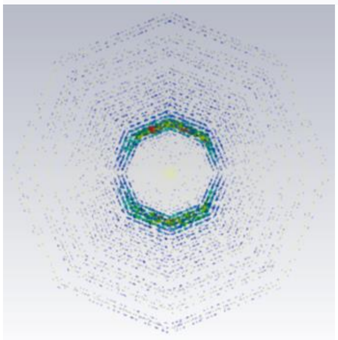
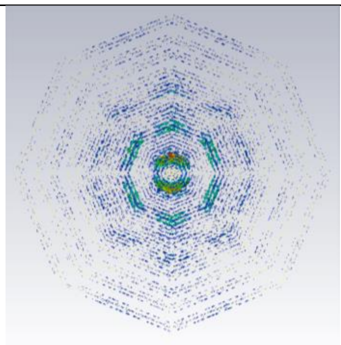


Fig. 11. PET-based Chipless RFID Tag S_{11} Simulated Result in Different Distances

Then, there is also an analysis on the surface current of the PET-based chipless RFID tag to determine whether each of the resonators operates at the given frequency. Each bit has its resonant frequency at where it operates, which can be viewed at surface current analysis. Table 5 shows the selected bit 1, 10, and 20 resonators for S_{11} resonant frequency and its surface current, respectively. The colour indicates the electromagnetic resonating at the gap of the resonator octagonal at each bit. Table 5 can be used to verify which resonator is active when the bit is 1 or inactive when the bit is 0.

Table 5
Surface Current at each Selected Bit for PET-based RFID Tag Design for S_{11}

No. of Bit	Frequency	Surface Current
1	0.84 GHz	
10	2.184 GHz	

20	6.924 GHz	

Finally, there is an on the far-field radiation pattern of the chipless RFID tag operating at the given frequency. Each bit has its resonant frequency at its operation, which can be viewed as a radiation pattern at far-field analysis. Table 6 enlists the selected bit 1, 10, and 20 resonators RCS resonant frequency and its radiation pattern whereas Table 7 enlists the selected bit 1, 10, and 20 resonators S_{11} resonant frequency and its radiation pattern, respectively. The redder colour indicates the higher gain at the gap of the resonator octagonal at each bit.

Table 6
Far-Field at each Selected Bit for PET-based RFID Tag Design for RCS

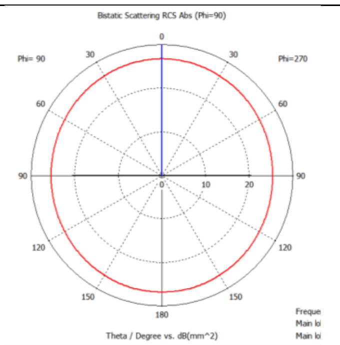
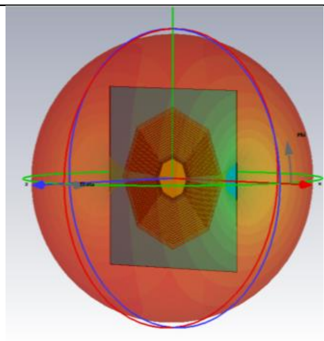
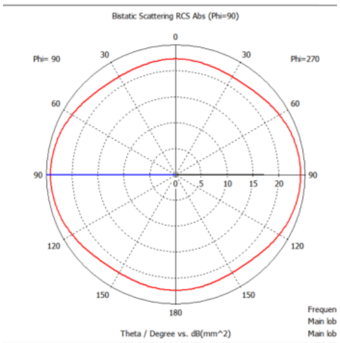
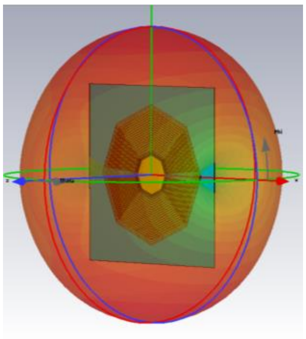
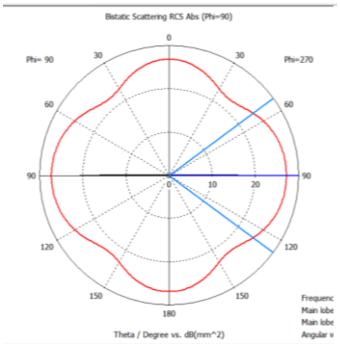
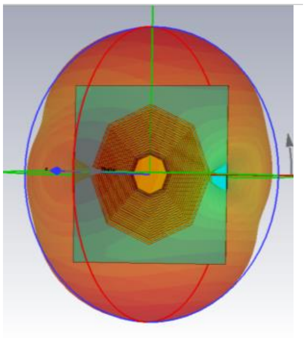
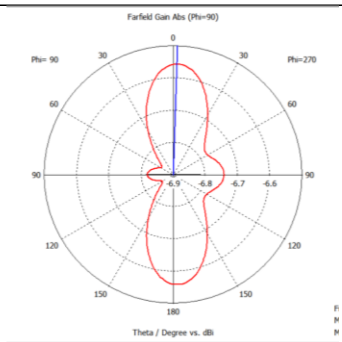
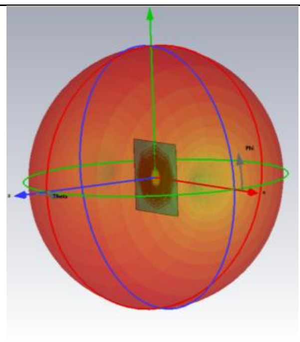
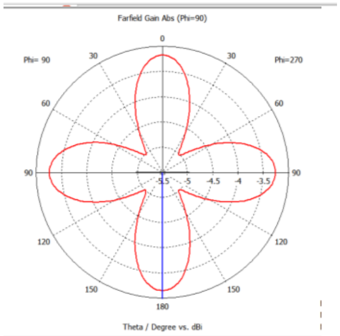
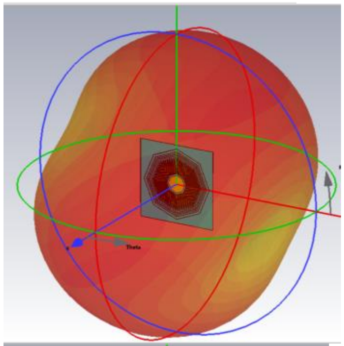
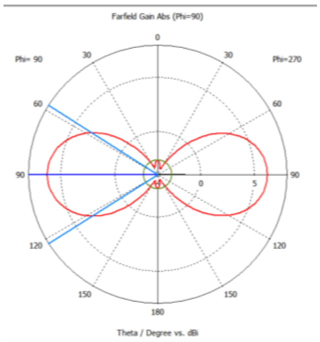
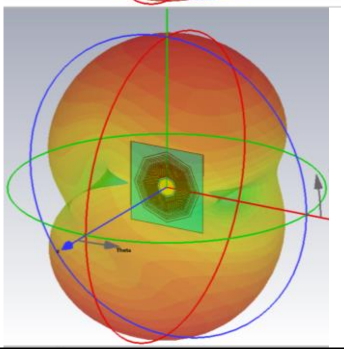
No. of Bit	2-Dimensional	3-Dimensional
1		
10		
20		

Table 7
Far-Field at each Selected Bit for PET-based RFID Tag Design for S_{11}

No. of Bit	2-Dimensional	3-Dimensional
1		
10		
20		

4. Conclusions

In conclusion, the PET-based chipless RFID tag is able to encode 20-bit data where 19-bits are used for identification, and one bit left is used for sensing, respectively. The resonator is designed to encode data at different frequencies with different width and length. The design and simulation is performed using the CST software to verify the frequency response for each different bit. The 20-bit chipless RFID tag occupied the frequency range for tracking/identification is from 3.00 to 10.00 GHz. The 19-bit can be assigned 2^{19} = 524,288 different tag identifications, so there are different frequencies for each resonator. This kind of chipless RFID tag can be applied for commercial products or systems in the near future.

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References

[1] Jusoh, WWI Wan, KA Mohd Annuar, S. H. Johari, M. H. Harun, and I. M. Saadon. "Motorcycle security system using GSM and RFID." *Journal of Advanced Research in Applied Mechanics* 16, no. 1 (2015): 1-9.

[2] *Al-Amir, Zaid, Firas Abdullah Al-Saidi, and Hussein Abdulkadir. "Design and implementation of RFID system." In 2008 5th International Multi-Conference on Systems, Signals and Devices, pp. 1-6. IEEE, 2008.* https://doi.org/10.1109/SSD.2008.4632787

[3] Herrojo, Cristian, Ferran Paredes, Javier Mata-Contreras, and Ferran Martín. "Chipless-RFID: A review and recent developments." *Sensors* 19, no. 15 (2019): 3385. https://doi.org/10.3390/s19153385

[4] Habib, Ayesha, M. Ali Afzal, Haleema Sadia, Yasar Amin, and Hannu Tenhunen. "Chipless RFID tag for IoT applications." In *2016 IEEE 59th International Midwest Symposium on Circuits and Systems (MWSCAS)*, pp. 1-4. IEEE, 2016. https://doi.org/10.1109/MWSCAS.2016.7870033

[5] Athauda, Tharindu, and Nemai Karmakar. "Chipped versus chipless RF identification: A comprehensive review." *IEEE Microwave Magazine* 20, no. 9 (2019): 47-57. https://doi.org/10.1109/MMM.2019.2922118

[6] Abdulkawi, W. M. and Sheta, A. F. A. “Printable Chipless RFID Tags for IoT Application”. *Proceeding of the 1st Int. Conf. on Computer Applications and Information Security (ICCAIS)* (2018): 1–4. https://doi.org/10.1109/CAIS.2018.8441955

[7] Rezaiesarlak, Reza, and Majid Manteghi. "Detection, Identification, and Localization in Chipless RFID Systems." In *Chipless RFID*, pp. 127-159. Springer, Cham, 2015. https://doi.org/10.1007/978-3-319-10169-9_5

[8] Jabeen, Iqra, Asma Ejaz, Sumrin Mehak Kabir, Adeel Akram, Yasar Amin, and Hannu Tenhunen. "Octagonal shaped flexible chipless RFID tag for Internet of Things." In *2019 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*, pp. 1-4. IEEE, 2019. https://doi.org/10.1109/ICECCE47252.2019.8940693

[9] Costa, Filippo, Simone Genovesi, Michele Borgese, Andrea Michel, Francesco Alessio Dicandia, and Giuliano Manara. "A review of RFID sensors, the new frontier of internet of things." *Sensors* 21, no. 9 (2021): 3138. https://doi.org/10.3390/s21093138

[10] Dey, Shuvashis, Jhantu Kumar Saha, and Nemai Chandra Karmakar. "Smart sensing: chipless RFID solutions for the internet of everything." *IEEE Microwave Magazine* 16, no. 10 (2015): 26-39. https://doi.org/10.1109/MMM.2015.2465711

[11] Vena, Arnaud, Etienne Perret, Darine Kaddour, and Thierry Baron. "Toward a reliable chipless RFID humidity sensor tag based on silicon nanowires." *IEEE Transactions on Microwave Theory and Techniques* 64, no. 9 (2016): 2977-2985. https://doi.org/10.1109/TMTT.2016.2594229

[12] Amin, Emran Md, Jhantu Kumar Saha, and Nemai Chandra Karmakar. "Smart sensing materials for low-cost chipless RFID sensor." *IEEE Sensors Journal* 14, no. 7 (2014): 2198-2207. https://doi.org/10.1109/JSEN.2014.2318056

[13] Genovesi, Simone, Filippo Costa, Michele Borgese, Francesco Alessio Dicandia, Agostino Monorchio, and Giuliano Manara. "Chipless RFID sensor for rotation monitoring." In *2017 IEEE International Conference on RFID Technology & Application (RFID-TA)*, pp. 233-236. IEEE, 2017. https://doi.org/10.1109/RFID-TA.2017.8098885

[14] Riaz, Muhammad Ali, Yassin Abdullah, Humayun Shahid, Yasar Amin, Adeel Akram, and Hannu Tenhunen. "Novel butterfly slot based chipless RFID tag." *Radioengineering* 27, no. 3 (2018): 776-783. https://doi.org/10.13164/re.2018.0776

[15] Adbulkawi, Wazie M., and Abdulfattah A. Sheta. "A compact chipless RFID tag based on frequency signature." In *2017 9th IEEE-GCC Conference and Exhibition (GCCCE)*, pp. 1-4. IEEE, 2017. https://doi.org/10.1109/IEEEGCC.2017.8447948

[16] Islam, Md Aminul, and Nemai Karmakar. "A compact printable dual-polarized chipless RFID tag using slot length variation in'I'slot resonators." In *2015 European Microwave Conference (EuMC)*, pp. 96-99. IEEE, 2015. https://doi.org/10.1109/EuMC.2015.7345708

[17] Harrop, Peter, and Raghu Das. "Printed and Chipless RFID Forecasts." *Technologies & Players* 2029 (2009)." Available online: *https://www.giiresearch.com/report/ix243391-rfid-forecasts-players-opportunities-2012-2022.html*

[18] Costa, Filippo, Michele Borgese, Antonio Gentile, Luca Buoncristiani, Simone Genovesi, Francesco Alessio Dicandia, Davide Bianchi, Agostino Monorchio, and Giuliano Manara. "Robust reading approach for moving chipless RFID tags by using ISAR processing." *IEEE Transactions on Microwave Theory and Techniques* 66, no. 5 (2017): 2442-2451. https://doi.org/10.1109/TMTT.2017.2779801

[19] Mulloni, Viviana, and Massimo Donelli. "Chipless RFID sensors for the Internet of Things: Challenges and opportunities." *Sensors* 20, no. 7 (2020): 2135. https://doi.org/10.3390/s20072135

[20] Borgese, Michele, Simone Genovesi, Giuliano Manara, and Filippo Costa. "Radar cross section of chipless RFID tags and BER performance." *IEEE Transactions on Antennas and Propagation* 69, no. 5 (2020): 2877-2886. https://doi.org/10.1109/TAP.2020.3037800