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REGULAR ARTICLE

Design and Analysis of a Concentric Ring Based Split Ring Monopole Antenna with Characteristic Mode Analysis (CMA) for IoT Communication Applications

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Significant advancement has been witnessed in the field of modern communication technology in last decade. Several wireless systems such as Wireless LAN, Wireless Fidelity (Wi-Fi) etc. are popular to connect devices to facilitate communication between them through internet technology. To access much faster communication, higher data rates are highly sought after with the upgradation of mobile communication generations (1G to 5G). Wideband/multiband antennas usually support multiple devices to get connected over a broad range of communication. As a benchmark of next generation communication technology, Internet of Things (IOT) is gaining a huge popularity in the field of wireless network. It ensures faster and secure communication among devices and cloud with high data rate. With this aim, we have proposed a new monopole antenna for IOT applications. The design consists of a new concentric ring based split ring patch and partial ground plane. It is implemented with characteristic mode analysis. The designed antenna operates in the ultra-wideband region with multiband characteristics at four bands of (1.5-1.9 GHz), (3.9- 4.2 GHz), (5.9-6.9 GHz) and (7.4-11.8 GHz) to cover for various IoT communication applications. The suggested design is inspected using analysis of characteristic mode, characteristic angle, eigen values, and modal significance. The distribution of surface current for the proposed circular shaped patch antenna is analyzed for mode of propagation by the theory of characteristic modes (CMA).

Keywords: Characteristic mode, Characteristic angle, Modal significance.

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1. INTRODUCTION

During the past few decades, the wireless technology has developed a lot and become a major part in the everyday life. Every household has many devices connected and operating using wireless technology through IoT interfacing. Devices like smartphones, laptops, tablets etc can be found everywhere in places like homes, offices, business organizations, public and private sectors etc. All such devices need to be connected to internet using Wi-Fi network and also communication using voice is done by phone calls using mobile networks. This can be a huge challenge from the manufacturer point of view. The products must be designed in a way manner that they are applicable in any part of the world effectively. The devices should be capable of working with old GSM technology all the way up-to the today's standard LTE network. To make this possible, the antenna utilized in the device should cover all ranges of frequency and must be effective. Designing such a lightweight, small, compact, robust, thin, flexible, and efficient antenna is a complex task.

It is very difficult to set or use the design rules and equations which leads the overall development of the system complicated when size of the antenna is too big. In those cases, other methods such as numerical methods and electromagnetic simulators such as HFSS, CST and IE3D can be used. The various properties of the antenna can be verified by using these software's. Although all the methods which are discussed above are more suitable for antenna design but those are having some drawbacks. They are not providing real knowledge and deep insights into antenna design. A recent, popular, and frequently used method Characteristic Mode Analysis (CMA) solves this problem efficiently.

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The characteristic modes theory (TCM) gives pattern of radiation and number of current distributions with respect to different frequency modes. A procedure to study the arbitrary shaped conducting bodies is developed. Again, the characteristic modes theory is revised for antennas designed for modern applications. New feeding techniques can be known by examining of the eigen current distribution in CMA analysis. By utilizing this approach, designing of compact ultra-wide band antenna mainly for Internet of Things and wireless communication can be developed easily.

The CMA analysis is similar or identical to the equations of method of moments (MoM). A new method is initiated for following procedures in theory of characteristic mode. Complicated shapes like fractal patch antenna can also be designed using this method. The consequence of notch frequency characteristics, effects of ground plane size and effects of miniaturization of monopole antenna can also be analyzed with the help of various modes in an antenna. In [1], a planar, dual-polarized and dual band-antenna is designed on a half-flex of substrate. The size of the antenna is 70.4 × 76.14 × 3.11 mm^3. In [2], a new, single band wearable antenna which has a double-mode operation with applications in 2.5 GHz band is designed. In work [3], a circular ring slot wearable antenna comprising structure of electromagnetic bandgap is developed for Industrial and Scientific and Medicinal (ISM) band applications. In [4], a metal watch strap based wearable antenna is proposed. In [5], a multi-mode UWB antenna with CMA analysis is reported. In [6-16], designing of antenna using the most popular and efficient method, the theory of characteristic modes is described.

In this work a circular oriented ring-shaped patch antenna is designed and various variables such as the S-parameters, gain constraint and current distribution that affect the radiating properties of antenna are given. The designed antenna is examined by the technique of CMA.

2. CHARACTERISTIC MODE ANALYSIS

The principle of Characteristic Mode was first introduced by Garbacz in the 20th century and after that it was modified by Harrington and Mautz [15]. One of the most important features of this analysis is, these modal solutions are calculated not only for complex and also for all arbitrary shaped conducting bodies, which are capable of showing any resonance. According to the principal definition, the modes of CMA are nothing but real current modes which are obtained numerically. By the very fact, that these modes provide quite accurate information about possible radiation patterns, are these modes vital for the planning of the antenna. The characteristic modes are independent from the excitation, they're dependent just on the form and therefore the size of conductive object [16]. Due to this the antenna design contains two parts, in first part the design has to be optimized and based on this specified resonant frequency and the radiation properties are often adjusted. The resonant frequency is going to be changed if the dimensions of the design is either minimized or maximized and also same equivalent situation happens with the radiation properties. In second part of the design, it is required to choose suitable feeding configuration to excite desire modes. For an accurate antenna design, usually a couple of dominant modes are sufficient to be analysed [5]. The characteristic modes theory (TCM) gives the amount of current and radiation diagram with reference to various modes of frequency. The present distribution which depends upon eigen vector and eigen value. The mathematical model of the characteristic modes that connects the current on conducting surface [15-16].

$$[l(J)E^i]\tan = 0 \tag{1}$$

Here the tan specifies the tangential components on the surface *S*. The operator '*l*' in the above equation is linear and is denoted by,

$$l(J) = jwA(J) + \Delta\Phi(J) \tag{2}$$

Here $A(J)$ and $\Phi(J)$ are the vector, scalar potentials, respectively. basically, the term $l(J)$ is specifying as electric intensity at any point in space.

$$Z(J) = [l(J)]^{tan} \tag{3}$$

The Z is complex impedance operator, and it can be written down as,

$$Z(J) = R(J) + jX(J) \tag{4}$$

The characteristic current modes are obtained from eigen value linear equation, which is given as,

$$X(J_n) = \lambda_n R(J_n) \tag{5}$$

Here real as well as imaginary parts of the impedance operator $Z = R + jX$ are R and X. Respectively, λ_n is the eigen value, (J_n) is eigen function. These CMA modes are completely depending only on size and shape of antenna and also independent of all kinds of excitations [15].

3. ANTENNA DESIGN AND MODELLING

In all iterations of a design, a circular patch antenna is designed on a low-cost Rogers RT/duroid substrate. Also, this is fed using a micro strip line of 50 Ω. This first iteration is a simple design. The dimensions of the objected antenna are shown in Table 1.

Table 1 – Dimensions of antenna

Parameters	L_1	W_1	L_2	W_2	R_1	R_2	R_3	D	W_l
Specifications in mm	90	110	16	4	16	8	4	16	2

3.1 Iteration 1

The structure executed in iteration-1 is shown in Figure 1. The corresponding S_{11} is shown in Figure 2.

By noticing the S_{11} parameters for the first iteration, we can notice that antenna is operating in different bands such as 1.6-3.2 GHz, 5-5.3 GHz, 7-9.6 GHz. The 3D gain plot at 5.3 GHz and 5 GHz are shown in Fig. 3 (a) and (b) respectively along with surface current presentation as depicted in Fig. 3 (c). The gain for the designed antenna in iteration-1 is also high (7.41 dB). The distribution of surface current of antenna states proper radiation of the power from the antenna.

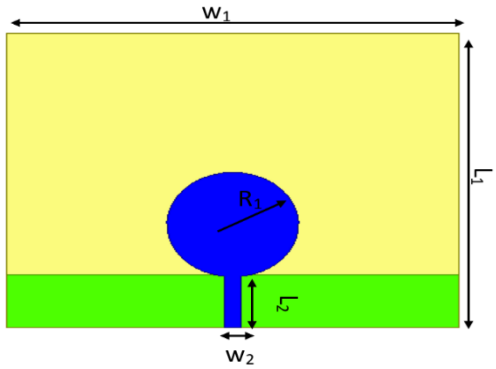


Fig. 1 – Top view of antenna iteration-1

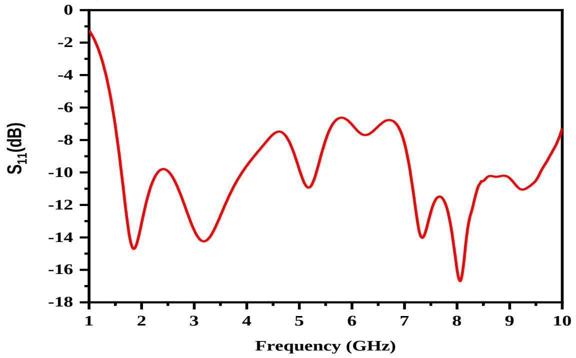
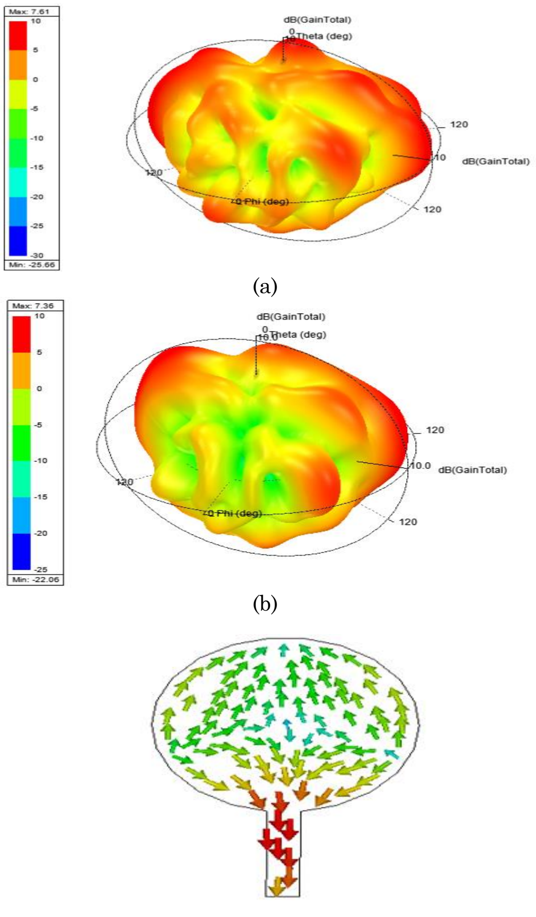


Fig. 2 – S_{11} plot of iteration-1 design



(a)

(b)

(c)

Fig. 3 – Gain Plot (a) 5.3 GHz (b) 5 GHz (c) surface current Distribution

As noticed from Figs. 4-6, the CMA results like characteristic angle, modal significance and eigenvalue show the operation of antenna in above stated bandwidths.

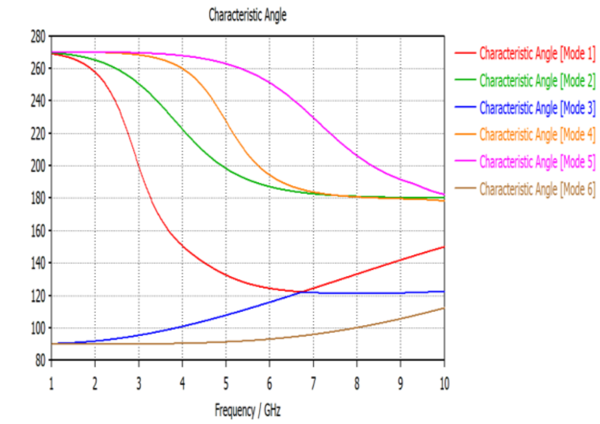


Fig. 4 – Frequency vs characteristic angle plot for iteration-1

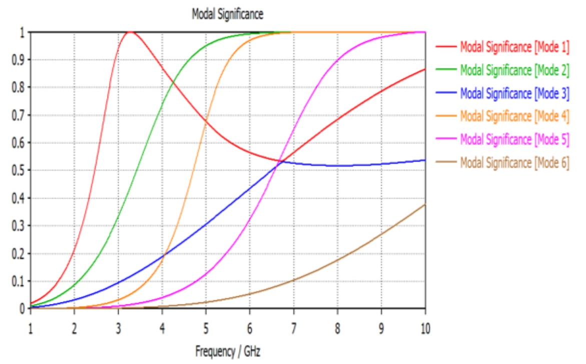


Fig. 5 – Frequency vs Modal Significance plot for iteration-1

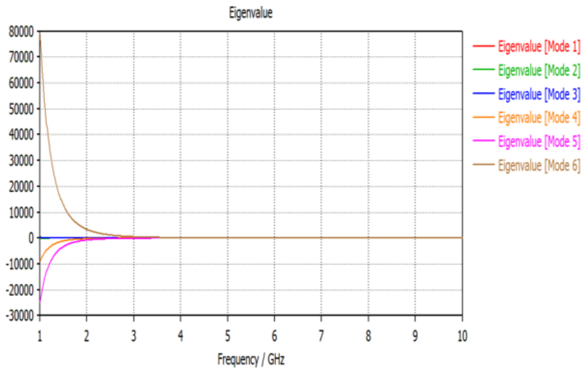


Fig. 6 – Eigen Value plot for iteration-1

3.2 Iteration 2

In this iteration a hole is made inside the circular shaped patch making it a ring like structure. A slit is also made in the centre of the ring horizontally. The structure is shown in Fig. 7. The corresponding S_{11} is shown in Fig. 8.

By noticing the S_{11} parameter for the second iteration, we can notice that the antenna is operating in different bands such as 2-2.4 GHz and 3.4-10.48 GHz. The distribution of surface current of antenna is also plotted in Fig. 9, which states proper radiation of the power from the antenna. The CMA results like characteristic angle, modal significance and eigenvalue are shown in Figs. 10-12, respectively.

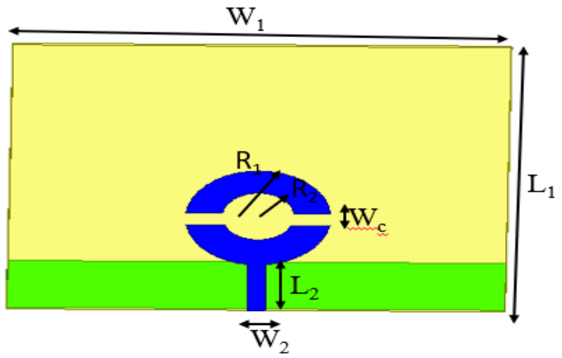


Fig. 7 – Top view of iteration-2 design

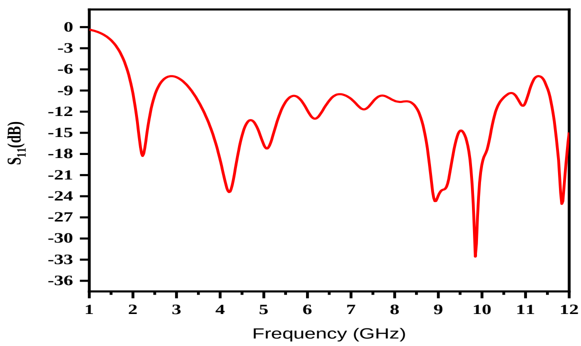


Fig. 8 – S_{11} parameter plot for iteration-2

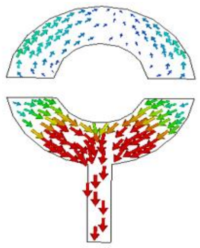


Fig. 9 – Surface current Distribution of antenna iteration-2

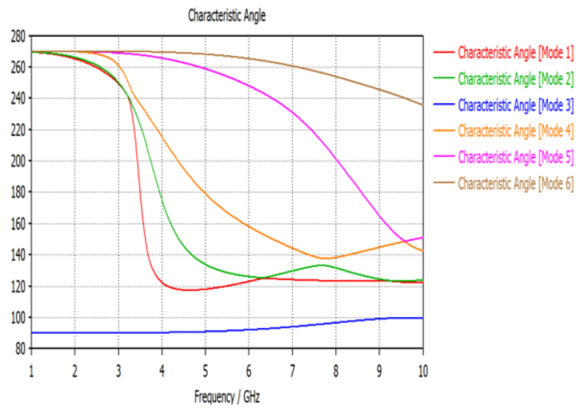


Fig. 10 – Frequency vs characteristic angle plot for iteration-2

3.3 Iteration 3

In the third iteration, three more smaller circular shaped patches are added on the top, left and right side of the ring that are presented in the previous iteration.

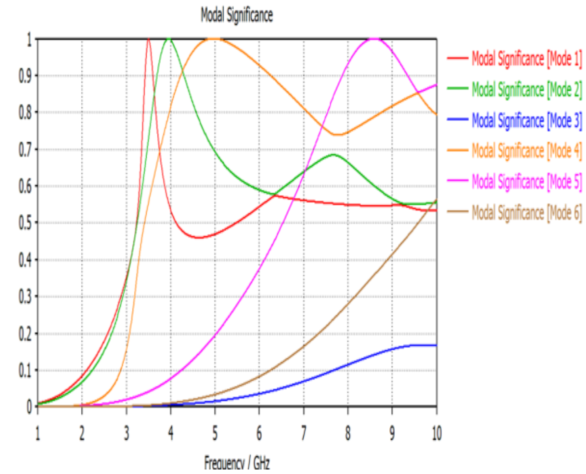


Fig. 11 – Frequency vs Modal Significance plot for iteration-2

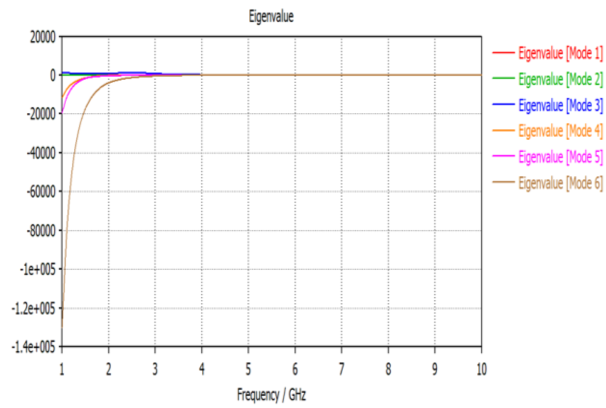


Fig. 12 – Eigen Value plot for antenna iteration-3

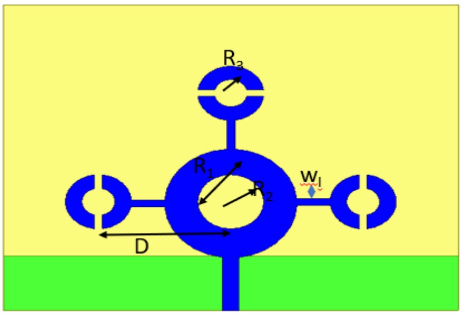


Fig. 13 – Top of the proposed antenna iteration-3

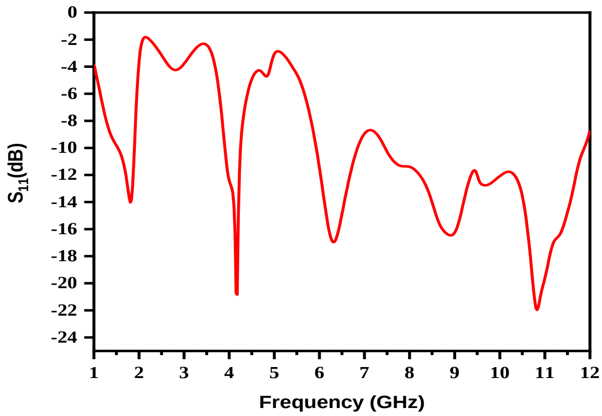


Fig. 14 – S_{11} parameters plot for iteration-3

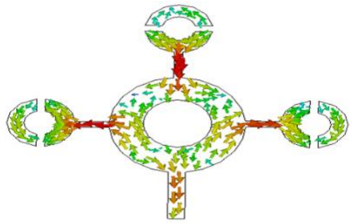


Fig. 15 – Surface current Distribution of antenna iteration 3

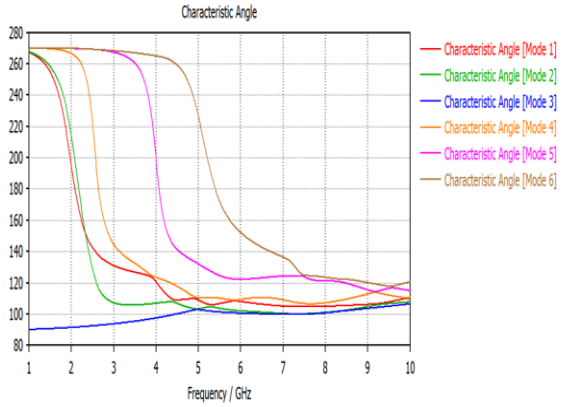


Fig. 16 – Frequency vs characteristic angle plot for iteration 3

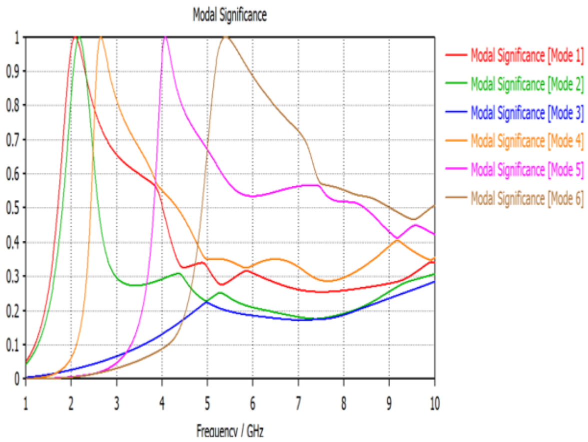


Fig. 17 – Frequency vs Modal Significance plot for iteration-3

Holes are made inside the smaller circular patches making it a ring like structure. Slits are also made in the centre of the rings horizontally and vertically. The geometry of the antenna in iteration-3 is shown in Fig. 13.

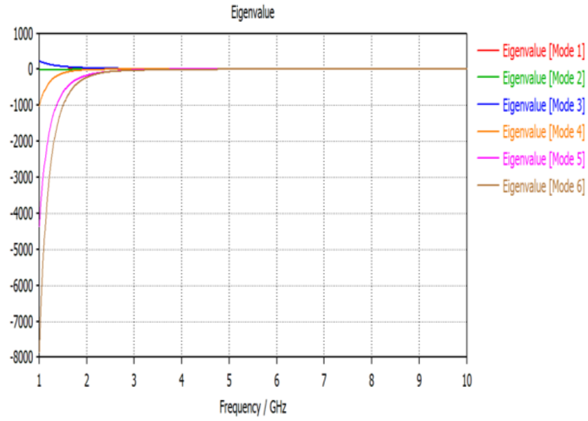


Fig. 18 – Eigen Value plot for antenna iteration3

The corresponding S_{11} is shown in Fig. 14. By observing the S_{11} parameters for the third (3^{rd}) iteration, we can notice that antenna operating in different bands such as (1.5-1.9 GHz), (3.9- 4.2 GHz), (5.9-6.9 GHz) and (7.4-11.8 GHz). The distribution of surface current of antenna is plotted in Fig. 15, which shows the proper radiation of the power from the antenna. The CMA results like characteristic angle, modal significance and eigenvalue for iteration-3 are shown in Figs. 16 to 18.

4. CONCLUSIONS

This paper dealt with development as well as analysis of a circularly patched micro strip antenna with using characteristic mode analysis. An antenna was designed, developed, analyzed, and optimized to make it suitable for IoT applications using both High Frequency Structure Simulator (HFSS) and also CST software. Various parameters such as S_{11} parameters, gain parameter of the antenna, distribution of surface currents and CMA results like characteristic angle, modal significance and eigenvalue are observed. The results of the designed antenna models prove that antenna operates at wide range of frequencies ranging from 1.5-1.9 GHz, 3.9- 4.2 GHz, 5.9-6.9 GHz and 7.4-11.8 GHz. These results make antenna applicable for IoT communication applications.

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Розробка та аналіз монопольної антени з розділеним кільцем на основі концентричного кільця з аналізом характерних режимів (CMA) для додатків зв'язку IoT

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За останнє десятиліття в галузі сучасних комунікаційних технологій спостерігався значний прогрес. Кілька бездротових систем, таких як Wireless LAN, Wireless Fidelity (Wi-Fi) тощо, популярні для підключення пристроїв для полегшення зв'язку між ними за допомогою інтернет-технологій. Щоб отримати доступ до набагато швидшого зв'язку, у зв'язку з оновленням поколінь мобільного зв'язку (1G до 5G) дуже потрібні вищі швидкості передачі даних. Широкосмугові/багатосмугові антени зазвичай підтримують кілька пристроїв для підключення в широкому діапазоні зв'язку. Як еталон комунікаційної технології наступного покоління, Інтернет речей (IoT) набуває величезної популярності у сфері бездротових мереж. Це забезпечує швидший і безпечний зв'язок між пристроями та хмарою з високою швидкістю передачі даних. З цією метою ми запропонували нову монопольну антену для додатків IoT. Конструкція складається з нової накладки розділеного кільця на основі концентричного кільця та часткової заземленої площини. Реалізується з аналізом характеристичного режиму. Розроблена антена працює в надширокосмуговій області з багатодіапазонними характеристиками в чотирьох діапазонах (1,5-1,9 ГГц), (3,9-4,2 ГГц), (5,9-6,9 ГГц) і (7,4-11,8 ГГц), щоб охопити різні комунікаційні програми IoT. Запропонована конструкція перевіряється за допомогою аналізу характеристичного режиму, характерного кута, власних значень і модального значення. Розподіл поверхневого струму для запропонованої патч-антени круглої форми аналізується на спосіб поширення за допомогою теорії характерних мод (CMA).

Ключові слова: Характерна мода, Характерний кут, Модальне значення.