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Feeding Methods for a Circular Shaped Multiband Patch Antenna at 5G, X and Ku Band to Quantify their Effects on Antenna Characteristics

Nitasha Bisht[1*], Praveen Kumar Malik[1], Sudipta Das[2]

[1] *Electronics and Communication Engineering Department, Lovely Professional University Phagwara, 144411, India*
[2] *Electronics and Communication Engineering Department, IMPS College of Engineering and Technology Nityanandapur, Malda-732103, West Bengal, India*

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The paper is a comparative analysis of coaxial feed and microstrip line feed for a slotted circular patch microstrip antenna. When various feeding techniques are used to increase impedance matching, the performance of several characteristic parameters, such as voltage standing wave ratio, radiation pattern, gain etc. are impacted. To determine the extent to which these variables are affected, a comparison study is conducted, and the results are provided in this work. With the help of High Frequency Structure Simulator (HFSS) 3D electromagnetic software the antenna is devised and simulated. The intended coaxial feed antenna resonates at 7.5 GHz, 12.5 GHz, and 15 GHz, with bandwidths of 1800, 720, and 360 MHz, respectively, and 5.63 dB as a peak gain. In contrast, the proposed micro-strip feed antenna resonates at 3.5, 7, 12.8, 15, 17.5 GHz with a bandwidth of 180, 450, 90, 1170, 2250 MHz and a peak gain of 6.57 dB. In terms of gain, bandwidth, and multiband characteristics, microstrip line feed has been shown to outperform coaxial probe feed. The antenna designed with dimension of 33.56 × 33.56 mm². The substrate used for the designing of circular patch microstrip antenna is FR4. The novel features of the designed antenna include its multiband properties and increased bandwidth. The proposed antenna can be utilized efficiently in X, Ku and lower 5G band.

Keywords: Circular patch, Coaxial probe feed, Fifth generation, Microstrip patch antenna, Microstrip feedline.

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1. INTRODUCTION

One of the best remedies to achieve the targets of the communication systems in a fast way is the fifth-generation (5G) technology [1-2]. In order to compose a 5G network, microstrip patch antenna technology is fascinating the researchers owing to its portability, compact form, low cost, simple mass production, and straight forward installation. As shown in Fig. 1, the structure of a microstrip patch antenna has three parts [3-4]. The typical layout has a copper radiating patch on the top, in the mid region, there is a dielectric substrate layer, and the lower most is a ground plane. Patch antennas, like all other types of antennas, require a feed line to transfer energy from the antenna's power supply to the antenna itself. The position of the patch antenna should be in such a way that the input impedance is 50 ohms to receive the most input power according to the theorem of maximum power transfer. Patch antennas can be nurtured using two categories of feeding methods in order to achieve the condition: connecting (micro-strip feed line and coaxial probe feed line) and non-connecting (aperture coupled and proximity coupled) feeding technique [5]. Such feeding strategies when performed at several frequency spectrum in order to increase impedance matching, the ability and performance of many characteristic features like gain, radiation pattern, bandwidth, etc. are affected. Hence, it is essential to understand these parameters while developing new antenna applications [6]. Broader impedance bandwidth is provided by a hexagonal microstrip patch antenna fed by an asymmetric microstrip feed line and a Fish-shaped patch antenna fed by a tilted feed [7-8], while good impedance matching is provided by a coaxial probe fed rectangular patch or a slotted ring-shaped patch with two feed ports [9-10].

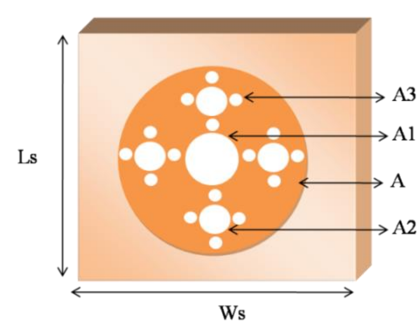

Fig. 1 – Circular patch microstrip antenna with slots

Multiband and improved bandwidth characteristics are provided by elliptical and circular ring-shaped patch antennas with defective ground structures and micro-strip line feed [11-12]. It is also possible to increase the operating bandwidth by making adjustments to the feed line, such as using a non-uniform transmission line, rotating or tapered feeding [13-16]. The proposed

* bisht19876@yahoo.co.in

antenna use a simple coaxial and microstrip line feeding without any tapering and defective ground structure provide wider bandwidth and multiband characteristics. So, novel features of proposed antenna are its multiband capabilities and its relatively large bandwidth. This paper describes the proposed work in terms of the following objectives:

1. Designing a circular patch antenna utilizing a coaxial probe and microstrip line feeding technology.
2. Simulation of optimal antennas using HFSS software.
3. Comparing the results of feeding strategies in order to quantify their effects on the observed antenna properties. These objectives will be pursued beginning in section 2 and continuing through section 5. Sections 2 and 3 study antenna design and feeding techniques, followed by Section 4, which presents a comparative analysis of both feeding techniques. Section 5 presents the comparison of current work with the previous ones, and Section 6 presents the conclusion.

2. DESIGN PROCEDURE

The following formulas mentioned in Table 1 can be used to calculate the basic antenna parameters for a circular microstrip patch antenna. Along with this Fig. 2 depicts the various iteration stages as well as the mechanism to compute the radius of inner circles.

Table 1 – Optimized dimensions of proposed antenna

Sr. No.	Parameter	Formula	Size (mm)
1.	Radius	$A_e = \frac{1.8412 \text{ x Vo}}{2 \text{ x } 3.14 \text{ x fr x } \sqrt{\text{Er}}}$	11.98
2.	Length of substrate	$L_s = L + 6H$	33.56
3.	Width of substrate	$W_s = W + 6H$	33.56
4.	Substrate with thickness	—	FR4/1.6
5.	Radius of circle after 1st iteration process (A1)	$N_1 = \text{№ } of\ circle = 5^1$ $L_1 = Scaling\ factor$ $for\ radius\ of\ circle =$ $= (1/3)^1 = 0.333$ So, $(0.333 \cdot 11.98 = 3.99)$	3.99
6.	Radius of circle after 2nd iteration process (A2)	$N_2 = \text{№ } of\ circle = 5^2$ $L_2 = Scaling\ factor$ $for\ radius\ of\ circle =$ $= (1/3)^2 = 0.111$ So, $(0.111 \cdot 11.98 = 1.32)$	1.32
7.	Radius of circle after 3rd iteration process (A3)	$N_3 = \text{№ } of\ circle = 5^3$ $L_3 = Scaling\ factor$ $for\ radius\ of\ circle =$ $= (1/3)^3 = 0.037$ So, $(0.037 \cdot 11.98 = 0.44)$	0.44

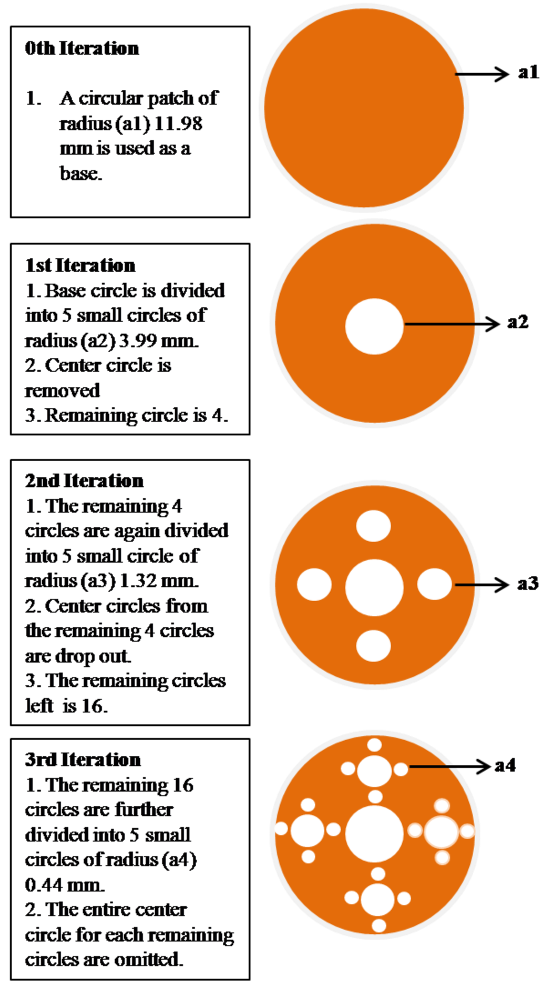

Fig. 2 – Iteration stages for the development of proposed antenna

3. FEEDING TECHNIQUE

Feeding or transmitting electromagnetic energy to a microstrip patch antenna can be done in a few different ways. Feeding plays a pivotal role in enhancing the input impedance matching of the antenna, thus helping to achieve optimal antenna performance. These two methods of feeding are the most prevalent ones:

A. Coaxial Probe Feed
B. Microstrip Line Feed

3.1 A. Coaxial Probe Feed

Microstrip patch antennas are often fed using the coaxial cable or probe feeding method. This is because it is the most prevalent technique. It is seen in Fig. 3, the internal conductor of the coaxial cable is passing through the dielectric and after that, it is soldered to the radiating metal patch. On the other hand, the ground plane remains connected to the outer conductor of the cable. Table 2 presents the parameters values calculated for coaxial probe feeding. This type of feeding system offers an advantage regarding its adjustment. It can be positioned wherever on the patch to match cable impedance with antenna input impedance. This type of feeding produces a low amount of spurious radiation. Its restricted bandwith is the most significant drawback. Therefore, it becomes essential for substrate to have a hole and the connector extrude out from the ground plane. Another issue which creates problems with impedance matching is increase in probe length of substrates that are thicker which inturn causes the input impedance to become more inductive.

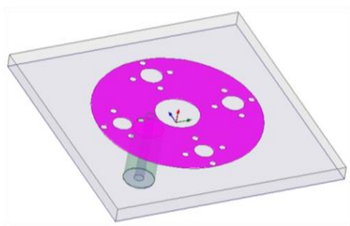

Fig. 3 – Coaxial probe feeding technique

Table 2 – Coaxial probe feed features

Label	Value (mm)	Particulars
R_I	0.63	Inner conductor feed radius
ε_r	2.1	Feed dielectric constant
RO	2.61	Outer conductor feed radius

3.2 B. Microstrip Line Feed

As illustrated in Fig. 4, edge of the microstrip patch is linked directly to the conducting strip. Such a type of feeding arrangement has the advantage that to give an even framework, the feed can be inscribed on the identical substrate. The width of the conducting strip is restricted than that of the patch. In microstrip line feeding, there is no requirement of any additional matching element to match the impedance between patch and feed line, only inset cut at junction is sufficient.

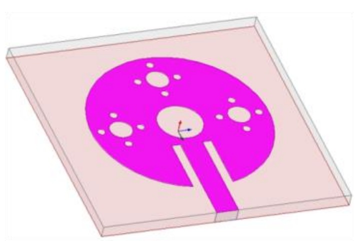

Fig. 4 – Microstrip feeding technique

Table 3 displays the computed parameters for microstrip line feeding. This can be accomplished by altering the position and dimensions of the inset cut. Therefore, due to its ease of construction, model simplicity and impedance matching, it is a simple feeding system. However, with the enhancement of the substrate thickness, spurious feed and surface waves radiations increases, ultimately reducing the bandwidth of antenna. Also, there is generation of cross polarized radiation by the feed radiation.

Table 3 – Microstrip line feed features

Label	Value (mm)	Particulars
FL	12.79	Length of feedline
FW	2.99	Width of feedline
GPF	1.2	Gap between the feedline and patch

4. COMPARATIVE ANALYSIS OF COAXIAL PROBE AND MICROSTRIP FEEDING

For comparing and contrasting, the designed antenna's performance metrics (gain, bandwidth, voltage standing wave ratio, reflection coefficient, and resonant frequency), two different feeding procedures (coaxial probe and microstrip line) have been used. The change in the S_{11}, VSWR and gain are shown in Figs. 5, 6, and 7 respectively.

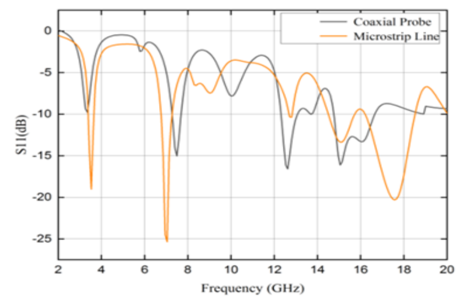

Fig. 5 – Comparison between S_{11} (dB) of coaxial probe and microstrip feedline antenna

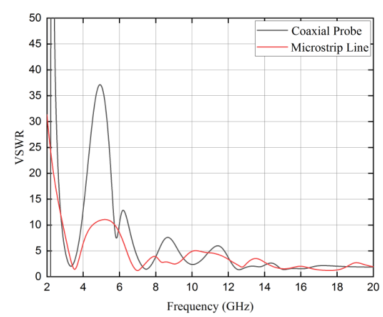

Fig. 6 – Comparison between VSWR of coaxial probe and microstrip feedline antenna

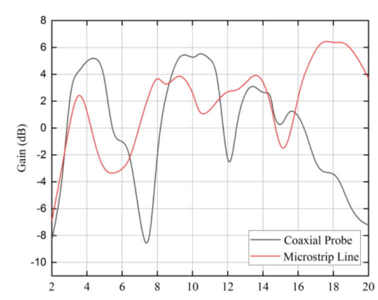

Fig. 7 – Comparison between Gain (dB) of coaxial probe and microstrip feedline antenna

The suggested antenna is shown to have a gain of 5.63 dB and a bandwidth of 1800 MHz, 720 MHz, and 360 MHz at 7.5 and 12.5 GHz, respectively, when fed with a coaxial probe, and at 3.5, 7, 12.8, 15, and 17.5 GHz with bandwidth 180, 450, 90, 1170, 2250 MHz respectively and gain of 6.57 dB, when fed with a micro-strip feedline. Both feedline methods will achieve an acceptable VSWR of less than two. The simulation results are collated and compared in Table 4. When compared to a coaxial probe feedline, the bandwidth and gain of a micro-strip feedline are superior. While a micro-strip feedline antenna has five frequency bands, a coaxial probe feed antenna only has three.

Table 4 – Comparison between coaxial probe and microstrip feed line simulated result

Antenna Design	Resonant Frequency (GHz)	Gain (dB)	Bandwidth (MHz)	Return Loss	VSWR	Band
Coaxial Probe Feedline	7.5, 12.5, 15	5.63	1800, 720, 360	–12.9, –16.11, –16.12	1.5, 1.3, 1.3	Triple
Micro-strip Feedline	3.5, 7, 12.8, 15, 17.5	6.57	180, 450, 90, 1170, 2250	–19, –25.3, –10.3, –13.3, –20.2	1.2, 1.1, 1.8, 1.5, 1.2	Penta

5. PERFORMANCE COMPARISON

Table 5 presents the comparison between the proposed work and other existing antenna. It is clear from the table that proposed work exhibits better bandwidth and gain as compare to reported antennas.

Table 5 – Comparison of reported studies

Reference	Size (mm2)	Resonant Frequency (GHz)	Bandwidth (MHz)	Maximum Peak Gain (dBi)
[3]	29.44 × 38.04	1.422. 1.791, 2.467	28, 188, 813	3.480
[4]	50 × 35	1.61, 2.83, 3.75, 5.24, 5.56	690, 130, 350, 180, 670	2.3
[11]	50 × 50	2.6, 6, 8.2	410, 1070, 4840	7.67
[14]	31 × 42	5.25, 5.5, 5.75	700	6.5
Proposed Work	33.56 × 33.56	3.5, 7, 12.8, 15, 17.5	180, 450, 90, 1170, 2250	6.57

6. CONCLUSION

In this study, a comparison is made between coaxial probe and microstrip feeding approaches for the circular patch antenna in order to assess their quantitative effects on various antenna properties. The comparative study reveals that the effect is less on the gain of a single patch antenna when coaxial probe feed is used in comparison to microstrip line feeding. This was discovered as a result of the comparison between the two types of feeding. When compared to microstrip feeding techniques (S_{11} = –19, –25.3, –10.3, –13.3, –20.2), the coaxial probe feed has a lower return loss (S_{11} = –12.9, –16.11, –16.12), however the microstrip line feed provides superior impedance matching. Microstrip feed patch antenna resonates at 3.5, 7, 12.8, 15, 17.5 GHz and offers a greater bandwidth (180, 450, 90, 1170, 2250 MHz) than coaxial probe feed (1800, 720, 360). The suggested antenna's novel features are its multiband capabilities and its relatively large bandwidth. This proves that the suggested antenna with microstrip feedline is suitable for lower-band 5G, X, and Ku wireless applications.

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Методи подачі багатодіапазонної патч-антени круглої форми в діапазоні 5G, X і Ku для кількісного визначення їх впливу на характеристики антени

Nitasha Bisht[1], Praveen Kumar Malik[1], Sudipta Das[2]

[1] *Electronics and Communication Engineering Department, Lovely Professional University Phagwara, 144411, India*
[2] *Electronics and Communication Engineering Department, IMPS College of Engineering and Technology Nityanandapur, Malda-732103, West Bengal, India*

Стаття є порівняльним аналізом коаксіального живлення та живлення мікросмужкової лінії для щілинної круглої мікросмужкової антени. Різні методи живлення використовуються для підвищення узгодження імпедансу впливають на роботу кількох характерних параметрів, таких як коефіцієнт стоячої хвилі напруги, діаграму спрямованості, посилення тощо. Для визначення ступіню впливу на ці змінні, проводиться порівняльне дослідження, результати якого представлені в даній роботі. За допомогою тривимірного електромагнітного програмного забезпечення High Frequency Structure Simulator (HFSS) антена розроблена та змодельована. Передбачувана коаксіальна фідерна антена резонує на частотах 7,5 ГГц, 12,5 ГГц і 15 ГГц із смугою пропускання 1800, 720 і 360 МГц відповідно та 5,63 дБ як пікове посилення. Навпаки, запропонована мікросмугова фідерна антена резонує на частотах 3,5, 7, 12,8, 15, 17,5 ГГц із смугою пропускання 180, 450, 90, 1170, 2250 МГц і підсиленням 6,57 дБ. З точки зору підсилення, пропускної здатності та багатосмугових характеристик мікросмужкова лінійна подача перевершує коаксіальну зондову подачу. Антена розроблена з розміром (33,56 × 33,56) мм². Підкладка, яка використовується для проектування круглої мікросмужкової антени, це FR4. До нових особливостей розробленої антени належать її багатодіапазонні властивості та збільшена пропускна здатність. Запропоновану антену можна ефективно використовувати в X, Ku та нижчому діапазоні 5G.

Ключові слова: Круговий патч, Коаксіальний зонд, П’яте покоління, Мікрополоскова патч-антена, Мікрополоскова лінія передачі.