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Proximity Coupled Dual Antenna Design For X Band Applications

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This paper presents the analysis and design of a proximity-coupled dual antenna for X-band applications. Proximity coupling, a widely used feeding technique, is employed to optimize the spatial allocation of the receiver antenna, resulting in a more compact and efficient antenna design. The proposed design consists of a simple dual-rectangular antenna, where one antenna is a rectangular microstrip patch resonating at 9.8 GHz, and the second antenna is fed by a microstrip line electromagnetically coupled with the radiating patch. The feed substrate increases the patch's height, contributing to improved performance in the proximity-coupled configuration. The dual antenna system consists of two antennas placed back-to-back, designed specifically for receiving and retransmitting signals. A coax-fed microstrip patch antenna and a microstrip line-fed patch are combined in this configuration. The substrate material used is FR4 epoxy. Despite the lossy nature of FR4, the dual antenna achieves a gain of 3 dB in both directions. The increased height of the overall antenna structure results in wide impedance bandwidth. The proposed design ensures efficient space utilization, making it a promising candidate for applications requiring compact, high-performance antennas. The results highlight the potential of this dual-antenna system for advanced wireless communication technologies.

Keywords: Dual antenna, Proximity Coupling, X-Band, Microstrip patch antenna, Dual resonance

1. INTRODUCTION

Frequency allocation in communication is a challenging task due to spectral scarcity. Emerging technologies like 5G and 6G require access to unoccupied frequency bands, driving the demand for new spectrum resources. As a result, experimental research in X-band communication [1-2] has also gained significant momentum. With the rapid advancements in wireless communication, Multiple-Input Multiple-Output (MIMO) antenna systems [3] have become a crucial technology for transceiver applications. In an m X n MIMO configuration, m antennas are designated for transmission, while n antennas are used for reception, enhancing communication performance through spatial diversity and multiplexing. Traditionally, MIMO systems rely on separate antenna elements; however, an alternative approach involves the use of a proximity-coupled feeding technique.

Proximity coupling [4-6] is an indirect feeding technique, also known as electromagnetic coupling. A proximity-coupled antenna is often referred to as an Electromagnetically Coupled Microstrip Antenna (ECMSA). This configuration consists of two substrates with different permittivity. In proximity coupling, the microstrip feed line is positioned between the two substrates, while the radiating patch is placed on top of the upper substrate. The coupling between the feed line and the radiating patch occurs through capacitance rather than direct contact. Designing and analyzing such antennas is more complex compared to conventional microstrip antennas. However, this feeding technique offers significant advantages, including minimal spurious radiation and high suppression of side lobes, due to the absence of physical contact between the feed line and the radiating patch.

Proximity-coupled antennas are widely adopted in multiband [7] and array antenna [8] designs due to their ability to improve impedance matching and bandwidth efficiency. In [9], the proximity feeding technique is suggested to improve the bandwidth for LTE applications. As proximity coupling enhances the bandwidth, this can be employed in 5G and beyond [10-11]. Proximity coupling is employed to reduce the overall antenna profile and ground plane dimensions in [12].

In this paper, the proximity coupling method is utilized to optimize the spatial allocation of the receiver antenna, leading to a more compact and efficient antenna design. The back-to-back connected antenna system is the novelty of this study.

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2. ANTENNA DESIGN

A simple dual-rectangular antenna utilizing proximity coupling has been designed for X band application. The design process begins with the development of a rectangular microstrip patch antenna resonating at 9.8 GHz. To maintain the same resonance frequency, a second antenna is designed, serving as a retransmitter.

2.1 Microstrip Patch Antenna

A microstrip patch antenna is a low-profile, lightweight antenna consisting of a radiating patch on a dielectric substrate with a ground plane beneath it. It is widely used in wireless communication due to its ease of fabrication, compact size, and planar structure. It has narrow bandwidth and low gain. A conventional microstrip patch antenna (see Fig. 1) with coaxial feed is designed as one of the antennas in the dual-antenna configuration. The dimensions of the antenna are determined using standard design equations described in equations (2.1.1) to (2.1.4), to ensure optimal performance at the target resonance frequency.

$$W = \frac{1}{2 f_r \sqrt{\mu_o \varepsilon_o}} \times \sqrt{\frac{2}{\varepsilon_{r+1}}} \qquad (2.1.1)$$

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{eff} \times \mu_o \varepsilon_o}} - 2\Delta L \qquad (2.1.2)$$

Where,

$$\varepsilon_{eff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\frac{h}{W}}} \qquad (2.1.3)$$

$$\Delta L = \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \times 0.412h \qquad (2.1.4)$$
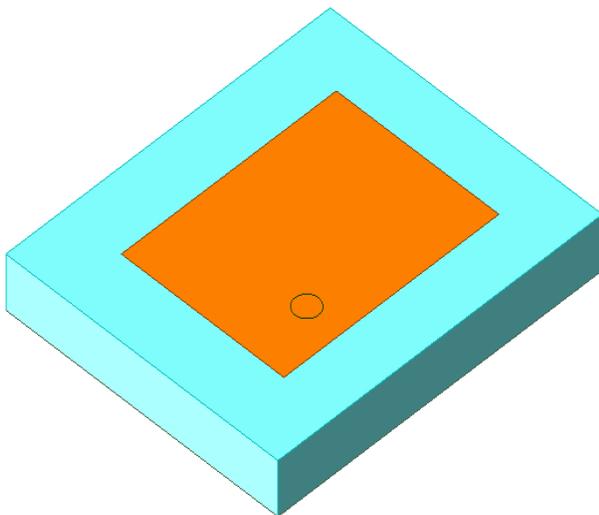
Table 1 – Dimension of the Microstrip Patch antenna

Design Parameters	Dimensions (mm)
Patch Width	9.30
Patch Length	7.031
Ground Width	14.04
Ground Length	11.771
Coax feed pin radius	0.5

2.2 Proximity Coupled Antenna

A microstrip patch antenna is known for its inherently narrow bandwidth and potential spurious radiation, especially at higher frequencies. To enhance bandwidth performance, a proximity-coupled feeding technique is employed. The proximity coupled microstrip patch antenna is shown in Fig. 2. This approach eliminates direct physical contact between the patch and the feeding system, thereby minimizing spurious radiation. The microstrip line is used to feed the patch. As the resonance frequency is same as the microstrip patch antenna, proximity coupled patch also lies with the same dimensions mentioned in Table1. The microstrip transmission line dimensions are presented in Table 2.

Table 2 – Dimension of the Microstrip transmission line

Design Parameters	Dimensions (mm)
Width	1.5
Length	15.5

The feedline is electromagnetically coupled with the patch. The substrate of micro stripline, increases the height of the patch in proximity coupling. The increased overall thickness of the microstrip patch antenna contributes to a wider bandwidth, making it suitable for meeting 5G communication requirements.
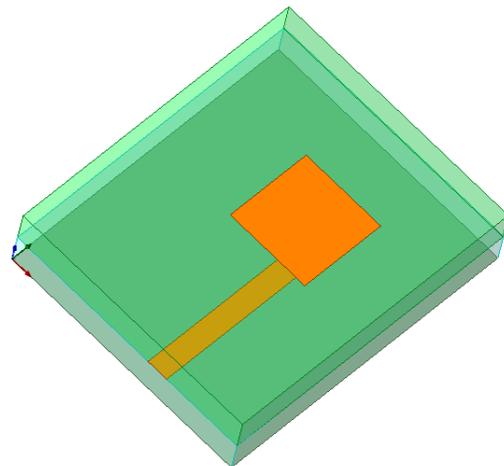

Fig. 1 – Coax fed Rectangular Microstrip patch antenna

Fig. 2 – Proximity coupled patch antenna

2.3 Dual antenna Design

Dual antenna consists of two antennas joined back-to-back for specific applications. Dual antenna is designed specifically for receiving and re-transmitting the signal. Both the elements in the dual antenna are designed for the same frequency. The dual-antenna configuration, shown in Fig. 3 consists of a microstrip antenna with a coaxial feed, serving as the receiver, and a proximity-coupled antenna with a coaxial feed, functioning as the transmitter. Both antennas have common ground. The feed point of both antennas should exactly coincide. As transmitter and receiver antennas share the common ground and coincided feed point, the space utilization in the device will be maximized.
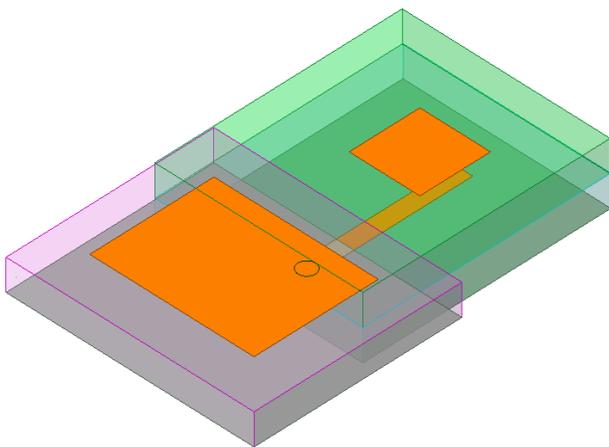

Fig. 3 – Proximity coupled Dual antenna

3. RESULTS AND DISCUSSION

Antenna is validated by its return loss and the radiation pattern. In this section the results of each phase of the antenna are discussed in detail.

3.1 Return Loss

Return loss is a measure of how much power is reflected back from an antenna instead of being radiated. It indicates how well the antenna is matched to the connected transmission line or feeding system. A high return loss means that most of the signal is transmitted or radiated, which is desirable for efficient antenna performance. For an antenna to perform optimally, it should have a good impedance match with the transmission line, typically around 50 Ohms. A well-matched antenna will have minimal signal reflection, which can be quantified by $-10\,\text{dB}$ return loss. The designed microstrip patch antenna is resonating at 9.8 GHz with 400 MHz bandwidth (see Fig. 4) and the proximity-coupled antenna also resonates at 9.8 GHz (see Fig. 5).
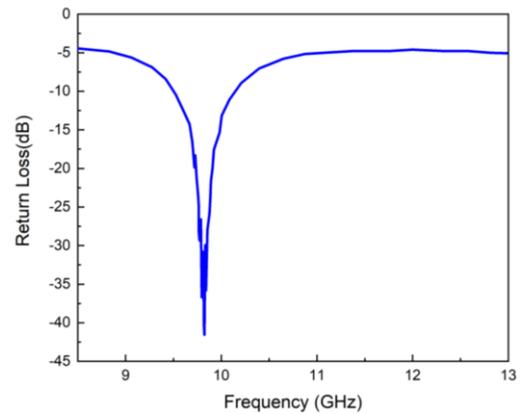

Fig. 4 – Return loss of microstrip patch antenna

In proximity coupled antenna the dual resonance is obtained at 13.5 GHz, which is not exactly matched with the characteristic impedance.
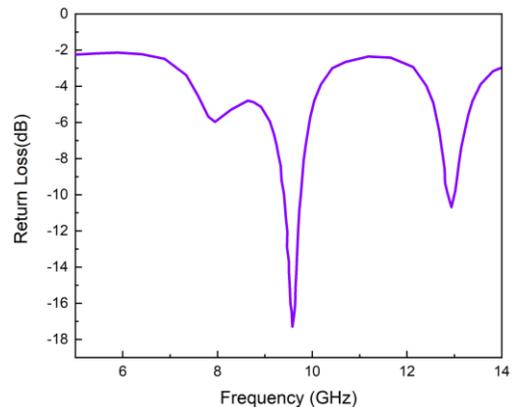

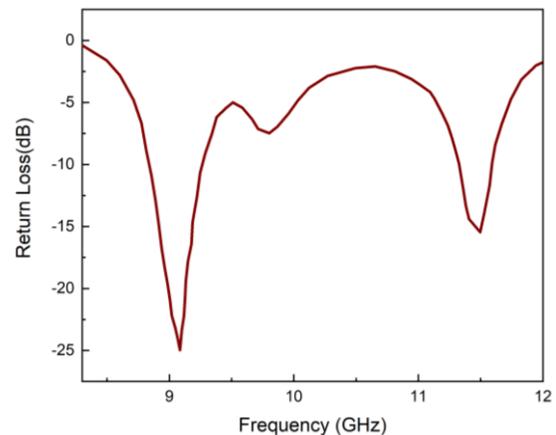**Fig. 5** – Return loss of proximity coupled antenna

Fig. 6 – Return loss of proximity coupled Dual antenna

In dual antenna two antenna are connected back-to-back. Hence, the resonance frequency of the patches is slightly altered and resonates at 9.08 GHz and 11.5 GHz. The shared ground affects the resonance slightly and achieves the dual band resonance.
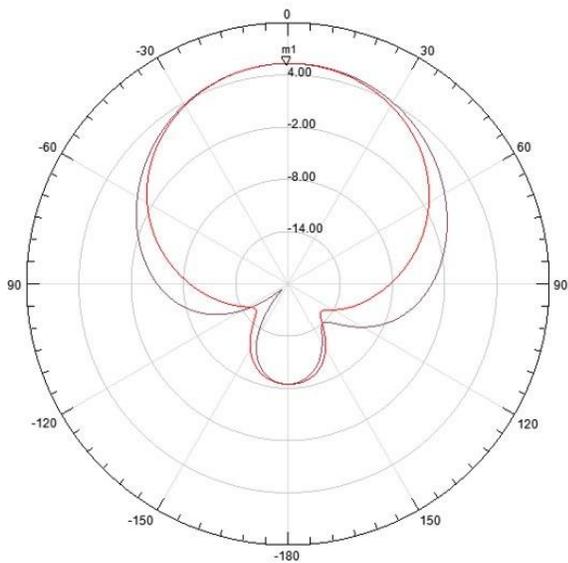
Fig. 7 – Radiation Pattern of Microstrip Patch antenna

3.2 Radiation Pattern

The radiation pattern of an antenna describes how the radiated energy is distributed in different directions. It visually represents the strength and direction of the electromagnetic waves emitted by the antenna. The radiation pattern of the microstrip patch antenna and proximity antenna are shown in Figs. 7 and 8.
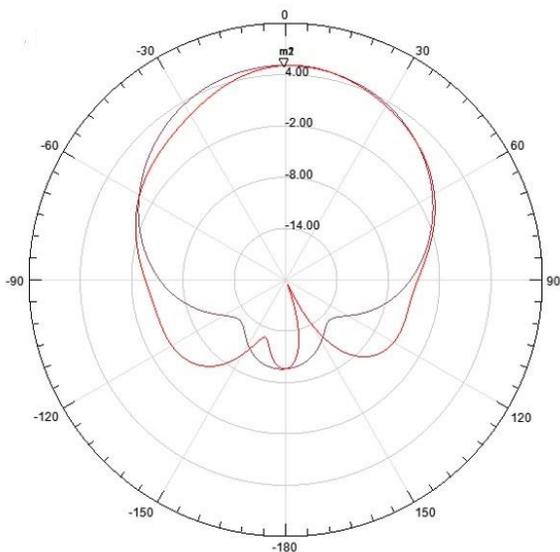

Fig. 8 – Radiation Pattern of proximity coupled patch antenna

The directive gain of the microstrip patch antenna is obtained as 5.23 dB whereas the proximity-coupled antenna is achieving a directive gain of 5.06 dB. Due to the reduced surface wave losses the proximity coupled antenna results high gain with wide beamwidth. In dual antenna the two different antennas are connected back to back. Hence the radiation pattern is obtained in the figure of eight and achieves the gain of 3.26 dB at each side. The H-plane radiation pattern combines the pattern of rectangular microstrip patch as well as proximity coupled patch and results in and highly directional pattern.
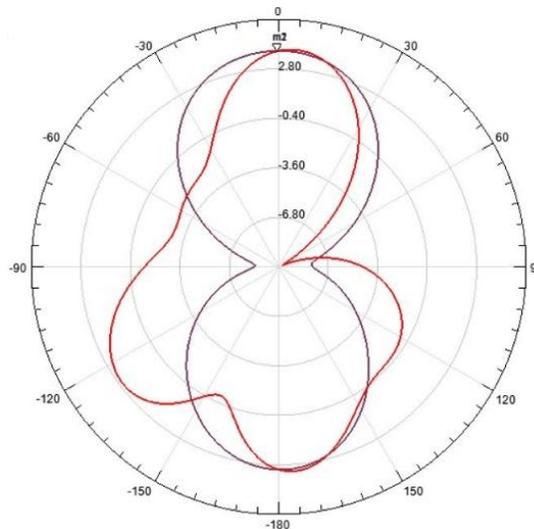

Fig. 9 – Radiation Pattern of proximity coupled Dual antenna

4. CONCLUSION

In this study, the receiver and transmitter antennas are designed using the proximity coupling technique, which enhances performance by minimizing direct physical contact between the feed and the radiating element. This indirect feeding approach effectively reduces spurious radiation, thereby improving the overall efficiency of the antenna system.

The proposed antenna achieves a gain of 3.26 dB, which contributes to enhanced signal strength and improved communication reliability. Additionally, the impedance bandwidth is significantly increased to 600 MHz due to the optimized height of the overall antenna structure. This increase in bandwidth allows for better frequency coverage, making the antenna suitable for broadband applications. Furthermore, the antenna exhibits dual resonance characteristics, which enable efficient operation at multiple frequency bands. The combination of wide bandwidth, high gain, and a broad beamwidth makes this antenna highly suitable for next-generation wireless communication systems, including advanced applications in 6G networks and beyond.

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Конструкція подвійної антени з безконтактним зв'язком для застосувань у діапазоні X

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У цій статті представлено аналіз та проектування подвійної антени з безконтактним зв'язком для застосувань у діапазоні X. Безконтактний зв'язок, широко використовуваний метод живлення, використовується для оптимізації просторового розподілу приймальної антени, що призводить до більш компактної та ефективної конструкції антени. Запропонована конструкція складається з простої подвійної прямокутної антени, де одна антена являє собою прямокутний мікросмужковий патч, що резонує на частоті 9,8 ГГц, а друга антена живиться мікросмужковою лінією, електромагнітно пов'язаною з випромінюючим патчем. Підкладка живлення збільшує висоту патча, що сприяє покращенню продуктивності в конфігурації з безконтактним зв'язком. Система подвійної антени складається з двох антен, розташованих спина до спини, спеціально розроблених для прийому та ретрансляції сигналів. У цій конфігурації поєднані мікросмужкова патч-антена з коаксіальним живленням та мікросмужкова патч-антена з лінійним живленням. Матеріалом підкладки є епоксидна смола FR4. Незважаючи на втратний характер FR4, подвійна антена досягає коефіцієнта посилення 3 дБ в обох напрямках. Збільшена висота загальної конструкції антени призводить до широкої смуги пропускання імпедансу. Запропонована конструкція забезпечує ефективне використання простору, що робить її перспективним кандидатом для застосувань, що вимагають компактних, високопродуктивних антен. Результати підкреслюють потенціал цієї системи з двома антенами для передових технологій бездротового зв'язку.

Ключові слова: Подвійна антена, Безконтактний зв'язок, X-діапазон, Мікросмужкова патч-антена, Подвійний резонанс.