A Novel Design of Gap-Coupled Sectoral Patch Antenna

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***Abstract*—Using gap coupling between the elements, an antenna of four sectors by cutting the slots through and through from a circular patch is designed for application in X-band. The bandwidth enhancement along with reduced sidelobes is obtained by marginally or fully moving one of the feeding sectoral patches diagonally away. The results are analyzed for different positions of the slot. A bandwidth of 1.2 GHz in X-band along with a reduced sidelobe level of -15.0 dB and a gain of 12.0 dBi is obtained. An analysis of mutual coupling and parasitic patch effect is also presented and discussed in this letter.**

***Index Terms*—Antenna gain, bandwidth, gap coupling, impedance.**

I. Introduction

A NUMBER of techniques have been proposed in order to improve the characteristics of antennas such as to enhance gain or widen the impedance bandwidth. Some of them resort to the material side by using a thicker substrate or bilayered substrate [1]–[3] or reducing the dielectric constant [4]. Gap coupling is one of the techniques being used by the researchers throughout the world [5]–[9]. Different types of gap-coupled antennas have been proposed by the contributors. In some applications, multifrequency operations are required; this can be achieved by gap coupling [10]. In [11] and [12], the experiment is performed on gap-coupled circular microstrip antennas, and mutual coupling is measured. In contrast to the corporate feed network, gap-coupled method is a good replacement to achieve wide bandwidth with an increased gain and reduced sidelobe level. Using gap-coupled method, the return loss of a mismatched microstrip-fed antenna can be decreased significantly [13]. This work analyzes if the gap-coupled technique may serve in those cases where the coaxial feeding method leads to a low-gain patch. Other methods, e.g., applying slots in order to improve the performance of a single-layer microstrip patch antenna, provide motivation for this work. Approaches like rectangular or circular slots take an undisturbed TM_{10} or higher as an essential starting point [14], [15]. Gap coupling in broadband microstrip antennas is therefore discussed in [16], which describes mostly probe-fed constellations. Different multiple resonance frequencies lead to wider impedance bandwidth and improved gain when losses are low with reduced sidelobe level. However, precise general design procedures are not given due to the complex behavior of the parameters.

In this letter, we have introduced a novel form of a gap-coupled antenna in which we divided the circular patch into four sectors through gap coupling, exciting one of the sectors by applying coaxial feeding. Antenna structures with parasitic patches enhance bandwidth as compared to a conventional patch antenna. A significant comparison is also shown for the excited sectoral patch at a distance of 2 mm up to a distance of 20 mm. It is clearly shown in the results how the radiation be affected with the introduction of different gap in between the sectoral patches.

II. Theory

Bandwidth enhancement can be achieved by using closely spaced elements or using parasitic patches. Different approaches have been implemented in order to improve the bandwidth of the antenna such as multilayered structures, single-layer multiresonant designs, aperture-coupled designs, etc. The coupling between the elements is a function of the patch size and gap between the patches [17], [18]. For a fixed unit-cell size, the coupling between the patch elements increases by reducing the spacing between them. However, if the size of the unit cell is reduced, a closer spacing between the patch elements is required so as to achieve the same level of coupling for larger unit-cell sizes.

In this letter, for bandwidth enhancement, the canonical circular patch antenna structure with parasitic patches is utilized. Only one sectoral patch is excited, and the other three patches acts as parasitic patches. These three nonfed sectoral patches alter the limits of resonant frequencies, which leads to an increase in the resulting impedance bandwidth. The impedance bandwidth is found to increase up to a distance of 20 mm from the center of the circular patch. At a distance less than 20 mm, there are two resonant modes. However, when the gap is maintained at a distance of 20 mm, the two resonant modes combine and therefore result in the enhancement of the impedance bandwidth. A wideband is obtained at this particular gap, after which the bandwidth starts reducing as the two resonant modes again separate.

In recent times, one of the topics of investigation is how the mutual coupling relates to the antenna radiation properties such as antenna gain and sidelobe level. The large mutual coupling leads to the reduction in the antenna radiation efficiency, decrease in antenna effective gain, etc., but adjacently also creates

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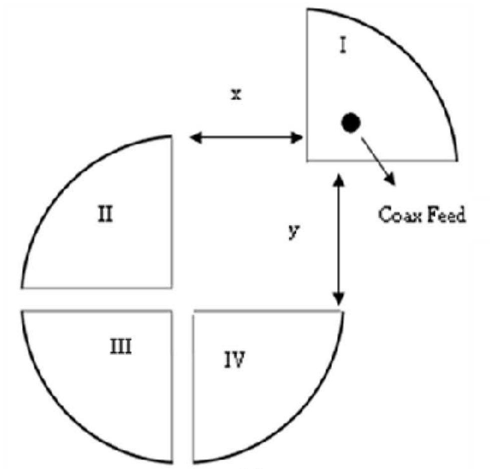
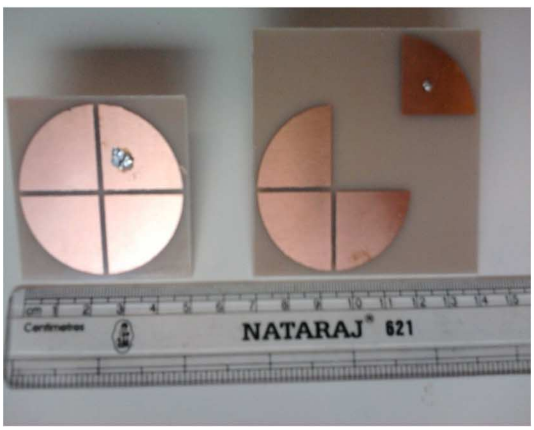


(a)



(b)

Fig. 1. Antenna design of sectoral patch antenna. (a) Geometry. (b) Prototype.

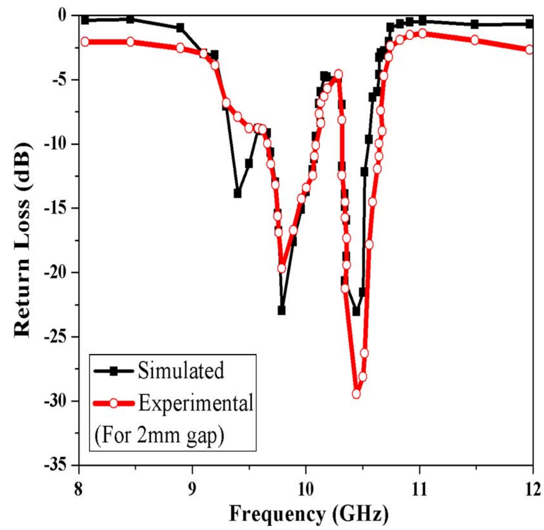


Fig. 2. Return-loss (in dB) variation with frequency (in GHz) when the four sectoral patches are unmoved (with 2-mm gap).

an effective pattern. Theoretical research has shown that the radiation properties of the printed antennas [19] and mutual coupling between printed dipoles are affected by the radiation fields and the type and the number of surface-wave modes propagating within the antenna substrate. In order to enhance the radiation properties, the antenna structure is divided into four sectoral patches using gap coupling. As the gap between one of the sectoral patches (excited patch) and the other three parasitic patches is increased, the mutual coupling starts reducing. This coupling effect results in the enhancement of the antenna gain, directivity, and reduction in the respective sidelobe level, which is very good for better antenna radiation and thus for wideband applications. A maximum value is reached, after which the radiation properties again start degrading due to large separation of sectoral patches.

III. Antenna Configuration and Design

The geometry of the antenna proposed is shown in Fig. 1, which comprises a gap-coupled sectoral patch antenna. The proposed gap-coupled antenna is printed on an FR4 substrate with permittivity of 4.1 and a loss tangent of 0.024. The dimension of the substrate when four sectoral patches are unmoved is (50×50) mm^2, and for moving sectoral patch antenna is (70×70) mm^2 as shown in Fig. 1(a). The thickness of the dielectric substrate used is $h = 1.59$ mm. The circular patch antenna is of radius $r = 23.5$ mm and is fed coaxially at 9 mm in order to achieve 50 Ω characteristic impedance. For the first case, a double gap of 2 mm each is introduced both vertically as well as horizontally as shown in the geometry. The circular patch after introducing a gap both horizontally as well as vertically forms four regions, namely regions I, II, III, and IV. Then, the feeding sectoral patch is moved slowly away by keeping the other three sectors unmoved. This feeding sector is moved up to a distance of $x = y = 20$ mm from the center at which the antenna shows a maximum impedance bandwidth with maximum gain. The prototype of the antenna designed is shown in Fig. 1(b).

IV. Results and Discussion

In order to show the performance of the antenna with changing gap between the sectoral patches, it will be compared through simulations and measurements. The proposed antenna structure is simulated using simulation software CST Studio Suite and experimentally tested using a vector network analyzer at different gaps.

A. Return-Loss Measurement at Different Gaps

The variation of return loss with the frequency is shown in Fig. 2. Fig. 2 shows the return loss variation for the first case when the circular patch antenna is divided into four sectoral patches. The gap introduced in between the four sectoral patches is 2 mm each. One of the sectoral patches is excited by employing a coaxial feed at a distance of 9 mm from the center of the circular patch. At this first step, all the four sectoral patches are unmoved. The antenna resonates in the X-band in the frequency range 9–11 GHz. Fig. 2 shows the simulated return loss variation with frequency and experimentally measured variation with frequency. At frequency 10.4 GHz, the antenna shows a maximum return loss of -24 dB. The experimentally measured resonating frequencies are 9.7 and 10.4 GHz. At frequency 10.4 GHz, the antenna shows a maximum return loss of -31 dB. However, the antenna does not show wideband characteristics. It gives a minor impedance bandwidth of about 1.6%. As we have given feed to just one of four sectoral patches,

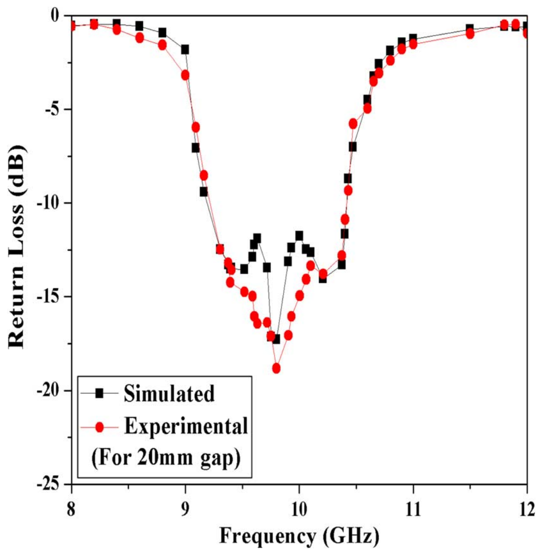


Fig. 3. Return-loss (in dB) variation with frequency (in GHz) for the sectoral patch at a gap of 20 mm.

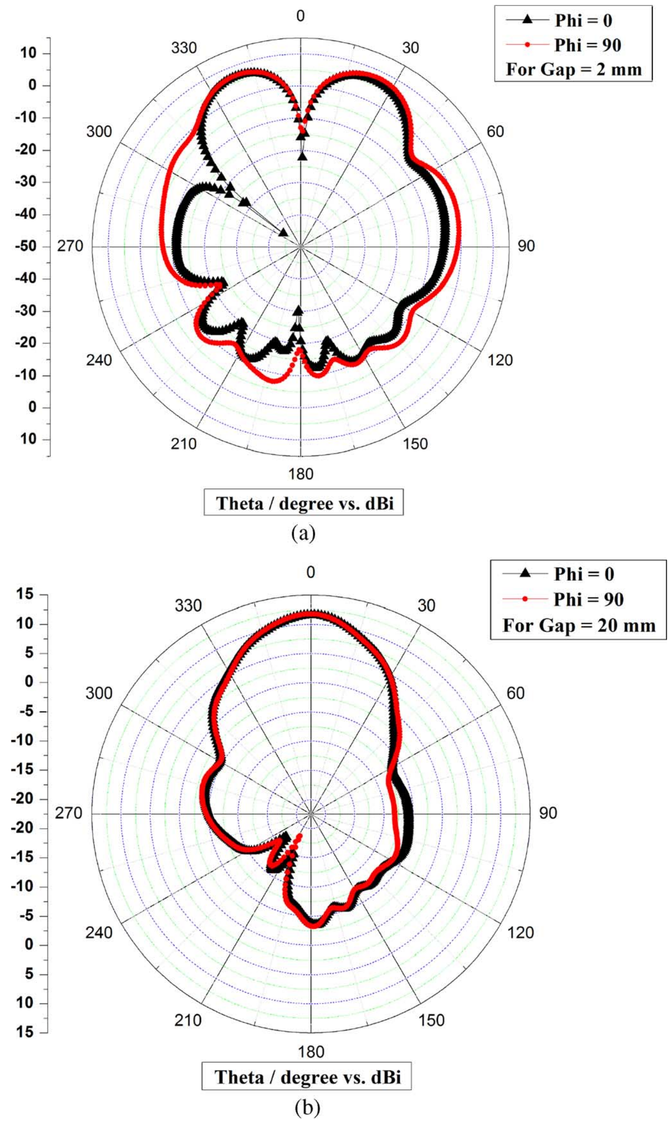


Fig. 4. Radiation pattern Directivity Abs (Phi $= 0$ and 90) between Theta degree versus dBi. (a) For gap $= 2$ mm. (b) For gap $= 20$ mm.

the other three act as parasitic sectoral patches. Due to coupling between the four sectoral patches, it acts as one antenna as a whole. When the excited sector is moved at an angle of 45° from the center, the impedance bandwidth goes on increasing up to a gap of 20 mm of the excited sectoral patch with feed at 29 mm. The maximum impedance bandwidth is reached when gap of the sectoral patch is maintained at a distance of 20 mm from the center with the coaxial feed at 29 mm.

Fig. 3 shows the simulated resonating frequencies, i.e., 9.5, 9.7, and 10.0 GHz. At these frequencies, antenna designed shows a triple resonance with a maximum return loss of -17 dB at resonating frequency of 9.7 GHz. The experimentally measured results as shown in Fig. 3 are also in good agreement with the simulated results showing a wideband at the same resonant frequency. At this gap, the antenna shows a wideband characteristic with the impedance bandwidth increased up to 12.3%. Thus, the results show an increase in the impedance bandwidth 1.6% to 12.3%, giving a wideband at the excited sectoral patch gap of 20 mm. By further increasing the gap of the excited sectoral patch from the center of the circular patch antenna in a direction 45°, the impedance bandwidth starts reducing. This is because of the coupling effect, which results in bandwidth reduction due to larger separation of the excited sectoral patch. At a distance of 20 mm, the antenna shows a wide impedance bandwidth, higher gain, and low sidelobe level. At this particular gap (20 mm), the different resonant frequencies combine and therefore result in a wideband in frequency range in X-band.

B. Radiation Pattern at Different Gaps

The radiation patterns for different gaps at the resonant frequency are shown in Fig. 4. The polar plots at the central resonant frequency of 10 GHz are therefore plotted at different gaps. Fig. 4(a) shows polar plot at frequency 10 GHz for the antenna structure when the four sectoral patches are unmoved. The plot is shown for Directivity Abs (Phi $= 0$ and 90) between Theta degree versus dBi. At frequency 10 GHz in the main-lobe direction 25.0°, the antenna gain is 7.8 dBi. Within 3 dB angular width in the direction 23.4° the sidelobe level is -7.8 dB. The maximum antenna gain is obtained when the excited sectoral patch is placed at a distance of 20 mm from the center of the circular patch antenna that is for $x = y = 20$ mm. At this distance, the antenna shows maximum antenna gain for the resonant frequency 10 GHz. In Fig. 4(b), in the main-lobe direction 0.0°, the antenna gain obtained is 12.0 dBi. The sidelobe level is reduced to a good extent that is, for 3 dB angular width in the direction 35.0°, it is reduced to -15.0 dB. Further increasing the gap of the excited sectoral patch from the other three sectoral patches leads to a degradation in the radiation properties of the antenna design proposed.

V. Conclusion

In this letter, a novel form of a gap-coupled sectoral patch antenna based on moving excited patch has been presented. Due to coupling in between the sectoral patches, the impedance bandwidth increases up to a certain distance, and the antenna proposed results in the wideband characteristics with perfect impedance matching. The gap-coupled antenna proposed is very helpful in high-frequency wideband applications and in pervasive wireless applications.

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