Broadband Proximity Fed Gap-Coupled Pair of Slot Cut Rectangular Microstrip Antennas

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ABSTRACT
The broadband microstrip antenna is realized by fabricating the slot cut patch on lower dielectric constant thicker substrate in conjunction with the proximity feeding technique. In this response is presented. The pair of slots reduces the resonance frequency of orthogonal TM_{02} mode of the patch and along with the fundamental TM_{10} mode yields broadband response. Further to optimize the bandwidth and gain, a gap-coupled configuration with parasitic rectangular patches is proposed. The gap-coupled configuration with patches coupled along X-axis yields bandwidth of more than 420 MHz whereas with patches gap-coupled along both the X and Y-axis, yields a bandwidth of nearly 470 MHz. In both the configurations, broadside radiation pattern with gain of more than 7 dBi is obtained.

Keywords
Rectangular microstrip antenna, Broadband microstrip antenna, Proximity feeding, Pair of rectangular slot, Higher order modes

1. INTRODUCTION
The broadband microstrip antenna (MSA) is more commonly realized by fabricating the slot cut patch on lower dielectric constant thicker substrate in conjunction with the proximity feeding technique [1 – 5]. In most of the reported design the patch is suspended in air thereby realizing dielectric constant of unity. The slot which is cut inside the patch can take different shapes like, U-slot, V-slot, and rectangular slot and it introduces a mode near the fundamental mode of the patch when its length equals either half wave or quarter wave in length. However, this simpler approximation of slot length against wavelength (i.e. the frequency) does not give accurate result while designing the antenna in given frequency band. The analysis to study the effects of slots in the broadband MSAs is reported [6 – 8]. The slot reduces the resonance frequency of higher order modes of the patch and along with the fundamental patch mode yields broadband response. The slot also modifies the surface current directions at higher order mode and aligns them in the same directions as that of the currents at fundamental mode and yields broadside radiation pattern over the complete bandwidth (BW) without any variation in the directions of principle planes.

In this paper, first proximity fed broadband pair of rectangular slot cut rectangular MSA (RMSA) is proposed. The analysis to study the effects of slots on the broadband response is presented. The resonance curve plots, surface current distributions and simulated radiation pattern plots were studied. The slot reduces the resonance frequency of higher order orthogonal TM_{02} mode of the patch and along with the fundamental TM_{10} mode yields broadband response. paper, broadband proximity fed pair of rectangular slot cut microstrip antenna in 1000 MHz frequency band is proposed. The analysis to study the effects of slot on the broadband

The slot changes the surface current directions at TM_{02} mode and aligns them in the same direction as that of the currents at TM_{10} mode. Thereby it gives broadside radiation pattern over the BW without any variations in the directions of E and H-planes. Further to increase the gain and BW of pair of slot cut RMSA, parasitic RMSAs of equal dimension were gap-coupled along the radiating edges of the slot cut RMSA. This configuration yields a BW of more than 420 MHz with broadside radiation pattern and gain of more than 7 dBi over the BW. Further the parasitic RMSAs were gap-coupled along both the edges of the proximity fed slot cut RMSA. This configuration yields the BW of more than 460 MHz. These MSAs were first optimized using IE3D software using infinite ground plane [9]. Further the measurements were carried out using R & S vector network analyzer to validate the simulated results. In measurements the patches were fabricated using copper plate having finite thickness and foam spacers were used to support the patches in air as well as to maintain the required air gap between the fed and parasitic patches. To simulate the effects of infinite ground plane, the measurements were carried out using larger square ground plane of side length 80 cm. The radiation pattern was measured in minimum reflection surroundings with required minimum far field distance between the reference antenna and antenna under test [10]. The gain was measured using three antenna method [10]. The dimensions of the fed and parasitic RMSAs were optimized to cover the 800 – 1200 MHz frequency band so that the proposed antennas will find applications in mobile communication environment.

2. BROADBAND SLOT CUT RMSA
The proximity fed pair of rectangular slot cut RMSA is shown in Fig. 1(a, b). To realize larger gain and BW, for RMSA, a substrate thickness of 3.0 cm ($0.093\lambda_0$) is selected. To control the coupling between patch and coupling strip, strip is placed in the plane of the patch. The RMSA dimension (L, W) are calculated such that it resonates in its TM_{10} mode at frequency of around 900 MHz. The proximity fed RMSA was simulated using IE3D software and its resonance curve plot is shown in Fig. 1(c). The plot shows two peaks, due to TM_{10} and TM_{02} modes. The surface current distribution at TM_{10} mode varies along patch length, which gives broadside radiation pattern with E-plane aligned along $\Phi = 0^0$. The surface currents at TM_{02} mode shows two half wavelength variations along patch width (as shown in Fig. 1(d)) which leads to conical radiation pattern (i.e. maximum in the end-fire direction) with E-plane aligned along $\Phi = 90^0$. Inside this patch, pair of rectangular

slots is cut along the non-radiating edges and the resonance curve plots for different slot length are shown in Fig. 1(d). The surface current distribution for slot length of 6 and 8 cm is shown in Fig. 2(a, b), respectively. With an increase in slot length, TM_{10} mode frequency nearly remains constant, as the surface currents at that mode are parallel to the slot length. The currents at TM_{02} mode are orthogonal to the slot length and hence with an increase in length, its frequency reduces and it comes closer to the TM_{10} mode frequency. With an increase in slot length more and more amount of surface currents are getting aligned along the horizontal direction inside the patch which changes the directions of radiation pattern from conical to broadside. This also changes the directions of E and H-planes from $\Phi = 90^0$ and 0^0, to 0^0 and 90^0, respectively.

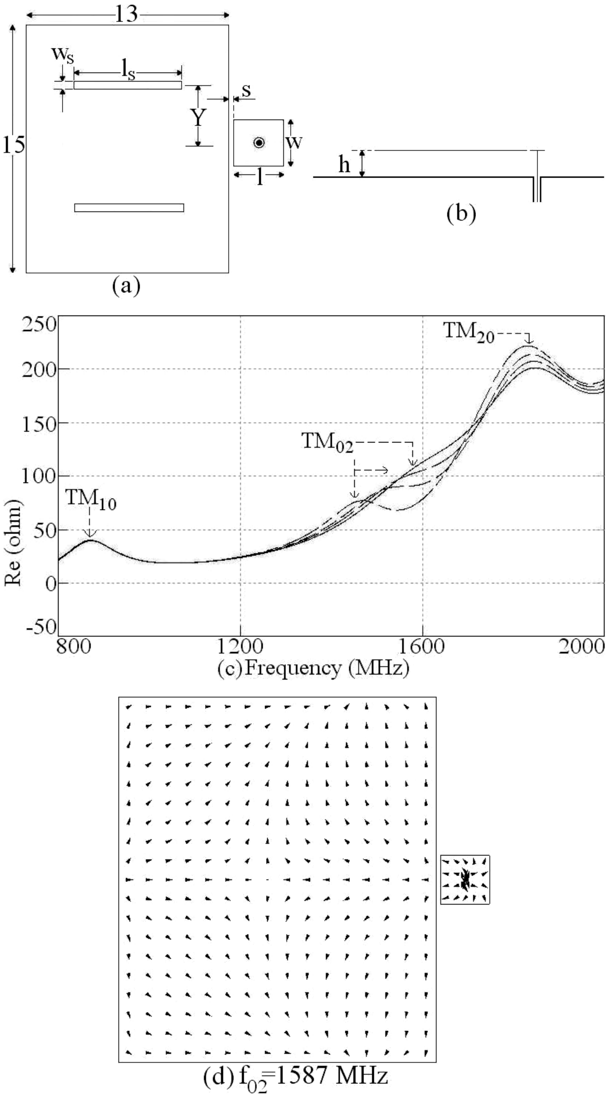


Fig. 1 (a) Top and (b) side views of proximity fed pair of slot cut RMSA, (c) resonance curve plots for (──) RMSA, (── ──) l_s = 4.0, (─ ─ ─) l_s = 5.0, (── ─ ──) l_s = 6.0, and (d) surface current distribution at TM_{02} mode for RMSA

The cross polar levels reduce with the slot length. The broadband response is realized when the spacing of modified TM_{02} mode is optimized with respect to TM_{10} mode such that the loop formed due to the coupling between them lies in the center in the smith chart as shown in Fig. 2(c). This is obtained for slot length of 10 cm. The impedance at the two modes is not optimum to realize the two loop positions (due to TM_{10} and modified TM_{02} modes) inside the VSWR = 2 circle. Hence the optimum BW is not obtained. To optimize the impedance and to increase gain and the BW, gap-coupled configuration of proximity fed rectangular slot cut RMSA with parasitic RMSAs are proposed as discussed in the following section.

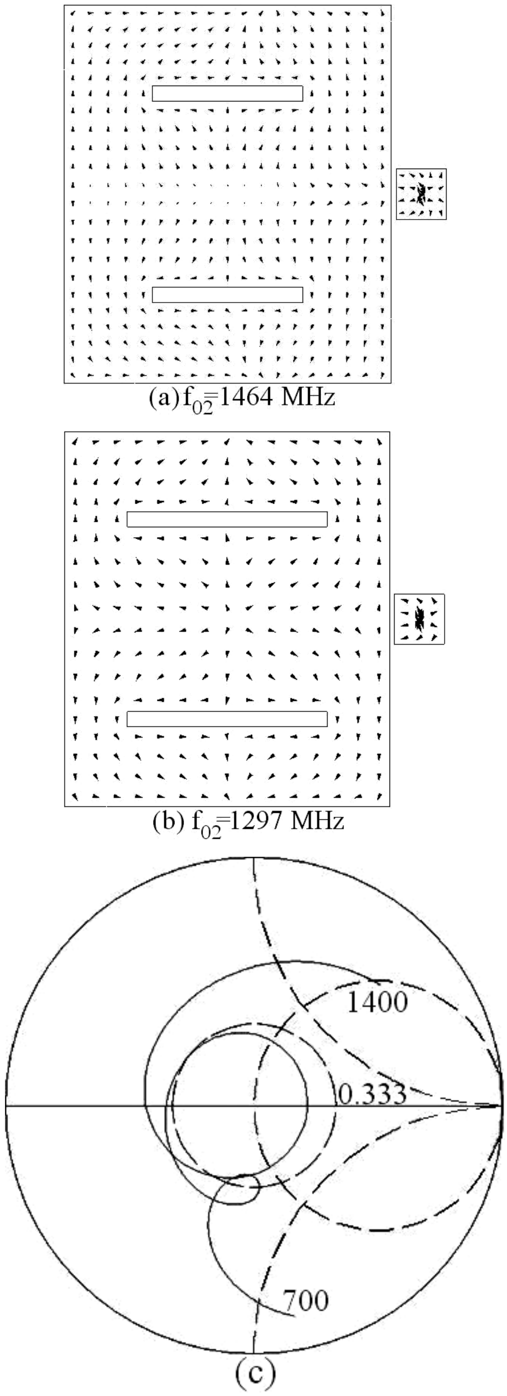


Fig. 2 Surface current distribution at modified TM_{02} mode for l_s = (a) 6 cm and (b) 8 cm, and (c) simulated input impedance plot for proximity fed pair of slot cut RMSA

3. BROADBAND GAP-COUPLED PROXIMITY FED SLOT CUT RMSAs

The parasitic RMSAs of equal dimensions were gap-coupled along the radiating edges of the proximity fed pair of slot cut RMSA as shown in Fig. 3(a). The dimensions of the two parasitic patches were taken to be the same so as to avoid any variation in radiation pattern from the broadside direction. The parasitic patch length was taken to be smaller than the fed patch length. This gives three resonance frequencies in the configuration, i.e. TM_{10} and modified TM_{02} mode on the proximity fed RMSA and TM_{10} mode on the parasitic RMSA. The broadband response is realized when all the three loops lies inside the VSWR = 2 circle. This is obtained for L = 11.0 cm and the simulated input impedance and VSWR plots are shown in Fig. 3(b). The simulated BW is 421 MHz (40%). The antenna was fabricated using the copper plate and the measurement was carried out using larger square ground plane of side length 80 cm. The measured BW is 434 MHz (42%) as shown in Fig. 3(b). The fabricated prototype of the configuration is shown in Fig. 4(a).

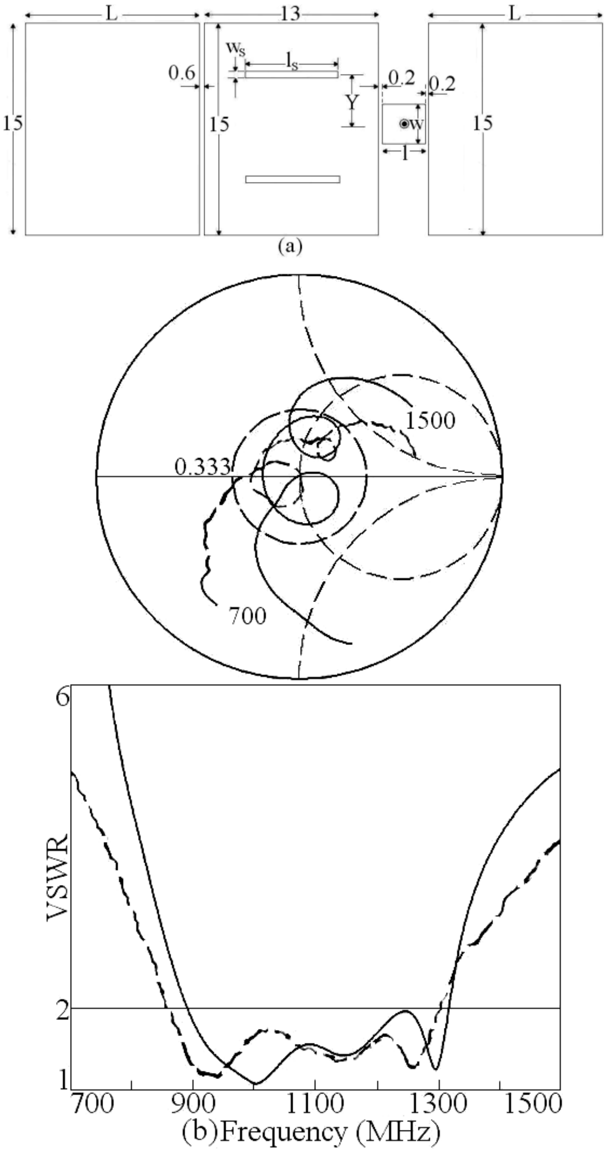


Figure 3 (a) Proximity fed pair of rectangular slot cut RMSA gap-coupled to RMSAs and its (b) input impedance and VSWR plots, (——) simulated, (— —) measured

The antenna pattern was measured over the BW and at the center frequency it is shown in Fig. 4(b). The gain variation over the BW is also shown in Fig. 4(c). The pattern is in the broadside direction with cross polar level less than 12 dB as compared to the co-polar levels. However, they increase towards the higher frequencies of BW, due to the higher order modes excited on the parasitic patches. The antenna gain is more than 7 dBi over the entire VSWR BW.

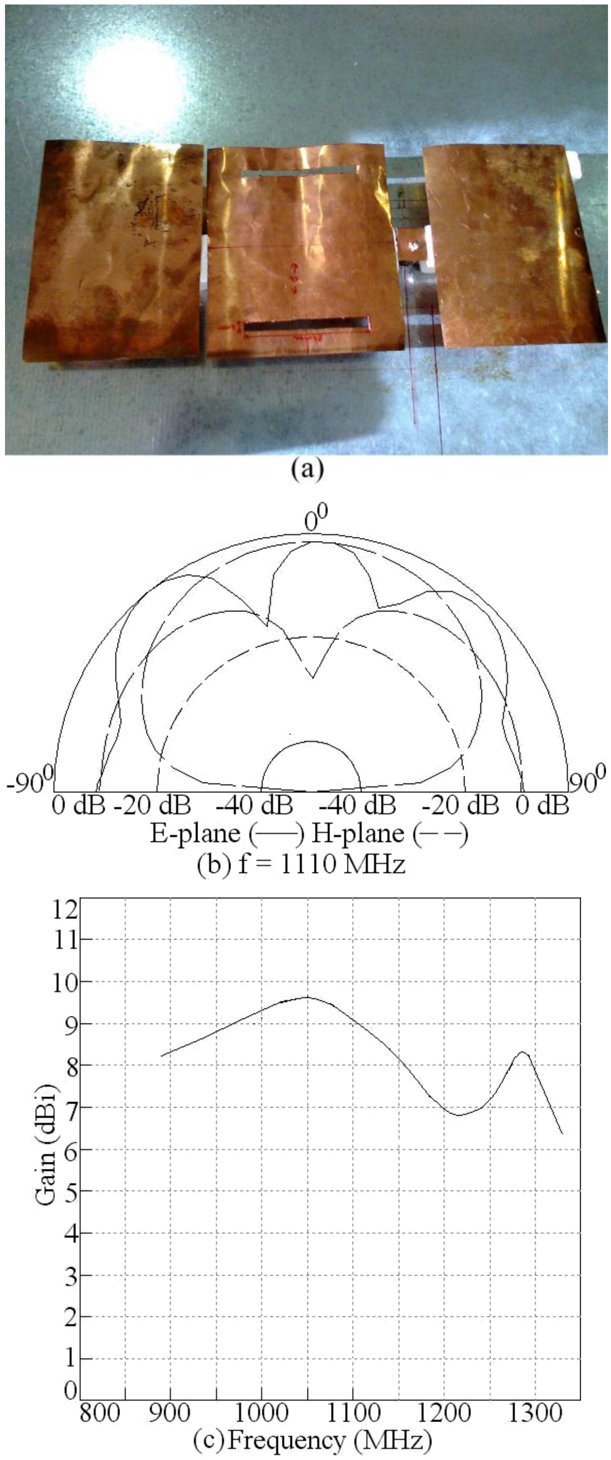


Figure 4 (a) Fabricated prototype, (b) radiation pattern at center frequency and (c) gain variation over BW for proximity fed pair of slot cut RMSA gap-coupled to parasitic RMSAs

In another gap-coupled configuration, the parasitic RMSAs are gap-coupled along non-radiating edges of the above gap-coupled configuration as shown in Fig. 5. The dimensions of the patches gap-coupled along the individual axis were taken to be the same. By optimizing fed and parasitic patch and the slot dimensions, an optimum broadband response around 1000 MHz frequency band is obtained as shown in Fig. 6(a). The simulated and measured BW's are, 467 and 475 MHz, respectively. The fabricated prototype of the configuration is shown in Fig. 6(b). The measured radiation pattern at the center frequency of BW and gain variation of the BW is shown in Figs. 7(a) and (b), respectively. The radiation pattern is in the broadside direction with higher cross polarization levels towards the higher frequencies of BW, which is due to the higher order modes present on the parasitic RMSAs. The peak antenna gain is very close to 10 dBi. In this gap-coupled configuration, an increase in gain and BW is smaller as compared to the previous gap-coupled configuration. However this configuration shows more stable gain characteristics. Since the radiation pattern measurement was carried out using large ground plane, the back-lobe radiation is negligible. With a BW of more than 400 MHz and gain of more than 7 dBi over most of the BW, the proposed configurations can find applications in mobile communication environment in 1000 MHz frequency band.

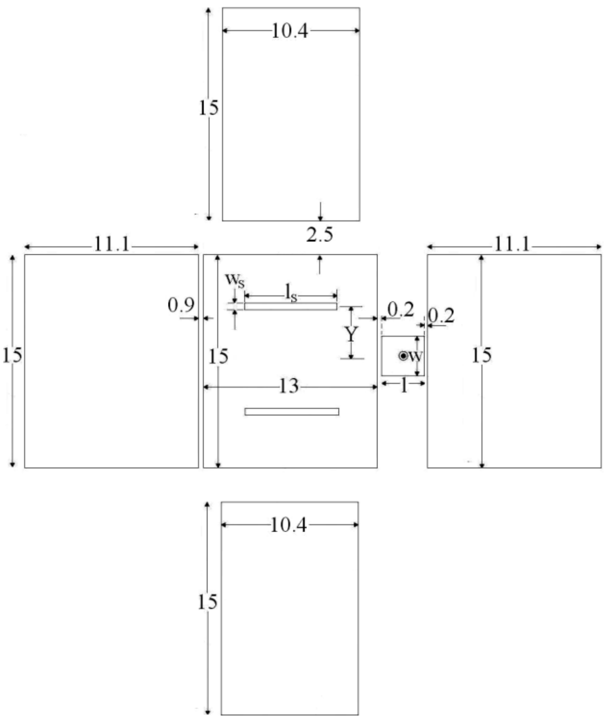
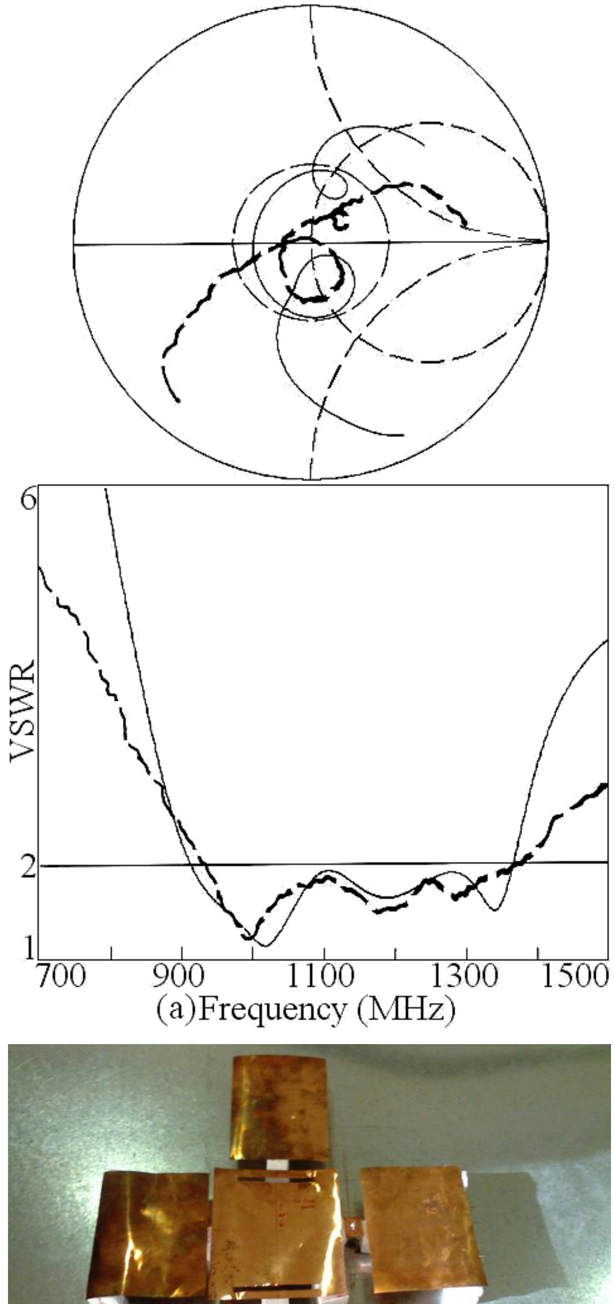


Figure 5 Proximity fed pair of slot cut RMSA gap-coupled to parasitic RMSAs

4. CONCLUSIONs

The proximity fed pair of rectangular slot cut RMSA is proposed. The analysis to study the effects of slots on the broadband response is presented. The slot reduces the resonance frequency of higher order TM_{02} mode of the patch and along with the fundamental TM_{10} mode yields broadband response. The slot also modifies the surface current directions at TM_{02} mode and thereby it gives broadside radiation pattern at that frequency. Further to improve upon the BW and gain, the gap-coupled configuration of slot cut RMSAs with parasitic RMSAs is proposed. The configuration with additional two patches yields BW of more than 420 MHz whereas with four parasitic patches, a BW of more than 460 MHz with better gain characteristic is obtained. The proposed configurations can find applications in mobile communication environment in 1000 MHz frequency band.



(b)

Figure 6 (a) Input impedance and VSWR plots, (──) simulated, (— —) measured and (b) fabricated prototype of proximity fed pair of slot cut RMSA gap-coupled to RMSAs along both the edges

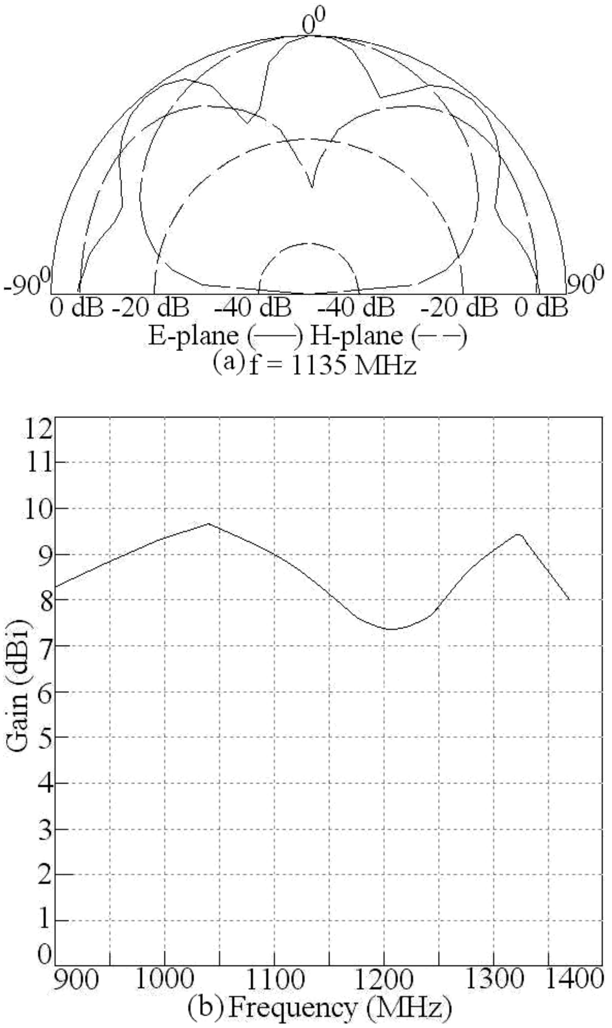


Figure 7 (a) Radiation pattern at center frequency and (b) gain variation over BW for proximity fed pair of slot cut RMSA gap-coupled to RMSAs along both the edges

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