Modified Slot-Loaded Multi-Band Microstrip Patch Antenna

Man-Shik Cho[1] · Il-Kwon Kim[1] · Han-Back Cho[2] · Jong-Gwan Yook[1] · Han-Kyu Park[1]

Abstract

In this paper, a triple-band planar antenna is proposed for the application to miniaturized automobile safety devices operating at X band(10.5 GHz), K band(24.15 GHz), and Ka band(34.3 GHz). The frequency ratio between the resonant frequencies of this antenna can be adjusted from 1.99 to 2.23 for both X band and K band by varying its slit length. Parasitic elements are added on the modified slot loaded antenna to obtain the third resonance. From numerical as well as experimental results, it has been confirmed that this type of antenna is appropriate for planar multi-band antenna systems.

Key words : Triple-Band, Frequency Ratio, Slit, Parasitic Elements, Modified Slot Loaded Antenna.

Ⅰ. Introduction

Many communication systems often require multiple frequency band operations and novel radiating structures would be necessary to accomplish this requirement. On the other hand, planar antenna exhibits the well known advantages of low cost, low weight and conformability, and their use in multi-frequency applications appears very attractive. For this reason, multi-band antennas have been studied by many researchers[1]~[3]. The multifrequency patch antennas found in the literature can be subdivided into two categories; multiresonator antennas and reactive loading ones. In multiresonator antennas, multifrequency behaviour is obtained by means of multiple radiating elements, each supporting strong currents and radiation at resonance. Multi-ring, multi-layer, and fractal sierpinski structure[3] are a few examples of this type. The reactive-loading patch antenna, which consists of a single radiating element having double resonant property is obtained by connecting coaxial line[4] or microstrip[5]. stubs to microstrip patch. The slot-loaded antenna is categorized to reactive loading antenna and the frequency ratio can be varied in the range from 1.6 to 2. The frequency ratio is defined in this work as the ratio of the third resonant frequency to the first resonant frequency. It is known that the frequency ratio of meander type slot loaded antenna is greater than two[6]. In this paper, a novel modified slot-loaded triple band microstrip patch antenna(MSLTA) is proposed to obtain frequency ratio greater two and additional parasitic elements are placed to obtain triple band operation. Proposed modified slot-loaded dual band microstrip patch antenna(MSLDA) consists of a rectangular patch loaded with parallel slots close to the radiating edges and inserted with four slits at the non-radiating edges. The additional parasitic elements are placed near the non-radiating as well as radiating edges of the antenna and these parasitic elements are excited with gap coupling.

Ⅱ. Modified Slot-Loaded Antennas

Conventional slot-loaded patch antenna(SPA) is shown in Fig. 1[7]. Its current distributions are shown in Fig. 2. It is clear that radiative property associated with the first mode is essentially the same as that of a patch without slots. The slots located close to the radiating

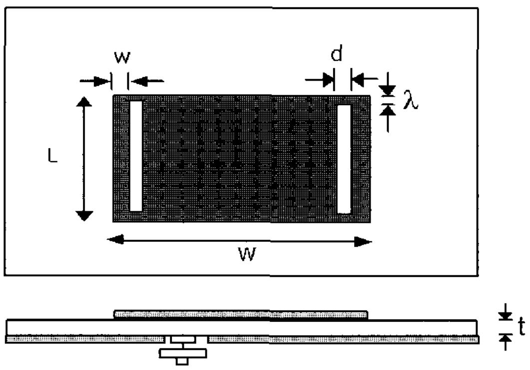

Fig. 1. Conventional slot loaded patch antenna.

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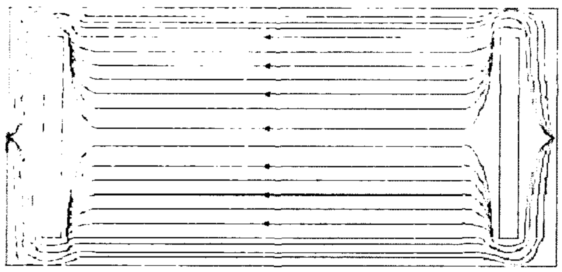
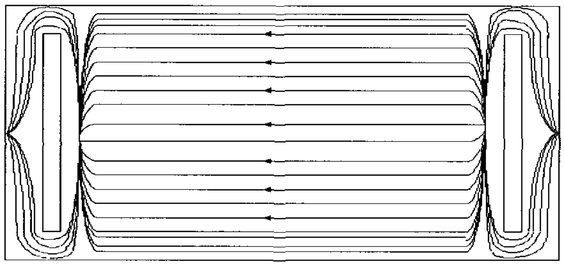


(a)



(b)

Fig. 2. (a) TM_{01} mode, (b) TM_{03} mode.

edges alter the current path as shown in Fig. 2. As a result, the current circulate around the slot and the current distribution of TM_{03} mode becomes very similar to that of the TM_{01} mode.

Since it is always not easy to obtain the frequency ratio greater than two with conventional slot-loaded antennas, other techniques would be required to achieve frequency ratio greater than 2. Since the first resonance is not much affected by slot loading, its frequency can be predicted by slightly modifying the well established formula for rectangular, unslotted patches[7].

$$f_{10}=\frac{c}{2(W+\triangle W'+\triangle W'')\sqrt{[\varepsilon_e(L/t,\varepsilon_r)]}} \tag{1}$$

where c is the velocity of light in free-space, and

$$\varepsilon_e(x,y)=\frac{y+1}{2}+\frac{y-1}{2}\left[1+\frac{10}{x}\right]^{-1/2} \tag{2}$$

$$\triangle W'=W\left(1.5\frac{w}{W}-0.4\frac{\lambda}{L}\right) \tag{3a}$$

$$\triangle W''=g\left(\frac{L}{t},\varepsilon_r\right)\cdot t \tag{3b}$$

and $g(x, y)$ is defined as

$$g(x,y)=\frac{1}{\pi}\,\frac{x+0.336}{x+0.556}\times\left[0.28+y+\frac{1}{y}(0.274+\ln(x+2.518))\right] \tag{4}$$

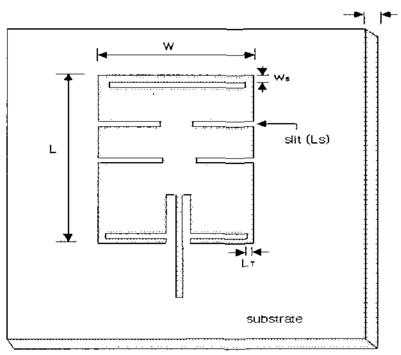
The third resonant frequency can be also predicted according to a simple transmission line model, which is derived by a direct inspection of the current distribution of the modified TM_{03} mode.

$$f_{30}=\frac{c}{2(L-2\lambda+d)\sqrt{\varepsilon_e(w/t,\varepsilon_r)}} \tag{5}$$

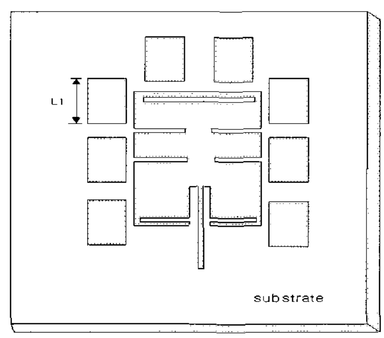
The formulas given above are very helpful to predict resonant frequencies of proposed antennas within a reasonable accuracy.

Modified slot-loaded antennas as shown in Fig. 3 (a) and (b) are proposed in this work; case (a) is a modified slot-loaded dual band mictrostrip patch antenna(MSLDA), while case (b) is a modified slot-loaded triple band micorstrip patch antenna(MSLTA). As shown in the figure, narrow slots are etched on the rectangular patch close and parallel to the radiating edges of the patch. The location of the slots in the patch is defined by the dimension L_T and W_S. W_S is chosen as 0.18 mm from the formulas in [7], and L_T is selected as 0.16 mm. This antenna utilizes inset-feeding method for the easy of fabrication and integration with another systems. The width of feeding line is 0.15 mm.

In Fig. 3 (a), an MSLDA is shown having two additional slits in non-radiating edges. With the slits the resonant frequencies of the antenna can be adjusted as a function of slit length.

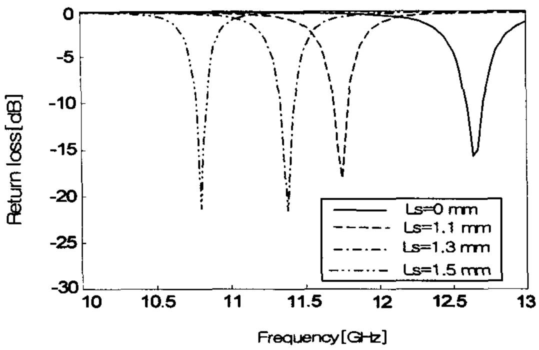


(a)

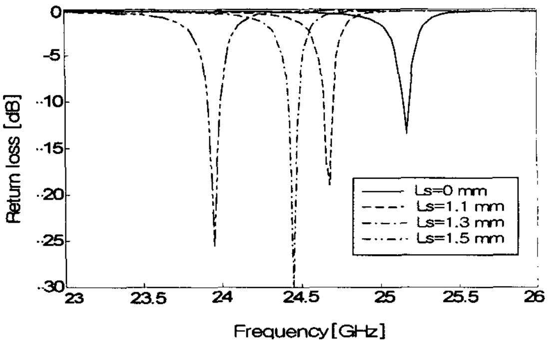


(b)

Fig. 3. (a) geometry of MSLDA.(t = 0.508mm).
(b) geometry of MSLTA.



(a) TM_{01} mode



(b) TM_{03} mode

Fig. 4. Return loss characteristics for different slit.

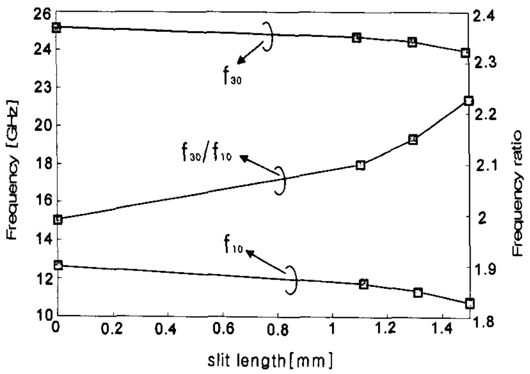
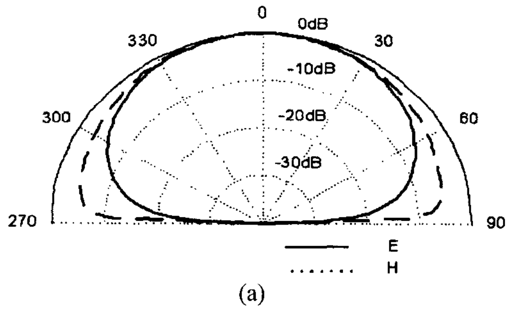


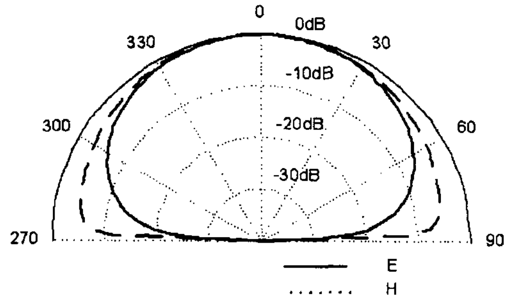
Fig. 5. f_{10} and f_{30}, and the frequency ratio(f_{30}/f_{10}) against slit length for MSLDA.

Fig. 4. depicts the return loss characteristics for three different slit lengths(Ls). It is clear that resonant frequencies of the 1st and 3rd TM modes are significantly lowered with the slits. Note that when the length of the slit is 1.5 mm, the frequency ratio becomes 2.23.

The ratio of the 1st and 3rd modes are displayed as a function of the slit length as shown in Fig. 5. It is clear that by increasing the slit length, both frequencies become lowered with different rate, resulting increased frequency ratio.



(a)



(b)

Fig. 6. (a) X-band radiation pattern.
(b) K-band radiation pattern.

For triple band operation, parasitic elements are augmented on the MSLDA to control third resonant behavior. As shown in Fig. 3 (b), the size of the main patch is 4.4 mm × 6.6 mm, while he parasitic patch is 1.5 mm × 2.5 mm. The resonant frequencies at X and K-band can be controlled by adjusting the main patch as described above, while the resonance at Ka-band an be controlled by varying the vertical length(L_1) of the parasitic patches. As shown in Fig. 6, the radiation patterns of the TM_{01} and TM_{03} modes are quite similar as expected.

Ⅲ. Fabrication and Measurement Data

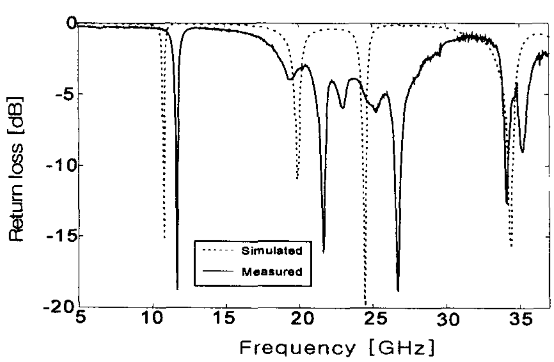
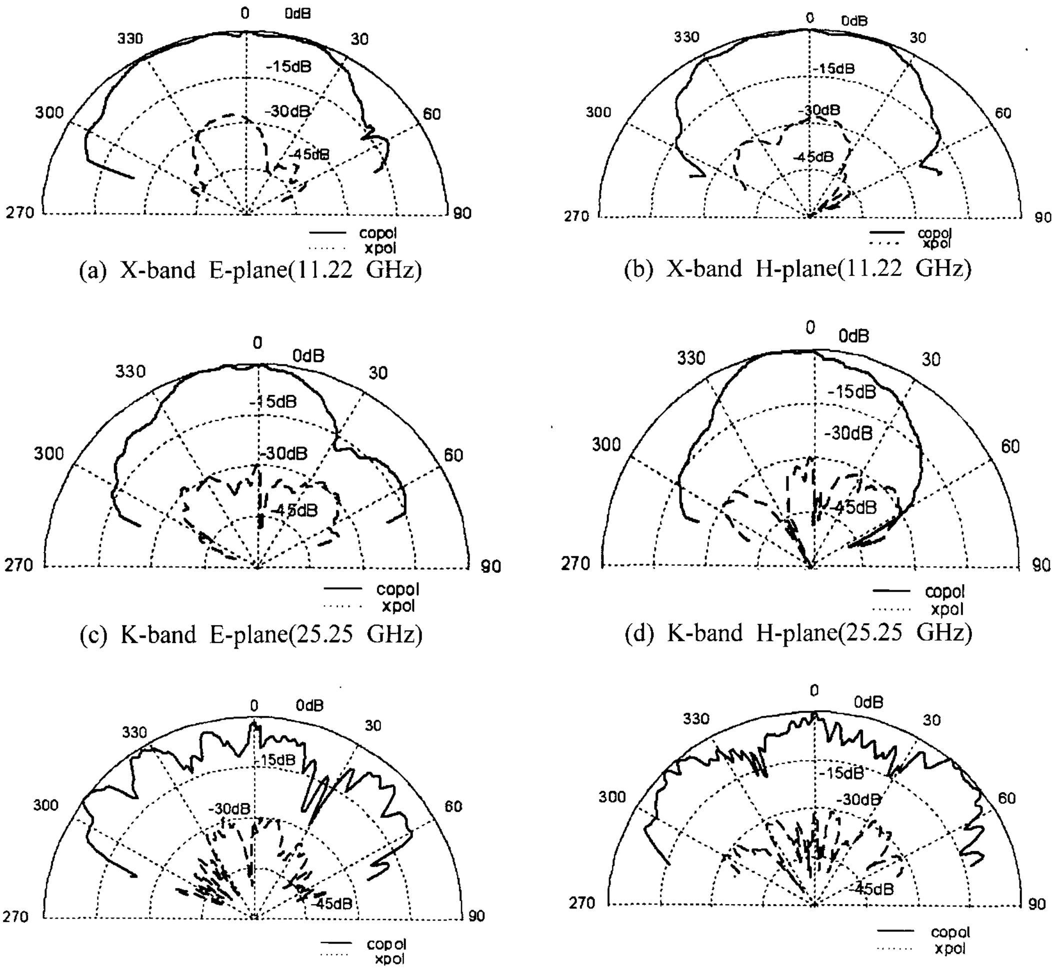


Fig. 7. Return loss of the triple band antenna.

Dual and triple-band antennas are fabricated on duriod substrate($\varepsilon_r = 2.5$), and the return losses of the proposed antennas are measured using vector network analyzer. In the dual band antenna, the resonant frequencies are 11.22 GHz and 25.25 GHz, and resulting frequency ratio is 2.25. In the triple-band antenna, the return loss is shown in Fig. 7 and resonant frequencies are 11.64 GHz, 26.34 GHz, and 34.6 GHz. It is found that the bandwidth(VSWR<2) of the antenna is relatively small; 120 MHz, 182 MHz, and 190 MHz for X, K, and Ka-band, respectively. The measured and calculated return losses of the antenna reveal reasonably good agreement and slight discrepancies are mainly due to fabrication tolerance. At the three different resonant frequencies, the measured co-pol and cross-pol radiation patterns in the E and H-plane cuts of the antenna are illustrated in Fig. 8. For the X, K, as well as Ka bands, the cross-pol(X-pol) radiation is less than −20 dB. Note that three are ripples in the radiation patterns, specially for the Ka-band measurement case, due to imperfect measurement setup in addition to the finite ground plane of the fabricated antennas.

Ⅳ. Conclusion

In this paper, a novel multi-band antenna structure is proposed for triple band application; X-band(10.5 GHz), K-band(24.15 GHz), and Ka-band(34.3 GHz). The frequency ratio of the antenna can be adjusted from 1.99 to 2.23 for both X-band and K-band by varying its slit length, and antenna size can minimized. The parasitic elements are augmented on modified slot loaded dual band antenna to obtain third resonance. This antenna utilizes inset-feeding method for the easy



(a) X-band E-plane(11.22 GHz)
(b) X-band H-plane(11.22 GHz)
(c) K-band E-plane(25.25 GHz)
(d) K-band H-plane(25.25 GHz)
(e) Ka-band E-plane(34.6 GHz)
(f) Ka-band H-plane(34.6 GHz)

Fig. 8. Measured E and H plane radiation patterns of MSLTA(Ls = 1.5 mm).

of fabrication and integration with another systems, and it can be used in multi-service and multi-band systems.

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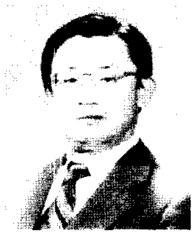

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