Enhanced Bandwidth of Planar L-shaped Open Slot Array Antenna with a Dipole-Like Radiation Pattern

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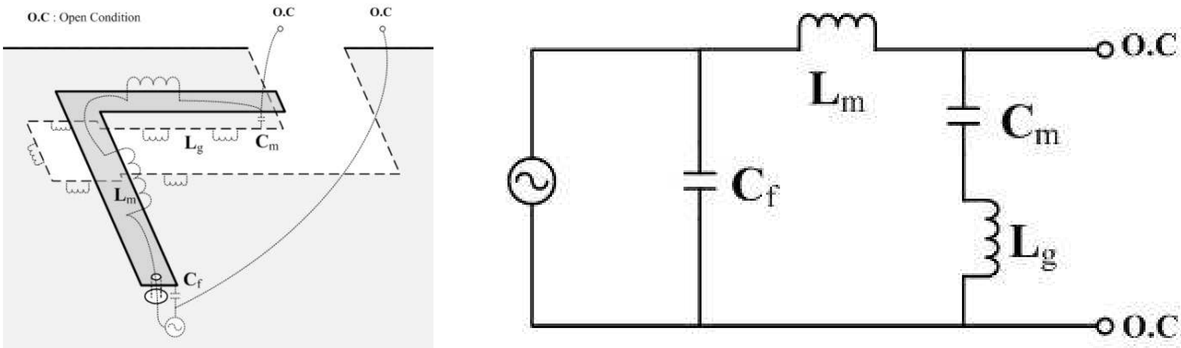
Abstract
A wide-band planar open slot array antenna is presented. It consists of a circular disk on the top of a feeding monopole probe and four L-shaped open slot array structure. By combining these two structures with microstrip lines, it acts as a LC resonator for radiation. The four L-shaped open slots are arranged to maintain a geometrical symmetry. As a result, the size of the antenna is miniaturized and it shows a dipole like radiation pattern. The proposed antenna is designed for the industrial, scientific and medical (ISM) frequency band (2.4GHz – 2.49 GHz). Experimental results show good agreement with the simulated ones.

Keywords: Slot-antenna, Microstrip to slotline transition

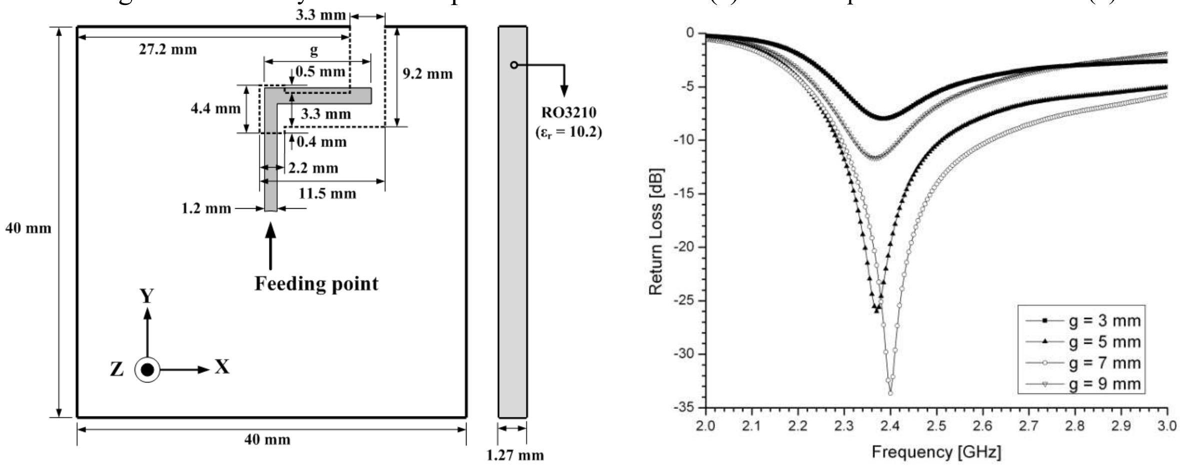
1. Introduction
In many wireless communication systems, an antenna which has a small size and wide impedance bandwidth is required. So, the issues of antenna miniaturization and bandwidth enhancement, has been studied using various methods in the field of radio communication systems [1], [2]. Recently, it is known that an efficient electrically small antenna (EESA) that has the improved efficiency and fractional band width, can be achieved using spherical shell of single negative (SNG) or double negative (DNG) material [3]. In particular, a coaxial feed small monopole enclosed in an epsilon-negative (ENG) shell structure is very attractive in its possibility of the total antenna size reduction [4]. However, most significant problem is that the ENG shell materials should be constructed artificially. In general, the impedance matching of an electrically small monopole antenna is very difficult due to high capacitive reactance of a small monopole antenna. In order to act as a LC resonator for radiation, a large inductance is needed for impedance matching. One effective way to match the input impedance and improve the impedance bandwidth of an antenna is to use the microstrip line coupled slot radiator structure on the finite ground plane. For the reduction of an antenna size and wide bandwidth, a quarter wave length resonant L-shape slot can be used effectively [5]. In this work, in order to obtain a small planar antenna with a dipole-like radiation pattern, the ground plane near the short monopole is partially removed by four L-shape slots and four narrow strips are connected from the short vertical monopole to the removed ground plane edges. As a result, most of currents flow through near edge of the L-shape slots. The proposed antenna structure is optimized by the 3-D field simulation tool, CST MWS (Micro Wave Studio) [6].

2. Microstrip to Slot-line Transition
Fig. 1 shows the layout of a microstrip to slotline transition and its equivalent circuit. When the signal is applied to the small monopole, it cannot radiate the energy by itself. Microstrip to slotline transition can be used to change layers to stimulate open slot antenna. In the equivalent circuit, $\mathbf{C_f}$ is a capacitance between a 50 Ω coaxial feeder line ground plane and a small vertical short monopole. L_m is an inductance of the horizontal conductor strip connected with a short monopole antenna. $\mathbf{C_m}$ is a coupling capacitance between the edges of conductor strip and ground plane. $\mathbf{L_g}$ is an inductance of a slot, and this value can be changed by the current path length variation through the ground plane.



(a) (b)

Figure 1: Geometry of microstrip to slotline transition (a) and its equivalent circuit model (b).



(a) (b)

Figure 2: (a) Geometry of a single L-shaped slot antenna and (b) the simulated return loss for different mmicrostrip line-length g.

The resonant frequency of the antenna is determined mainly by the parameter value of C_f and $\mathbf{L}_g$. Fig. 2 shows a single L-shaped slot antenna with a finite size ground plane and the simulated return loss for different microstrip length g. It is designed on a Rogers-3210 substrate (relative dielectric constant = 10.2, thickness = 1.27 mm) and it is excited by a 50 Ω coaxial connector. The microstrip line and open stub circuit can be regarded as a capacitive element and the L-shape slot line acts as an inductive element, and the combined system with these two elements forms a LC resonator. The resonant frequencies are changed by the variation of the microstrip line length g.

3. Antenna Design

Fig. 3 shows the geometry of the proposed antenna which consists of a SMA connector, and four L-shape slots, and four narrow coupling microstrip lines. A combination of a square plate and a circular disk gap are electromagnetically coupled with an inner conductor of the SMA connector. As a result, a capacitance is generated by the inner conductor of the SMA connector. Other capacitances are generated by four inverted L-type conductor open stubs and the ground plane, also. In order to generate an inductance component these horizontal parts of the inverted L-type stub conductor strips are merged with four L-type open slots in the ground plane. The four microstrip-lines are electromagnetically coupled with a circular top plate of a monopole. By optimizing the proposed antenna structure, impedance matching of the antenna can be easily achieved. By changing the length of the L-type stubs and slots on the ground plane, the operating frequency of the antenna can be changed.

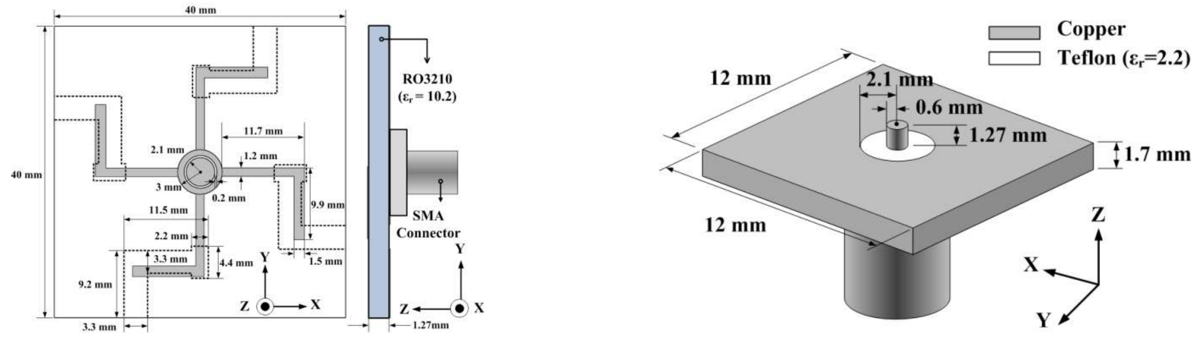
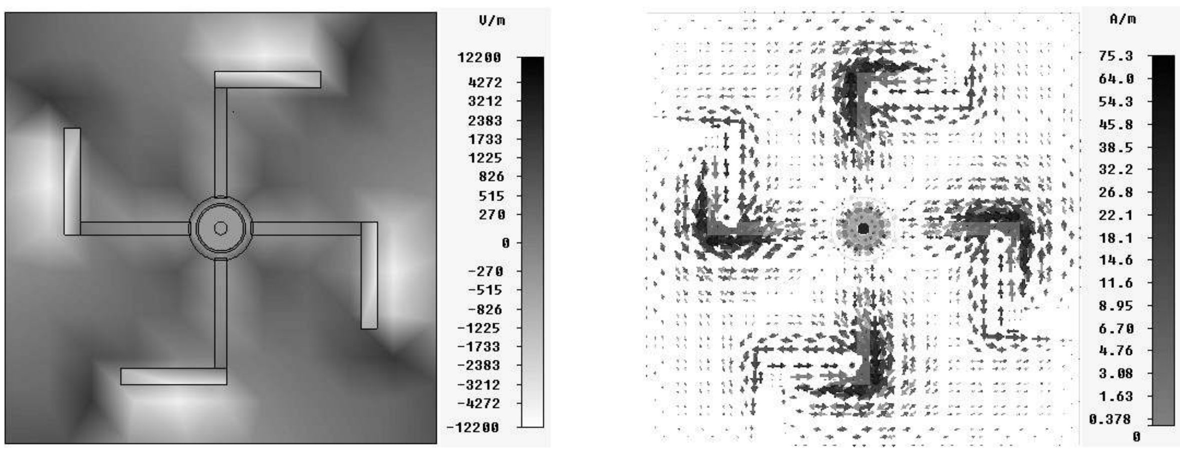


Figure 3: Geometry of the proposed antenna and SMA connector.

The L-shaped slot edges on the ground are opened for improving radiation efficiency, and four slots are located symmetrically in order to get a balanced radiation power pattern. The inner conductor of the SMA connector is used as a short monopole.

4. Simulation and experimental results

Fig. 4 shows the simulated normal E-field and surface current distributions at the resonant frequency of the antenna. The normal E-field is concentrated at the edges of ground. The currents flow along the inverted L-shaped stub conductor strips and the edge of L-shaped slots. Fig. 5 shows the photographs of the fabricated antenna. The total ground plane size of the fabricated antenna is 40 mm × 40 mm, and the monopole probe height of the proposed antenna is 1.27 mm. The comparison of the simulated and measured return loss for the proposed antenna structure is shown in Fig. 7. The measured resonant frequency is 2.36 GHz and impedance bandwidth (VSWR ≤ 2) is found to be about 180 MHz (2.31 ~ 2.49 GHz). Fig. 6 shows the comparison of the measured and simulated radiation patterns over the frequency range of 2-3 GHz. The fabricated prototype antenna exhibits a dipole-like radiation pattern with a vertical linear electric field polarization. The measured maximum gain and radiation efficiency of the antenna is 1.87 dBi and 80.9 % at 2.36 GHz, respectively.



(a) (b)

Figure 4: (a) Normal E-field distribution and (b) surface current distribution.

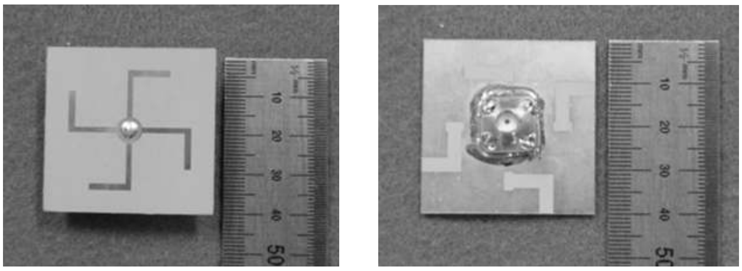


Figure 5: Photographs of the fabricated antenna.

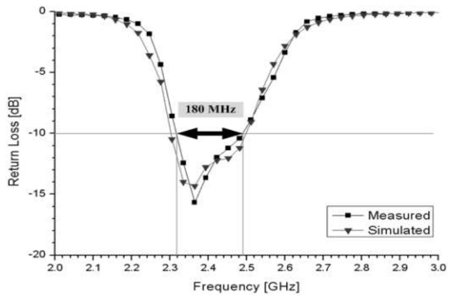
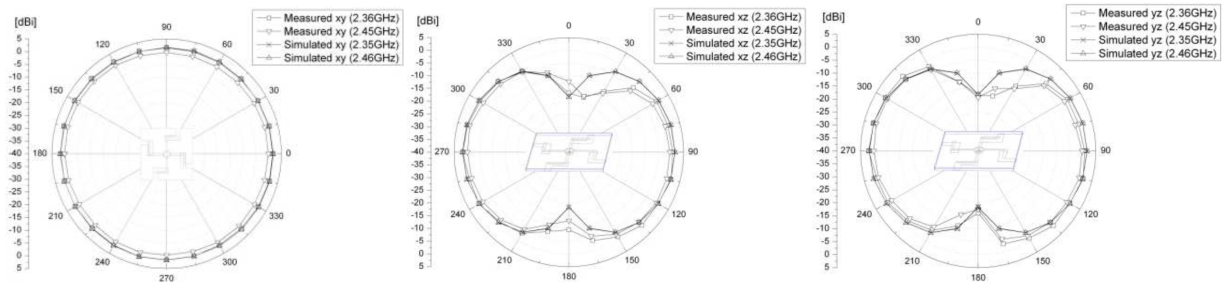


Figure 6: Simulated and measured return loss.



(a) (b) (c)

Figure 7: Comparison of the simulated and measured radiation patterns; (a) xy – plane, (b) xz – plane, (c) yz – plane.

5. Conclusions

A wide-band planar antenna with four elements L-shaped slot array on the ground plane is designed and fabricated and measured. The proposed antenna occupies a volume of 40 mm × 40 mm × 1.7 mm. The measured bandwidth of the antenna is found to be about 180 MHz (7.5 %) at 2.36 GHz and it shows a dipole-like radiation pattern with a high efficiency. It can be applied to ISM frequency band wireless communication system.

References

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Acknowledgments

This work was supported by the "GRRC" Project of Gyeonggi Provincial Government, Korea.