A Study of a Multi-band Antenna Using a Coupling Phenomenon

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1. Introduction

In recent years, various kinds of wireless mobile communications have been developing rapidly. Therefore, multi-band mobile devices are required for wireless services such as mobile phones, GPS, television broadcasting. In order to integrate mobile services, a multi-band antenna is needed.

In this paper, we propose a novel multi-band antenna using plural conductive wires with a coupling phenomenon. This antenna is constructed in a simple structure. Using a coupling phenomenon between wires, the currents of particular modes are excited on the antenna to give the multi-band characteristics. The operating principle of the proposed antenna will be presented more in detail. The design of operating frequencies, the bandwidth widening and the radiation characteristics are investigated.

2. Structure of the Proposed Antenna and Operating Principle

Fig.1 shows the structure of a proposed antenna which has three wires of the length about 100mm in the case X1=X2=0. The three wires are connected with each other at point A, but are opened at point B. The antenna is fed at the centre point C of #1 wire. The #1 wire has two cranks. The #1 wire is close to #2 wire at the lower crank than the feed point, and close to #3 wire at the higher crank than the feed point. It is expected that coupling phenomenon occurs in each portion.

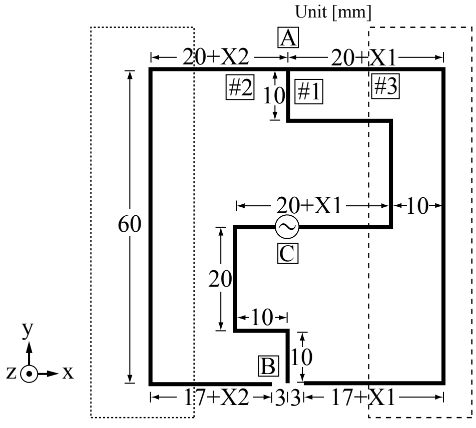


Figure 1: Configuration of Proposed Antenna

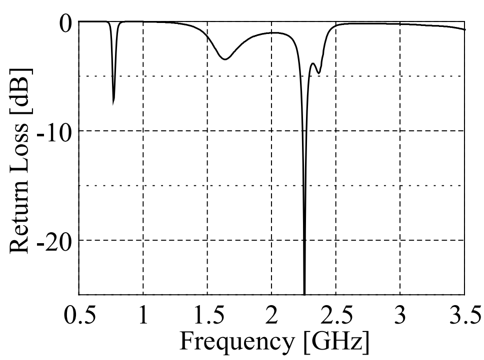
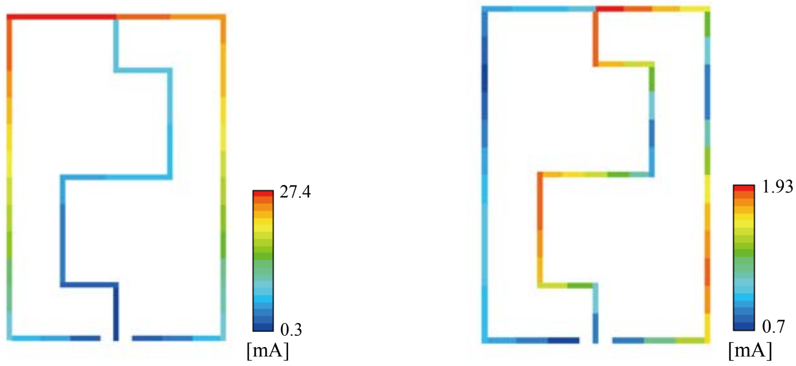


Figure 2: Frequency Characteristics of Return Loss (X1=X2=0)

The proposed antenna in the case X1=X2=0 is analyzed using the moment method. Fig.2 shows the resultant frequency characteristics of return loss. As shown in this figure, the antenna has multi-bands for operation. The return loss is about -7dB at 0.77GHz and less than -25dB at 2.26GHz, respectively.

In order to clarify the operation principle of this antenna, the current distribution in the case X1=X2=0 is analyzed. Fig.3 shows the results at each resonant frequency. At 0.77GHz, the current is distributed on the #2 and #3 wires. The current is hardly distributed on the #1 wire due to a coupling effect. The current distribution on #2 and #3 wires looks sinusoidal with a half period. Actually, the total length of the wires is 194mm which is equal to a half-wavelength of 0.77GHz. It is thought that the antenna works as a looped half-wavelength dipole.

At 2.26GHz, the current is distributed on the #1 and #3 wires, but hardly distributed on the #2 wire due to a coupling effect. The current distribution on the #1 and #3 wires looks sinusoidal with three half periods. Total length of the wires is 197mm which is equal to three half-wavelengths of 2.28GHz. It is thought that the antenna works as looped three half-wavelength dipoles.



(a) At 0.77GHz (b) At 2.26GHz

Figure 3: Current Distribution (X1=X2=0)

3. Design of Resonant Frequencies

In this chapter, the design of high and low resonant frequencies is investigated [1]. According to chapter 2, the high resonant frequency is determined by the total length of #1 and #3 wires. In Fig.1, keeping the size inside the broken line square frame, the size X1 is varied through X2=0. Therefore, the loop length including #1 and #3 wires is changed while the coupling effect between #1 and #3 wires is not changed. The simulated characteristics of resonant frequencies versus X1 are shown in Fig.4. High resonant frequency becomes lower in proportion to X1. Low resonant frequency is also varied slightly. This is because low resonant frequency depends on the length of #3 wire.

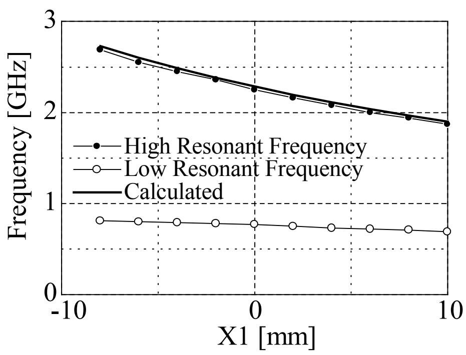


Figure 4: Resonant Frequencies versus X1 (X2=0)

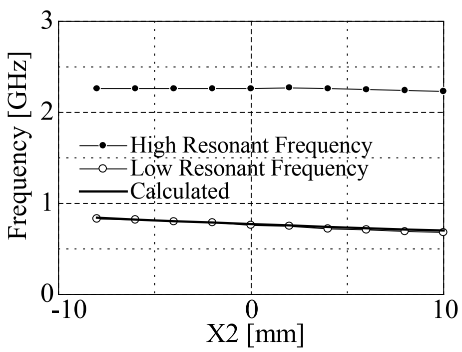


Figure 5: Resonant Frequencies versus X2 (X1=0)

Assuming that the looped three half-wavelength dipoles exist on #1 and #3 wires, the resonant frequency is calculated, as shown in Fig.4. These calculated frequencies agree with the above analytical resonant frequencies well.

The low resonant frequency is determined by the total length of #2 and #3 wires. In Fig.1, the size X2 is varied through X1=0. The simulated characteristics of resonant frequencies versus X2 are shown in Fig.5. Low resonant frequency becomes lower in proportion to X2. However high resonant frequency is not varied. Assuming that a looped half-wavelength dipole exists on #2 and #3 wires, the resonant frequency is calculated, as shown in Fig.5. These calculated frequencies agree with the above analytical resonant frequencies well.

From the above, it is confirmed that the high and low resonant frequencies of the proposed antenna can be designed separately.

4. Bandwidth Widening in High Resonant Frequency

Making a resonant frequency close to another resonant frequency, the bandwidth can be widened. For this investigation, the antenna structure is changed as shown in Fig.6 [2]. The portion of #1 wire close to #3 wire is shortened. The portion of #1 wire close to #2 wire is also shortened. This antenna in the case X3=0 is analyzed using the moment method. Fig.7 shows the resultant frequency characteristics of return loss. From the result, it is confirmed that the bandwidth in high resonant frequency is widened.

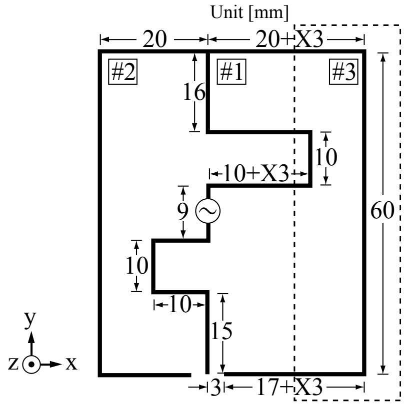


Figure 6: Configuration of Proposed Antenna

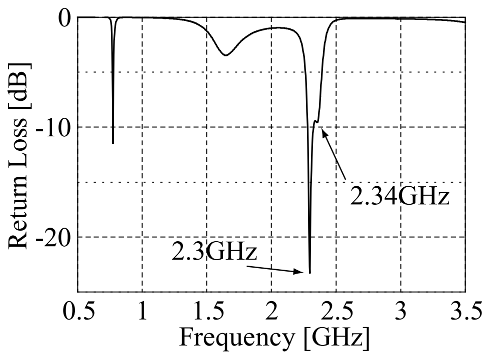


Figure 7: Frequency Characteristics of Return Loss (X3=0)

Because of the antenna structure change, two resonant frequencies of 2.26GHz and 2.37GHz in Fig.1 are varied to 2.3GHz and 2.34GHz in Fig.7, respectively. Thus two resonant frequencies are close to each other. Therefore, the bandwidth in high resonant frequency is widened. At 2.3GHz, the current is distributed on #1 and #3 wires. On the other hand, at 2.34GHz the current is distributed on #1 and #2 wires. The total length of #1 and #3 wires is equal to the total length of #1 and #2 wires. However each resonant frequency is slightly different. As the result, the bandwidth where the VSWR is less than 2 (return loss is less than -9.54dB) is widened from 1.4% (Fig.1) to 3.4% (Fig.7).

The bandwidth widening will now be further investigated. In Fig.6, if the broken line square frame is pulled to the right side, the total length of #1 and #3 wires and the total length of #1 and #2 wires increase. However the increase of the total length of #1 and #3 wires is longer than the increase of the total length of #1 and #2 wires. Therefore the resonant frequency depending on the #1 and #3 wires is varied more rapidly than the resonant frequency depending on the #1 and #2 wires. When the broken line square frame in Fig.6 is moved right to X3=1mm, the frequency characteristics of return loss are analyzed. And then the feeding point is adjusted taking account of the impedance matching. Fig.8 shows the result. As the result, the bandwidth is widened from 3.4% (Fig.7) to 5.3%.

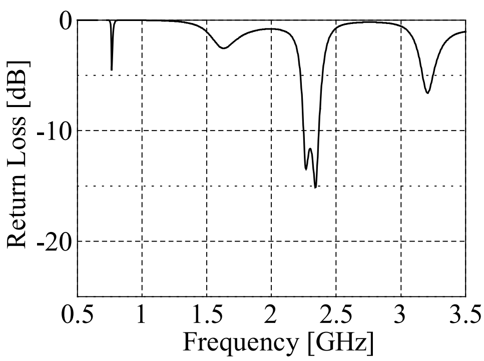


Figure 8: Frequency Characteristics of Return Loss (X3=1mm)

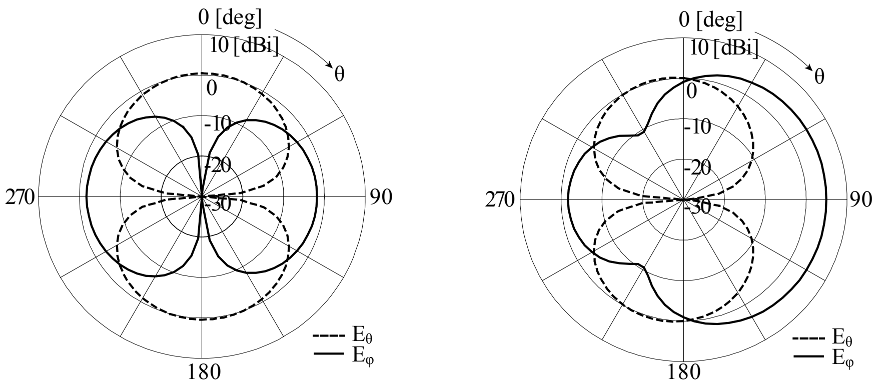
5. Radiation Characteristics

The radiation patterns of the antenna shown in Fig.6 are analyzed at the low and high resonant frequencies in the case X3=0. Fig.9 shows E_θ and E_φ patterns in x-z plane with θ in reference to z axis at 0.77GHz and 2.3GHz. At 0.77GHz, the E_θ pattern shows so-called "8" letter pattern. The E_φ pattern shows "8" letter pattern also, but is perpendicular to the E_θ pattern. At 2.3GHz, the E_θ pattern shows "8" letter pattern also. The E_φ pattern shows almost omni-directional pattern, but is not symmetrical with respect to the right (θ=90deg.) and left (θ=270deg.) sides.

The current distribution of this antenna is roughly the same as one shown in Fig.3. Then, we interpret the radiation patterns in relation to the current distribution shown in Fig.3.

In general, an E_θ pattern in x-z plane is determined by the current distribution parallel to x axis. At 0.77GHz, actually in Fig.3(a), the peak current is distributed on the top of the antenna in x axis. An E_φ pattern in x-z plane is determined by the current distribution parallel to y axis. The current parallel to y axis is distributed on #2 and #3 wires. These currents are in-phase, but their directions are opposite with each other. Therefore, the E_φ pattern shows "8" letter pattern.

At 2.3GHz, as shown in Fig.3(b), one of the peak currents is distributed on the top of the antenna in x axis. The current is distributed on the same wire as 0.77GHz. This is because almost same E_θ pattern occur at both frequencies. The current parallel to y axis is distributed on #1 and #3 wires. The unsymmetrical E_φ pattern is probably caused by some kind of wave guidance effect due to the phase relation between these current distributions.



(a) At 0.77GHz (b) At 2.3GHz

Figure 9: Radiation Pattern in x-z plane (X3=0)

6. Conclusion

In this paper, we have proposed the novel multi-band antenna using plural conductive wires with a coupling effect. As the results, the high operating frequency can be designed by adjusting the total length of #1 and #3 wires. The low operating frequency can be independently designed by adjusting the total length of #2 and #3 wires. The bandwidth in high resonant frequency is widened from 1.4% to 5.3% by adjusting the frequency of a parasitic resonance. The E_θ and E_φ patterns in x-z plane at 0.77GHz and 2.3GHz show "8" letter pattern or almost omni-directional pattern.

References

[1] K.Saegusa, J.Hsiao, S.Fujishiro, T.Takano, "Designing the Resonant Frequencies of a Multi-band Antenna Using a Coupling Phenomenon," Proc. of the 2009 IEICE Society Conference, B-1-91, 2009.

[2] K.Saegusa, S.Fujishiro, T.Takano, "A Study of Bandwidth Widening of a Multi-band Antenna Using a Coupling Phenomenon," Proc. of the 2010 IEICE General Conference, B-1-100, 2010.