Bandwidth Enhancement of Two-element Diversity Antenna with Hybrid Coupler

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1. Introduction

With the developments of mobile communications technology, an interest in built-in antenna has been increased in mobile terminal applications. The problems for the antenna size reduction are the decrease of the frequency bandwidth and efficiency. The use of parasitic elements and a parallel resonance with an added element are presented to enhance the bandwidth [1] [2], it is necessary to find the most suitable place to install into mobile terminals and improve depleted efficiency.

This paper proposes two-element antenna a with hybrid coupler to expand the bandwidth. The hybrid coupler provides two output ports to give the diversity effect by in and out of phase excitation [3], then this proposed antenna also provides the diversity effect. Details of the design and analysis of the proposed antenna to obtain the bandwidth enhancement and diversity effect are described and are demonstrated experimentally by the prototype antenna.

2. Antenna Design

For bandwidth enhancement, it is necessary for S_{11} and S_{22} to be wide band, and for S_{12} to be also wide band because the narrow bandwidth of S_{12} causes depleted radiation efficiency. Fig. 1 shows the geometry of proposed antenna assumed it for large mobile terminals like notebook PC. The dielectric substrate of relative constant ε_r=2.6 with thickness of 1.6 mm is used as antenna elements. Antenna elements are printed two small inverted F antennas, resonating at 2 GHz with its bandwidth of 150MHz (7.5%) as shown in Fig. 2. These two inverted F antennas are connected to a 90 degree hybrid coupler through coaxial cables as transmission lines. Those with different lengths are used to change the input impedance to each antenna element and the characteristic of proposed antenna according to length.

Fig. 3 shows the S-parameter characteristics of proposed antenna when the length of coaxial cable is changed. Fig. 3 (a) shows the bandwidth of S_{11} is more than four times wider than that of a single inverted-F antenna for the lengths of two coaxial cables of (TL1, TL2)= (1.5λ, 2λ) as case 1. On the other hand, the bandwidth is almost the same as the single antenna for case 2 of (TL1, TL2) = (1.75λ, 2λ). As shown in Fig. 3 (b), the bandwidth of S_{22} by the cable length change is almost the same with S_{11}. The bandwidth of S_{12} less than -10 dB for the case 1 is very narrow, while that for the case 2 is wide as shown in Fig. 3 (c). The bandwidth of S_{12} is not improved by the feed circuit to increase the bandwidth of S_{11} and S_{22} in the case 1, while S_{11} and S_{22} are narrow bandwidth for the wide, S_{12} in the case 2. In short, this feed circuit enhances the frequency bandwidth of S_{11} (S_{22}) or S_{12}.

The degradation of S_{12} increases the mutual coupling between two antennas, which reduces the radiation efficiency of this antenna system. The radiation efficiency is an important evaluation factor for small antennas, then we use the case 2 to suppress the mutual coupling and improve the S_{11} and S_{22} by the matching circuits as shown in Fig. 4. Inductance and capacitance components are adjusted by the value of elements. To obtain the impedance matching in wide frequency range, we introduce multi-resonances as shown in Fig. 5.The matching circuit consists of a shunt capacitance

for S_{11} and a series inductance for S_{22}, where insertion losses are less than -1 dB. Fig. 6 shows the S-parameter characteristics with/without matching circuits. The matching circuits enhance the bandwidths of both S_{11} and S_{22}<-10 dB by 56 %, those are 234 MHz. The S_{12} is also enough low in the frequency band of S_{11} and S_{22}. The matching circuits and hybrid coupler feeding are a good combination to improve the input characteristics of two antenna systems.

3. Experimental Result

In this section, the characteristic of proposed antenna as case2 is demonstrated by experiments. Fig. 7 shows the S-parameter of experiments with/without matching circuits. The bandwidths of S_{11} and S_{22}<-10 dB are almost the same as a single inverted-F antenna without matching circuits, those are 160 MHz, while those are 235 MHz and 255 MHz with matching circuits and are 47 % and 59 % wider bandwidth enhancement than a single element. The S_{12} with matching circuits is about 200 MHz narrower than that without those, however, it is still wide enough for the practical applications. The experiments show that the proposed feeding system is effective to enhance the frequency band width of input characteristics of a pair of antennas.

Figs. 8 and 9 show the measured radiation patterns of proposed antenna. The patterns are different each other because of the different phase feeding. To evaluate the diversity effect of these patterns, the correlation coefficient is calculated by the complex pattern using the following equation [4]

$$\rho = \frac{\int_0^{2\pi}\int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} E_1 E_2^* r^2 \sin\theta d\theta d\phi}{\sqrt{\int_0^{2\pi}\int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} E_1 E_1^* r^2 \sin\theta d\theta d\phi \int_0^{2\pi}\int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} E_2 E_2^* r^2 \sin\theta d\theta d\phi}}$$

where E_1 and E_2 are complex radiation patterns of Figs. 8 and 9, respectively and * denotes the complex conjugate. This evaluated coefficient of 0.23 is low enough for the diversity antenna of mobile terminals.

4. Conclusion

This paper presented the antenna achieve both the bandwidth enhancement and diversity effect. The proposed antenna was composed of two elements with a 90 degree hybrid coupler. By adjusting the length of two coaxial cables for the feeding, we demonstrated that either S_{11} (S_{22}) or S_{12} could be improved. We used the cable lengths to enhance the bandwidth of S_{12} not to decrease the radiation efficiency and the bandwidths of S_{11} and S_{22} were extended by adding the matching circuits. Different radiation patterns obtained by the proposed feeding circuit, we obtain the coefficient of 0.23, low enough for the diversity reception.

References

[1] Kin-Lu Wong, et. al., “Dual-Band Flat-Plate Antenna With a Shorted Parasitic Element for Laptop Applications” IEEE Trans. Antenna Propagation., vol. 53, No. 1, Jan. 2005.

[2] S. Sekine, et. al., “Broadband characteristic of inverted-F antenna by parallel resonance mode” IEICE Tech. Report, AP2001-204, Feb. 2002 (in Japanese).

[3] H. Soutome, et. al., “Experimental Demonstration Polarization Diversity Antenna Construction for Wireless Terminal” IEICE Soc. Conf. (in Japanese), 2006, B-1-134.

[4] N. Kuga, et. al., “Planer Multi-Sector Beam Antennas” IEICE Soc. Conf. (in Japanese), 1997, SB-1-8.

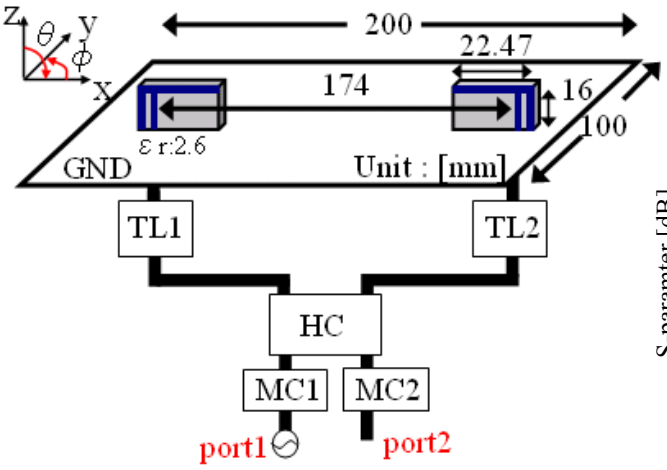


Figure 1: Geometry of proposed antenna
(HC: Hybrid Coupler, TL: Transmission Line
MC: Matching Circuit)

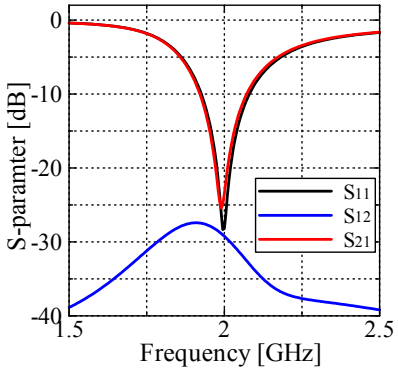
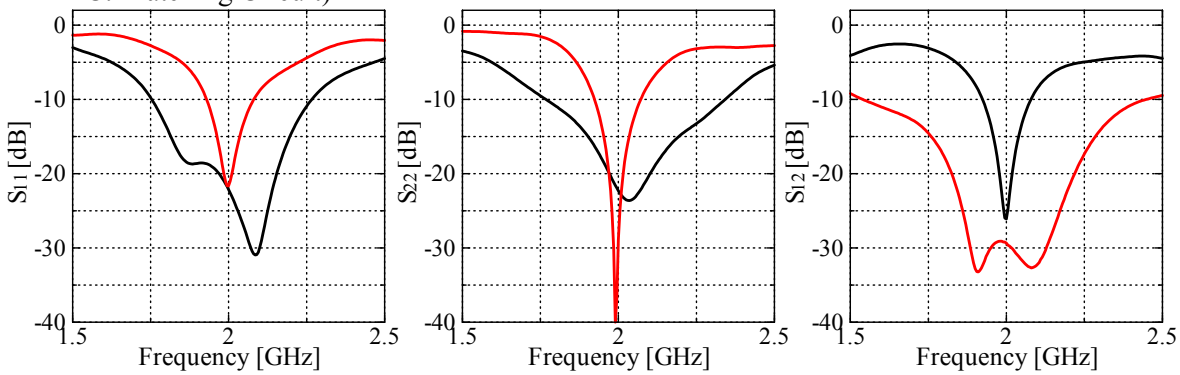
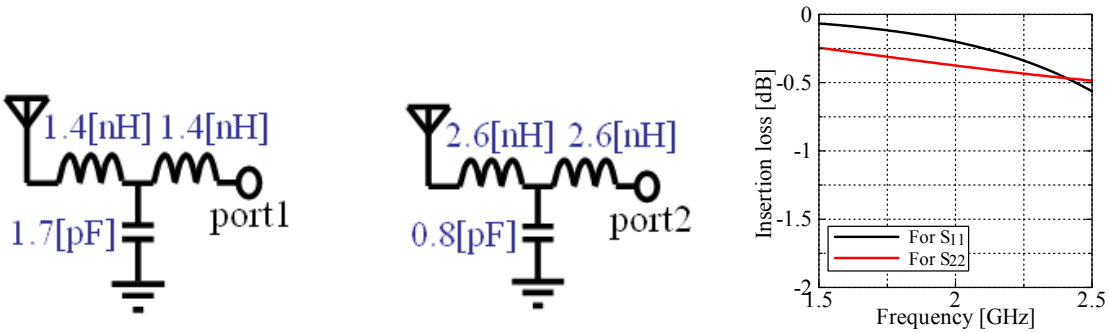


Figure 2: S-parameter of inverted F antenna



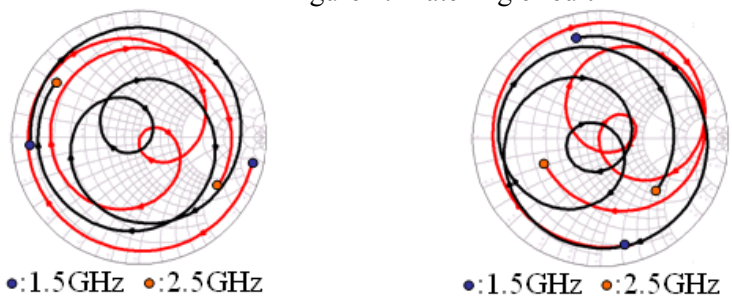
(a) S_{11} (b) S_{22} (c) S_{12}

Figure 3: Influence of S-parameter by the difference of length of two coaxial cables
(black : case1, red : case2)



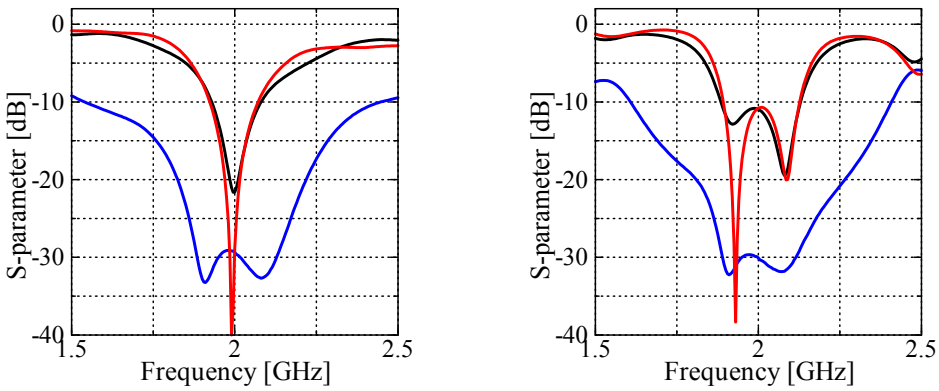
(a) For S_{11} (b) For S_{22} (c) Insertion loss

Figure 4: Matching circuit



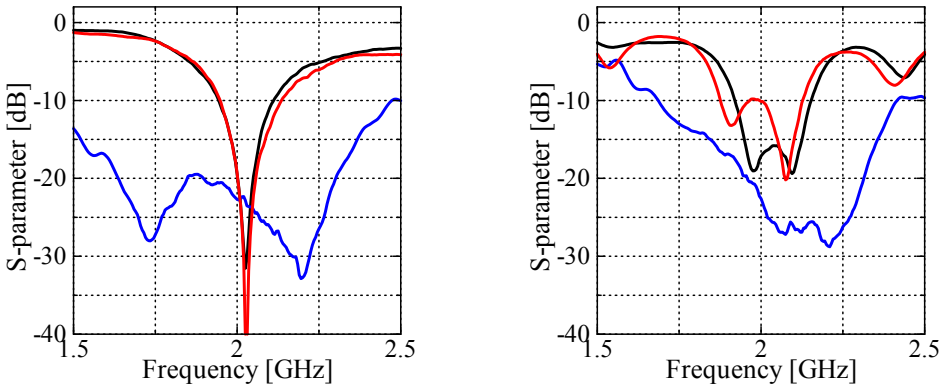
(a) w/o matching circuits (b) w/ matching circuits

Figure 5: Smith chart (start: 1.5GHz, end: 2.5GHz, interval of symbol: 100MHz)
(black: S_{11}, red: S_{22})



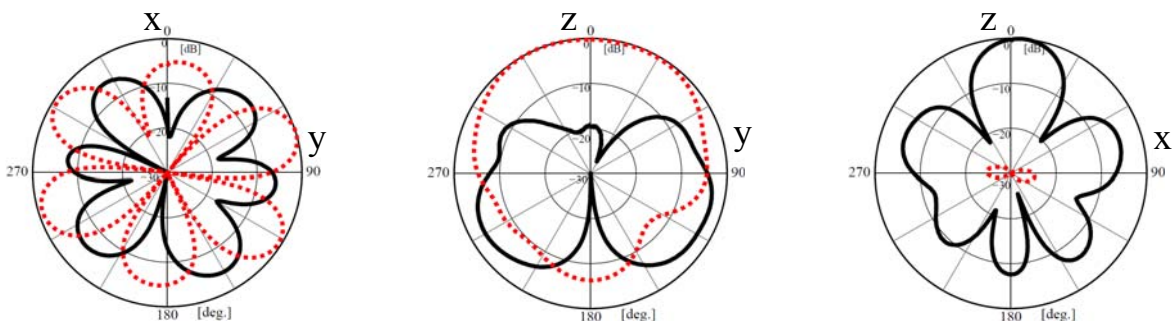
(a) w/o matching circuits (b) w/ matching circuits

Figure 6: Calculated S-parameter of proposed antenna
(black : S_{11}, blue : S_{12}, red : S_{22})



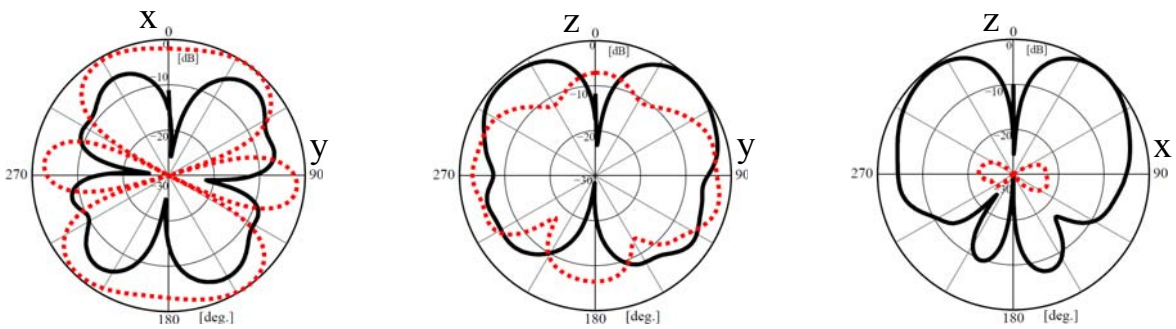
(a) w/o matching circuits (b) w/ matching circuits

Figure 7: Measured S-parameter of proposed antenna
(black: S_{11}, blue: S_{12}, red: S_{22})



(a) xy-plane (b) yz-plane (c) zx-plane

Figure 8: Radiation pattern (port1), black: E_θ, red: E_φ



(a) xy-plane (b) yz-plane (c) zx-plane

Figure 9: Radiation pattern (port2), black: E_θ, red: E_φ