# Bandwidth Enhancement of Two-element Diversity Antenna with Hybrid Coupler

\*Masato KOMATSU , Hiroyuki ARAI
Department of Electrical and Computer Engineering, Yokohama National Univ.
79-5 Tokiwadai, Hodogaya-ku, Yokohama-shi 240-8501, Japan
E-mail: komatsu@arailab.dnj.ynu.ac.jp

#### 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  $\epsilon_r$ =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)=  $(1.5\lambda, 2\lambda)$  as case 1. On the other hand, the bandwidth is almost the same as the single antenna for case 2 of (TL1, TL2) =  $(1.75\lambda, 2\lambda)$ . 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<sub>12</sub> 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<sub>11</sub> and S<sub>22</sub> 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<sub>11</sub> and a series inductance for S<sub>22</sub>, 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<sub>11</sub> and S<sub>22</sub><-10 dB by 56 %, those are 234 MHz. The S<sub>12</sub> is also enough low in the frequency band of S<sub>11</sub> and S<sub>22</sub>. 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<sub>11</sub> and S<sub>22</sub><-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<sub>12</sub> 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<sub>1</sub> and E<sub>2</sub> 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<sub>11</sub> (S<sub>22</sub>) or S<sub>12</sub> could be improved. We used the cable lengths to enhance the bandwidth of S<sub>12</sub> not to decrease the radiation efficiency and the bandwidths of S<sub>11</sub> and S<sub>22</sub> 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

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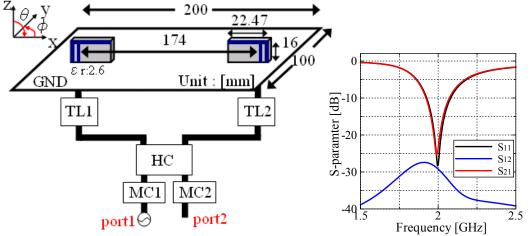


Figure 1: Geometry of proposed antenna

Figure 2: S-parameter of inverted F antenna

(HC: Hybrid Coupler, TL: Transmission Line

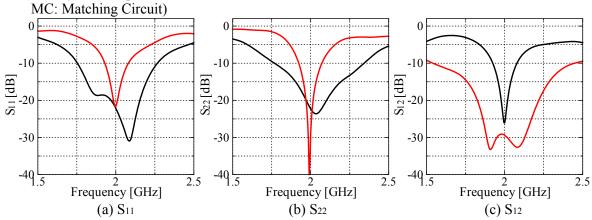


Figure 3: Influence of S-parameter by the difference of length of two coaxial cables (black : case1, red : case2)

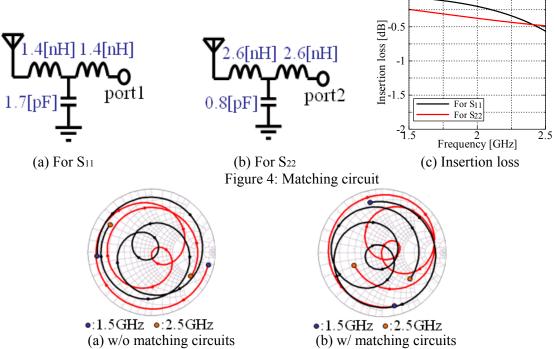


Figure 5: Smith chart (start: 1.5GHz, end: 2.5GHz, interval of symbol: 100MHz) (black: S11, red: S22)

