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DIVERSITY ANTENNA LOADED WITH VARIABLE CAPACITORS FOR EFFECTIVE COMBINING

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1. Introduction

High quality transmission techniques are desired for applications such as indoor wireless LAN and mobile systems. Moreover, the demand for them grows rapidly due to the expansion of services. However, mobile systems are often used under NLOS multipath environments. Using the mobile systems in such environments degrades the transmission quality through fading. Diversity reception is an important technique to reduce the fading and there are some combining techniques for it. Maximal ratio combining (MRC) and equal gain combining (EGC) allow high diversity gain. However, combining in baseband needs the same number of A/D converters as branches and combining in the RF process needs some phase shifters so that MRC and EGC have some problems for power consumption, cost and size.

On the other hand, a new combining technique which uses variable capacitors has been proposed (Fig. 1)[1]. Advantages of this structure are that signals are detected by only one receiver and that the hardware architecture is simple. The phase of the signals is controlled by variable capacitors loaded in series and the signals are combined. However, effective combining has not been achieved due to a narrow range of controlling reactance. Therefore, in this paper, we propose a diversity antenna loaded with variable capacitors in parallel to the antennas. We evaluate the performance of a two branch diversity antenna that consists of half-wave dipole antennas under NLOS multipath environment to check its feasibility. In addition to that, we load the output part with a variable capacitor in order to reduce the impedance mismatch between the combiner output and the receiver input. Finally, we show that the performance of the proposed system with three variable capacitors is close to the selection combining (SC) process.

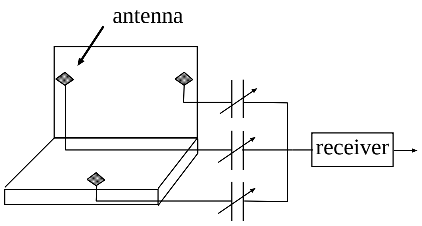

Figure 1: Diversity antenna loaded with variable capacitors in series

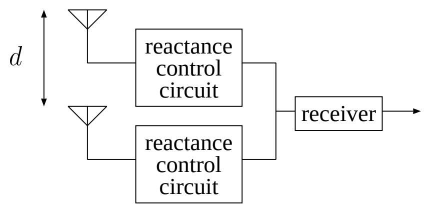

Figure 2: Considered model

2. Proposed system

We evaluate the performance of the two branch diversity antenna that consists of half-wave dipole antennas (Fig. 2) under NLOS multipath environment for a feasibility study. Figure 3 illustrates the equivalent circuit of the diversity antenna loaded with variable capacitors in series, which has already been reported[1]. In Figure 3, the part enclosed with broken lines indicates the equivalent circuit of the antenna. In this model, we assumed a large distance between the antennas so that the mutual coupling between each antenna was ignored. It has been reported

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that in this model, the range of reactance control was so narrow that there was no effective combining made[1]. In order to improve the range of the reactance control, we propose the diversity antenna loaded with variable capacitors in parallel. Figure 4 illustrates the equivalent circuit of the proposed system loaded with variable capacitors in parallel. The parts enclosed with dotted lines indicate the equivalent circuits of the reactance control circuits. Although it is expected that the system with variable capacitors in parallel can archive a wide range of the reactance control, a large change in reactance imply a large change in the input impedance seen looking into each branch. Therefore, impedance mismatch between load of the output and each branch is caused. In order to prevent this mismatch, we also consider a system loaded with a variable capacitor at the output(Fig. 5).

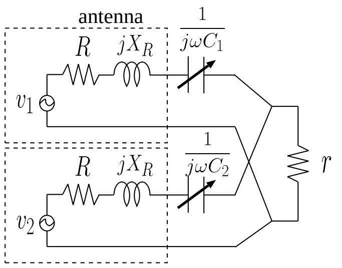

Figure 3: Equivalent circuit of the system loaded with variable capacitors in series

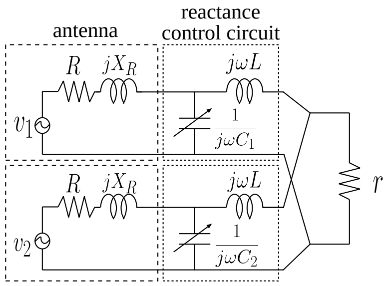

Figure 4: Equivalent circuit of the system loaded with variable capacitors in parallel

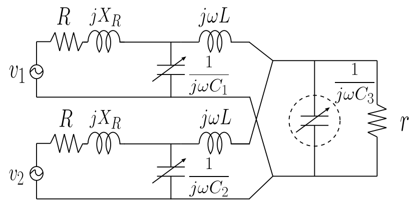

Figure 5: Circuit loaded with variable capacitor to the output

3. Diversity antenna gain(DAG)

When signals are combined in the RF process, it is necessary to consider some specific factors of degradation of the performance, for example, impedance mismatch which is a specific problem of RF signal processing. Moreover, the most important point is maximization of the output considering all the factors of the degradation of the performance.

We use diversity antenna gain (DAG)[2], which can evaluate the total performance of the system which include an antenna system and propagation environment such as layout of antennas, incoming wave distribution and so on. If the fading is slow, the outage probability is a good criteria to measure the link quality. DAG–OP is defined as the gain of SNR at a specific outage probability with respect to a reference antenna at the same propagation environment. The DAG–OP is represented as

$$F = \frac{\Gamma_{\text{div}}}{\Gamma_{\text{ref}}}, \tag{1}$$

where Γ_{div} is the SNR at a specific outage probability for the diversity reception case and Γ_{ref} is the SNR at the same outage for the reference antenna.

Moreover, in order to evaluate the performance of the proposed system, we compared the proposed combining to the SC and MRC techniques[3][4].

4. Simulation condition

We assume an indoor environment, the incident waves are modeled to be arrival from arbitrary 3D directions with the constant probability. Therefore, the distribution functions $P_\theta(\Omega)$ and $P_\phi(\Omega)$ of $\theta-$ and $\phi-$ polarization components of incident plane waves, respectively, are expressed as

$$P_\theta(\Omega) = P_\phi(\Omega) = \frac{1}{4\pi}. \tag{2}$$

In Figs. 3, 4, and 5, $R + jX_R$ is the complex impedance of the half-wave dipole antenna and is 73.1+j42.5 Ω. Moreover, we set the inductor L as 1nH on the reactance control circuit and the load r at the output as $R/2$. The operating frequency is 5GHz. In the monte-carlo simulation, incident waves are modeled by six rays with the random angles of arrival, the constant amplitude and the random phase values. Distance between each antenna is one wavelength. The reactances of the variable capacitors are varied to archive the maximum output power at the load of the output. The simulation is repeated 100,000 times. The control range of the variable capacitors is from 0.7pF to 6.0pF corresponding to the TOSHIBA 1SV287 varactor diode.

5. Simulation results

In general, the output voltage v can be expressed as $v = \mathrm{A}v_1 + \mathrm{B}v_2$. Therefore, the phase difference between A and B corresponds to the equivalent phase rotation of the combiner. Figures 6 and 7 show the phase rotation of the combiner for series and parallel capacitors configuration, respectively. It is obvious that the range is only ± 25 degrees for the serial configuration, while that is ± 143 degrees for the parallel configuration. The results show that the parallel configuration can realize a wider phase control range than the one in series.

Figure 8 illustrates the reflection coefficient of the antennas and reactance control circuits referred to the output load for the parallel capacitors configuration. It can be seen that C_3 can improve mismatch.

Figure 9 illustrates the cumulative probabilities for the SC, MRC and the proposed system with conditions as identified above. The DAG–OPs which satisfy outage probability of 5 percent are 8.2dB for MRC, 6.7dB for SC. Moreover, it can be also seen that 2.5dB when loaded with variable capacitors in series, 5.9dB when loaded in parallel without variable capacitor C_3 for matching and 7.1dB at when loaded in parallel with C_3. The result indicates that the system with variable capacitors in parallel without C_3 gives higher performance by 3.4dB than the system loaded in series, moreover the performance of the proposed system by using three capacitors is close to the selection combining process.

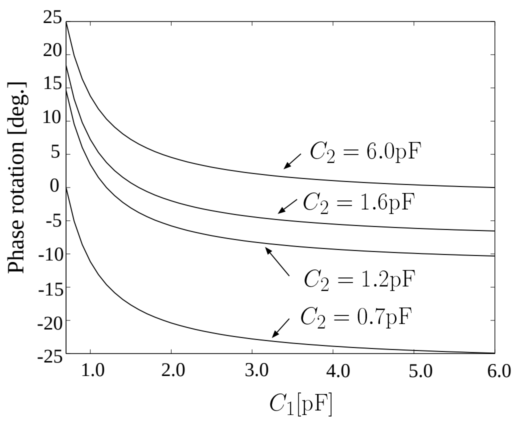

Figure 6: Controllable range of phase in the series-capacitors configuration

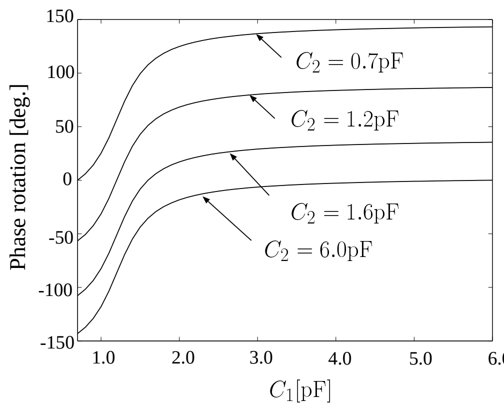

Figure 7: Controllable range of phase in the parallel-capacitors configuration

6. Discussion and conclusion

The diversity antenna loaded with the variable capacitors in parallel can realize a wider range of phase control against the incident voltage on the antenna than the one in series. This is because the system with variable capacitors in parallel affects both the real part and imaginary part of the term of the impedance which allow for phase change. Theoretically, if the phase of the incident voltage can be controlled more than ± 90 degrees by controlling the C_1 and C_2, the proposed system can obtain a higher performance than the SC. Although the case with the

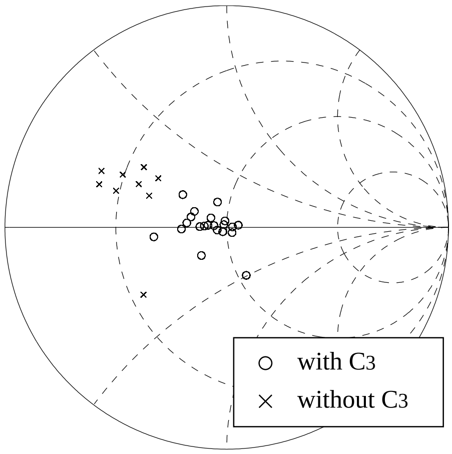

Figure 8: Reflection coefficient

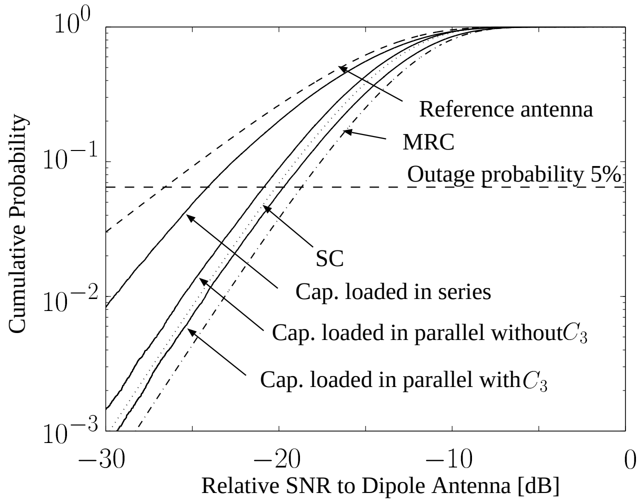

Figure 9: Cumulative probability

variable capacitors in parallel without C_3 make it possible to control more over $\pm$ 90 degrees, a better performance has not been achieved. This is because there is an impedance mismatch between each branch and the output load. However, the case with the variable capacitor C_3 for matching to the output reduces this mismatch. Thus, we show that the performance of the proposed system by using three capacitors is close to the SC.

For future work, it is necessary to take into account several issues which are brought by increasing number of branches, optimization of the parameters for the reactance control circuit and the equivalent circuit of the antenna, and cases which include interference. In addition, the calculation time grows exponentially when the number of variable capacitors increases, and thus it is also necessary to take into account the method to optimize the variable capacitances.

Acknowledgement

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