Automatic Impedance Matching of a Tablet Type 4-Branch MRC Array Close to the Human Hands

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1. Introduction

Digital broadcasting terrestrial services have been spread all over the world. A portable TV is held by the human hands when a user watches terrestrial digital broadcasting while walking. Hence, we must consider the electromagnetic interaction between the antenna and the human hand. The factors causing the performance degradation of a 4-branch MRC array have been studied. The results show that impedance mismatch loss emerging at the branch elements is the major factor among various loss factors caused by the human hands [1]. To overcome this difficulty, we proposed a method of the mitigation of impedance mismatch using a varactor diode, and the effectiveness of the method was confirmed by experiments [2]. However, the method of controlling voltages impressed at the diodes automatically was not fully examined.

This paper presents basic investigations on the automatic impedance matching implemented in a 4-branch MRC array used for a digital broadcasting portable TV set. In the first step, three-dimensional estimation functions were evaluated by theoretical analysis in order to investigate the possibility of adopting the gradient method as an optimization algorithm. Considerations were also given on the stability and convergence properties of the algorithm. Finally, assessments of communication quality, such as the signal bit error rate (BER), were conducted to gain useful knowledge of the way and the degree to which the proposed automatic impedance matching might impact the reduction of the signal-to-noise ratio (SNR) for achieving the prescribed BER.

2. Analysis of the Automatic Impedance Matching

Fig. 1(a) shows the analytical model for a portable TV set held with both hands, comprising two monopole antennas and two inverted L antennas (ILA). The analysis is conducted with the model being placed in the horizontal configuration, representing a practical use condition when a user watches TV. The electrical properties of the human hands are \( \varepsilon_r=57 \) and \( \sigma=0.87 \) S/m. Frequency for the simulation is 600MHz. Electromagnetic analysis was carried out by the method of moments. Fig. 1(b) shows the analytical model for the maximum ratio combining (MRC) diversity antenna used for the simulation.

Fig. 2 shows the impedance matching circuit using varactor diodes, \( C_1 \), \( C_2 \) and \( C_3 \). Since the input impedance of the branch elements is varied by changing the geometrical relationship between the antenna and the hand, the optimum combination of capacitances of the varactor diodes is also changed in accordance with the location of the human hands [2]. Thus, the automatic impedance matching that has the ability to control the impedance status adaptively needs to be employed. Fundamental characteristics, such as stability and convergence properties for the steepest gradient algorithm, are primarily determined by the three-dimensional estimation function [3].

In this paper, the reflection power \( P_r \) for each branch element is chosen as an objective function for optimising the impedance status, as shown in Fig. 2, and the three-dimensional surface for the reflection power is estimated. The procedure for calculating \( P_r \) is described in the followings. In the first step, the admittances, \( Y_{C1} \), \( Y_L \) and \( Y_{C2} \), are calculated, as in Eq. (1), (2) and (3), and then the impedance \( Z_{C3} \) is calculated using Eq. (4). The voltage reflection coefficient \( \Gamma \) with respect to the reference plane (d) is calculated from Eq. (5). Now, we can obtain the reflection power \( P_r \) from Eq. (6).
In Eqs. (1) – (4), the capacitance $C_i$ ($i=1, 2, 3$) is assumed to be changed in accordance with the following equation.

$$C_i = \frac{C_0}{\left(1 - \frac{V_i}{\Phi_D}\right)^n}$$

where $C_0$ is the capacitance of the varactor diode when the bias voltage equals zero ($V_1=0$). $\Phi_D$ is the diffusion potential, and $n$ is an integer determined by the C-V curve profile of the diode.

Fig. 3 shows the three-dimensional surface obtained from the reflection power $P_r$ of MONO#1 when the hand location, $h1=h2$, is 4 cm. It can be seen from the figure that there is no local minimum in the surface. Furthermore, the differentiation can be carried out at the location of the global minimum since one can observe a smooth surface in the entire region to be estimated. It is confirmed from these considerations that the steepest gradient method can be used for optimising the reflection power $P_r$. However, the surface has a moderate slope in the vicinity of the global minimum. This nature in the estimation function may result in a long convergence time, and thus needs to be further studied in our future work.

Fig. 4 shows the measured VSWR characteristics as a function of the location of hand at 600MHz. In the figure, the dotted lines show the case where the free-space matching, meaning the absence of hands, is applied. The solid lines indicate the case where the matching condition is achieved by adjusting the bias voltage of the varactor diodes using a manual control at each hand location. It can be seen from Fig. 4 that a good VSWR condition less than 1.5 can be achieved by adjusting the bias voltages in all the hand locations.

3. BER Characteristics

The purpose of the automatic impedance matching is to improve the receiving performance of a portable TV in practical conditions. Thus, BER characteristics are calculated when a user holds a portable TV in a multipath fading environment. In this paper, 64QAM signals used for the full-segmentation in the digital broadcasting terrestrial system are adopted.

As shown in Fig. 5, the analysis is conducted using a channel model of the two-dimensional angular power spectrum simulating a Rayleigh fading environment [4]. The MRC function is achieved using the MMSE algorithm. By applying the MMSE condition to the output signal of the array, the optimum weight vector is calculated at each snapshot during the sequence of moving the array in a fading environment. In the simulation, the channel response is created in consideration for both vertical and horizontal components of radiation patterns of the antenna elements, and the cross polarization power ratio (XPR) in a fading environment is taken into account.

Fig. 6 shows the average BER characteristics as a function of the average input SNR. The hand location, $h1=h2$, is 6 cm. Frequency for the simulation is 600MHz and XPR is -6 dB. Fig. 6 shows that the average SNR required for achieving $BER = 10^{-3}$ is reduced by 3 dB when the matching condition is optimized by changing the bias voltage of the varactor diodes, indicated by the solid
line, compared with the free-space matching case, indicated by the dotted line. It is confirmed from these considerations that the proposed automatic impedance matching is effective in reducing the required SNR in an actual multipath fading environment.

4. Conclusion

This paper presents basic investigations on the automatic impedance matching of a 4-branch MRC array for tablet type digital broadcasting terrestrial TV receivers. By considering the three-dimensional estimation function, the possibility of adopting the steepest gradient method as an optimization algorithm is shown. BER characteristics were also analyzed, and the effectiveness of the proposed automatic impedance matching is confirmed. Future work includes the fabrication of an actual hardware and the execution using optimization software implemented in a computer.

References

Fig. 3 Surface of the estimation function (MONO\#1)

Fig. 4 VSWR vs. hand location (with/without mismatch)

Fig. 5 Radio propagation model

Fig. 6 Average BER characteristics