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A SINGLE-FEED PLANAR ANTENNA FOR TERRESTRIAL DTV RECEPTION IN MOBILE COMMUNICATION

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Abstract—Japanese terrestrial broadcasting was completely converted to digital television (DTV) broadcasting on 470–710 MHz as of July 2011. However, fading phenomenon resulting from standing waves is a factor in quality deterioration in TV and mobile communication technologies. Suppression of this is needed for many kinds of technologies. A broadband single-feed planar antenna composed of two antenna components, a Broadband Planar Monopole Antenna (B-PMA) and a Broadband Planar Slot Antenna (B-PSA), is proposed for reducing deterioration of reception due to the fading across the DTV band. Reflection coefficients and radiation patterns analyzed by the Finite Difference Time Domain (FDTD) method and compared with measured results indicate that the proposed antenna is broadband compared with a conventional antenna studied previously. A field experiment is conducted in the DTV band. The results of the field experiment indicate clearly that the proposed antenna efficiently suppresses fading resulting from standing waves across the band.

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1. INTRODUCTION

Wireless applications have rapidly developed in mobile communications. Especially in broadcasting, many wireless systems that focus on reception by cellular phones and vehicles have been proposed and put to practical use with the development of terrestrial Digital Television (DTV).

In Japan, terrestrial analog television broadcasting was completely converted to DTV broadcasting on 470–710 MHz as of July 2011. In relation to this, an Ultra High Frequency (UHF) antenna which is suitable for vehicles is necessary.

In mobile communications, fading results from standing waves which causes deterioration of the reception. Electromagnetic waves that are transmitted from a broadcasting station or cell tower interfere with waves reflected from buildings and form standing waves in urban areas bristling with buildings. Depending on the distribution of the standing waves, changes in the received signal level (fading) may occur. Thus, it is important to reduce the deterioration in reception quality due to this fading in mobile communications. With this goal, many kinds of technologies have been developed to suppress fading [1–8].

We previously proposed an antenna that efficiently improves the reception by combining a Planar Monopole Antenna (PMA) and a Planar Slot Antenna (PSA) [1]. The antenna is single-feed and does not require a phase shifter, a combiner, or a switching circuit, leading to cost-saving, miniaturization, and weight-reduction of the receiving system. However, the previous study was focused on the principle of improving the receiving characteristics; therefore, the bandwidth of the antenna was narrow and for this reason it was not suitable for practical use in receiving Japanese terrestrial DTV. Thus, broadbanding of the antenna was required.

This paper proposes an antenna that is able to receive the terrestrial DTV band and suppresses fading due to standing waves. The proposed antenna is composed of a Broadband Planar Monopole Antenna (B-PMA) as an electric antenna and a Broadband Slot Antenna (B-PSA) as a magnetic antenna with a single-feed structure. Based on the fact that an elliptical element broadens the bandwidth of an antenna [9, 10], this element of the antenna is elliptically shaped.

The reflection coefficient and radiation patterns of the proposed antenna and the antenna components are first simulated by the Finite Difference Time Domain (FDTD) method [1, 11–13]. Based on the simulated results, antennas are fabricated, and the reflection coefficient and radiation patterns are measured and compared with the simulated results. A field experiment is then conducted in the UHF band in order to verify the improvement in receiving characteristics.

Section 2 discusses the structure of the proposed antenna, and Section 3 discusses the structures of the B-PMA and the B-PSA components of the proposed antenna and compares the simulated reflection coefficient and radiation patterns with the measured results. Section 4 discusses the structure and characteristics such as the reflection coefficient and radiation patterns of the proposed antenna. The simulated characteristics are compared with the measured ones. Section 5 discusses the method and results of the field experiment conducted to verify suppression of fading due to standing waves in the frequency band of terrestrial DTV. Finally, Section 6 presents the conclusions.

2. STRUCTURE OF THE PROPOSED ANTENNA

The structure of the proposed antenna is illustrated in Figure 1. It is composed of the B-PMA and the B-PSA. It has an elliptical element and a conducting ground plane with a slot printed on the same side of a dielectric substrate (relative permittivity: ε_r). The conducting ground is L_g in length and W_g in width. The dielectric substrate is $L_g + L_d$ in length, W_g in width, and h in thickness. The elliptical element has a major axis of L_e, a minor axis of W_e, and an eccentricity of e. The

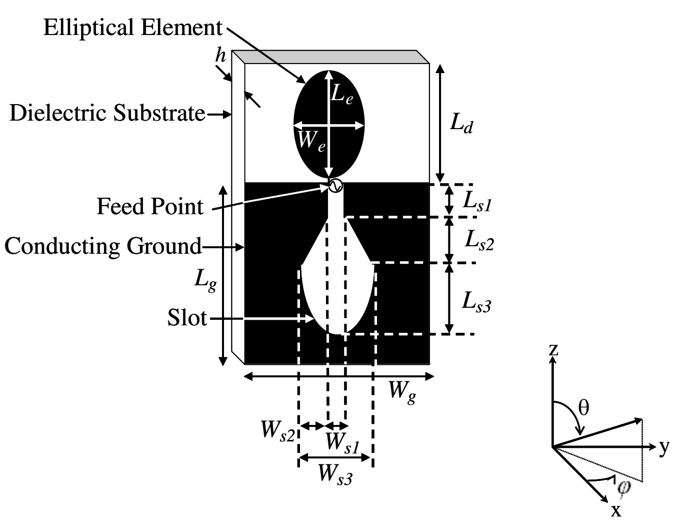

Figure 1. Structure of the proposed antenna.

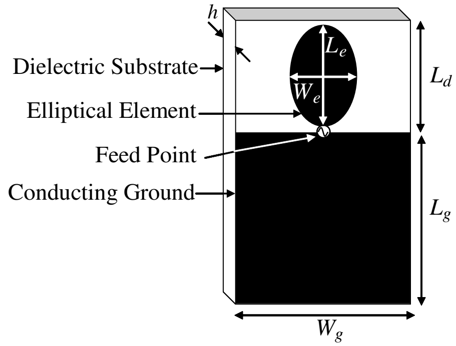

Figure 2. Structure of the B-PMA.

eccentricity is described by the following equation:

$$e = \sqrt{1 - \left(\frac{W_e}{L_e}\right)^2} \tag{1}$$

The slot is loaded in a conducting ground whose dimensions are L_{s1}, L_{s2}, and L_{s3} in length and W_{s1}, W_{s2}, and W_{s3} in width. Here, L_{s3} and W_{s3} form a semi-ellipse, and are half of the major axis and the minor axis. Also, a feed point is placed on the same side as the conducting ground and the elliptical element.

3. ANTENNA COMPONENTS

3.1. Broadband Planar Monopole Antenna (B-PMA)

A B-PMA structure depicted in Figure 2 is one antenna component of the proposed antenna. It has an elliptical element and a conducting ground printed on a dielectric substrate, with parameters the same as the proposed antenna. Here, the eccentricity e is defined in Equation (1).

Figure 3 presents the simulated results for the reflection coefficient [14]. It compares a solid line representing the B-PMA with a dotted line representing the conventional narrowband PMA discussed in [1]. The parameters of the B-PMA are set as follows: $L_e = 140$, $W_e = 112$, $e = 0.6$, $L_g = W_g = 230$, $L_d = 200$, $h = 3\,\text{mm}$, $\varepsilon_r = 7.35$. In the figure, the $-10\,\text{dB}$ bandwidth of the PMA is 152.1 MHz and that of the B-PMA is 1120.5 MHz. Thus, the B-PMA has a broader bandwidth than a conventional PMA, with a relative bandwidth of 127.3%. Figure 4 also verifies that the B-PMA is suitable for receiving Japanese terrestrial DTV.

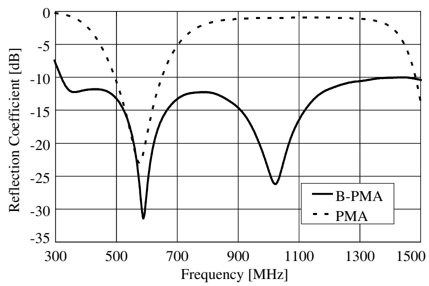

Figure 3. Simulated reflection coefficient. (B-PMA: $L_e = 140$, $W_e = 112$, $e = 0.6$, $L_g = 230$, $W_g = 230$, $L_d = 200$, $h = 3\,\text{mm}$, $\varepsilon_r = 7.35$).

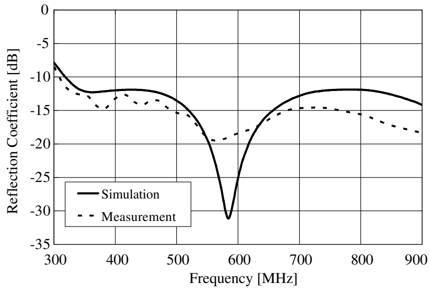

Figure 4. Reflection coefficient of the B-PMA. ($L_e = 140$, $W_e = 112$, $e = 0.6$, $L_g = 230$, $W_g = 230$, $L_d = 200$, $h = 3\,\text{mm}$, $\varepsilon_r = 7.35$).

Based on the simulated results, a same-sized B-PMA is fabricated in order to measure the reflection coefficient and radiation patterns. A glass substrate ($h = 3\,\text{mm}$, $\varepsilon_r = 7.35$) of the type used for car windows is chosen as the dielectric substrate, and the B-PMA is connected to a $50\,\Omega$ coaxial cable through a $50\,\Omega$ coaxial connector. Here, the core of the coaxial connector is soldered to the elliptical element, and the outer conductor is soldered to the conducting ground. A vector network analyzer is used to measure the reflection coefficient.

Figure 4 compares the measured result of the reflection coefficient with the simulated result. It can be seen in the figure that the simulated result corresponds with the measured one and that the fabricated B-PMA meets the bandwidth requirement for Japanese terrestrial DTV.

The radiation patterns are presented in Figure 5. Here, the radiation patterns in the xy-, xz-, and zy-planes were measured with a log periodic antenna as the transmitting antenna and the antenna being measured on a turntable as the receiving antenna. In order to minimize the effects of re-radiation due to current flowing on the coaxial cable, the coaxial cable was set along the rotary shaft of the turntable. Figs. 5(a) and (b) plot the electric field component E_φ in the xy- and xz-planes, and Fig. 5(c) plots E_θ in the zy-plane. The measurement frequency is 590 MHz, which is the center frequency of the Japanese terrestrial DTV band. Each figure is normalized by the maximum value of each characteristic. The measured results correspond well with the simulated ones in each plane.

The measurement conditions for the reflection coefficient and radiation patterns with the coaxial cable and coaxial connector and

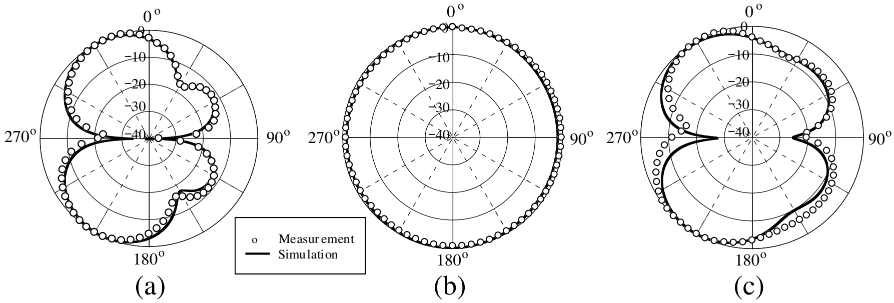

Figure 5. Co-polarized radiation patterns of the B-PMA at 590 MHz. (a) E_φ in the xy-plane. (b) E_φ in the xz-plane. (c) E_θ in the zy-plane.

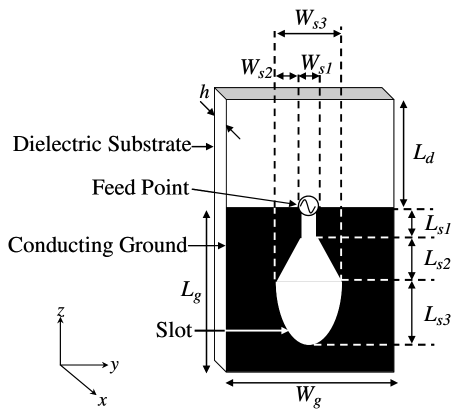

Figure 6. Structure of the B-PSA.

the measurement frequency described above are the same as for the subsequent antenna measurements.

3.2. Broadband Planar Slot Antenna (B-PSA)

The B-PSA structure depicted in Fig. 6 is the other antenna component of the proposed antenna. It has a conducting ground with a slot printed on a dielectric substrate, with parameters the same as the proposed antenna.

The simulated results for the reflection coefficient are given in Fig. 7 [14]. In the figure, the solid line represents the B-PSA and the dotted line represents the conventional narrowband PSA discussed in [1]. The parameters of the B-PSA are set as follows: $L_{s1} = 48$,

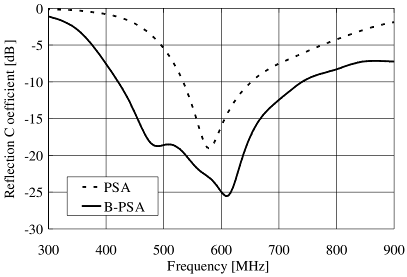

Figure 7. Simulated reflection coefficient. (B-PSA: $L_{s1} = 48$, $L_{s2} = 48$, $L_{s3} = 96$, $W_{s1} = 7$, $W_{s2} = 40$, $W_{s3} = 87$, $L_g = W_g = 230$, $L_d = 200$, $h = 3\,\text{mm}$, $\varepsilon_r = 7.35$).

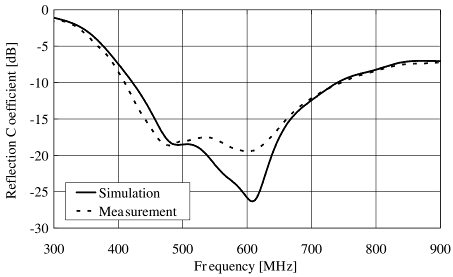

Figure 8. Reflection coefficient of the B-PSA. ($L_{s1} = 48$, $L_{s2} = 48$, $L_{s3} = 96$, $W_{s1} = 7$, $W_{s2} = 40$, $W_{s3} = 87$, $L_g = W_g = 230$, $L_d = 200$, $h = 3\,\text{mm}$, $\varepsilon_r = 7.35$).

$L_{s2} = 48$, $L_{s3} = 96$, $W_{s1} = 7$, $W_{s2} = 40$, $W_{s3} = 87$, $L_g = W_g = 230$, $L_d = 200$, $h = 3\,\text{mm}$, $\varepsilon_r = 7.35$. By comparison, the $-10\,\text{dB}$ bandwidth of the conventional PSA is 116.0 MHz and that of the B-PSA is 316.1 MHz. Therefore, it is evident that the B-PSA has a broader bandwidth than a conventional PSA, with a relative bandwidth of 54.3%. Fig. 7 also verifies that the B-PSA meets the bandwidth requirement for Japanese terrestrial DTV.

On the above basis, a same-sized B-PSA is fabricated in order to measure the reflection coefficient and radiation patterns. In common with the B-PMA, a glass substrate ($h = 3\,\text{mm}$, $\varepsilon_r = 7.35$) of the type used for car windows was chosen as the dielectric substrate. The antenna was connected to a $50\,\Omega$ coaxial cable through a $50\,\Omega$ coaxial connector. Here, the core of the coaxial connector is soldered to the right side of the conducting ground (positive direction of y in Fig. 6), and the outer conductor is soldered to the left side of the conducting ground (negative direction of y in Fig. 6).

Figure 8 compares the measured result for the reflection coefficient with the simulated one. It is evident from the figure that the simulated result corresponds well with the measured one, and that the fabricated B-PSA meets the bandwidth requirement for Japanese terrestrial DTV.

Figure 9 presents the co-polarized radiation patterns of the B-PSA. Figs. 9(a) and (b) plot the electric field component E_φ in the xy- and xz-planes, and Fig. 9(c) plots E_θ in the zy-plane. From the figures, the measured results correspond well with the simulated results in each plane.

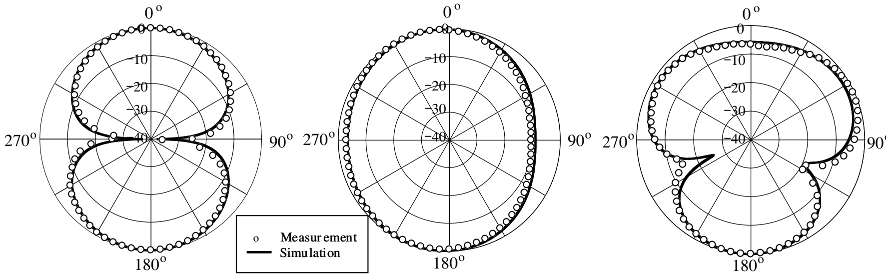

Figure 9. Co-polarized radiation patterns of the B-PSA at 590 MHz. (a) $E_\varphi$in the xy-plane. (b) E_φ in the xz-plane. (c) E_θ in the zy-plane.

4. CHARACTERISTICS OF THE PROPOSED ANTENNA

4.1. Simulated Results

The proposed antenna is composed of two components, the B-PMA and the B-PSA. These components are analyzed in order to meet the bandwidth requirement for Japanese terrestrial DTV discussed in the previous section. Here, it is composed without changing the parameters of the elliptical element, slot, conducting ground, or dielectric substrate as follows: $L_e = 140$, $W_e = 112$, $e = 0.6$, $L_{s1} = 48$, $L_{s2} = 48$, $L_{s3} = 96$, $W_{s1} = 7$, $W_{s2} = 40$, $W_{s3} = 87$, $L_g = W_g = 230$, $L_d = 200$, $h = 3\,\text{mm}$, $\varepsilon_r = 7.35$.

Figure 10 compares the reflection coefficient of the proposed antenna and that of the conventional narrowband Single-Feed Planar Antenna for Electric and Magnetic Fields Reception (SPAEM) discussed in [1]. In the figure, the solid line denotes the proposed antenna, and the dotted line denotes the SPAEM. The SPAEM has a bandwidth of 140.1 MHz. In contrast, the proposed antenna has a bandwidth of 608.2 MHz and 79.6% in relative bandwidth, thus meeting the bandwidth requirement for Japanese terrestrial DTV.

4.2. Measured Results

Based on the simulation, a same-sized antenna is fabricated. For the dielectric substrate, a glass substrate of the type used for car windows is chosen, the same as for the components. A 50 Ω coaxial cable is connected to the feed point of the antenna through a 50 Ω coaxial connector, with the core of the coaxial connector soldered to the right side of the conducting ground (positive direction of y in Figure 1) and

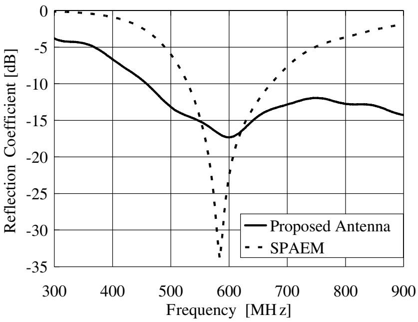

Figure 10. Simulated reflection coefficient. Proposed Antenna: $L_e = 140$, $W_e = 112$, $e = 0.6$, $L_{s1} = 48$, $L_{s2} = 48$, $L_{s3} = 96$, $W_{s1} = 7$, $W_{s2} = 40$, $W_{s3} = 87$, $L_g = W_g = 230$, $L_d = 200$, $h = 3\,\mathrm{mm}$, $\varepsilon_r = 7.35$).

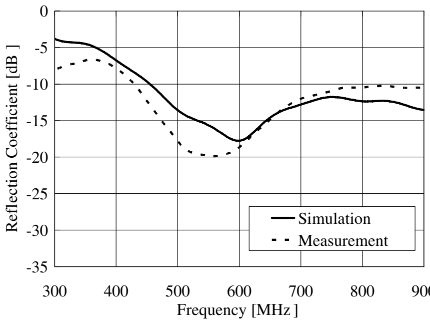

Figure 11. Reflection coefficient of the proposed antenna. ($L_e = 140$, $W_e = 112$, $e = 0.6$, $L_{s1} = 48$, $L_{s2} = 48$, $L_{s3} = 96$, $W_{s1} = 7$, $W_{s2} = 40$, $W_{s3} = 87$, $L_g = W_g = 230$, $L_d = 200$, $h = 3\,\mathrm{mm}$, $\varepsilon_r = 7.35$).

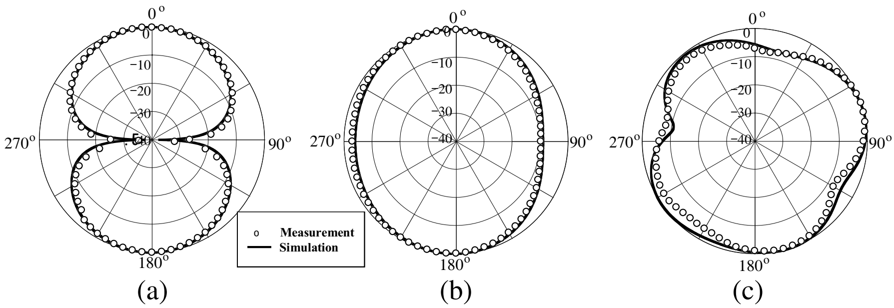

Figure 12. Co-polarized radiation patterns of the proposed antenna at 590 MHz. (a) E_φ in the xy-plane. (b) E_φ in the xz-plane. (c) E_θ in the zy-plane.

the outer conductor soldered to the left side of the conducting ground (negative direction of y in Figure 1).

The fabricated antenna is measured and the results are compared with the simulated ones. A comparison of the reflection coefficient is presented in Figure 11. In the figure, the measured result agrees well with the simulated one, and shows that the fabricated antenna is suitable for receiving terrestrial DTV.

Figure 12 presents the co-polarized radiation patterns of the proposed antenna. Figs. 12(a) and (b) plot the electric field component

E_φ in the xy- and xz-planes, and Fig. 12(c) plots E_θ in the zy-plane. These results indicate that the measured results correspond well with the simulated ones in each plane.

5. FIELD EXPERIMENT

5.1. Experiment System

A field experiment was conducted using a B-PMA, a B-PSA, and the proposed antenna to verify that the proposed antenna reduces quality deterioration due to fading resulting from standing waves across the frequency band of Japanese terrestrial DTV. The target frequencies in the experiment are 571.76 MHz, 607.74 MHz, and 655.76 MHz. These are the lowest, the middle, and the highest frequencies of the terrestrial DTV band, which is transmitted vertically polarized from the station to the location of the experiment. The three frequencies are the sound carrier frequencies for each channel. The received signal levels with the fabricated antennas are measured with a spectrum analyzer at the three frequencies.

On a sufficiently large roof of a building at the receiving point 5.8 km from the transmitting station, a 2 m moving route (measurement route) is set up by a wall that generates standing waves. Here, the transmitting station is placed 38° from the wall. The measuring antennas are placed on a wooden tripod set up on a wooden carriage moving along the measurement route. The height is set at 2.62 m for the lowest channel, 2.37 m for the middle channel, and 2.28 m for the highest channel, because these were the heights at which the strongest signals were received in a preliminary measurement. The proposed antenna is set up with the element pointed in the vertical direction in order to receive the vertically polarized electric field; the edge of the conducting ground plane is directed toward the station in order to receive the magnetic field with the slot. The B-PMA, the B-PSA, and the proposed antenna are moved in the same direction along the same moving route to measure the received signal levels. Each antenna was measured several times at each frequency.

5.2. Results of Field Experiment

Figures 13(a), (b), and (c) present the results of this field experiment for each frequency. The received signal levels are normalized by the maximum value of each characteristic. The phase, wavelength, and received level change of the results are considered.

First, the phase of the received signal patterns are considered. A phase difference of a quarter-wavelength exists between the electric

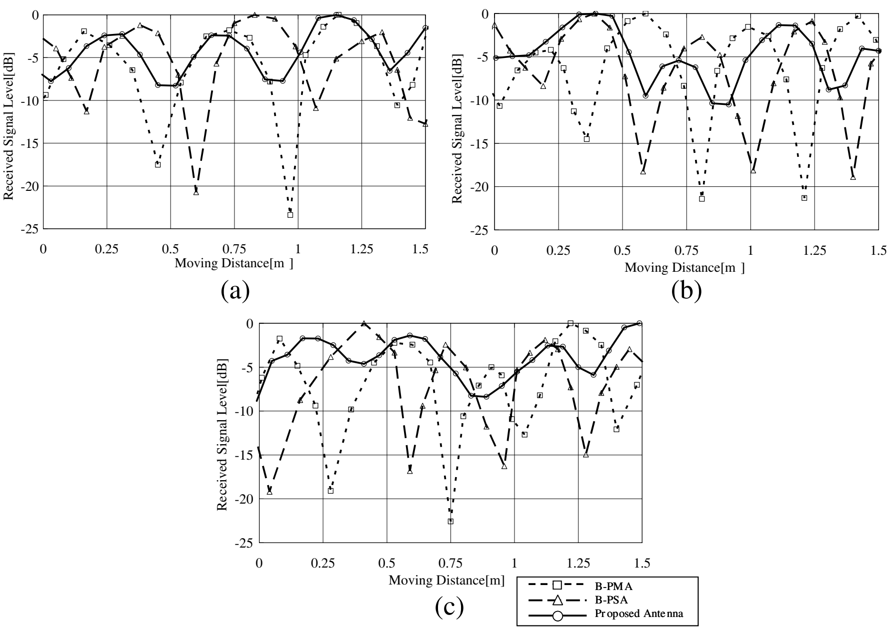

Figure 13. Results of field experiment. (a) 571.76 MHz. (b) 607.74 MHz. (c) 655.76 MHz.

field and the magnetic field in the standing waves [15]. Because the B-PMA receives the electric field and the B-PSA receives the magnetic field, a phase difference occurrs between these received signal patterns. From Fig. 13, the maximum signal levels of the B-PMA and the B-PSA appear alternately; the maximum signal level of the B-PSA is detected near the minimum signal level of the B-PMA, and the maximum signal level of the B-PMA is detected near the minimum signal level of the B-PSA.

Second, with regard to wavelength, a half-wavelength on the measurement route becomes 1.62 times the half-wavelength for each channel, because the transmitting station and the measurement route are angled at 52°. This half-wavelength on the measurement route will be called the theoretical half-wavelength. The measured half-wavelengths of the B-PMA and the B-PSA for several channels are averaged and compared with the theoretical ones. As a result, the average measured half-wavelength and the error between the measured and theoretical values was 440 mm and 3.27% for the lowest channel, 399 mm and 0.28% for the middle channel, and 370 mm and 0.26% for the highest channel.

Finally, the change in the received signal level is considered. The average changes in received signal levels for the lowest channel are 17.39 dB with the B-PMA, 13.47 dB with the B-PSA, and 6.18 dB with the proposed antenna. Those for the middle channel are 16.21 dB, 14.28 dB, and 6.68 dB, respectively. Those for the highest channel are 14.94 dB, 14.81 dB, and 4.69 dB, respectively. Using the proposed antenna, the changes are largely suppressed because it combines the functions of both the B-PMA and the B-PSA.

From these experiment results, it becomes evident that the proposed antenna, composed of the B-PMA and the B-PSA, improves the receiving characteristics across the frequency band used for Japanese terrestrial DTV.

6. CONCLUSIONS

A broadband single-feed planar antenna for mobile communication, composed of a broadband planar monopole antenna (B-PMA) and a broadband planar slot antenna (B-PSA), was proposed to reduce deterioration of reception quality by fading due to standing waves.

The reflection coefficient and radiation patterns of the components (the B-PMA and the B-PSA) were analyzed by the FDTD method. By using elliptically shaped elements, their bandwidths were made broader than those of conventional antennas. Based on a simulation, the antenna components were fabricated and their characteristics were measured. The measured results agreed well with the simulated ones.

The proposed antenna was constructed by combining two antenna components with a single-feed structure and then analyzed by the FDTD method. It was fabricated and the characteristics were measured. The results of the simulation corresponded well with those of the measurement.

A field experiment was conducted to verify the ability of the antenna to reduce quality deterioration due to fading resulting from standing waves. The experiment measured the received signal levels of the proposed antenna and its two components (the B-PMA and the B-PSA) across the frequency band used for Japanese terrestrial DTV, namely 470–710 MHz. Although the received signal levels of the B-PMA and the B-PSA changed significantly because of the reception of standing waves, the change in the signal level of the proposed antenna was much smaller. Moreover, the measured half-wavelength agreed with the theoretical one with high accuracy. In addition, the experiment verified that the proposed antenna reduced deterioration of the received signal level by a single-feed structure without using a phase shifter, a combiner, or a switching circuit. Therefore, the proposed antenna is useful for reducing received signal deterioration due to fading resulting from standing waves in mobile communications.

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