# A Novel Electromagnetically Coupled Microstrip Antenna with a Rotatable Patch for Personal Handy-Phone System Units

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***Abstract*—In this paper, we propose a novel electromagnetically coupled microstrip antenna with a rotatable patch to overcome the problems associated with the conventional whip antenna for the personal handy-phone system (PHS). The structure of the newly developed antenna installed in actual PHS units is described. Its fundamental characteristics such as radiation pattern, bandwidth, and gain are shown. The performance of the antenna in actual propagation environments is also clarified. It is shown that this novel antenna is superior to the conventional whip antenna and achieves efficient performance in commercial PHS service.**

***Index Terms*—Electromagnetically coupled microstrip antenna, rotatable patch.**

## I. Introduction

FOR hand-held-type portable telephones in cellular and microcellular radio mobile communication systems, the whip antenna is commonly used because of its simplicity. However, it has four main problems.

The first problem is the degradation in effective gain seen with unit inclination. Since unit inclination causes polarization mismatching between the portable telephone antenna and base-station antenna, the effective antenna gain of portable telephones in land-mobile propagation environments is degraded when the portable telephone units are inclined [1]. The second problem is the degradation experienced in antenna gain due to operator proximity [2]. The third problem is the RF exposure experienced by the users [3]. The omnidirectional radiation pattern of whip antennas in the horizontal plane leads to a strong degradation in antenna gain and a significant amount of RF exposure. The fourth problem is antenna breakdown and poor handling as the whip antenna extends beyond the unit.

Assessing these problems discovers three requirements. The first is an antenna structure that keeps the polarization direction vertical regardless of unit inclination. The second is a directional radiation pattern to reduce the RF exposure and gain degradation caused by operator proximity. The last is a built-in-type antenna to overcome the problem of breakdown and poor handling.

In this paper, we propose a novel electromagnetically coupled microstrip antenna with a rotatable patch that fulfills these requirements. Section II introduces the structure of the newly developed antenna as installed in actual personal handy-phone system (PHS) units. Section III shows the variation in radiation pattern with inclination angle of the PHS unit. Section IV describes the impedance characteristics such as resonant frequency and bandwidth. Section V describes the gain characteristics. Section VI illustrates the performance of the newly developed antenna in actual propagation environments and Section VII presents some final conclusions.

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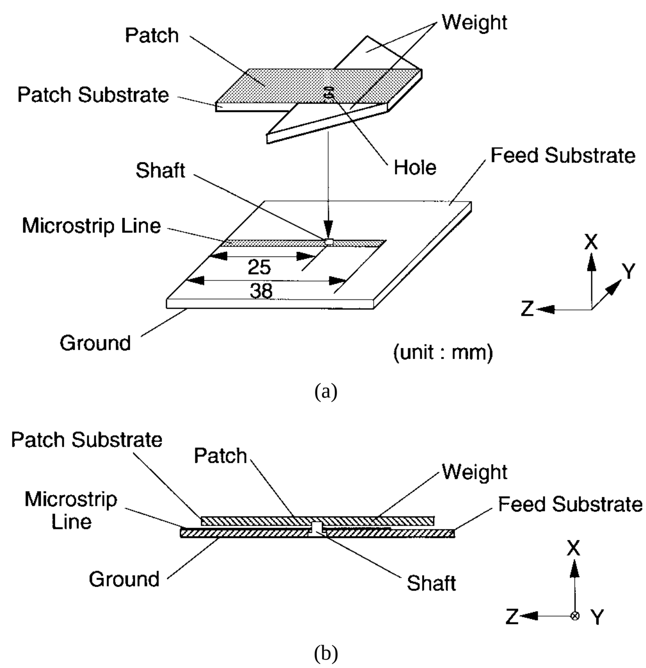


Fig. 1. Configuration of proposed antenna. (a) Geometry of layers. (b) Cross-sectional view.

## II. Antenna Configuration

Fig. 1 shows the configuration of the proposed antenna. The metallic rectangular patch completely covers the patch substrate. The weight is an integral part of the patch substrate. A microstrip line is located on the bottom feed substrate. The characteristic impedance of the microstrip line, which feeds the patch electromagnetically, is 50 Ω. The shaft pierces the bottom feed substrate and the microstrip line and is inserted into a hole in the patch substrate. Consequently, the patch lies on top of the feed substrate and can rotate freely around the shaft.

Fig. 2 shows the configuration of the newly developed antenna installed in PHS units. The antenna is attached to the RF package and is mounted on the back side of the unit [4]. When the unit is inclined in the $Z$-$Y$ plane, the patch

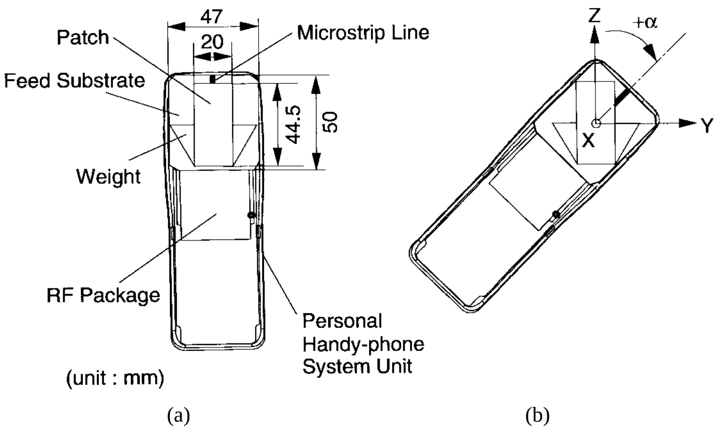


Fig. 2. Configuration of newly developed antenna installed in the PHS unit. (a) Upright. (b) Inclined.

rotates and remains vertical because of the weight [as shown in Fig. 2(b)] where $\alpha$ represents the unit's inclination angle from the $Z$ axis. Therefore, the polarization direction of the new microstrip antenna is always kept vertical and there is no effective gain degradation due to inclination. This antenna also reduces the degradation experienced in antenna gain due to the proximity of the operator's body because of its directional radiation pattern, which offers very low levels toward the operator. Furthermore, this antenna requires no handling by the user and is less prone to breakdown because of built-in-type antennas. Since this antenna needs only natural gravity to hold the patch vertical and can continuously change the polarization direction with respect to the unit, there is none of the time lag needed for switching the RF port as is performed by electrical switching systems. In addition, it leads to lower unit prices because no expensive electrical components (such as switches) are used and it has a relatively simple structure.

The length of the patch is chosen to resonate at the 1.9-GHz band. The length of the microstrip line was determined experimentally so that good impedance matching is achieved at the inclination angle of 0°. The sizes of the feed substrate and rotatable patch are 50 × 47 mm and 44.5 × 20 mm, respectively. The thickness and relative dielectric constant of both the feed substrate and the patch substrate is 1.6 mm and 3.6, respectively. The weight is determined so that the patch rotates freely. The volume of the whole antenna including both the feed substrate and patch is about 7 $cm^3$.

## III. Radiation Pattern

Fig. 3 shows the variation in measured radiation patterns of both the proposed antenna and the conventional quarter-wavelength whip antenna with respect to inclination angle $\alpha$, where 0 dBd represents the maximum radiation strength of a half-wavelength dipole antenna. The measuring frequency is 1.9065 GHz, the center frequency of the PHS band. The inclination is in the $Z$-$Y$ plane, as shown in Fig. 2. The radiation patterns were measured for vertically polarized waves. It is seen that the shape and maximum radiation strength of the radiation pattern of the new antenna are kept constant regardless of unit inclination. Considering the conventional quarter-wavelength whip antenna, the shape, and maximum

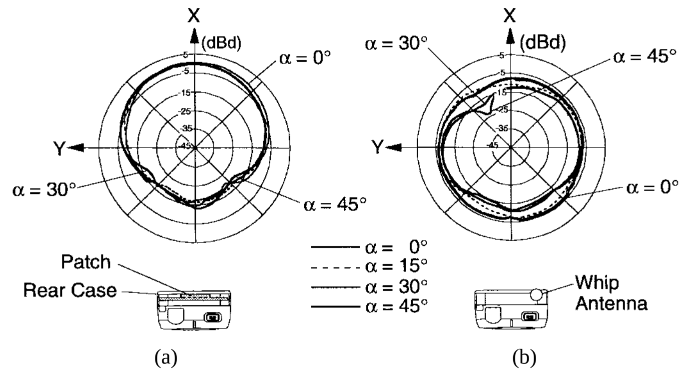


Fig. 3. Radiation pattern change with unit inclination angle. (a) Proposed antenna. (b) Conventional whip antenna.

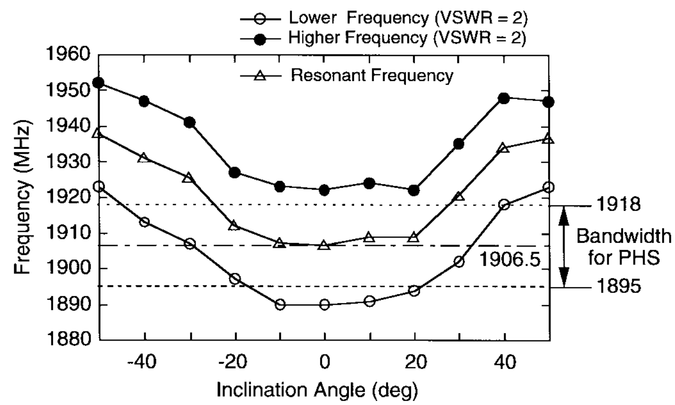


Fig. 4. Variation in resonant frequency and bandwidth with unit inclination angle.

radiation level of the radiation pattern significantly change with unit inclination.

## IV. Impedance Characteristics

Fig. 4 shows the measured resonant frequency and bandwidth of the proposed antenna installed in the unit, as shown in Fig. 2. The bandwidth is estimated for a voltage standing wave ratio (VSWR) $\leq 2$. It is seen that both the resonant frequency and bandwidth vary with inclination angle. This is because the electromagnetic coupling between the patch and microstrip line changes with patch rotation. The asymmetry in the shape is believed to be caused by fabrication errors. The maximum resonant frequency separation from the center frequency of PHS band due to unit inclination is 31.4 MHz. The resonant frequency corresponding to the shorter edge length of the patch is obtained at the inclination angle of 90°. Obviously, patch rotation must restricted mechanically to obtain the desired VSWR's.

Fig. 5 shows the effective bandwidth which is the overlap between the bandwidth of VSWR $\leq 2$ and the frequency band of 23 MHz needed for PHS. It is found that the effective bandwidth decreases as the unit inclination angle increases. The effective bandwidth needed for PHS is achieved over inclination angles of 0° to ±20°. The bandwidth performance is narrow and not sufficient for PHS given the definition VSWR $\leq 2$. The bandwidth achieved is about 58% of that needed for PHS use. Further development is desired to increase

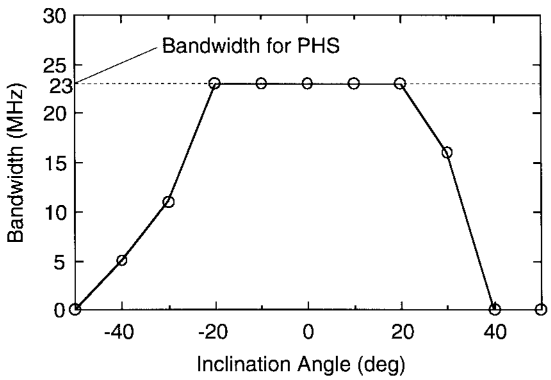


Fig. 5. Variation in bandwidth for PHS with unit inclination angle.

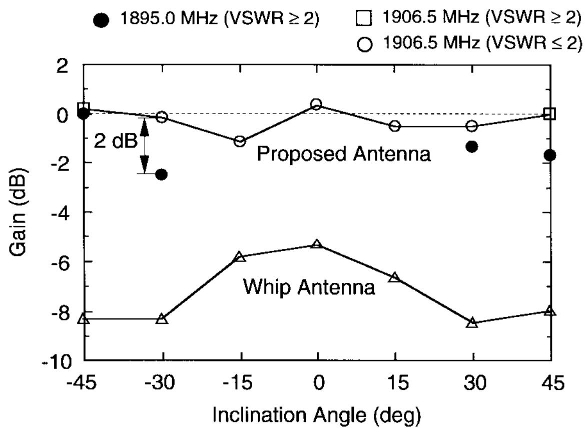


Fig. 6. Variation in gain with unit inclination angle.

the bandwidth. The worse input impedance degrades only the received and transmitted signal levels and does not increase the noise level nor create other problems. Because time-division multiple access/time-division duplex (TDMA-TDD) system is adopted and transmitting power is very low in PHS, there is no power leakage from Tx to Rx and the electrical components, such as amplifiers, experience negligible problems due to the reflected power caused by the worse impedance matching. We confirmed that no change in the impedance characteristics of the new antenna is observed when the unit is held by hand to the side of the human head.

## V. Gain

Fig. 6 shows the variation in gain of the newly developed antenna and that of a conventional quarter-wavelength whip antenna with inclination angle. In Fig. 6, open circles express the gain measured at the PHS center frequency of 1906.5 MHz for the VSWR $\leq 2$, open squares express the gain measured at PHS center frequency for the VSWR $\geq 2$, and the dotted closed circles represent the gain measured at PHS lower frequency of 1895 MHz of the VSWR $\geq 2$. The open triangles represent the gain for the whip antenna.

It is seen from Fig. 6 that the proposed antenna has no significant degradation in gain over the inclination angle of $\pm 50°$ and achieves the peak gain of about 0 dBd. In these figures, 0 dBd represents the maximum radiation level of a half-wavelength dipole antenna. The maximum degradation in gain measured at the frequency of the VSWR $\geq 2$ is about 2 dB compared to that measured at the frequency of the VSWR $\leq 2$. It is clarified that the new antenna has sufficient gain performance and possesses no practical problem from the standpoint of gain even its bandwidth performance is not sufficient for PHS. The degradation in gain of the conventional quarter-wavelength whip antenna with unit inclination is about 2.7 dB. These results clarify that the proposed antenna is superior to the conventional quarter-wavelength whip antenna and achieves sufficiently high gain.

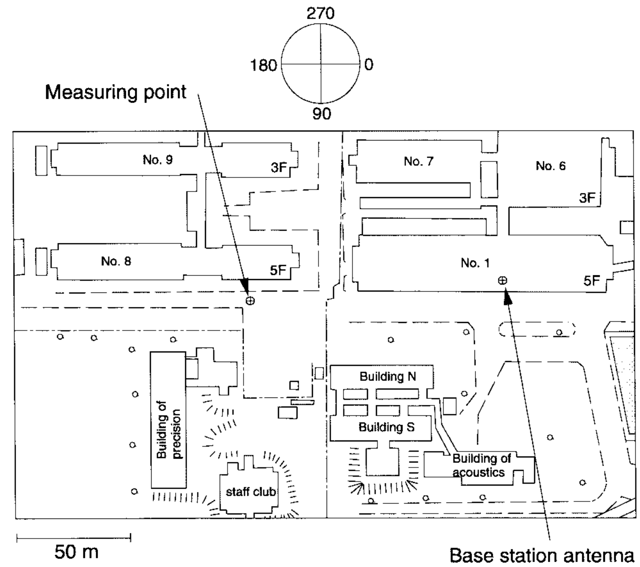


Fig. 7. Map of measuring point.

## VI. Performance in Actual Propagation Environments

The received signal levels were measured to clarify the performance of the proposed antenna as installed in PHS units and tested in actual propagation environments. An actual PHS base station was used in the measurements.

Fig. 7 shows the map locating the measuring point. A whip antenna was used as the base-station antenna. The base-station antenna was mounted on an internal wall of the second floor of a building so the waves transmitted from the base-station antenna must pass through the windows of the building. The distance between the base-station antenna and measuring point was about 110 m in a straight line. The azimuth angle is defined in Fig. 7.

Fig. 8 shows the variation in received signal level with respect to the azimuth angle that the direction perpendicular to which the patch (or $X$ axis; Fig. 2) is pointing. In this case, the PHS unit is upright, i.e., the inclination angle is 0°. The received signal level of the whip antenna was measured and shown only at the azimuth angle of 0° because of its omnidirectional radiation pattern in the horizontal plane. It is seen that the received signal level of the proposed antenna decreases as the PHS unit rotates in the horizontal plane. From a qualitative view, the level variation of the azimuth angle corresponds to the level variation shown in Fig. 3. It is seen that the received signal level of the proposed antenna is higher than that of the whip antenna in the main lobe region from 0 to 90°, while the received signal level of the proposed antenna is lower than that of the whip antenna in the backlobe region from 90 to 180°.

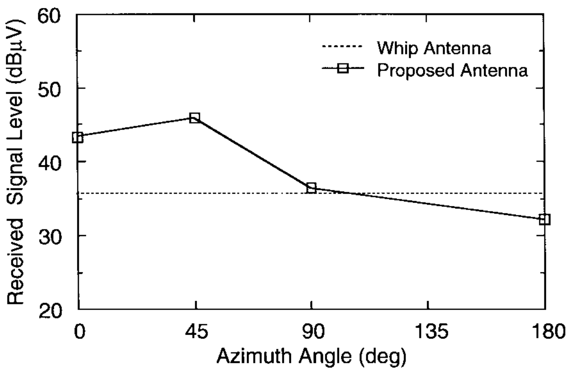


Fig. 8. Variation of received signal level with azimuth angle.

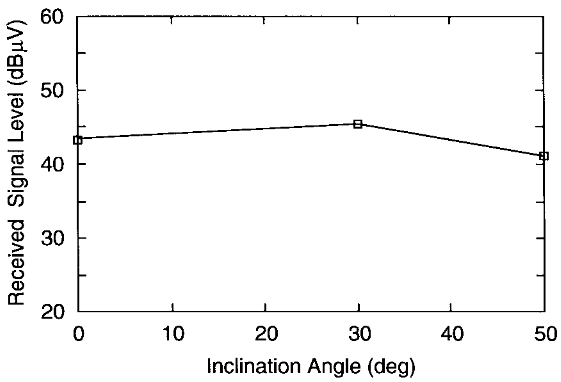


Fig. 9. Variation of received signal level with inclination angle.

Fig. 9 shows the variation in received signal level with respect to the inclination angle of the PHS unit when the patch is pointing at the 0° in azimuth. It is confirmed that the novel antenna has no significant degradation in received signal level over the inclination angle of 50° in actual propagation environments. The degradation of the received signal level at the inclination angle of 90° is lower than that of the conventional patch antennas or whip antennas because there is no degradation of gain until the inclination angle of 50°.

## VII. Conclusion

A new electromagnetically coupled microstrip antenna with freely rotating patch was proposed to avoid the four problems of the conventional whip antennas for the PHS unit: the effective gain degradation with unit inclination in land-mobile propagation environments, the degradation experienced in effective antenna gain due to operator proximity, the RF exposure of the users, antenna breakdown, and poor handling. The structure of the newly developed antenna installed in actual units used for the PHS was described. The fundamental characteristics such as the radiation pattern, bandwidth, and gain were shown. The performance of the novel antenna in actual propagation environments was also clarified. The new antenna is superior to the conventional whip antenna and achieves high enough performance to support PHS commercial services.

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