A SPACE DIVERSITY BIDIRECTIONAL ANTENNA USING PROBE EXCITED RECTANGULAR RING

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1. Introduction

The investigations of the mobile antenna at the base station are of interest lately. Generally, the omnidirectional antenna is employed to cover the approximated circle area. To increase the zone size for applying to the long and narrow path service area such as the highway, the tunnel, and the corridor; the bidirectional antenna is installed in place of the omnidirectional ones. The conventional bidirectional antennas are made up by combining two unidirectional antennas such as Yagi pointed in opposite directions or the omnidirectional antenna such as monopoles excited by appropriate phase [2]. The antenna constructed by this technique suffers from feeder loss and complicated structure that results in expensiveness. Thus, researches and developments on bidirectional antenna have been continuously conducted. The bidirectional narrow patch antenna (BNPA), which has narrow patches on both sides of a narrow dielectric substrate fed by a parallel stripline is easily fabricated by printing patches and feeding network on a substrate. However, BNPA has low radiation efficiency. The radiation efficiency can be improved by adding two opposing parasitic patches to a BNPA to form the so-called BNPA-P [3]. It was found that gain is higher than a collinear antenna of the same length. For a wide street about the width ranging from *30* to *60* meters, a BNPA element is developed to be a bidirectional rod antenna (BIRA) that possesses an optimum beam shape [4]. Furthermore, a bidirectional antenna using two notch antennas cut in a sheet of conductor above a ground plane was proposed to extend the coverage of a relay station in booster system inside tunnel [5]. To suppress the cross polarization in the H-plane of this notch antenna, the crank shaped antenna modified from the original notch antenna was proposed [6]. It was found that the radiation patterns of these antennas are tilted up from the mounting wall and they should be tilted downward in order to cover the service area. This was accomplished by using the crank shaped antenna with the parasitic elements for gain enhancement [7]. From these aforementioned literatures, it is evident that development of a bidirectional antenna that has suitable characteristics for a particular application is desired. Moreover, cost effective must be considered since the number of cell is very large. Therefore, a bidirectional antenna using a linear probe excited a rectangular ring [8] was proposed. It was pointed out that a moderate gain bidirectional antenna could be easily realized with a very cost effective. Furthermore, to applying this antenna in the multipath-fading environment, the diversity bidirectional antenna using a linear probe excited a rectangular ring is necessary. This paper presents the diversity bidirectional antenna using probe excited rectangular ring. First to design the bidirectional antenna, a choice of the ring width and height that yields the propagation in dominant mode is chosen. The ring length that provides the maximum directivity is determined. This optimum ring width, height and length is used as the antenna design parameters. Then, the diversity performance such as correlation coefficient, mean effective gain and diversity gain of two-branch antenna are investigated.

2. A Space Diversity Bidirectional Antenna using Probe Excited Rectangular Ring

The structure of a bidirectional antenna using probe excited rectangular ring consists of a linear electric probe of length l aligned along the z axis, and this probe is surrounded by a rectangular ring of the width a and height b. At the two ends of the ring, there are rectangular apertures on the planes $x = -c/2$ and $z = c/2$, respectively, as shown in Fig.1. The diversity bidirectional antenna using a linear probe excited a rectangular ring is composed of two branches of bidirectional antenna using a linear probe excited a rectangular ring as illustrated in Fig.2. It is noted that the distance between each antenna is d. This parameter is significant to investigate the diversity characteristics of the antenna.

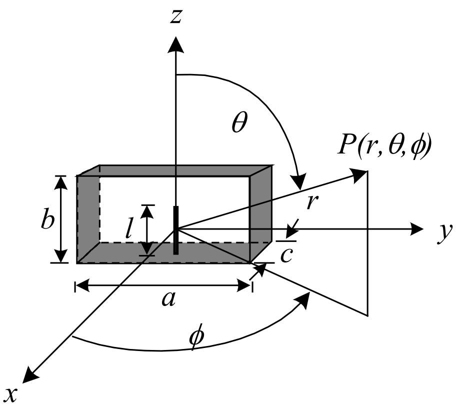


Fig.1 Antenna structure

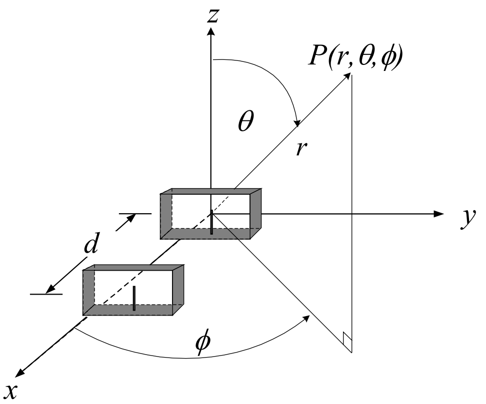
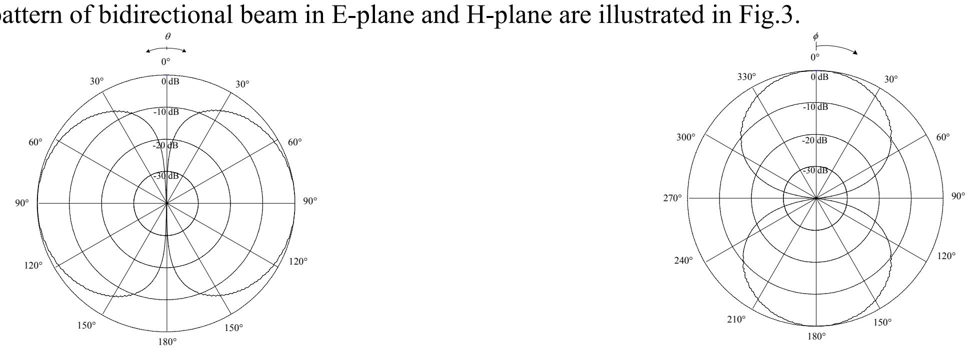


Fig.2 Diversity antenna

3. Radiation Characteristics

From the investigation [8], it is found that the optimum ring width, height and length are *0.69λ*, *0.35λ* and *0.25λ* for the operating frequency of *1.9065* GHz. These parameters are used as the design parameters for a single element of a bidirectional antenna using probe excited rectangular ring. It is evident that the directivity of an element is *6.33* dBi with the half power beamwidth in E-plane and H-plane of *84.54* and *57.70* degrees, respectively. There is no side lobe in case of using single element of probe excited rectangular ring. The radiation pattern of bidirectional beam in E-plane and H-plane are illustrated in Fig.3.



(a) E-plane (b) H-plane

Fig.3 Radiation pattern

4. Diversity Performance

4.1 Theoretical Expression of Diversity Characteristics

The expression for calculation of diversity characteristics such as correlation coefficient, mean effective gain, diversity gain and diversity antenna gain are shown in this section.

4.1.1 Correlation Coefficient

The correlation coefficient of two-branch diversity antenna can be expressed as [9]

$$\rho_e = \frac{|R_{12}|^2}{R_{11}R_{22}}, \tag{1}$$

where R_{ij} (i,j = 1,2) is the covariance of the two received voltages induced from the complex electric field patterns ($E_{\theta i}$, $E_{\phi i}$) and ($E_{\theta j}$, $E_{\phi j}$) defined by

$$R_{ij} = 2KP_H \int_0^{2\pi}\int_0^{\pi} [XPR \cdot E_{\theta i}(\theta,\phi)E^*_{\theta j}(\theta,\phi)P_\theta(\theta,\phi) + E_{\phi i}(\theta,\phi)E^*_{\phi j}(\theta,\phi)P_\phi(\theta,\phi)]\sin\theta d\theta d\phi, \tag{2}$$

where the subscripts i and j are the first and second branch of the diversity antenna, respectively. K is proportionality constant and $E^*(\theta,\phi)$ denotes the complex conjugate of $E(\theta,\phi)$. The best result, zero correlation, is achieved when the complex electric field patterns of the two branches are orthogonal and non-overlapped to each other.

4.1.2 Mean Effective Gain

In multipath environment, the radiation pattern of the antenna is insufficient to represent the performance of the antenna. Therefore, the more appropriate parameter, mean effective gain (MEG) which is composed of radiation pattern, propagation model and cross-polarization power ratio (XPR) is suggested. The antenna that has high value of MEG means its radiation pattern can efficiently cover the specific service area. The mean effective gain can be written by

$$G_e = \int_0^{2\pi}\int_0^{\pi}[\frac{XPR}{1+XPR}G_\theta(\theta,\phi)P_\theta(\theta,\phi)+\frac{1}{1+XPR}G_\phi(\theta,\phi)P_\phi(\theta,\phi)]\sin\theta d\theta d\phi \cdot \quad (3)$$

4.1.3 Diversity Gain and Diversity Antenna Gain

The diversity gain G_{div} is defined as the difference of the average carrier-to-noise power ratio (CNR) at a certain value of bit error rate (BER) (usually at 10^{-3}), between the BER curve of the CNR envelope of the diversity combine output, and that of the single reference antenna output under the Rayleigh fading environment. The diversity gain with respect to BER is defined by the following [10]

$$G_{div} = \frac{\Gamma_{non}}{\Gamma_{div}}, \quad (5)$$

where Γ_{non} is the average carrier-to-noise power ratio (CNR) at the prescribed BER when the signals are received by the single branch non-diversity antenna which has the greater CNR of the two branches . Γ_{div} is the average CNR is case of diversity reception. The average BER of the diversity antenna due to time varying attenuation can be obtained.

$$\overline{P}_e = \int_0^{\infty} p_e(\gamma)p(\gamma)d\gamma, \quad (6)$$

where $p_e(\gamma)$ is the conditional BER when the instantaneous CNR at the detector input is γ in the Rayleigh fading channel. $p(\gamma)$ is the PDF of the instantaneous CNR after combining. From (6), the average BER can be calculated in the followings. $p(\gamma)$ of the receiving signals for the two-branch selective combining diversity under unequal median value and correlated signal condition is given as follows [11]

$$p(\gamma) = \frac{d}{d\gamma}p_r(\gamma), \quad (7)$$

where

$$p_r(\gamma) = 1 - e^{(-\frac{\gamma}{\Gamma})}Q\left(\sqrt{\frac{2\gamma}{r\Gamma(1-\rho_e)}}, \sqrt{\frac{2\rho_e\gamma}{\Gamma(1-\rho_e)}}\right) - e^{(-\frac{\gamma}{\Gamma})}\left(1 - Q\left(\sqrt{\frac{2\rho_e\gamma}{r\Gamma(1-\rho_e)}}, \sqrt{\frac{2\gamma}{\Gamma(1-\rho_e)}}\right)\right), \quad (8)$$

where Γ is the average CNR of the first branch, ρ_e is the correlation coefficient of the signal envelopes. r is the median value ratio defined by

$$r = \begin{cases} r_m; r_m \le 1 \\ \frac{1}{r_m}; r_m > 1 \end{cases} \quad (9)$$

and

$$r_m = \frac{G_{e1}}{G_{e2}} \quad (10)$$

where G_{e1} and G_{e2} are the mean effective gain of diversity branch 1 and 2, respectively.
Q is the Marcum's function defined by

$$Q(\alpha,\beta) = 1 - \int_0^{\beta} tI_0(\alpha t)e^{\left(-\frac{\alpha^2+t^2}{2}\right)}dt, \quad (11)$$

where I_0 is the modified Bessel function of the first kind of zeroth order.

$p_e(\gamma)$ of the π/4 shifted Quadrature Phase Shift Keying (π/4 QPSK) signals, the modulation technique employed in the Personal Communication Telephone system, with delay detection in Additive White Gaussian Noise (AWGN) channel is calculated by the following equation

$$p_e(\gamma) = \frac{1}{4\pi\sqrt{2}}\int_0^{2\pi}\frac{e^{\left[-\gamma\left(1-\frac{\cos t}{\sqrt{2}}\right)\right]}}{1-\frac{\cos t}{\sqrt{2}}}dt \quad (12)$$

By substituting (7)-(12) into (6), the average BER can be calculated.
The most effective parameter to assess the performance of the diversity antenna id the diversity antenna gain because it includes the correlation coefficient and the mean effective gain characteristics. It is defined as a product of the mean effective gain and the diversity gain of the diversity antenna.

$$DAG = \begin{cases} G_{e2} \cdot G_{div}; r_m \le 1 \\ G_{e1} \cdot G_{div}; r_m > 1 \end{cases} \quad (13)$$

4.2 Results of the Analysis

The correlation coefficient of two-branch diversity antenna as a function of the distance between each branch is illustrated in Fig.4. It is obvious that the optimum correlation coefficient is obtained for some particular spacing such as 0.9λ, 1.4λ and 1.9λ. These spacing can be used as the guideline for the design of the diversity antenna. The mean effective gain of the antenna for various ring lengths is also calculated as shown in Fig.5. It is apparent that when the ring length is larger, the mean effective gain is lower. The maximum mean effective gain is realized when the ring length is 0.25λ.

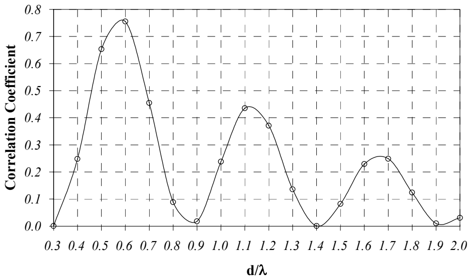


Fig.4 Correlation Coefficient

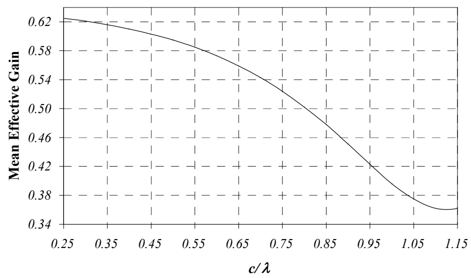


Fig.5 Mean Effective Gain

To clarify about the diversity performance of the antenna, the diversity gain and diversity antenna gain is also determined from Fig.6. It is found that the diversity gain is *8.5* dB. The corresponding diversity antenna gain is *6.5* dBi.

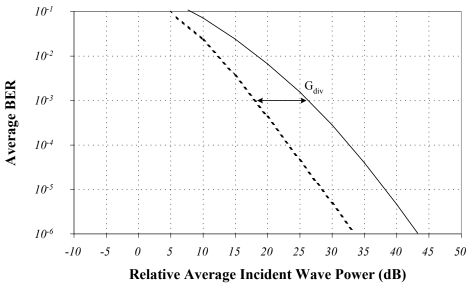


Fig.6 Diversity Gain

5. Conclusions

The diversity bidirectional antenna using probe excited rectangular ring is proposed in this paper. The radiation characteristics of a bidirectional antenna using probe excited rectangular ring is reported. Then the diversity performances are investigated. It is found that the simple and cost effective antenna to perform diversity bidirectional antenna is obtained. This antenna is very useful in multipath environment.

Acknowledgements

The authors would like to express the sincerely thank to Prof. T.Wakabayashi, Dr.K.Meksamoot and Miss P.Keowsawat for their valuable discussions.

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