A Study on Received Signal Spectrum of Antenna with Periodically Variable Directivity

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Abstract—In this study, we obtain periodically time-variable antenna pattern of the antenna based on the equivalent weight vector method with approximated continuous reactance. According to the antenna pattern we analyze the received signal spectra which are frequency-shifted by the time-variable antenna pattern. We compare the spectra to those obtained by the experiments and verify the antenna pattern analysis.

Index Terms—ESPAR antenna, time-variable antenna pattern, antenna pattern diversity, path diversity.

I. INTRODUCTION

In wireless communication systems, fading has been a significant problem since it degrades the quality of received signals. One of promising techniques against fading at receivers is diversity reception. In the diversity reception, diversity gain can be obtained by appropriately combining multiple signals or diversity branches which experience statistically independent fading.

We have proposed diversity scheme using antenna whose directivity or antenna pattern can periodically change by time-variation [1]. The antenna consists of an active and several parasitic elements for time-variable antenna patterns by applying combinations of dc and sinusoidal voltages to VR (Variable Reactance) elements which terminate the parasitic elements. The received signals can be divided into signals without and with frequency-shift by time-variable antenna pattern.

To evaluate the fundamental characteristics of the antenna, we have designed and fabricated the antenna. According to the discrete simulation and measurement of the antenna pattern by applying different dc voltage to VR elements, we have confirmed that the antenna can provide different amplitude and phase effects on different direction [1]. In addition, we have observed non-linear distortion in the discrete time-variation of antenna pattern [2].

In this study, we derive continuous time-variation of antenna pattern based on the analysis using an electromagnetic simulator for 2-element antenna, and also compare the spectrum of the antenna pattern.

II. ANALYSIS OF TIME-VARIABLE ANTENNA PATTERN

In this section, we obtain a time-variable antenna pattern of a 2-element dipole antenna based on the directivity analysis called equivalent weight vector method for ESPAR antenna with static applied voltages [3].

The admittance matrix Y of 2-port network is given by

$$Y = \begin{bmatrix} y_{00} & y_{01} \\ y_{10} & y_{11} \end{bmatrix} \tag{1}$$

where y_{00} and y_{11} are self admittance of active and parasitic elements, respectively, y_{01} and y_{10} are mutual admittance between active and parasitic elements. Here, we assume $y_{00} = y_{11}$ and $y_{01} = y_{10}$ due to the symmetric structure of the antenna and reciprocity theorem [3]. The periodically time-variable equivalent weight vectors $w_0(t)$ and $w_1(t)$ are given by

$$\begin{bmatrix} w_0(t) \\ w_1(t) \end{bmatrix} = A^{-1} \begin{bmatrix} v_s \\ 0 \end{bmatrix} \tag{2}$$

where v_s is inner voltage and

$$A = Y^{-1} + \begin{bmatrix} z_s & 0 \\ 0 & jx(t) \end{bmatrix} \tag{3}$$

where z_s is output impedance and $x(t)$ is the reactance of the parasitic element which varies with time. After mathematical manipulation of (2), we have

$$\begin{bmatrix} w_0(t) \\ w_1(t) \end{bmatrix} = \frac{v_s}{|A|} \begin{bmatrix} z_{00} + jx(t) \\ -z_{10} \end{bmatrix} \tag{4}$$

where z_s is output impedance, z_{00} and z_{10} are components of Y^{-1}, and $|A|$ is determinant of matrix A. In this study, we approximate reactance $x(t)$ to a dc biased sine function which is given as

$$x(t) = x_d + x_a \sin \omega_s t \tag{5}$$

where x_d is dc component, x_a is amplitude of the sinusoidal component, ω_s is the angular frequency of applied sinusoidal voltage to VR element. The corresponding frequency f_s relates to ω_s as $\omega_s = 2\pi f_s$. The values x_d and x_a are obtained by the least square method from calculated reactance based on the specification of VR elements. The array factor $D(\phi, t)$ for azimuth angle ϕ and at time t is given by inner product of the equivalent weight vector and steering vector as

$$D(\phi, t) = \begin{bmatrix} 1 & \exp\left(j\frac{2\pi d}{\lambda}\cos\phi\right) \end{bmatrix} \begin{bmatrix} w_0(t) \\ w_1(t) \end{bmatrix} \tag{6}$$

$$= \frac{v_s}{|A|} \left\{ z_{00} - z_{10} \exp\left(j\frac{2\pi d}{\lambda}\cos\phi\right) + jx(t) \right\} \tag{7}$$

where d is the distance between active and parasitic elements.

TABLE I
PARAMETERS FOR ANTENNA PATTERN ANALYSIS.

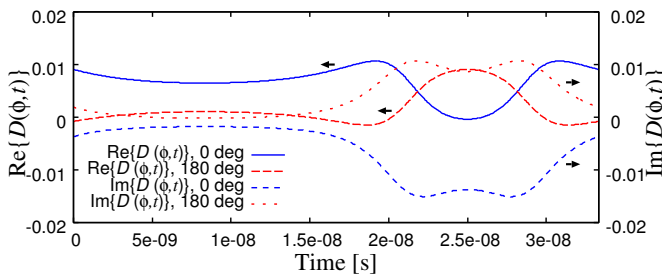| Parameters	Values
Target frequency f_c	500 MHz
Radius of antenna elements r $(= \lambda/300)$	0.0020 m
Length of antenna elements l $(= \lambda/2)$	0.3000 m
Distance between elements $d = \lambda/8$	0.0750 m
Self admittance y_{00}, y_{11}	1.7023e-03 - j1.5881e-02 S
Mutual admittance y_{01}, y_{10}	4.6387e-04 - j1.5109e-02 S
Output impedance z_s	50 + j 0 Ω
Inner Voltage v_s	1.0 + j 0 V
Capacitance of VR (1SV287 [4]) C	1.2, 1.4, 1.8, 2.3, 3.7, 5.6, 6.7 pF
Reactance $x_c = -1/2\pi f_c C$	-265, -227, -176, -138, -86, -56, -47 Ω
Frequency of applied sinusoidal voltage f_s	30 MHz
FFT points	512

Fig. 2.   Real and imaginary parts of antenna pattern $D(\phi, t)$ when we use adjusted values of $x_d = -58$ and $x_a = 22$.

Fig. 1.   Real and imaginary parts of antenna pattern $D(\phi, t)$ when $x_d = -142$ and $x_a = 102$.

Fig. 3.   Spectum of antenna patterns and relative received power obtained through experiments.

III. NUMERICAL RESULTS

The parameters used for antenna pattern analysis are listed in Table I. The real and imaginary parts of $D(\phi, t)$ for $\phi = 0°, 180°$ during a period $T_s = 1/f_s$ when $x_d = -142$ and $x_a = 102$ are shown in Fig. 1. We have confirmed that amplitude and phase of the antenna pattern can change for time. However, the real and imaginary parts of $D(\phi, t)$ do not vary in sinusoidal manner. Thus, it can expected that the antenna pattern includes harmonic components of f_s which would decrease signal power for diversity. The distortion could be caused by the non-linearity of the VR element and operation to obtain equivalent weight vectors. To reduce the non-linearity, we set the reactance $x_d = -58$ and $x_a = 22$. Then the obtained antenna patterns are shown in Fig. 2. The waveforms have become close to sinusoidal shapes.

The power spectra of the antenna pattern shown in Figs. 1 and 2 are shown in Fig. 3. The values are normalized by those of dc component when $x_d = -142$ and $x_a = 102$. The received power obtained by experiments using the antenna whose parameters are the same as our previous work [1] are also plotted in Fig. 3. The values are normalized by those at dc. Note that the length of parasitic element of the antenna used in the experiment is longer than that of active element. We find that there are harmonic components in the spectra as we expected. The tendency of the relative power between at dc and at f_s is well approximated by the derived time-variable antenna pattern. It can be observed that the non-linear components at $2f_s$ and $3f_s$ are greatly suppressed by the adjusted reactance.
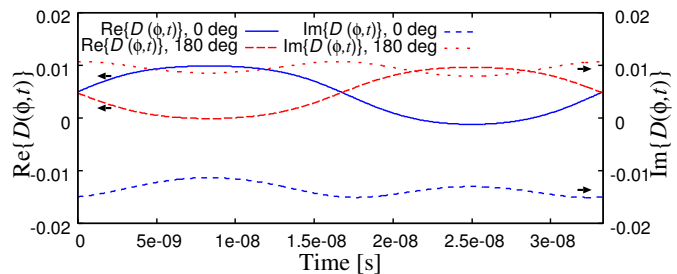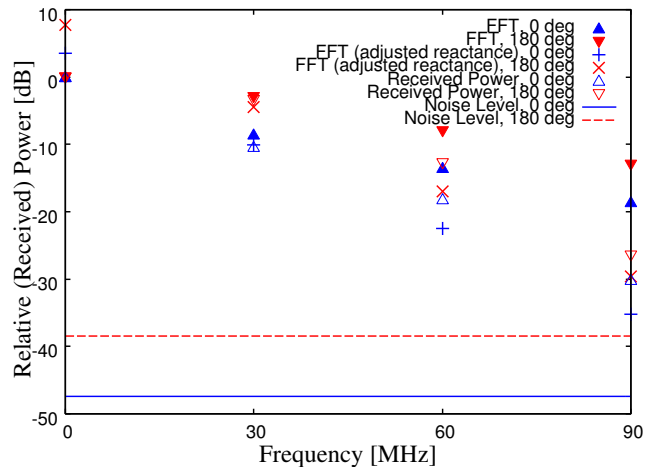
IV. CONCLUSION

In this paper, we derive continuously periodically time-variable antenna pattern consisting of an active and a parasitic elements. Also we perform spectral analysis of the antenna pattern and compare the spectra with experimental results. We find that for different directions the antenna can provide different waveforms of antenna pattern. Through the comparison between power spectrum of the antenna patterns and experimental results of received power, we confirm that the derived antenna patterns can provide well approximated power at dc and f_s.

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