Envelop Detection of a Spinning Linear Radiation Pattern Based on Diode Detector Algorithm for Amplitude Modulation

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Abstract: A spinning linear pattern is often used to measure the axial ratio of circularly polarized antennas. The maximum and minimum envelopes of the spinning linear pattern indicate the semi-major and semi-minor axes, respectively, of an elliptically polarized wave. However, there is large volume of sampled data between the maximum and minimum envelopes, which is not useful. Therefore, an envelope extraction method for a spinning linear pattern using a diode detector algorithm was proposed in this study. The diode detector algorithm was applied by solving the circuit equation using the calculus of finite differences. Through numerical verification, envelopes could be successfully extracted. An averaging method was applied to obtain smoother envelopes.

Keywords: Circularly polarized wave, spin-linear, pattern, envelope detection, amplitude modulation, diode detector

Classification: Antennas and propagation

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1 Introduction

A spinning linear pattern [1][2] is often used to measure the axial ratio (AR) of circularly polarized (CP) antennas. The maximum and minimum envelopes of the spinning linear pattern indicate the semi-major and semi-minor axes, respectively, of an elliptically polarized wave. However, there is a large volume of sampled data between the maximum and minimum envelopes, which is not useful.

The objective of this study is to extract the maximum and minimum envelopes from the measured spinning linear pattern. There are several methods to achieve this. One method to extract the maximum envelope is to take the local maximum from the data [2]. However, this method fails when the local maximum does not capture the real envelope. Another method is to apply low-pass filtering for a rippled curve [3]. However, this method does not work because it cannot distinguish between the maximum and minimum envelopes. Therefore, the diode detector algorithm for amplitude modulation (AM) [3][4] is adopted for the detection of envelopes in this study. The data of a spinning linear pattern are regarded as input voltage values of a diode detector circuit for AM. The circuit equation for the diode detector is solved numerically using the calculus of finite differences. The proposed algorithm was verified using sample data.

Section 2 presents an overview of the spinning linear pattern measurement, and Section 3 describes the proposed algorithm for envelope extraction using a diode detector. The verification of the proposed algorithm using the sample is covered in Section 4.

2 Spinning linear pattern measurement

Figure 1 (a) shows the typical measurement setup of a spinning linear pattern. An elliptically polarized wave radiated by the transmitter (Tx) antenna is received by the receiver (Rx) antenna. The Tx antenna is rotated about the vertical axis to change the angle of interest, while the Rx antenna is rotated about the axis that includes the Tx and Rx antennas to capture the semi-major and semi-minor axes of the elliptically polarized wave radiated by the Tx antenna. Figure 1 (b) shows an example of the spinning linear pattern of a waveguide crossed-slot antenna [5][6][7]. The maximum (E_{max}) and minimum (E_{min}) envelopes indicate the semi-major and semi-minor axes, respectively, of an elliptically polarized wave. The difference E_{max}-E_{min} (dB) indicates the axial ratio (AR) of the elliptically polarized wave. The ripples in envelopes are due to interference between direct and diffracted waves.
3 Diode detector algorithm for envelope extraction

To extract the maximum and minimum envelopes, a diode detector circuit [3] for AM, as shown in Fig. 2, is used. Capacitor $C$ and resistor $R$ are connected in parallel after the diode. When $v_{in} < v_{out}$, the diode is OFF, and the capacitor discharges the stored charge, resulting in current flow from the capacitor to the resistor. When $v_{in} \geq v_{out}$, the diode is ON, and $v_{out}(t) = v_{in}(t)$. Therefore, the following equations are obtained.

\[
\begin{align*}
\frac{1}{C} \int_{t=0}^{t} i(t)dt &= -Ri(t) \quad (v_{in} < v_{out}) \\
v_{out}(t) &= v_{in}(t) \quad (v_{in} \geq v_{out})
\end{align*}
\]

By considering $v_{out}(t) = Ri(t)$, Eq. (1) becomes
\[
\begin{aligned}
\frac{1}{CR} v_{\text{out}}(t) &= -\frac{d}{dt} v_{\text{out}}(t) \quad (v_{\text{in}} < v_{\text{out}}) \\
v_{\text{out}}(t) &= v_{\text{in}}(t) \quad (v_{\text{in}} \geq v_{\text{out}}).
\end{aligned}
\]  

(2)

By applying the calculus of finite differences, we get
\[
\frac{d}{dt} v_{\text{out}}(t) = \frac{v_{\text{out}}(t) - v_{\text{out}}(t-\Delta t)}{\Delta t}.
\]  

(3)

The upper equation in Eq. (2) becomes
\[
\frac{1}{CR} v_{\text{out}}(t - \Delta t/2) = -\frac{v_{\text{out}}(t) - v_{\text{out}}(t-\Delta t)}{\Delta t}.
\]  

(4)

By approximating \( v_{\text{out}}(t - \Delta t/2) \) in the left-hand side of Eq. (4) as
\[
v_{\text{out}}(t - \Delta t/2) = \frac{v_{\text{out}}(t) + v_{\text{out}}(t-\Delta t)}{2},
\]  

(5)

Eq. (2) can be reduced as
\[
v_{\text{out}}(t) = \begin{cases} 
2 - \frac{\Delta t}{2R} v_{\text{out}}(t - \Delta t) & (v_{\text{in}} < v_{\text{out}}) \\
2 + \frac{\Delta t}{2R} v_{\text{in}}(t) & (v_{\text{in}} \geq v_{\text{out}})
\end{cases}.
\]  

(6)

Eq. (6) can be used to calculate the envelope of the spinning linear pattern by considering \( v_{\text{in}}(t) \) as the measured data ( \( t \to \theta, v_{\text{in}} \to \) spinning linear pattern, \( v_{\text{out}} \to \) envelope).

Fig. 2. Diode detector circuit for amplitude modulation and waveform.

4 Numerical verification

The envelope extraction algorithm explained in Section 3 was applied to the measured spinning linear pattern shown in Fig. 1 (b), and the line with “Cal. (diode detector algorithm)” in Fig. 3 shows the extracted maximum and minimum envelopes. To extract the maximum envelope, all the measured values of the spinning linear pattern are added by an appropriate positive value \( A \) so that the envelope becomes positive, because the diode detector circuit is valid only when \( v_{\text{in}} \geq 0 \). After detecting the envelope, the detected envelope is subtracted by \( A \) again for correction.

To extract the minimum envelope, all the values are subtracted by a positive value \( B \) so that the minimum envelope becomes negative. Then, the sign of the data is flipped to change the problem for maximum envelope detection, and the
maximum envelope detection scheme is performed in the same manner. The sign of the envelope obtained is flipped again, and the addition of $B$ gives the desired minimum envelope.

The decay time constant $CR$ should satisfy the condition $1/f_c < CR < 1/f_0$ to track envelopes, where $f_c$ and $f_0$ are frequencies of rapid spinning pattern and ripple due to interferences which correspond to the carrier and signal frequency in AM. By following to the condition, $CR = 20$ is chosen in this study.

The envelopes extracted using the diode detector algorithm still have small ripples. To eliminate the ripples, sliding average for neighboring three data points with multiple (20 times in this study) processing was performed for the result obtained by diode detector algorithm. The averaged envelopes are shifted to hold the previous maximum and minimum values. The averaged results are indicated as “diode detector algorithm w/ averaging” in Fig. 3. Fig. 3 (a) shows the simulated result for given amplitude modulated signal to show the effectiveness of the proposed algorithm. The results of the diode detector algorithm with averaging are smoother than the results without averaging, and the nearest to the envelope $y_1(\theta)$. This shows effectiveness of the proposed method. The proposed envelope detection method was also applied to the measured data in Fig. 1 (b). The extracted smooth envelopes were shown in Fig. 3 (b). Although the algorithm described in Section 3 is for linear magnitude, the algorithm can be also applied to dB magnitude because the objective is just data processing. The effectiveness of the proposed method for the measured data is also confirmed.

\[
\begin{align*}
  y_0(\theta) &= \cos(2\pi f_c \theta) (1 + m \cos(2\pi f_0 \theta)) - (1 + m) \\
  y_1(\theta) &= m(\cos(2\pi f_0 \theta) - 1)
\end{align*}
\]

(a) Simulation with given signal.

(Parameters close to the measured data is used. $f_0 = 0.05, f_c = 3, m = 0.5$)
5 Conclusion

An envelope extraction method for a spinning linear pattern using a diode detector algorithm was proposed. The diode detector algorithm was applied by solving the circuit equation with the calculus of finite differences. Through numerical verification, envelopes could be successfully extracted. The averaging method was applied to obtain smoother envelopes. The proposed method will be useful in the post processing of a spinning linear pattern to reduce the data size and obtain axial ratios.

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