Direction Finding by Time-Modulated Circular Array with Amplitude Comparison

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***Abstract* – In this paper, a novel direction finding method using the power spectrum characteristics in parallel with the amplitude comparison is proposed in time-modulated circular array (TMCA). The direction of arrival (DoA) of the incident signal in azimuthal angular range of 360° is estimated by the TMCA with high accuracy. In addition, angular ambiguity is reduced through the amplitude comparison without additional hardware. As a result of the direction finding performance by proposed method is provided with a four-element TMCA.**

***Keywords* — Direction finding, time-modulated circular array (TMCA), amplitude comparison.**

I. INTRODUCTION

Direction finding (DF) is widely used in RF systems such as wireless communication and military applications. Generally, in order to estimate the angle of the incident signal in azimuthal angular range of 360°, the amplitude comparison method, the interferometer method, and the spatial spectrum estimation method are used for DF [1-2]. The amplitude comparison method has a simple system, but it has the lower accuracy than the phase based DF methods while these have the complex system. The spatial spectrum estimation method has used for high DF accuracy, however, it is complex because of the computation algorithm [2]. Recently, direction finding methods using time-modulated array (TMA) have been researched because these have high resolution, while these have low hardware complexity [3-4]. The four-element TMA DF method by scanning the null of received patterns is proposed [3]. But it is complex to control the switches of the elements, because the various switching time sequence is necessary to scanning the null.

In this paper, in order to estimate the DoA in the azimuthal angular range of 360°, the time-modulated circular (TMCA) is used with low hardware complexity and high accuracy. But the angular ambiguity is occurred by symmetric received patterns of the TMCA when using only the power spectrum ratio. Therefore, amplitude comparison is implemented in parallel with the spectrum characteristics without additional hardware so as to reduce the angular ambiguity.

II. THEORY

The proposed structure of the four-element TMCA for DF is shown in Fig. 1. Each element with the radius R of the TMCA is connected to single-pole-single-throw (SPST) switches. The modulation function $U_n(t)$ for each n^{th} element

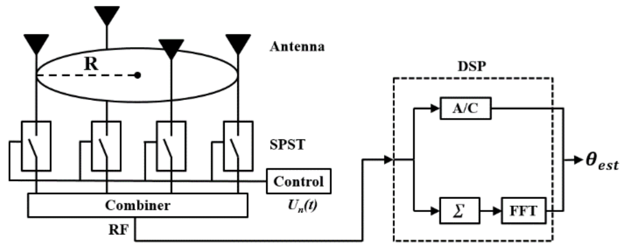

Fig. 1. The proposed structure of the 4-element TMCA

by switches is expressed as

$$U_n(t) = \begin{cases} 1, & (n-1/N)T_P < t \le (n/N)T_P \\ 0, & else \end{cases}, \qquad (1)$$

where N is a number of antennas and T_P is the modulation period. Since $U_n(t)$ is a period function, Eq. (1) can be expressed m^{th} harmonic coefficient by Fourier series as

$$\alpha_{n,m} = \frac{1}{T_p}\int_0^{T_p} U_n(t)e^{-j2\pi F_p t}, \qquad (2)$$

Then the received signal after SPST switches with the modulation expressed as

$$s(\theta, t) = \sum_{m=-\infty}^{\infty} e^{j2\pi(F_0+mF_p)t} \sum_{n=1}^{N} \alpha_{mn} C_n(\theta)\,, \qquad (3)$$

where F_0 is the carrier frequency and $C_n(\theta)$ is the received signal of the n^{th} element. The TMCA consists of the identical elements uniformly spaced along a circle. Therefore, the element amplitude and phase should be considered as it is a function of element position. Since the directional antenna was used for estimate the Sector of Arrival (SoA), the received signal of the n^{th} element corresponding to angle is given as [5]

$$C_n(\theta) = E_n(\theta - (n-1)\tfrac{2\pi}{N})e^{jkRcos\left(\theta-(n-1)\frac{2\pi}{N}\right)}. \qquad (4)$$

where E_n is the function of the elements. The received signal of the four-element TMCA can be expressed by linear matrix equation with the harmonic components [4] as

$$\begin{bmatrix} \alpha_{1,-2} & \cdots & \alpha_{4,-2} \\ \vdots & \ddots & \vdots \\ \alpha_{1,+2} & \cdots & \alpha_{4,+2} \end{bmatrix} \begin{bmatrix} E_1 & \cdots & E_1 \\ \vdots & \ddots & \vdots \\ E_4 & \cdots & E_4 \end{bmatrix} \begin{bmatrix} e^{jkRcos\theta} \\ e^{jkRcos(\theta-\frac{\pi}{2})} \\ e^{jkRcos(\theta-\pi)} \\ e^{jkRcos(\theta-\frac{3\pi}{2})} \end{bmatrix} = \begin{bmatrix} \gamma_{-2} \\ \gamma_{-1} \\ \gamma_0 \\ \gamma_{+1} \\ \gamma_{+2} \end{bmatrix}, \qquad (5)$$

where γ is harmonic components of received signal by fast

Fourier transform (FFT) in digital signal process (DSP). The Eq. (5) can be expressed as

$$\Psi \bar{A} \bar{P} = \bar{\Gamma}. \tag{6}$$

The estimated incident signal angle θ by TMCA is calculated by the inverse matrix of Eq. (6) following as

$$\theta_{TMCA} = \frac{\pi}{4} + \sin^{-1}\left[\frac{\ln\left(\frac{[\bar{A}^{-1}\Psi^{-1}\bar{\Gamma}]_2}{[\bar{A}^{-1}\Psi^{-1}\bar{\Gamma}]_1}\right)}{jkR\sqrt{2}}\right]. \tag{7}$$

III. NUMERICAL SIMULATION RESULTS

The normalized received patterns at the fundamental and the harmonic frequencies are shown in Fig. 2, obtained from a four-element TMCA when R is 0.5 λ with patch antennas. As shown in Fig. 2, the received patterns have symmetry at every 90°. Accordingly, the power spectrums after the FFT of the received signal are identical periodically at every 90°. Thus, the direction ambiguity is occurred by periodicity. However, the amplitudes at each switching time are varied depending on the direction. For example, the amplitude and the power spectrum is shown in Fig. 3 when the directon of arrival is 0° and 90°. Therefore, to reduce the direction ambiguity, amplitude comparison method is implemented to determine the sector. The SoA is defined as the range where the n^{th} element gain is higher than the others. Therefore, sector S_i in the range of 90° is determined by comparison of the matrix component in Eq. (6) following as

$$S_i = \{\bar{A}_i > \bar{A}_j\}.\ (i \neq j, i = j = 1, 2, 3, 4) \tag{8}$$

Finally, the angle θ_{est} of the incident signal is estimated by

$$\theta_{est} = (S_i - 1) \times 90 + \theta_{TMCA} \tag{9}$$

In order to evaluate the performance of the proposed method, the root mean-square-error (RMSE) is provided by simulations with 500 different incident signals. The RMSE of the proposed direction finding method results according to different SNRs is shown in Fig. 4.

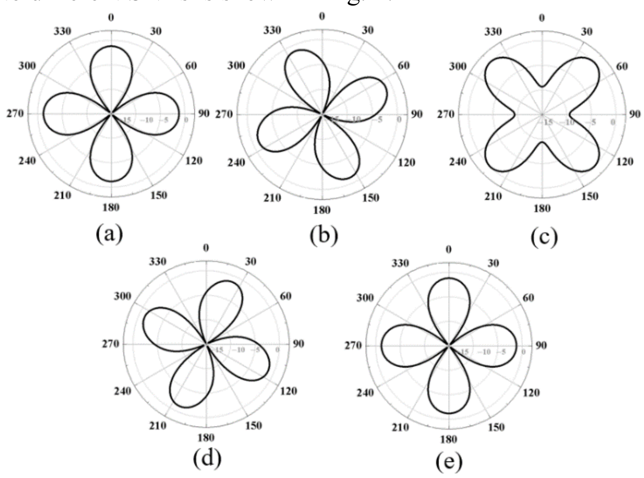

Fig. 2. Normalized received patterns at the fundamental and the m^{th} harmonic frequency of TMCA, (a) $m = -2$, (b) $m = -1$, (c) $m = 0$, (d) $m = +1$, (e) $m = +2$

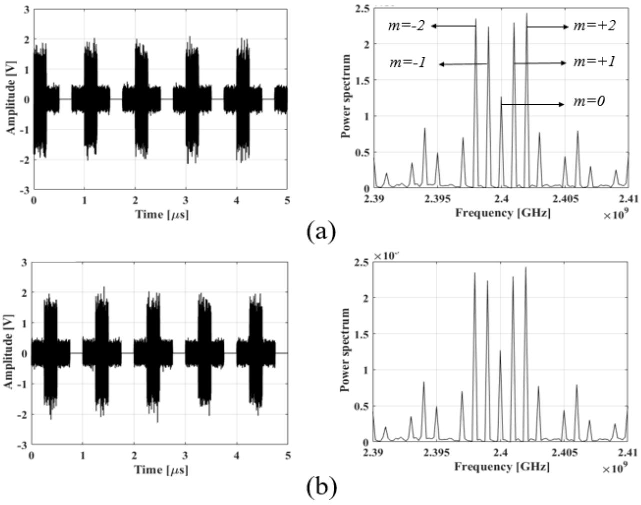

Fig. 3. The amplitudes and the power spectrums of the received signal at different angles (a) 0°, (b) 90° at the F_0 = 2.4 GHz, F_p = 1 MHz

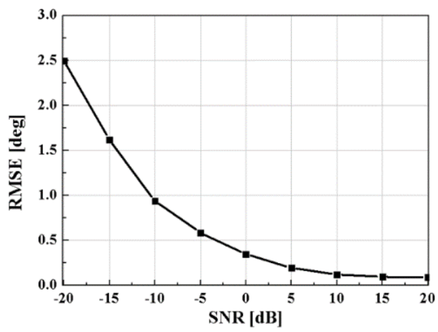

Fig. 4. RMSE of direction estimation according to SNR

IV. CONCLUSION

A novel direction finding method based on TMCA is proposed to estimate the incident signal angle in the direction range of 360°. In addition, proposed method reduced the angular ambiguity without additional hardware. Through the proposed method and structure, the direction finding results indicated that incident signal can be estimated with high resolution.

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