Single-Sideband Time-Modulated Phased Array With 2-bit Phased Shifters

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Abstract- A novel single-sideband (SSB) time-modulated technique with 2-bit phase shifters is proposed. The time-modulated module is implemented by adding periodic phase modulation to 2-bit phase shifters, which is simpler without performance loss compared to existing SSB time-modulated method. During one modulation period, four phase states (0, π/2, π, 3π/2) of 2-bit phase shifters are switched in sequence. After the modulation, the SSB time modulation is realized and the main power is distributed to the first harmonic component. The feasibility of the proposed method is verified by experiments. The undesired harmonics are efficiently suppressed. Meanwhile, ±40° beam scanning range are realized through the proposed module.

I. INTRODUCTION

Conventional phased array system includes plenty of phase shifters and attenuators. For high accuracy and low sidelobe, 6-bit or more digital phase shifters and variable attenuators are usually exploited. The use of large number of phase shifters and attenuators makes the control module complicated, which further increases the cost and complexity of the phased array. Time-modulated arrays have the advantages of low cost and high accuracy of amplitude and phase control. However, their efficiency and flexibility need to be improved [1].

The efficiency of time-modulated array is related to feeding network efficiency and harmonic efficiency, and there have been many related studies. To improve feeding network efficiency, the reconfigurable power divider is applied to time-modulated array [2]. In order to improve harmonic efficiency, 1-bit phase shifters are utilized to suppress the fundamental and even harmonic components in [3]. And in [4], an in-phase/quadrature (I/Q) complex modulation technique was proposed to realize single-sideband time-modulated phase only weighting. In [5], an SSB time-modulated module with multiple branches was proposed to suppress most of the unwanted harmonic components. In addition, the reconfigurable power divider was used in the I/Q modulator [6], which can improve feeding network efficiency and harmonic efficiency simultaneously.

In this conference paper, we propose a novel SSB time-modulated method with 2-bit phase shifters. During one modulation period, four states (0, π/2, π, 3π/2) of the 2-bit phase shifters are switched in sequence to concentrate the main power into the first harmonic, while useless harmonics are suppressed. The proposed method has a simpler structure compared to existing SSB time-modulated methods.

The remainder of this manuscript is organized as follows. Section II provides the mathematical theory of the proposed module. In Section III, a L-band 8-element time-modulated array with the proposed module is fabricated and tested to verify its effectiveness. Finally, some conclusions are drawn in Section IV.

II. MATHEMATICAL FORMULATION

Fig. 1 shows the configuration of the proposed module. The RF switches are modulated periodically with the function

\[
U(t) = \begin{cases} 
1, & t_{n1} + mT_p < t < t_{n1} + \tau + mT_p \\
\text{e}^{j\pi/2} t_{2n} + mT_p < t < t_{2n} + \tau + mT_p \\
-1, & t_{3n} + mT_p < t < t_{3n} + \tau + mT_p \\
\text{e}^{j3\pi/2} t_{4n} + mT_p < t < t_{4n} + \tau + mT_p 
\end{cases}
\]

(1)

where \(T_p\) is the modulation period (\(f_b=1/T_p\)), \(t_{n1}, t_{2n}, t_{3n}, t_{4n}\) are the switch-ON time instants, \(\tau\) is the duration of switch-ON time (\(\tau \leq 0.25T_p\)).

\(U(t)\) can be decomposed by the Fourier series in frequency domain as

\[
U(t) = \sum_{h=-\infty}^{\infty} A_{hn} e^{j2\pi hf_p t}.
\]

(2)

Assume that

\[
t_{3n} - t_{n1} = t_{4n} - t_{2n} = 0.5T_p,
\]

(3)

\[
t_{n1} = t_{2n} + 1/4T_p.
\]

(4)
**REFERENCES**

1. G. Ni, C. He, J. Chen, Y. Liu and R. Jin, "Low Sideband Radiation Beam Scanning at Carrier Frequency for Time-Modulated Array by Non-Uniform Period Modulation," IEEE Trans. Antennas Propag., vol. 68, no. 5, pp. 3695-3704, May 2020.
2. J. Chen, C. He, X. Liang et al., "Efficiency Improvement of Time Modulated Array With Reconfigurable Power Divider/Combiner," IEEE Trans. Antennas Propag., vol. 65, no. 8, pp. 4027-4037, Aug. 2017.
3. S. Farzaneh and A. Sebak, "A novel amplitude-phase weighting for analog microwave beamforming," IEEE Trans. Antennas Propag., vol. 54, no. 7, pp. 1997-2008, July 2006.
4. A. Yao, W. Wu and D. Fang, "Single-Sideband Time-Modulated Phased Array," IEEE Trans. Antennas Propag., vol. 63, no. 5, pp. 1957-1968, May 2015.
5. H. Li, Y. Chen and S. Yang, "Harmonic Beamforming in Antenna Array With Time-Modulated Amplitude-Phase Weighting Technique," IEEE Trans. Antennas Propag., vol. 67, no. 10, pp. 6461-6472, Oct. 2019.
6. Q. Chen, J. Zhang, W. Wu and D. Fang, "Enhanced Single-Sideband Time-Modulated Phased Array With Lower Sideband Level and Loss," IEEE Trans. Antennas Propag., vol. 68, no. 1, pp. 275-286, Jan. 2020.