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DESIGN OF A BROADBAND FREQUENCY OFFSET VAN ATTA ARRAY

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Abstract—A novel broadband Van Atta array operating in a broadband with frequency offset characteristic is proposed. A single sideband mixer is introduced to achieve sideband choice without utilizing filters which make this array have excellent performance and wider applications than the conventional Van Atta array. The simulated results of the amplitude and phase of the array show that this antenna array can achieve retrodirectivity with frequency offset and good isolation in a broadband. The experimental performance of the array is observed within the frequency range from 2.8 GHz to 3.4 GHz.

1. INTRODUCTION

Retrodirective array is widely used in military and commercial applications in recent years [1, 2]. It can retransmit a wave to the same direction as it is arriving without the prior knowledge of the incoming signals. The characteristics of high link gain and low cost make the retrodirective array useful in many fields, including automatic pointing and tracking [3], phase conjugate resonators [4] etc.

The Van Atta array is one of the major approaches to achieve retrodirectivity which is proposed by Van Atta in 1959. The received signal is retransmitted by the corresponding antenna pair connected with equal length. This array requires plane frontwave and array distribution. Several new techniques have been introduced to Van Atta array in recent years, which lead to higher performances [5, 6]. The frequency offset can achieve good isolation and compensate for

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the beam pointing error introduced by antenna element directivity [7]. The usual frequency offset retrodirective array often operates in a single point or narrow band. Broadband Van Atta array shown in [8] and [9] has retrodirectivity without the frequency offset characteristic.

This paper proposes a broadband frequency offset Van Atta array which consists of dual-polarized aperture-coupled antenna array [10–13] and single sideband mixers [14–16]. This structure has special characteristic of automatic sideband choice without filters which can achieve frequency offset with a broadband operation. To certify the validity of the technique, the proposed array is fabricated and measured. Both the simulated and measured results show good performance, and this array is suitable for simple transponder for applications of RFID and communication.

2. PROPOSED SYSTEM

2.1. Array Design

Received signal of Van Atta array is reradiated by the antenna pairs in which each pair is connected by the transmission lines with equal length. Since the Van Atta array does not need the local oscillator and phase conjugation mixer, it has wider bandwidth which is simply limited by the bandwidth of the antenna array.

In [7], a little frequency offset which is achieved by mixer is introduced in the Van Atta array. This array has better isolation and wider application than the conventional Van Atta array. In the case that the retransmitting frequency is lower than the receiving frequency, the beam pointing error caused by the polar pattern directivity of the array element can be implemented to a certain extent. The offset frequency should be very small to ensure good beam-pointing performance, thus the upper and lower sidebands of the mixer are within the operating band, and the filter cannot work in the broadband applications. Therefore, this type of antenna often works in narrow band or a point frequency.

Figure 1 shows the diagram of the proposed system. A single sideband mixer is introduced into the conventional frequency offset Van Atta array. A single sideband mixer based on the Hartley phasing-type single sideband modulator can be an upconverter that generates a single sideband suppressed carrier signal without utilizing filters. A dual-polarized antenna is used to ensure good isolation between the received and retransmitted signal. This bidirectional structure minimizes the array size. The amplifier can be introduced to increase the effective radiated power.

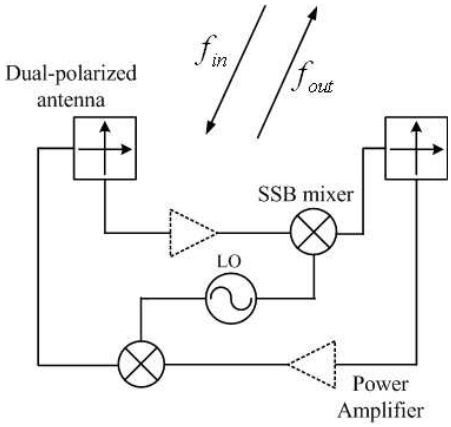


Figure 1. Diagram of the broadband frequency offset Van Atta array.

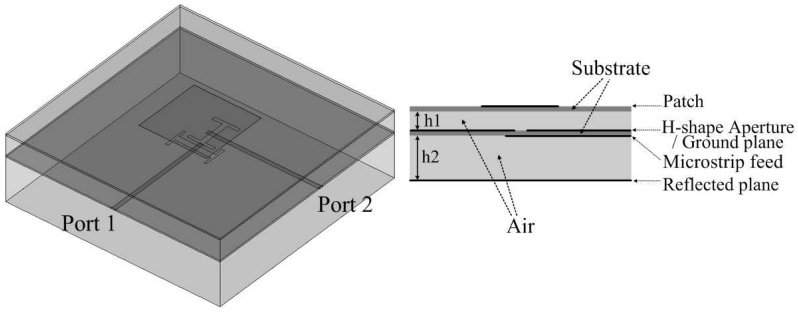


Figure 2. Structure of the aperture-coupled antenna.

Broadband characteristic is obtained using the single sideband mixer in a frequency offset Van Atta array. The bandwidth of the array depends on the bandwidth of the antenna array and the mixers.

2.2. Dual-polarized Antenna

Dual-polarized antenna is commonly used in order to reduce the size and cost of retrodirective array. The aperture coupling structure is one type of dual-polarized antenna which shows good performance of wide bandwidth and high isolation between the radiating element and the feed network.

A dual-polarized microstrip antenna which is fed by the two orthogonal coupling slots is shown in Fig. 2. The ground plane is located on the top side of the lower layer on which two orthogonal slots are etched, and the microstrip feed lines are put on the opposite

side. Power is coupled to the patch radiator from the feed lines via the aperture-coupled structure. The air layer between the two dielectric layers is used to increase the thickness of the upper substrate that results in reducing the average relative dielectric constant which leads to wider bandwidth. For enhancing the front-to-back ratio of the proposed antenna, a reflected plane is used below the lower dielectric substrate.

2.3. Single Sideband Mixer

As shown in Fig. 3, the single sideband (SSB) mixer consists of two mixers, local oscillator (LO) power divider, intermediate frequency (IF) power divider and a radio frequency (RF) power combiner. The inputs of the LO and IF of the two mixers have a phase difference of 90°. Let the LO signal be $\sin(\omega_{LO}t)$ and the IF signal be $\sin(\omega_{IF}t)$, given that the signals of two paths have equal amplitudes, thus the total output is

$$\begin{aligned} E_{out} &= E_1 + E_2 \\ &= E_0 \sin(\omega_{LO}t+\varphi_1)\sin(\omega_{IF}t+\varphi_2)+E_0\cos(\omega_{LO}t+\varphi_1)\cos(\omega_{IF}t+\varphi_2) \\ &= E_0\cos(\omega_{LO}-\omega_{IF}+\varphi_1-\varphi_2)\,t \end{aligned} \quad (1)$$

The upper sideband cancels while the lower sideband adds up at the output port. It also shows that the IF signal phase is reversed and the LO signal phase keep unchangeable. The performance of single sideband mixer depends on the amplitude and phase balance of the two channels, the carrier suppression is determined by the LO-RF isolation of the mixer. The key of an effective design is to have good consistent amplitude and phase characteristics in the balanced mixers and bridge hybrids. In this array, the frequency of LO is lower than the input signal, thus the output is the frequency offset signal with the unchanged phase.

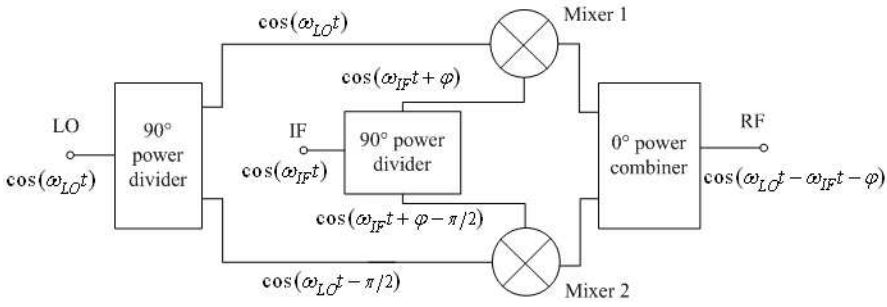


Figure 3. Diagram of the SSB mixer.

2.4. System Simulation

Considering an S-band broadband Van Atta array, the RF frequency is from 2.8 GHz to 3.4 GHz. Let the convention gain of a single mixer be -8 dB, the simulated amplitude error is ± 0.15 dB, and phase error is $\pm 2^\circ$. The input signal amplitude is -32 dBm, and the desired output of the SSB mixer is the lower sideband.

The simulation model is built up by Agilent Advanced Design System. The amplitude and phase performance of the array are considered. The RF frequency is 3.1 GHz, and the offset frequency ($\Delta f = f_{in} - f_{out}$) is 70 MHz. The simulated spectrum is shown in Fig. 4.

The amplitude of the output signal is -40.378 dBm at 3.03 GHz and -75.54 dBm at 3.17 GHz, and the sideband suppression is 35.162 dB. Let the input phase of two channels be 60° and 10° respectively, the corresponding output phases at 3.03 GHz are 61° and 8°. The phase error is within 3° which can ensure the phase characteristic of the Van Atta array.

A simulation is also done to show the broadband performance of the array. In the input frequency ranging from 2.8 GHz to 3.4 GHz, the same results are obtained as above. Thus this kind of array can achieve broadband retrodirectivity.

3. EXPERIMENTAL RESULTS

To certify the above analysis, an S-band frequency offset array is implemented. All mixers and antenna array are fabricated on Taconic

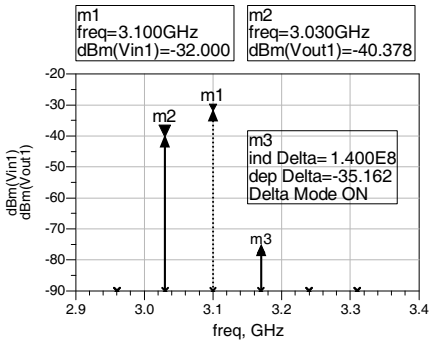


Figure 4. Simulated spectrum of the array.

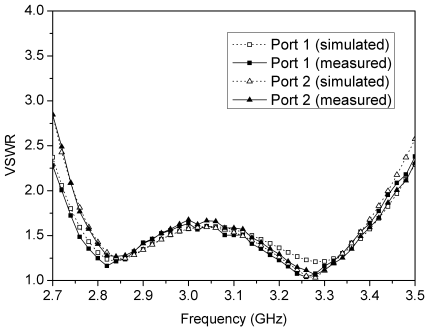
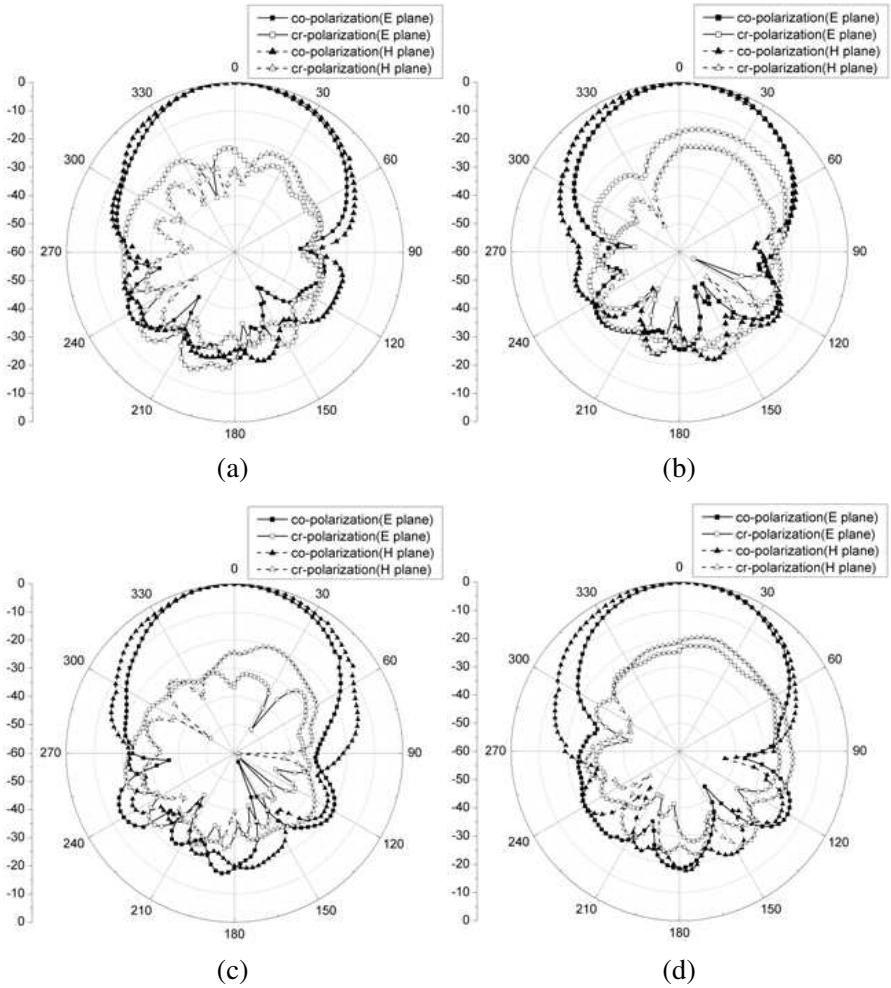


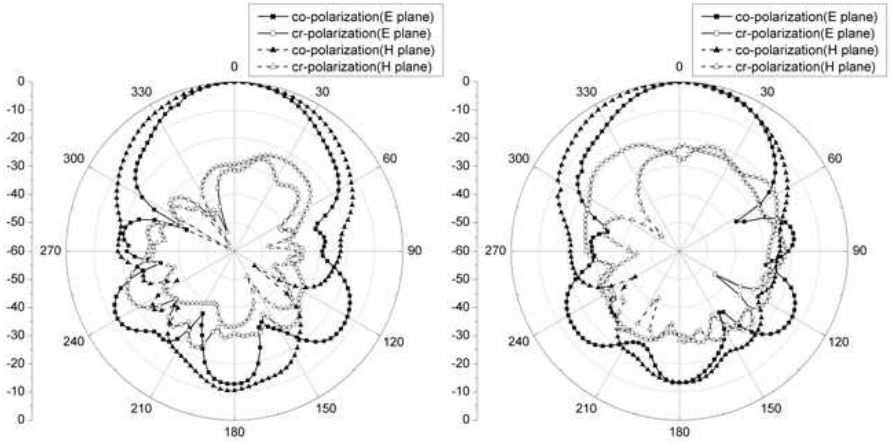
Figure 5. Simulated and measured results of VSWR of antenna element.

TLC-32 ($\tan\delta = 0.003$) substrate with a dielectric constant of 3.2 and thickness of 0.79 mm.

The antenna array is built up and simulated by the full-wave EM simulator (Ansoft HFSS). The antenna array consists of two-element dual-fed antenna array for orthogonal polarization reception arranged with an array spacing of $0.6\lambda_0$, where λ_0 is the wavelength of the center frequency. The dimension of the array is $160 \times 100 \times 28\,\text{mm}^3$. Fig. 5 shows the measured and simulated VSWR. The measured radiation patterns of the antenna element are shown in Fig. 6.

The single sideband mixer is built up with the up-converter mixer SIM-U712H+ whose LO drive is the IF signal. The RF 0° and 90°





(e) (f)

Figure 6. Measured radiation patterns of antenna element. (a) Port1 at 2.8 GHz, (b) Port2 at 2.8 GHz, (c) Port1 at 3.1 GHz, (d) Port2 at 3.1 GHz, (e) Port1 at 3.4 GHz, (f) Port2 at 3.4 GHz.

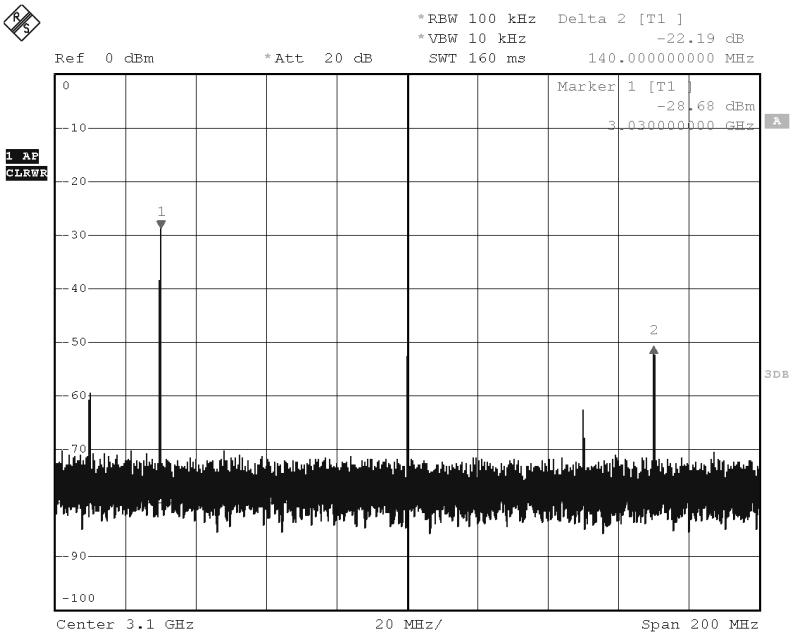


Figure 7. Measured output spectrum.

power divider is SCN-2-35+ and QCN-34+ respectively. The IF 90° power divider is LRPQ-70J. These chips are from Mini-Circuits. The measured conversion gain and unwanted sideband suppression of the single sideband mixer are better than −8.9 dB and 20.5 dB respectively in the operating band. The measured output spectrum at 3.1 GHz is shown in Fig. 7, and the amplitude of the input signal is −20 dBm.

The photograph of the completed broadband frequency offset array is shown in Fig. 8. The input RF frequency is changed from 2.8 GHz to 3.4 GHz, and the LO frequency is 70 MHz. The measurement setup is shown in Fig. 9. In the bistatic measurement, the position of the RF horn is fixed while the IF horn is moved in the range of $-90^\circ < \theta < 90^\circ$. In the monostatic measurement, the RF horn and IF horn are moved together.

Figure 10 shows the monostatic radiation patterns. The steering range of the proposed array is approximately ±30° from broadside. Fig. 11 shows the bistatic patterns for a source at −20°, 0°, 10°, 30° of the proposed array, and the patterns are separately normalized to 0 dB. For each of these incidence angles, the bistatic RCS patterns are measured at three different output frequencies 2.73 GHz, 3.03 GHz and 3.33 GHz, corresponding to the input frequencies 2.8 GHz, 3.1 GHz and 3.4 GHz respectively. The proposed array works well at different angles of incidences. The discrepancies caused by measurement environment and nonidealities in amplitude and phase balance among array element can be accepted.

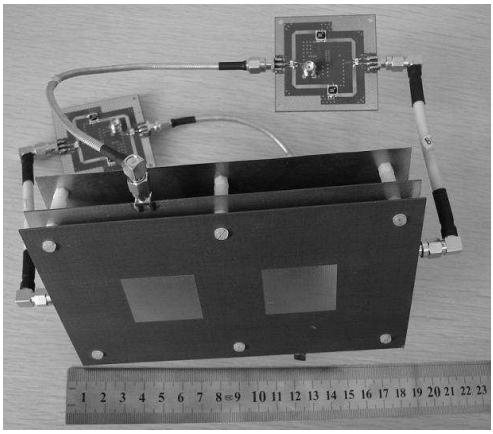


Figure 8. Photograph of the broadband frequency offset array.

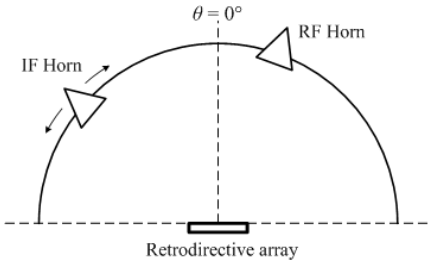


Figure 9. Measurement setup.

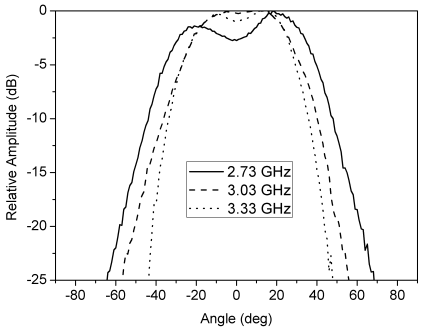


Figure 10. Monostatic radiation patterns received at 2.73 GHz, 3.03 GHz and 3.33 GHz.

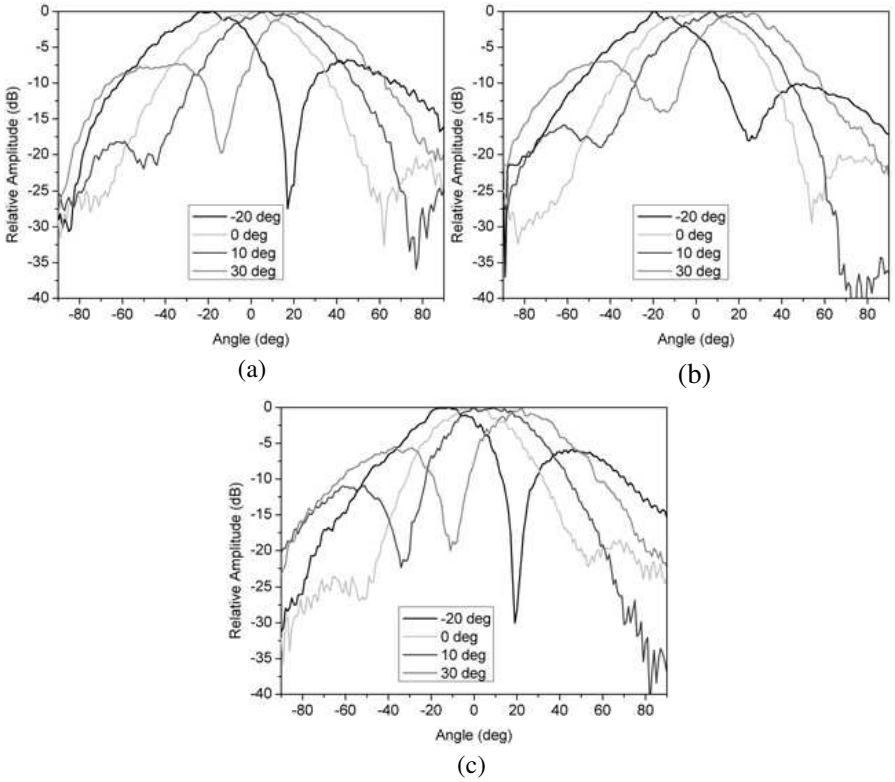


Figure 11. Bistatic RCS patterns at different frequencies. (a) 2.73 GHz, (b) 3.03 GHz, (c) 3.33 GHz.

4. CONCLUSION

A novel broadband frequency offset Van Atta array is proposed. By connecting the aperture-coupled dual-polarized antenna and single sideband mixer which can achieve sideband choice without filters, the proposed array shows good retrodirectivity with frequency offset characteristic in a broadband. In this structure the isolation between received and retransmitted signals is achieved by dual-polarized antenna and low frequency offset circuit. The two-element prototype is implemented. Retrodirectivity is observed within the frequency range from 2.8 GHz to 3.4 GHz. The proposed array is suitable for applications of RFID and communication.

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