Research on the Scheme and Performance of Linear SA in CDMA Application

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***Abstract*—Firstly, this paper researches on the scheme of amplitude weighting(AW) for smart antenna(SA) beam-forming in linear array. With the proposed mathematical model in this paper, QPSK base-band AW is an effective method for linear SA to realize multi-user and multi-direction transmission, by which the perfect directional beam-forming can be realized with low complexity and low cost. Secondly, this paper analyses the performance of linear SA with 6 array elements(AEs) in different application scenarios. Compared with carrier phase-shifting, the implementation scheme of beam-forming by AW has the feature of easy to implement and high reliability, so that the popularization and application of SA is possible.**

Keyword-smart antenna (SA); beam-forming; amplitude weighting (AW); QPSK;6 array elements(AEs)

I. INTRODUCTION

Recently, smart antenna(SA) application in CDMA mobile communication system is a very important research direction as well as the basis of future multiple-input multiple-output(MIMO) system. Consequently, the application research of SA has great practical value. SA, based on the phase-controlled antenna array(PCA) technique, is an effective method to increase the frequency and power efficiencies for mobile communication systems. With the directional beam-forming of SA, we can realize the instant tracking and orientation for mobile terminals in a cellular mobile communication system. In CDMA mobile communications system, generally, due to the complexity of realization, SA is mainly employed in base station transceiver. To perform the perfect directional beam-forming, the direction of arrival (DOA) of mobile station (MS) signal should be acquired firstly from uplink, and then with this DOA the directional beam-forming of downlink is possible.

The effect of space division multi access (SDMA) formed by SA directional receiving and transmission is expected to be utilized to separate multi access interference (MAI) and multi path interference (MPI) in CDMA system, which can improve system spectrum utilization greatly and increase the number of users in a given channel bandwidth or CDMA code-channel. The effect of SA SDMA is originated from the directional reception and transmission principle of phase controlled array antenna. If directional reception and transmission is to be realized in base station (BS), DOA of MS must be known.

Reference [1] states that it could realize downlink beam-forming in base-band after the direction of arrival (DOA) estimation in the uplink, but it has not given the implementation scheme of beam-forming with QPSK base-band signal. Reference [2] presents the block diagram of downlink beam-forming, which is base-band weighting and can form k-beam. Pointing out in [3, 4, 5, 6], the directional transmission of SA can be achieved with the method of beam-forming by base-band weighting, but the specific implementation principle and implementation method has not been shown. Many authoritative monographs [7, 8, 9, 10] on SA only give the principle of PCA, i.e. the basic method of directional transmission by carrier phase-shifting weighting. Literatures [11, 12, 13, 14] on downlink beam-forming only give the interrelated matrix solutions of downlink beam-forming, and have not given the relation among the interrelated matrix solutions, DOA and the direction vector of SA or the related processing. Many patents [15, 16, 17, 18] related to TD-SCDMA system also remain at the level of matrix solutions. One chief engineer of ZTE R&D center has said in [19] "In addition, comparing to extensive research of uplink adaptive beam-forming technique, the downlink performance has become the 'bottle-neck' for the systems performance, so that there is an urgent need for the method of effective downlink adaptive beam-forming." The top authority [20] of TD technique said "The current application of SA technique is an initial state of multi-antenna technique. In the future it will become more powerful multi-antenna technique, which would have the functions of beam-forming, space-time multiplexing (i.e. MIMO) and SDMA." Therefore, it has been shown in those patents and articles that the research on SA in CDMA basically remains at the stage of theoretical research by mathematics, which sharply does not match the conclusion that SA has been widely used in mobile communication system for TD-SCDMA.

Owing to the difficulty in realizing the accurate phase-shifting in the radio frequency and the large output of side lobe and insertion loss introduced by radio frequency power amplifier, people think that beam-forming by base-band weighting is an effective method for SA to realize directional transmission, while the relevant literature about the principle or method of beam-forming by base-band weighting have not been found.

Firstly, this paper gives the direction vector of SA and its principle of downlink beam-forming, and then derives an equivalent expression of beam-forming by amplitude weighting (AW) based on that by phase-shifting weighting (PW) in line array. According to the expression, we can derive the schematic diagram, which uses the QPSK signal by AW to achieve the beam-forming for SA in line array. The correctness of scheme will be proved by the simulation results. It also shows some simulation performance of 6-AE in line array in the CDMA application. Compared with carrier phase-shifting, the implementation scheme of beam-forming by AW has the feature of easy to implement and high reliability, so that the popularization and application of SA is possible.

II. Direction Vector of SA and Its Principle of Downlink Beam-Forming

Structure of even line array is illustrated in Figure 1. Assuming that the angle between the normal plane and the receiving signal is φ, then the delay of the receiving signals between the neighboring two AEs is $d\sin\varphi$, correspondingly, the phase between them is $\frac{2\pi}{\lambda}d\sin\varphi$. Making the phases of receiving signals by each AE respectively $[\varphi_1,\varphi_2\cdots\varphi_N]$, we can draw the schematic diagram of carrier phase-shifting weighting for beam-forming, shown in Figure 2, where

$$\varphi_n=\frac{2\pi}{\lambda}(n-1)d\sin\varphi\ ,\ n=1,2,\cdots N \tag{1}$$

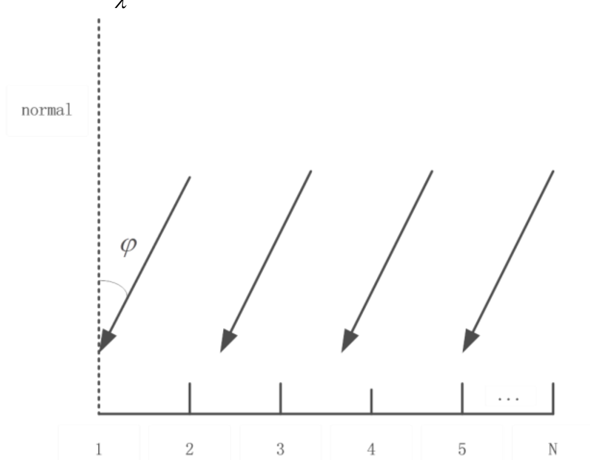


Fig.1. Diagram of even linear array

φ_n is regarded as the intrinsic phase of the nth AE, which is related to the array position and the DOA of signal, i.e. φ .The values of phase-shifter inserted are respectively $[-\varphi_1,-\varphi_2\cdots-\varphi_N]$, used to offset the impact of the intrinsic phase, shown in Figure 2. Assuming that the receiving signal of the first AE is $S(t)=\cos wt$, and then the formula of the phase-shifting weighting signal is as follows:

$$\begin{aligned}S_r(t)&=\cos(wt+\varphi_1-\varphi_1)+\cos(wt+\varphi_2-\varphi_2)+\cdots+\cos(wt+\varphi_N-\varphi_N)\\&=N\cos wt\end{aligned} \tag{2}$$

If the impact of noise is not considered temporarily, the gain of beam-forming for SA, i.e. $G_{SA}=20\lg N(dB)$ can be obtained. Because φ_n is related to the DOA, when the value of the phase-shifter is determined, G_{SA} is related to the number of code channel, thus, forming the function of directional receiving, which is regarded as the diversity reception of array antenna.

The schematic diagram in Figure 2 can also be used to understand the principle of beam-forming for transmitting. Assuming that the transmitting carriers are the same frequency and the phase-shifters are not introduced, the transmitting carrier exist the phase difference. Otherwise, there is no phase difference and can realize the diversity transmitting.

Customarily, the intrinsic phase parameters of SA above can be expressed by the complex formula, that

$$\phi=[1,e^{-j\frac{2\pi}{\lambda}d\sin\varphi},\cdots,e^{-j\frac{2\pi}{\lambda}(N-1)d\sin\varphi}] \tag{3}$$

Frequently, the parameters above are called the direction vector of SA, which are necessary and sufficient parameters for SA. Making the weighting parameter of the receiving signal is

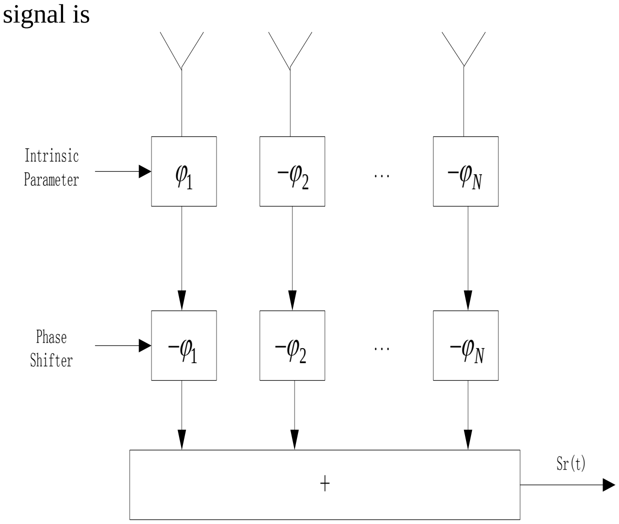


Fig.2. Schematic diagram of carrier phase-shifting weighting for beam-forming

$$w=[1,e^{j\frac{2\pi}{\lambda}d\sin\varphi},\cdots,e^{j\frac{2\pi}{\lambda}(N-1)d\sin\varphi}] \tag{4}$$

Thus,

$$Sr(t) = \sum w_n S(t) e^{-j\varphi_n} = NS(t) \quad (5)$$

Consider that the high angle θ has an impact on DOA in Figure 3, where θ is an intersection angle of DOA and array plane. And then the delay of the receiving signals between the neighboring two AEs is $d\sin\varphi\sin\theta$, correspondingly, the phase between them is $\frac{2\pi}{\lambda} d\sin\varphi\sin\theta$. The direction vector of SA is as follows:

$$\phi = [1, e^{-j\frac{2\pi}{\lambda} d\sin\varphi\sin\theta}, \cdots, e^{-j\frac{2\pi}{\lambda}(N-1)d\sin\varphi\sin\theta}] \quad (6)$$

For convenience, the impact of high angle θ is not considered.

The schematic diagram of beam-forming for multiple-direction in downlink is shown in Figure 4. In the condition of directional transmission in downlink, it needs to detect the user's DOA and then make sure the direction vector of SA., which is the sufficient parameter to realize the directional transmission.

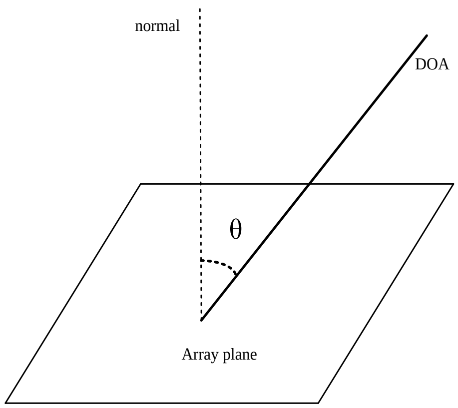


Fig.3. High angle's impact on DOA

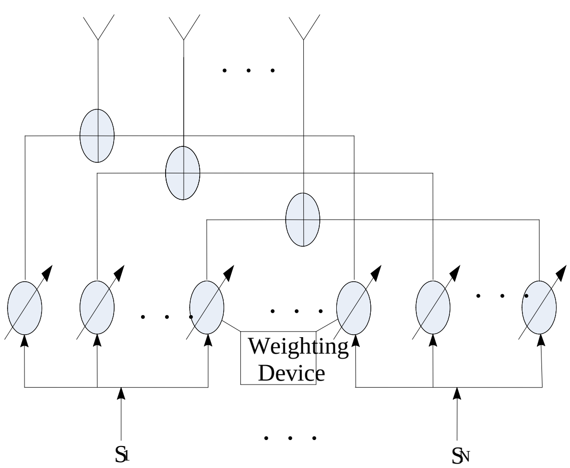


Fig.4. Schematic diagram of beam-forming for multiple-direction in downlink

In the condition of multi-user and multi-direction transmission, the PCA gives the basic principle of beam-forming, i.e., feeding a different phase current into each AE by inserting a phase-shifter in each AE circuit system, so that the radio waves given by each AE are able to realize superposition in phase, and then form the synchronism diversity transmitting gain of some specific direction.

III. THE IMPLEMENTATION SCHEME OF BEAM-FORMING BY AMPLITUDE WEIGHTING

The two carrier signals for orthogonal modulation in QPSK modulation can be shown as following:

$$\sin(wt-\theta)\ ,\ \cos(wt-\theta) \quad (7)$$

Their corresponding complex formulas can be written as:

$$\mathrm{Re}[e^{jwt}e^{-j\theta}]\ ,\ \mathrm{Im}[e^{jwt}e^{-j\theta}] \quad (8)$$

According to the above complex formulas of orthogonal carrier, the following formulas are derived

$$\begin{aligned}\cos(wt-\theta) &= \mathrm{Re}[e^{jwt} - e^{-j\theta}] \\ &= \mathrm{Re}[e^{-j\theta}]\cos wt - \mathrm{Im}[e^{-j\theta}]\sin wt\end{aligned} \quad (9)$$

$$\begin{aligned}\sin(\omega t-\theta) &= \mathrm{Im}[e^{j\omega t}e^{-j\theta}] \\ &= \mathrm{Im}[e^{-j\theta}]\cos\omega t + \mathrm{Re}[e^{-j\theta}]\sin\omega t\end{aligned} \quad (10)$$

According to the expressions above, the circuit diagram of directional transmission for SA realized by AW can be derived.

Circuit structure unit of a modulator is illustrated in Figure 5. The upper part in figure 5 is for the realization given by $\cos(wt-\theta_{mn})$, which realizes the I-phase space-frequency modulation and results in the I-phase carrier phase-shift with θ_{mn}. Where θ_{mn} is the carrier phase-shift of the mth subscriber signal in the nth AE. $I_m(t)$ is the input data of I-phase path in downlink QPSK modulator, which is the chip information stream of the input data spread and scrambled. The real part and image part of weighted coefficient w_{mn} generated by the generation circuit are

$$\mathrm{Re}(w_{mn}) = \mathrm{Re}[e^{-j\theta_{mn}}] \quad (11)$$

$$\mathrm{Im}(w_{mn}) = \mathrm{Im}[e^{-j\theta_{mn}}] \quad (12)$$

Thus,

$$\mathrm{Re}[w_{mn}] = \cos[-\pi(n-1)\sin\varphi_m] \quad (13)$$

$$\mathrm{Im}[w_{mn}] = \sin[-\pi(n-1)\sin\varphi_m] \quad (14)$$

φ_m is the DOA of the mth user.

IV. IMPLEMENTATION SCHEME OF BEAM-FORMING BY AMPLITUDE WEIGHTING IN MULTI-DIRECTION

In the third section, we obtain the circuit unit of QPSK modulator based on the fundamental of baseband beam-forming. It can be seen that the modulation process of each path signal I-phase or Q-phase includes two independent processes: space-domain modulation and frequency-domain modulation. In this section, we discuss the beam-forming method of multiple subscriber directions based on the modulator circuit unit proposed. The simplified model of QPSK modulator is given. From Figure 5, in the modulator scheme, space domain modulation signal (11) and (12) of each user is different with the result of different DOA for different subscriber m. But two orthogonal signals $\cos(wt)$ and $-\sin(wt)$ are same not only for the signals of I-phase path and Q-phase path but also for each subscriber. Thus, a simplified circuit structure is obtained as shown in Figure 6. In the simplified circuit structure, adders M_{n1} and M_{n2} contain all space domain modulators needed by each user, while multipliers M_{n3} and M_{n4} only contain two frequency modulators respectively as shown in Figure 5.

For the mth user data in Figure 6, $I_{\text{I}m}$ and $I_{Q\text{m}}$ denote the input signal of I-phase path; $Q_{\text{I}m}$ and $Q_{Q\text{m}}$ denote the input signal of Q- phase path. With the simplified circuit shown in Figure 4.Base-band beam-forming circuit needed with N transmission directions can be drawn,shown in Figure7.

The circuit block of baseband QPSK modulation beam-forming of N subscribers is given in Figure 7.

The generation process of N baseband modulation signals is similar with Figure 5.

V. THE SIMULATION RESULTS

There are different scenarios in which a signal with one or multi code channel transmits to the same direction, or multi code channels transmits to different direction, the effect of beam-forming from QPSK modulation data of every code channel will be considered in these scenarios. We have found that the polarity of QPSK modulation data in multi-channel parallel transmission will have great impact on the beam diagram of SA directional transmission.

Based on the above modulation beam-forming scheme, some simulation results are presented in this section, with simulation software matlab 7.0. Assuming that SA is a N=6 element line array with the AE space of $\lambda/2$.

Beam pattern for a code channel is shown in Figure 8. Figure 8 (a) and Figure 8 (b) respectively give the beam pattern of QPSK modulator for I and Q paths with the same data values in the direction of 90° and 30° ,where data of I path denotes the data stream $I_m(t)$ after series parallel transformation, as well as that of the Q path. Because the carriers of I and Q are orthogonal, the values of data I and Q have no impact on beam diagram formed by SA. By figure 8 for the directional beam of single code channel in single direction by using 6-AE in line array, better performance could be achieved by tracking the mobile station. RAKE receiver is unneeded for that situation.

Beam pattern for two code channels and two directions is shown in Figure 9. The direction of beam slightly offsets in the direction of 30° in Figure 9 (a), when the data of 2-user fed to I path and Q path is same. It is also shown that amplitudes of two directions have a slight increase, which may be caused by introducing adjacent beam interference. While the data is opposite, the amplitudes of beam have a big drop, shown in Figure 9 (b), whose impact waiting for further study.

Beam pattern for two code channels is shown in Figure 10, which is in the direction of 60°and 45°. Because of less phase difference between them, the two beams can be superimposed as one. When the data of 2-user is opposite, the amplitude of beam changes slightly.

Beam pattern is given in Figure11 (a),in the direction of 30°、60°、90°、120°、150° ,where the transmitting data of each code channel is"1".If the transmitting data of $I_1 = Q_1 = -1$ is "-1" and the other is "1", the beam pattern is given in Figure 11 (b).

The simulation results above are satisfied with the requirement of infinite reflector, and also it requires that there is no beam existing in the opposite direction. However, it is difficult to satisfy the above condition in practical application.

The simulation results in the case of no-reflector are shown in Figure 13 (a), Figure 13 (b), Figure 14 (a)and Figure 14 (b) .

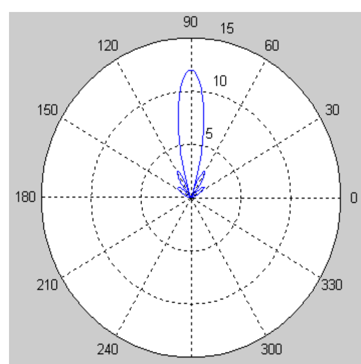


Fig. 8 (a) Direction of 90°

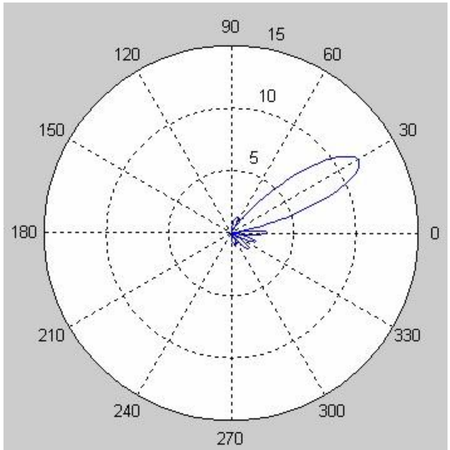


Fig. 8 (b) Direction of 30°

Fig.8. Beam pattern of single-user and single-direction.

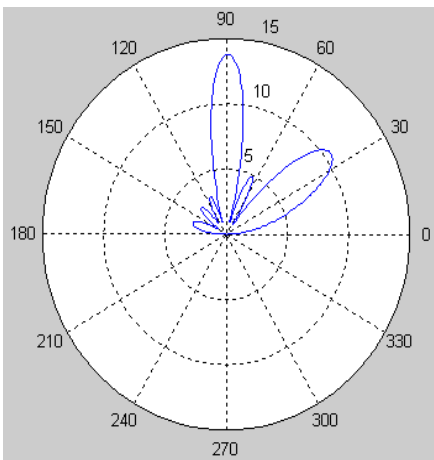


Fig. 9 (a) $I_1 = I_2 = 1\ Q_1 = Q_2 = 1$

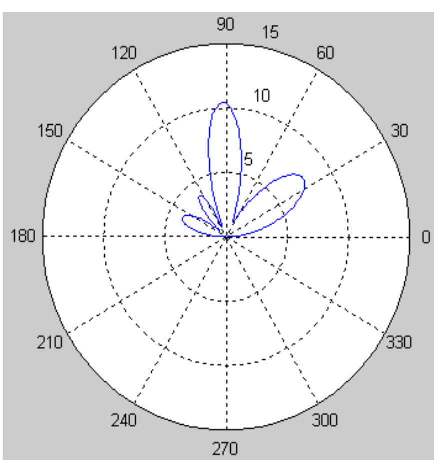
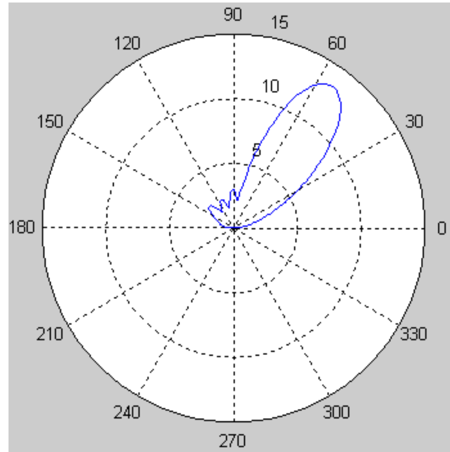
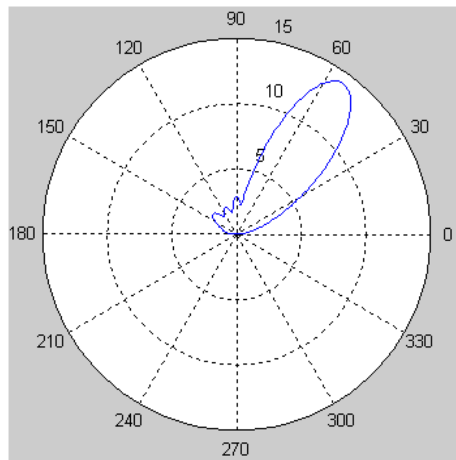


Fig. 9 (b) $I_1 = -I_2 = 1\ Q_1 = -Q_2 = 1$

Fig.9. Beam pattern of two-user and two-direction



$I_1 = I_2 = 1\ Q_1 = Q_2 = 1$



$I_1 = -I_2 = 1\ Q_1 = -Q_2 = 1$

Fig.10. 2-user and direction differs 15°

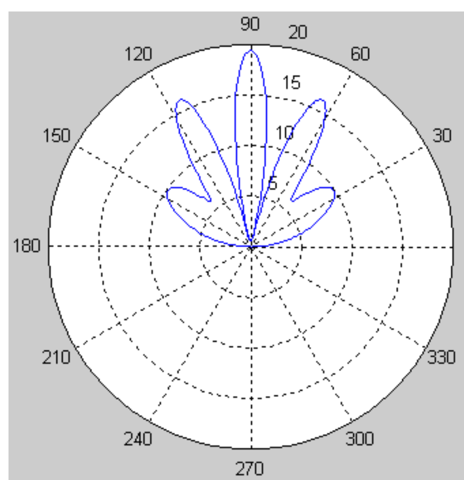


Fig. 11 (a) All transmission data “1”

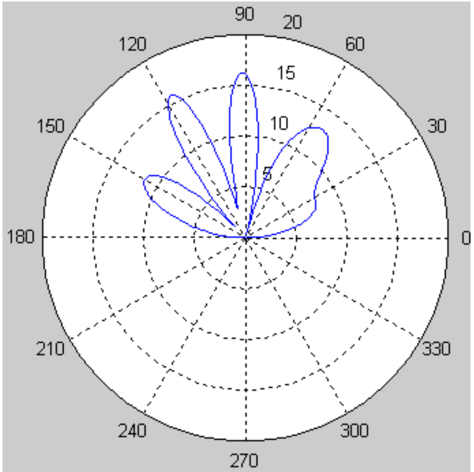


Fig. 11 (b) I_1= Q_1=-1, the other data “1”

Fig.11. Result of 5-direction

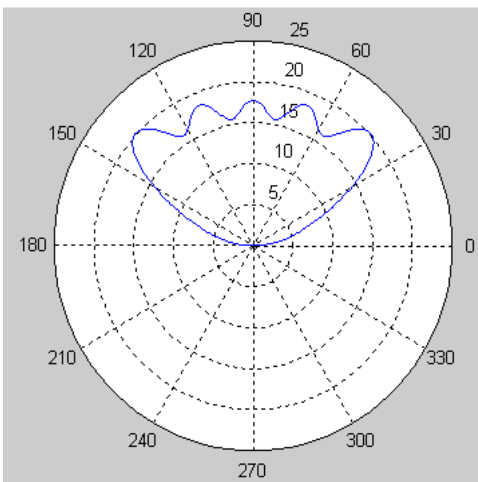


Fig.12. Result of 9-direction

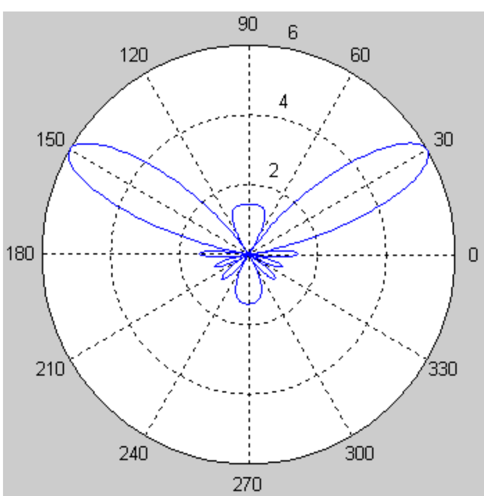


Fig. 13 (a) Direction of 30°

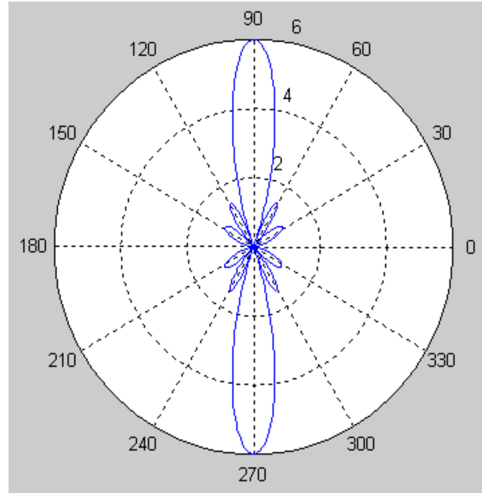


Fig. 13 (b) Direction of 90°

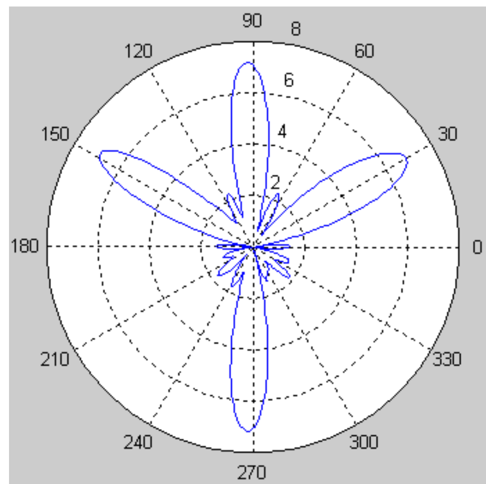


Fig. 14 (a) Direction of 30°and 90°

$I_1 = I_2 = 1 Q_1 = Q_2 = 1$

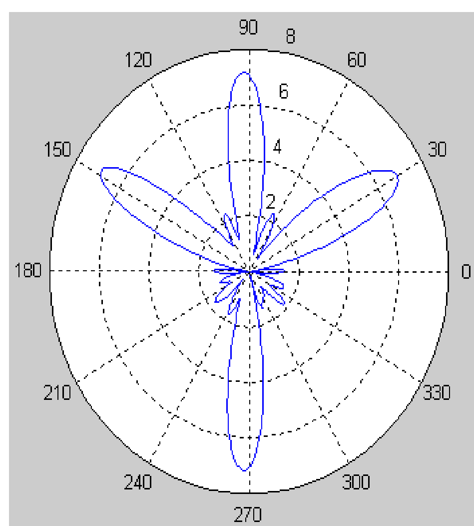


Fig. 14 (b) Direction of 30°and 90°

$I_1 = I_2 = 1 Q_1 = Q_2 = -1$

VI. CONCLUSIONS

This paper has studied the scheme and performance of linear SA with 6-AE in different application scenario in detail. With a reflector and in the situation of single direction and signal code channel, there is no MAI and MPI in the system , so the RAKE receiver is not needed.When the number of directions and code channels increases,the scheme still has a good performance.Considering that the moderate direction is the necessary condition for CDMA system maintaining stable working, it is founded that the stability of SA CDMA system is not well in the condition of transmitting to multi-direction when the direction is very near. With no-reflector,there is always another beam in the opposite. In a word,compared with carrier phase-shifting, the implementation scheme of beam-forming by AW is easy to ensure stable system performance when linear SA with 6-AE is introduced to TDD-CDMA system.

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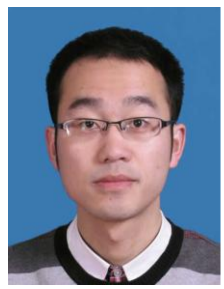
AUTHOR'S PICTURE & BIOGRAPHY



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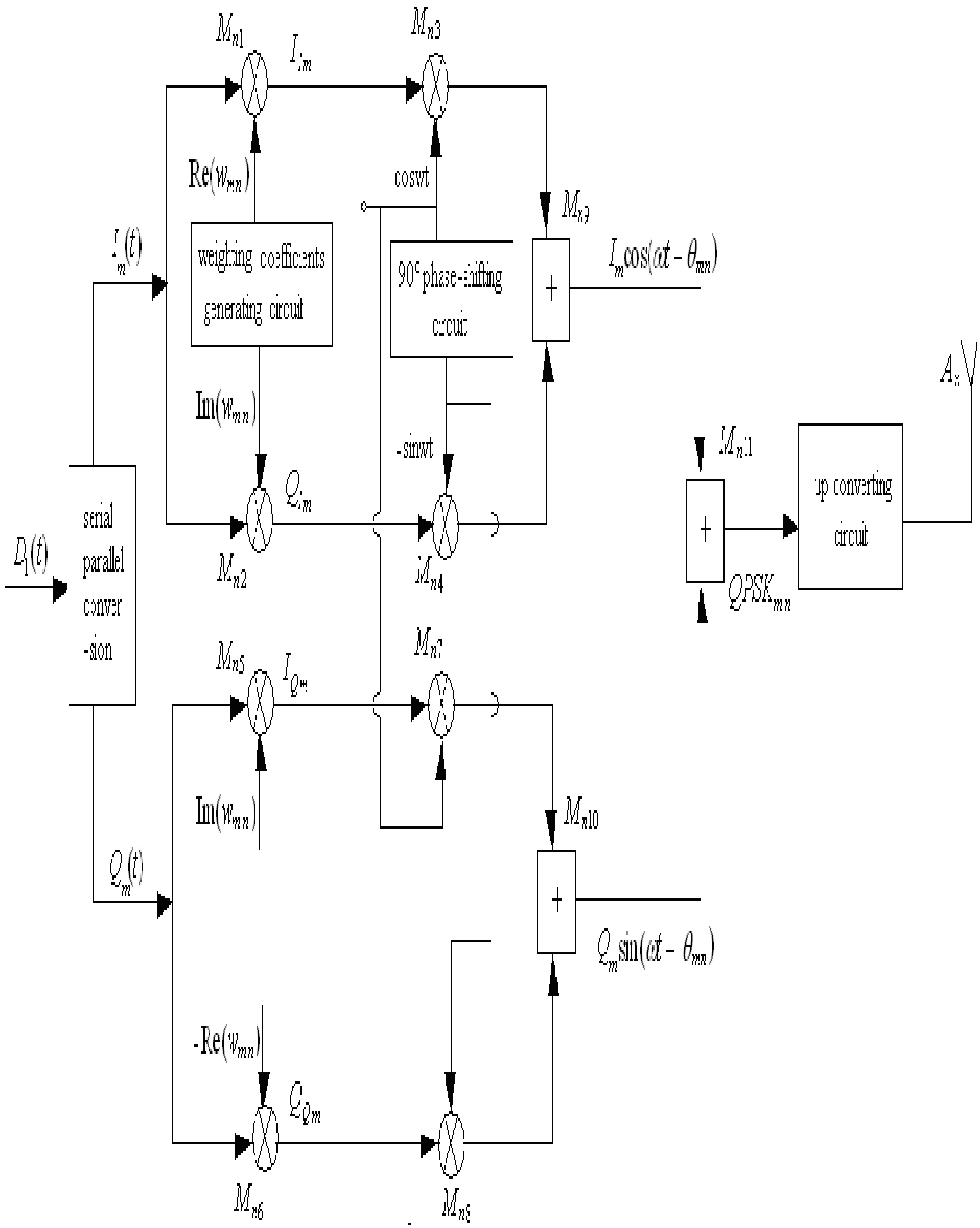

Fig5. Beam-forming modulator circuit unit

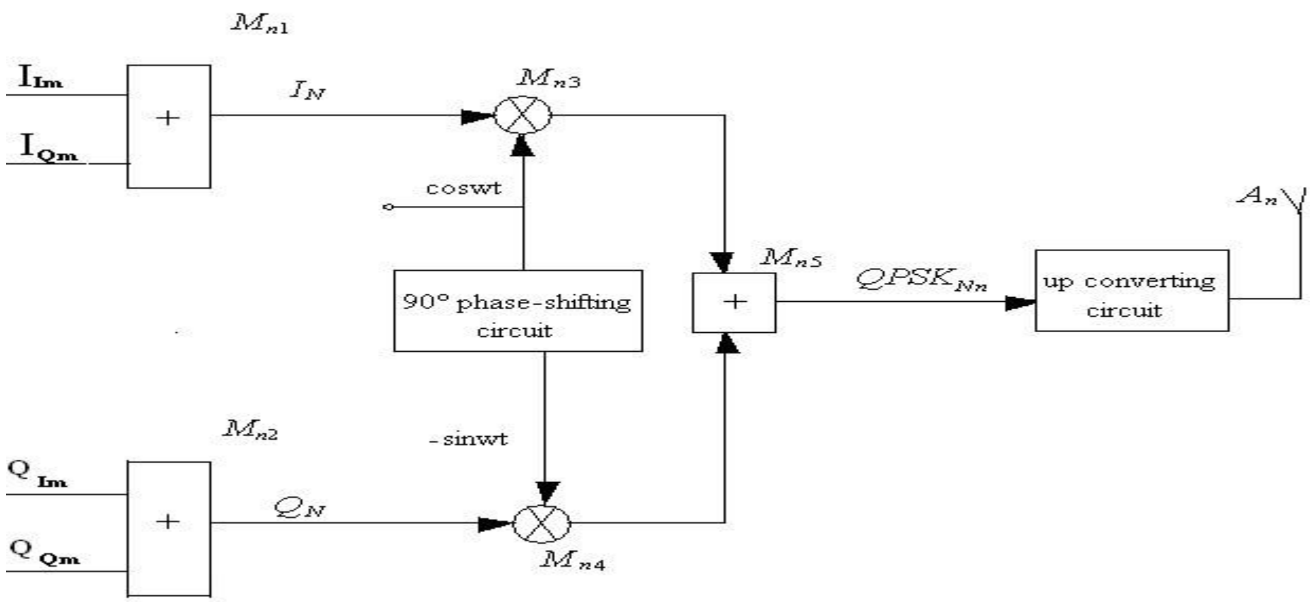

Fig.6. Simplified form of the QPSK modulation

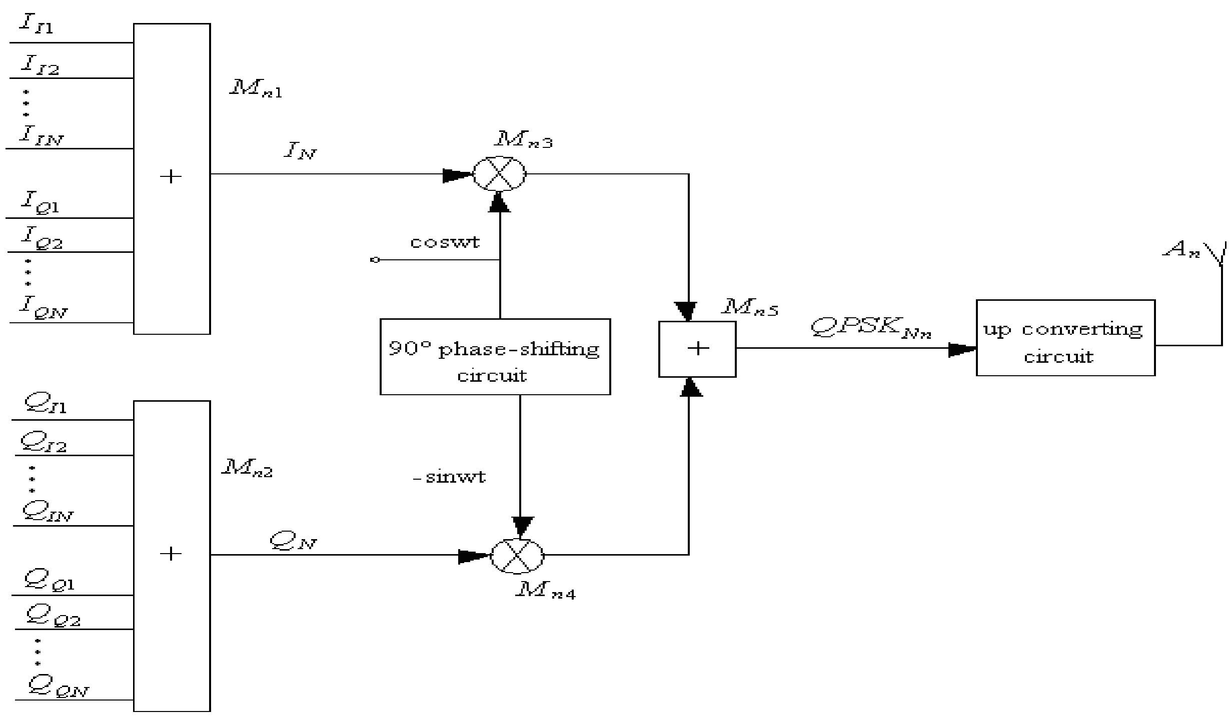

Fig.7. N-direction modulation beam-forming