
The Method of Beam-forming for SA in Line Array by Amplitude Weighting

Jijiang Chen¹, Haiyang Fu¹, Hui Fang¹

1. Nanjing University of Posts and Telecommunications, Nanjing P.R. China
chenjijiang060703@126.com, fuhuy@njupt.edu.cn, 1010010110@njupt.edu.cn

Abstract—QPSK base-band amplitude weighting (AW) is an effective method for smart antenna (SA) in line array to realize multi-user and multi-direction transmission. However, none of relevant materials has given out its principle or implementation scheme. According to the direction vector of SA and its principle of downlink beam-forming, this paper presents the basic principle and specific implementation scheme of this AW method, and then proves its correctness through simulation. 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.

Keywords-smart antenna (SA); phase-controlled antenna array (PCA); beam-forming; amplitude weighting (AW); QPSK

I. INTRODUCTION

The digital mobile communication system has three basic multiple access methods: frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA). These access techniques are achieved in frequency domain, time domain and code domain, but the spatial resource has not been effectively applied, which should be developed and utilized further. Based on phase-controlled antenna array (PCA), the transmitting and receiving of directional narrow-beams can be realized by smart antenna (SA) technique, with the effect of spatial division multiple access (SDMA) to improve the spectrum and energy efficiencies further. Significantly, the influence of multi-path interference (MPI) and multiple access interference (MAI) will be reduced sharply by PCA, whereas the number of simultaneous communication's code channels or users will be improved substantially to achieve directional transmission. Compared with omni antenna, the PCA also can cover a large range by a smaller launch power.

SDMA function of SA comes from the principle of directional transmission by PCA. PCA gives the basic principle of beam-forming, i.e., feeding a different phase current into each array element(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. It is also expected to obtain a higher transmitting gain by array antenna in multiple-input multiple-output (MIMO) system. However, there are big

differences between the principle of MIMO and that of PCA, especially the principle of how to use MIMO to obtain gain is worth further studying.

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

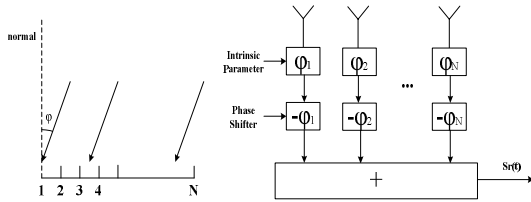


Fig1. Diagram of even line array Fig2. Schematic diagram of carrier phase-shifting weighting for beam-forming

Fig1 illustrates the structure of even line array. 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 $[\varphi_1, \varphi_2 \dots \varphi_N]$, we can draw the schematic diagram of carrier phase-shifting weighting for beam-forming, shown in Fig2, where

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

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 $[-\varphi_1, -\varphi_2 \dots -\varphi_N]$, used to offset the impact of the intrinsic phase, shown in Fig2. Assuming that the receiving signal of the first AE is $S(t) = \cos \omega t$, and then the formula of the phase-shifting weighting signal is as follows:

$$S_r(t) = \cos(\omega t + \varphi_1 - \varphi_1) + \cos(\omega t + \varphi_2 - \varphi_2) + \dots + \cos(\omega t + \varphi_N - \varphi_N) = N \cos \omega t \quad (2)$$

If the impact of noise is not considered temporarily, the gain of beam-forming for SA, i.e. $G_{SA} = 20 \lg N(\text{dB})$ 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 Fig2 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

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

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

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

Thus,

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

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:

$$\sin(\omega t - \theta), \cos(\omega t - \theta) \quad (6)$$

Their corresponding complex formulas can be written as:

$$\text{Re}[e^{j\omega t} e^{-j\theta}], \text{Im}[e^{j\omega t} e^{-j\theta}] \quad (7)$$

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

$$\cos(\omega t - \theta) = \text{Re}[e^{j\omega t} e^{-j\theta}] = \text{Re}[e^{-j\theta}] \cos \omega t - \text{Im}[e^{-j\theta}] \sin \omega t \quad (8)$$

$$\sin(\omega t - \theta) = \text{Im}[e^{j\omega t} e^{-j\theta}] = \text{Im}[e^{-j\theta}] \cos \omega t + \text{Re}[e^{-j\theta}] \sin \omega t \quad (9)$$

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

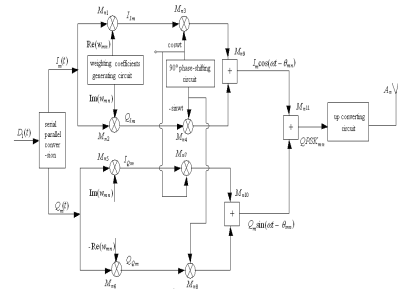


Fig3. Beam-forming modulator circuit unit

Fig3 illustrates the circuit structure unit of a modulator. The upper part in this fig is for the realization given by $\cos(\omega t - \theta_{mn})$, 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

$$\text{Re}(w_{mn}) = \text{Re}[e^{-j\theta_{mn}}] \quad (10)$$

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

$$\text{Thus, } \text{Re}[w_{mn}] = \cos[-\pi(n-1)\sin\varphi_m] \quad (12)$$

$$\text{Im}[w_{mn}] = \sin[-\pi(n-1)\sin\varphi_m] \quad (13)$$

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. Firstly, we give the simplified model of QPSK modulator. From Fig 3, in the modulator scheme, space domain modulation signal (10) and (11) of each user is different with the result of different DOA for different subscriber m. But two orthogonal signals $\cos(\omega t)$ and $-\sin(\omega t)$ 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 as shown in Fig 4 is obtained. 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 Fig 3.

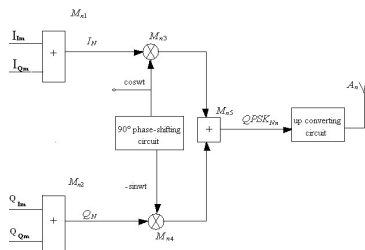


Fig4. Simplified form of the QPSK modulation

For the mth user data in Fig 4, I_{1m} and I_{Qm} denote the input signal of I-phase path; Q_{1m} and Q_{Qm} denote the input signal of Q- phase path. With the simplified circuit shown in

Fig 4, we can draw base-band beam-forming circuit needed with N transmission directions. See Fig 5.

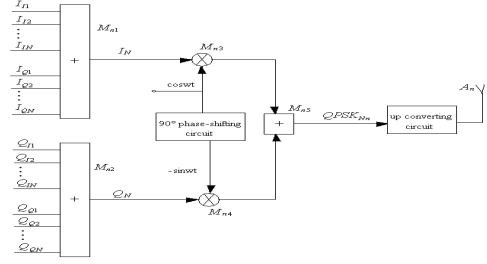


Fig5.N-direction modulation beam-forming

The circuit block of baseband QPSK modulation beam-forming of N subscribers is given in Fig 5.

The generation process of N baseband modulation signals is similar with Fig 3 and omitted here.

V. THE SIMULATION RESULTS

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

Fig6 shows the beam pattern for a code channel. Fig6 (a) and Fig6 (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 fig6 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.

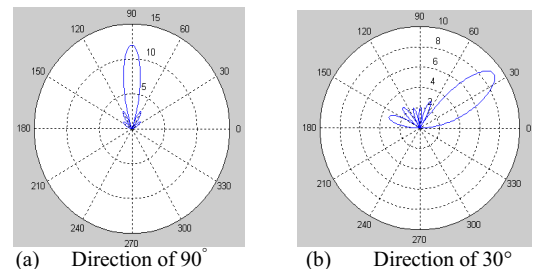


Fig6 Beam pattern of single-user and single-direction

Fig7 shows the beam pattern for two code channels and two directions. It is shown in Fig7 (a) that the direction of beam slightly offsets in the direction of 30° , 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 Fig7 (b), whose impact waiting for further study.

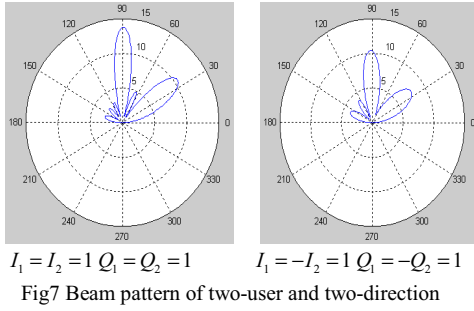
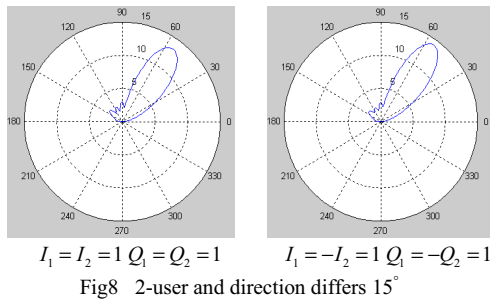
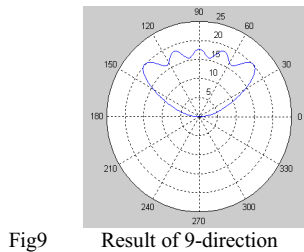


Fig8 shows the beam pattern for two code channels, which is in the direction of 60° and 45° . Because of less phase difference between them, the two beams can be superimposed as one. When the data of 2-user is opposite, the amplitude of beam changes slightly.

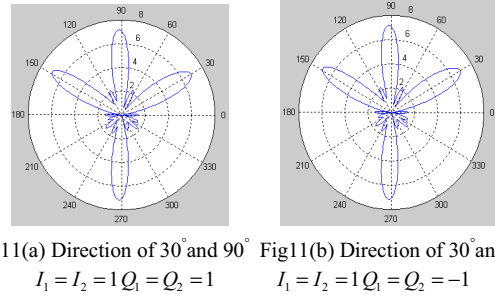
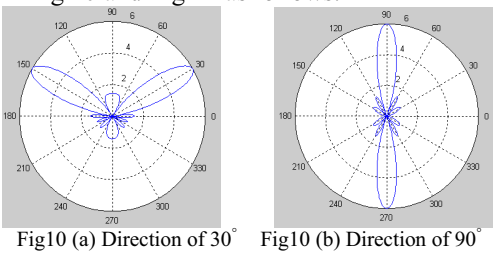


Beam pattern is given in Fig9, in the direction of 30° , 45° , 60° , 75° , 90° , 105° , 120° , 135° and 150° , where the transmitting data of each code channel is same.



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 Fig 10 and Fig 11 as follows:



VI. CONCLUSIONS

Based on PCA, the transmitting and receiving of directional narrow-beams can be realized by SA technique, with the effect of SDMA to improve the spectrum and energy efficiencies further. Significantly, the influence of MPI and MAI will be reduced sharply by PCA, whereas the number of simultaneous communication's code channels or users will be improved substantially to achieve directional transmission. Compared with omni antenna, the PCA also can cover a large range by a smaller launch power.

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 AW based on that by 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.

REFERENCES

- [1] Zhongxing Telecommunication Equipment Co., Ltd, Principle and realization of ireless System for TD-SCDMA , Posts & Telecom Press, 2007.12
- [2] Liang Ma, Smart Antenna for Wireless Communications IS-95 and Third Generation CDMA Applications [M], China Machine Press, 2002.8
- [3] Ayman F.Naguib and Aroryaswami Paulraj, Capcit Improvement with Base-Station Antenna Arrays in Cellular CDMA[J]. IEEE Trans. on Vehicular techn, 2000,43(3): 691-698.
- [4] Ayman F.Naguib, Aroryaswami Paulraj and Thomas Kailath, Performance of CDMA Cellular Networks with Base-Station Antenna Arrays: the Downlink [J]. IEEE 1994
- [5] Hsueh-Jyh Li and Ta-yung Liu, Comparison of Beamforming Techniques for W-CDMA Communication Systems [J]. IEEE Trans.on Vehicular techn, vol.52. NO.4.July 2003
- [6] Klaus Ingemann Pedersen, Preben Elgaard Mogensen and Juan Ramiro-Moreno, Application and Performance of Downlink Beam-forming Techniques in UMTS [J].IEEE Communications Magazine. October 2003
- [7] Nanjing Institute of Electronic technology, Phase-Controlled Array Antenna handbook [M], Electronic Industry Press, 2008.1
- [8] Ming Liu, Chaowei Yuan, the Technology and Application of Smart Antenna [M], China Machine Press, 2007.1

- [9] Wei Yang, Junshi Chen, *Array Antennas Technology in Mobile Communication* [M], Tsinghua University Press, Beijing Jiaotong University Press, 2005.10
- [10] Ahmed El Zooghby, *Smart Antenna Engineering* [M], 2005 ARTECH HOUSE, INC., Norwood
- [11] Josef Johannes Blanz, Apostolos Papathanassion, "Smart Antennas for Combined DOA and Joint Channel Estimation in Time-Slotted CDMA Mobile Radio Systems with Joint Detection," *IEEE transactions on vehicular technology*, Vol.49, No.2, 2000
- [12] Shaoli Kang, Shihe Li, *Algorithm of Downlink Beam-Forming Based on Uplink Parameter in TD-SCDMA System* [J], *Journal of China Institute of Communications*, 2002, 23(8): 67-71.
- [13] Qunying Wu, Shihe Li, *Downlink Beam-forming in TD-SCDMA System for Time delay spread and angle spread channels*[J], *Signal Processing*, 2002, 18 (5): 427-430..
- [14] Seungwon Choi, Donghee Shim, *A Novel Adaptive Beam-forming Algorithm for a Smart Antenna System in a CDMA Mobile Communication Environment* [J]. *IEEE Trans. on Vehicular technol.*, Vol.49, NO.5, September 2000, PP:1793-1806
- [15] Datang Mobile Communication Equipment Co., Ltd, *the Method of Beam-forming for SA and Base-band Signal Processor*, China Patent No. 200710098415.7
- [16] Zhongxing Telecommunication Equipment Co., Ltd, *one Generating Method of Sending Weight on Multi-user Beam-Forming*, China Patent No. 200810145717.X
- [17] Dingqiao Telecommunication Technology Co., Ltd (HuaWei), *one Method of Downlink Beam-forming in TDD System*, China Patent No.200710119516.8
- [18] Putian Information technology Research institute, *one Method of Beam-forming Combining Space with Time* , China Patent No.200510059383.0
- [19] Yanwen Wang, *Current Research and Development of Beam-forming for SA*, *Zhongxing Telecommunication Technology*, 2003.6
- [20] *Developing Smart Antenna Technology of TD-SCDMA with Strong Determination—An Interview to Shihe Li-the Father of TD-SCDMA Standard*, *Telecommunication Technology*, 2008.3, pp.11-12, www.ttm.com.cn