The Phase-Shifting Network Design of Electronically-Steered Smart Antennas for TD-SCDMA Systems

Yejun He
College of Information Engineering
Shenzhen University
Nanhai Road, Nanshan District
Shenzhen, 518060, P.R.China
heyejun@ieee.org

Xiangzi Han
Mobi Antenna Technologies
(Shenzhen) Co. Ltd.
Langshan Road, Nanshan District
Shenzhen, 518060, P.R.China
shaxiao10@yahoo.com.cn

Francis C.M. Lau
Department of Electronic and
Information Engineering
The Hong Kong Polytechnic
University, Hong Kong, China
encmlau@polyu.edu.hk

ABSTRACT

This paper firstly introduced some principles of the phase-shifting network of an electronically-steered smart antenna for TD-SCDMA systems. Secondly, we described the principle of a phase-shifter. The proposed phase-shifter is used in TD-SCDMA systems and is simulated by the Ansoft HFSS software. Simulation results show that the proposed phase-shifter can obtain better angle of phase-shifting. The phase-shifting network based on the proposed phase- shifter can also attain efficient downtilt angle.

Categories and Subject Descriptors

B.4.2 [**Input/Output Devices**]: Channels and controllers

General Terms

Measurement, Design, Experimentation, Theory

Keywords

Phase-Shifting Network, Smart Antenna, TD-SCDMA, Radition Pattern, Downtilt Angle

1. INTRODUCTION

We study electronically-steered smart antennas for TD-SCDMA systems. In the electronically-steered smart antennas, the downtilt angle can be electronically adjusted. According to the number of elements, TD-SCDMA smart antennas are classified into three groups: eight-element antennas, six-element antennas and four-element antennas[1]. In each group, there are four kinds of downtilt angles: zero degree, three degrees, six degrees and nine degrees. Recently, eight-element antennas and six-element antennas with downtilt angle of zero degree have been widely used by base-station manufacturers[2]. Since eight-element antennas have two additional elements compared to six-element antenna arrays, the performance of eight-element antennas, which can be controlled easies, are better than that of six-element antennas. However, eight-element antenna arrays are more expensive than six-element antenna arrays. Also, the windward area of the former is bigger than that of the latter, resulting in a more difficult installation of eight-element antenna arrays. Thus, the requirements on the antenna pedestal and poles are very high. In the above smart antennas, the phase-shifting network is a key component. By using a phase-shifter to control the phase of each array element, the downtilt angle is changed[3-4].

The rest of this paper is organized as follows. In Section 2, the principle of the phase-shifting network of a smart antenna is introduced. In Section 3, the principle of the phase-shifter is described. The simulation results of the phase-shifter are given in Section 4 and the conclusion is presented in Section 5.

2. THE PRINCIPLE OF THE PHASE-SHIFTING NETWORK OF TD-SCDMA SMART ANTENNA

2.1. Implementation of Electronically-Steered Downtilt Angle for a Phase-Shifting Network

In general, the downtilt angle of an antenna can be changed mechanically or electronically. The mechanically-downtilt adjustment changes the angle between the antenna and the vertical plane by means of adjusting the antenna fixture. It is a complex operation that results in the deformation of the antenna horizontal cover. The electronically-downtilt adjustment gradually increases the phase weight relative to an antenna element without downtilt angle in order to make the main beam producing the downtilt.

Denote the element number by N, the spacing between two adjacent array elements by d, the wavelength by λ, the initial antenna downtilt angle by θ. The phase difference between two adjacent antenna elements, denoted by $\Delta\Phi$, is given as[5]

$$\Delta\Phi = 360 \times d \times \sin\theta / \lambda \,. \qquad (1)$$

When the antennas do not produce any downtilt angle, the phase weights are initially set as $\delta_1, \delta_2, \cdots, \delta_n$, respectively. Therefore, if the initial downtilt angle equals θ, the corresponding phases are: δ_1, $\delta_2 + \Delta\Phi$, $\delta_3 + 2\Delta\Phi$, ..., $\delta_n + (n-1)\Delta\Phi$.

Currently, the frequency bands used by TD-SCDMA broadband electronically-steered smart antennas include 1880~1920MHz, 2010~2025MHz and 2300~2400MHz. For example, if we set the center frequency as 2140 MHz, the element spacing as 115 mm and the number of elements as 10, the relationship between the weighted phase difference and the downtilt angle is shown in Table 1.

Table 1. The relationship between weighted phase difference and downtilt angle

weighted phase difference / downtilt angle	$\Delta\Phi$
0°	0
1°	5.15
2°	10.30
3°	15.46
4°	20.60
5°	25.74
6°	30.87
7°	36.00

By selecting the phase weightings, the downtilt angle of the main beam is initially set. The typical beamforming pattern is shown in Figure1, Figure 2 and Figure 3. For example, the downtilt angle in Figure1 is 2 degrees.

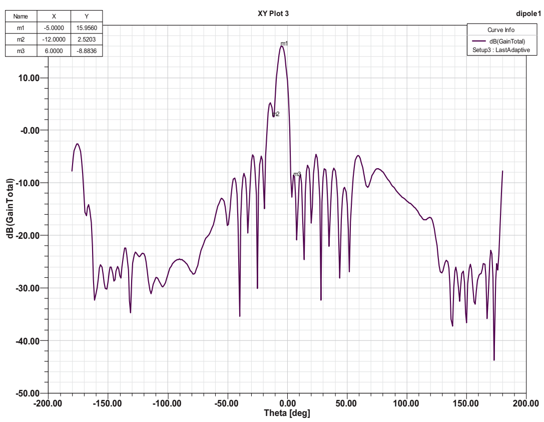

Figure 1. The beamforming pattern with a 2-degree downtilt angle.

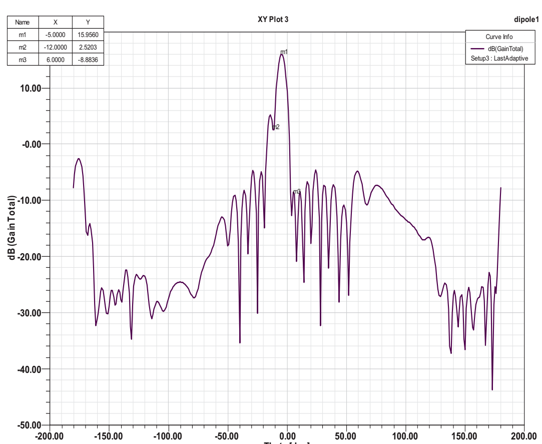

Figure 2. The beamforming pattern with a 5-degree downtilt angle.

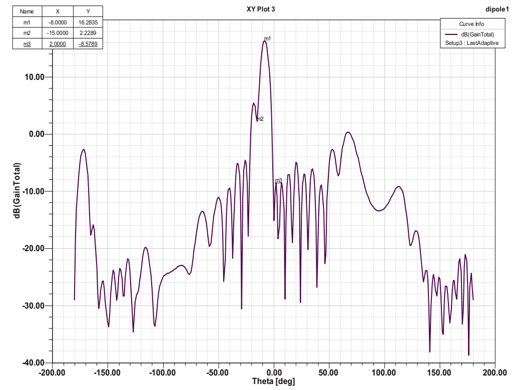

Figure 3. The beamforming pattern with an 8-degree downtilt angle.

2.2 The Adjustments of Weighted Phase

The downtilt angle in a conventional TD-SCDMA antenna is usually fixed. If the traffic demand of the cell changes and the cell coverage has to be re-configured, someone has to get access to the cell site and adjust the downtilt angle of the antennas accordingly. However, the cell sites are usually not easily accessible and it is therefore not convenient to make the adjustments. Using TD-SCDMA electronically-steered smart antennas with phase shifter can resolve this problem. During the measurement as well as in the actual application environments, the antenna downtilt angle can be adjusted in real-time by means of controlling the phase of the phase-shifter so as to satisfy the coverage requirements.

The phase-shifting network in the antenna is shown in Figure 4. It can be seen that the input phase of the respective element varies with the phase of phase-shifter. When each phase-shifter has an identical phase shifting value, the phase weights of the elements form an arithmetic sequence and the downtilt of the main beam is achieved.

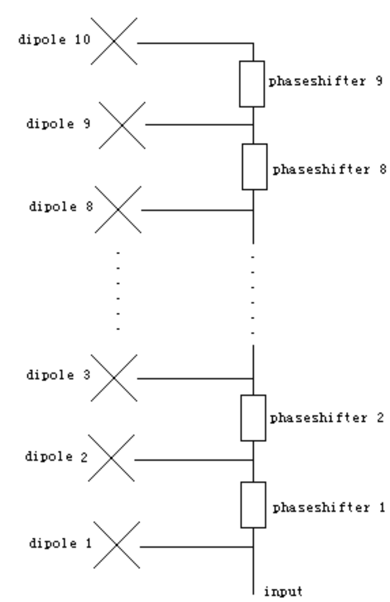

Figure 4. The block diagram of phase shifting network.

3. THE PRINCIPLE OF THE PHASE SHIFTER

The phase difference between the two ends of a uniform transmission line is given

$$\varphi_2 - \varphi_1 = \beta l = 2\pi l / \lambda_p \quad (2)$$

where l represents the distance between the two ends, β is a phase constant of the transmission line and λ_p is a wavelength. From (2), it can be seen that there are two kinds of methods to change the phase: one is to change β , i.e. employing a medium phase-shifter; the other is to change l ,i.e. employing a physical phase-shifter. These two kinds of phase-shifters are described as follows.

3.1 The Medium Phase-Shifter

The consistent change in phase shifting can be obtained by means of changing the permittivity of the medium while conserving the characteristic impedance. Figure 5 shows a particular medium phase-shifter.

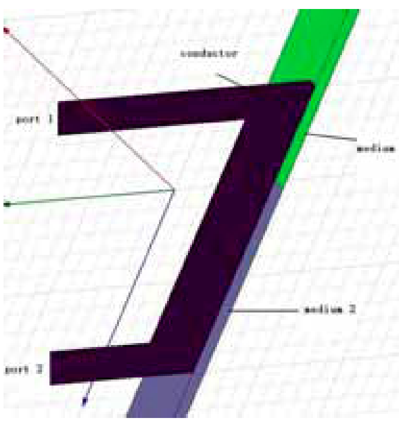

Figure 5. The medium phase-shifter.

The length of the conductor is l . The relative permittivity of Medium 1 is ε_1 while the relative permittivity of Medium 2 is ε_2, where $\varepsilon_1 > \varepsilon_2$. By adjusting the location of the interface between Medium 1 and Medium 2，the phase constant of the microstrip line is changed. For example, when Medium 1 is completely beneath the conductor, the phase constant of the microstrip line is maximum and the inserted phase of the microstrip line is also maximum. Similarly, when Medium 2 is completely beneath the conductor, the phase constant of the microstrip line is minimum and the inserted phase of the microstrip line is also minimum. Thus, phase shifting is performed by varying the overalapping area between the conductor and the two media.

3.2 The Physical Phase-Shifter

The physical phase-shifter changes the access length of the transmission line in order to change the phase-shift. A commonly used physical phase-shifter is shown in Figure 6. When this phase-shifter works, the access phases of the two output ports are controlled by the position of the input port. Another method is to increase the number of the concentric circles according to the number of array elements. Let the radius ratio of respective arc be 1：3：5 …. . Then during the gliding process of the shifting pole, the phase change of each element becomes ……-5△θ，-3△θ，-△θ，△θ，3△θ，5△θ……such that the phase change of respective port represents an arithmetic sequence. When the number of array elements is odd, we take the radius ratio of the respective arc as 1：2：3……，and we append an array element without phase change in the center of the array. Thus, during the gliding process of the shifting pole, the phase change of each element becomes ……-3△θ，-2△θ，-△θ，0，△θ，2△θ，3△θ……, which also conform to an arithmetic sequence. By means of adjusting the phase of each element, the downtilt angle of antenna is changed.

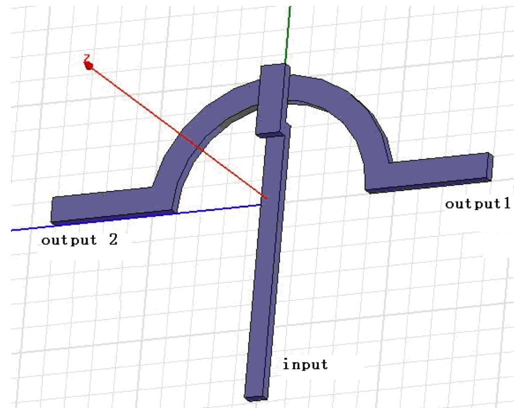

Figure 6. The physical phase shifter.

4. THE SIMULATION OF THE PHASE SHIFTER

As an example of the medium phase-shifter, one medium is air and the other medium is a chinaware whose relative permittivity is very big so as to satisfy the requirements of phase shifting. The main parameters of the phase-shifter include maximum phase shifting, link loss, the standing wave and so on. Simulation results are shown in Figure 7 to 9. The working frequency is in the range of 1.8-2.4GHz.The phase difference between two ports is shown in Figure 7.

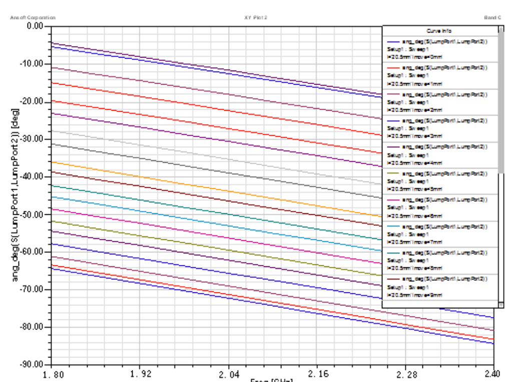

Figure 7. The phase difference between two ports

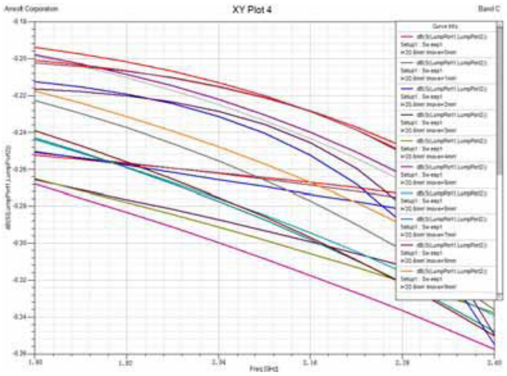

Figure 8. The link loss.

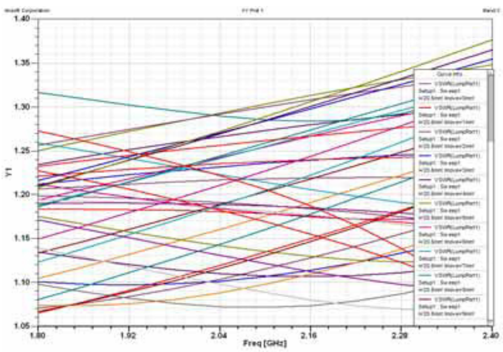

Figure 9. The standing wave variation during the gliding process of the slide.

Various of different colourful lines represent the phase difference between two ports when the slide locates on different positions. The phase difference between two ports is also known as the phase shift. From Figure 7, it can be seen that the maximum phase shifting of the phase-shifter is $-4^\circ-(-64^\circ)=60^\circ$. This satisfies the requirements of the downtilt range of 0~10°.

In Figure 8, each different colourful lines denote the line loss between two ports. It can be seen that the line loss between two ports for a single phase-shifter is less than 0.36 dB.

In Figure 9, the standing wave during the gliding process of the slide is lower than 1.38. All parameters conform to the practical TD-SCDMA smart antenna applications.

5. CONCLUSIONS

In this paper, the phase-shifting network of electronically-steered smart antenna for TD-SCDMA systems has been designed. Some relevant principles are also introduced. In the design process of phase-shifting network, due to the operating frequency ranges of 1880-1920MHz, 2010-2025MHz and 2300-2400MHz, it is adequate to investigate the center frequency of these frequency bands. The proposed phase-shifter is also applied in TD-SCDMA smart antennas. Simulation results of the phase-shifter all conform to the TD-SCDMA smart antenna standard.

6. ACKNOWLEDGMENTS

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