1x2 and 1x4 Switched Beam Antenna Arrays for UHF Band RFID System

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Abstract

A switched beam technique applied to UHF band RFID reader is proposed. The proposed switched beam circuit composed of power divider, phase shifter, and beam controlling logic circuit is implemented on 1x2 and 1x4 array antenna, and resulted in a -30 to 30 degrees beam switching range in three discrete angles, and -50 to 50 degrees beam switching range in five discrete angles, respectively. This technique not only increases antenna gain and extends sensing range, but also reduces the possible EMI interference. In addition, this array antenna can help effectively cancel or attenuate mutual interference among RFID tags. These advantages greatly improve the performance of a RFID system in terms of scan efficiency and read rate, which makes RFID applications even more appealing.

1. Introduction

In the recent, many wireless technologies have been proposed for various potential applications: digital video broadcasting, GSM mobile phone, Bluetooth, WiMAX, RFID [1]. Around these technologies, RFID is the very important technique for logistics, retails, cargo managements. Since 2003 Walmart announced the RFID technology applied in their retail systems, many manufacturers and companies followed this trend and began to design, manufacture various RFID systems to support all the needs.

In general, a RFID system consists of reader controller, reader antenna, tag [2], and the associated command/control software. And the most important determining factor for properly operating RFID system, however, is determined by the RF field environment presented between reader antenna and tag. At the present time many RFID systems use dipole or patch antennas to radiate and receive RF energy but these antennas with fixed radiation patterns. This constraint makes the RFID system operating very difficult in many applications. The solution for this drawback is using many individual antennas and by trial-and-error experience set up the required RF field environment for the uses. This procedure is lack of efficiency and could not help for larger system. The proposed switched beam antenna array system could be a good solution and could provide flexible radiation beam steering capability for setting up RF field environment without many trial tests.

Basically switched beam antenna array consists of phase shifters [3-4], branch line couplers [5] or rat-race hybrids [6], and power dividers [7] to adjust power ratios and phase differences among the radiators and forming the designed radiation pattern and beam directions. The phase difference adjustment in phase shifters is normally controlled by electronic switch for fast response time. In the past this technique was used in military as phase array antenna for tracking, searching airplane or missile etc. At the present time, due to the low cost of RF switch and components, switched beam antenna can be implemented in very acceptable cost. In this paper we proposed 1x2 and 1x4 switched beam antenna arrays for UHF band RFID reader use.

2. Array Antenna Analysis

The proposed 1x2 antenna array consist one equal power divider, two phase shifters shown in Fig. 1(a). The array configuration is shown in Fig. 1(b). The radiator is basically dipole type antenna with total length e, placed above the ground plane at height d. The dipole has metal strip length 2a, width f, and fabricated on FR-4 substrate. Two radiators separate at distance g between the feeders of each radiator.

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The ground plane made by Aluminum plate having width x and length y. The distance between the radiators determines the grating lobe generation [9] which is the unwanted radiation we needed to prevent because the grating lobe shares the radiation energy and reduces the total radiation efficiency. For designing array antenna, the phase angle and scan angle have the relation as:

$$\psi = nkd(\sin\theta - \sin\theta_0) \tag{1.a}$$

where ψ is the phase angle, n is the number of radiator, d is the element spacing, $kd\sin\theta$ is the inter-element phase shift, θ_0 is the scan angle or beam angle, k is the wave number and has the following relation with wavelength.

$$k = {2\pi \cdot f}/{c} = {2\pi}/{\lambda} \tag{1.b}$$

c represents velocity of light, f is frequency, λ is wavelength.

The far field electric field radiated from equal spacing antenna array has the expression [10]:

$$E_a(\theta) = \sum_{n=0}^{n-1} a_n e^{jnkd(\sin\theta - \sin\theta_0)} \tag{1.c}$$

where a_n is the array-amplitude taper coefficient, , n is the number of radiator, d is the element spacing, $kd\sin\theta$ is the inter-element phase shift, θ_0 is the scan angle or beam angle, k is the wave number having the following relation with wavelength. By adequate assigning these values the maximum radiation direction could be controlled by phase difference θ between two adjacent radiators.

Traditional phase shifter needs a long transmission line for the required phase shifting. We use a reduced technique to shrink the length of the transmission line. The design rules [11] are shown as follows

$$Z_n = \frac{Z\sin\theta}{\sin 2\theta_n - (\cos 2\theta_n - \cos\theta)\tan\theta_n} \tag{2.a}$$

$$\frac{\tan\theta_{on}}{\omega \cdot Z_{on}} = \frac{2(\cos 2\theta_n - \cos\theta)}{\omega \sin 2\theta_n} \frac{\sin 2\theta_n - (\cos 2\theta_n - \cos\theta)\tan\theta_n}{Z\sin\theta} \tag{2.b}$$

Where Z is the characteristic impedance of transmission line, θ is the electrical length of transmission line, Z_n is the characteristic impedance of transmission line in reduced section, θ_n is the electrical length of transmission line in reduced section, ($\theta_n < \theta/2$), Z_{on} is the characteristic impedance of open stub section, θ_{on} is the electrical length of open stub.

3. Array Antenna Design and Measurement

In this section, we describe the designs of 1x2 and 1x4 switched beam antenna array prototypes. The radiation characteristics are analyzed by HFSS (high frequency structure simulator). The major materials used for fabrication are FR-4 substrate, Aluminum plate, copper wire, 50 ohm coaxial cable.

The antenna array depicted in Fig.(1b) has the following dimensions: distance between two radiators is 200mm counted from the feed points, radiator height above from ground plane is 40mm, dipole length is 60mm and width is 4mm, size of Aluminum plate are 460mm (x), 250mm (y). The simulation results from HFSS show the maximum gain value is approximated at 9.03dBi.

The reduced size phase shifter circuits design to meet the above requirements could find by (2.a)-(b). Applying these results to LineGauge in IE3D the physical dimension of the phase shifter delay line are determined. Fig. 2(a) shows the phase shifter configuration, the upper and lower path possesses 60 degree phase difference, where θ=40°, φ =60° at 915MHz could meet the requirements. Between two transmission lines placed RF switches (HMC544). This switch is made by integrated circuit and needs +5V DC power supply for the operation. Four capacitors block the DC current flows from switches to the other circuits. The capacitance value is 330pF for all the capacitors. Fig. 2(b) shows the layout of phase shifter circuit. Fig. 2(c) shows the measured frequency responses of scattering parameters $|S_{11}|$ and $|S_{21}|$ in 0-2 GHz. Solid and dashed line represent the return loss $|S_{11}|$ and the insertion loss $|S_{21}|$ when θ is 40°. The value of $|S_{21}|$ is -0.658dB and $|S_{11}|$ is -43.46dB at 915MHz. Solid and dashed line with rectangular mark represent the return loss $|S_{11}|$ and insertion loss $|S_{21}|$ when phase (θ+ψ) is 100°. In this condition, $|S_{21}|$ is -0.884dB and $|S_{11}$ is -16.64dB at 915MHz. The phase difference between two states is shown in Fig. 2(d). When the frequency is at 915MHz, the phases (θ+ψ) and (θ) have phases -199.045° and -136.13°. The phase difference is 62.885°, the deviation is 2.885° compared with the simulated results from HFSS.

Fig. 3(a) shows the photo of 1x2 switched beam antenna array. Input signal is divided equally by two-way Wilkinson power divider. The signal then goes through the phase shifter circuit. The output signal phase depends on the control signal from control logic circuit. The timing signal sent to control logic circuit is formed by 555 timer. This timer offers maximum 20KHz switching speed in this circuit. The speed of the timer could adjust for others applications. The simulated and measured return loss at input port of 1x2 antenna array are -20dB and -24dB at 915MHz. The maximum radiation direction located at θ=1.7°, 345°, and 18.5° correspond to the conditions of 0°, +60°, and -60° phase difference of two radiators. These results are shown in Fig. 3(b). Fig. 4(a) shows the 1x4 switched beam antenna array. Input signal are divided equally by three Wilkinson power dividers. The signal then goes through 4 bits phase shifter circuit. The maximum radiation direction located at θ=0.26°, 347.4°, 17°, 325.3° and 37.1°. These measured radiation patterns are shown in Fig. 4(b).

4. Conclusion

This paper described a switched beam technique applying to UHF band RFID reader antenna. The array contains linear polarized dipoles, power combining circuit, phase shifter, and the switch beam controlling logic circuits. Two prototypes were designed, 1x2 and 1x4 antenna array, the antenna beam switched range is from -30 to +30 and -60 to 60 degree in azimuth plane and possesses three and five discrete directions, respectively. The switched sequence could be manual or automatic setting. These antenna arrays were already used in vehicle management system in NCUT campus, for vehicle entering and leaving control.

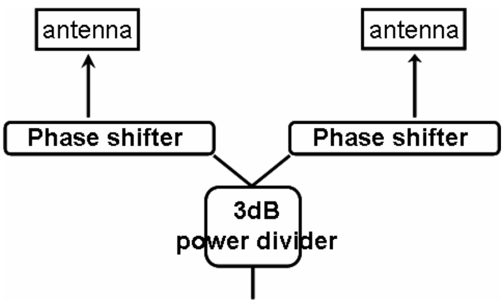

Fig.1(a) The switched beam 1x2 array antenna

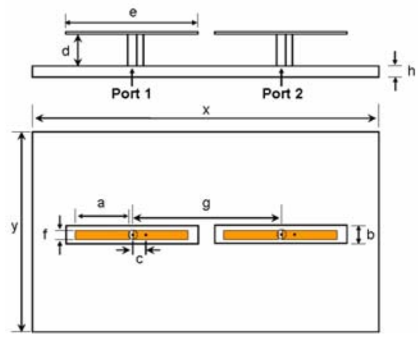

Fig. 1(b) The configuration of switched beam 1x2 array antenna

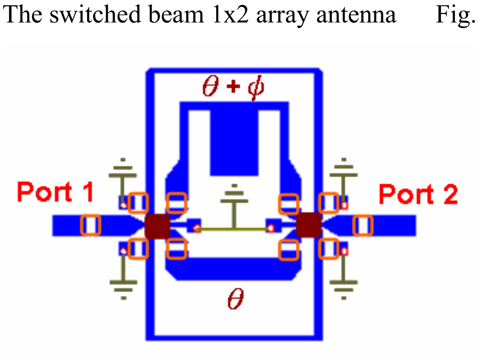

Fig. 2(a) The configuration of phase shifter structure

Fig. 2(b) The layout of phase shifter circuit

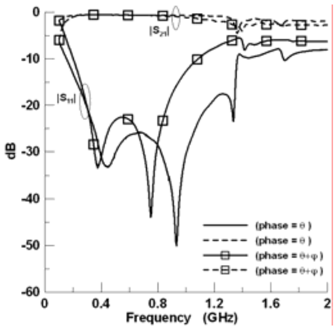

Fig. 2(c) The measured $|S_{11}|$ and $|S_{21}|$ of the phase shifter

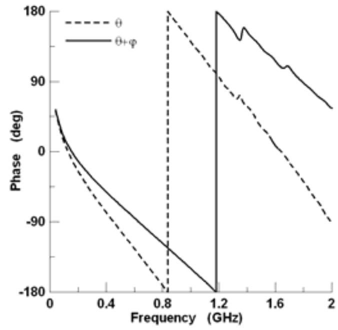

Fig. 2(d) Measured phase data of the phase shifter


Fig. 3(a) Photo of 1x2 switched beam antenna arrays

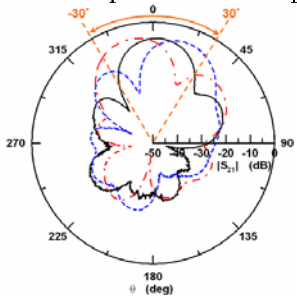

Fig. 3(b) Measured radiation pattern in φ plane

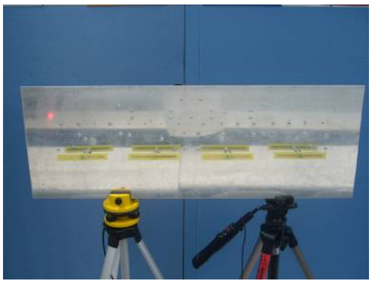
Fig. 4(a) Photo of 1x4 switched beam antenna arrays

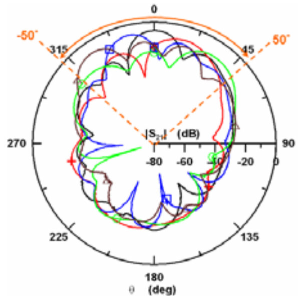

Fig. 4(b) Measured radiation pattern in φ plane

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