Design and Analysis of a Beam Forming Network for WLAN Application

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ABSTRACT
In recent years, high-speed wireless communication is in vogue. In wireless communication systems, multipath fading, delay and interference occurred by reflection or diffraction. In a high-speed wireless communication, it becomes a necessity to separate desired signal from delay or interference signal. Thus to overcome these problems Smart antenna systems have been developed. The arrays by themselves are not smart; it is the digital signal processing that makes them smart. The process of combining the signals and then focusing the radiation in a particular direction is often referred to as digital beam forming. Smart antennas are most often realized with either switched-beam or fully adaptive array antennas. A smart antenna system consists of an antenna array, associated RF hardware, and a computer controller that changes the array pattern in response to the radio frequency environment, in order to improve the performance of a communication or radar system. In the switched beam system there is the beam forming network which will form the multiple fixed beams and cover certain angular are. Now the switched beam system consists of a beam forming network, which forms the multiple beams looking in the different directions. Now there are two approaches to get the multiple fixed beams, one is Butler Matrix Array and another one is Blass Array This thesis presents the Design,AND Analysis of a beam forming network as a key component of a switched beam smart antenna system, operating at 5.3GHz for WLAN with a dielectric substrate, FR4 of $\varepsilon_r = 4.9$ and $h=1.6$mm. Conception details, simulation results and measurements are also given for the components (microstrip antenna, hybrid couplers, cross-coupler, phase shifter) used to implement the matrix. In this dissertation, mathematical calculations for all the components using MATLAB is done and then every individual component is designed using the commercial software SONNET. Then these entire components have been combined on a single substrate and simulated using SONNET.

I. INTRODUCTION
Smart antenna [6] is one of the most promising technologies that will enable a higher capacity in wireless effectively reducing multipath and co-channel interference. This is achieved by focusing the radiation only in the desired direction and adjusting itself to changing traffic conditions or signal environments. Smart antennas [6] employ a set of radiating elements arranged in the form of an array. The signals from these elements are combined to form a movable or switchable beam pattern that follows the desired user. In a Smart antenna system the arrays by themselves are not smart, it is the digital signal processing that makes them smart [6]. The process of combining the signals and then focusing the radiation in a particular direction is often referred to as digital beam forming [7]. Smart antennas are most often realized with either switched-beam or fully adaptive array antennas. An array consists of two or more antennas (the elements of the array) spatially arranged and electrically interconnected to produce a directional radiation pattern. A smart antenna system consists of an antenna array, associated RF hardware, and a computer controller that changes the array pattern in response to the radio frequency environment, in order

Fig.1 Block diagram of 4x4 Butler matrix array
to improve the performance of a communication or radar system. Switched-beam antenna [8][9] systems are the simplest form of smart antenna. By selecting among several different fixed phase shifts in the array feed, several fixed antenna patterns can be formed using the same array. The appropriate pattern is selected for any given set of conditions. An adaptive array controls its own pattern dynamically, using feedback to vary the phase and/or amplitude of the exciting current at each element to optimize the received signal.

Smart or adaptive antennas [9] are being considered for use in wireless communication systems. Smart antennas can increase the coverage and capacity of a system. In multipath channels they can increase the maximum data rate and mitigate fading due to cancellation of multipath components. Adaptive antennas can also be used for direction finding, with applications including emergency services and vehicular traffic monitoring. Smart Antennas can be used to achieve different benefits. The most important is higher network capacity, i.e. the ability to serve more users per base station, thus increasing revenues of network operators, and giving customers less probability of blocked or dropped calls. Also, the transmission quality can be improved by increasing desired signal power and reducing interference.

II. ANALYSIS AND DESIGN

90° HYBRID

Fig2. Geometry of 90° Hybrid

Quadrature hybrid [17] or 90° hybrid is a well known device used for its ability to For $Z_0 \leq 44 - 2 \approx$ ,

$$\frac{W}{h} = \frac{2}{\pi} \left\{ B - \log(2B-1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left[ \log(B-1) + 0.39 \cdot \frac{0.61}{\epsilon_r} \right] \right\} \quad (1)$$

Generate signals 90 degree out of phase at its outputs. Through Even-Odd mode analysis it can be shown that the $S$ matrix will have the following form. From the above figure it is evident that the quadrature hybrid has four ports, port 1 is the input port, port 2 is the output port, port 3 is the coupled port and port 4 is the isolated port. When power is applied to the port 1 it is equally distributed in port 2 and port 3 and port 4 is isolated since no power reaches it. There is a 90° phase difference between port 2 and port 3. Basically the 90° hybrid is made by two main transmission lines shunt connected by the two secondary branch lines. It has two 50Ω and two 35.4Ω transmission lines with length $\lambda/4$ [18]. So the perimeter of the square is approximately equal to one wavelength.

The formulae for finding the length and width to height ratio of the microstrip lines

CROSSOVER

In the butler matrix array [19][20] the signal path has to physically crossover [18] while maintaining the high isolation. This could be made by letting one of the microstrip go over the other one, like a bridge, by adding a substrate between them. But this gives extensive work during the manufacturing and the signal is perhaps nevertheless coupled or affected by the discontinuities. Another possibility could be to use a multilayer substrate with ground plane in the middle and the circuit elements on the both sides. The major disadvantage is that it cannot be manufactured without professional help and that the vias are complex to be modeled in the simulation. Now in this paper the crossover is implemented by cascade of the two 90° hybrids with slight modification on line widths. The geometry of the crossover is given below.

Fig3 Geometry of Crossover
PHASE SHIFTER

The phase shifter [20] is implemented using microstrip transmission lines. The length of the line corresponding to 45° phase shift is given by the formula

\[ \Phi = \frac{2\pi}{\lambda} L \]  

Where L is in meters, \( \phi \) is in radians. \( \lambda \) is the wavelength in the microstrip line. The wavelength in the microstrip transmission line is given by

\[ \lambda = \frac{\lambda_0}{\sqrt{\varepsilon_{\text{reff}}}} \]  

Where \( \lambda_0 \) is the free space wavelength and \( \varepsilon_{\text{reff}} \) is the effective dielectric constant of the microstrip line. Since the phase shift is implemented using simple transmission line therefore it is linearly frequency dependent.

III. EXPERIMENTAL SETUP AND RESULTS

At first the important mathematical calculations for finding the dimensions of all the individual components is done using MATLAB and then the individual components are designed and simulated using SONNET. After getting good results all the individual components are combined on a single substrate to implement the Butler matrix and simulated using SONNET.

90° HYBRID

90° hybrid [23][24] is made by two main transmission lines shunt connected by the two secondary branch lines. It has two 50Ω and two 35.4Ω transmission lines with length \( \lambda/4 \). So the perimeter of the square is approximately equal to one wavelength. At first the length and width of the shunt and series transmission lines are calculated by using the equation. Now with the calculated values the 90° hybrid is designed and simulated by using commercial software SONNET. The optimum design is given below.

Fig. 4 Optimum design of 90° Hybrid at 5.3GHz.

Simulation results of 90° hybrid

Fig. 5 Current distribution at 5.3GHz

CROSSOVER

The crossover [24] is implemented by cascade of the two 90° hybrids with slight modification on line widths. The crossover is implemented by 50Ω microstrip line. Optimum design is given below.

Fig 6. Optimum design of crossover at 5.3GHz

Fig 7. VSWR1, VSWR2, VSWR3, VSWR4 at 5.3 GHz.

PHASE SHIFTER

In this paper -45° phase shifter [2][23][24] is used. The phase shifter is implemented using the microstrip lines and the length of the microstrip lines are calculated by the eq. Optimum design is given below.
IV. 4X4 BUTLER MATRIX ARRAY
From the previous discussion it is evident that all the individual components are designed and simulated. The simulation results of the components are satisfactory. Now all the individual components are combined on a single substrate FR4 to implement the butler matrix array [3]. Optimum design of butler matrix array is given below.

Fig 8  phase shifting = -49.21°

Fig 9. Optimum design of 4x4 butler matrix array at 5.3GHz

Fig 10. Coupling levels $S_{15}$, $S_{16}$, $S_{17}$, $S_{18}$ at 5.3 GHz

V. CONCLUSIONS
This thesis presents the Design, Analysis and Gain enhancement of a 4x4 planar Butler matrix array for WLAN application. Initially all the necessary formulae for dimensions of hybrid coupler, crossover, phase shifter and radiating elements are evaluated using MATLAB. Then all the components are designed and simulated using commercial software SONNET. After achieving proper simulation results of all individual components, these components are then combined on a single substrate and simulated using SONNET. Here a high dielectric constant is considered for the design, hence after studying the simulation results of individual components and the whole structure it is evident that high loss has occurred and after observing the radiation pattern of the whole matrix when all the ports are excited it is evident that properly four fixed overlapping beams are not coming due to losses. To improve the radiation pattern and the gain, a stacked antenna array is designed with the butler matrix array. Basically another layer of dielectric with the same dielectric constant is placed above the whole matrix. Four rectangular patches of modified width and length are placed on the second layer. After simulation of the new structure of the butler matrix array, better radiation pattern is achieved and the gain is also satisfactory. Basically after seeing the radiation pattern of the new structure it is evident that four overlapping fixed beams are coming. But still losses are there due to high dielectric constant. These designs will cover 120° cellular area, for larger coverage the design should be extended to 8x8 matrix. Also to increase the gain, different kinds of radiating elements should be used.

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