Design of Optimal Antenna Array for Mobile Communication

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Abstract: -
This paper presents the design of an optimal microstrip patch antenna array for use with handheld units. The Array consists of two elements. Design structure, size and performance parameters of the antenna elements/array are optimized. This antenna array can provide good properties required for personal handy phones. It has wide bandwidth with steerable radiation pattern and can adjust its pattern by changing phase of elements. Thus the beam can be steered in required direction, while null is in the direction of interference for adaptive operation.

Keywords: - optimal antenna array, steerable radiation pattern, interference, handheld units, probe feed, and adaptive algorithm.

1 Introduction

As wireless communication systems evolve, service quality and capacity are of primary importance. To ensure reliable communication over a mobile radio channel, a system must overcome multipath fading, polarization mismatch, and interference. The trend towards low power hand held transceivers increases all of these challenges. Even if broader spectrum is allocated, demand for higher data rate services and steadily increasing numbers of users will motivate service providers to seek ways of increasing the capacity of their systems. Also, for wireless communication systems, it is normally necessary to develop small, lightweight and low profile antennas having a wide bandwidth. Another desirable characteristic is a steerable radiation pattern [1], which is achieved by using antenna arrays. The solution to these problems is to introduce antenna arrays at handset [2, 3, 4].

In this paper we design an optimal antenna array operating at 2.4GHz. These 2-element antenna array features are wide bandwidth with steerable radiation pattern and can adjust its pattern by changing phase of elements. Thus the beam can be steered in required direction and the null in the direction of interference for adaptive operation.

The paper is organized as follows: in section 2, handheld arrays are discussed**.** Adaptive algorithm with optimum weights is presented in Section 3. The design of antenna array is described in section 4. Results and discussions are in section 5.

2 Handheld Arrays

In antenna literature, a number of smart antenna arrays for base station applications have already been proposed [5, 6]. However, only little effort has been considered for developing antenna array receivers suitable for handsets. In fact, there are several difficulties with the implementation of such a solution at the handset level. First, the space on the handset device is limited, which does not allow us to implement an antenna array with enough elements for efficient spatial signal processing. The second problem is related to the movement of the mobile that provides an omnidirectional scenario. Third, the cost and the complexity of the implementation at every mobile are much greater than the implementation at each base radio station. Besides these difficulties, the adaptive algorithm for signal processing at the handset phone has to be fast, needs only a few simple calculations, and requires a simple hardware implementation. Also, peer-to peer systems of handheld transceivers that use antenna arrays can achieve reliability comparable to systems of single-antenna handheld units, with less transmitter power, resulting in lower overall power consumption and increased battery life.

3 Adaptive Algorithm and Optimum Weights

To optimize some property of the received signal the complex weights for each element of the array can be calculated. This does not always result in an array pattern having a beam maximum in the direction of the desired signal but does yield the optimal array output signal. Most often this is accomplished by forming nulls in the directions of interfering signals.

To optimize the element weights, for two element array as shown Fig.1, we minimize the mean squared error between the array output and the reference signal d (t). Optimizing SINR will lead to weights that differ by a scalar multiplier from the weights shown in Fig.1. The derivation proceeds as for the case of omni directional elements, and the solution for the optimum weights is

$w_{opt} = R_{xx}^{-1} r_{xx}$ ------------ (1)

Where $R_{xx} = X(t)X^H(t)$ is the signal covariance matrix and $r_{xd} = d^*(t)X(t)$. This is the same as the expression for the optimum weights for an array with isotropic elements. In this case, however, R_{xx}, r_{xd}, and hence w_{opt} are functions of the angles of arrival of the L+1 signals, and of the element patterns.

Let us consider the two-element array at the mobile handset. Considering the desired signal $S(t)$ arriving from direction θ_d and interference signal $I(t)$ arriving at θ_i. Both the signals have same frequency f_0. The signal from each element is multiplied by a complex variable weight and the weighted signals are then summed to form the array output.

The output of the two element array in fig1 is given as

$Y(t) = A\, e^{j2(\pi)fo}(w_1 + w_2)$ ------------ (2)

For $Y(t)$ to be equal to $S(t)$ it is necessary that

$R(w_1) + R(w_2) = 1$ ------------- (3)

$I(w_1) + I(w_2) = 0$ ------------- (4)

Where R , I are real and imaginary values.

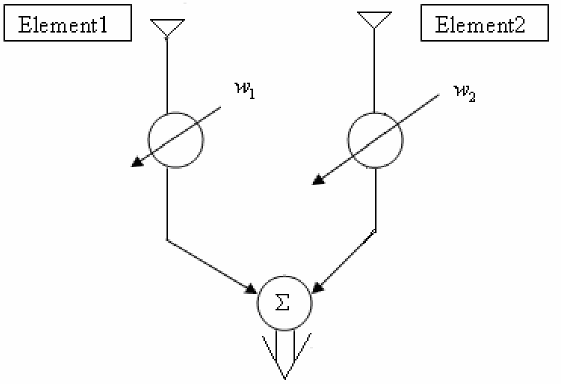


Fig.1: Two-element array with variable weights

The incident interference signal arrives at element 2 with a phase lead w.r.t element 1 of value of $2(\pi)(1/\lambda)\sin(\frac{\pi}{6})$ that amount to $\pi/2$. Consequently the array output due to the interference is

$Yi(t) = Ne^{j2(\pi)ft} w_1 + Ne^{j(2(\pi)ft+\frac{\pi}{2})}$ ------ (5)

For array interference response to be zero it is necessary that

$R(w_1) + R(jw_2) = 0$ ------------- (6)

$I(w_1) + I(jw_2) = 0$ ------------ (7)

Simultaneous solution of above equations yields

$w_1 = \frac{1}{2} - j\frac{1}{2}$ ----------- (8)

and

$w_2 = \frac{1}{2} + j\frac{1}{2}$ ---------- (9)

With these weights, array will accept the desired signals while simultaneously rejecting the interference signals [7]. This means the array will form a null towards the direction of the interference i.e. reflected signal. The adaptive antennas utilize the signal processing algorithms to continuously distinguish between desired and interfering signals.

4 Antenna Array Design

Microstrip antennas possess attractive features such as low profile, lightweight, small volume, mechanically robust and low production cost. Also to achieve directional radiation pattern, without increasing the size of individual elements, we need to deploy an array. To obtain a compact antenna array system, a microstrip antenna that operates in the 2.4 GHz ISM band is used as a radiating element. Using this microstrip antenna, we designed and simulated a new experimental 2-element array prototype. We use only two elements array because there is size problem when designing array at handset level.

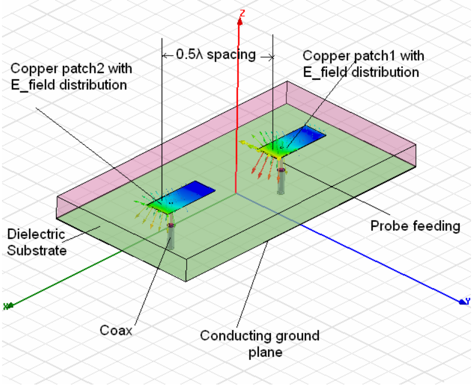


Fig.2: Model of two elements array with 0.5λ spacing

The geometry of the designed patch antenna array is shown in Fig.2, which comprises of two rectangular patch elements each of 1.1×2.5cm sizes, which are supported by substrate of FR4_epoxy layer with height 1cm having dielectric constant of 4.4, placed above probe feed line. The probe fed patch has several key advantages. The feed network, including phase shifters and filters, is isolated from the radiating elements via the ground plane. Due to this feature the spurious radiation is minimized and it is the most efficient feed method because the probe is in direct contact with the element. The substrate material having lower dielectric constant has been selected to provide higher value of bandwidth, directivity and efficiency for microstrip antennas. Initially the spacing between elements is taken 0.5λ for no side lobes and small size.

The simulating Tool, HFSS, has produced all the simulation results. Several parametric tests have been done for better matching. Then optimization is done, to reduce size up to a specific limit, which can give desirable characteristics for an optimal antenna array. Similarly other characteristics like bandwidth, directivity, gain and power efficiency were also optimized using the specified Tool to get better values with small size.

5 Results & Discussions

Better matching has been obtained, namely S11= -25dB≤-10dB at fr = 2.4 GHz as shown in Fig.3. The bandwidth at the resonance frequency has been increased to 270MHz for VSWR less than 2. The Directivity obtained is more than 7.7dB while Gain obtained is 7dB. The VSWR is 1.18, which is less than 2, while the Radiation efficiency obtained is 85%. In Fig.4 the Radiation pattern for same phase delays between elements has been shown.

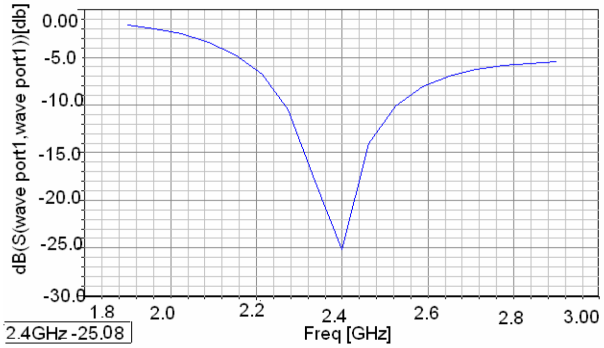


Fig.3: Return Loss for 2-element patch array with 0.5λ spacing

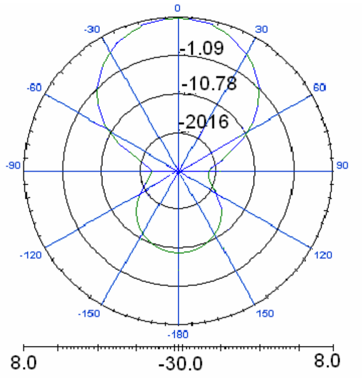
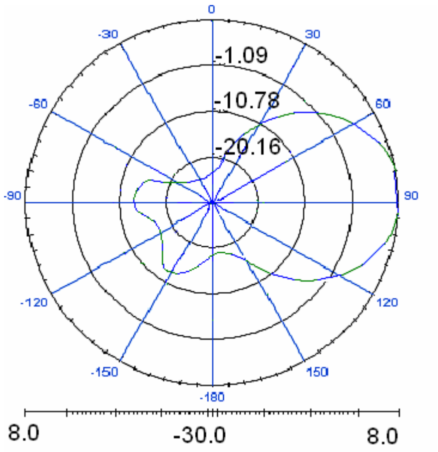


Fig.4: 2D Rectangular Plot of far field radiation pattern at -180≤ θ≤180, (ϕ=0°)

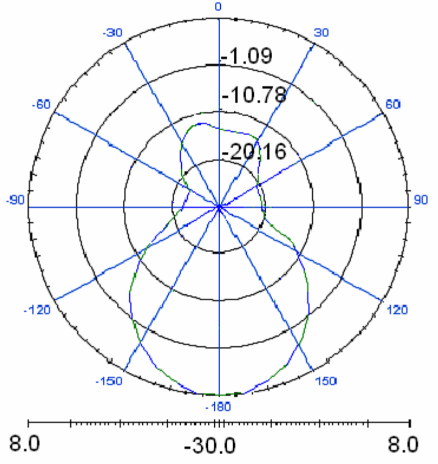
Different spacing between elements starting at 0.5λ has been simulated and analyzed, as depicted in Table.1. For spacing less than 0.5λ there is coupling between the elements of the array. At exactly 0.5λ spacing, we get less coupling and no side lobes. As the spacing between the elements is further increased the beam becomes sharp and the directivity increases up to 8.8dB at 0.9λ spacing but its drawback is that side lobe level increases and the array total volume increases.

Table 1: Shows effect of element spacing on Directivity

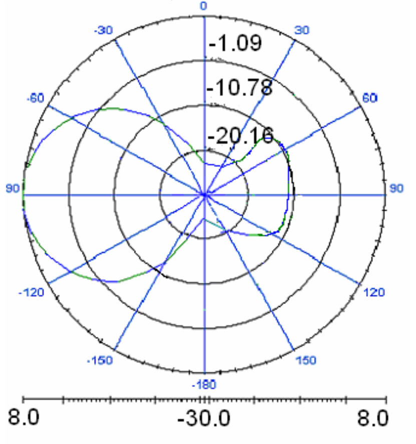
Element spacing, n	Directivity (dB)
0.5 λ	7.7
0.6 λ	7.9
0.7 λ	8.33
0.8 λ	8.5
0.9 λ	8.8



(ϕ=90°)



(ϕ=180°)



(ϕ=270°)

Fig.5: 2D Radiation pattern in the azimuth plane at the same elevation angle (θ) for different feed schemas for the Microstrip patch antenna arrays showing the beam steering characteristic.

6 Conclusions

An optimal microstrip patch antenna array for use with handheld unit of mobile wireless communication has been designed and optimized. This antenna array provides wide bandwidth, better matching, high directivity with steerable radiation pattern and adjusts its pattern by changing phase of elements. Thus the beam can be steered in required direction, using control algorithms, and the null in the direction of interference for adaptive operation in real time. The designed structure technique is useful for smart antennas.

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