Multibeam Antenna System Using Passive Beamforming Networks For Broadband Wireless Communications

Dr. John Howard and Jasmin Desai
ET Industries
Boonton, NJ 07005, USA
jh@etiworld.com, jasmin@etiworld.com

Abstract— **This paper introduces a novel approach of providing multiple narrow beams using a single antenna for high frequency broadband wireless applications. It incorporates passive beamforming networks along with beamshaping circuits to reduce side lobe levels into adjacent beams. The complexity of software programs in beamforming networks is eliminated by using passive microwave components and transmission lines. This design helps implementing beamforming networks at the radio frequency (RF) stage without any signal degradation and interference within multiple beams. A multibeam antenna system increases user capacity and throughput as well as provides a higher quality of service and spectral efficiency.**

Index Terms — **Beamformer, Antenna, Array, Multibeam, Beamshaping.**

I. System Overview

The multibeam antenna using the Space Division Multipe Access (SDMA) concept is a major breakthrough in solving the problems of limited spectrum and user capacity. It offers a high capacity in a limited frequency spectrum without any major technological changes [1]. SDMA is implemented by most wireless service providers to better utilize available spectrum. However, SDMA is conventionally restricted to three sectors in a 360 degree coverage. Using a multibeam antenna system, the number of sectors can be increased up to 48. Consequently, this system can increase the number of subscribers with improved quality of service. This is made possible through the beamforming networks' ability to reuse frequency and mitigate interference.

This system can transmit data, voice and video signals in multiple directions and at long distances without the need for repeater stations. The result is that cost is minimized and reliability, quality and subscriber numbers are all increased substantially. Instead of using a short distance (low gain) omni directional antenna, this long distance (high gain) narrow beam directional antenna is used. Normally a long distance antenna would increase the number of subscribers in a single direction. However, It prevents subscribers in all other directions from using the system. The proposed system has solved this problem with the help of multibeam techniques that can either simultaneously or sequentially reemploy the high gain antenna so that the spherical coverage of the omni directional antenna can be achieved along with the substantial increase of subscribers in all directions. A further increase in capacity can be achieved by frequency reuse techniques.

The multibeam system is a hardware solution which utilizes a phased array antenna and proprietary Optibeam beamformer networks developed by Electromagnetic Technologies Industries Inc. (ETI). It eliminates the requirement of any software programs and external power sources which make it more robust in a harsh environment. The rest of the paper is organized as follows: Section II explains the design of multibeam antenna in detail. The beamformer design is discussed in section III. Section IV shows the performance results of the multibeam antenna system and section V provides areas of application. Finally, we conclude in section VI.

II. Antenna Design

The major components of the proposed multibeam antenna system are the antenna and the beamforming network. The antenna consists of small antenna elements, such as dipole or patch antenna, arranged in an array. The beamformer provides the required phase to all antenna elements in order to generate beams in various directions. The design parameters for both components are equally important and they are explained in more detail herein.

The antenna in our proposed system uses a patch antenna as an array element. Patch antennas are based upon microstrip printed circuit technology. The advantages of using a patch element are compact size, low manufacturing cost, less weight, ease of installation and high reliability. Each element is fed with different amplitude and phase according to the direction of radiation. The elements then combine with different phases in the far field and form a narrow beam. Our antenna is designed as a linear phased array with equal interelement spacing and progressive phase shift across it [2] [3].

The spacing between each element is maintained to be $\lambda/2$ at center frequency. The feed point is selected to be at the center line of the patch. However, the exact position is determined by experimental results of input reflection measurements. Besides the feed point, the shape of the patch is also selected carefully to have voltage standing wave ratio (VSWR) less than 1.5. We selected the feed point to be slight higher than the center point which gave better performance in our range of operation. Other design parameters of the patch element are

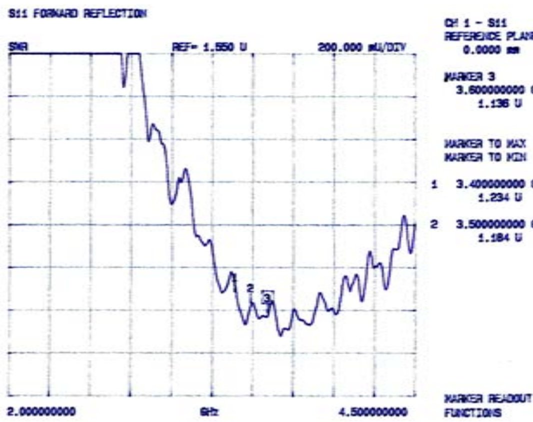

Fig. 1. Input Reflection Measurement of Multibeam Antenna

- Resonant frequency = 3.7 GHz
- Substrate height = 0.030 inch
- Dielectric constant = 2.2
- Patch length = 1.575 inch
- Patch width = 0.710 inch
- Feed point = slight higher than center
- Polarization = vertical

Many patch antennas are arranged linearly on a single dielectric substrate to achieve an azimuthal beamwidth of 15 degree and vertical beamwidth of 7 degree. The design of a 4 beam antenna requires a minimum of 4 arrays of patch elements [4]. The gain of the antenna is 26 dB and front to back ratio of more than 30 dB with side lobe level 20 dB lower than the main lobe. The performance of a 4 beam antenna system is verified using the vector network analyzer and the results are shown in Figure 1. The operating range of the antenna is 3.2 to 4.2 GHz with the VSWR less than 1.5.

III. Beamformer design

The beamformer is a complex network comprising passive microwave components are used to provide the required phase and amplitude to the RF energy between the antenna and transceivers. The beamforming network in antenna arrays shapes the beams and steer their direction electronically without any mechanical motion. The beamformer is designed by considering time or frequency domain analysis. In this paper, we have selected frequency domain beamforming networks for broadband applications [5] [6] [7] [8].

In order to minimize the RF signal loss and maintain signal properties, such as phase and amplitude, the beamformer is placed closed to the antenna or it is integrated with the antenna assembly. In the present example, the beamformer is placed near the antenna and the phase across the array is maintained using phase matched cables as shown in figure 2. These phase matched cables have an accuracy of $\pm 1°$. The length of cables is selected to be 36 inches with insertion loss less than 0.5 dB.

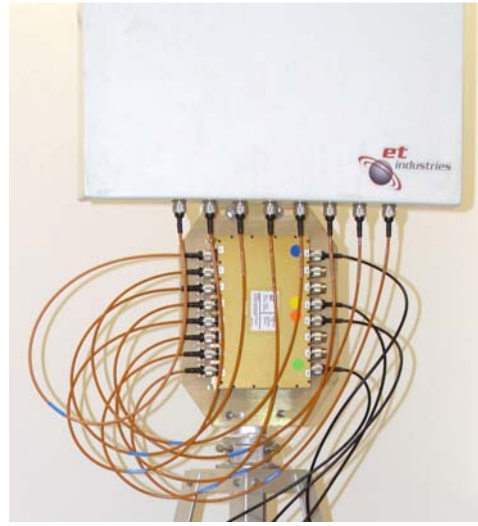

Fig. 2. Multibeam Antenna System

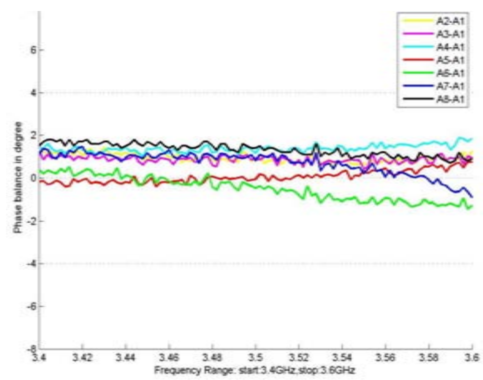

Fig. 3. Phase balance results

In this example, the beamformers are designed using a combination of quadrature couplers, microwave hybrids and phase shifters in order to accomplish the phase requirements to generate 4 beams in a 60 degree sector. Fully symmetrical 90 degree hybrid junctions can be utilized for vector addition to create desired phase weights. The hybrids are integrated taking advantage of inherent impedance transformations thus reducing the insertion loss by minimizing the use of matching transformers. A 4 beam antenna beamformer is designed to operate for the 3.4 to 3.6 GHz band. The performance is measured using the Agilent N5230A network analyzer connected to the Agilent U3042A multiport test setup in 3.4 to 3.6 GHz range. Figure 3, 4 and 5 show the results of a typical 8 beam beamformer.

IV. System performance

The multibeam antenna radiation pattern is measured in an open environment in the frequency range of 3.4 to 3.6 GHz. The beamformer is connected to the antenna using phase

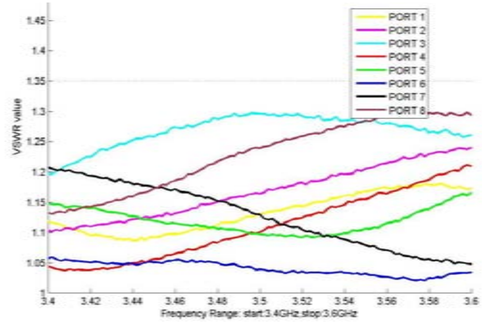

Fig. 4. Input VSWR performance

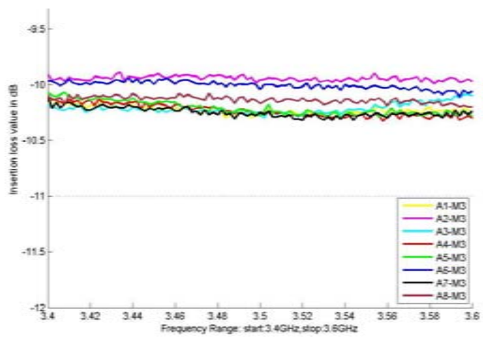

Fig. 5. Insertion loss between i/p and o/p ports for 8X8 beamformer

matched RF cables. The beamformer inputs are supplied with four different center frequencies and each has a 7 MHz wide channel. These frequencies are 3.440, 3.480, 3.520 and 3.580 GHz. The input RF power is 5 dBm and the received power is measured at 200 meter distance using a spectrum analyzer. The received signal power is measured at every 2.5 degrees on a circle drawn with 200 meter radius considering a 4 beam antenna as a center. The practical radiation pattern is presented in Figure 7. The theoretical radiation pattern is also shown in Figure 6 using MATLAB simulation.

V. Applications

The analysis in the previous section indicates that six such antennas can be arranged to provide 360 degree coverage for wireless communications. Potential application of this multibeam antenna system is in Worldwide Interoperability for Microwave Access (WiMAX) and cellular networks. It drastically increases the user capacity and spectral efficiency.

VI. Conclusion

The space division multiple access based multibeam antenna system increases the network capacity and the throughput by providing frequency reuse. The design parameters of the antenna and the beamformer are explained thoroughly. The performance of the entire system is verified in an outdoor environment and is compared with the theoretical results simulated in MATLAB. From the results shown above it is evident that the experimental results confirm the design and theoretical calculations of the multibeam antenna system.

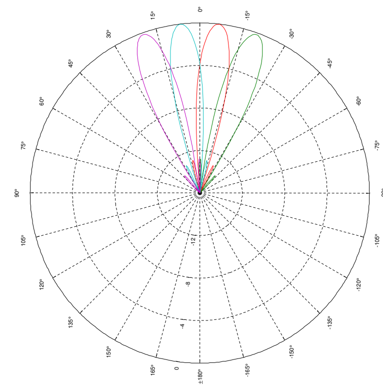

Fig. 6. Theoretical 4 beam Antenna Pattern

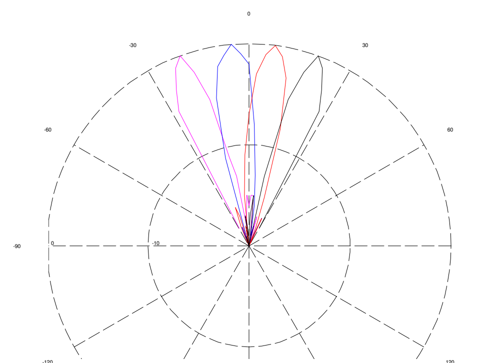

Fig. 7. Practical 4 beam Antenna Pattern

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