Clever Dumb Antenna: Passive Multibeam Antenna for Broadband Wireless Communication

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***Abstract* — A passive multi-beam antenna systems with beamforming technology that can be used to increase quality of service, network capacity, and spectrum to meet the current and future demand of data usage and network capacity is presented. The system presented can produce as many as 32 narrow high-gain beams in a 120° sector with beam crossing set to be between 3 to 10 dB. Each beam provides a capacity and throughput multiplication over a traditional cell site. Frequencies can be reused in a sector resulting in a spectrum multiplication of as many as 32 times. With the use of multiplexers several channels can be combined and transmitted in each beam providing multi-band/ multi-channel transmission with a single antenna system to further increase user capacity and throughput.**

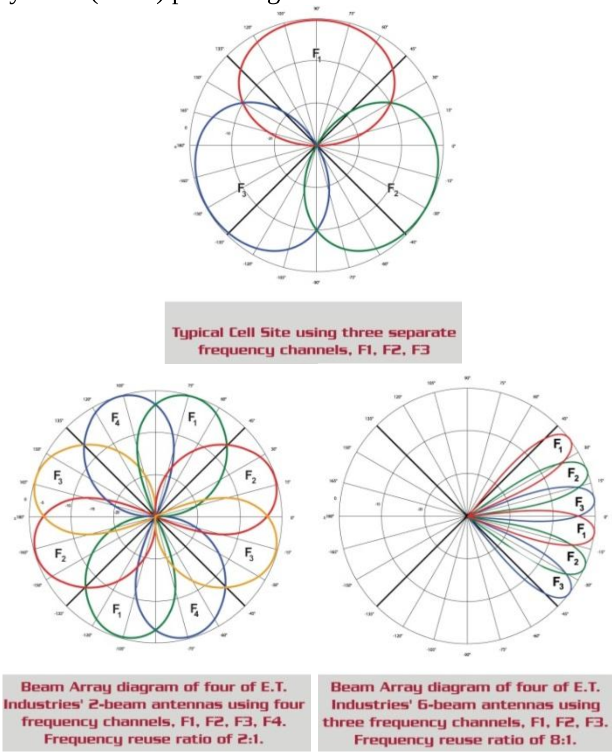
***Index Terms* — Beamforming Networks, Frequency Reuse, Multifrequency Antennas, Phased Arrays, Spectrum Multiplier Antenna**

I. INTRODUCTION

Multi-beam antennas can provide increased wireless capacity with enhanced spectral efficiency. A method to enhance spectral efficiency is to use space division multiple access (SDMA) techniques. SDMA methods provide higher user capacity in a limited frequency spectrum. SDMA techniques are implemented by most wireless providers to optimize the use of available spectrum [1]. Typically, wireless providers use three sectors in a 360° coverage area. With the passive multi-beam antenna system spectrum and capacity can be multiplied as many as 32 times within 360° coverage, providing 96 dual polarized beams. The benefit of such a system is higher data throughput, higher customer capacity, increased spectral efficiency, and reduced number of cell sites versus traditional coverage [2]. With the use of multiplexers, several frequency channels can be merged and transmitted into a single beam producing a multi-channel sector. For every channel that is transmitted into the beam, an increase in capacity and throughput factor is obtained.

II. MULTI-BEAM ANTENNA SYSTEM

Multi-beam antenna systems are the solution to the ever growing demand of data usage and network capacity in urban environments. Multi-beam phase array antenna systems can divide up a 360° cell site into several narrow high-gain sectors. Fig. 1 shows a typical cell site with three 120° sector antennas and multi-beam antenna systems (MAS) producing more sectors.



Typical Cell Site using three separate frequency channels, F1, F2, F3

Beam Array diagram of four of E.T. Industries' 2-beam antennas using four frequency channels, F1, F2, F3, F4. Frequency reuse ratio of 2:1.

Beam Array diagram of four of E.T. Industries' 6-beam antennas using three frequency channels, F1, F2, F3. Frequency reuse ratio of 8:1.

Fig. 1: Traditional versus Multi-beam Comparison

Each beam is accurately spatially aligned by a beamforming network while a beam-shaping network shapes the radiation envelope of each lobe. The beam former network focuses each beam in a specific direction electrically and the beam-shaping network minimizes the possibility of interference radiating from the antenna in a sector. Because the beams are narrow and are focused in a specific direction, the individual beams are spatially isolated. Although the gains of these antennas are higher than the traditional antennas currently being deployed (15-16dBi), the systems presented herein can achieve the same footprint if required by tilting the antenna. Otherwise, the gain can be employed to reduce the number of site in an area. The gain of such a multi-beam antenna is 18- 27dB.

As the number of narrow non-overlapping beams/sectors in a cell site increases so does the capacity and throughput. Although Fig. 1 illustrates several different frequencies being reused, UMTS where frequencies reused in a single site and also adjacent sites are a standard method of communication can also be used to increase capacity and quality of service. With the use of multiplexers with this system, multi-channel sectors in one or multiple bands can be created allowing for multi-carrier and multi-channel support.

The antenna system being presented is named as the "Clever Dumb Antenna" because it contains all passive components. A growing trend in communication industry is the use of tunable smart antennas. These antenna systems are commonly paired with variable microwave components such as phase shifters controlled by microprocessors which can be used to move the position of the beam in both azimuth and elevation to target densely populated areas. However, tunable components require additional power sources and are not as reliable. The clever dumb antenna system provides complete 360° coverage at all times. Being a passive system, it is robust and does not require a power source and maintenance.

III. BEAMFORMING NETOWRK (BFN)

A beamforming network (BFN) is a network comprised of several passive microwave components. As the number of beams increase so does the complexity of the BFN. The BFN provides the required phases and amplitudes of signal between the antenna and system transceivers. A BFN shapes the beams from the antenna array and steers their directions electronically without need for mechanical motion. Such a system can be designed with time or frequency domain analysis of the electrical and microwave components. An example of a simple BFN is a 4 by 4 butler matrix that can be produced with four 90° hybrids and two 45° phase shifters connected in the block diagram shown in Fig. 2 where the M1 through M4 represents the input of the signal and A1 to A4 are the connections to the antenna [3].

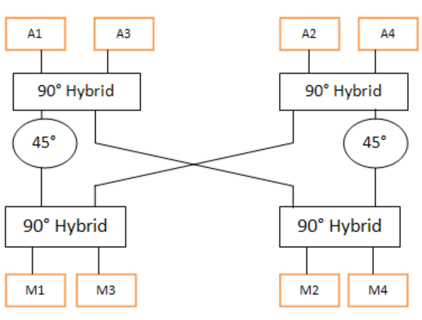


Fig. 2: 4 x 4 Butler Matrix BFN

This type of beamforming networks can be designed to be broadband and can provide multi-band coverage allowing for multi-band and multi-channel coverage [(4)]. More complex butler matrix BFN such as the 8x8 or the 16x16 butler matrix can be designed to produce additional beams but the design realization becomes very difficult with increasing numbers of passive microwave components and cross overs needed to obtain the correct phases [5]. An equation used to obtain the phase per a given mode of the butler matrix is:

$$\Psi = \frac{(2k-1)(n-1)\pi}{N} \tag{1}$$

k = mode of matrix
N = total number of output modes
n = output port number
Ψ= Phase output in Radians

Using the equation above, the phase of each output can be calculated for each mode with any number of outputs. The phases of each output for each mode can be seen in the table below in Fig. 3.

	A1	A2	A3	A4
M1	0°	45°	90°	135°
M3	0°	-135°	90	-45°
M2	0°	135°	-90°	45°
M4	0°	-45°	-90	135°

Fig. 3: 4 x 4 Butler Matrix Phase Chart

IV. Passive Multi-beam Antenna System

The passive multi-beam antenna system consists of several antenna array columns adjacent to each other. The picture on the left seen in Fig. 4 below shows the beamforming network connected to one of ETI's antenna while the picture on the right is another type of antenna design that allows for reconfiguration.

Fig. 4: ETI Multi-beam Antenna Systems

Phase matched cables are used to connect from the beamforming network to the antenna system to maintain the correct steering position of the multi-beam system. The passive multi-beam antenna system employs complex passive beamforming techniques to allow for frequency reuse. Interference between each beam is reduced using a propriety technique. In addition, beam-shaping methods are deployed to reduce side lobe levels to minimize interference between beams [6]-[7]. An example of a multi-beam antenna system radiation pattern can be seen in Fig. 5 below.

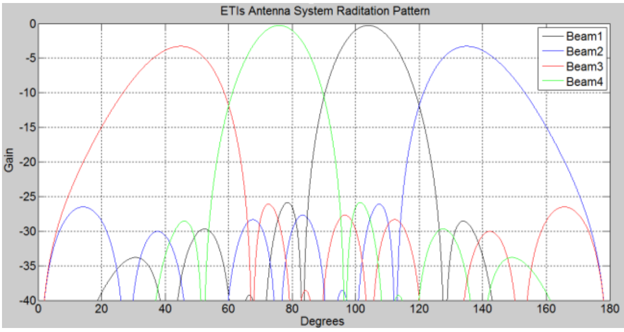


Fig. 5: Radiation Pattern of a 4 Beam Antenna System

The multi-beam system being shown produces 4 beams in a 120° sector. The system produces side lobe levels 25dB below the maximum gain of the main beam. Because of this, all 4 beams can transmit at the same time effectively, with minimal interference. The number of beams for a given sector of 90° or 120° can be modified with a change in the beamforming network while using the same antenna. This gives the user an option of upgrading a similar system with fewer to a more advanced system with a larger number of beams to meet user and data demand growth. An example of performance specification a beamforming network is shown in Fig. 5.

V. CONCLUSION

A traditional 360° cells sites is divided up into three sectors. With the passive multi-beam antenna systems, spectrum and capacity can be multiplied as many as 32 times within 360° coverage, providing 96 dual polarized beams. The benefit of such a system is higher data throughput, higher customer capacity and increased spectral efficiency. The beam crossing can be designed to cross between 3 to 10 dB with side lobe levels of 25dB, allowing the system to be used for GSM and UMTS. As the number of beams increases, so does the capacity and throughput. With the use of multiplexers, multi-channel sectors can be created to further enhance the benefits of the system. The multi-beam antenna system is clearly the solution to the ever growing demand of data usage and network capacity for the finite amount of spectrum.

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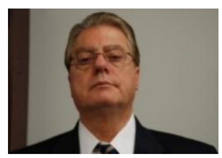

Dr. John Howard founded Electromagnetic Technologies Industries, Inc. (ETI) in 1996 after a 20-year career at some of the world's leading technology companies. He has held senior engineering positions at companies the likes of Merrimac Industries, Narda (Loral) Microwave Corporation, RCA Astro Lab - Satellite Systems Division, Marconi Space and Defence Systems - Corporation Radar and Missile Systems Division and the British Aerospace Corporation. During his extensive career, Dr. Howard has managed to make time to share his knowledge and experience as an Assistant Professor at Chelsea College, University of London, UK from 1976 thru 1978 and then as an Adjunct Professor at Polytechnic of New York in Farmingdale, NY from 1983 thru 1984 and finally as an Adjunct Professor at New Jersey Institute of Technology from 1989 thru 1993.Dr. Howard's work has earned him several awards including the Marconi Space and Defence Systems Award in 1980 for his work in Innovative Electronic Countermeasures Solution and the RCA Award for Authors & Inventors in 1983.Dr. Howard boasts over 85 published papers on Antennas, Beamformers, Defense and Telecommunications Systems, Filters, Microwaves and Electromagnetic Theory. While attending University College Cardiff, University of Wales University College London, University of London and Chelsea College, University of London he earned degrees in Electrical and Electronic Engineering, Microwave Engineering, Microwaves and Modern Optics and most notably a Ph.D. in Satellite and Terrestrial Communications.

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Chuck has worked for ETI since 2011 with a focus on antenna design and beamforming networks for RF systems. He holds a BS in Electrical and Computer Engineering at Worcester Polytechnic Institute. Mr. Fung's experience includes the design and manufacture of low profile, directional, high gain antennas for Wi-Fi applications. His computer work involves the design, programming, construction, and testing of robots.