A Polarization Diversity Multi-Beam Antenna for ZigBee Applications

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Abstract — The paper presents a cognitive antenna (dubbed GEN 2) based on the Self-Structuring Antenna (SSA) technology, which dynamically alters its aperture to maximize Signal-to-Noise-Ratio (SNR) in challenging RF environments. The GEN 2 antenna provides polarization-diversity as well as two distinct beams per polarization (total of four beams). It has a simple SSA configuration utilizing self-structuring feed and is effective in improving SNR for ZigBee applications. The GEN 2 antenna is also compatible with MIMO implementation.

***Index Terms* — WiFi, ZigBee, Adaptive, Polarization Diversity, Multi-Beam, MIMO, Selection Diversity, SSA.**

I. Introduction

Both polarization diversity and multiple beams are effective ways of increasing Signal-to-Noise-Ratio (SNR) in challenging RF environments [1-5]. Polarization diversity is a cost-effective way to increase SNR using a single aperture [3,6] while employing multiple beams has been shown to consistently increase the channel capacity in low as well as high SNR cases in non-line-of-sight settings. This paper evaluates the effectiveness of a polarization diversity antenna with multiple beams in improving SNR for ZigBee applications in indoor environments. The antenna is Monarch Antenna, Inc.'s GEN 2 antenna, the prodecessor to GEN 1, which provided only polarization diversity [6]. As in GEN 1, GEN 2 also utilizes the self-structuring feed feature of the Self-Structuring Antenna (SSA) configuration and has four distinct broad beams [7]. Any one of the beams can be selected in an adaptive fashion based on the Received Signal Strength Indicator (RSSI) with the aid of a control algorithm and DC control signals, which drive the RF switches on the antenna aperture. The control algorithm can be a simple set of instructions installed on a micro-controller on the wireless device and only micro-Amps (at 3Volts) are needed to operate the RF switches.

II. DESCRIPTION OF THE ANTENNA

Figure 1 shows the antenna board with a female SMA connector for RF and a 5-wire connector for DC control (Ground, Supply, and three independent control voltages). The aperture, feed network and the control lines are etched on the top side of a 2-sided PCB board made of 0.093" (2.36mm) thick Isola FR408 laminate with 0.5oz copper deposit on both sides in a microstrip arrangement. The horizontal dimensions are 154mm x 154mm. Backside of the antenna is solid copper and is responsible for the hemi-spherical coverage as depicted in Figure 2.

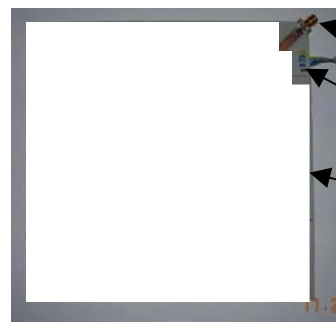

Fig. 1. Polarization Diversity Multi-Beam (GEN 2) Antenna printed on 0.093" (2.39mm) FR4 (Isola FR408) with nominal parameters of $\varepsilon_r = 3.77$ and $\tan\delta = 0.012$. Copper cladding is 0.5 oz on each side. The aperture design is not shown due to patent filing in progress.

Figure 2 shows the hemi-spherical (frontal) coverage of the GEN 2 antenna, which has a broad high gain pattern toward the side of the board, on which the aperture is etched and a low gain pattern toward the back of the board (which is solid copper). Measured Front-To-Back Ratio (FBR) is 13dB, which contributes about 3dB increase to the frontal gain.

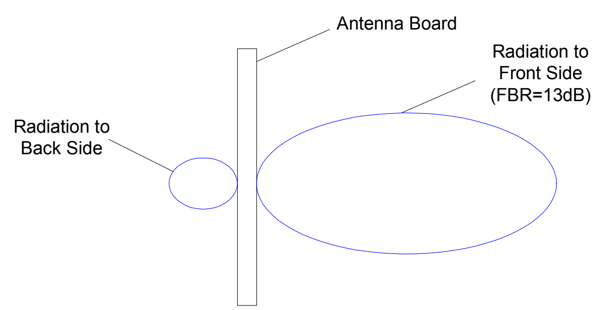

Fig. 2. Frontal Coverage of GEN 2. Front-To-Back Ratio (FBR) is 13dB.

The Antenna is capable of radiation and reception at either vertical or horizontal polarization with two beams per polarization as shown in Figure 3. The operation is accomplished via a control software running on a laptop and pushing out control DC signals through a USB adapter as shown in Figure 4. When integrating the GEN 2 into a wireless device, this control algorithm would reside in a microcontroller.

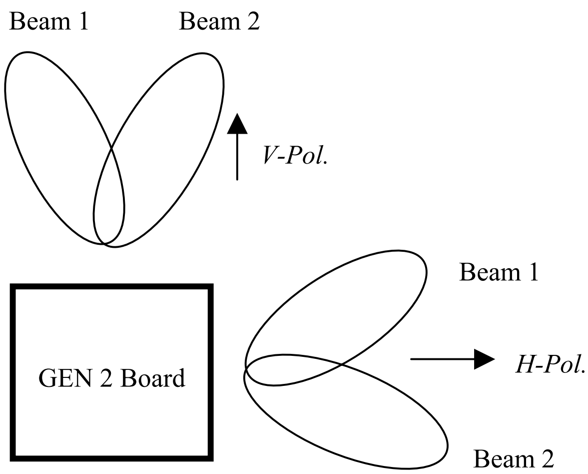

Fig. 3. Two Beams per Polarization (Total of Four Beams).

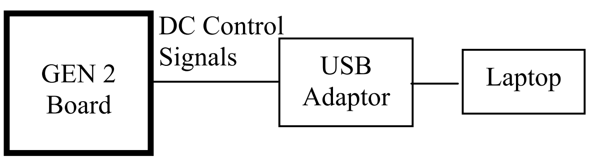

Fig. 4. Control of the antenna board by a Laptop via a USB Adaptor.

III. ANECHOIC CHAMBER AND THE MEASURED GAIN PATTERNS

Figure 5 shows the measurement setup, which consists of a Vector Network Analyzer (VNA) connected to the high gain horn and the antenna under test housed inside the anechoic chamber with a noise floor of -60Db (with respect to a calibrated S_{21}). All of the measurement data have been collected using this set up. Figure 6 shows the vertical and horizontal polarization gain patterns measured. The maximum gain values for each beam are obtained by comparing the s21 values to those obtained for a reference half-wave resonant dipole with a gain of 1.5dBi.

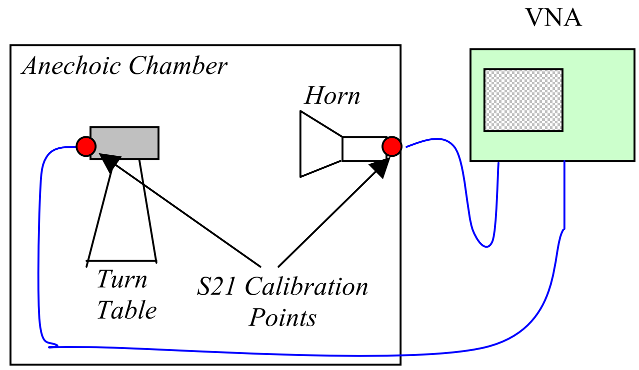

Fig. 5. S21 Measurement Setup in Monarch's Anechoic Chamber in Belleville, Michigan. Chamber is rated for 400 MHz – 6GHz with a Noise Floor of -60dB after calibration.

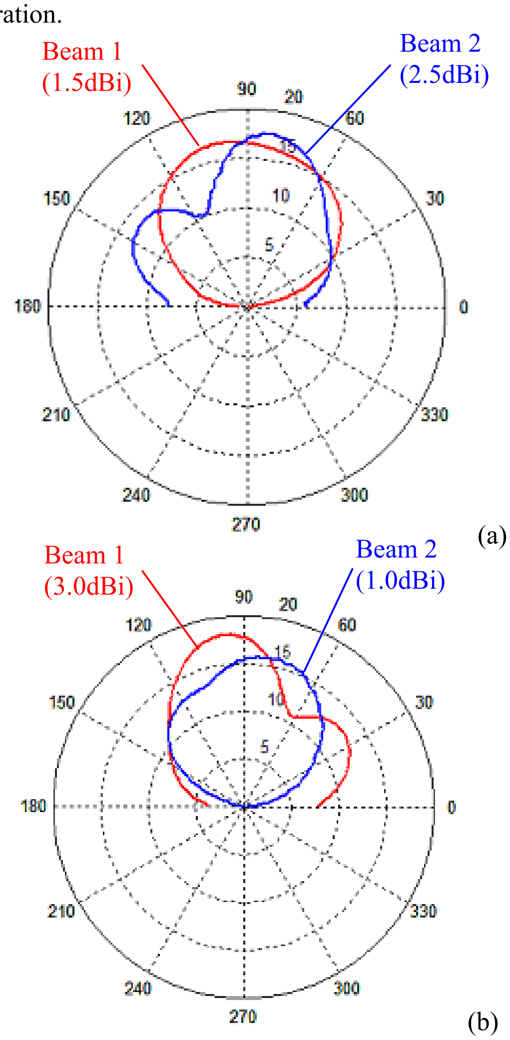

Fig. 6. Four beams generated by the GEN 2 antenna. (a) Vertical Polarization Beams, (b) Horizontal Polarization Beams.

IV. ZIGBEE MEASUREMENT SETUP

Meshbean E1 Development Boards

Figure 7 shows the two Meshbean E1 development board units from Meshnetics, which provide low rate wireless data transmission using ZigBee protocol [8]. The units are called the *Coordinator* and the *End Node* and are used in this study to test the effectiveness of GEN 2 in improving RF link quality. Figure 7 shows both units fitted with monopole antennas and this set up is used as reference for measuring the improvement provided by the GEN 2.

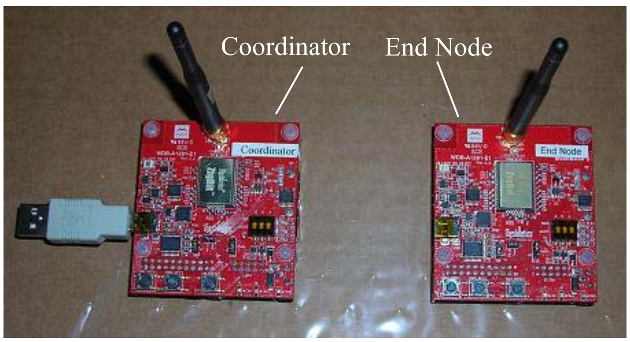

Fig. 7. Meshbean E1 development boards from Meshnetics. The shown set up, where both the Coordinator and the End Node are fitted with a monopole antenna is used as reference for evaluating the GEN 2 performance.

ZigBee Link with Monopoles

When monopoles are used on both the Coordinator and the End Node (see Fig. 7), the setup is as shown in Fig. 8. A software running on the laptop pulls Received Signal Strength Indicator (RSSI) data from both the Controller and the End Node (though they are often same numbers due to reciprocity of the RF link). Figure 8 also shows a picture of how the Coordinator is connected to the laptop via the USB port.

ZigBee Link with GEN 2

For testing GEN 2 antenna, in reference to Figure 8 above, the monopole on the Coordinator is replaced with the GEN 2 antenna as shown in Figure 9. Also shown are pictures of the actual setup and the USB adapter used to generate parallel DC control signals to select the beams. Laptop has two pieces of software running simultaneously: One software pulls the RSSI data from both the Coordinator and the End Unit while the second software generates DC control signals to switch among the four independent beams.

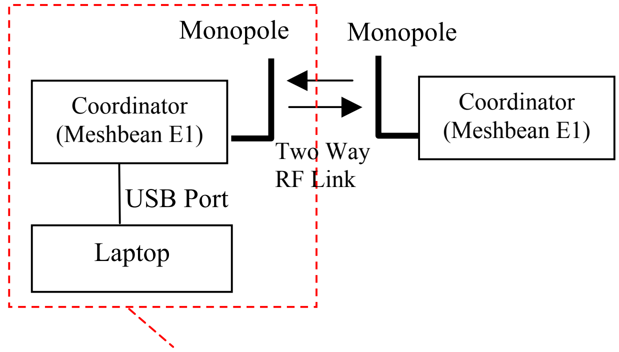

Fig. 8. ZigBee Setup with monopoles on both units.

V. PERFORMANCE OF GEN 2

Monarch's facility in Belleville, Michigan was used for assessing the performance of the GEN 2. Figure 10 shows the floor plan of the second floor of Monarch's facility, where the Controller was placed in the Conference room while the End Unit was moved from one location to another (Storage 1, 2 and Office 1,2,3) to record the RSSI. First, both units had monopoles connected to them as shown in Fig. 8 while the End Unit was placed such that the monopole is vertical (aligned with the Controller) and also horizontal (not aligned with the Controller). For both the vertical and horizontal cases, the RSSI was recorded. In the next step, the Controller was connected to the GEN 2 antenna along with all the interface hardware needed to control the antenna as shown in Fig. 9 while the monopole remained on the End Unit. For each of the End Unit locations and for each orientation of its monopole (vertical and horizontal), RSSI was observed for each of the four beams of GEN 2 and the highest RSSI value was recorded (one of the four beams always gives the highest RSSI).

The values indicated on the floor plan in Figure 10 under each location are the improvements in RSSI when GEN 2 is connected to the Controller (as opposed to the monopole) for both the vertical (V) and the horizontal (H) orientations of the End Unit's monopole. The improvement is significant with an average value of 9.4dB. The difference is more pronounced when the End Unit is horizontally placed since this represents a polarization mismatch when both units are connected to a monopole (and the GEN 2 is able to correct for the polarization).

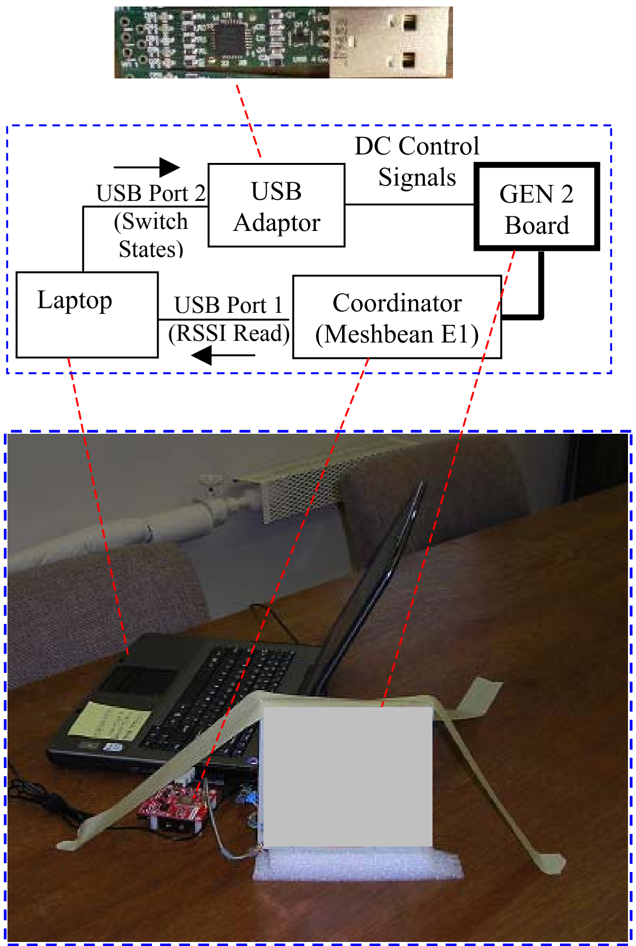

Fig. 9. ZigBee Setup with GEN 2 antenna on the Coordinator (End Unit is always connected to a

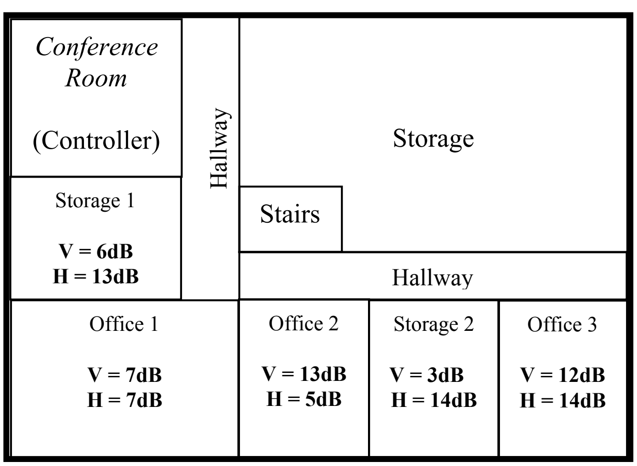

Fig. 10. Floor plan of the second floor of Monarch's facility where the indoor tests were conducted, showing the improvement in RSSI by the GEN 2 antenna over the monopole in units of dBm. Average improvement is 9.4dB.

VI. SUMMARY

A polarization-diversity multi-beam antenna (dubbed GEN 2) has been presented for improving SNR in ZigBee and WiFi applications. Measurements were conducted for ZigBee indoor cases and the results are expected to be similar for WiFi applications. An average of 9.4dB improvement in SNR was observed when one of the units were fitted with the GEN 2 antenna and this number is expected to increase when both units are fitted with the GEN 2. The antenna is a simple implementation of the SSA technology and serves to illustrate the value of the self-structuring antenna (SSA) technology.

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