# A Compact Wideband MEM Switched Diversity Antenna for Indoor Mobile Channels

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*Abstract* — **In this paper we introduce a wideband three-element diversity antenna for compact wireless communication systems operating at the 4-6 GHz band. A series of experiments to characterize the diversity performance of the antenna for non-line-of-sight (NLOS) indoor multipath environments have been conducted. From these experiments, we calculate envelope correlation, power imbalance, and diversity gain. We also use this structure as a basis for another diversity antenna, with RF MEM switches providing different reception/transmit characteristics for switched diversity signals. A novel printed circuit board (PCB)- compatible RF MEMS process technology employed to construct the system on RT/Duroid5880 is discussed. Radiation characteristics of the MEM switched antenna are also provided.**

## I. INTRODUCTION

The multipath propagation effects caused by environments with scattering such as indoors, urban, and rural areas are viewed as impairment and complicate wireless communications. On the other hand, recent works [1] have shown that environments with multipath richness possess decorrelated channels that can be exploited to turn multipath distortion into an asset by enhancing channel capacity. Typically multi-element antennas (MEAs) employing different diversity techniques (spatial, polarization, pattern) are used to access the decorrelated channels of multipath environment and to improve reliability and quality of mobile links experiencing multipath fading and interference. A diversity antenna, which may consist of multiple antennas or a single reconfigurable antenna, provides different reception characteristics, thus, received signals are decorrelated at some level. Different reception characteristics can be achieved through differences in spatial location, state of polarization, and radiation pattern of the antenna. Improved signal-to-noise-ratio (SNR), channel capacity, bit-error rate and power savings are the benefits of diversity MEA. Besides diversity MEA, signal processing techniques and coding/decoding schemes are few other important aspects of wireless communications systems. In this study, we shall treat diversity MEA only. Furthermore we employ a novel PCB compatible RF MEMS technology to integrate antennas with RF MEM switches for switched beam diversity.

Wideband diversity MEA providing a high enough SNR to support high-speed broadband communications applications in the 4-6 GHz propagation channel is of our particular interest. A two-element broadband antenna integrated with RF MEM switches on glass produced with typical MEMS processes has been previously introduced [2]. In this work, we use three elements of the same antenna structure and monolithically integrate them with RF MEM switches on PCB using a novel RF MEMS technology.

The paper is organized as follows. In section II, we investigate the diversity performance of the proposed three-element antenna structure. To this end, we conduct a series of experiments to determine the correlation coefficients between the signals received over the three antennas, power imbalance between diversity branches and diversity gain. Section III provides a brief discussion of PCB-compatible MEMS technology, an important contribution of this study. A proof of concept is provided through a three-element switched beam diversity antenna on RT/Duroid5880 ($\varepsilon_r$=2.2, tan$\delta$=0.0004). Radiation characteristics of the antenna are provided and discussed. Section IV concludes the paper.

## II. ANTENNA CONFIGURATION AND DIVERSITY CHARACTERIZATION

### *A. Configuration*

Fig.1 illustrates the configuration of the three-element antenna, used for diversity experiments. The impedance and radiation characteristics of the individual element of this antenna ("cactus antenna") were given in [2]. It has a 50% impedance bandwidth covering the 4-6GHz band. In this work, we concentrate our efforts on its diversity performance. Decorrelation among signals received over each antenna element is achieved through different orientations of three antenna elements as well as physical element displacement. In other words this antenna



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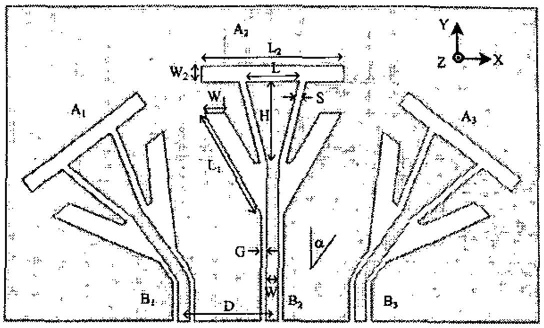



Fig.1 Three-element diversity antenna configuration (Dimensions are in mm) $L_2$=25, $W_2$=3.5, $L_1$=28.6, $W_1$=4.8, H=18, L=12, S=0.15, G=0.25, W=2.6, D=10; α=45 degree, Substrate: RT/Duroid5880, thickness=1.52mm

achieves its overall diversity performance from spatial, polarization and pattern diversity.

*B. Experimental setup and results*

Fig.2 illustrates the components of the experimental setup for diversity evaluation of the three-element antenna. On the transmitter end, a 4 GHz RF signal generated by HP83630L synthesized swept-cw generator with 0dBm is amplified and radiated by a dipole with 30dBm power level. This signal is received by two (A1 and A2, or A1 and A3) of the three-element cactus antenna at each experiment run. Received signals are amplified, followed by filtering unwanted signals, and then, detected by E4412A power sensor. Lastly, they are measured by E4418B power meters. The data are collected through a GPIB card and processed by computer.

During the experiments, the transmitter, located in a typical laboratory environment, is kept stationary while the receiver end is moved along five different predetermined paths (C1, C2 C3, C4, C5) over a distance of 7 meters at approximately 1m/s speed. The sampling rate is 14 samples/second. 1000 samples are obtained by moving the receiver end back and forth along the paths for

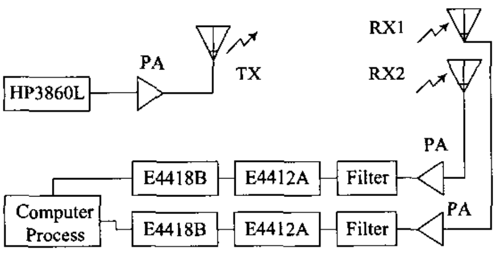
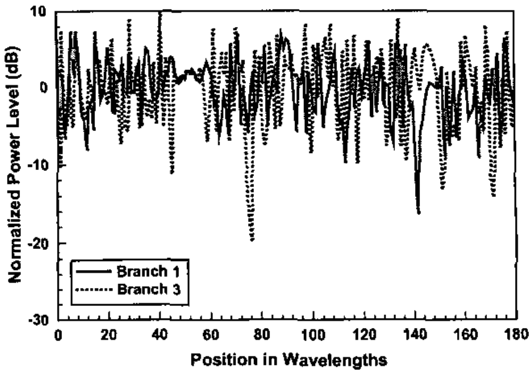
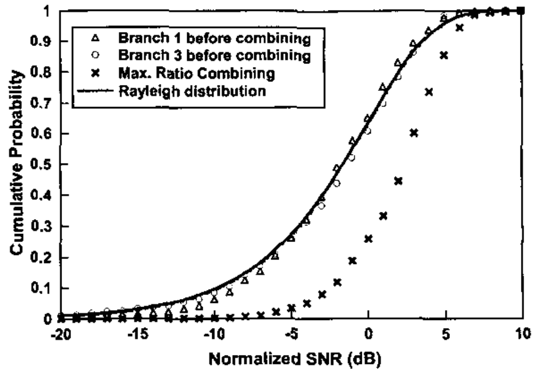



Fig.2 Illustration of equipment setup for antenna diversity evaluation




(a)




(b)

Fig.3 (a) Averaged fading envelopes of the signal strengths for path C4 from ports 1 and 3 (P1, P3). (b) Cumulative distribution function of signal strengths before and after diversity combining.

each experiment. The laboratory rooms where measurements are performed have different sizes and contain various barriers. These rooms are located at the third floor of the Engineering Gateway Building of the University of California Irvine. The paths are chosen such that NLOS is ensured between transmitter and receiver.

Fig.3a shows typical fading envelopes of the recorded signal power level of two diversity branches (B1 and B3). These envelopes are normalized with respect to mean of the stronger branch. Normalization is essential to preserve the power balance information, which is important for determining diversity gain of the antenna. The cumulative distribution functions of these envelopes as well as the signal at the diversity combiner output are shown in Fig.3b. Rayleigh distribution, which represents pure multipath environment, is also given as a reference in this figure. From these plots diversity gain of 6.2 dB is observed for 10% probability level. Maximum ratio combining is employed in these measurements. The power correlation coefficients ($\rho_P$) of branch signals are calculated by the equation (1).

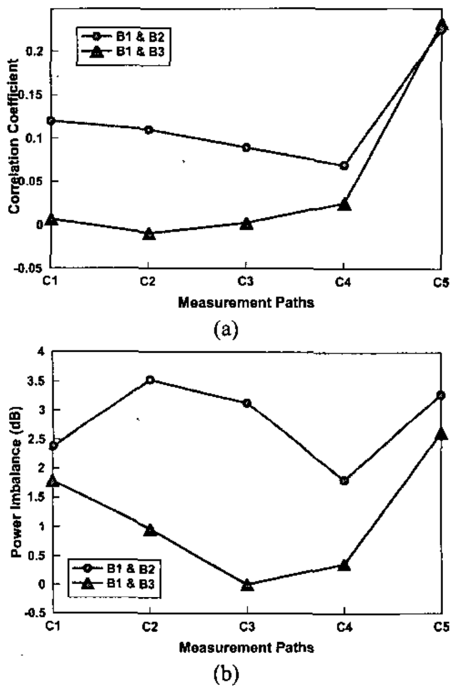



Fig.4 (a) Power correlation coefficients (b) power imbalance between diversity branches as a function of different paths

$$\rho_P = \left(\sum_{i=1}^{N} X_i \cdot Y_i\right) \times \left[\left(\sum_{i=1}^{N} X_i^2\right)\left(\sum_{i=1}^{N} Y_i^2\right)\right]^{-1/2} \quad (1)$$

Where $X_i = S_1(i) - 1$, $Y_i = S_2(i) - 1$, N=1000. $S_1(i)$ and $S_2(i)$ represents normalized received power level for each branch, respectively. The power correlation coefficients and power imbalance between diversity branches of B1 and B2, and B1 and B3 as a function of different paths are shown in Fig.4a and Fig.4b, respectively. Low values of correlation coefficients and similar power levels in each branch indicate that the proposed antenna structure can provide high diversity gain in indoor multipath environments. Fig.5 shows the diversity gain for maximum ratio diversity combining at the 10% probability level for different paths. Diversity gain values of 4-6.5 dB are achieved. Diversity gain from port 1 and 3 is higher than that of from port 1 and 2. This is due to the lower correlation coefficient and power imbalance of the diversity branches of B1and B3, compared to those of B1 and B2.

## III. Antenna Integrated with RF MEM Switches

### *A. PCB Compatible MEMS Technology*

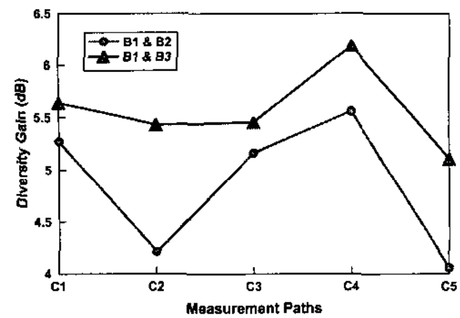



Fig.5 Diversity gain at 10% probability as a function of different paths

RF MEM switches have been the device of choice for reconfigurable applications due to their superior switching performances such as very low insertion loss, high isolation, and ultra-low power requirement. One drawback, however, has been the limited choice of substrates for these switches. This has prevented MEMS reconfigurable antennas from achieving excellent system level performance, as that offered by low cost RF MEMS. A typical MEMS reconfigurable antenna consists of elements integrated with discretely packaged RF MEM switches. RF MEM switches are fabricated on substrates such as silicon, GaAs, and glass with the antenna elements being constructed on a different substrate (typically PCB), for low dielectric constant/loss to ensure good radiation and impedance characteristics. Discretely packaged RF MEM switches are then attached to PCB substrate and wire bonded to the antenna elements. Matching circuits are also required to preserve the VSWR of the system. This approach is expensive due to the individual packaging of the MEM switches; wirebonds and matching circuits also increase complexity and loss. On the other hand, the breakthrough advantage of PCB-compatible RF MEMS technology lies in making possible RF MEM switches on *any* PCB substrate, plus monolithically integrating antenna elements with switches on this same substrate. System level packaging then allows for reduced cost and, by eliminating all wirebonds and most of the matching circuits, reduced loss, complexity, and size. This process technology calls for two novel process techniques, low-temperature (90-170 °C) high-density inductively coupled plasma chemical vapor deposition (HDICP CVD) and compressive molding planarization (COMP). HDICP CVD is required to deposit $SiN_x$ at low temperatures in order to be compatible with typical operation temperatures (150-200 °C) of PCBs. COMP is used to planarize uneven surfaces of sacrificial photoresist layer for switch membrane formation. A more detailed discussion on this fabrication technology and its use for monolithically

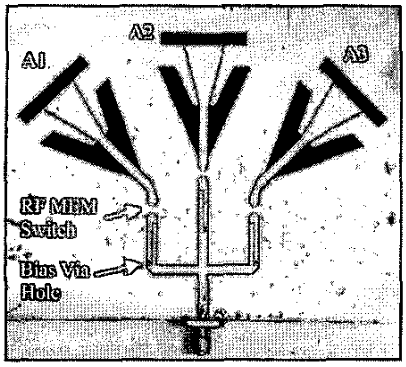



Fig.6 Photograph of the diversity antenna integrated with RF MEM switches

integrating RF MEM switches with three-dimensional antenna elements on a PCB substrate are given in [3] and [4] respectively.

*B. Fabrication and measured radiation patterns*

As a proof of concept for the PCB compatible RF MEMS process technology, we integrate the three-cactus antenna elements with RF MEM switches described in Section II to create a MEM switched diversity antenna. A Photograph of the fabricated system is shown in Fig.6. Three MEM switches located on CPW feed lines are employed for selection (or switched) diversity combining, where only one particular signal branch at a given time is selected and is connected to the receiver. Selection diversity schemes with one-port antenna systems offer economical and practical advantages over multi-port diversity schemes where maximum ratio combining is typically used.

To fabricate the antenna system, we employ the same fabrication technology described in [3] and [4]. In this antenna we exploit well-established PCB via hole process to create bias circuitry for the MEM switches. Vertical vias run from the central electrode of each switch to the other metallic layer of the PCB. It is worth noting that using vertical vias, which are not possible for glass substrate, allows bias circuitry to be fabricated on the opposite metallic layer of PCB to the layer of antennas. This results in more real estate available for antenna, thus more antenna elements, which is critical for capacity enhancement in wireless communication systems.

By selecting the ON and OFF states of the switches we can either activate a particular single antenna (A1, A2 or A3) or create a superposition radiation pattern by activating more than one antenna. Fig.7 illustrates the measured x-y plane co-polar radiation patterns corresponding to the sequential individual activation of

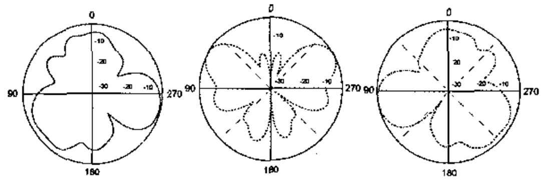



Fig.7 Measured co-pol radiation patterns from each antenna element in the x-y plane when the three switches are sequentially activated

the three single antennas. As a result of the inter-element 45° rotation angle, radiation patterns with 45° rotation can be clearly distinguished in the figure. With appropriate activation angular or polarization discrimination of a useful weak signal from an unwanted strong interference can be performed in multipath scenarios. For example the axis of the active element can be oriented to the direction of the strong interference.

## V. CONCLUSION

Radiation and diversity characteristics of a wideband compact diversity MEA have been studied for indoor multipath environments. This antenna structure achieves low correlation coefficients and power imbalance between branch signals and thus provides high diversity gain. Novel PCB compatible RF MEMS technology has been employed to fabricate a diversity antenna monolithically integrated with RF MEM switches on PCB substrate. RF MEM switches have been used to select a particular diversity branch for performing selection diversity combining.

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