AN INTEGATED CMOS INTERFERENCE CANCELLER FOR MIMO SYSTEMS

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Abstract — **In this work, we present for the first time the theory and CMOS prototype for a interference canceller that improves the signal integrity and radiated pattern of closely spaced antennas for MIMO systems. The theory and prototype have been evaluated in a WLAN testbed demonstrating improvements of 3 to 4 dB in maximum radiated power. This improvement translates into 50-80 % improvement in transmission distance, 40% reduction in power and 10x improvements in BER**

I. INTRODUCTION

Due to the cost of radio spectrum, and the limited supply, there is always pressure to deliver more spectrally efficient solutions, thereby increasing the network capacity at a lower cost per user. Third generation wireless systems are expected to trigger an explosion in wireless internet and data applications by delivering far higher data rates than previously possible. To keep pace with demand, research has been conducted on antenna arrays and multiple-input multiple-output (MIMO) wireless systems [1]. It has been shown that MIMO systems with n-transmitting and m-receiving antennas can achieve an average channel capacity that is approximately min(n,m) times higher than with a single antenna and the same overall transmitting power. This has led to many new challenges in signal transmission and recovery. The key challenge is how to practically achieve the potential capacity of MIMO systems. Current research on multiple antenna systems has been limited to the base station due to power, size and bandwidth constraints of the mobile environment, and limitations in the physical size of the mobile device. In typical mobile devices (e.g. cellular phones, laptops), 2-4 or more antennas can now be employed due to the development of new compact antenna designs.

When multiple antennas are involved, either at different frequencies or at the same frequency as in diversity solutions, distances between 17% and 33% of the wavelength ($\lambda/6$, $\lambda/3$) are considered as a compromise of isolation and compactness requirements [2]. Further reducing the spacing between antennas has a negative impact on gain, directivity, throughput, beam shape, reach, and efficiency as the isolation degrades and more coupling between antennas is introduced. In typical systems for WLAN or 3G Cellular Modules a minimum isolation of 15dB is required [2]. Antenna isolation results in greater flexibility to move the antenna closer to each other without suffering a performance degradation hit and/or resorting to retune the antennas.

In this work a novel interference canceller is introduced. The interference canceller results in improved isolation between closely spaced antennas. Results show more than 30dB isolation for $\lambda/10$ spaced antennas.

II. IMPLEMENTATION AND ANALYSIS OF THE INTERFERENCE CANCELLER SYSTEM

The proposed interference canceller, shown in Fig. 1, acts to suppress/cancel interfering transmit signals coupled onto closely spaced antennas that are in a "dormant" mode (i.e. non-transmitting state). The interfering signals are the result of leakage/common ground current coupling, free space (radiation) coupling and surface waves. The proposed solution can also deal with systems that have multiple antennas transmitting at any time (i.e. in a non-dormant mode). Decoupling the transmit signal from adjacent antennas results in improved transmit signal integrity and an optimal radiation pattern. The improvements are in efficiency, directivity, beam shape, throughput and reach.

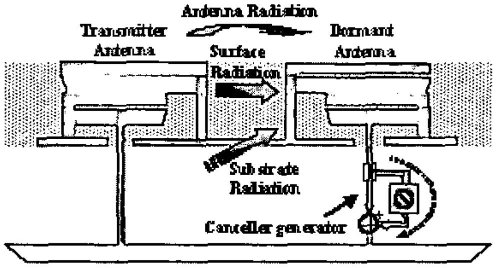

Fig. 1. Interference canceller principle

Previous reported methods [3]-[5] attempt to improve isolation between transmit and receive paths either via improved switch methods or by introducing mode suppression materials.

In the proposed interference canceller system, we directly tap off the electromagnetic (EM) coupled signal of the dormant antenna for use as a sample reference signal as illustrated in Fig. 1. The canceller then generates an emulation signal, which is adjusted in magnitude and phase such that it cancels the coupled signal off the dormant antenna. The tapped signal is fed through a delay element and variable gain amplifier.

Conceptually, the delay could be determined apriori based on the frequency of the carrier signal because of the narrow-band nature of the signal. However, such an approach is inadequate because it is difficult to realize precise delay values in the presence of IC process variations. Furthermore, this would assume a specific trace length between the cancellation IC and the antenna. We thus follow an adaptive approached that learns the value of both the phase delay and gain factor based on interference energy minimization. Specifically, the tapped (and compensated) signal is monitored with an energy detector circuit. The phase and gain are adjusted to empirically reduce the amount of interference to a predetermined level. It is important to realize that using this interference canceller approach in MIMO systems allows one to conserve power by optimizing the partial activation mode and increasing its duration.

Fig. 2 shows the reduction in electromagnetic coupling achieved by canceling the interfering transmitting signal off a "dormant" antenna; i.e. non-transmitting. Both of the figures in Fig. 2 show the simulated surface current distribution for a pair of compact folded-dipoles separated by 0.1λ. The left-hand antenna pair of Fig. 2 is for the uncompensated situation. Here the excitation of the dormant (right) antenna is clear and is the result of the undesired coupling. As shown on the right of Fig. 2, however, this unintended coupling can be largely removed by using the proposed cancellation approach as demonstrated by the near zero current distribution over the dormant antenna.

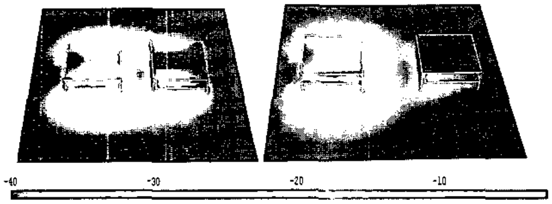

Fig. 2. EM coupling before and after cancellation

To view the benefit of interference cancellation from another perspective, the effect on the transmitting mode (left antenna in Fig.2) is shown in Fig.3. The left-hand figure here depicts the simulated radiation pattern of a single antenna system. The middle figure shows the pattern for a two antenna system where the second antenna is dormant and placed λ/10 away from the transmitting antenna. The addition of this second antenna reduces the maximum gain of the pattern from 4.9dBi to 3.9dBi. However, by using the proposed cancellation approach, the effect of the dormant antenna can be largely removed as demonstrated by the restoration of the gain to 4.7dBi. It should be noted that the interference canceller, in addition to directivity restoration, results in redirecting/reshaping the transmitted beam to the designed one, i.e. the isolated antenna case. This beam restoration results in 3 to 4 dB gain improvement to the design direction of maximum radiation. The overall effect of all these improvements translates into a 4x-5x improvement in transmission distance, 40% reduction in power and 10x improvements in BER.

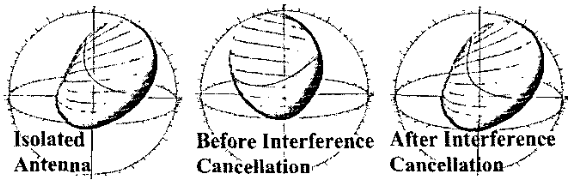

Fig. 3. Left: Directivity of radiation pattern for a single antenna (4.9dBi). Center: Directivity of radiation pattern for a pair coupled antennas before cancellation (3.9dBi). Right: Directivity of radiation pattern for a pair of coupled antennas after cancellation (4.7dBi).

III. Interference Canceller Implementation and Measured Results

To validate the proposed cancellation strategy introduced in the previous section, various paired patch antenna structures operating at 2.4GHz for 802.11 b/g applications have been fabricated and characterized on FR4 material. The designed paired patch antennas are separated by distances ranging from λ/10 to λ/2. The insert in Fig. 4 shows a λ/10 spaced paired patch antenna prototype. Additionally, Fig. 4 shows the input reflection coefficient of a patch antenna and the coupling between the paired patch antennas for different spacing. Clearly, the coupling is strongest for the λ/10 spaced patch antennas. The coupling for the different spaced paired antennas varies from -15 to -28 dB at 2.4GHz.

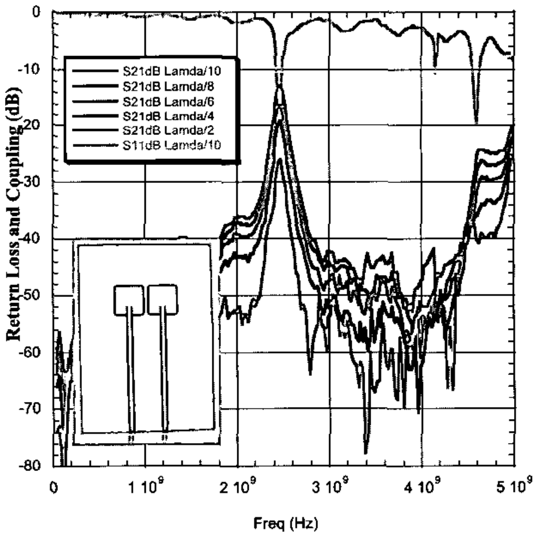

Fig. 4. Input reflection Coefficient of a patch antenna and EM coupling for different spacing paired patch antennas.

The interference canceller IC was designed and fabricated in standard 0.18μm CMOS and the circuit micrograph is shown in Fig. 5.

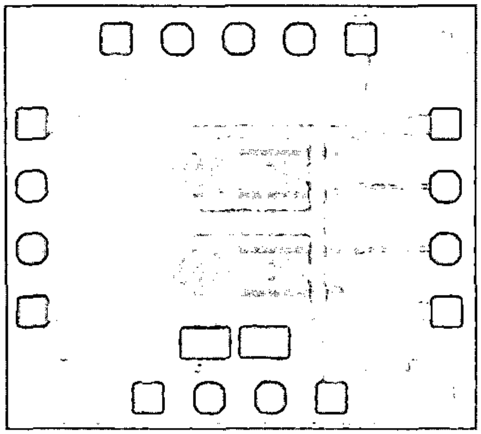

Fig. 5. CMOS 0.18µm chip micrograph and block diagram of the interference canceller.

The major function blocks of the interference cancellation IC are highlighted in Fig. 6. These blocks are the coarse/fine tune alignment, variable gain amplifier (VGA), and subtraction node. The coarse/fine tune alignment and VGA adjust the phase and magnitude of the tapped signal to match the incurred interference. The cancellation node then removes unwanted coupling from the dormant antenna.

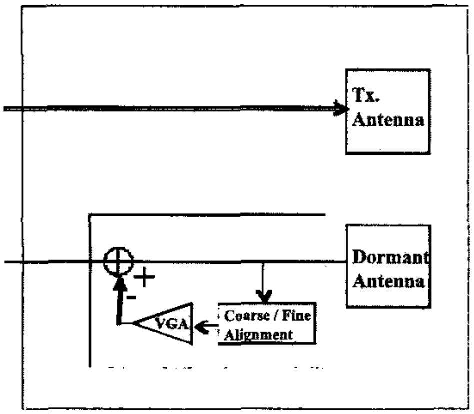

Fig. 6. CMOS 0.18µm chip micrograph and block diagram of the interference canceller.

Fig. 7 shows the performance improvement in transmit power spectrum for the λ/10 spaced patch antennas before and after interference cancellation for a fixed input power feeding the transmit antenna, i.e. one of the antennas is powered up with a fixed input power while the other one is dormant. The interference canceller results in a 1.08dB improvement in antenna gain which is achieved by the improvement in transmitted power. Fig. 8 on the other hand shows the cancelled EM coupled signal off the dormant antenna. A 32dB improvement in isolation is achieved for a 2x1 testbed of single patch antennas around 2.4GHz. This is extremely important in applications requiring extremely low receiver sensitivities, such as GPS (sensitivity less than -140 dBm) and low-power bio/chemical/explosive sensors.

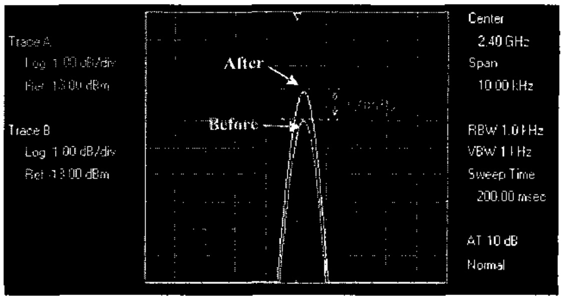

Fig. 7. Patch antenna coupling spectrum before and after EM Cancellation

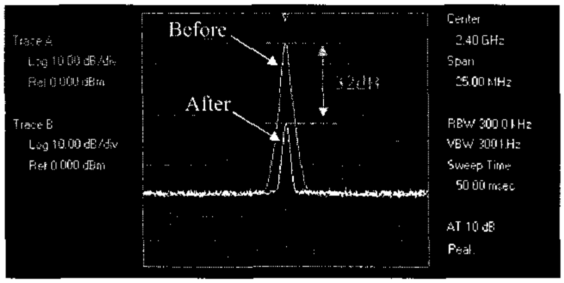

Fig. 8. Patch antenna coupling Spectrum before and after EM cancellation.

VII. CONCLUSION

In this work, we present for the first time the theory and CMOS prototype for an interference canceller that improves the signal integrity and radiated pattern of closely spaced antennas for MIMO systems. The theory and prototype have been evaluated in a WLAN testbed demonstrating improvements of 3 to 4 dB in maximum radiated power. These improvements translate into increased transmission distance (50-80%), power budget reductions (40%), and BER improvement (10x). We believe that the novel architecture and its validation represent a significant advancement in the development of compact, high performance diversity MIMO systems.

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