An Active Interference Canceller for Multistandard Collocated Radio

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***Abstract* — This paper proposes a novel active interference cancellation system that allows simultaneous operation of multi-standard collocated radios. It addresses specifically, the coexistence problem of closely spaced Bluetooth and 802.11b WLAN radio systems on a mobile wireless device. The suggested technique uses a small replica of the aggressing signal tapped off from the transmit antenna to generate a cancellation signal across the entire receive band. A prototype of the solution has been implemented on an FR-4 board, which consists of an emulation filter to model the coupling channel; and amplitude, delay and phase alignment of the cancellation signal. The required VGA and phase aligner have also been fabricated on chip with a 0.18 μm CMOS technology using active circuitry. Cancellation of up to –30 dB of in-band interference has been measured. The integrated components dissipate 15mW of power.**

***Index Terms* — Active circuits, bandpass filters, delay-lines, interference, phase shifters, spread spectrum communication.**

I. INTRODUCTION

The nature of growth in the wireless communications industry dictates that networking radios will be increasingly collocated in both frequency and space. This potentially places the multiple functionalities of wireless personal area networks (WPANs) and wireless local area networks (WLANs) at the users disposal while maintaining the benefits of spectral efficiency. The short range Bluetooth WPAN standard and the longer range Wi-Fi (IEEE 802.11b) that occupy the heavily used 2.4 GHz ISM band offer just such an example. However, despite the spread spectrum technologies employed in the above-mentioned radios and their complementary functions, their deployment in close proximity will necessarily lead to time-frequency collisions and interference.

Interference levels between Bluetooth and 802.11 WLAN radios for various situations have been quantified in the literature, in [1]. In [2], a probabilistic analysis of the interference environment is conducted and extended by simulation models of the Bluetooth and 802.11 Medium Access Control (MAC) and Physical Layer (PHY). The authors report a 25% packet loss while studying the performance of a Bluetooth module in the presence of WLAN interference. Similarly, the probability of 802.11 packet error in the presence of interference from a Bluetooth system is quantified in [3]. More recently, [4]-[5] offer simulations of these mutual interference phenomena with detailed models of the corresponding MAC and PHY layers.

As discussed in [5], various approaches may be adopted to suppress interference phenomena. Steps may be taken at the MAC or driver layer, but they have their limitations. For instance, software layer solutions will usually prevent simultaneous operation of the two radios. In this work, we propose a solution that is constituted in the PHY. Such a method is usually more exhaustive, allows simultaneous operation, and addresses the interference problem near the source.

This paper is divided into four sections. In section II, a brief description of the system is provided. This includes an overview of measured results that characterize and formulate the problem, and the general nature of the solution that is proposed. Section III discusses our implementation of the proposed solution. Here, we examine as proof of concept, a system devised on FR-4 material with discrete components, which achieves the desired objective of cancellation. This is followed by a description of MMIC designs that have been used to fabricate some of the above-mentioned components in a standard Silicon CMOS technology to replace their discrete counterparts on the board. Finally, measurement results are presented in section IV, followed by concluding remarks.

II. DESCRIPTION OF THE SYSTEM

A. Problem Formulation

In order to estimate the magnitude of the problem, various sets of paired patch-antenna structures were fabricated on an FR-4 material. These were designed for operation at 2.4 GHz.

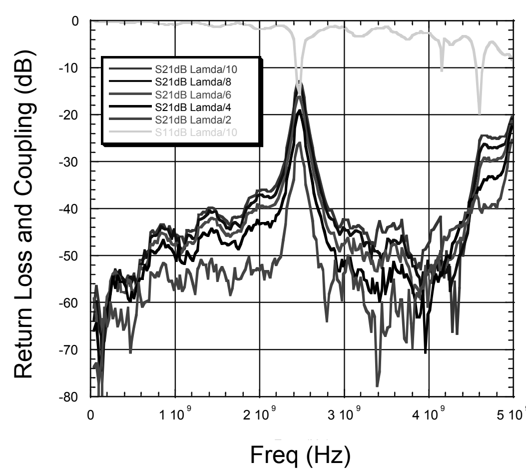

Fig. 1. Return loss and coupling for spaced patch antennas.

As shown in a previous work by the authors [6], a significant amount of coupling between the antennas was observed. Distances ranging from λ/2 to λ/10 separated the antennas. Fig. 1 shows the input reflection coefficient for an antenna and the coupling between antennas. The coupling is most at a spacing of λ/10, as expected, and it varies in magnitude from –13 dB to –27 dB for different spacings.

B. Proposed Solution

A Bluetooth aggressor is GFSK modulated with a bandwidth bit period product of 0.5. It is inherently narrow – band in the context of our problem with a symbol rate of 1 MS/s, occupying any of 79 RF channels in the 2400-2483.5 MHz band. The channels are defined by a pseudo-random hopping sequence, packet timing and access code, with a maximum hop rate of 1600 hops/s. The maximum transmit power is 20 dBm. An 802.11b signal uses complementary code keying (CCK), and occupies one of 3 non-overlapping 22 MHz channels in the same 2.4 GHz band. A maximum transmit power of 30 dBm is permitted.

In general, the cancellation technique employed may be represented as in Fig. 2.

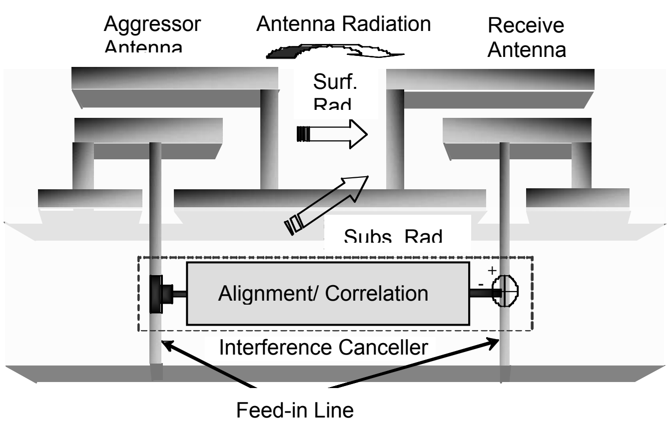

Fig. 2. Interference sources and cancellation mechanism.

Here, a downscaled replica of the transmitted signal is tapped off at the transmit end by means of a power-splitting device and passed through a cancellation unit. The generated cancellation signal is then combined with the received signal at a 180^0 phase differential. Control mechanisms are used to perform the appropriate amplitude and phase alignments. In some full-duplex systems, a loop cancellation method is used to generate narrow-band nulls at desired frequencies to achieve similar isolation. An example of such a method is discussed in [7].

The cancellation chain achieves the task of correlating the tapped-off model of the interfering signal with the coupled signal at the 802.11 receiver. Adjusting the amplitude, delay and phase of the tapped-off signal to match the coupled signal performs the correlation. Since the carrier frequency is much higher than the data rate, the modulation of the transmitted signal does not complicate the problem and correlation can be achieved by amplitude, phase and delay adjustments alone. Also, an emulation filter models the coupling channel in the correlation chain. While it is possible to cancel the narrow band interferer without the use of such a filter, the advantages of such a technique are many. First, narrow band cancellation methods are impractical when the interfering transmitter, or the receiver or both use spread spectrum technology. Second, the generation of a wideband cancellation notch not only suppresses the interferer but also the coupled broadband noise from the transmitter. Third, by band-limiting through the emulation filter, the coupled noise may be prevented from decorrelating for a larger time interval allowing easier cancellation as suggested in [8]. Power detection is used at the receive end to ensure successful cancellation.

III. Design and Implementation

A. Prototype Board

As a first step towards creating a prototype, a design as in the schematic of Fig. 3 was fabricated on FR-4 material, using several off-the-shelf components.

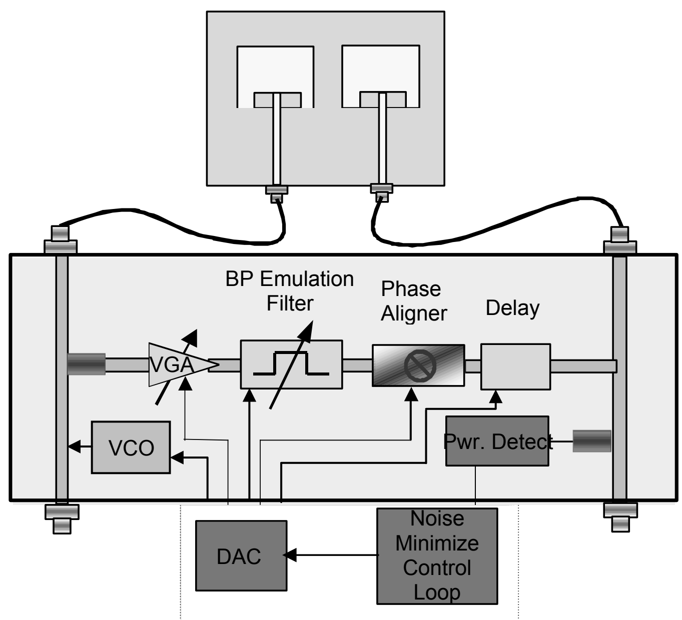

Fig. 3. Simplified schematic of interference canceller.

These include a VGA, 360^0 controllable phase shifter and delay line. The coupling channel has a bandpass characteristic and is roughly constant for a given physical configuration of the antennas. Under mobile conditions, small changes in the magnitude of coupling are observed. The coupling channel was modeled throughout the 83.5 MHz pass band by means of a varactor diode and other discrete components. In an alternate form, two pilot signals at frequencies near the band edges were injected into the transmit antenna and minimized at the receive end. The use of two pilot signals in this configuration yields optimal cancellation throughout the band as against providing a sharp null at a certain frequency, as we shall show in a subsequent graph.

B. MMIC Design

The components in the correlation chain can be integrated on-chip if they are implemented in a standard IC process. With this as an objective, the amplitude and phase adjustment circuits were designed in a 0.18 μm CMOS technology. These designs were achieved by a voltage controlled Gilbert cell-based VGA and a 180^0 range analog active phase rotator. These circuits operate from a 1.8V supply and were capable of accepting a few hundred mV of input swing. The designs did not use any inductive elements. Fig. 4 shows the circuit schematic of the Gilbert-cell VGA, and a die photograph.

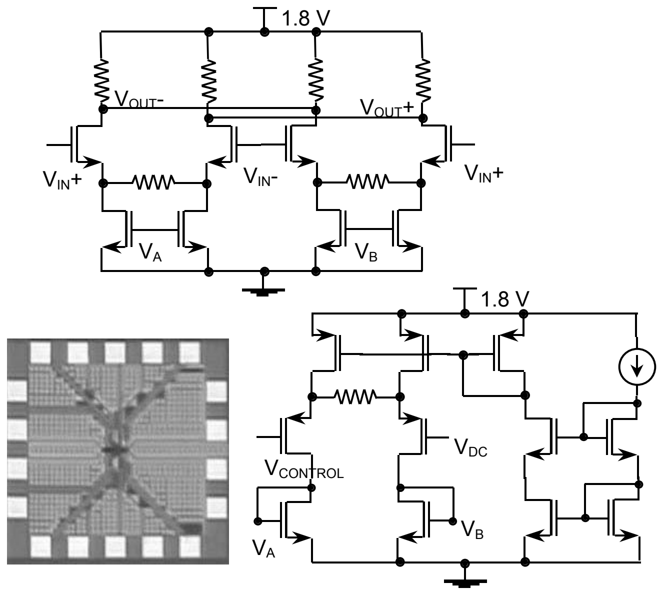

Fig. 4. Schematic circuit diagram of VGA and current source.

The total delay through the VGA was around 40ps at 2.4 GHz, and the AC 3-dB bandwidth was ~6 GHz. While the VGA can be used to perform the required amplitude adjustment, it can also provide a fixed 180^0 phase shift by tuning $V_{CONTROL}$ around V_{DC}.

Many approaches may be used to design the phase rotator. One method involves designing an exact 90^0 phase shifter that works in the entire 2.4 GHz band and two variable attenuators, to generate a 360^0 phase range. A delay-interpolator technique was used to design the circuit in this work. Such a circuit provides an excellent degree of continuous phase control throughout the desired range. Also, the phase tuning range required from this circuit is 180^0. Since the VGA may be used to provide an in-phase or 180^0 out of phase signal to the rotator at the same amplification, the two modes combined can produce a 360^0 control range. A block diagram depicting the operation of the phase aligner is shown in Fig. 5 for simplicity. Schematics are also shown for salient portions of the circuit.

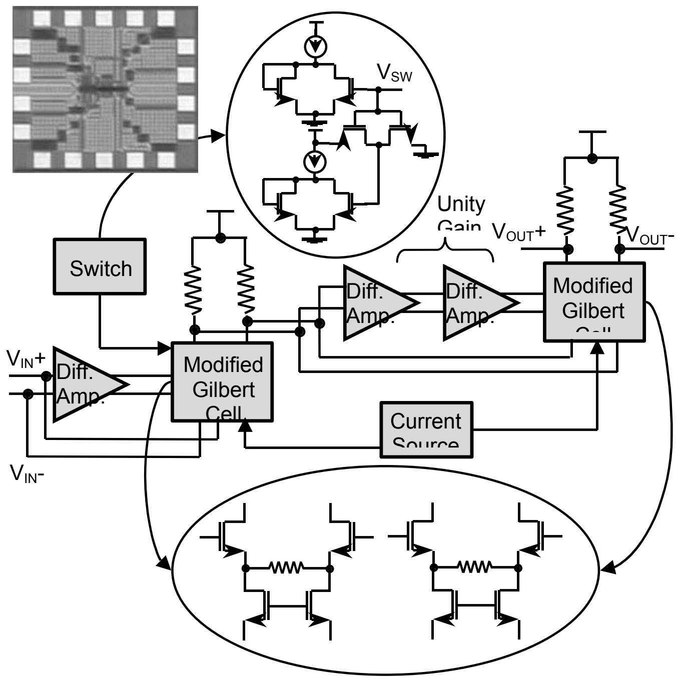

Fig. 5. Simplified schematic of 360^0 range controllable active phase rotator, and microphotograph of die.

All the differential amplifier stages shown are resistively loaded and provide a fixed delay at unity gain. A Gilbert cell is so modified as to allow each differential pair to accept different inputs. The outputs are, however, summed as in a regular Gilbert cell. The second half of the circuit consisting of two differential amplifier stages cascaded with a modified Gilbert cell, provides a phase range of $\sim 130^0$. This is accomplished by staggering the input to one of the differential pairs of the modified cell by the total delay of the two differential amplifier stages. At the output, any intermediate phase can be obtained by appropriately controlling the currents in the two differential pairs. The current source used is similar to that in Fig. 4, and allows the use of a 1.8V supply with a differential amplifier without encountering voltage headroom problems. Switching between the differential pairs of the modified cell in the first half of the circuit provides the remainder of the required 180^0 phase range. The rotator thus designed had an AC 3-dB bandwidth of 400 MHz.

IV. Results and Conclusion

Measurements were performed on the canceller system to study its impact on the coupling characteristic. The emulation filter was adapted to the coupling channel in the presence of signals at 2.4 GHz. A plot showing the transmission parameters through the coupling channel before and after interference cancellation is presented in Fig. 6.

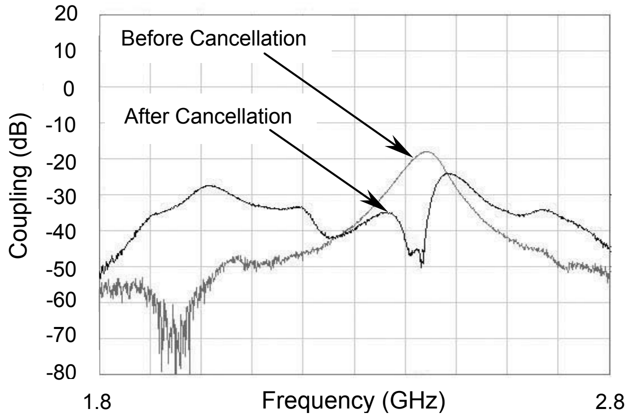

Fig. 6. Coupling spectrum before and after interference cancellation.

A polar chart representation of the transmission characteristics is shown in Fig. 7, along with a photograph of the prototype board.

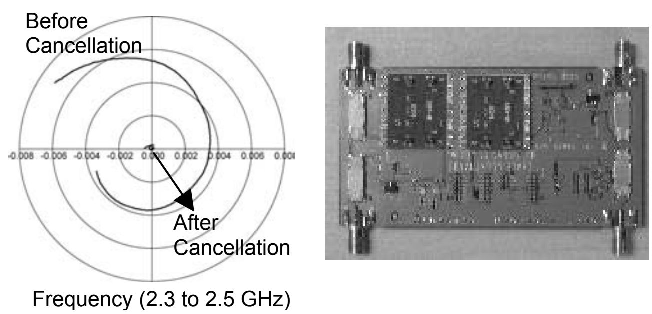

Fig. 7. Coupling spectrum parameters on polar plot, and photograph of board.

As seen in the above graphs, a maximum cancellation magnitude of 30 dB is observed in the 2.4 GHz band. This reduced the coupling due to the interferer, from –18 dB to –48 dB in band. For another physical configuration of the interferer, the interference was reduced from –27 dB to –56.6 dB in band, representing a total cancellation of 29.6 dB. However, this approach does not produce uniform cancellation throughout the band. It was observed that introducing two pilot tones at the transmit antenna for minimization, allowed optimal cancellation across the entire spread spectrum band, as shown in Fig. 8.

The interference canceller system presented in this work adopts a novel approach to the Bluetooth/ WLAN interference environment. The active circuits designed so far help provide a small form factor solution to the problem of simultaneous operation. As a subsequent step, the remaining circuits in the correlation chain are to be integrated on chip to form a relatively low-power cancellation system. The power consumption in the active circuitry in their present form is less than 20 mW.

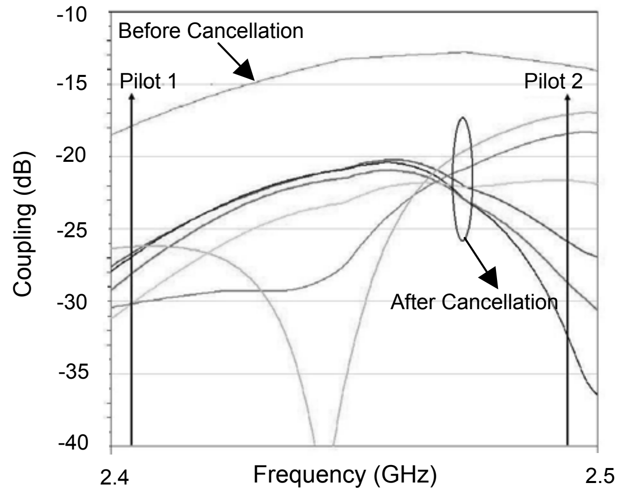

Fig. 8. Interference cancellation with the aid of two pilot tones for various phase adjustments in the correlation chain.

Cancellation levels of –15 dB to –30 dB across the 2.4 GHz band are achieved by the proposed system in its different manifestations. These translate to improved signal-to-noise ratio (SNR) in the aggressed receiver and allow it to decode the desired signal in the close proximity of an operating interferer. This objective is achieved with minimal penalty to transmitted signal power, receiver noise and total power consumption. When fully integrated, such a canceller will offer a viable solution for use in mobile devices, not only in the 2.4 GHz band, but also for other frequencies and radios.

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