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Digital Controlled Co-channel Feedback Interference Cancellation System with Broadband Cancellation

Heungjae Choi[#1], Yongchae Jeong[#2], Chul Dong Kim[*3], and Jaehoon Yun[*4]

[#] *Department of Electronics and Informations Engineering, Chonbuk National University, Jeonju, Republic of Korea*

[1] streetpoet@chonbuk.ac.kr

[2] ycjeong@chonbuk.ac.kr

[*3] *SEWON Teletech, Inc., Anyang, Republic of Korea*

[3] chuldkim@sewon-teletech.co.kr

[*4] *Electronics and Telecommunications Research Institute, Daejeon, Republic of Korea*

[4] jhyun@etri.re.kr

Abstract— **In this work, a digital controlled co-channel feedback interference cancellation system is proposed to reduce the feedback interference signal in the wireless repeater system. Frequency hopping spread spectrum pilot tone is adopted for the adaptive group delay detection of the feedback path. Amplitude, phase, and group delay of the feedback path are automatically detected and controlled through the comparison algorithm using DSP. Adaptive feedback cancellation of over 30dB is achieved with the proposed system for the signal bandwidth of 20MHz in Korean RFID band.**

I. Introduction

A feedback interference, defined as the undesirable interference signal directly radiated from the transmitter (Tx) antenna to the receiver (Rx) antenna in the same site, is the major limiting factor in the design of all kinds of system of which the input and output frequencies are same such as a hearing aid and a communication repeater. Since the system performance can be tremendously degraded due to the feedback interference signal, a number of researchers have been involved in the field of feedback interference cancellation system (ICS) design [1]-[3].

Usually, a signal cancellation is achieved by loop cancellation mechanism such as carrier cancellation loop and intermodulation distortion cancellation loop in feedforward power amplifier design, for example [4][5]. Also, Group delay matching as well as amplitude and phase balance in a loop is critical for broadband signal cancellation. Although adaptive feedback interference cancellation system (AF-ICS) is reported in a recent work, the bandwidth of the cancelled signal is fairly limited due to the group delay mismatching [6].

In this work, a new method is proposed to detect the group delay of an arbitrary transmission path with frequency hopping pilot tone. Using gain/phase detector with digital signal processor (DSP), gain, phase, and group delay of the feedback path are detected and controlled simultaneously. Then, digital controlled co-channel interference cancellation system is implemented and measured.

II. Design Theory of Digital Controlled Co-channel Feedback Interference Cancellation System

Fig. 1 shows the analog controlled co-channel feedback interference cancellation system [7]. Samples of correction signal and output signal can be extracted from port-C and port-D, respectively. Comparing those signals, amplitude and phase of the correction path can be automatically controlled to reduce the feedback interference. However, the group delay time adjuster (GDTA), the essential device for the broadband signal cancellation, is manually controlled [8]. Therefore, the system in Fig. 1 cannot be categorized as a completely automatic system.

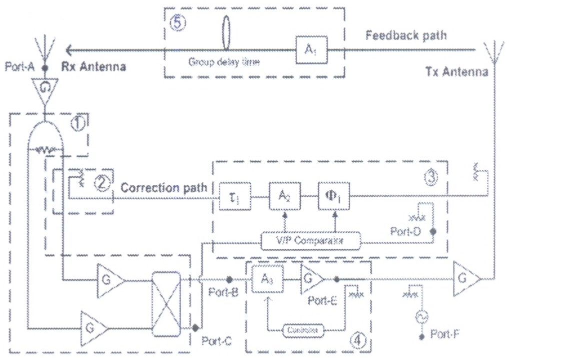


Fig. 1 Co-channel feedback interference cancellation system using analog control.

A. Proposed System Configuration

Simplified block diagram of the proposed digital controlled interference cancellation system is shown in Fig. 2. The target operating frequency is Korean RFID band (908.5~914MHz) and the output power is 1 watt (30 dBm). It consists of four main modules such as RF module, detector module, DSP module, and CDMA module. Basic cancellation mechanism and theory of operation of RF module is well explained in the previous work. Frequency hopping pilot tone generation through up-down conversion, and gain/phase detection take place in the detector module. DSP module calculates group delay and adjusts control voltages of variable attenuator (V_A), variable phase shifter (V_Φ), and the GDTA ($V_{\tau L}$, $V_{\tau C}$). CDMA waveform is produced at the CDMA module.

Usually group delay in a DSP controlled system is compensated in a discrete way according to discrete chip time. Therefore the signal cancellation bandwidth problem occurs in an adaptive system. Main advantage of the adaptive digital control of the GDTA in the proposed system is that continuous group delay variation can be obtained, improving the cancellation bandwidth of the adaptive system.

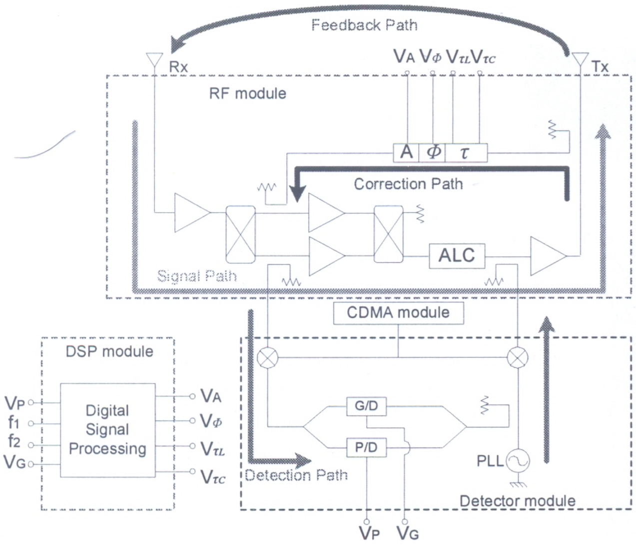


Fig. 2 Block diagram of the proposed digital controlled interference cancellation system.

B. Main Algorithm of Feedback Path Characterization

To design and implement a wholly automatically controlled interference cancellation system with broadband cancellation, gain, phase, and group delay of feedback path need to be characterized. Gain and phase can be easily obtained by gain/phase detector. Group delay can be expressed as Eq. (1)

$$GD = -\frac{\partial \phi}{\partial \omega} = -\frac{1}{2\pi}\frac{\phi(f_2)-\phi(f_1)}{f_2-f_1}. \quad (1)$$

If the two frequency components and phase responses are known, the group delay can be calculated as shown in Fig. 3. So frequency hopping is adopted to obtain two phase responses (Φ_1, Φ_2) at two separate frequencies (f_1, f_2).

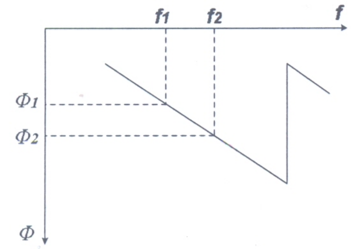


Fig. 3 Feedback path group delay calculation by the phase detector and pre-defined hopping frequencies.

Since the proposed system is a kind of transmitter, those pilot tones should follow the out-of-band spectrum emission regulation. So the hopping frequencies need to be set between the pass band (908.5~914 MHz). We selected 909.5 MHz and 912.5 MHz as f_1 and f_2, respectively. Also, it should not affect the desired signal at the signal path of Fig. 2. Therefore, rather than continuous wave (CW) pilot tone, CDMA waveform is adopted as a type of spread spectrum to spread the energy of the pilot tone at the frequency domain, minimizing the interference to the in-band signal.

Block diagram for CDMA waveform generation is expressed in Fig. 4. After mixing the 1-bit data of 9.6 kbps with the Pseudo Noise (PN) code data of 1.2288 Mbps, the mixed signal is then transmitted to the 48-tab FIR pulse shaping filter. Then the generated 10-bit sequence is converted to analog waveform by digital-to-analog converter (DAC). Since the operation frequency of a DAC is pretty low, we used a DAC evaluation board equipped with internal output mixer. The output frequency of the CDMA generator is 74.5 MHz. EP2C20F484C7N FPGA chip and AD9857 evaluation board are used for CDMA waveform generation.

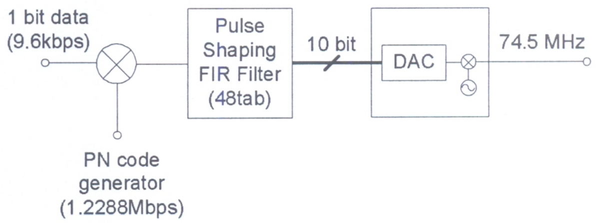


Fig. 4 CDMA waveform generation to be used as a pilot signal.

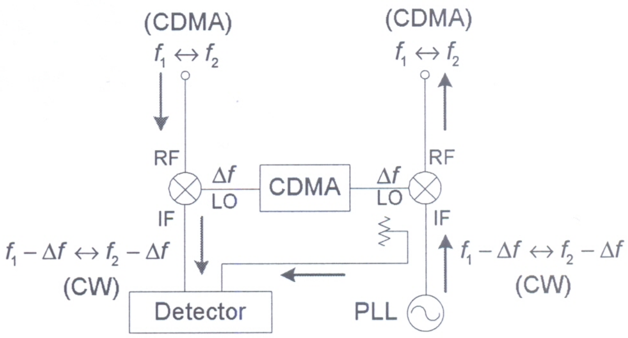


Fig. 5 Up-down conversion of the spread spectrum pilot tone.

The spread spectrum pilot tone generation is explained in Fig. 5. Δf is the output frequency of the CDMA generator. Frequency hopping is controlled by PLL. When the PLL generates two frequencies of f_1-Δf and f_2-Δf (CW), those components are input to IF port of a mixer, then mixed with Δf (CDMA), producing f_1 and f_2 as RF signal (CDMA). This CDMA signal is transmitted to the Tx antenna of RF module. After passing through feedback path of Fig. 2, it is down converted mixed with original CDMA signal of Δf, and then the restored CW tones are applied to the detector. Comparing those restored CW signals with the sampled output of PLL, gain and phase of feedback path can be decided. Using given values, f_1-Δf and f_2-Δf are set by 835 MHz and 838 MHz, respectively.

Fig. 6 shows a digital control part. Output voltages of the gain detector (V_G) and the phase detector ($V_{P(f1)}$, $V_{P(f2)}$) are converted to digital domain through analog-to-digital converter (ADC), and then applied to DSP. Those voltages are then used to estimate the gain, phase, and group delay of feedback path. Control voltages (V_A, V_Φ, $V_{\tau L}$, $V_{\tau C}$) of the circuits of correction path are then determined by the comparison algorithm with the look up table (LUT). LUT includes the relation of input voltage to output attenuation for variable attenuator, input voltage to output phase shift for variable phase shifter, and input voltage to output group delay variation for the GDTA. Some voltage level matching is realized by op-amp between the output of ADC and the correction circuits, because the output voltage range of ADC is smaller than the required control voltage of the analog control circuits. TMS320C6416T DSP of Texas Instruments and 16-bit AD/DA PIOX-16 DCM converter of MicroLAB Systems are used for digital control part.

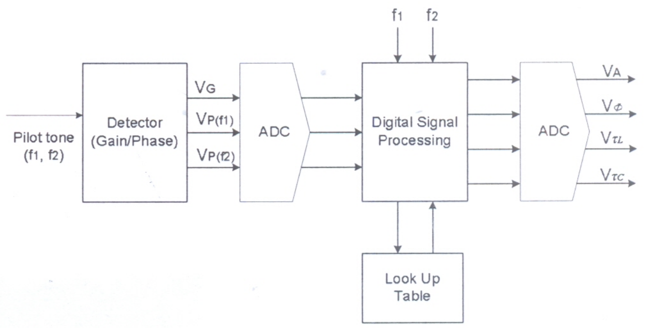


Fig. 6 Simplified signal flow of digital control part.

III. Experimental Results

The feedback cancellation performance is measured with CDMA IS-95A 4FA and WCDMA 4FA signal to observe the broadband cancellation characteristic. Bandwidths of the two signals are 5 MHz and 20 MHz, respectively. To identify the cancelled signal, two types of signals are used. CW represents the desired received signal in Rx and CDMA represents the unwanted feedback signal from Tx. Fig.7 (a) shows the spectrum with correction path not operating. Spectrum after cancellation is shown in Fig. 7 (b). We could obtain cancellation effect of the feedback interference signal about 31.04 dB when the correction path is operating, without any effect on the received signal. Cancelled feedback signal is near noise level, so the amount of cancellation would be larger.

Since the operation bandwidth of the Korean RFID band is between 908.5~914 MHz, 5 MHz signal would be enough to satisfy the cancellation bandwidth. Nevertheless, we also measured the performance with WCDMA 4FA signal of 20 MHz bandwidth to observe the cancellation bandwidth limitation. Measured cancellation level is as much as 31.63 dB for the entire 20 MHz. But in this case, slight slope is observed near the center frequency of the cancelled feedback signal as shown in Fig.8 (b). Since there is no broader signal source than WCDMA 4FA in the laboratory equipment, it is impossible to find the bandwidth limitation.

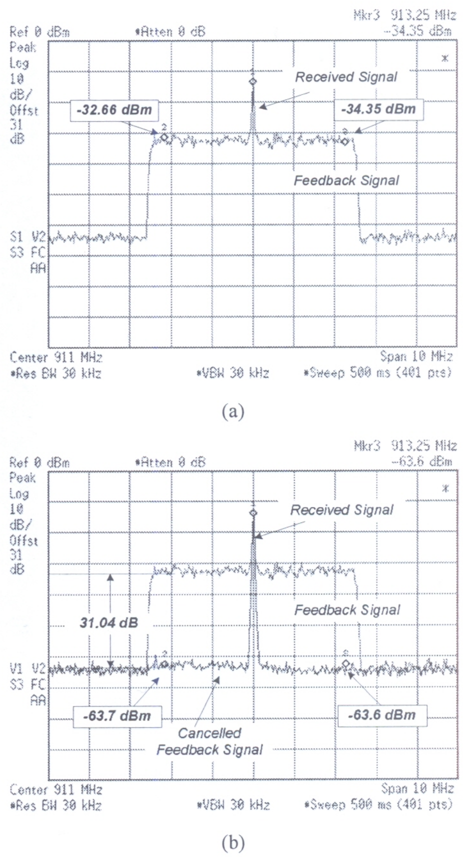
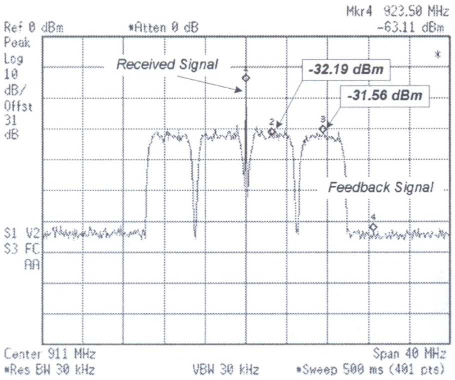
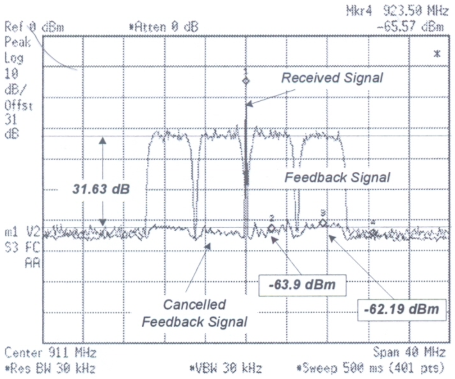


Fig. 7 Measured feedback cancellation characteristic with CDMA IS-95A 4FA signal (5MHz BW) (a) without correction path (b) with correction path.



(a)



(b)

Fig. 8 Measured feedback cancellation characteristic with WCDMA 4FA signal (20MHz BW)(a) without correction path (b) with correction path

IV. CONCLUSION

Fully adaptive digital controlled co-channel feedback interference cancellation system is proposed and measured in this work. Over the previous analog control system proposed by the authors, digital controlled feedback cancellation system shows equivalent performance with broad cancellation band.

The proposed feedback cancellation system can be used to various applications such as RFID transponder, repeater, and all kinds of systems using same input and output frequency.

ACKNOWLEDGMENT

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Exhibition Hall, 12:30 – 13:50, Monday 27 October 2008

EuWiTPoster continues next page…

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