Channel Selective RF Receiver with Spectrum Sensing System

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1. Introduction

In recent, an efficient spectrum management has been issued for a limited frequency resource. Cognitive Radio (CR) technologies have been studied and suggested to allocate channels adaptively by checking the signal existence at each channel. However, the most of the CR technologies reported on the IEEE 802.22 standard are based on digital processing from down-converted baseband signal. Although these technologies has accurate resolution by digital processing, they have limitations such as long processing time and large energy consumption due to the down-conversion and demodulation of received signals [1-2]. In case of the only RF processing technique proposed by GEDC (Georgia Electronic Design Center) of Georgia Tech., U.S., even though the spectrum sensing is performed at an RF front-end, it conducts the dual-loop processing of the coarse sensing and the fine sensing with complicated and expensive process to be applied to low power consumed RF systems such as USN [3].

In this paper, a spectrum sensing method is proposed based on an RF front-end system for low power consumed wireless connectivity services, which can be suitable for channel selective RF receivers. The proposed sensing method can solve the problems such as low-speed, high power-consumption with channel selectivity. By converting the received carrier frequency to a DC voltage, the proposed system can sense the channel in use. Because it has a simple architecture, low power-consumption, and fast processing time without down-conversion and demodulation, the proposed spectrum sensing method can apply to wireless connectivity sensor network systems.

2. The Proposed Spectrum Sensing Method

The proposed spectrum sensing method is based on the conversion of a received carrier frequency to a DC voltage. The fundamental theory is utilized from frequency demodulation technique. The configuration of the spectrum sensing method with quadrature detection is shown in Fig. 1. The processing can be explained by following equations [4]. A received signal, $x_c(t)$ with carrier frequency, ω_c is excited to two input ports of a mixer with 90^o phase difference as driven in eq. (1).

$$x_c(t) = A_c \cos[\omega_c t + \phi(t)]$$
$$x_d(t) = A_d \cos[\omega_d t + \phi(t - t_1) - 90^o] \cdots\cdots (1)$$

where $\phi(t)$ is the phase of the signal. The phase delay according to departure of the input signal can be expressed as follows;

$$\phi(t) - \phi(t - t_1) = t(d\phi / dt) = 2\pi t\, f_{\Delta} a(t),$$

where the frequency deviation of f_Δ is the frequency difference between a centre carrier and an input signal. The output signal of the mixer can be proportional to the frequency deviation as following eq. (2).

$$\begin{aligned} y(t) &= x_c(t)x_d(t) = A_c A_d \cos[\omega_c t + \phi(t)]\cos[\omega_d t + \phi(t-t_1) - 90^o] \\ &= \tfrac{1}{2} A_c A_d \sin[\phi(t) - \phi(t-t_1)] \approx \tfrac{1}{2} A_c A_d [\phi(t) - \phi(t-t_1)] \\ &= \tfrac{1}{2} A_c A_d [2\pi t\, f_\Delta a(t)] \\ &= A_c A_d t\, f_\Delta a(t) = K_f\, f_\Delta a(t) \quad \cdots\cdots (2) \end{aligned}$$

where K_f is a constant and *a(t)* is the demodulated message signal.

Because the modulation scheme of the proposed system is on-off keying (OOK) with uniform amplitude, y(t) is linear to the received signal frequency for narrow frequency deviation region. While the OOK symbol of 'one' presents constant voltage output, the symbol of 'zero' shows no signal. The characteristic for frequency to output signal level has been achieved as shown in Fig. 2.

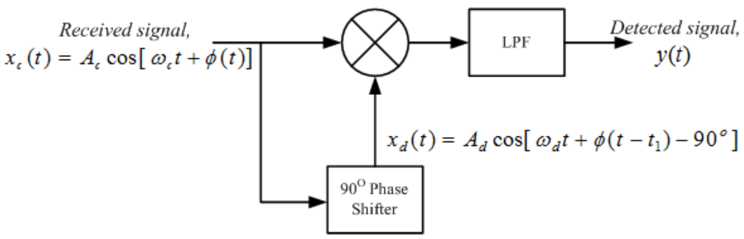


Figure 1. Configuration of the Frequency-to-DC Converter.

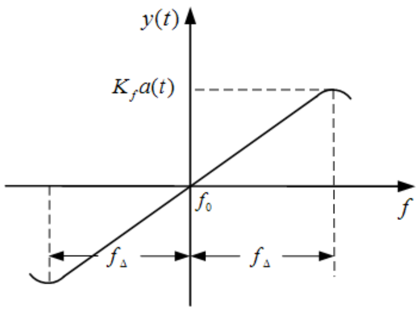


Figure 2. Output Signal Level for Received Frequencies.

3. Frequency-Agile Receiver System with Channel Selection

The configuration of the proposed spectrum sensing receiver system is presented in Fig. 3. The proposed receiver is composed of two major sections of a communication receiver and a spectrum sensor. The spectrum sensing process can be achieved in the spectrum sensor system. When the RF signal is received at the antenna, the spectrum sensor system operates. The received RF power is fixed by a limiter to deliver constant amplitude into the detecting mixer. A T-junction power divider is designed with impedance matching. From mixer detection, voltage level output can be obtained while the OOK modulated signal is ON state. When the OOK input is OFF, no output is detected. Therefore, the output signal at the mixer detector is flattened through integrators to transmit a DC level signal to the base band processor. From the control of the baseband processor, the selective channel can be detected by the communication receiver. This proposed process allows for high speed spectrum sensing with reduced cost and power consumption.

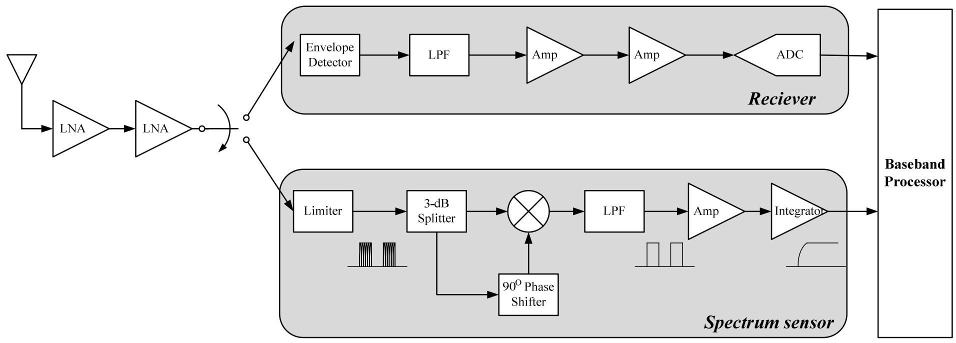


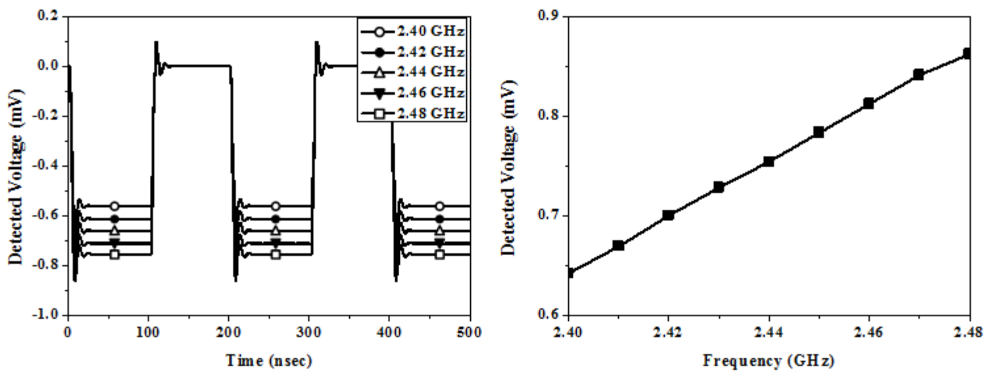
Figure 3. Configuration of the Proposed Spectrum Sensing Receiver.

4. Performance Evaluation of the Proposed Spectrum Sensing System

The performance of proposed system has been evaluated for the frequency sensitivity. Fig. 4 shows the detected output voltage levels for the input signals with the data-rate 10 Mbps and duty cycle of 50 % at 2.4 GHz ISM band. Fig. 4 (a) presents the output of the mixer-LPF detector with inverted polarity. During incoming RF signal, the output voltage level is distinguished for different input carrier frequency. In Fig. 4 (b), tt is presented that the output voltage level method is linear according to input frequency in the proposed spectrum sensing method. Because the difference of the output level is too small to make a distinction between channel bands, the detected output level is amplified and integrated by OP-amps and integrators. Fig. 5 shows the output signal of the proposed spectrum sensor. The output voltage varies from 12 to 16 volts. As shown in Fig. 5 (a), the constant signal level can be transmitted to the baseband processor. From the overall difference of the output voltage of 4.12V, the channel allocation corresponding to each detected voltage in the 2.4 GHz ISM band is presented in the Table. 1.

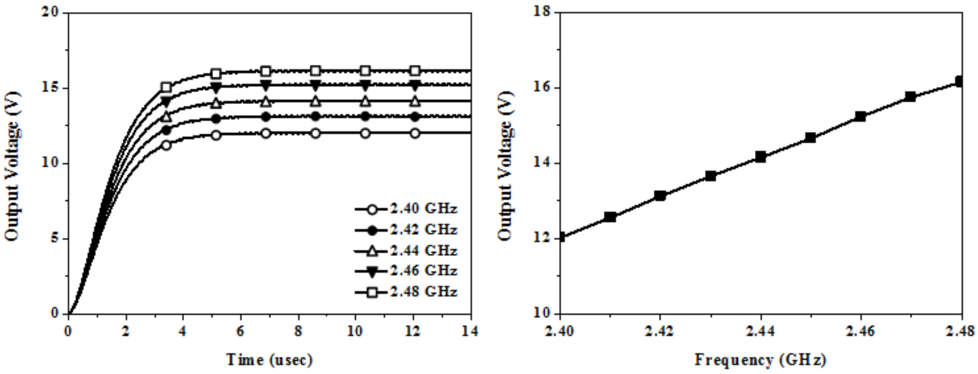
5. Conclusions and Discussions

In this paper, the spectrum sensing method at an RF front-end stage is proposed using a frequency-to-DC conversion. The proposed system has a simple architecture and an outstanding linearity and a low-cost design. The proposed system can be operated with spectrum cognition for low-power, low-cost ubiquitous sensor networks. From the capability of the channel selectivity, a ubiquitous sensor network can be designed with excellent spectrum and power managements.



(a) (b)

Figure 4. Spectrum Detected Output for Received Carrier Frequencies.
(a) Detected Signals. (b) Absolute Maximum Detected Voltages.



(a) (b)

Figure 5. The Output Signals to BB for Received Carrier Frequencies.
(a) Output Signals. (b) Absolute. Maximum Output Voltages.

Table. 1 Output Level for Received Signal Frequency at Each Channel

Channel	Frequency Band (GHz)	Output Voltage (V)	Channel	Frequency Band (GHz)	Output Voltage (V)
1	2.400~2.405	12.10 ~ 12.35	9	2.440~2.445	14.15 ~ 14.40
2	2.405~2.410	12.35 ~ 12.60	10	2.445~2.450	14.40 ~ 14.60
3	2.410~2.415	12.60 ~ 12.90	11	2.450~2.455	14.60 ~ 14.90
4	2.415~2.420	12.90 ~ 13.15	12	2.455~2.460	14.90 ~ 15.20
5	2.420~2.425	13.15 ~ 13.40	13	2.460~2.465	15.20 ~ 15.45
6	2.425~2.430	13.40 ~ 13.70	14	2.465~2.470	15.45 ~ 15.65
7	2.430~2.435	13.70 ~ 13.95	15	2.470~2.475	15.65 ~ 15.90
8	2.435~2.440	13.95 ~ 14.15	16	2.475~2.480	15.90 ~ 16.15

Acknowledgments

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References

[1] IEEE 802.22 WG on Wireless Regional Area Networks, “Functional Requirements for the 802.22 WRAN Standard,” http://www.ieee802.org/22/.

[2] Z. Zhao, Z. Peng, S. Zheng, and J. Shang, “Cognitive Radio Spectrum Allocation using Evolutionary Algorithms,” *IEEE Trans. Wireless Communications*, vol. 8, no. 9, pp.4421-4425, Sep. 2009.

[3] J. Park, T. Song, J. Hur, S. M. Lee, J. Choi, K. Kim, K. Lim, C.-H. Lee, H. Kim, and J. Laskar, "A Fully Integrated UHF-Band CMOS Receiver With Multi-Resolution Spectrum Sensing (MRSS) Functionality for IEEE 802.22 Cognitive Radio Applications," *IEEE J. Solid-State Circuits*, vol. 44, no. 1, pp. 258-268, Jan. 2009.

[4] A. B. Carlson, *Communication Systems: An Introduction to Signals and Noise in Electrical Communication*, 3rd edition, McGraw-Hill, Singapore, pp.259-263, 1986.