A Low-Power Correlation Detector For Binary FSK Direct-Conversion Receivers

J. Min, H-C. Liu, A. Rofougaran, S. Khorram, H. Samueli and A. A. Abidi

Integrated Circuits and Systems Laboratory
Electrical Engineering Department
University of California
Los Angeles, California 90095-1594, USA

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Abstract

A multiplierless binary FSK detector with 82 dB of dynamic range is presented. The proposed detector is well-suited for low-power direct-conversion receivers used in wireless communications systems employing FSK modulation.

Introduction

Frequency-shift keying (FSK), often in continuous-phase format, is widely used in wireless communications systems such as pagers and frequency-hopped transceivers [1]. The modulated waveform has constant envelope and narrow power spectra. At the receiver, noncoherent detection is often employed to reduce the hardware complexity. Direct-conversion receivers also have been gaining much attention recently for portable communications applications where low power is a key requirement. A direct-conversion architecture receiver translates the received signal from RF directly to I-Q baseband signals for quadrature detection. This eliminates image-reject filters and other IF components, and thus enables a complete monolithic transceiver in one- or two-chip solution. Therefore, it is critical to find an efficient FSK baseband detector for such a direct-conversion receiver. Conventional IF FM detectors such as a limiter-discriminator are not suitable. Some new baseband binary FSK detectors for DECT and radio paging systems have been proposed [2-4]. It is well-known that the optimum FSK detector is a correlation detector [5]. However, this detector is not often used in practice owing to the complexity of the required circuits. We propose a simple multiplierless binary FSK correlation detector for use in a direct-conversion receiver. The quadrature input signals are first hard-limited using a limiting amplifier with high dynamic range, thus eliminating a multi-bit analog-to-digital converter (ADC) or automatic gain control (AGC).

Implementation

In a sampled-data binary FSK correlation detector, the following magnitude is evaluated for the received signal $\tilde{s}$:

$$C(f_t) = \left| \frac{1}{N} \sum_{n=0}^{N-1} \tilde{s}(nT_s) \{ \cos(2\pi f_t n T_s) + j \sin(2\pi f_t n T_s) \} \right| \quad (1)$$

where f_t is the tone frequency to be detected, and N is the oversampling ratio (T_{baud}/T_s). We have sought a simple implementation for this algorithm. Since FSK signaling requires only the frequency information and not the amplitude, the quadrature input signals are first hard-limited (Fig. 1). Before hard-limiting, of course, a lowpass channel filter selects the baseband signal from neighboring channels. Given the wide dynamic range (typically 80 dB) of the radio channel, the baseband FSK detector must handle this range to avoid any gain control at RF. A CMOS limiting amplifier [6] capable of more than 80 dB of dynamic range has been built to fulfill this requirement. However, limiting introduces odd harmonics of the original tones. These harmonics are aliased after sampling, potentially corrupting the orthogonality of binary FSK tones applied to the digital correlation detector. However, if N is an integer multiple of four ($4i$), it may be shown that distortion due to harmonic aliasing is avoided. This guarantees that the generated harmonics are symmetric about half of the sampling frequency, retaining the Hermitian property of each I-Q signal. The detector must then only discriminate between signal energy at positive or negative frequency $\{+F_{tone}, -F_{tone}\}$.

The input signal must be correlated with sine and cosine components for a quadrature correlator. Since the input signal is already hard-limited, the reference tone needs not be a pure sinusoid. In our approach, square waves with the proper tone frequency are used instead. Thus, an XNOR gate may be used as a 1-bit multiplier for signal correlation. Harmonics resulting from square waves can, after aliasing, downconvert undesired parts of the signal spectrum to baseband [7]. However, when the input signal is filtered and hard-limited, the spectrum at the harmonics is due to the input signal itself. Thus, when the oversampling ratio constraint is met, there is no extra degradation. The integrate-and-dump (I&D) block is implemented with a simple accumulator, and its clocks are generated by a separate clock recovery loop [8]. As shown in equation (1), the correlation detector also requires a magnitude calculation unit. In our architecture, an absolute-value addition block replaces a conventional squaring multiplier. Thus, a truly multiplierless FSK detector is obtained with little performance degradation. The I-Q local tone generator is implemented with a 1-bit output numerically controlled oscillator (NCO), rather than a full-precision direct digital frequency synthesizer. The tone frequency to be detected is fully programmable by controlling the input control word of the quadrature NCO.

Measurements

Two basic requirements for binary FSK direct-conversion receivers are low power and high inherent dynamic range. All blocks shown in Fig. 1 have been implemented in 1-μm CMOS, and consume 5 mW from 3V. Fig. 2 shows the measured dynamic range of the detector. Measurements were made with $F_{tone} = \pm 160$ kHz, $F_{baud} = 160$ kHz, $F_s = 10.24$ MHz, and $N = 64$. The inherent dynamic range of the detector is 82 dBm at a BER of 10^{-3}. This result is higher than those reported for other FSK detectors [3, 9]. The minimum detectable signal power at the BER of 10^{-3} was measured to be -72 dBm, which is mostly dominated by the input noise of the limiting amplifier. The upper limit, however, is set by the maximum output swing of the stage driving the limiter, which is 1 Vpp for the test case. For the detector alone, there is no inherent upper limit and the limiter input may swing to the power supply. Higher dynamic range may be achieved by dissipating more power in the hard-limiter stage; however, this is not necessary since 82 dB of dynamic is sufficient for the radio channels encountered in most wireless applications.

Conclusion

A multiplierless implementation of binary FSK correlation detection has been presented. Architectural simplifications applied to the design make it low power. With proper choice of the oversampling ratio ($4i$), the proposed detector maintains the orthogonality of binary FSK tones without harmonic aliasing, and thus minimizes performance degradation due to 1-bit correlation. The measured dynamic range of the detector is 82 dB at the BER of 10^{-3}. This FSK detector is suitable for monolithic integration into direct-conversion receivers used in wireless communications systems.

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Figure captions

Figure1: Multiplierless binary FSK correlation detector

Figure2: Measured dynamic range of the binary FSK detector

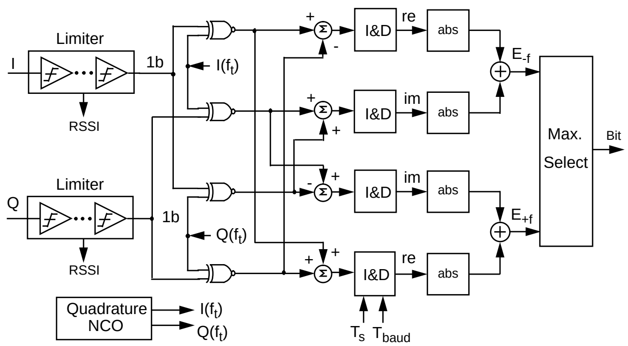

Figure 1.

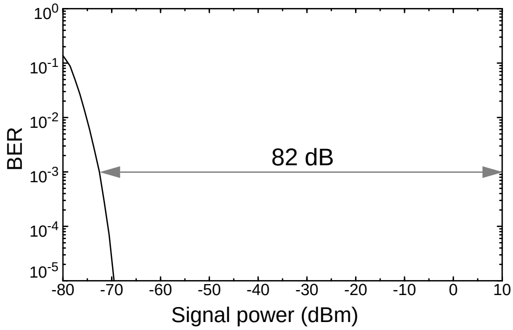

Figure 2.