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Real-time Narrow-Band Frequency-Shift Keying (FSK) Receiver

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Abstract

We introduce a real-time narrow-band Frequency-Shift Keying (FSK) receiver that is immune of the two fundamental drawbacks of conventional FSK receivers, namely the rigid dependence of bandwidth on data rate and the stringent frequency difference requirement. This receiver is based on Real-Time Analog Signal Processing (R-ASP) technology and uses a novel ring-resonator type phaser for high accuracy FSK demodulation. Given its real-time nature, it may lead to ultra-fast and ultra-low-latency communication systems.

1 Introduction

A conventional frequency-shift keying (FSK) demodulator fundamentally relies on the orthogonality between harmonic signals of (two or more) different frequencies [1]. Therefore, the corresponding modulation frequencies must obey the relation

$$\Delta f = f_\mathrm{k} - f_\mathrm{l} = n\frac{1}{T} = nR, \qquad (1)$$

where the subscripts k and l are integers denoting two modulation frequencies, n is an integer, T is the symbol duration, and hence also the integration time of the demodulator's integrators, and $R = 1/T$ is the data rate. This constraint has two consequences. First, the system's bandwidth is proportional to the data rate. Since the radio-frequency spectrum is a scarce resource, this naturally represents an unfavorable feature. For example, a 1 Gb/s data rate would imply a bandwidth of 1 GHz in binary FSK. Such a bandwidth may be easily attained in the X-band, but becomes challenging at lower frequencies. Second, the frequencies must be exactly separated by a multiple of the data rate. This imposes the requirement of high-precision, and hence high cost, oscillators in both the modulating and demodulating parts of the FSK system.

Real-Time Analog Signal Processing (R-ASP) is a paradigm-shifting technology [2] that may pave the way to a myriad of electromagnetic systems operating from microwaves all the way to the THz spectrum. Several R-ASP applications have already been demonstrated at microwaves, such as real-time Fourier transformation [3], pulse compressive transmission [4], and frequency sniffing [5]. R-ASP is based on highly dispersive devices with specified group delay versus frequency responses called phasers, that may be implemented in C/D-section [6, 7, 8, 9, 10] and cross-coupled resonator [12] technologies.

We leverage here R-ASP technology to design an FSK receiver that overcomes those two aforementioned issues of conventional FSK receivers while featuring even greater simplicity. This receiver uses a new type of phaser, a ring-resonator phaser, to achieve high-sensitivity detection and hence highly reliable FSK demodulation. We provide a proof-of-concept of this receiver, and will present a complete experimental demonstration at the conference. Note that the real-time nature of the system may also lead to extremely transmission speed that would be unachievable with DSP-based conventional FSK receivers.

2 Receiver Principle

Figure 1 shows the proposed real-time FSK receiver. The

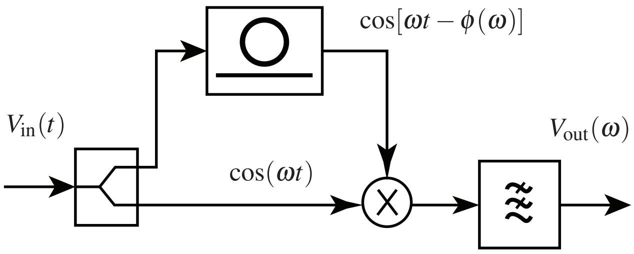

Figure 1. Proposed R-ASP FSK receiver.

receiver operates as follows. First, the incident FSK-modulated signal, $V_\mathrm{in}(\omega,t) = \cos(\omega t)$, is equally divided into two paths, one of which contains the phaser that is the key element of the system. The wave in the two paths, $\cos(\omega t)$ and $\cos[\omega t - \phi(\omega)]$, are then mixed together, leading to the signal

$$\cos(\omega t)\cdot\cos[\omega t - \phi(\omega)] = \frac{\cos[2\omega t - \phi(\omega)] + \cos[\phi(\omega)]}{2}. \qquad (2)$$

This signal is then low-pass filtered, which leads to the following output

$$V_\mathrm{out}(\omega) = \frac{\cos[\phi(\omega)]}{2}. \qquad (3)$$

Note that this signal does not depend any more on time but only on frequency, and may hence be used as a frequency demodulator. This is accomplished by mapping the frequency onto the voltage via an appropriately designed phaser, i.e. a phaser exhibiting the phase response $\phi(\omega)$ that optimally discriminate the FSK frequencies for successful demodulation. We will use here a ring-resonator phaser, as indicated in Fig. 1, because this phaser is highly dispersive and hence provides a great frequency sensitivity for FSK.

Equation (3) shows that the proposed receiver, in contrast to conventional FSK receivers [Eq. (1)], does not involve any fundamental dependence between the data rate and the bandwidth and any fundamental constraint in terms of the detectable modulation frequencies. Moreover, the proposed receiver is inherently real-time in nature and is therefore not suffering from latency and speed limitation.

Note that, in this application, the phaser may in principle be replaced by a nondispersive (limiting case of a phaser with zero dispersion) component, such as a simple transmission line section, with phase response $\phi(\omega) = (\omega/V_\mathrm{p})\ell$, where v_p and ℓ are the phase velocity and length of the section, respectively. However, the required length (ℓ) would be prohibitively large. For example, obtaining a 2π phase shift, as typically desirable to exploit the entire amplitude range of the cosine function in (3), for an FSK frequency difference $\Delta f = 4$ MHz would require a transmission line section in the order of 38 meters. This clearly explains the need for a dispersive structure.

3 Results based on Physical Model

This section present proof-of-concept simulation results for the proposed receiver. Figure 2 shows the phase and group delay of the designed phaser, which is shown in the inset. The ring resonates at 5.24 GHz. A 2π phase shift is achieved over the small bandwidth of $\Delta f = 8$ MHz about the center frequency. The rate of phase shift, or in other words the group delay, is very important as it allows a narrow-bandwidth operating system.

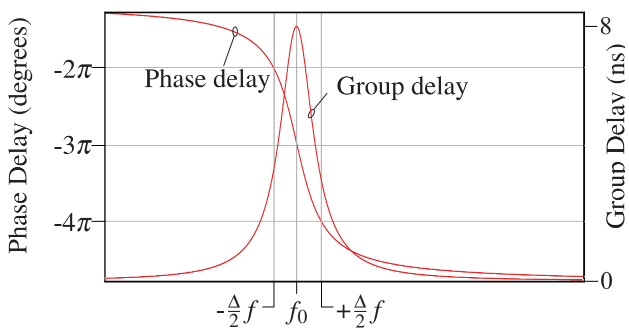

Figure 2. Group and phase delay of the ring-resonator phaser versus frequency.

Figure 3 presents the output of the overall receiver system. Two frequencies of unit amplitude are fed to the real-time FSK receiver, 5.24 GHz and 5.25 GHz, corresponding to a fairly narrow-band system of 10 MHz. The output is mapped to $V_\mathrm{max} = 3$ V and $V_\mathrm{min} = 2$ V and where t is in units of the symbol duration T, in this case every step is 57 ns.

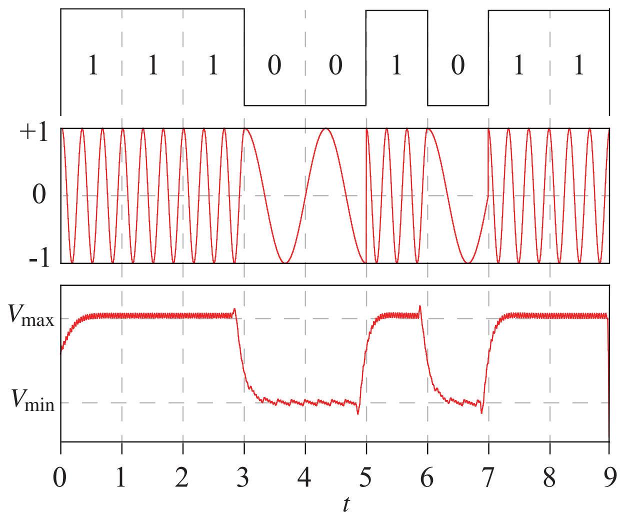

Figure 3. Full-simulated results of the real-time FSK receiver system.

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