A Binary Phase Shift Keying Demodulator using Pulse Detection

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Abstract – **In this paper, a novel binary phase shift-keying demodulator is proposed and demonstrated experimentally. The circuit operates by differentiating the modulated signal twice in order to generate sharp pulses at every 180° phase transition. After the differentiation process, the pulses are fed to an absolute value circuit that converts the negative pulses into positive pulses. The pulses enter a monostable-multivibrator to elongate them in time for final detection by a trigger flip-flop. The output of the flip-flop is the demodulated baseband signal.**

I. INTRODUCTION

A variety of communications and telemetry systems use binary phase-shift keying (BPSK) as their modulation method. Among the more widely known of these systems are the Inmarsat-C satellite network using a data rate of 600 bps and the Global Positioning System (GPS) using a data rate of 9.6 kbps.

In BPSK modulation, the phase of the carrier shifts in increments of 180° when there is a bit transition in the baseband signal. Generating a BPSK signal at the transmitter is a relatively simple task: the core of the circuit consists of a single mixer that multiplies the carrier with the bipolar baseband digital signal. The demodulation process, however, is considerably more complex.

For coherent detection of BPSK waveforms, the signal is multiplied by a locally generated carrier. One example of a coherent detector is the "squaring loop" [1,2] in which the BPSK signal is passed through a square-law device that removes the modulation from the carrier. A phase-locked loop (PLL) with a voltage-controlled oscillator (VCO) operating at twice the carrier frequency locks to the modulation-free signal. The VCO signal is subsequently frequency-divided by a factor of 2 to produce the original carrier, which can then be used to demodulate the BPSK signal using a frequency mixer. Another widely used coherent PLL-based BPSK detector, is the Costas Loop [3], which was originally proposed to demodulate single-sideband AM signals. This approach consists of a dual phase-locked loop (PLL) with an in-phase (I) and a quadrature (Q) arm. One advantage of the Costas Loop over the squaring loop is that it does not require a frequency-divider, which is difficult to implement as the carrier frequency reaches beyond the microwave range. One further example of a coherent detector is the so-called `remodulator' or inverse modulator [4]. In this type of receiver, the incoming signal is demodulated using a frequency mixer and the recovered baseband signal is used to remodulate the incoming BPSK signal using a second mixer. The output of the second mixer contains a modulation-free carrier component, which is subsequently fed to a phase-locked loop for tracking.

Other receivers use the method of carrier phase estimation; these systems do not use a PLL but they still rely on a local oscillator to detect the information [5,6]. In contrast to the coherent detectors, some BPSK demodulators exist that do not use a local oscillator [7,8]. These demodulators belong to the class of noncoherent detectors.

In this paper, a novel BPSK demodulator circuit is presented. The demodulator detects the discontinuities in the modulated carrier caused by bit transitions in the baseband signal. After every detected transition, a flip-flop is triggered to signify a change in the data waveform. The concept was demonstrated experimentally. By eliminating the need for a local oscillator and its associated PLL, this demodulator can potentially reduce the power consumption and cost of a receiver for use in hand-held applications. This paper is organized as follows: in Section II the principle of operation of the demodulator is discussed, Section III is dedicated to the circuit implementation, Section IV presents the experimental results, and Section V concludes the work.

II. PRINCIPLE OF OPERATION

A block diagram of the proposed demodulator is shown in Figure 1. The BPSK signal enters a differentiator circuit followed by a second differentiator. At every bit transition, the first differentiator generates a small pulse due to the discontinuity created by the 180° jump in phase of the carrier signal. The second differentiator accentuates the pulse generated by the first differentiator leading to a pulse with a larger magnitude. This pulse provides an indication that a phase transition has occurred and that there is a bit transition in the digital baseband signal. The differentiators generate either positive or negative pulses depending on whether the baseband bit transition is 0 to 1 or 1 to 0, respectively. To convert the negative pulses into positive pulses, an "absolute value" circuit was used. This circuit will be described shortly. The next component in Figure 1 after the absolute value is a monostable-multivibrator (MS-MV), whose purpose is to elongate the short-duration pulses

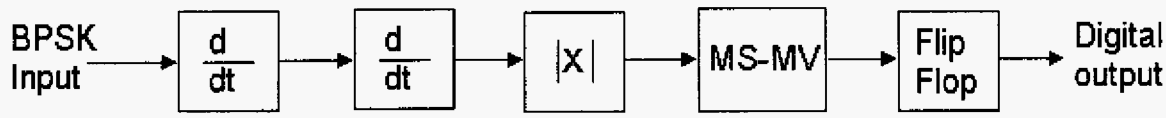

Figure 1 – Proposed BPSK demodulator using pulse detection

generated by the differentiators so that the pulses can be registered by the subsequent logic circuitry. The final element of the demodulator is a trigger flip-flop, which changes logic states every time there is a pulse from the multivibrator. Since each pulse signifies a bit transition, the output of the flip-flop is the demodulated signal.

Pulse Generation by the Differentiator Circuits

It would seem that one differentiator circuit would be enough in order to register the discontinuity in the BPSK signal. However, a single differentiator does not generally suffice, as will be explained in turn.

Consider an unmodulated carrier, $y(t) = \sin(\omega t)$. A BPSK-modulated signal can be written as the product of the baseband digital signal, $m(t)$, and the carrier,

$$b(t) = m(t)*y(t)$$

Ideally, $m(t)$ should transition instantaneously from –1 to +1 and vice-versa. If this were the physically possible, then a single differentiation operation on $b(t)$ would generate an infinite pulse at the bit transition and the second derivative would not be necessary. In reality, of course, the transition is continuous. In this discussion, a transition from –1 to +1 will be studied occurring in the vicinity of $t = 0$ and it will be modelled using a hyperbolic tangent function,

$$m(t) = -\tanh(\alpha t).$$

The constant α determines the 'slope' of the transition from –1 to +1. From a circuits perspective this is related to the rise and fall times of the digital electronics that generate the baseband signal. If, for instance, the bit transition is to occur inside a time-span of one-tenth of the period, T, of the carrier signal, then α ˜ 20/T, or α ˜ 3.2 ω.

Suppose that $b(t)$ enters the demodulator in Figure 1, and that the differentiation process is ideal. In this case, the output will be,

$$db/dt = \omega\cos(\omega t)\tanh(\alpha t) + \alpha\sin(\omega t)\mathrm{sech}^2(\alpha t). \quad (1)$$

Accordingly, the output of the second differentiator is,

$$d^2b/dt^2 = -\omega^2\sin(\omega t)\tanh(\alpha t) + 2\alpha\omega\,\mathrm{sech}^2(\alpha t)\cos(\omega t) - 2\alpha^2\mathrm{sech}^2(\omega t)\tanh(\alpha t)\sin(\omega t). \quad (2)$$

Evaluating these two derivatives at $t = 0$ reveals that, $db/dt|_{t=0} = 0$, and $d^2b/dt^2|_{t=0} = 2\omega\alpha$. A graph of these two derivatives in the vicinity of $t = 0$ is shown in the bottom half of Figure 2. The angular frequency, ω, was normalized to unity, and $\alpha = 3.2\omega$. It is clear from these graphs that the second derivative is necessary in order to generate a pulse at the bit transition. As t becomes larger than T/2, the first and second derivatives reduce to: db/dt ˜ $\omega\cos(\omega t)$ and d^2b/dt^2 ˜ $-\omega^2\sin(\omega t)$. The implication for the proposed demodulator is that the magnitude of the pulse generated by the second derivative should be significantly larger than ω^2 for detection by the subsequent electronic circuits. Actual differentiators implemented using RC networks, have a high-

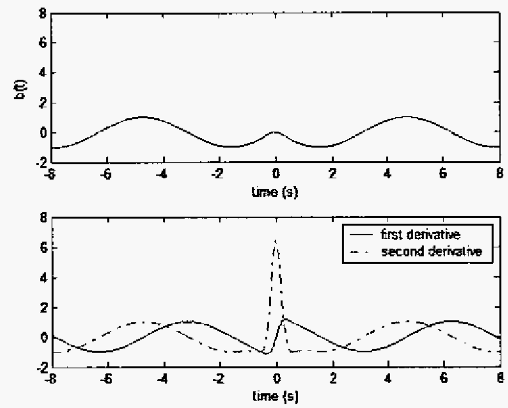

Figure 2 – The top graph is the BPSK waveform, and the bottom graph shows the first and second derivatives.

pass filtering characteristic and therefore the waveforms described previously will exhibit attenuation. This attenuation must be taken into account so that the pulses are larger than the threshold switching voltage of the digital electronics that follows the differentiators.

Now suppose that the carrier signal has some phase angle, f, such that $y(t) = \sin(\omega t + f)$. In this case, the magnitude of the second derivative pulse will vary, and the first derivative will start to exhibit peaking at t = 0. This state of affairs reaches its most pronounced behavior when f = π/2. Figure 3 shows the graphs of the derivatives for f = π/2. In this case, the first derivative is at a maximum at $t = 0$ with a value of 3.2, and the second derivative has a value of 0. However, as one moves slightly away from $t = 0$, the second derivative changes rapidly and it reaches a maximum absolute value of 9.2. If derivative signals are directly converted into voltages, the pulse generated by the second differentiator is 2.9 times larger than the pulse generated by the first differentiator, which makes detection straightforward.

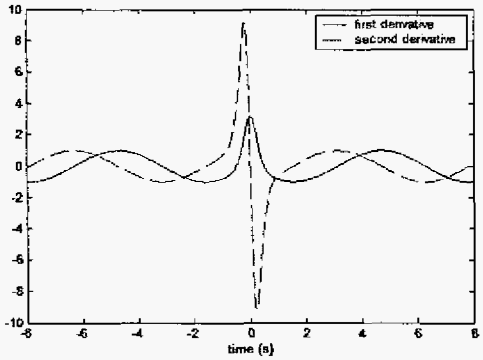

Figure 3 – First and second derivatives when carrier signal has a phase shift of $\pi/2$.

In summary, the second derivative is crucial for finding the bit transitions in the BPSK-modulated signal, and in particular when f = 0.

II. IMPLEMENTATION

Either passive or active differentiators (Figure 4) can be used in the demodulator system. The passive differentiators have the advantage that they can be used up to very high carrier frequencies. The active differentiators operate at lower frequencies but they can have gain, meaning that extra amplification stages are not necessary. For the proof-of-concept implementation in this work, the active differentiator was used.

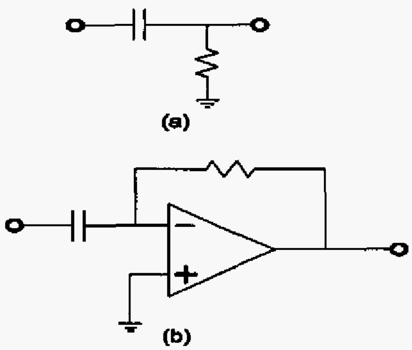

Figure 4 – Differentiator implementations (a) passive for high-frequency applications and (b) active.

The negative pulses were converted to positive pulses using the logic-based absolute value circuit in Figure 5. In the top branch, the input signal enters an exclusive OR gate (XOR), which has its second terminal connected to ground. In this manner, the XOR gate produces a pulse if the input signal is positive. In the bottom branch, the input is inverted and then it enters an XOR gate. The bottom XOR gate generates a pulse if the original input signal is negative. The outputs of the top and bottom XOR gates enter a third and final XOR gate, which combines the two signals and the result is a train of positive pulses only.

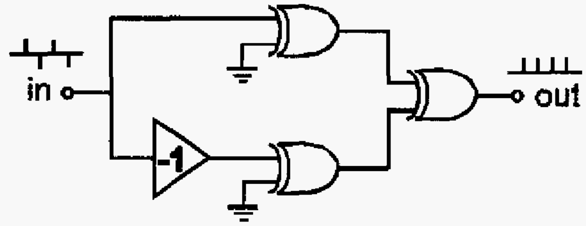

Figure 5 – Logic-based 'absolute value' circuit to convert negative pulses into positive pulses.

The monostable-multivibrator circuit was introduced into the demodulator system because the second differentiator would sporadically exhibit a 'ringing' behavior in which two pulses would be generated in quick succession. The effect of this ringing would be to trigger the flip-flop twice and therefore produce a false bit transition. By using the multivibrator after the differentiator the first pulse was elongated far enough that the ringing behavior would be eliminated and the flip-flop would only trigger once instead of multiple times.

IV. EXPERIMENTAL RESULTS

The demodulator in Figure 1 was implemented experimentally using a data rate of 10 kbps. Figure 6 shows the incoming modulated signal on the top trace, and the bottom trace depicts the pulses generated at every bit transition by the differentiators after they have passed through the absolute value circuit. It is seen that at each 180° phase jump there is a pulse, which will subsequently enter the MS-MV to be elongated. Figure 7 depicts the incoming BPSK-modulated signal and the output of the trigger flip-flop, which is the demodulated baseband signal.

In many practical systems, the BPSK-modulated waveform is filtered before transmission in order to limit the spectral bandwidth of the signal. This filtering is done in order to meet tight out-of-band spurious signal specifications

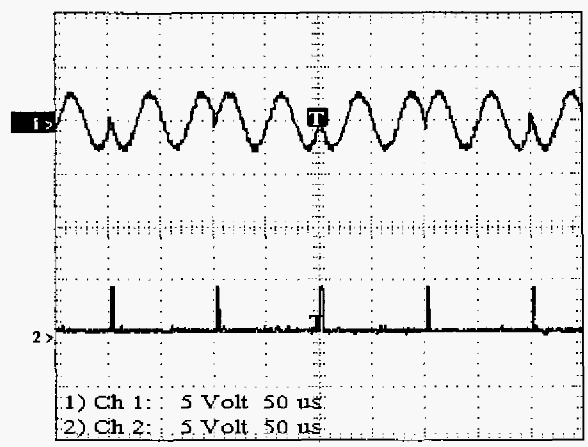

Figure 6 – Input BPSK-modulated signal (top trace), and pulses generated at every baseband bit transition (bottom trace)

which are meant to prevent unwanted interference in adjacent channels. In such a bandlimited signal, the carrier experiences a more gradual phase jump at every digital bit transition. As a result, the magnitude of the pulses generated by the differentiators (Figure 4) can potentially be reduced to the extent that they fall below the threshold voltage of the logic gates that follow. To mitigate this condition, a low threshold-voltage Schmitt trigger can be used after the second differentiator in order to register each pulse and restore the pulse values to a high-enough voltage for logic processing.

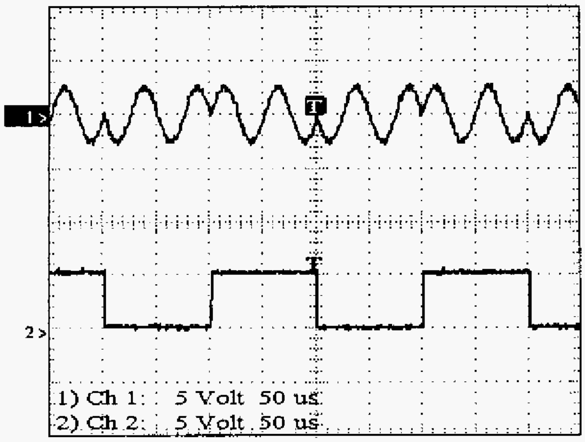

Figure 7 – Input BPSK modulated signal (top trace) demodulated waveform (bottom trace)

V. CONCLUSION

A new binary phase shift keying demodulator has been demonstrated that operates by generating pulses at every 180° phase jump in the carrier. The pulses are used to trigger a flip-flop, whose output is the demodulated signal. This circuit has the capability of operating up to very high data rates by using passive differentiator circuits followed by gain stages, if necessary, in order to trigger the subsequent logic circuitry. The limiting factor in the speed of operation are the rise and fall times of the circuits used in the logic circuitry after the differentiators.

Acknowledgements

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