University of Kentucky

EE 422G - Signals and Systems Laboratory

Lab 6 – Bit Detection with the Correlation Receiver

Objectives:

- Understand the principles that make the matched filter and correlation receivers optimal detectors for waveforms in noise.
- Implement the correlation receiver for detecting signals in noise.
- Implement the match filter for decoding bit streams received from noisy, bandlimited channels, and computing bit error rates.

1. Background

In modern digital communication systems, information – including speech, video, and computer data – must be transmitted to other locations before it can be used. In general, noise corrupts the signal during transmission. This noise may arise from many sources, including interference from another transmitter or inclement weather conditions. The purpose of the receiver is to accurately discern what information was transmitted, even in the presence of this noise.

The problem of recovering signals corrupted by noise has many solutions. The correlation receiver can be shown to be the best solution (optimal) for recovering digital data encoded using a known, but arbitrarily shaped, waveform in the presence of additive white Gaussian noise (AWGN). A correlation receiver basically compares the received signal to the waveforms it expects to receive, each of which is mapped to a known bit representation. For example, consider the signal of Fig. 1a. If the transmitted waveform is corrupted by noise, the received signal may look like the solid-lined plots of Figs. 1b and c. For a correlation operation, the received signals values are aligned with a template (shown in the dashed lines of Figs. 1b and c), and the sum of products between the received signal and template are taken over an interval equal to the length of the ideal waveform. The correlation will be greatest when the expected signal is aligned with the received signal, as shown in Fig. 1b. A lesser response occurs as the misalignment increases. Fig. 1c shows the misalignment resulting in the minimum response (largest negative number). The correlation receiver often uses signals that are zero-mean to exploit the cancellation between positive and negative values in the correlation sum.

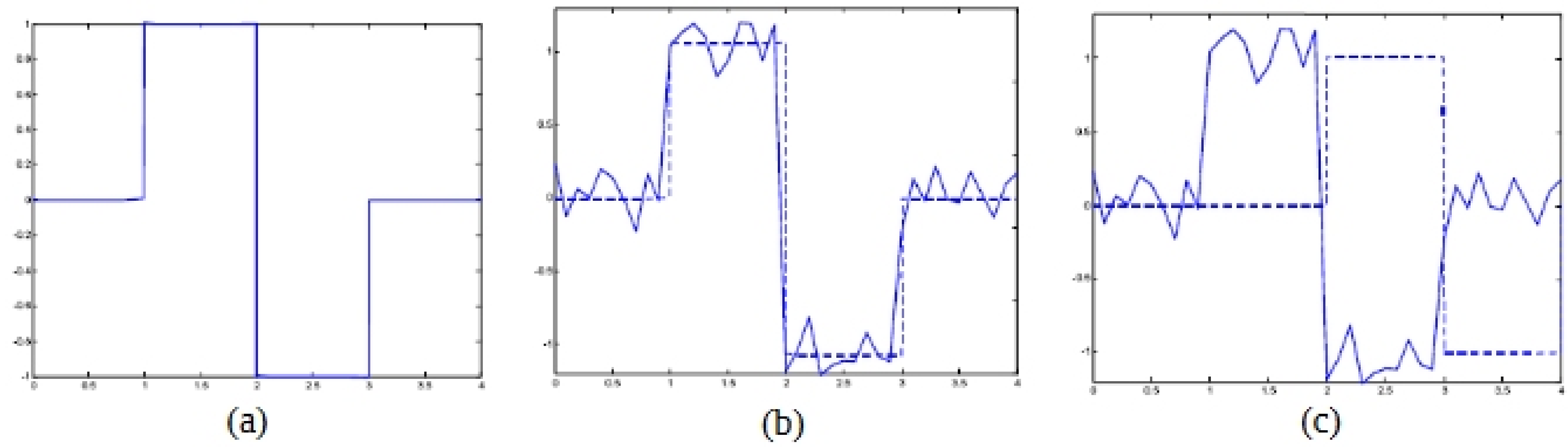

Figure 1. (a) Ideal transmitted waveform. (b) Matched alignment with noisy received waveform for maximum correlation receiver response. (c) Mismatched alignment with noisy received waveform for minimum correlation receiver response.

A correlation receiver therefore segments the signal into intervals that are synchronized with the bit intervals, and integrates the product of the received signal and template over the interval to produce correlation values. The correlation values become detection statistics used to estimate the bit value for each interval. In the case of bits there are only 2 possible symbols, so 2 correlation receiver would operate in parallel. Each would have a different template for the possible bit signals. The parallel channel with the greater correlation value would correspond to the detected bit. The synchronization of the segment intervals requires that both the source and receiver have the same clock signal or some way to synchronize before applying the correlation receiver. An example of this receiver is shown in Fig 2, where $f_0(t)$ is the template for the 0 bit, $f_1(t)$ is the template for the bit 1, and T is the synchronized bit interval. Every T seconds the input is correlated with the template and the correlation output is sampled to obtain the detection statistics. In this case the decision rule is to simply decide on the bit whose template has the best match (largest value). A bit error occurs when noise or bandwidth limitations result in an incorrect decision. The numbers of errors per bit is referred to as the bit error rate.

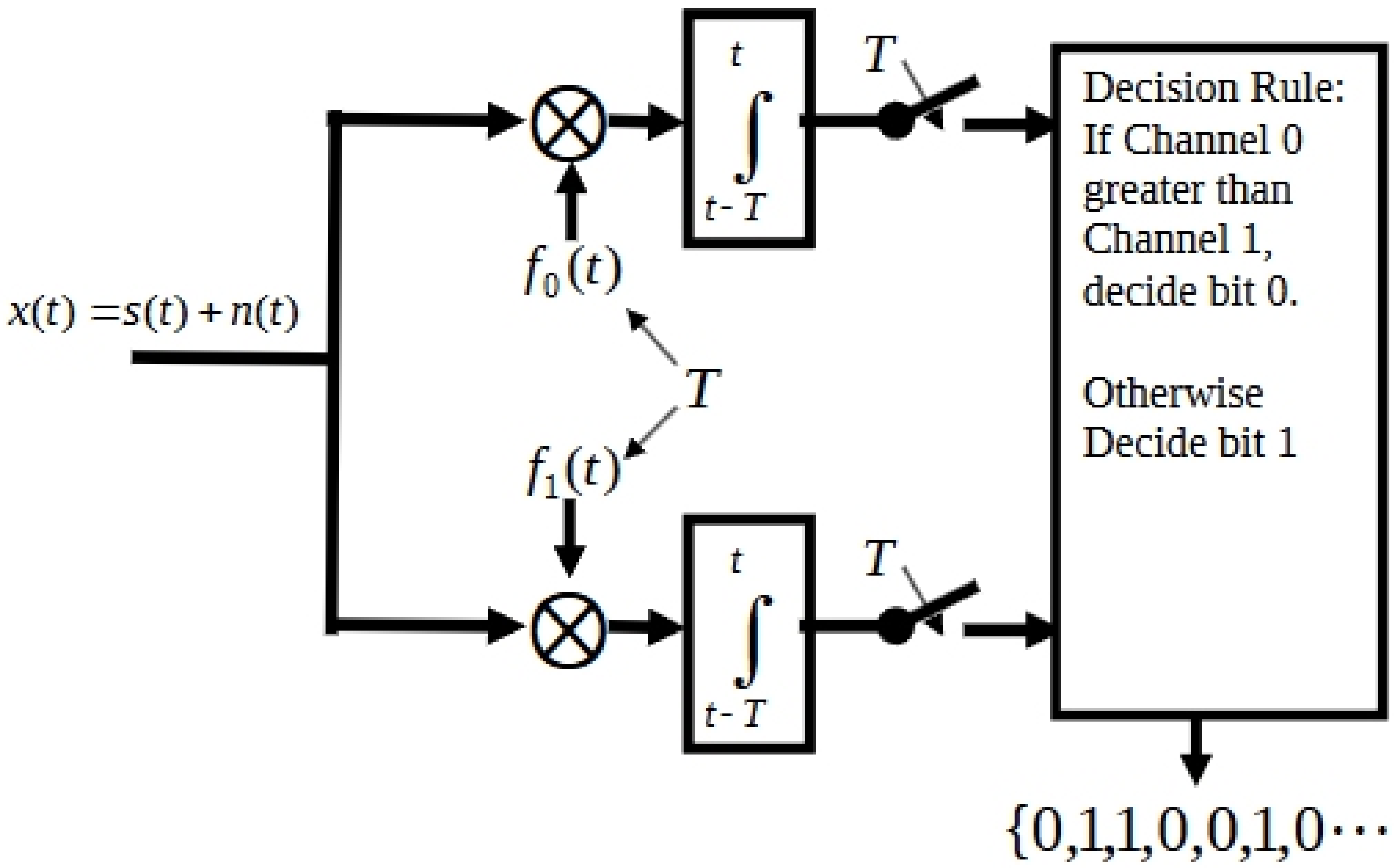

Figure 2. Correlation receiver synchronized to waveform intervals for bit sequence detection.

In cases where a physical event emits signals apart from clock synchronization, the receiver must detect the signal as well as estimate when the signal was emitted. This is typically the case for sonar or radar systems, where the time of the received echo depends on the distance between the target and receiver. The detection of the echo signal indicates the presence of a target, and the time at which the echo returns indicates the distance between the target and receiver. In this case intervals for correlation cannot be predetermined. Therefore, the signal template is slide continuously over the received signal producing a continuous output from which a decision is made on whether a target is present. This is typically done with a simple threshold. If there is a match with the signal of interest, the output will significantly exceed the values of the correlation receiver when no signal of interest is present. An example of the correlation filter implemented as a matched filter for this case is shown in Fig. 3. The signal of interest is a tapered sine wave. The top set of 3 waveforms in Fig. 3 show the signal, added noise, and the continuous set of detection statistics for the template that matches the signal. The lower 3 waveforms show the case when no signal is present (noise only). Note that at the detection statistics near 0.2 seconds the correlation output reaches a maximum for the case when a signal is present. This value is at least one order of magnitude greater than any of the outputs for the noise only signal. If accurate statistics about the noise are available, the threshold can be set to achieve a specific false-alarm rate. In general, there is a trade-off between the false-alarm rates (the likelihood that noise is mistaken for a signal) and the detection rate (likelihood that a target will be detected when present). A high threshold will result in a lower false alarm rate but also a lower detection rate, and vise versa.