Communication Systems Engineering

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The M-phase decision-feedback tracking loop also has a phase ambiguity of $2\pi/M$, necessitating the need for differentially encoding the information sequence prior to transmission and differentially decoding the received sequence at the detector to recover the information.

9.2.4 Differential-Phase Modulation and Demodulation

The performance of ideal, coherent phase modulation/demodulation is closely attained in communication systems that transmit a carrier-signal along with the information signal. The carrier signal component may be filtered from the received signal and used to perform phase-coherent demodulation. However, when no separate carrier signal is transmitted, the receiver must estimate the carrier phase from the received signal. As indicated in the preceding section, the phase at the output of a PLL has ambiguities of multiples of $2\pi/M$, necessitating the need to differentially encode the data prior to modulation. This differential encoding allows us to decode the received data at the detector in the presence of the phase ambiguities.

In differential encoding, the information is conveyed by phase shifts relative to the previous signal interval. For example, in binary phase modulation the information bit 1 may be transmitted by shifting the phase of the carrier by 180° relative to the previous carrier phase, while the information bit 0 is transmitted by a zero-phase shift relative to the phase in the preceding signaling interval. In four-phase modulation, the relative phase shifts between successive intervals are 0°, 90°, 180°, and 270°, corresponding to the information bits 00, 01, 11, 10, respectively. The generalization of differential encoding for $M > 4$ is straightforward. The phase-modulated signals resulting from this encoding process are called *differentially encoded.* The encoding is performed by a relatively simple logic circuit preceding the modulator.

Demodulation and detection of the differentially encoded phase-modulated signal may be performed as described in the preceding section using the output of a PLL to perform the demodulation. The received signal phase $\Theta_r = \tan^{-1} r_2/r_1$ at the detector is mapped into one of the M possible transmitted signal phases $\{\theta_m\}$ that is closest to Θ_r. Following the detector is a relatively simple phase comparator that compares the phases of the detected signal over two consecutive intervals to extract the transmitted information. Thus, phase ambiguities of $2\pi/M$ are rendered irrelevant.

Coherent demodulation of differentially encoded phase-modulated signals results in a higher probability of error than the error probability derived for absolute-phase encoding. With differentially encoded signals, an error in the detected phase due to noise will frequently result in decoding errors over two consecutive signaling intervals. This is especially the case for error probabilities below 10^{-1}. Therefore, the probability of error for differentially encoded M-ary-phase-modulated signals is approximately twice the probability of error for M-ary-phase modulation with absolute phase encoding. However, a factor-of-2 increase in the error probability translates into a relatively small loss in SNR, as can be seen from Figure 9.15.

A differentially encoded phase-modulated signal also allows another type of demodulation that does not require the estimation of the carrier phase. Instead, the received signal in any given signaling interval is compared to the phase of the received signal from the preceding signaling interval. To elaborate, suppose that we demodulate the differentially encoded signal by multiplying $r(t)$ with $\cos 2\pi f_c t$ and $\sin 2\pi f_c t$ and integrating the two products over the interval T. At the k^{th} signaling interval, the demodulater output is

$$r_k = \sqrt{\mathcal{E}_s}\, e^{j(\theta_k - \phi)} + n_k \tag{9.2.41}$$

where θ_k is the phase angle of the transmitted signal at the k^{th} signaling interval, ϕ is the carrier phase, and $n_k = n_{kc} + jn_{ks}$ is the noise vector. Similarly, the received signal vector at the output of the demodulator in the preceding signaling interval is

$$r_{k-1} = \sqrt{\mathcal{E}_s}\, e^{j(\theta_{k-1} - \phi)} + n_{k-1} \tag{9.2.42}$$

The decision variable for the phase detector is the phase difference between these two complex numbers. Equivalently, we can project r_k onto r_{k-1} and use the phase of the resulting complex number; that is,

$$\begin{aligned} r_k r_{k-1}^* = {} & \mathcal{E}_s e^{j(\theta_k - \theta_{k-1})} + \sqrt{\mathcal{E}_s}\, e^{j(\theta_k - \phi)} n_{k-1} \\ & + \sqrt{\mathcal{E}_s}\, e^{-j(\theta_{k-1} - \phi)} n_k + n_k n_{k-1}^* \end{aligned} \tag{9.2.43}$$

which, in the absence of noise, yields the phase difference $\theta_k - \theta_{k-1}$. Thus, the mean value of $r_k r_{k-1}^*$ is independent of the carrier phase. Differentially encoded PSK signaling that is demodulated and detected as described above is called *differential PSK* (DPSK).

The demodulation and detection of DSPK using matched filters is illustrated in Figure 9.18. If the pulse $g_T(t)$ is rectangular, the matched filters may be replaced by integrate-and-dump filters.

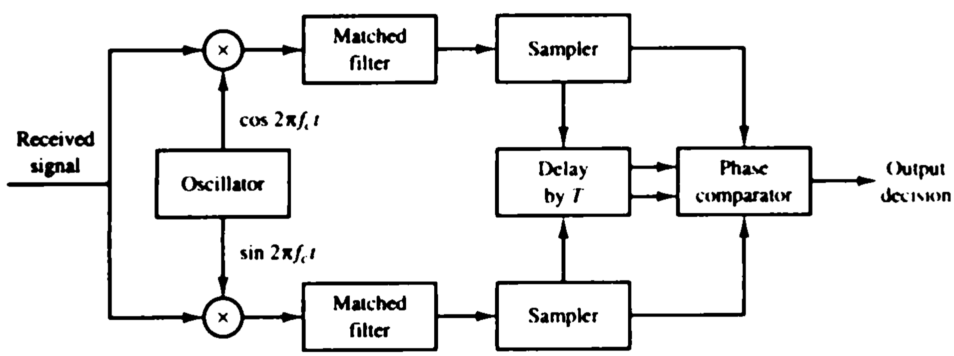

FIGURE 9.18. Block diagram of DPSK demodulator.

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