

Assignment # 3 CEP Solution:

System outputs: Enhanced ECG signal with the 60-Hz elimination

Processed ECG signal for heart rate detection

60-Hz eliminator:

Harmonics to be removed:	60 Hz (fundamental) 120Hz (second harmonic) 180Hz (third harmonic)
3-dB bandwidth for each filter:	4Hz
Sampling rate:	600Hz
Notch filter type:	Second-order IIR
Design method:	Pole-zero placement
Bandpass filter:	
Passband frequency range:	0.25–40Hz
Passband ripple:	0.5 dB
Filter type:	Chebyshev fourth order
Design method:	BLT method
DSP sampling rate:	600Hz

Let us carry out the 60-Hz eliminator design and determine the transfer function and difference equation for each notch filter and bandpass filter. For the first section with the notch frequency of 60 Hz, applying Eqs. (8.47)–(8.50) leads to

$$r = 1 - \left(\frac{4}{600} \right) \times \pi = 0.9791$$

$$\theta = \left(\frac{60}{600} \right) \times 360^\circ = 36^\circ.$$

We calculate $2\cos(36^\circ) = 1.6180$, $2r\cos(36^\circ) = 1.5842$, and

$$K = \frac{(1 - 2r\cos\theta + r^2)}{(2 - 2\cos\theta)} = 0.9803.$$

Hence it follows that

$$H_1(z) = \frac{0.9803 - 1.5862z^{-1} + 0.9803z^{-2}}{1 - 1.5842z^{-1} + 0.9586z^{-2}}$$

$$y_1(n) = 0.9803x(n) - 1.5862x(n-1) + 0.9802x(n-2) + 1.5842y_1(n-1) - 0.9586y_1(n-2).$$

Similarly, we yield the transfer functions and difference equations for the second section and the third section as

Second section:

$$H_2(z) = \frac{0.9794 - 0.6053z^{-1} + 0.9794z^{-2}}{1 - 0.6051z^{-1} + 0.9586z^{-2}}$$

$$y_2(n) = 0.9794y_1(n) - 0.6053y_1(n-1) + 0.9794y_1(n-2) + 0.6051y_2(n-1) - 0.9586y_2(n-2)$$

Third section:

$$H_3(z) = \frac{0.9793 + 0.6052z^{-1} + 0.9793z^{-2}}{1 + 0.6051z^{-1} + 0.9586z^{-2}}$$

$$y_3(n) = 0.9793y_2(n) + 0.6052y_2(n-1) + 0.9793y_2(n-2) - 0.6051y_3(n-1) - 0.9586y_3(n-2).$$

$$H_4(z) = \frac{0.0464 - 0.0927z^{-2} + 0.0464z^{-4}}{1 - 3.3523z^{-1} + 4.2557z^{-2} - 2.4540z^{-3} + 0.5506z^{-4}}$$

$$y_4(n) = 0.0464y_3(n) - 0.0927y_3(n-2) + 0.0464y_3(n-4) \\ + 3.3523y_4(n-1) - 4.2557y_4(n-2) + 2.4540y_4(n-3) - 0.5506y_4(n-4).$$

Hum noise created by poor power suppliers, transformers, or electromagnetic interference sourced by a main power supply is characterized by a frequency of 60-Hz and its harmonics. If this noise interferes with a desired audio or biomedical signal [e.g., in electrocardiography (ECG)], the desired signal could be corrupted. It is sufficient to eliminate the 60-Hz hum frequency with its second and third harmonics in most practical applications. We can complete this by cascading with notch filters with notch frequencies of 60, 120, and 180Hz, respectively. Figure 1 in CEP question depicts the functional block diagram.

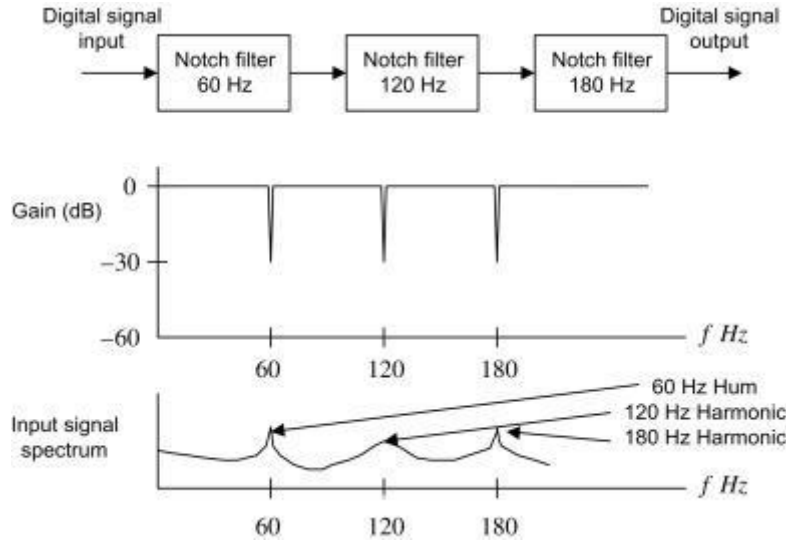


Figure 1: Functional Block Diagram of Notch filter with three different frequencies

Now let us apply the 60-Hz hum eliminator to an ECG recording system. The ECG is a small electrical signal captured from an ECG sensor. The ECG signal is produced by the activity of the human heart, thus can be used for heart rate detection, fetal monitoring, and diagnostic purposes. The single pulse of the ECG is depicted in Figure 2, which shows that an ECG signal is characterized by five peaks and valleys, labeled P, Q, R, S, and T. The highest positive wave is the R wave. Shortly before and after the R wave are negative waves called Q wave and S wave. The P wave comes before the Q wave, while the T wave comes after the S wave. The Q, R, and S waves together are called the QRS complex.

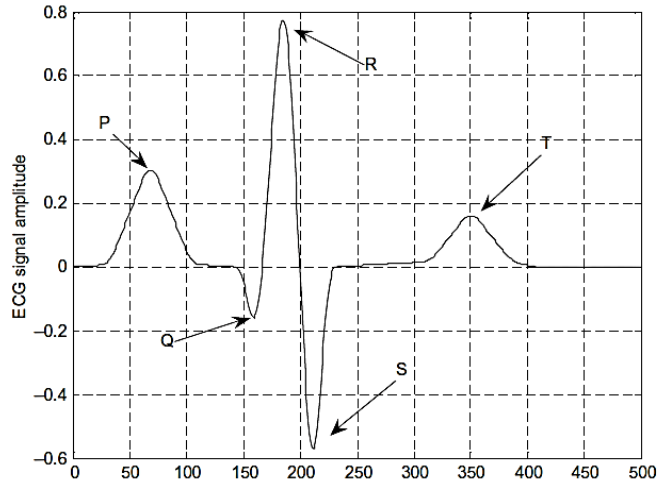


Figure 2: Characterization of ECG Peak

The properties of the QRS complex, with its rate of occurrence and times, highs, and widths, provide information to cardiologists concerning various pathological conditions of the heart. The reciprocal of the time period between R wave peaks (in milliseconds) multiplied by 60,000 gives instantaneous heart rate in beats per minute. On a modern ECG monitor, the acquired ECG signal is displayed for the diagnostic purpose.

However, a major source of frequent interference is the electric-power system. Such interference appears on the recorded ECG data due to electrical-field coupling between the power lines and the electrocardiograph or patient, which is the cause of the electrical field surrounding mains power lines. Another cause is magnetic induction in the power line, whereby current in the power line generates a magnetic field around the line. Sometimes, the harmonics of 60-Hz hum exist due to the nonlinear sensor and signal amplifier effects. If such interference is severe, the recorded ECG data becomes useless.

In this application, we focus on ECG enhancement for heart rate detection. To significantly reduce the 60-Hz interference, we apply signal enhancement to the ECG recording system, as shown in Figure 3. The 60-Hz eliminator removes the 60-Hz interference and has the capability to reduce its second harmonic of 120Hz and third harmonic of 180Hz.

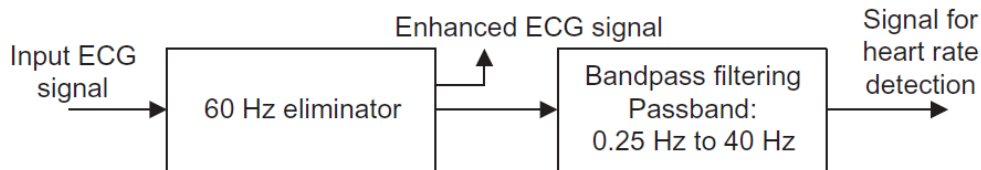


Figure 3: ECG Signal Enhancement System

The next objective is to detect the heart rate using the enhanced ECG signal. We need to remove DC drift and filter muscle noise, which may occur at approximately 40Hz or more. If we consider the lowest heart rate as 30 beats per minute, the corresponding frequency is $30/60 = 0.5$ Hz. Choosing the lower cutoff frequency of 0.25Hz should be reasonable.

Thus, a bandpass filter with a passband from 0.25 to 40Hz [range from 0.67 to 40Hz, discussed in Webster (2009)], either FIR or IIR type, can be designed to reduce such effects. The resultant ECG signal is valid only for the detection of heart rate. Note that the ECG signal after bandpass filtering with a passband from 0.25 to 40Hz is no longer valid for general ECG applications, since the original ECG signal occupies the frequency range from 0.01 to 250Hz (diagnostic-quality ECG). The enhanced ECG signal from the 60-Hz hum eliminator can serve for general ECG signal analysis (which is beyond the scope of this book). We summarize the design specifications for the heart rate detection application in this complex engineering problem.