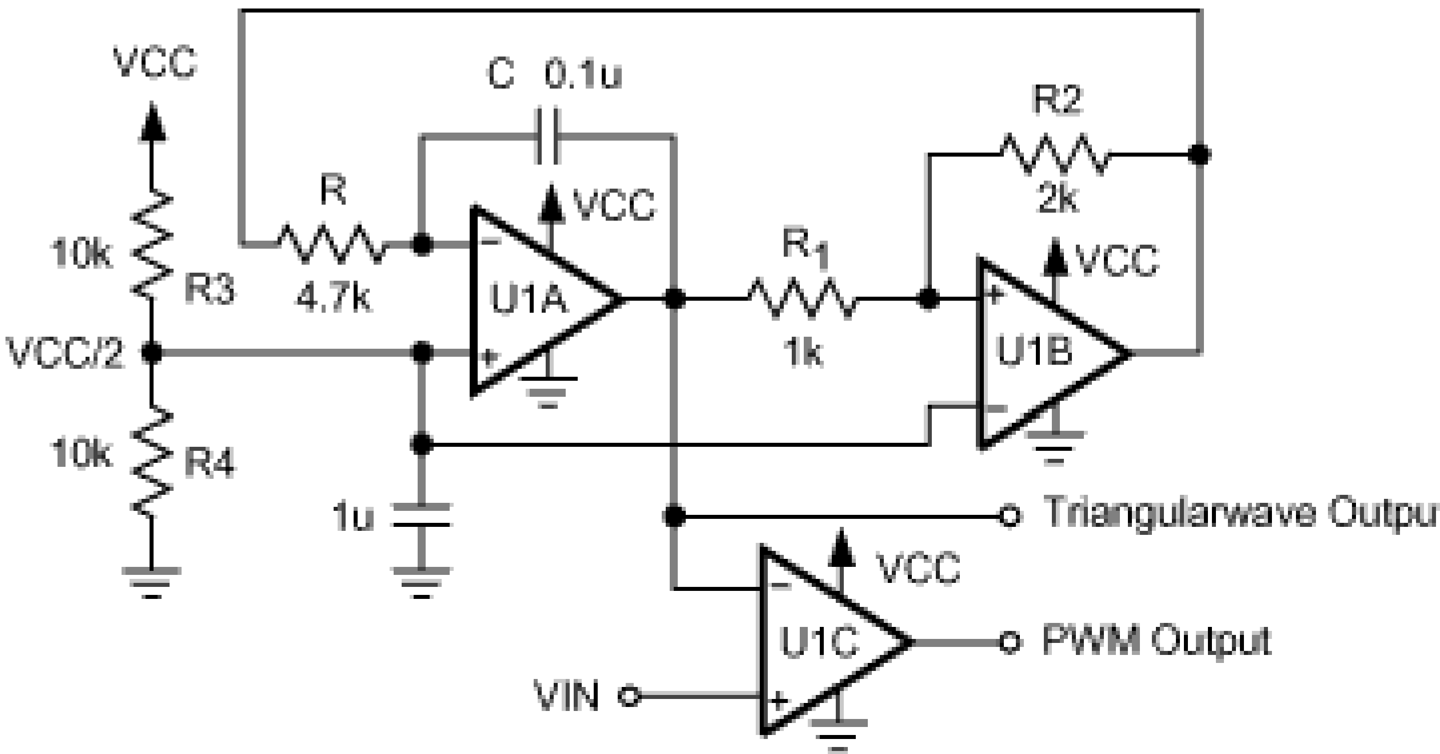
Pulse Width Modulation

- Pulse width modulation (PWM) is a technique in which a series of digital pulses is used to control an analog circuit. The length and frequency of these pulses determines the total power delivered to the circuit. PWM signals are most commonly used to control DC motors, but have many other applications ranging from controlling valves or pumps to adjusting the brightness of an LED.
- The digital pulse train that makes up a PWM signal has a fixed frequency and varies the pulse width to alter the average power of the signal. The ratio of the pulse width to the period is referred to as the duty cycle of the signal. For example, if a PWM signal has a 10 ms period and its pulses are 2 ms long, that signal is said to have a 20 percent duty cycle.

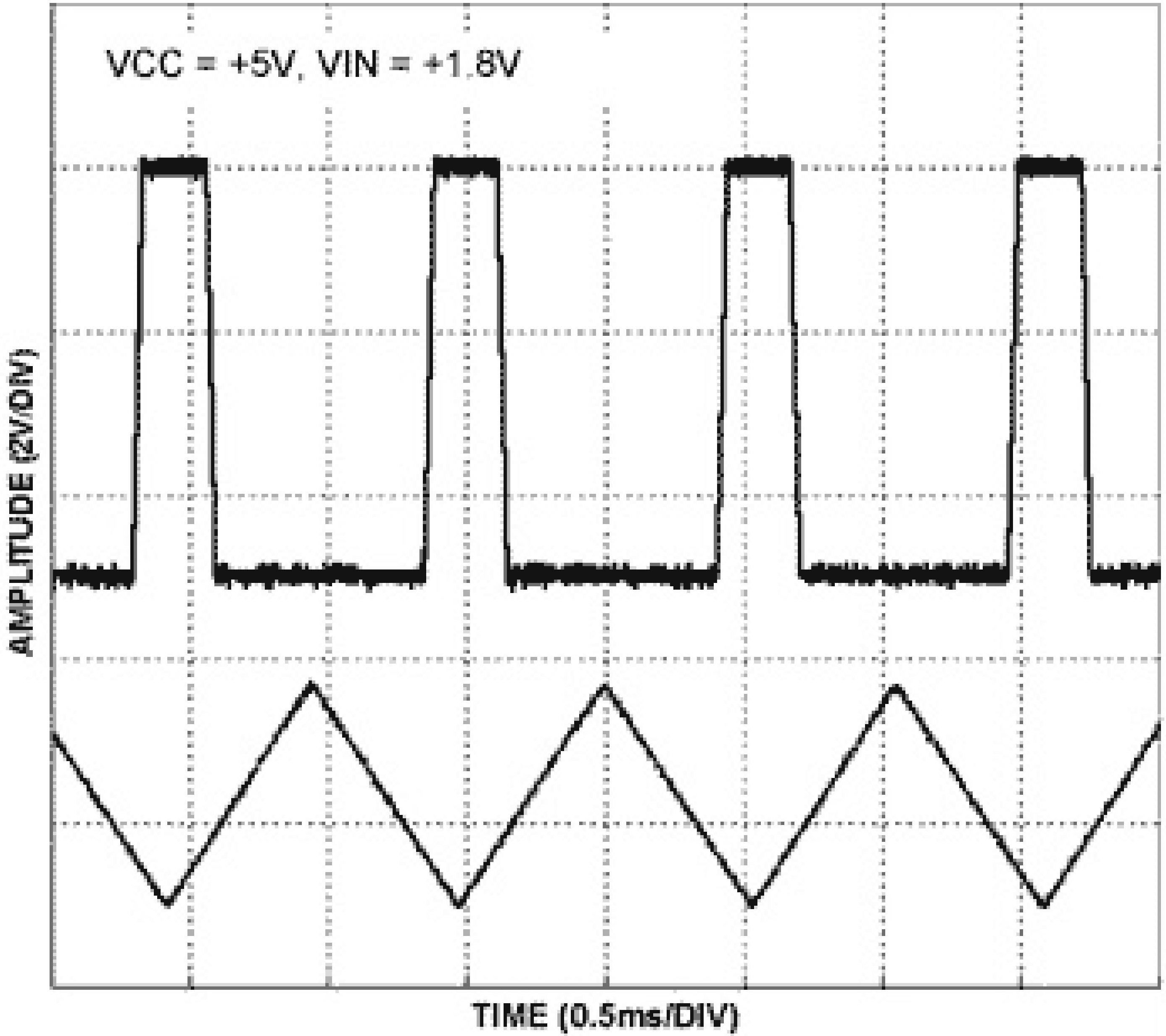
- PWM can be used to reduce the total amount of power delivered to a load without losses normally incurred when a power source is limited by resistive means. This is because the average power delivered is proportional to the modulation duty cycle. With a sufficiently high modulation rate, passive electronic filters can be used to smooth the pulse train and recover an average analog waveform.
- High frequency PWM power control systems are easily realizable with semiconductor switches. The discrete on/off states of the modulation are used to control the state of the switch(es) which correspondingly control the voltage across or current through the load. The major advantage of this system is the switches are either off and not conducting any current, or on and have (ideally) no voltage drop across them. The product of the current and the voltage at any given time defines the power dissipated by the switch, thus (ideally) no power is dissipated by the switch. Realistically, semiconductor switches are non-ideal switches, but high efficiency controllers can still be built.



A PWM signal is generated by comparing a triangle wave signal with a DC signal.

This 3-Op-Amp Circuit produces a triangular wave and a variable-pulse-width output.

U1A and U1B form a triangle-wave generator. U1B is a comparator.

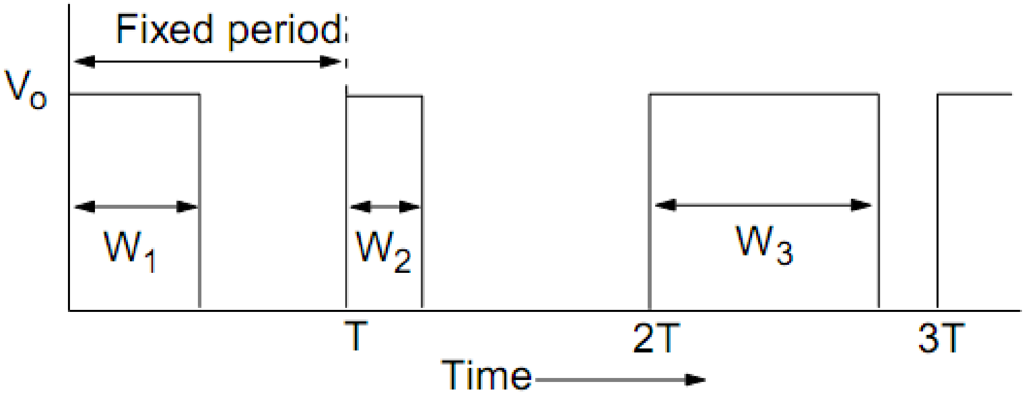


Waveforms created by the 3-Op-Amp Circuit

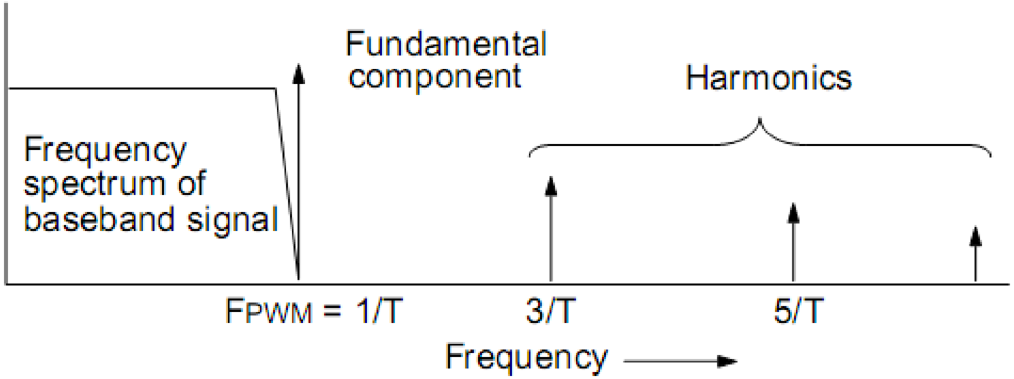
- U1A is configured as an integrator and U1B as a comparator with hysteresis. At power up, the comparator's output voltage is assumed to be zero.

Using PWM to Generate Analog Output

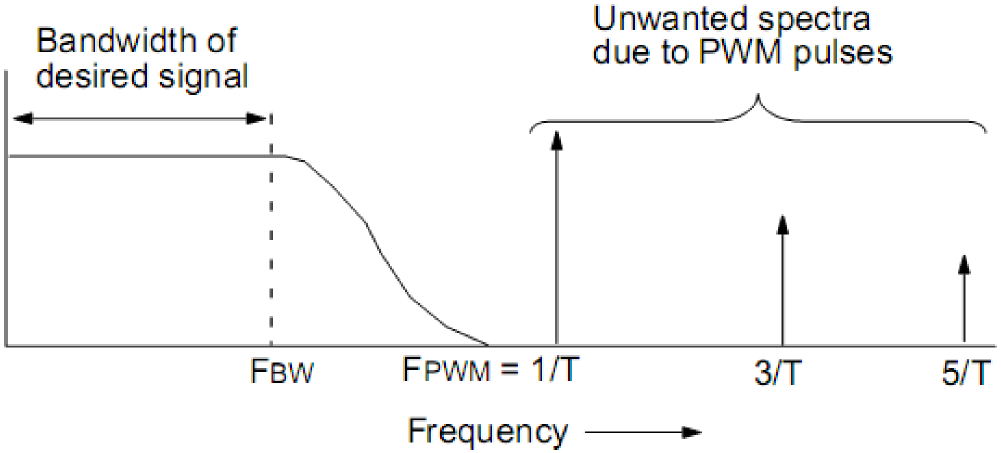
- PWM can be used as an inexpensive digital-to-analog (D/A) converter. A wide variety of microcontroller applications exist that need analog output but do not require high-resolution D/A converters.
- Conversion of PWM waveforms to analog signals involves the use of analog low-pass filters.
- In a typical PWM signal, the frequency is constant, but the pulse width (duty cycle) is a variable. The pulse width is directly proportional to the amplitude of the original unmodulated signal.



Typical PWM Waveform



Frequency Spectrum of a PWM Signal

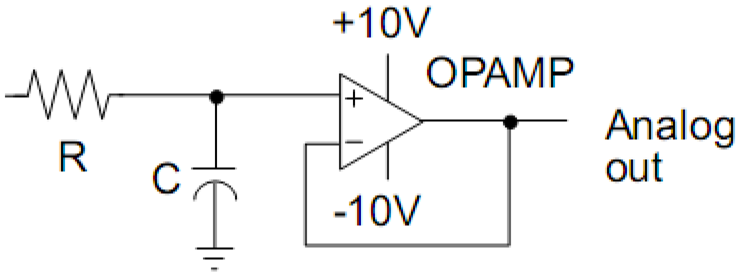


External Low-Pass Filter

$$F_{PWM} = K\,F_{BW}$$

$$K >> 1$$

Signal BW
4 kHZ → PWM
K = 5 →



$$F_{PWM} = K\,F_{BW} = 20\,\text{kHz}$$

Choose the -3 dB point at 4 kHz

$$RC = \frac{1}{2\pi f} = 3.98(10^{-5})$$

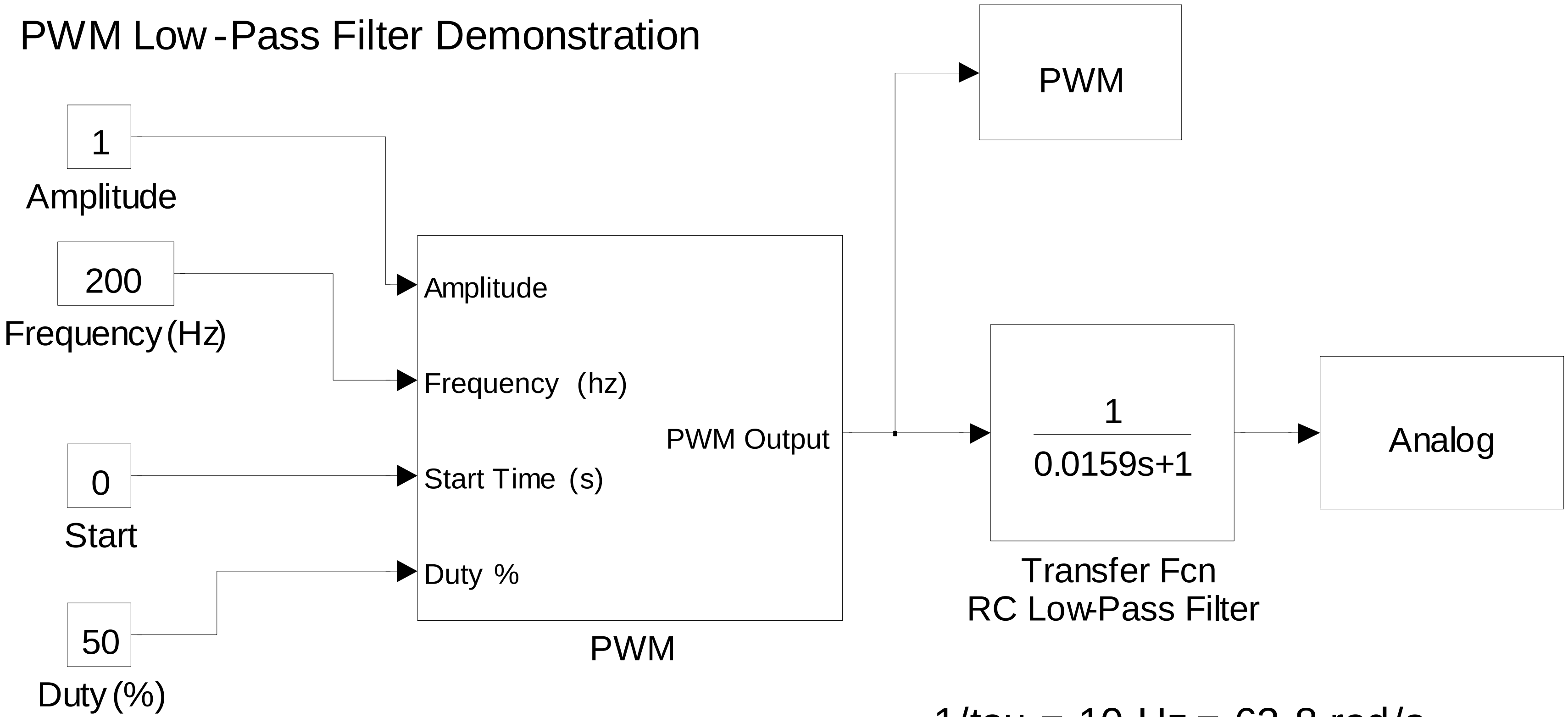
$$R = 4.0\,\text{k}\Omega \quad C = 0.01\,\mu\text{F}$$

$$f = 20\,\text{kHz}$$

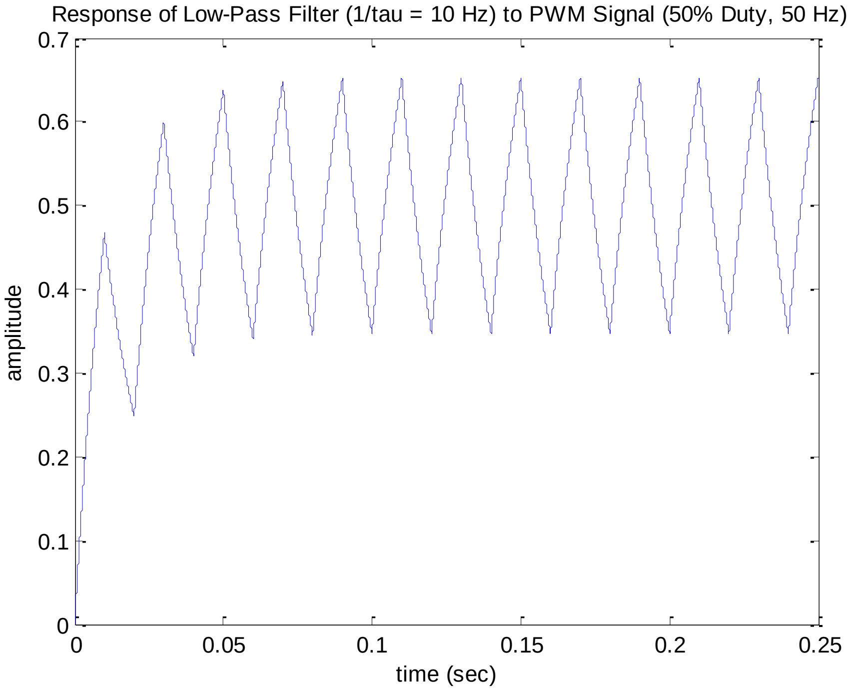
$$\text{dB} = 20\log_{10}\frac{1}{\sqrt{(2\pi f \bullet RC)^2 + 1}} = -14.2\,\text{dB}$$

If the -14 dB attenuation will not suffice, a higher-order active low-pass filter may be necessary or a higher PWM frequency.

PWM Low-Pass Filter Demonstration

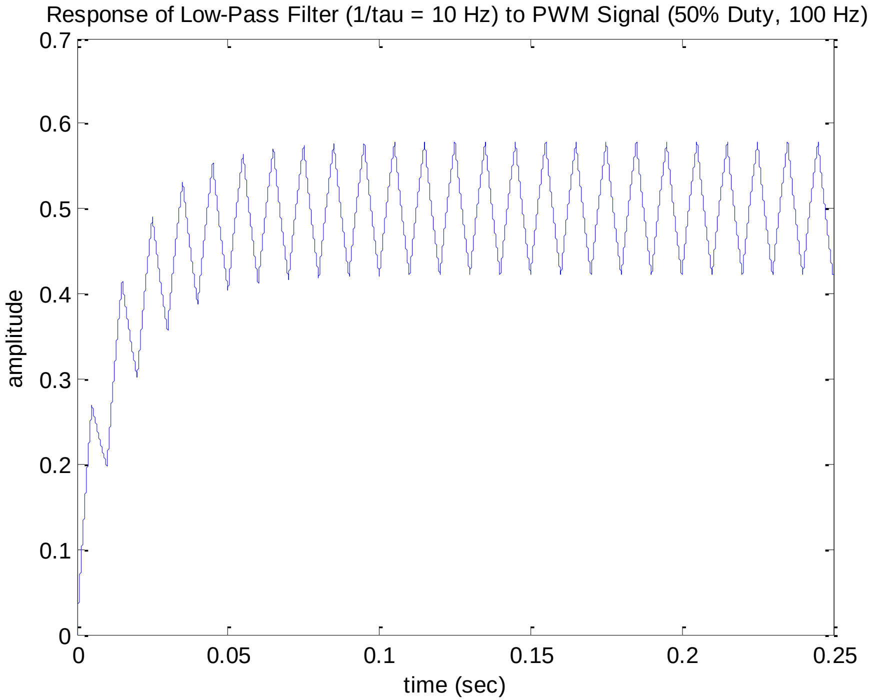


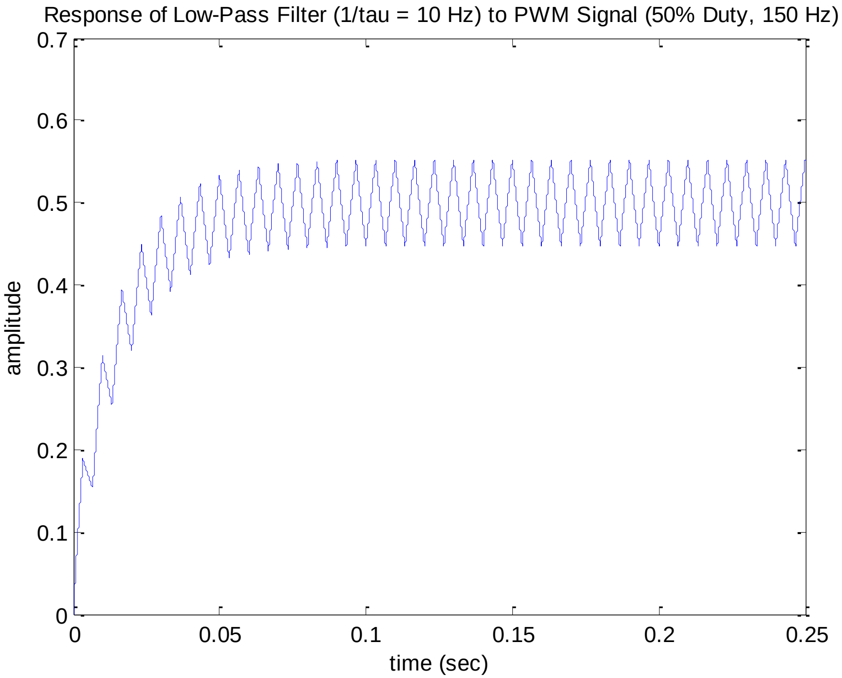
1/tau = 10 Hz = 62.8 rad/s
PWM Frequency K = 5, 10, 15, 20



PWM 50 Hz

PWM 100 Hz





PWM 150 Hz

PWM 200 Hz