Using a Mechanical Chopper with a PEM to Measure V_{DC}

TECHNICAL NOTE

It is standard practice to use the ratio V_{AC}/V_{DC} for analyzing PEM-based optical systems, where V_{DC} is the "average" value of the signal. For example:

$$R_{1f} = \frac{V_{1f}}{V_{DC}} \quad (1)$$

$$R_{2f} = \frac{V_{2f}}{V_{DC}} \quad (2)$$

V_{1f} and V_{2f} may be measured by a lock-in amplifier and V_{DC} by an electronic DC voltmeter. The resulting ratios have the advantage that the measurement is not sensitive to fluctuations in light intensity, changes in optical transmission, etc.

There are some cases, however, where it is advantageous to use AC methods for detecting the average signal voltage, V_{DC}. One example is if there is a source of DC signal, perhaps unstable, that is not related to the modulated optical signal being studied. The most common method is to use a mechanical chopper with a lock-in amplifier. (The chopper should always be placed close to the light source.) A "chopped" PEM signal is shown in Figure 1.

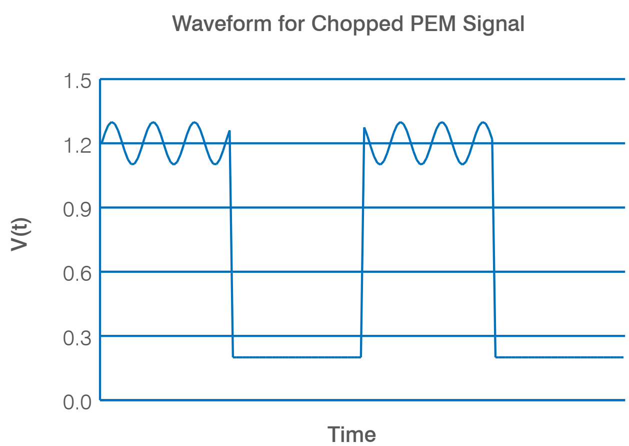


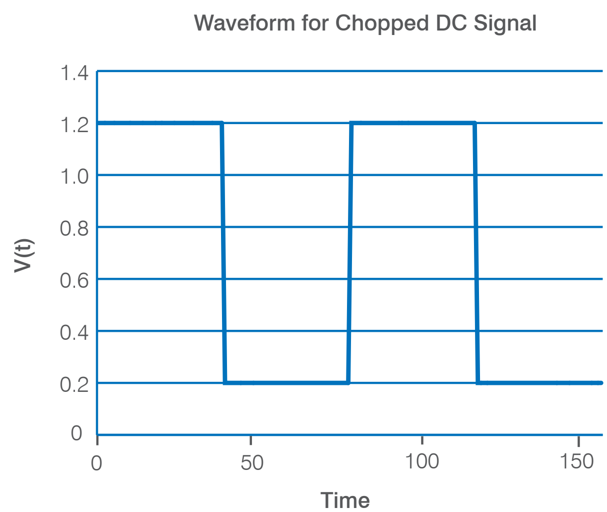
Figure 1 shows a PEM-modulated signal with amplitude 0.1 chopped by a mechanical chopper. If there were no chopping, V_{DC} from the optical signal would be 1.0 and there is an unwanted DC signal of 0.2. We will assume that the chopper performs "square wave" chopping with a duty cycle of 50%, that is, the optical signal is blocked exactly 50% of the time. Compared with a continuous (unchopped) optical signal,

- The average or DC intensity is ½ the unchopped value.
- Any 1f signal intensity is ½ the unchopped value
- Any 2f signal intensity is ½ the unchopped value

We can work with these new values, the ratios of V_{AC}/V_{DC} will be the same as they were before, since the factor of ½ is common to all terms.

USE OF A LOCK-IN AMPLIFIER TO MEASURE V_{DC}

If a lock-in amplifier is used to measure V_{DC}, however, the lock-in output $V_{chopper}$ is not precisely the value V_{DC}. To understand this, let us examine an example of a waveform of a chopped DC light source (Figure 2).



In the example above, the chopped square-wave signal has a peak-to-peak value of 1.0. The average signal is 0.7 but 0.2 of this is the unwanted contribution caused by dark current, stray room light, etc. We wish to measure V_{DC} of the chopped optical signal, which in this case is 0.5.

This waveform may be represented by a Fourier series of the form

$$V(t) = \frac{a_0}{2} + \sum_n a_n \cos(n\omega t) + \sum b_n \sin(n\omega t) \qquad (3)$$

By inspection, $a_0/2 = 0.7$. From calculation $a_1 = 0$ and $b_1 = 0.6366$. But the amplitude of the square wave is 0.5 (1/2 the "peak-to-peak" value). The lock-in amplifier measures the rms value of the fundamental or first harmonic at 1f of the square wave signal. To convert to voltage amplitude it must be multiplied by √2.

We may now write a relationship between the chopper signal measured by the lock-in amplifier ($V_{chopper}$) and V_{DC}.

$$\sqrt{2}V_{chopper} = \frac{.6266}{.500}V_{DC} \qquad (4)$$

or

$$V_{DC} = \frac{\sqrt{2} \text{ x } .5}{.6366}V_{chopper} = 1.1107V_{chopper} \qquad (5)$$

Although specific numbers were used in this evaluation, the constant 1.1107 has universal validity for square wave choppers with 50% duty cycle.

EXPERIMENTAL MEASUREMENT OF V_{DC} AND $V_{CHOPPER}$

The above section gives the theoretical relationship between V_{DC} and $V_{Chopper}$. The costant of proportionality in equation 3 may also be determined with an experiment. The procedure follows.

1. The PEM may be on or off, as you prefer. In either case, the light source should be ON.
2. Connect a digital voltmeter to the output of the detector. Measure the DC voltage output of the detector. Call this V_1
3. Now block the light at the location of the chopper. Again measure the output of the detector. Call this V_2.
4. $V_{DC} = V_1 - V_2$. Note that V_2 is the contribution to the detector output due to dark current, stray light, instrumental imbalance, etc. If V_2 is negative, be sure to follow the law of subtraction of a negative number.
5. Now connect the detector output to the lock-in amplifier used for demodulating the mechanically chopped signal. Measure the lock-in amplifier output.
6. Calculate the experimental constant K in the equation

$$V_{DC} = KV_{chopper} \qquad (6)$$

Hinds Instruments, Inc | 7245 NW Evergreen Pkwy | Hillsboro, OR 97124 | USA
T: 503.690.2000 | Fax: 503.690.3000 | sales@hindsinstruments.com