Optical Power Meter Basics

Introduction

An optical power meter measures the photon energy in the form of current or voltage from an optical detector such as a semiconductor, a thermopile, or a pyroelectric detector. Newport's 1936/2936-R Series Optical Power Meters are among the most versatile power meters in the market, and the electronics adapt to a number of signal measurement tasks: DC current or voltage, AC peak-to-peak current or pulse voltage, or integrated DC current or voltage signals. This versatility is required to handle various signals that the detectors generate. The user then selects among the available operating states when using the meter. In this white paper, basic power meter design principles are reviewed to help the user properly use the power meter for the most accurate measurements.

Analog Signal Flow

The detector data is introduced to the 1936/2936-R Series by way of a calibration module specific to the detector in use. At power up, the power meter downloads information about the detector from the calibration module or the detector internal memory. Based on the calibration module preprogrammed data, the meter learns the set of operating states available to the detector. The detector signals can follow many different paths through the input amplifier chain. A block diagram of analog signal flow is shown in Figure 1. The actual flow path depends upon the detector type and the mode of measurement.

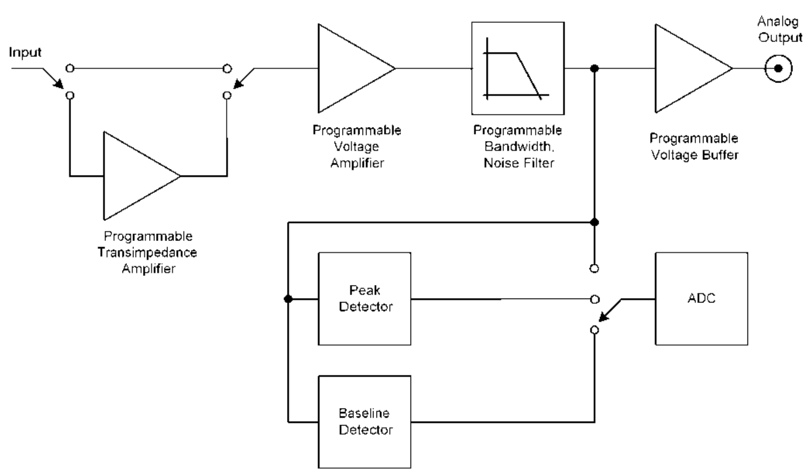

Figure 1 Model 1936/2936-R Series Analog Signal Flow Diagram

The analog signal flow path is primarily determined by the responsivity units of the detector. The numerator of these units indicates how the meter must be configured in order to obtain a calibrated optical measurement. Analog signal flow is independent of whether single or continuous measurements are made.

Responsivity units and signal flows for the various detector families are listed in Table 1.

Detector Family	Resp. Units	Mode	Amplifier Path	Peak-Baseline
Photodiode	A / W	DC	I	No
Photodiode	A / W	Peak-Peak	I	No
Photodiode	A / W	Integral	I	No
Thermopile	V / W	DC	V	No
Thermopile	V / W	Integral	V	No
Pyroelectric	V / J	Pulse	V	Yes

Table 1 Analog Signal Flow Paths.

Digitized Signal Flow

An analog-to-digital converter captures the input signal for digital processing. The input signal has the units of current or voltage depending upon how the input amplifier chain was configured. This digitized signal moves through a number of process steps that may or may not alter the digitized value depending upon the operating state of the meter. Each of these possible-processing steps is discussed further.

Gain

Gain processing accounts for the signal gain of the input amplifiers. The output is the product of the digitized value and the amplifier gain.

Zero Offset

The zero offset output is equal to the input value less the zero reference value.

Responsivity Map(s)

This process scales the input value in accordance with current calibration wavelength and the responsivity map downloaded from the detector calibration module. The output of this process, i.e. the measurement value, is the digitized input value divided by the responsivity associated with the current calibration wavelength or the user defined calibration value.

Units Correction

Unit's correction adjusts a measurement value to account for the display units selected. When the display units are equal to the detector signal units, i.e. equal to the numerator of the responsivity units, Table 1, the measurement value is not adjusted. Otherwise the digitized value is adjusted to account for detector responsivity and/or additional unit conversions such as W-to-W/cm^2.

Typical Detector Signals

The flexibility of the optical power meter analog signal flow is required so that it may properly measure the signals that various types of detectors make.

Basic optical power or energy measurements are related to a measured detector signal, *S*, in the following way:

$$\mathrm{P\ or\ E} = \frac{\mathrm{S}}{\mathrm{R}_{\lambda}}$$

Where: R_λ = Detector responsivity at λ
S = Detector signal

Newport's 918D/818 Series photodiode detectors provide a current signal. The 1936/2936-R Series is capable of 1pA resolution in order to provide the highest sensitivity performance with these detectors. To yield the detectivity, signal-to-noise ratio, and accuracy that is expected from a semiconductor photodiode, a transimpedance amplifier is employed (Figure 2).

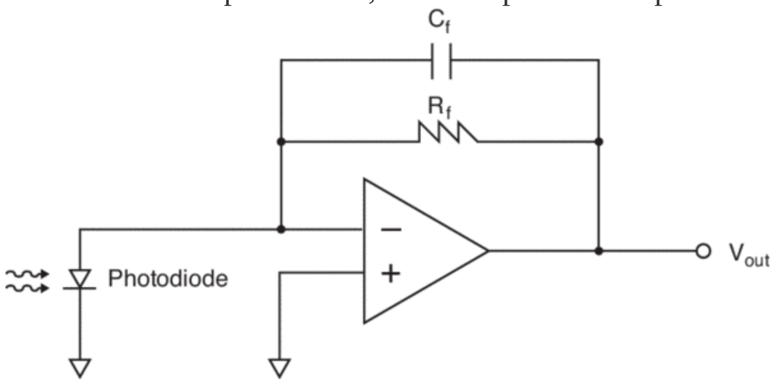

Figure 2 Tranimdepance Amplifier Diagram

The advantage that the transimpedance amplifier has over other amplifier configurations is that it does not bias the photodiode with a voltage as the current starts to flow from the photodiode. Typically, one lead of the photodiode is tied to the ground and the other lead is kept at virtual ground by means of the minus input of the transimpedance amplifier. The resultant bias across the photodiode is then kept at virtually zero volts, a condition that helps minimize dark current and noise, and helps increase linearity and detectivity.

Effectively the transimpedance amplifier causes the photocurrent to flow through the feedback resistor, which creates a voltage, V = iR, at the output of the amplifier. With the value of the precision feedback resistor in the meter known, the current can be calculated with a very good accuracy.

Thermopile Detector Signals

When interfacing with a Newport thermopile or pyroelectric detector, the optical power meter measures voltage. There is, however, a considerable difference in how the measurement must be made between the two types of detectors. The optical meter's circuitry must be designed and configured to accommodate the two different types of voltage sources. The 1936/2936-R is capable of 76.3nV resolution in order to reach the sensitivity limits of thermopile detectors.

Thermopile detectors produce very slow bandwidth voltages (≈1 Hz) that can be measured in the sub-millivolt levels. One of the main concerns when trying to resolve such low voltages is to compensate for, or eliminate, thermoelectric voltages caused by dissimilar metals, which are generated in the connections and printed circuit board. It is somewhat ironic that the desirable physical effect that generates the voltage in a thermopile detector is similar to the undesirable effects that are present in the connections and printed circuit board. Precautions must be taken when choosing the electrical components to help minimize the unwanted thermoelectric voltages. Additionally, to accurately resolve small voltages, the optical meter must be able to zero any offset voltage due to temperature drift of the components and the thermopile.

Thermopile detectors respond with a voltage signal that slowly changes in incident optical power. The time constant of most thermopile detectors is on the order of 1 to 10 seconds.

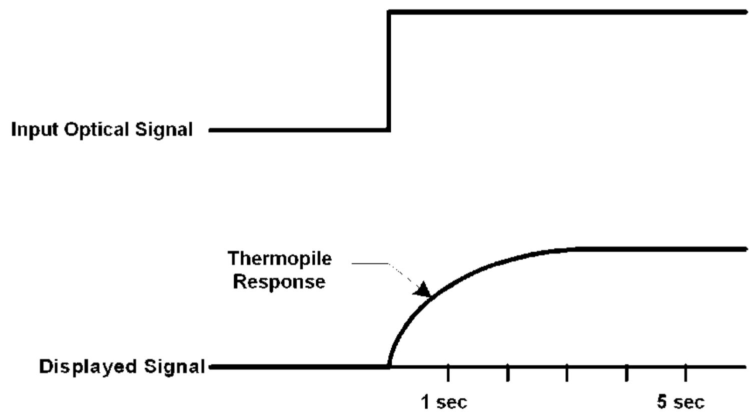

Figure 3 Thermopile Signals exhibit 1 to 10 second time constants.

Peak-to-Peak (Photodiode) Detector Signals

The 1936/2936-R Series allows one to make peak-to-peak measurements of time varying signals from semiconductor photodiode detectors. Since optical power is a zero bounded positive quantity, signals from a detector observing such modulated light will similarly be zero bounded positive signals.

To make a peak-to-peak measurement, the power meter captures both the maximum and minimum values of the sampled detector signal.

Analog Output

The Model 1936/2936-R Series provides an analog output for signal monitoring. The analog output is the actual amplified detector signal and is uncorrected for the effects of the detector's responsivity, calibration, and ZERO. The analog output signal is a representation of what the meter "sees" at its input. However, the analog output signal may be filtered if the user selects any cutoff frequency from the drop down menu of the analog filter. Also, the analog output signal is amplified and scaled to the selected analog output level

The analog output maximum level corresponds to the maximum full-scale input range the meter is set on. For example, if one selects the analog output level at 1.0 V into 50 Ω, and the meter is set on 250 mW maximum full-scale input range, the analog output signal will have a transfer function of 250 mW/1.0 V. Therefore, if the analog output BNC is connected to an oscilloscope or voltmeter with 50 Ω input impedance and the user reads 0.5 V, the detector power is 125 mW.

Signal Filtering

The 1936/2936-R Series offers the user a unique option to filter the detector signal. There are two programmable filters that can be used individually or together to condition the detector signal: the Analog Filter and the Digital Filter. This flexibility is offered to the user to improve the measurement precision for different detectors.

The Analog Filter is hardware based programmable low-pass filer. The user can select the following settings: 5 Hz, 1 kHz, 12.5 kHz, and 250 kHz.

The digital filter gives an average of the most recent 10, 100, 1000, or 10000 samples, depending on the user's selection. When less than the selected number of samples has been acquired since the last reset of the digital filter, the output is the average of all the values received.

It is well known that white noise has large spectrum. The noise level increases with bandwidth. The higher the noise, the higher the minimum signal that can be measured. The quality of the measurement can be linked to the signal-to-noise ratio (SNR): the higher the SNR, the better the measurement precision of very small signals. In order to increase the SNR the user may choose to cut the bandwidth of the meter, depending on the detector signal.

For example, if the detector is modulated with a sine wave of 800 Hz, the user may choose to set the Analog filter to 1 kHz to increase the SNR and be able to measure very small signals. Also, cutting the bandwidth at 1 kHz does not affect the measurement. However, if the modulation frequency is 800 Hz, but the signal is a square, the user may opt to cut the bandwidth higher, at 12.5 kHz, to let the signal harmonics be unfiltered and minimize the distortion. Of course, in this case, the noise in the system will increase with the square root of the bandwidth. The user needs to assess the tradeoffs in his measurement, taking advantage of the 1936/2936-R Series high flexibility in setting the proper filters for the measurement.

Generally, the 5 Hz filter is used for CW Continuous measurements. However, the 1936/2936-R Series can measure the amplitude of AC signals down to 0.01 Hz, so the 5 Hz filter can be used for any modulating signal below 5 Hz.

The Digital Filter is a moving average filter that can be set at 10, 100, 1000, or 10000 measurements. These values can be changed by the user. If the digital filter is set on 10, the average value is computed on 10 measurements, in a First In First Out (FIFO) fashion. The Digital Filter helps the SNR the same way as the Analog Filter does. With both filters on, low level, continuous signals can be measured with a high degree of accuracy.

The Analog Filter is always applied to the entire amplifier chain of the meter. Therefore, the user will see the detector signal filtered at the Analog Output BNC. The Digital Filter is a digital signal-processing filter and is only applied to the calculated measured values that are displayed on the meter screen. While the displayed values may have both filters applied, the Analog Output can only have the Analog Filter applied to the signal. Because of that, the user may see a difference in the way the signal is filtered between the displayed values and the Analog Output values.

Conclusion

In this white paper, we reviewed the basic principles of an optical power meter by dividing it into the analog and the digital signal flow blocks. Various measurements considerations for different types of detectors are then briefly discussed. The analog output and the signal filtering setting offer flexibility in measuring not only the CW signals but also modulated or pulsed signals.