Characterizing a laser receiver

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Precise characterization of an optical receiver is an important step in the design and checkout of a laser system. This article presents practical procedures for characterizing three parameters: range of linearity in the relation of input light to output signal, minimum detectable light level, and spectral response. The procedures are applicable to all optical receivers, but the example in each case is the silicon photodiode.

Input-output linearity

The electro-optical system for measuring input-output characteristics is best understood with the aid of the typical linearity plot accompanying the schematic in Fig. 1. Two light signals are superimposed on the sensor's photoactive surface. The tungsten light source, operated from a regulated direct-current supply, is variable in intensity across several decades through the use of a variable aperture and a variable distance between source and sensor. The second light source is a small light-emitting diode driven with a regulated alternating-current supply. The current to the diode is chosen so that the light output is always much less than the intensity of the tungsten source. The photodiode produces two electrical outputs superimposed; the first is a DC signal reproducing the tungsten source, the second an AC signal reproducing the diode source. These two signals are registered respectively by a precision AC voltmeter and a precision DC voltmeter placed in parallel at the output of the operational amplifier. Since the DC tungsten source produces a light output at least 100 times greater than the AC diode's, it sets the basic operating point on the linearity curve.

The AC signal can be considered a small rider on top of this DC background bias point. Thus the AC diode's light signal samples the slope (responsivity) at the bias point established by the strong DC light level. A change in linearity at any point on the typical curve would be represented as a change in slope and therefore would cause the AC meter shown in the schematic, which samples the diode signal, to register a change. In practice, the AC meter is set at 100% for that DC bias level which is at approximately the midpoint of the range to be covered. Thus any deviation from 100% on the AC meter is a direct indication of a deviation from perfect linearity of the sensor when the DC light bias level is moved across the range available to it.

This measurement system is also useful in establishing that high light level at which the sensor begins to saturate. As the DC light level is increased toward the saturation value, the AC meter begins to decrease from 100%, falling faster and faster as the DC level is decreasing, until it reaches zero, at which point further increases in DC light level produce no change in output signal current of either a DC or AC value. This new linearity test system can be compared with the traditional technique which employs neutral-density filters of varying magnitudes to establish varying irradiance on a photosensor. With neutral-density filters, one is never quite sure of the magnitude of the errors associated with three effects: the absolute calibration of the neutral density filter, the spectral transmission of the neutral-density filter across the range through which the sensor is responsive, and reflection effects between the surfaces of several neutral-density filters placed in series, and between a neutral-density filter and the sensor surface itself. The technique eliminates all these possibilities for error.

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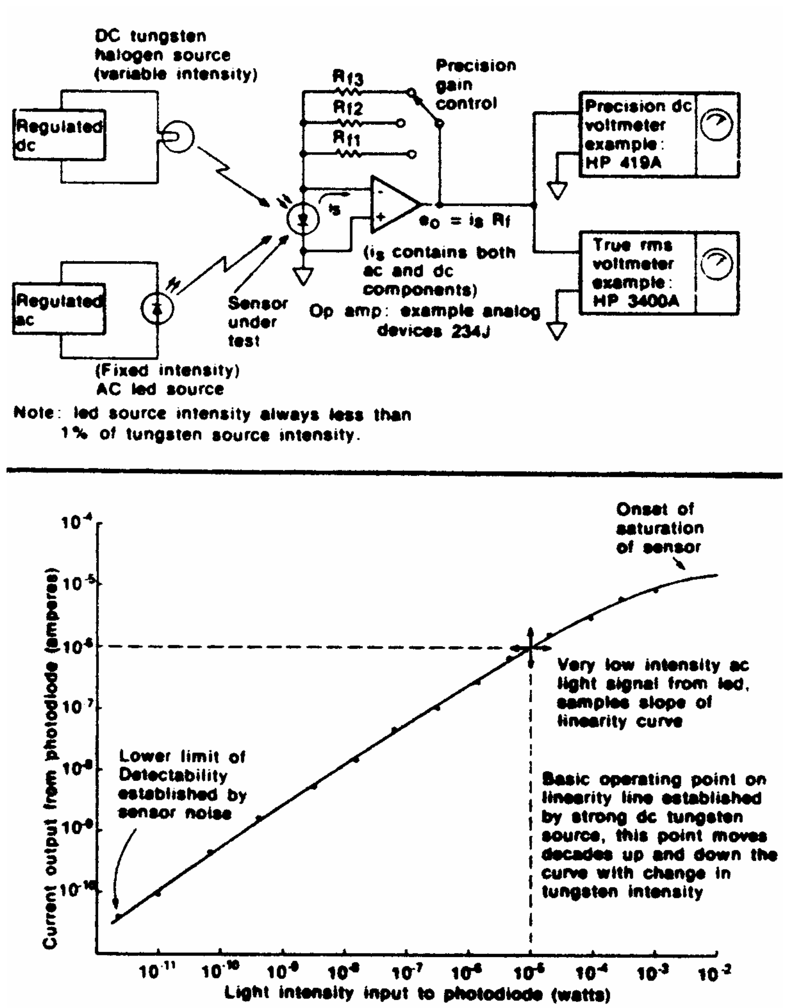

Fig 1 At top, setup for automatically measuring linearity of the ratio of a photosensor's light input to its current output. Below, typical input-output linearity plot for a silicon photodiode showing a typical operating point for automatic measurement of the setup above.

The noise-equivalent power of an optical receiver is that input light power which produces an output signal just equal to the dark noise signal inherently produced by the detector. This NEP is a function of the center frequency and the bandwidth of the measurement setup shown in Fig. 2. The noise voltage output is what is actually measured, and this must be related to an input light power level which produces a signal voltage just equal to this noise voltage.

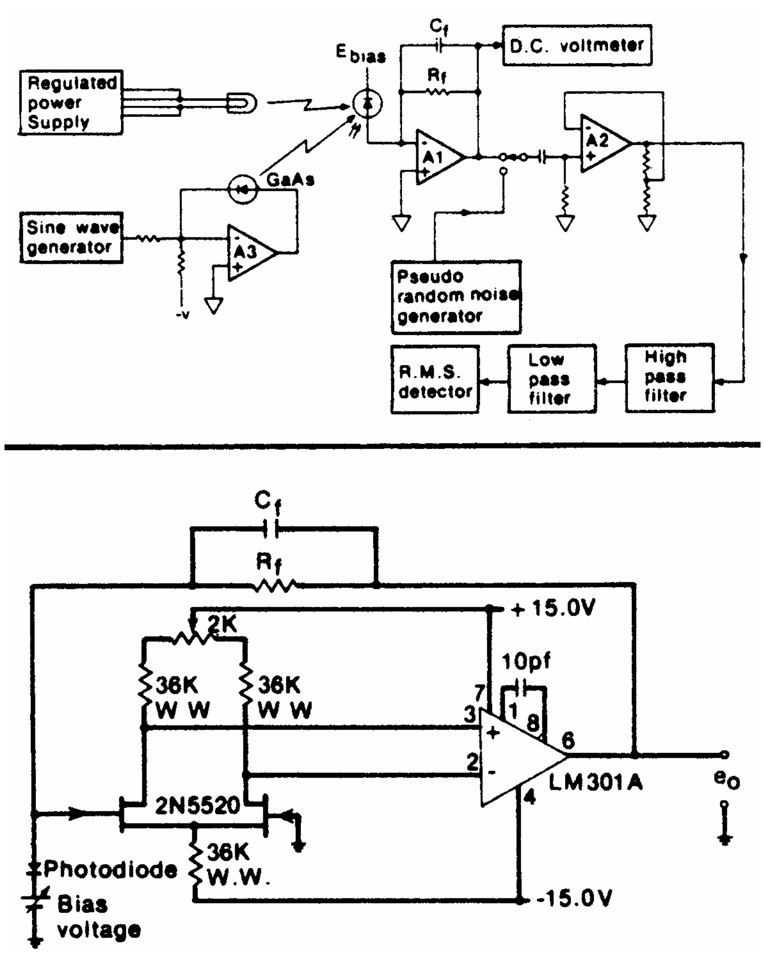

Fig 2 At top, setup for measuring noise. *Below* it is schematic of details of preamplifier A1

One can approach the problem in two ways: by calibrating a light source at very low power, then varying the known light power falling on the sensor until the output signal is 1.4 times the dark-noise signal; or by calibrating the sensor's responsivity at higher power from a calibrated light source, measuring the sensor's linearity to be sure its responsivity at low light levels is equivalent to its responsivity at high light levels, and obtaining the noise equivalent power by dividing the measured dark noise current by the responsivity. The latter technique is the simplest choice with sensors which exhibit nearly perfect linearity between high light levels, at which calibrated standard lamps operate, and low light levels at which the noise-equivalent power will actually be characterized.

In these noise-equivalent power measurements it is important to obtain a preamplifier with a lower noise value than in the sensor under test. Such a preamplifier A1 is shown in the schematic at the bottom of Fig. 2. The photodiode current is fed into the summing junction of an inverting operational amplifier A1: this amplifier is designed for both low current noise and low voltage noise. The signal is then fed into a capacitively coupled non-inverting operational amplifier A2, then through a fourth-order high-pass, active Butterworth filter and through a similar low-pass filter forming a one-octave bandpass filter. The filtered output is then fed to a true root-mean-square detector where the noise voltage is measured. To calibrate the system, A1 is replaced with a pseudo-random noise generator. The frequency response of amplifiers A1 and A2 is checked by illuminating the photodiode from a gallium-arsenide light-emitting diode driven from the inverting operational amplifier A3. This amplifier is used to drive the diode with a current proportional to the oscillator voltage and the bias derived from –V.

To provide constant illumination to the diode, a subminiature T-1 type lamp is powered from a remote-sensing, regulated power supply. The supply leads and the remote-sensing leads are soldered to the lamp leads. The design of the power supply is critical to these measurements because the lamp's light output varies as the 3.5th to 3.6th power of the applied voltage. The reference voltage of the power supply is derived from an IN829A reference diode, and a low-noise differential amplifier is used to compare the voltage on the lamp with that of the reference. The IN821 diode series is significantly less noisy than any other series of reference diodes in the frequency band of 0.1 hertz to 10 kilohertz known to the writer. This series of diodes is highly recommended as references, but the user should be cautioned that the voltage noise below about 100 Hz varies by about 100 to 1 from manufacturer to manufacturer and diode to diode.

Because both the lamp and the photodiode are temperature-sensitive, it is important that both be protected from temperature fluctuations and from air currents. This is especially true for noise measurements below about 50 Hz. Mechanical vibrations, particularly near the resonant frequency of the lamp filament, also introduce noise into the measurement. Commonly both the lamp and the diode are rigidly held within an aluminum block, which is shock-mounted and shielded from air currents. Resistors in A1 and the feedback resistor R_f must be selected for low flicker noise. Wirewound resistors should be used where possible.

The noise current of an illuminated silicon photodiode is shown in Fig. 3. Above one microampere of photocurrent the noise is practically independent of the applied bias voltage from 0 to 15 volts, the upper limit tested. The noise current is within experimental error of the predicted shot noise levels from 10 Hz to 2 kHz, but below 10 Hz it rises somewhere between –3 and –6 decibels per octave. It has not been possible to determine satisfactorily whether the excess noise shown is due to the diode, the light source or another cause, so the data is worst-case but may not be truly representative of the diodes themselves. For photocurrents below 1 μamp including the dark condition, the noise is a function of the applied bias, since the leakage current contribution increases with bias voltage. This planar-diffused photodiode is comparatively free of 1/f noise.

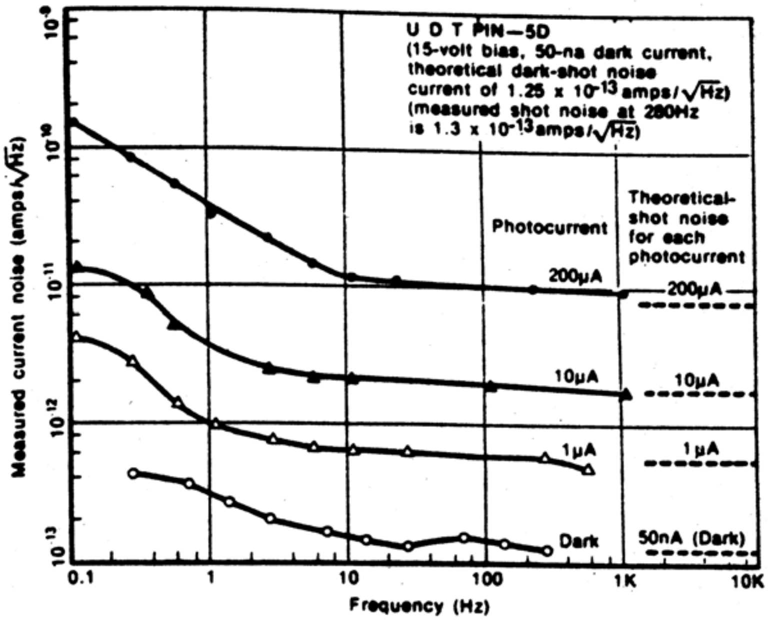

Fig 3 Noise current of an illuminated UDT silicon photodiode, PIN-SD

With the variety of monochromators available, one would imagine that measurement of a photosensor's precise spectral response would be easy. This is not the case, because available monochromators are designed to determine precisely the output wavelength but to take no account at all of variations in output intensity with wavelength. One must, therefore, either calibrate the output intensity of a monochromator with a calibrated detector, or continuously normalize the response from an unknown sensor with the response from one that is known. The latter technique is shown in Fig. 4, which demonstrates the use of a vacuum thermopile and electronic ratio circuitry to provide a normalized spectral response plot of an unknown sensor. This technique rests on the assumption that the vacuum thermopile is spectrally flat across the wavelength of the measurements. For precise spectral response measurements, this assumption must be checked carefully.

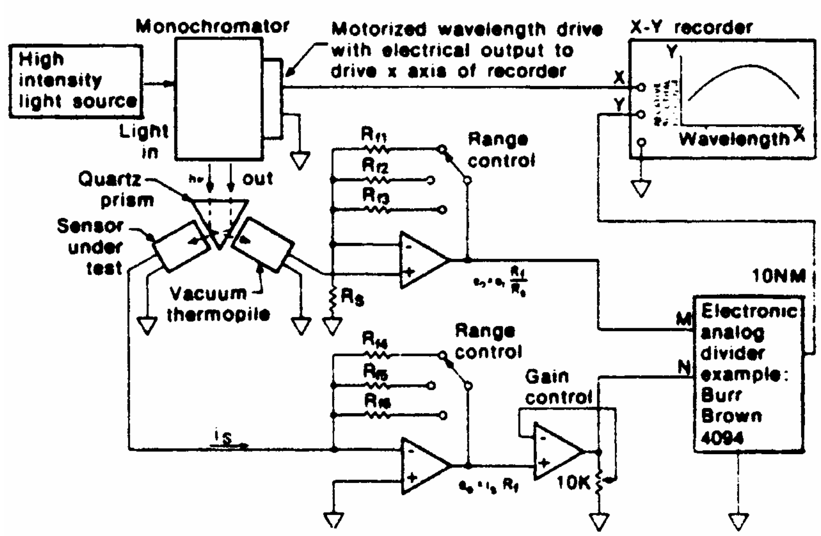

Fig 4 System for automatic plotting of spectral response

A second technique obtains constant power output by the use of a corrective-height aperture in the monochromator's optical train, which normalizes the spectral variations of the source, the lens system and the circularly variable interference filter forming the spectrally selective element.

This document was assembled from scans of the original entitled "Characterizing a laser receiver" by Paul H. Wendland, founder of United Detector Technology. It appeared in a column called "Focus on Techniques" in the October 1973 issue of Laser Focus, pp. 73-75. Minor reformatting has been done to improve readability. Sometime around 1975 I began referring to the technique as the AC/DC method, along with Mike Lind and Jon Geist, and that descriptor is still in common use.

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