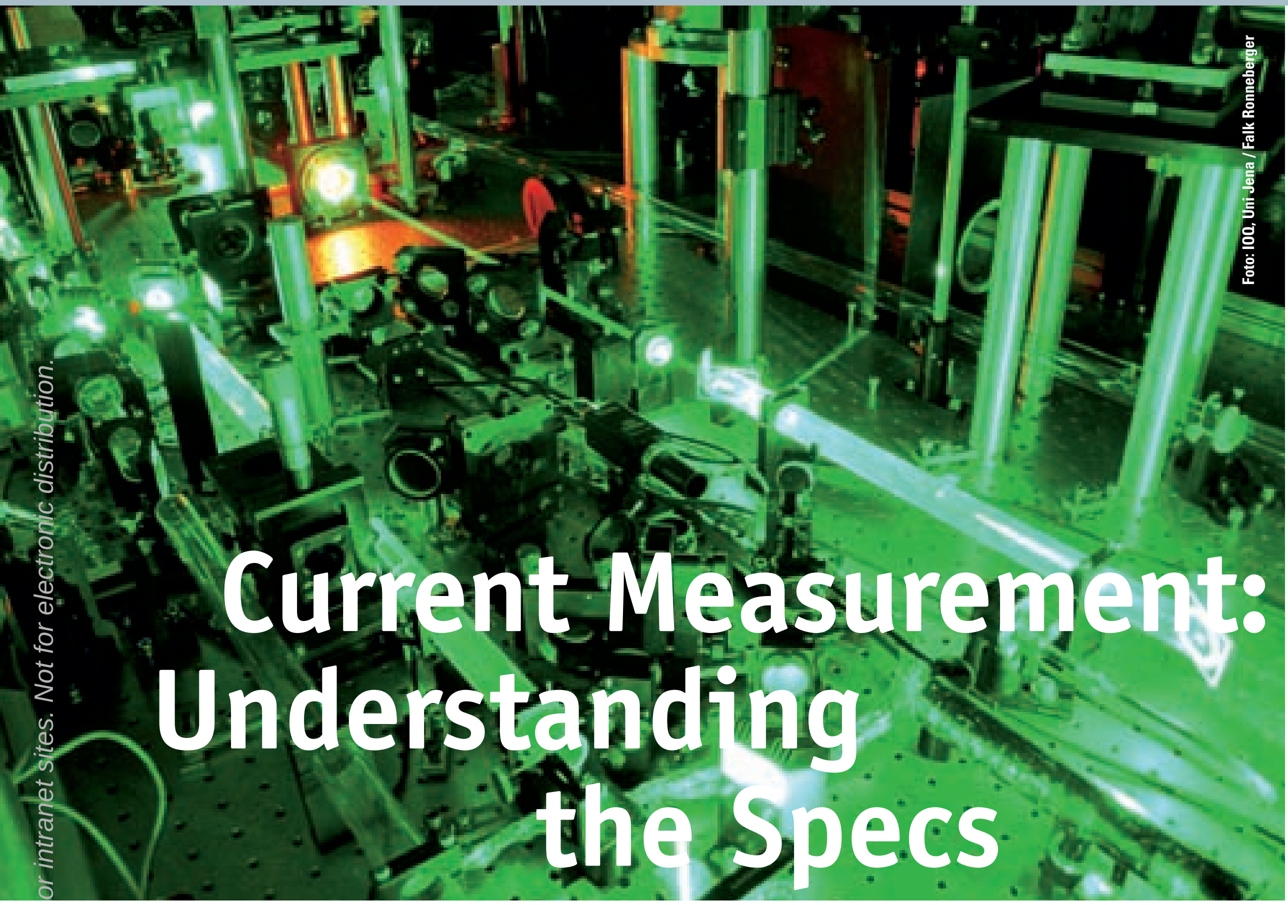


Foto: IOQ, Uni Jena / Falk Ronneberger

The measurement of optical power is an integral part of most photonic applications. Further more, the output of a photodiode must be converted into a voltage and amplified

Current Measurement: Understanding the Specs

A USER'S GUIDE TO CHOOSING A PREAMPLIFIER FOR OPTICAL DETECTORS

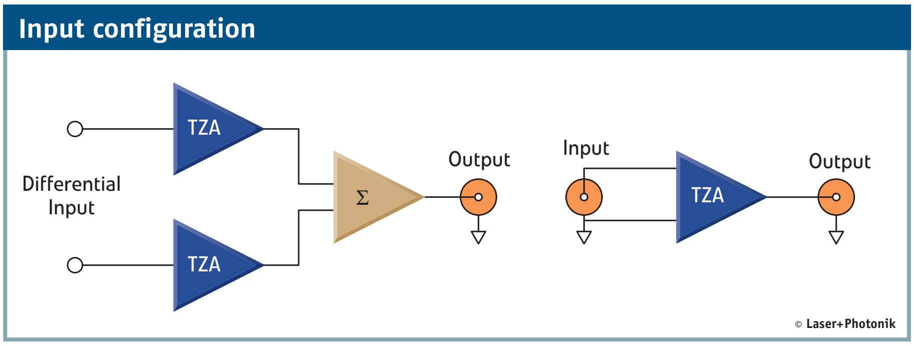
The data sheet of a transimpedance amplifier supplies all of the information required to select a suitable instrument – assuming the data can be interpreted and analyzed correctly.

STEVE WRIGHT

Practically every photonic application requires the measurement of optical power in some manner. At some point in the chain of signal generation and processing, there will be a photodetector whose output must be converted to a voltage. This conversion may be trivial and uncritical – such as the generation of a digital 0 and 1 output of a photoelectric barrier. Other tasks may be much more daunting, such as the simultaneous recording of four photodiodes through four decades of power in order to perform precision measurements of polarization states in real time.

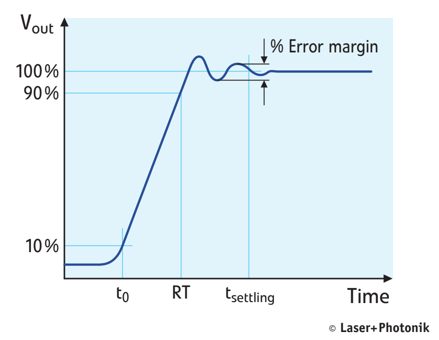
Both of these examples have one thing in common: the photo-generated current must be converted to a voltage for the subsequent signal processing. This task must be performed as quickly and precisely as required for the application in consideration of the cost-effectiveness. This point in the measurement chain is critical as distortions imposed on the signal cannot be removed later. Just as an imaging processing software is not able to reinstate information into a photograph which has been blurred.

Not only photodiodes generate small currents (femtoamps, fA to milliamps, mA) which must be precisely converted and amplified. There are photomultiplier tubes (PMTs) for spectroscopy or particle physics (nanoamps, nA to mA output currents), scanning tunnelling microscopes (picoamps, pA to nA), ionisation detectors (nA to microamps, µA), pyroelectric detectors for IR measurement, for example for laser energy measurement (nA to mA) and piezoelectric detectors for extremely precise motion and pressure measurements (fA to µA). All of these transdu-



1 **Differential (left) and single-ended (right) input configurations**

Settling time



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2 The signal oscillates and settles following a step input. RT – rise time, $T_{setting}$ – settling time

cers require appropriate transimpedance amplification.

The following user's guide to the selection of this preamplifier is limited to linear amplifiers since these are the most ubiquitous for precise metrological applications.

Perusal of the data sheet of a transimpedance amplifier (TZA), as current-to-voltage amplifiers are denoted in technical jargon, will supply all of the information required for an intelligent selection. In order to organize the large amount of information, we classify the various parameters as referring to the signal input or output as well as specifications of the logic control and mechanical data.

Input specifications

■ **Input current range** – This is the maximum current for a given gain range which can be amplified linearly. The chosen current range must be higher than the largest input current expected. However, the range should not be chosen too large since this will be detrimental to the signal-to-noise ratio and in the case of a subsequent digitisation, the digital resolution will be too coarse.

■ **Input configuration** – We discern between differential and single-ended input configurations (fig. 1).

In the differential input there are two signal inputs, one for each of the electrodes of the photodetector enclosed within an outer shield (usually grounded). Since most photodetectors only have two electrodes, for example the anode and cathode of a photodiode, this configuration allows for a potential free (floating) connection. When using a photodiode, this has an advantage in linearity since in this case, the photodiode is operated in a true short-circuit configuration. Any configuration with a definite potential reference on the photodiode leads to forward biasing and consequently to non-linear response at higher currents. Furthermore, the differential configuration has the advantage that disturbances which are imposed on both signal lines are cancelled due to the common mode rejection of the amplifier.

The single-ended configuration is required if the photodiode is to be reverse biased. This technique shifts the saturation point to higher powers (that is, the detector can measure higher power linearly) and the photodiode reacts more quickly.

■ **Noise equivalent current (NEI)** – Here we find information about the noise of the amplifier itself. This noise is superimposed onto the noise of the signal and therefore limits the ability of the amplifier to detect low current levels. Since this noise is a statistical, bipolar quantity, it is specified as an RMS (root mean square) value.

Contrary to the bandwidth limited signals of interest, noise is broadband and covers the full gain spectrum of the amplifier. Therefore, the total noise level at the output depends on the bandwidth of the amplifier. For this reason, two methods are commonly used to represent the NEI: the spectral current noise density (possibly as a function of the frequency) or the total NEI integrated over the full amplifier bandwidth. For example, a constant spectral noise density of 1pA/√Hz over a bandwidth of 1MHz leads to a total integrated NEI of 1 pA/√Hz x √1 MHz = 1 nA_{RMS}. Specifying in A/√Hz is useful in cases where the bandwidth of the amplifier will be modified, for example with a band pass or low pass filter. If the amplifier is to be used unmodified, then the specification of A_{RMS} is more practical for the user. As the above example ▶

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▶ shows, care must be taken when comparing amplifiers from different suppliers: the spectral current noise density is always numerically smaller than the total NEI by the factor √(bandwidth).

One must also consider the fact that when viewing the output of an amplifier on an oscilloscope, one will actually be more inclined to observe the peak-to-peak noise. This value is typically five to six times as large as the RMS value. Furthermore, the observed noise level is that of the amplifier under test as well as that of the input amplifier of the oscilloscope – a non-negligible distortion when testing a good quality transimpedance amplifier. In order to properly observe the noise of the device under test, one should amplify the TZA output with a low noise voltage-amplifier before connecting to the oscilloscope.

Output specifications

- **Gain or output scale** – The purpose of a linear transimpedance amplifier is to convert a current into a linearly proportional voltage according to $V_{out} = G \times I_{in}$, where G is the gain of the instrument. Note that the unit of G is $[G] = V/A = \Omega$. The gain should be chosen such that the expected signal current (including all noise and disturbances) will use up as much of the dynamic range of the instrument as possible without clipping.
- **Output voltage range** – This is the specification of the range of possible output values: 0 to 5 V or −10 to +10 V as typical examples.
- **Rise / fall time)** – An amplifier cannot react infinitely quickly to changes in the input. A useful measure of the speed of response is the time required for the output to go from 10 to 90 percent of a step input change. This is called the rise time (or fall time if the change is negative) and is related to the bandwidth. In many cases the following relationship will hold: $RT = \ln(9)/(2\pi f_{3dB}[Hz]) = 0{,}35/(f_{3dB}[Hz])$, where RT is the rise time and f_{3dB} is the bandwidth of the amplifier.
- **Settling time** – This parameter indicates the amount of time required for the output to settle and remain within a defined tolerance of the steady-state output following a step input. For a 1 percent tolerance, this time is typically about twice the rise time. These concepts are depicted in Fig. 2.
- **Accuracy** – A measure of the deviation of the actual output from the true output - usually given in percent. Important: accuracy is not resolution! An instrument

INFO: A Practical Example of the Application of this User's Guide

A system for the real time measurement of polarization states can be realized by splitting the beam to be analysed into four partial beams. The polarization of each of these beams are then modified in a specific manner such that the measurement of the power of each of the four sub-beams is sufficient to determine the four Stokes parameters [1]. The system in our example is to be able to determine polarization extinction ratios (PER) of up to $1 : 10^4$. The input is designed for an optical input power of 5 mW. The detected signals should be digitised with 10-bit resolution at a rate of 10 kS/s using a 0 – 5 V A/D converter.

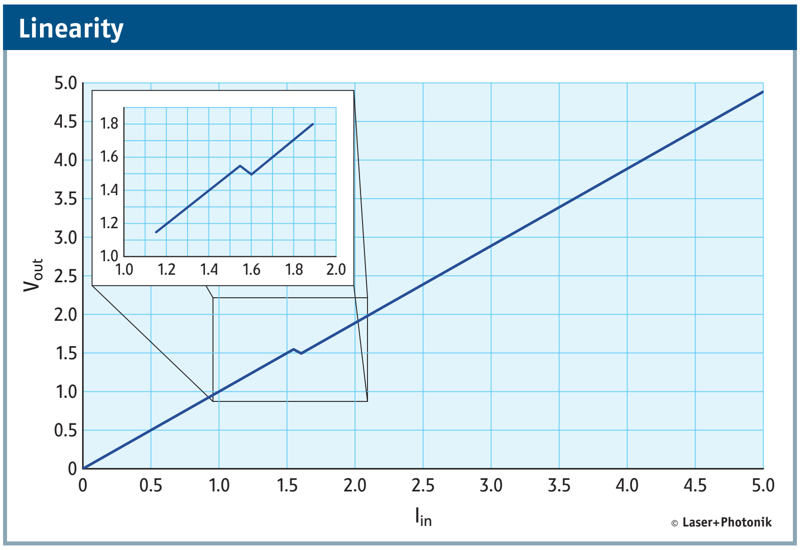
In order to determine the required specifications of the transimpedance amplifiers linking the four photodiodes to the A/D converters, we proceed as follows:

- There are four channels to be measured, so either four single channel or one four channel amplifier is required. The latter solution will require less space and will cost less.
- The output range of the amplifiers should be 0 to 5 V.
- The maximum input signal is 5 mW over all four channels (less losses) ≈ 1 mW per channel ≈ 0.5 mA per channel using silicon photodiodes. Therefore the *lowest gain* should be $5\,V/0.5\,mA = 10^4\,V/A$.
- The lowest power to be measured may be determined from the required PER of 10^4: $I_{min} = 0.5\,mA/10^4 = 5 \times 10^{-8}\,A = 50\,nA$. Thus the *highest gain* should be $5\,V/50\,nA = 10^8\,V/A$. *Therefore we require an amplifier with at least five gain ranges in decade steps or 15 gain ranges in a 1-2-5 gain pattern.*
- In order to realize the required 10-bit resolution ($= 2^{10} = 1024$) the *total equivalent noise level* must be less than 50 nA/1024 ≈ *50 pA*.
- The required speed of the amplifier may be determined from the digitization rate as follows: 10 kS/s means that the amplifier must settle within $1/(10\,000\,s^{-1})$ = *100 µs*. If the *settling time* is not specified, this will approximately correspond to a rise time of 50 µs or a bandwidth of 0.35/50 µs = 7 kHz.
- A high quality transimpedance amplifier should have an *accuracy of at least 1 percent*.
- For this application, a good linearity is required. Furthermore, the *gain step error should be under 1 percent* since the system requires the dynamic measurement of widely varying currents over the full dynamic range of the amplifier (50 nA bis 500 µA).
- This application is slow enough (~ 7 kHz) that the output impedance is not relevant.
- Since the amplifier will be rapidly switched through all gain ranges on sub-ms time scales, the interface must be of the direct line type (unprotocolled). The high sensitivity (50 pA noise level) requires a galvanic decoupling of the interface.
- The high sensitivity dictates furthermore that the amplifier be packaged in a small, well shielded enclosure so that it may be placed as close to the photodiodes as possible.

The ›TZA45u100M6GD4‹ with differential inputs and 6 gain ranges in decade steps or the ›TZA2u100M16GS4‹ with single-ended inputs and 16 gain ranges in 1-2-5 separation are particularly well suited for this application (photo).

LITERATURE

1 Edward Collett: ›Polarized Light‹; Marcel Dekker Inc., New York, NY/ USA 1993



3 Gain step error will be observed when switching from one gain range to the next

can have a high resolution and still output inaccurate (ie: false) values.

■ **Linearity** – A measure of the deviation of the gain of an amplifier from a true linear response. This is usually specified in percent or dB. In this context, it is important to note that amplifiers with several gain ranges which can be used to scan an input changing over a large dynamic range should also accurately reproduce the output when switching from one gain to the next (gain step error, see **fig. 3**).

■ **Output impedance** – This is the apparent impedance of the amplifier as seen as a signal source. It becomes important to match the amplifier impedance to the signal cable and the load when higher frequency signals (> 200 kHz) are to be transmitted over long paths (> 1 m). This impedance matching will suppress back reflections and signal distortion. The standard for metrological signal transmission is 50 Ω impedance.

Control logic and mechanical data

■ **Interface** – How will the amplifier be controlled: via manual switches or an electrical interface? This decision depends on whether the unit will be integrated into an automated system or if it will be used in a laboratory, for example. If the unit is to be controlled via an electrical interface, direct line control (as opposed to say an RS-232 interface) is often advantageous. The control occurs almost instantly without the delay involved with a protocolled interface. Sensitive applications in which the amplifier is controlled directly from a PC require a galvanically isolated interface to avoid disturbances from the typically very noisy PC communication.

■ **Enclosure type and size** – This point may at first seem to be of lesser importance but actually has a profound effect on the results obtained. Since the signals of interest in photonic applications are typically very small, it is necessary to avoid disturbances as much as possible. A good amplifier is therefore kept small to allow mounting as close as possible to the signal source. Also, the design of the enclosure is important to ensure good electromagnetic shielding. ■

Summary: A Practical Example

The important specifications of a TZA can be grouped into input and output parameters as well as data concerning the control logic and mechanical data. The Info-box demonstrates the use of the information in this article in the form of a practical user's guide to the selection of an appropriate instrument.

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