

Transimpedance Amplifier O/E Converter Design

A block diagram of the amplified O/E converter of the HP 83481A 155/622-Mbit/s optical plug-in module is shown in Fig. 1. The photodiode functions as a detector whose output current reproduces the envelope of the received optical signal. The detected electrical signal is then amplified by a preamplifier which is followed by a postamplifier capable of driving a 50-ohm load. A variety of devices can serve as photodetectors, including p-i-n photodiodes, avalanche photodiodes, phototransistors, and photoconductors. However, for high-speed instrumentation applications, the p-i-n photodiode is favored because of its performance, simplicity, and price.

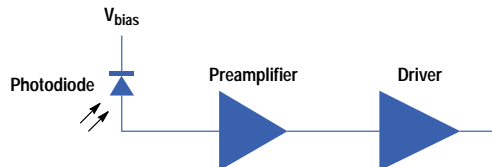


Fig. 1. Block diagram of amplified O/E converter.

The sensitivity and dynamic range of the amplifier are largely determined by the design of the preamplifier. Preamplifiers can be classified into two basic categories: voltage amplifiers and transimpedance amplifiers. The generalized schematic of a voltage amplifier is shown in Fig. 2. The photocurrent, i_{pd} , develops a voltage across a load resistance R_L and this voltage is amplified by a voltage amplifier with gain A . To use this converter for instrumentation applications the following relationship must be satisfied:

$$\frac{1}{2\pi R_L C_T} \geq B.$$

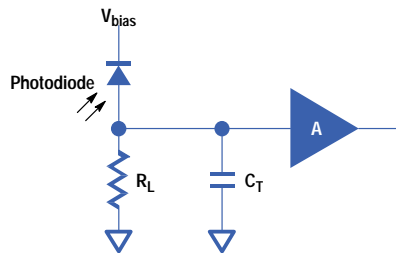


Fig. 2. Photodiode with voltage amplifier.

The dominant pole frequency formed by load resistor R_L and capacitance C_T must be larger than or equal to the desired bandwidth B , provided that the preamplifier bandwidth is sufficiently higher. C_T is the total capacitance at the input of the preamplifier, consisting of the diode capacitance, preamplifier input capacitance, and various parasitic capacitances. However, the sensitivity of this converter is relatively low, because only a small voltage signal is developed across a small load resistor R_L , while the Johnson noise current generated is relatively large. A low value for R_L is required to satisfy the above bandwidth relationship. The variance of the equivalent noise current for this front end is:

$$\langle i^2 \rangle = \frac{4kTFB}{R_L},$$

where R_L is the load resistance, F is the amplifier noise figure, B is the bandwidth, k is Boltzmann's constant, and T is the absolute temperature.

From this equation it can be seen that if we can increase the load resistance and somehow maintain the overall bandwidth we can reduce equivalent input noise current and therefore improve the converter sensitivity. This can be achieved by employing the transimpedance design. Here the load resistor R_L is connected as a feedback resistor on an inverting voltage preamplifier with gain $-A$ as shown in Fig. 3. Provided that the preamplifier bandwidth is sufficiently high, the overall bandwidth will be:

$$B = \frac{1 + A}{2\pi R_L C_T}.$$

This equation shows that the bandwidth is increased by a factor of $1 + A$ over that of a voltage amplifier converter with the same R_L and C_T .

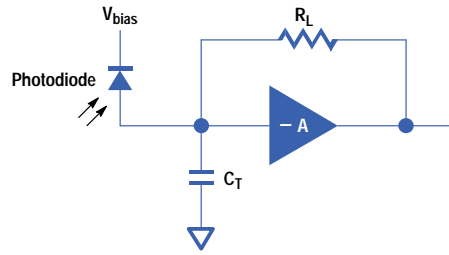


Fig. 3. Photodiode with transimpedance amplifier.

Furthermore, the strong negative feedback around the preamplifier decreases its susceptibility to component variation and improves the dynamic range over the voltage amplifier converter by the ratio of the open-loop gain to the closed-loop gain.

The main concern in using a transimpedance amplifier is its ac stability. The output current feedback formed by resistor R_L in conjunction with capacitance C_T results in input voltage feedback and 90 degrees of phase shift at the input of the voltage amplifier. The inverting amplifier contributes a phase shift of 180 degrees. This means that an additional 90-degree shift in the preamplifier would guarantee oscillations. In practice we need to maintain a minimum phase margin of approximately 45 degrees up to the frequency at which the preamplifier open-loop gain becomes less than one. In other words, the pole formed by $R_L C_T$ should be the dominant pole in the circuit to achieve the best stability, and the pole internal to the voltage preamplifier should be substantially higher in frequency so as not to influence the overall frequency response. However, to achieve the highest possible frequency response, C_T is often minimized so that the dominant input pole frequency approaches the preamplifier internal pole frequency. This results in frequency response peaking. The gain increase at high frequencies improves the slew rate of the transimpedance amplifier, but introduces a certain degree of overshoot and undershoot, and moving those two poles even closer together results in additional ringing, ultimately leading to oscillations.

The gain of the transimpedance amplifier is expressed in ohms and its gain-bandwidth product is expressed in ohm-Hz. For a given device technology and circuit design the gain-bandwidth product is constant, so it is possible to trade bandwidth for gain provided that the ac stability is maintained.

The driver amplifier in Fig. 1 provides the final amplification of the signal. It can be as simple as a buffer amplifier to drive a low-impedance load or it can provide an additional gain and signal conditioning function.

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