



# A linear, low-noise, low-power optocoupler amplifier for bolometric detectors

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## Abstract

We present an optocoupler with differential inputs and balanced output, which was realized to make galvanic decoupling in a bolometric detector read-out chain. The circuit configuration incorporates a true differential optocoupled feedback, with low bias current in LEDs and photodiodes. Large Common Mode (CMRR) and Power Supply (PSRR) Rejection Ratio, low crossover distortion, high dynamic range, low noise and power dissipation have been achieved. © 1998 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

The signal frequency bandwidth of bolometric detectors extends from DC to a few hundreds Hz [1]. Consequently, mains interference coming from ground loops may impair the energy resolution. A linear optocoupler capable of separating ground connections between the front-end and further processing stages and thus reducing interference noise is described in this paper. Special consideration is given in circuit realization, to optimize noise performances. Compared to the classical solution, LEDs and photodiodes have been biased at very low current levels to minimize their shot noise. The input stage is true differential while the output

stage is able to drive a twisted pair cable. In the next section circuit description and experimental results are given.

## 2. Circuit description and experimental results

A standard linear optocoupler uses a pair of photodiodes matched to a single LED, all of them put together inside a single package. One of the two photodiodes and the LED are the feedback elements of an Operational Amplifier (OA) [2,3]. The photodiode is connected to the inverting input (the non-inverting input is at ground potential), while the LED is connected at the OA output. The feedback is such that a positive current injected into the inverting input will flow into the photodiode: the feedback, irrespectively of the possible LED

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non-linearity, imposes the LED to emit the appropriate current, to generate a photocurrent into the photodiode. The LED illuminates evenly the output photodiode, which has a different ground reference than the input LED and photodiode; the result is the mirroring of the input current to the output photodiode. To obtain bipolar operation, the photodiodes need to be biased with a current equal to the maximum expected input current, to be able to mirror the input current even when it is driven in the opposite direction. This causes a large shot noise due to the bias current of the photodiodes.

Instead, the circuit of Fig. 1 allows to obtain bipolar operation, although a very small bias current is used for biasing [4]. The OA  $A_1$  is optically feedback by means of two LEDs,  $LE_1$ ,  $LE_2$  coupled to two photodiodes  $PD_{A1}$ ,  $PD_{A2}$ . The LEDs are connected in series and biased at a constant voltage  $V_{REF}$ . For  $V_{max} = 0$  V, both LEDs pass the same small current  $I_{REF} \sim 100 \mu\text{A}$ , as  $V_O$  and  $V_A$  are at ground potential. In that case there is no current across  $R_A$ , and  $I_A = I_B = HI_{REF} \sim 1 \mu\text{A}$ , as the optical coupling efficiency  $H$  is typically 0.5–1%.

When a differential voltage  $V_i$  is applied, assuming ideal OAs, a current  $i = I_A - I_B = V_i/R_A$  is delivered by the signal source, while  $PD_{A1}$  and  $PD_{A2}$  remain biased at 0 V. The sign of  $V_i$  makes one of the two diodes,  $PD_{A1}$  or  $PD_{A2}$ , to pass the photocurrent  $i$ . This imbalance comes from the series connection of the LEDs which forces:  $I_{REF}^2 = I_{LA}I_{LB} = I_A I_B / H^2$ . Each LED is also coupled to a second photodiode, which is connected at the output stage. The currents of the input

stage photodiodes are replicated at the output stage, where  $PD_{B1}$  and  $PD_{B2}$ , also biased at 0 V, inject a current  $(I_A - I_B)$  into  $R_B$ . The overall differential voltage gain will be unity as the input and output feedback resistances,  $R_A$ , are equal. The reference LED  $LE_{REF}$  induces a current  $HI_{REF}$  in each photodiodes at the  $GND_{REF}$  side of the balanced output stage: the balanced output  $V_O - V_{OREF}$  can drive a twisted pair to very long distances, as common mode disturbances are in this way strongly attenuated.

If  $I_{Dmax}$  is the maximum current each photodiode can handle, while  $V_{imax}$  is the maximum expected input signal, we have  $I_{Dmax} = V_{imax}/R_A$ . The maximum signal-to-noise ratio, the dynamic range,  $(S/N)_{MAX}$ , results:  $(S/N)_{MAX} = \{I_{Dmax}/\sqrt{2q(6HI_{REF})}\} \{1/\sqrt{1 + (V_T/V_{imax})(I_{Dmax}/HI_{REF})}\}$ , where  $V_T = kT/q$ . As an example we consider the case  $V_{imax} = 10$  V,  $I_{Dmax} = 100 \mu\text{A}$ ,  $HI_{REF} = 1 \mu\text{A}$ . Then  $(S/N)_{MAX} \sim 72 \times 10^6$  (26 bits) for 1 Hz BW,  $\sqrt{V_{in}^2} = 138$  nV/ $\sqrt{\text{Hz}}$  and  $R_A = 100$  K $\Omega$ . In the classical configuration, where the current  $I_{Dmax} = 100 \mu\text{A}$  must bias the photodiode, the dynamic range results in  $(S/N)_{MAX} \sim 12.5 \times 10^6$  (23.5 bits) for the same conditions: with the circuit of Fig. 1 an improvement of a factor of about 6 in the  $S/N$  performance is obtained.

The optocoupler monolithic chip used for the realization of the circuit of Fig. 1 was the IL300 by Siemens. The OA was a quad LM6144 in the input stage, a dual LM6142 both by National for the output stage. The obtained dynamic performances were a frequency bandwidth of about 50 kHz and an integral non-linearity of 0.6% in  $\pm 9$  V of

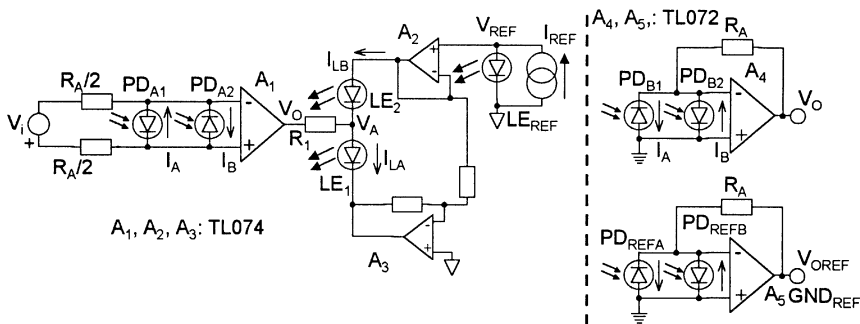


Fig. 1. Schematic diagram of the new differential input, balanced output optocoupler.

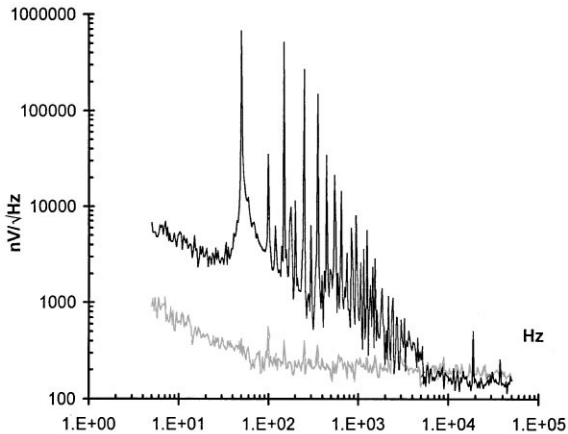


Fig. 2. Optocoupler noise spectra. Upper: no ground separation, 100 m of shielded cable. Lower: ground separation, 100 m of twisted pair cables.

output swing. No crossover distortion was observed, thanks to the antiparallel bias used for the photodiodes. Common Mode Rejection Ratio was 104 dB from DC to about 100 Hz, rolling off to 40 dB at 100 kHz. Output voltage was highly insensitive with respect to power supply changes.

The advantages that can be obtained with the use of the optocoupler are evident from the noise spectra of Fig. 2. The upper spectrum represent the measured noise after 100 m of a shielded cable which connects the optocoupler to the spectrum analyzer after passing close to mains interference sources. In this case, ground separation in the circuit is suppressed, in which case the optocoupler behaves as a simple unity gain buffer stage. The power contained in the 10 kHz BW shown is about  $2.64 \times 10^6 pV_{\text{RMS}}^2$ . The lower dashed curve of Fig. 2 shows the optocoupler noise when 100 m of shielded twisted pair is used and the ground of the input

and output stages are separated. Now the mains interferences are not present and the power resulted only  $1870 pV_{\text{RMS}}^2$ , a factor 1500 of reduction. Note that the white part of the noise is about  $140 \text{ nV}/\sqrt{\text{Hz}}$ , as expected.

### 3. Conclusions

A differential input, balanced output isolation amplifier for bolometric detectors uses true differential optical feedback with low bias current in the optoelectronic components. Shot noise is in this way minimized. In comparison to classical optocouplers, the input voltage range of this new circuit does not depend on the biasing current. S/N is therefore large, a dynamic range of about 26 bits (for 1 Hz BW) is obtained. A balanced, optically coupled output stage is suitable to drive a twisted pair cable for long-distance signal transport.

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### References

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