

# CHARACTERIZATION OF THE OPA350 OPERATIONAL AMPLIFIER AT CRYOGENIC TEMPERATURES

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**Abstract:** *As part of the development of EMIR, an infrared multiobject spectrograph for the Gran Telescopio de Canarias (GTC), the OPA350 operational amplifier is being successfully used at cryogenic temperatures (77K). The use of off-the-shelf electronics (not specifically designed for cryogenics) is advantageous since it allows us to get signal amplification very close to the detector without the need of special components.. This helps to keep the signal integrity along the analogue chain at the very low cost of commercial components. However, since commercial components are not specified for cryogenics, some tests have to be performed to check if their main parameters are kept within acceptable values and if the chips behave in a reliable way.*

*In this paper, both the procedures and the results of the OPA350 tests are presented. They will be used not only to confirm the good performance of the chip in cryogenics, but also as a guideline for the tests to be carried out in other chips for future instruments.*

**Key words:** *Cryogenics infrared, OPA350, EMIR, GTC.*

## 1. INTRODUCTION

The OPA350 is a single-supply rail-to-rail CMOS operational amplifier. Its main parameters (low noise, very low bias current and relatively high speed) together with being single-supply (and, therefore, having a low power consumption) make it an ideal component to be used with infrared detectors. That is why during the development of EMIR, an infrared instrument for the

Gran Telescopio de Canarias (GTC), it was considered as a possibility for the amplification of the detector analogue output in the fan-out board, where a HAWAII-2 detector is being used at 77K.

Using amplification so close to the detector eases a lot of the difficulties in keeping noise and interference under control. Since the OPA350 is a commercial component not specified for cryogenics its cost is very low (\$1.30 per unit). However, some questions immediately arise. Will it work in cryogenics? Even if it is successful, what will be the amplifier parameters when cold?

We have been using the OPA350 for more than 3 years with good results and with the certainty that possible changes in the parameters were not affecting the detector science data. Even so, we have performed some detailed tests to obtain the exact chip parameters in cryogenics. This allowed us not only to establish those parameters, but also to validate the test circuits so that they can be applied to other chips in the future. Our idea is to create a database of commercial chips working in cryogenics so that they can be used with conviction.

## 2. THE OPA350 OPERATIONAL AMPLIFIER

Manufactured by Burr-Brown (now part of Texas Instruments), this CMOS amplifier is available in various formats. For EMIR, the space-saving SSOP-16 surface mount OPA4350 chip was used. There are 4 amplifiers per chip. The results in this paper refer to that particular format.

The main parameters at room temperature are a white noise of  $5 \text{ nV}/\sqrt{\text{Hz}}$ , a bandwidth of 38 MHz, a slew rate of  $22 \text{ V}/\mu\text{s}$ , a bias current of 0.5 pA and a voltage offset of around  $\pm 150 \mu\text{V}$  (maximum  $500 \mu\text{V}$ )

The tests to obtain chip parameters were initially performed at room temperature. The results were, as expected, similar to those on the datasheet, which allowed us to validate the test circuits. Then, the chips were cooled and the tests repeated to obtain the cryogenic parameters.

In Fig. 1 a detail of a previous version of the EMIR fan-out board populated with an OPA4350 chip is shown.

## 3. COOLING CONSIDERATIONS

The OPA4350 has shown reliable and repetitive behavior at 77K. However, some considerations must be taken into account. If the chip is kept off when cooled it is possible to encounter problems when attempting to power-up the chip at 77K. The chip will either consume a lot of current or

very little. However, after some attempts it will consume the correct value. From that moment forth, if a soft-start voltage regulator is used (we are using a REG103 from Burr-Brown), which rises the voltage slowly (in  $\sim 1$  ms), it will be possible to turn on the chip as many times as desired in repetition (see test bench in Fig. 2).

However, requiring multiple attempts is not desirable. The solution is as simple as keeping the chip on while cooling. If we use a soft-start voltage regulator when cold, the chip can be turned on and off in a repeatedly manner without requiring previous attempts. It appears that keeping the chip powered during cooling minimized the lattice distortion resulting from possible thermal stresses.

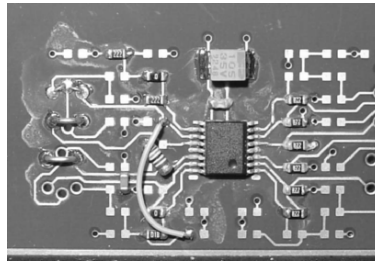


Figure 1. OPA4350 in a previous version of the EMIR fan-out board.



Figure 2. Test bench used to obtain parameters in cryogenics.

#### 4. TEST CIRCUITS AND RESULTS

The chip has been working correctly for almost 3 years at 77K. However, the results presented in this section were obtained at 115K, the temperature of the Printed Circuit Board (PCB) containing the chips. Tests will be

repeated in the future for a PCB temperature of 77K (that is not necessarily the chip's internal temperature, whose value is unapparent).

#### 4.1 Noise

The circuit in Fig. 3 allows us to obtain the input noise density of the amplifier. The offsets are used to guarantee that the output is within range. The noise at the output is basically due to the input noise of the first amplifier. The noise due to the remainder of the amplifiers and to the offsets is negligible in this circuit.

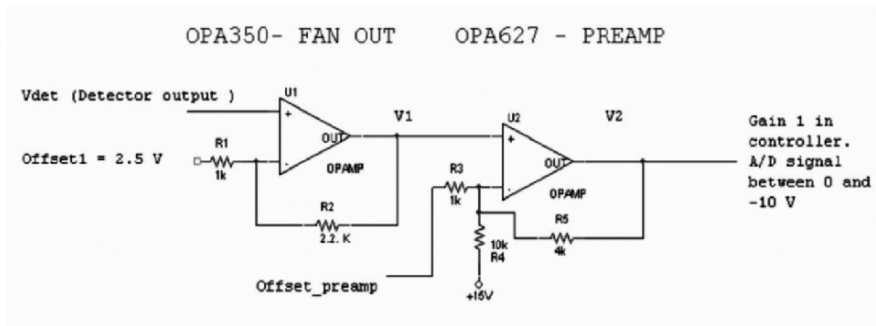


Figure 3. Circuit used for obtaining the amplifier input noise density.

The total amplification is so high (~68000) that even a low resolution digitizer such as a digital oscilloscope is enough to obtain the data. The noise density is obtained by calculating a Fourier transform of the data. Sharing the total gain among several amplifiers allow us to keep the system bandwidth at a relatively high value. By doing so the noise density can be calculated at frequencies of at least 100 kHz in order to ensure that it is white noise.

The main result is that the noise variations are small. When cold, there seems to be a very slight increase in the  $1/f$  noise of the amplifier and a decrease (around 25%) in the white noise.

#### 4.2 Offset Voltage and Bias Current

The nominal bias current at room temperature is so low (0.5 pA) that no tests were carried out in cryogenics. Although there could be small changes, they are not expected to vary the bias current in an appreciable way, in the sense that it will be kept in the range of a few pA or less.

As for the offset voltage, in this chip it depends appreciably both on the common mode voltage at the inputs of the amplifier and the temperature. Even though there is a clear dependence of the offset on temperature, the

maximum voltage offset observed at the input is kept at a similar value (700  $\mu\text{V}$  at 115K versus 500  $\mu\text{V}$  at room temperature). In the future, tests must be performed to determine if the offset drift with temperature is similar under the chip nominal temperatures and in cryogenics.

### 4.3 Bandwidth and Slew Rate

For this test, the operational amplifier was configured as a non-inverting amplifier with a gain of 2. The Bode Diagram of this non-inverting amplifier was obtained, both at room temperature and at 115K. The bandwidth for small signal is similar at both temperatures (see Fig. 4).

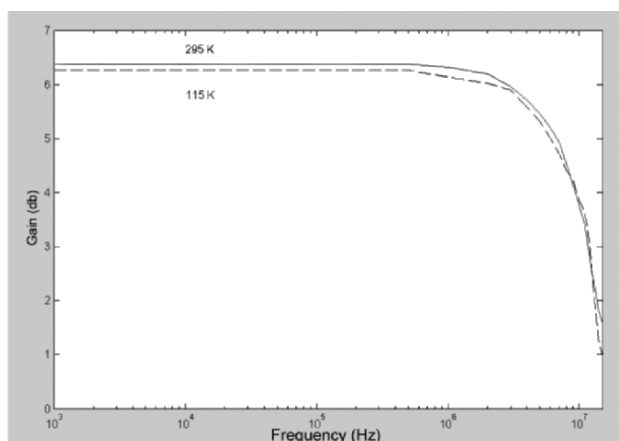


Figure 4. Bode diagram at 295K and 115K.

However, the slew rate decreases with temperature. At 295K a value of 24.7  $\text{V}/\mu\text{s}$  was measured (the datasheet value is 22  $\text{V}/\mu\text{s}$ ). At 115K the slew rate was only 13.0  $\text{V}/\mu\text{s}$ .

## 5. CONCLUSIONS

The main conclusions of our tests are:

- The chip behaves in a repetitive and reliable way provided that it is kept on during cooling and a soft-start regulator is used to power up the chip at cryogenic temperatures.
- The amplifier input noise when cold increases very slightly regarding 1/f noise, while white noise decreases in around a 25% at 115K.

- The maximum offset voltage increases slightly at 115K but is kept in the same order of magnitude.
- The bandwidth for small signal is kept at a similar value, but the slew rate decreases appreciably when cooling the amplifier (it is approximately divided by 2 at 115K).
- The test circuits used to obtain the parameters, although simple, give the correct results. They have been, therefore, validated at room temperature.

## 6. FUTURE WORK

The good results obtained for the OPA350 working under cryogenic conditions make us optimistic about the use of other commercial chips for near-infrared instruments. More detailed tests will be performed on the OPA350 at 77K (the current parameters were obtained at 115K) and several other chips will be tested in the near future at the Instituto de Astrofísica de Canarias (IAC). We aim at getting a database of commercial off-the-shelf components that behave correctly in cryogenics, so that we can use them in the future with guarantee and knowing their detailed behavior (that is, their parameters and reliability).



Barry Burke (left) receives his asteroid citation (see Lifetime Achievement Awards, p. xxiii) from James Beletic as Jenna Beletic watches, and Charlotte Cumani (in back) tries to escape.