Construction of the Detector

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1 Introduction

It is our intention to share the experience we have been acquired during these last years for the construction of detectors for gravitational waves using cadmium-sulphide (CdS) photoresistors.

Here, we will try to give all necessary informations including drawings, diagrams and pictures and all electrical diagrams used for power supply, anode current regulator and temperature regulators.

Moreover, we will give informations for putting into operation the detector, including the initial period we have called "*formatting*", in which, with passing the time, the detector becomes more and more sensitive to gravitational waves.

2 Detectors currently under operation

As far as our CdS detectors, today situation is the following.

Detector N. 1 This is the first detector built by P. Galletti (at the end of 1993) and put into operation in the first months of 1994 [1].

The sensor itself uses a 6 digits FUTABA dispaly, as constant light source, and one CdS photoresistor placed inside two thermostatic enclosures (internal and external). The internal enclosure, where the sensor is kept at constant temperature of approximately 35 ^oC, has been installed in the first months of 1994 and uses an electrical heating system.

In the second half of 1996 it has been installed the external enclosure in which, through an heating-cooling system built with Peltier cells, the inside temperature is maintained constant around $25 \div 26$ ^oC. This second enclosure contains the internal one whit the sensor, the power supply and the anode current regulator.

The voltage readings (V_{CD}) at Wheatstone bridge terminals are carried out *every 20 minutes* by means of a home-made Analog to Digital (A/D) conversion system, connected to a Personal Computer (PC) via RS 232.

The detector is still operating, and during this period of time it had only few minor problems that have not impared its operation.

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[1] This device has been described, in its essential aspects, on **A Detector for Gravitational Waves** (Part 1): *Description and operation of the Detector.*

The signal of this detector has been recording continuously since the end of April 1994 and it is published monthly on our web site `www.omirp.it`.

Detector N. 2 This device was built at beginning of 1997 and it started to work in the second half of the same year.

This detector used a single thermostatic enclosure, similar to **the Detector N. 1**, in which the temperature is maintained to approximately 35 ^oC. Therefore, the sensor was sensitive to daily excursions of the ambient temperature.

Moreover, in summer, when the ambient temperature exceeded $30 \div 32$ ^oC, it had problems with regulating the temperature of the sensor because of oscillations.

The sensor had five CdS photoresistors, which only three were of the same type of **Detector N. 1**.

This detector worked regularly until 2000. The (three) photoresistors of the same type gave results according with **Detector N. 1**. The others two photoresistors, instead, did not worked satisfactorily.

At the beginning of 2000, we decided to keep this detector transportable. So that, we built a chassis in order to install the equipments and new batteries.

The transfer of power supply to the new batteries disturbed the detector but without imparing its operation (the sensor has always been mantained feeded).

In November 2000, the original thermostatic enclosure was replaced with a new one, more stable and precise. During such an operation the anodic current regulator was disturbed (fortunately, whitout going out of service!) for some seconds, in which the voltage filament reached its lowest value of -2.7 V (it was limited by the zener diode that was placed to protect the filament itself).

Before that, the voltage filament was of $-1,840$ mV, with an anodic current set to $3,760$ μA. Once the regulator operation was set up, the voltage filament had increased up to $-1,540$ mV, with the anodic current set, again, to $3,760$ μA.

In the following months the voltage filament decreased, slowly, until the end of December 2000, and stabilized itself to $-1,750$ mV. The detector continued to operate even if its sensibility was reduced.

Before summer 2002 an external thermostatic enclosure, based in a Peltier cells heating/cooling system, was in the meantime set up and put into operation.

In addition, the power supply as well as the anodic current regulator had troubles and, than, it was necessary to correct manually the anodic current setting by the multiturns trimmer of the LM 337 used to set the voltage filament.

In order to avoid such a continuous manual adjustments, at the end of 2002 we decided to replace the anode regulator as well as the power supply.

On 7 February 2003, during this operation a new variation of the voltege filament occurred, similar to the previous one, but with a longer duration (few minutes). Anyway, we completed the replacement of the power supply and the anodic current regulator and at the end we set the anodic current to the initial value of $3,760$ μA but the voltage filament was far beyond $-1,500$ mV. In the following months the voltage filament started to come down, but much more slowly than the previous time.

Following this second and more serious accident the three (good) photoresistors stopped working definitively. At the end of August 2003 we put the detector out-of-service.

We have told about the story of this detector because, we think, it can be useful to anyone who wants to attempt in the construction of these devices.

Detector N. 3 This detector was built in the second half of 2002 and was energized, for the first time, on 29 December of the same year.

The detector has been built completely independent and transportable. It contains all the experience we have been acquiring in the construction of these devices. The detector has a 6 digits FUTABA display and 6 CdS photoresistors, all having different characteristics (we have named them with letters "a", "b", "c", "d", "e", and "f"). The photoresistor "b" is of the same type we used on **Detector N. 1**, photoresistors "c", "d" and "e" were purchased (see RS Components catalog) while photoresistors "a" and "f" was taken from photocells of old burners.

After the detector was set up, it has been placed in a dark place (cellar), with minimum ambient temperature variations. The external thermostatic enclosure was installed only after some months (June 2004). Up today, the detector has been working reliable and satisfactorily.

All the electrical circuits built by ourselves have shown to be reliable and precise. The regulation of sensor temperature as well as the anode current are very good. Only the anode voltage is a little disturbed by the ambiente temperature (around 1 mV) because the power supply as placed outside the external enclosure.

At the end of March 2003 the photoresistor "b" stopped increasing, continuously, its resistance and started with first (positive) variations of voltage at the Wheatstone bridge terminals. In the following months this photoresistor has been continuing to improve its sensitivity.

We can state that sensitivity to *fast and small variations* was acquired after few months, while the sensitivity to *slow and large variations* has been acquired after, approximately, $9 \div 10$ months.

About the others 5 photoresistors only the photoresistor "f" (photocell of an old boiler burner), after more than 1 year of operation, has shown to have some sensitivity to fast voltage variations. For the slow and large voltage variations, instead, the sensitivity is, up today, quite nil and it is overlaid by temperature variations even if very small (few thounsandths of ^oK!). The others 4 photoresistors are still continuing to increase their resistance.

Graph D3_1 shows the voltage variations at the Wheatstone bridges terminals, recorded daily, from the end of December 2002 until August 2003.

Since 28 August 2003 the detector was put into continuous recording by Agilent 34970A data logger, with a reading every minute and since 1 of September 2003 the voltage signal of photoresistor "b" is published monthly on the web site `www.omirp.it` as well as **Detector N. 1**.

Detector N. 2bis. On the “ruins” of **Detector N. 2** we have built a new detector.

The main scope of this new device was for testing some different photoresistors we provided.

The effort nedeed to set up this detector has been smalle because most of the electronic circuits and equipments were already available. As a display it was used the same of the **Detector N. 2** and, on it, we have placed 4 new photoresistors (named with letters “a”, “b”, “c” and “d”). The photoresistor “a” comes from a photoelectric cell of a boiler burner, the photoresistor “b” is one of the three (good) ones that were installed on **Detector N. 2**, while the others two (“c” and the “d”) are cadmium-selenide (CdSe) type.

The detector was energized, for the firs time, on 29 November 2003. Just few days after, the internal thermostatic enclosure was put into operatiom while, on 9 of December 2003, the external one was set up.

Graph D2bis_1 shows the behavior of the signals recorded during this period of operation.

3 Construction of the detector

The principle of operation of the CdS detector is very simple but its construction and putting into operation require much care. It is a very sensitive equipment that, in order to work properly, it must satisfy some important requirements that we can sumarize in the following:

1. the temperature of the sensor has to be maintained constant within *few milli-Kelvin*;
2. the anodic current has to be maintained constant within *1 micro-Ampère* or less;
3. the anodic tension has to be maintained constant within *1 milli-Volt* or less.

Moreover, is necessary to keep in mind that:

- CdS photoresistors are very sensitive to temperature variations. Very small temperature variations (e.g. few hundredth of ^oK) alter sensitively the sensor operation.

  The excursions of the ambient temperature must be kept to minimum, specially if the sensor does not have the external thermostatic enclosure. Therefore, once it has been puto into operation, it is advisable to place the detector in a place without humidity, magnetic and electric fields (e.g. video, etc...) and far from heat and light sources (also the heat radiates by persons who are in the vicinities can disturb it!);

- the sensitivity to the gravitational waves *is acquired after a long period of operation* (approximately 1 year) that we called “formatting”. With passing of months the photoresistor, if not disturbed, acquires more and more sensitivity;

- once built and put into operation, *the detector does not be de-energized.* Variations, also minimal, of the anodic current as well as anodic voltage *disturbs it up to lose the sensitivity acquired during "formatting" period.*

  If the power supply interruption is short (e.g. few seconds), the sensor restarts to work properly after a period depending on how long it is;

- temperature variations, also of some ^oK, strongly, alter the operation of the sensor but *without losing its sensitivity to the gravitational waves.* After few hours the temperature has been brought back to its value, the sensor restart to work properly.

It is important *to build the detector with an high degree of reliability*, as far as the power supply and the anodic current regulator. In order to obtain this, without spending a lot of money, we have made by ourselves the most of the necessary equipments.

3.1 Material and main components

In describing the construction and the putting into operation the detector relating to drawings, picture, electrical diagrams, graphs, etc..., we will refer to **Detector N. 3**, which is the one that contains most of our experience in the construction of these devices.

3.1.1 Vacuum diode (display)

As a constant source of light for the photoresistor we have used a vacuum diode display. In such a way, we have achieved a source of light whose intensity is very stable with the time. The dispalys (vacuum diode) we have used up to now have been taken from old digital clock, or scales. All the active elements (anodes) which constitute the digits (including dots) of the display are connected together in order to have a single luminous source as uniform as possible.

It is a good practice to place the the vacuum diode working point (I_a, V_a) as much as possible close to the "plateau", because variations of the anodic current I_a have not to influence too much the anodic voltage V_a and viceversa. In this way the regulation of the anodic current is more stable and precise.

In case of a 6 digits FUTABA display, the ones we have used up today in our detectors, the working point is between $V_a \approx 12 \div 13\ V$ and $I_a \approx 3.5 \div 4.0\ mA$. It has to keep in mind that, at the same light intensity, more digits the display has, higher are the anode current and the voltage filament. Before putting it into operation, it is good practice to feed the display for some weeks in order to "clean-up" the filament and anodes, getting a more stable operation. That is worth even more if the display is quite new or it has been out of service for a long time.

3.1.2 Photoresistors

CdS photoresistors have shown their capability to be sensitive to the gravitational waves even if reasons are still unknown [2].

Up today, CdS photoresistors that have shown to work better than any other are the ones used on **Detector N. 1** and the "b" on **Detector N. 3**.

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[2] see to this respect **A Detector for Gravitational Waves** (Part 4): *The detector's "puzzle"*.

Already in 1997, with the construction of **Detector N. 2**, we found out that other types of photoresistors, available in the market, do not work satisfactorily.

Photoresistors that seem to work properly re the ones available before 1990. Perhaps, it is still possible to find them in some old electronic equipments such as photocells. In 1994, when we realized their "strange" capabilities, we found few of them in some electronic stores in Rome.

The (final) fixing of photoresistors to the display is made with transparent cyanide glue. Furthermore, photoresistors have to be shielded with two adhesive strips of black paper in order to form a slit of light of, approximately, $1 \div 1.5$ *milimeter* width. Photoresistors have to be placed on the display in order to have their photoconductive bands perpendicular to the slit. The sensor, that is the dispaly with its photoresistors, is protect against the external light wrapping it with black adhesive paper and/or black tape. The sensor must be, also, shielded from the electromagnetic fields by wrapping it with a conductive net or sheet of aluminum.

It is useful to install on the display more than one photoresistor, of different type. Photoresistors not sensitive to gravitational waves could be used to control the stability of the display as source of light as well! It could be, also, useful to install on the dispaly a photodiode or a phototransistor (they are not sentitive to gravitational waves!) as light meters.

3.2 Wheatstone bridge

A Wheatstone bridge has been used to measure the resistance of (each) photoresistor. The reference arm of the bridge is made by two 10 $k\Omega$, 1/2 W and 1 % precision resistences. Resistances are metallic layer type with low thermal coefficient (less than 50 $ppm/^oC$). On the other arm of the bridge is placed the photoresistor (upper side) and the variable resistance DVR (lower side) needed to balance the bridge.

In such a way, *an increase of the photoresistor resistance corresponds to a decrease of voltage difference*, (V_{CD}), between the bridge terminals. We have preferred to use a jerkily type variable resistance DVR (16 positions) because it is more precise and reliable. For this purpose we have used two 8 positions DIL switches with golden contacts. Also in this case resistances are 1/2 W metallic layer type with low thermal coefficient (better than 50 $ppm/^oC$). The 16 values of the DVR resistance we used are shown in **Table 1**.

Table 1: (Variable) resistance DVR

DIL n. 1:	75	39,2	20	10	7,5	3,92	2	1	=	158,6200	$k\Omega$
DIL n. 2:	750	392	200	100	75	39,2	20	10	=	1,5862	$k\Omega$
Total									=	160,2062	$k\Omega$

In such a way it has been possible to make a variable resistance from 0 Ω up to a maximum value of 160.2062 $k\Omega$, with a minimun step of 10 Ω. If, with passing the time, the photoresistor resistance exceeds the maximun value, it is necessary to add (without interrupting the circuit!) a new resistance in series to the DVR (e.g. 100 $k\Omega$). For those photoresistors that have, since the beginning, a value greater than 160 $k\Omega$, it is better to make a more suitable DVR value (e.g. 1^{st} resistance of 100 $k\Omega$ and 16^{th} resistance of 20 Ω, etc...). The opposite can be made for the photoresistors that have, at beginning, a lower value of resistance.

The Wheatstone bridge is fed on the upper side (A) by, approximately, 12 V and on the lower side (B) by, approximately, -8 V, in order to have an overall voltage, V_{AB}, of about 20 V. Between intermediate C and D points, to avoid e.m. noise, it is good practice to place a (polyester) capacitor of, at least, a ten of μF.

3.3 Power supply

The voltage levels (stabilized) needed for the detector are the following:

- $+18$ V for operational amplifiers (positive);
- $+12$ V for the anode of display and Wheatstone bridges (upper side);
- variable from approximately -1.5 V to approximately -2.5 V for the display filament (modulated by the anode current regulator);
- -8 V for Wheatstone bridges (lower side) and operational amplifiers (negative).

To build the power supply, it has been demonstrated that variable regulators LM 317 (positive) and LM 337 (negative) are a good choice. It is better to make, in particular for the LM 317 that produces the voltage of $+12$ V for the anode display, a selection in order to use regulators that have a lower temperature coefficient. In such a way a more stable voltage control, within the mVolt, with ambient temperature variations of some ^oC may be obtained [3].

The resistances used for regulators voltage dividers are 1/2 W, metallic layer, with low thermal coefficient (better than 50 $ppm/^oC$). The electrolitic capacitors must be of good quality (and long time-duration), with working voltage high enough (e.g. 100 V_L for the positive regulators, 63 V_L for the negative ones). The voltage divider for the LM 337 of the display filament must have a multiturns trimmer of good quality in order to carry out, manually, the voltage adjustments that, in the case of the 6 digits FUTABA display has to be, at least, between -1.5 V and -2.5 V. On the ouput of LM 337 which feeds the filament it is required to insert a capacitor (e.g. 10 μF) to avoid oscillations. Moreover, to protect the filament of display against possible over-voltages a zener diode of 2.7 V (or 3.3 V) and 1 $Watt$ at least has to be inserted.

3.4 Regulation of the anode current

The control of anodic current of the display is carried out by modulating the filament voltage. The solution that has been used consists of injecting, by a regulator, a control current into the reference node of LM 337 that generates the filament voltage .

Such a system has the advantage that, after a simple balancing, it is possible to disconnet temporarily the anode current regulator, leaving fed the filament by a constant voltage.

The balancing is made by means of multiturns trimmer of LM 337. In this way the detector works less precise but it can be still maintained into operation. In this mode

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[3] A simple way to carry out the selection of LM 317 is following: with the regulator fed with a low voltage (e.g. 5 V), connect it so that the output voltage is equal to its internal reference (1.25 V). Therefore, short-circuit the output terminal in order to heat-up the device and see the variation of the reference voltage.

of operation, it is necessary to adjust the anodic current by varying the filament voltage with the multiturn trimmer.

Concerning the original configuration used for **Detector N. 1**, we have brought out some improvements to the current regulator that have allowed to obtain a stability for the anodic current better than 100 nA.

The anodic current is sensed by means of a 100 Ω resistor placed on the anode and a differential circuit which consists of a Wheatstone bridge and an operational instrumentation amplifier (AD 621 or similar) to convert the current in a voltage signal. The variable resistance of the Wheatstone bridge is a DVR type with 16 positions, quite similar to one used for the Wheatstone bridges of photoresistors, with the maximum value of approximately 16 $k\Omega$ (1^{st} resistance of 7.5 $k\Omega$ and 16^{th} resistance of 1 Ω).

The gain of AD 621 is set in order to have a simple correspondence between the amplifier (voltage) output and the anodic current, such as 1 mV per μA. The output voltage drives a regulator (AD 711 or similar) with a Proporzional+Integral (P+I) action and whose output (voltage) is converted into the (control) current for LM 337 by means of a 10 $k\Omega$ resistance placed directely in series on the output. The two 100 Ω resistors of the differential circuit, as well as the variable resistance DVR, must be metallic layer with a low thermal coefficient.

The capacitor used for the integral action of the regulator must be of high quality polyester, with a very low leakage current. The value of the resistance to be placed in series to the regulator output depends on values chose for the voltage divider of LM 337. It is better that such a resistance has to be selected for a (maximum) filament voltage correction to avoid that a regulator failure generate high anodic current variations. In the **Appendix A.1** there is the method we used to make such a choice.

The (P+I) regulator must have switches to carry out the MAN/AUTO selection. Before switching the regulator into AUTO mode, it is necessary to balance its output in order to avoid any flow of control current, which would disturb the photoresistors. during the balancing, it is necessary also to discharge (e.g. short-circuiting) the capacitor of the integral action [4].

With the regulator in MAN mode it is possible to vary the anodic current by modifying the filament voltage by means of multiturns trimmer of LM 337 and, with the regulator in AUTO mode, the anodic current can be set by means of the variable resistance DVR.

Periodically, it is advisable to set to zero the control current, in order that current regulator does not carry out high corrections for the filament voltage. This can be obtained acting, with the regulator in AUTO mode, on multiturns trimmer of LM 337 (this operation has to be performed with caution and by small step variations, in order to allow the regulator to make compensation).

With passing the time, the filament voltage varies. At beginning it diminishes (in absolute value) due to filament “clean-up”. After that, the filament voltage starts to increase (that is, towards negative values) due to the (slow) exhausting vacuum diode.

For **Detector N. 1** we can say that, after one year of operation, the increase of filament voltage became approximately 1 mV per week. So that, in 10 years of operation the filament voltage has increased of approximately 0.5 V!

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[4] To avoid such a manual operation for the regulator balancing, it can be used an automatic balancing circuit (balance regulator).

3.5 Temperature regulation

In order to maintain the temperature of the sensor within few milli-Kelvin it is necessary the use of two thermostatic enclosures (internal and external). The internal enclosure, which is the most important, maintains the sensor temperature constant to approximately 35 ^oC, while the external one is used to compensate the ambient temperature variations, by maintaining inside a constant temperature of $20 \div 25$ ^oC.

3.5.1 Internal thermostatic enclosure

The internal thermostatic enclosure, which contains the sensor (display+photoresistors), is built with 20 *mm* thick plywood tables, externally covered with slabs of polystyerene of 30 *millimeter* thick and glued to the wood tables. Externally, the polystyrene is protected with a 4 *millimeter* thick plywood sheet glued to it.

Between the wood tables and the polystyrene slab a sheet of conducting material (e.g. copper fabric, aluminum sheet, etc...) is placed to shield the sensor from radio frequency electromagnetic fields.

The (inner) dimensions of the thermostatic enclosure are the followings: $100\ mm \times 200\ mm \times 125\ mm$ ($width \times length \times height$).

The thermostatic enclosure is continuously heated by means two (redundat) NPN type power transistor (TIP 132 or similar) mounted on an heat sink of approx. 2 $^oC/W$ fixed on the enclosure ceiling. The heating system is fed by 12 V batteries system and each power transistor is current-driven by means of an (current driver) operational amplifier (CA 3130 or similar).

Such a solution is quite different respect to the one used for the **Detector N. 1**, which was based on an heating system made by resistances it is more efficient and allows a control of the thermal power with a linear characteristic (control voltage vs. thermal power), which improvea the dynamic performance of regulator (resistances, due to Joule heating, have a quadratic characteristic which makes difficult to achieve optimal regulation at low heating power).

The enclosure must be built with care, avoiding air leakages, thermal bridges, etc.... If well built, with an external temperature of $20 \div 25$ ^oC, this enclosure need less than 1 W of heat in order to be maintained at 35 ^oC of temperature.

The air circulation inside the enclosure is obtained two (redundant) axial miniature fans ($40 \times 40\ mm$), mounted on bearings, in order to have high reliability and long-time duration. The speed of the fans has to be (electronically) varied to optimize the dynamic of the regulation. In this case, the heat released by fans is not meaningful (few tens of Watt), it is better to avoid changing it too often. When necessary, it has to be carried out slowly in order to give enough time to the temperature regulator to compensate.

The temperature inside the enclosure is measured by two probes made with negative coefficient (NTC) resistors. One of them is used for regulation and the other one is, used for indication, is placed very close to the photoresistor.

In order to reduce the noise temperature induced by the kinetic energy of the air hiting the probe, it is worth to reduce the speed of air inside the enclosure as well as shielding the probe used for the regulation (e.g. by an aluminum hairnet that wraps the probe itself). In such a way the fans wear is also reduced.

The resistance of (NTC) probes is measured by a Wheatstone bridge whith an instrumentation operational amplifier (AD 623 or similar), referenced with a voltage of +5 V.

The voltage reference must have a good stability (within milli-Volt) in order to avoid battery voltage variations may disturb the temperature measurement. For this scope a voltage regulator, such as the LM 7805, can be used or, better, a precision voltage reference (AD 586 or similar).

The NTC resistors are drop type with a nominal resistance less than 100 $k\Omega$ (25 ^oC). The variable resistance of the Wheatstone bridge is DVR type, made with a single DIP switch (8 positions), with a maximum value of approximately 160 $k\Omega$.

The gain of the instrumentatuion amplifier (AD 623) is set in order to have a correspondence between the output voltage and the temperature of, approximately, 1 V per ^oC.

The Proportional+Integral ($P+I$) action temperature regulator (AD 711 or similar) voltage output ($0 \div 10\ V$) set the reference for the current drivers of NPN power transistors. The characteristic voltage-to-current of the driver is $1\ V \approx 0,02\ A$. that is, with 10 V in input the heating current is approximately 0.2 A, with a thermal power about 2 Watt. The heating system (fan, power transistor, current driver and temperature probe) is redundant, one is normally operating and the other in stand by.

It is, also, useful to add a battery-powered digital thermometer, 0.1 ^oC precision, with a double dispaly to have a direct reading of internal/external temperatures of the enclosure as well as a (digital voltmeter with 3+1/2 digits) to monitor the regulator output.

3.5.2 External thermostatic enclosure

The external thermostatic enclosure is required to compensate the variations of ambient temperature. This enclosure is not strictly necessary if the detector is in a suitable place and protected against: temperature variations, circulation of air, light, infrared radiation (e.g. presence of persons), etc...

The temperature inside the enclosure is maintained to a constant value corresponding, more or less, to the average value of ambient temperature of the place where the detector works (e.g. $20 \div 25\ ^oC$), so as to reduce the electrical energy consumption.

The enclosure is built with 20 mm thick plywood tables, covered externally with slabs of polystyrene of 20 mm glued to tables. The polystyrene is externally protect with a 4 mm plywood sheet glued to it. The (internal) dimensions of the enclosure are $500\ mm \times 400\ mm \times 500\ mm$, ($width \times length \times height$) in order to contain the (internal) thermostatic enclosure with the sensor inside it.

The temperature regulation is accomplished by an heating-cooling system based on Peltier cells. The control of the Peltier cells current is carried out with an “H” bridge having, in the two arms, a couple of complementary power transistors (darlington) with, at least, a ten of Ampére (e.g. MJ 2501/MJ 3001 or similar).

The use of the “H” bridge allows the continuous crossing of warm-cold and viceversa, by only the (automatic) reversal of current through Peltier cells. In order to have a more effective control, it is preferred to drive the Peltier cells in current rather than in voltage mode.

The temperature measurement is carried out in the same way of the internal thermostatic enclosure. Also the temperature regulator, with a Proportional+Integral (P+I) action, is quite similar. The circulation of the air inside the enclosure is maintained with an axial fan ($60 \times 60\ mm$) with an electronically controlled speed. The temperature probe is mounted close to the suction of the fan.

The Peltier cells are two of 50 W each and placed in series (thermally) [5]. On the electrical side, they can be connected in parallel (with a power supply of $15 \div 18$ V and a maximum current of 10 A), or in series (a power supply of $30 \div 35$ V and a maximum current of 5 A). The second solution has shown better results also for the electric power consumption.

With this type of regulation, it easy to maintain a constant temperature inside the enclosure within ± 0.2 ^oC.

The power supply (unstabilized) is directly connected to grid (220 Vac) because its failure does not create any serious problem, inasmuch the internal thermostatic enclosure is in a position to compensate, mostly of the ambient temperature variations.

All the equipments are not redundant because it is not a critical regulation. Peltier cells may be placed on the top of the enclosure, by accomplishing an opening of approximately 50 $mm \times 60$ mm for the passage of the heat. Inside the enclosure an heat sink of $1 \div 1,5$ $^oC/W$ should be enough while, outside it, one of, at least, of 0.5 $^oC/W$ is needed. The two heat sinks are connected together with an aluminum block, with a cross-section of 50×60 mm. The (two) Peltier cells are mounted between the heat sinks and the aluminium block .

The external fan, of axial type, has a cross-section of (120×120 mm). The same air can be used, also, to cool the power transistors of the "H-bridge". The fan is needed only for cooling and it shold have the capability of varying, manually, the speed (e.g. by using an LM 317) as function of temperature requirements.

For electrical power saving, the transformer of the power supply must be multiple outputs (e.g. 5 V, 10 V, 12 V, 15 V, etc...) in order to set manually the voltage of Peltier cells, based on the effective nedeeds.

3.6 Batteries and external power supply

The detector is fed with a double voltage of $+24$ V and -12 V. $+24$ V is generated by two lead batteries, automobile type , of 12 V and $45 \div 50$ Ah connected in series. -12 V it is obtained with two batteries of the same type connected in parallel. The -12 V system has an higher capacity ($90 \div 100$ Ah) because it feeds also the internal thermostatic enclosure.

Such a system gives an autonomy of operation for the detector (including the internal thermostatic enclosure) of $15 \div 20$ days.

Batteries are maintained charged (in pad) with two power supplies, stabilized, connected to the grid.

The power supply for the $+24$ $theV$ system is designed for a maximum current of 2.5 A, while the -12 V one is designed for 5 A.

The power supplies are set with an output voltage, respectively, of $+26.5$ V and -13.25 V. They have been chosen with such a values in order to keep low the leakage current through batteries themselves and extend the life of the same. In this way, the batteries, if of good quality and checked periodically, can reach up $8 \div the 10$ years of life.

The batteries replacement has to be done maintaining (always!) the detector fed, avoiding excessive voltage variations and using, in such an operation, temporary diodes

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[5] If the excursions of the ambient temperature are not so high, it can be sufficient only one single Peltier cell

to avoid dangerous current exchanges between them.

3.7 Wiring

The most part of the electronic circuits have been built by using vetronite multi-holes cards with a 2.54 $mm \times 2.54$ mm spacing (e.g. laboratory Eurocard of 160×100 mm).

All the electrical connections of components on the card are made by the a "wire-wrap" cable of 24awg and 28awg soldered to them.

The main electrical connections among batteries and power supplies have been done with cable having $4 \div 6$ mm^2 cross-section. The other electrical connections use paired wire (two and/or three leads) with a (minimum) 0.5 mm^2 cross-section.

Connections of the photoresistors to the Wheatstone bridges have been done with multiple pole shielded cable with a leads cross-section of 0.25 mm^2, with the shield connected to 0 V. A shielded cable (2 leads plus shield) with a (minimum) cross-section of 0.5 mm^2 is used to connect the display to the power supply (with the shield connected to cathode).

3.8 Chassis

The detector with its (internal) thermostatic enclosure has been arranged on a chassis built with 30 mm thick plywood tables on which there are placed also the (four) batteries.

The (external) thermostatic enclosure has been built in two parts. The lower part is fixed to chassis in order to increase its stiffness while the upper part, on which Peltier cells are placed, is removable.

The overall dimensions (plant) of the equipment are $1,000$ $mm \times 500$ mm with a total height of approximately 600 mm. The total weight, batteries included, is approximately of 80 kg.

4 Controls and tuning

To put the detector into operation it is advisable to proceed in the following way.

Step 1. Connect the power supply to the display without inserting the anode current regulator. Check for the voltages and verify the range for filament voltage by means the multiturns trimmer of LM 337.

Step 2. Put into service the (internal) thermostatic enclosure without the sensor, by helping yourself with a (digital) thermometer to check for internal and external temperatures.

Optimize the parameters of the temperature regulator (proportional gain K_p and integration time T_I) carring out, first of all, variations of the set-point by using the variable resistance DVR and following by step variations of the fan speed, and checking for attainment of the new (stable) conditions without oscillations and/or long time response.

Such checks have to be done in the range of operation temperatures, at least between 20 ^oC to 40 ^oC).

Step 3. Put the dispaly into the thermostatic enclosure by installing, instesd of photoresistors, high stability resistors of approximately $50 \div 100\ k\Omega$ and connect them to the Wheatstone bridges. In this way the operation of Wheatstone bridges can be checked.

Varying the temperature inside the thermostatic enclosure, the voltage difference V_{CD} between the bridge terminals has to be constant and the noise less than a milli-Volt.

Step 4. Replace the high stability resistors with an NTC of some tens of $k\Omega$). In this way is possible to check also the operation of the Wheatstone bridges, the zero adjusting by DVR as well as the noise due to the temperature regulation.

Step 5. At this point the anode current regulator can be put into operation (AUTO mode).

Because the anode regulator operates by injecting a current signal into the reference node of LM 337 that generate the filament voltage, before doing that it is necessary to balance the regulator. If the balancing regulator is not available, this can be accomplished by short-circuiting the capacitor of the integral action and modifying the output with the resistance DVR (set-point).

Once the regulator has put into AUTO mode the short-circuit of the capacitor has to be removed.

It has to be kept in mind that this operation generates a (small) variation of the anodic current (the regulator itself will try to null the regulator driving error) which can be (manually) compensated by modifying a little bit the DVR. More or less the same operation has to be made before putting out of service the regulator.

It is advisable, also, to place on the display a photodiode or a photo-transistor. In such a way the stability of the emitted light of the display can be verified as well as the regulation of the anodic current.

Step 6. It is suggested to maintain into continuous operation the display, the anodic current regulator and the the (internal) thermostatic enclosure temperature regulation for a long period (e.g. few months) in order to verify their reliability. During such a period, the dispaly "cleans-up" itself and its operation becomes more stable.

Step 7. At this point, replace NTC's with photoresistors, and place, again, the sensor into the thermostatic enclosure. The photo-diode (or photo-transistor), if any, can be left inside for periodic checks of the display operation.

Step 8. Increase, gradually, the temperature of the sensor to approximately 35 ^{o}C.

Stabilizing the temperature of the sensor may require hours.

Step 9. In the first period of operation, it is not necessary the (external) thermostatic enclosure, because the variations of the photoresistor's resistance are high. Only after some months, when the voltage variations at the Wheatstone bridge terminals will become quite low, less than a ten of mVolt per day, it can be put into service also the (external) thermostatic enclosure which, as we already said, to reduce the infuence of environmental conditions.

5 Periodic controls and recording of data

The measure of the voltage at the Wheatstone bridge terminals is not critical. A digital multimeter with 3 figures and 1/2 and with an input resistance of at least 10 $M\Omega$ is enough. An input resistence of 1 $M\Omega$ may disturb a little the photoresistors.

As alternative, for each Wheatstone bridge a unit gain amplifier (buffer) with FET input operational can be used. It is advisable to avoid direct measurements of the anodic current as well as the anode voltage. For the anodic current it is enough to check voltage variations on the output of the instrumentation amplifier (AD 621), while the anode voltage can be checked through (approx. 12 V) LM 317 output, unless to use, also in this case, a FET input buffer.

At the beginning, in the first months of photoresistors "formatting", one or two (manual) reading per day are sufficient. When the voltage at the Wheatstone bridges terminals has reduced quite a lot the initial continuous decreasing and the first signal variations starts, the automatic data acquisition systemit can be put into service.

A reading every $10 \div 20$ minutes is sufficient for the large intensity gravitational waves, while it is necessary to increase it to, at least, a reading per minute if faster variations have, also, to be recorded (the detector is in a position to "see" also up to $1,000$ Hz).

Once the photoresistors "formatting" is accomplished, on the graphs is possible to see:

- large voltage variations (from some milliVolts up to more than 100 mV, lasting up to many days, which correspond to waves of large amplitude ("fork" shaped), generated by the collapses of the nuclei of Mupltiple Nucleus Quasars (MNQ);
- voltage variations of $1 \div 5$ mV with a time-duration from less than 1 minute up to several minutes, which corresponds to the birth of a "new" matter consisting of hydrogen bubbles ("notches");
- voltage variations of few hundreds of micro-Volt and time-duration of few seconds or less than one second, corresponding to stars falling on extra-massive celestial objects like MNQ's nuclei;
- voltage variations of few ten of microVolts and whose frequencies are approx. above $10 \div$ Hz, corresponding to the falling of smaller celestial objects (planets, etc...) on MNQ's nuclei.

5.1 Balancing of the Wheatstone bridges

At the beginning and in the first months of operation the resistance of the photoresistors varies significantly and it is necessary to balance, frequently, the Wheatstone bridges of the photoresistors. It is better does not exceed voltage differences between the bridge terminals of $1 \div 1,5$ V in order to avoid altering the operation of the photoresistors during the bridge balancing as well as excessive compression of signal made by the bridge itself.

It has to keep in mind that *an excessive voltage variations through the photoresistor alters the inner dissipation because of Joule heating* and photoresistors operation needs hours to be restored.

5.2 Variations of the environmental conditions

If the ambient temperature variations disturb the detector operation, in particular for the anode voltage, there are the following two possibilities:

- put the detector into a temperature controlled dark place, without the presence of people;
- put the power supply and, eventually, also anodic current regulator inside of the (external) thermostatic enclosure.

5.3 Data acquisition

It is a good choice to use the Agilent 34970A automatic data acquisition system. Each “slot” (Agilent 34970A can accept up to a maximum of three) is able to acquire enough signals to monitor completely the detector (photoresistors, voltages, currents, temperatures, etc...).

For the precision of readings, 5 figures and 1/2 are enough (even if 34970A automatic voltmeter can reach up to 6 digits and 1/2). The Agilent 34970A can be connected with the PC via RS 232 port or through the IEEE-488 interface.

However, other data acquisition systems can be used for the same task such Fluke Hydra system, PC with data acquisition cards placed directly inside it (e.g. National Instruments), progammable controllers (PLC) with a supervision software, etc...

6 The “formatting” of photoresistors

Up today (after more than two years) the situation concerning the formatting of photoresistors used for **Detector N. 3** is following:

- the main photoresistor, after only few months of operation has significantly reduced its resistance variation (increase) and, after approximately 6 months it started to show its first voltage variations. After approx. 9 months its “formatting” become better and the agreement with the **Detector N. 1** was good.
- At beginning, one of the burner’s photocells has shown an opposite behavior respect to all others, with a decrease of its resistance. After approximately $8 \div 10$ months the resistance stopped decreasing and started to increase very slowly. This photoresistor seems to be sensitive only to the fast gravitational waves (up to few hours of variation), even if its sensitivity is low (approx. $3 \div 5$ times less the one of the main photoresistor).
- the others 4 photoresistors, up today, still continue to increase continuously their resistance. Only one of them (a small dimensions photoresistor, used in some cameras) seems to have got some sensitivity to the short time-duration gravitational waves.

It is important to notice that as the photoresistors are “formatted” they become less sensitive to temperature variations!

7 Conclusions

We hope to have given useful informations concerning the construction and set up of the detector of gravitational waves that uses CdS photoresistors.

Perhaps, we have not been enough exaustive about photoresistors to be used for this detector. On this subject, we are running some tests with the **Detector N. 2 bis**, whose preliminary results indicates that CdS/CdSe photoresistors have higher sensitivity to gravitational waves.

A APPENDIX

A.1 Control of the filament voltage

The continuity of currents in the reference node "O" of LM 337, neglecting the current through pin "Adj", gives (v. **Figure 1**):

$$\frac{V_C - V_O}{R_C} - \frac{V_O}{R_B} = \frac{V_0 - V_f}{R_A} \tag{1}$$

from which the voltage V_f can be obtained:

$$V_f = V_C \; \frac{\dfrac{1}{R_C}}{\dfrac{1}{R_B} + \dfrac{1}{R_C}} - V_{ref} \; \frac{\dfrac{1}{R_A} + \dfrac{1}{R_B} + \dfrac{1}{R_C}}{\dfrac{1}{R_B} + \dfrac{1}{R_C}} \tag{2}$$

with,

$$V_{ref} = V_O - V_f \equiv 1.25\ V$$

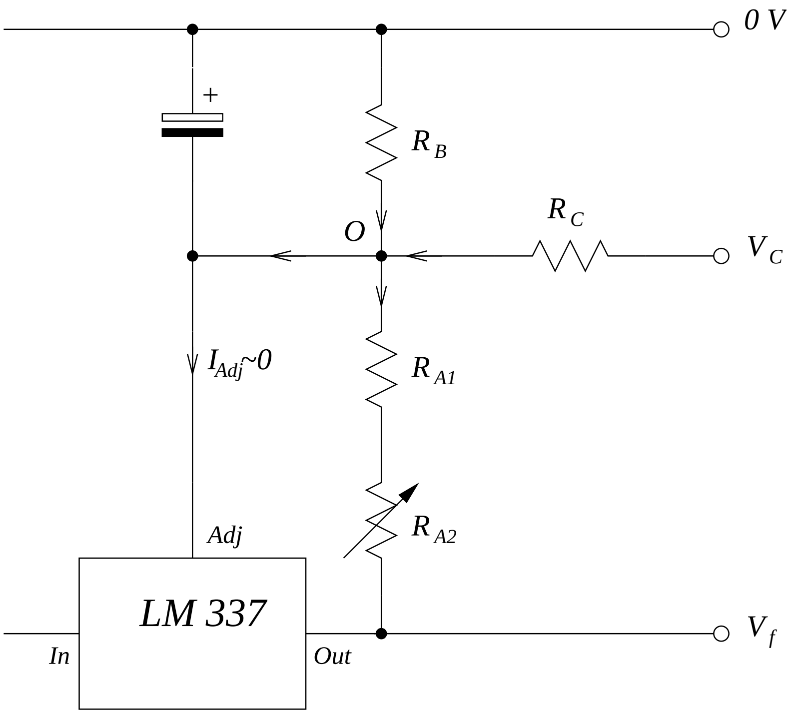

Figure 1: Control of the voltage filament

Because of with $V_c \approx 0$ it has to be $-2.5\ V \leq -1.5 V_f \leq\ V$, is necessary that:

$$-2.5 = -1.25 \left(\frac{R_B}{R_{A1}} + 1 \right) \tag{3}$$

and,

$$-1.5 = -1.25 \left(\frac{R_B}{R_{A1} + R_{A2}} + 1 \right) \tag{4}$$

where, in (2) we have neglected the term $1/R_C$. Therefore,

$$\frac{R_B}{R_{A1}} = \frac{2.5}{1.25} - 1 \equiv 1$$

and,

$$\frac{R_B}{R_{A1} + R_{A2}} = \frac{5.5}{1.25} - 1 \equiv 0.2$$

from which the following relation is obtained:

$$\frac{R_{A2} + R_{A1}}{R_{A1}} = \frac{1}{0.2} \equiv 5$$

Choosing the multiturns trimmer R_{A2} of 1 $k\Omega$ one obtains:

$$R_{A1} \equiv R_B = 290\ \Omega\ (= 470\ \Omega \parallel 750\ \Omega)$$

If you want that the maximum variation of V_f does not to exceed 0.5 V, with a control voltage V_C ranging from $+15$ V to -5 V, the R_C resistance on the regulator output must have a value higher than:

$$R_C = \left(\frac{15+5}{0.5} - 1\right) R_B = 39\ 290 \approx 10\ k\Omega$$