LIGO-T880057-00-R

A Reflective Quadcell Position Sensor

§1 Introduction

We have developed a version of a 'shark detector' or a shadow position sensor designed to meet the conflicting demands of low noise, good vacuum practice, and minimum mechanical disturbance of the object that requires sensing. The detector is an SD225-23-21-040 quadrant cell from Silicon Detector Corpororation. It has a hole in its center through which light from an IRED can shine. The light reflects off a polished surface with a dark spot that produces a shadow on the detecor. This allows a measurement of two degrees of freedom in a plane parallel to the detector.

The quadcell, IRED and some buffer electronics are housed in a compact head made from copper and aluminum. Long wires carry the signals to the electronics which consist of preamps for the individual photocells and differential amplifiers to measure the difference in ouput between opposite quadrants.

§2 Mechanical Design

§2.1 *Ray Optics*

The position detection scheme relies on the shadow technique where an opaque mask blocks the path of light between the source and the detector. Our work is a simple variation on a technique which has found wide use in the gravitational wave community. The mask rests on the object whose position one wishes to determine. Using two cells in a differential mode, the motion of the mask can be measured with some rejection of intensity noise in the light source.

This sensor design departs from the usual practice which has an LED and photodetector opposite each other with the shadow being cast by an edge of the mass or a tab attached to the mass.The technique in this particular case uses a quadcell detector with a hole in its center which allows the light source to be placed behind the detector. A reflective surface with a dark area of an appropriate size placed in front of the detector then completes the system. The unfolded diagram shows that the net result is the same as in the standard design.

This scheme has an advantage over edge detection in that it can take advantage of the noise immunity which comes from a differential detection scheme. There may also be some extra design freedom from being able to place sensors at places other than at an edge, although this scheme has only been tested looking at flat reflecting surfaces. It does not involve the addition on any protruding masks to the object whose motion is being measured, an advantage which is shared with edge detecting schemes.

The dimensions of the various components have to take into account factors such as the beam divergence of the IRED, the active area of each individual quadrant and the required dynamic range. The beam profile measured with the IRED appropriately positioned behind the quadcell must be matched to the size of the quadcell. The final gap spacing of 7mm between the IRED and the reflecting surface produces a bright spot on the quadcell that essentially covers it. (The half-angle divergence is 22.3 degrees which gives an illuminated region of about 5.7 mm in diameter. This compares well with the 5.72 mm diameter of the quadcell's total active area.)

The size of the opaque surface projected back on to the quadcell has to be larger than the dead area at the center, but somewhat smaller than the total active region. The best result comes from an experimental attempt to measure the position gain. It is a square 3/32" to a side and oriented as shown in the diagram.

The reflective surface consists of a polished flat on the mass facing the sensor. Currently, we make the spot with dull black tape. We need to come up with a method more consisitent with good vacuum practice.

§2.2 *Physical Layout of Sensor Head*

The physical construction of the sensor head consists something to hold the quadcell and IRED and a means to align the sensor to its proper equilibrium position. The quadcell sits in a copper holder that has holes for the leads and one in the center for the IRED. The IRED (TIL24) is soldered in the hole and a thin wire is also soldered to the cathode. The case of the IRED is the contact for its anode, which is thus grounded to the metal part of the sensor head. A teflon pad insulates the quadcell from the holder since the quadcell case is the ground for each photodiode. A copper coverplate holds the quadcell in place. Again, a teflon ring insulates the cover plate from the quadcell.

This combination is then attached to an aluminum extender that serves to hold the sensor at the right distance from the surface. A thin sheet of indium provides good thermal contact between the copper and the aluminum. Inside this extender sits the 1 M feedback resistors for the preamp and the two dual FET's that serve as buffers for the signal. We have used 1 percent thick film surface mount resistors, but regular precision resistors with epoxy removed can also be used. The roll off capacitor is 75 pf mica with the epoxy covering removed. (The epoxy comes off if you hit it with a hammer.) The wires are 32 gauge with teflon insulation. We also use teflon shrink wrap.

This extender cylinder is attached to an aluminum mounting plate. Again, a thin sheet of indium is placed between the two to establish good thermal contact. The mounting plate fits onto a specially designed stage that is mounted on the surface which serves as the fixed reference. The stage allows alignment of the position sensor in two dimensions with the proper equilibrium position. Hold down screws then can clamp the sensor head in this position.

Twelve wires then go to a 14 pin connector. These include:1 quadcell ground, 1 case ground, 1 FET power, 1 IRED power, 4 signals out from the FET's and 4 feedback signals. We connect two complete sensor heads to one electronics box.

§2.3 *Thermal Budget*

One application we envisage for these sensors is to mount them on the shell mass of a nested compound suspension. In this application, the sensor is poorly heat sunk to the outside world. The largest source of heat in the sensor is the IRED. To minimize the heating, we have chosen a bias current of 10 mA, or a dissipation of 11 mW. The FETs are biased so that they dissipate only 0.15 mW each, or 0.6 mW per sensor head. Our estimate of the temperature rise this will cause assumes the head is in good thermal contact with the shell mass, which cools by radiation. If the emissivity of the shell is 5 percent, the temperature rise will be about 4K. We will check this estimate soon with an in-vacuum measurement.

§3 Electronic Design

The electronics fits on a NIM sized board designed to accept two complete sensor heads. The connector size and numbers require a double wide module. The outputs are all standard BNC connectors.

The first stage is the preamp electronics. The photodiodes are all connected in a modified transconductance circuit. The modification is the FET used as a buffer for the wire which goes to the op-amp inverting input. Opposite quadrants are wired to the two well-matched FETs in a U403. An OP-227 serves as the preamp because it has low voltage noise and the two op-amps are well matched. The 75 pf roll off capacitor across the 1M feedback resistor gives a pole at 2.1 KHz. The ground wire for the quadcell needs a small resistor (7.5 Ohms) in series with ground.

The next stage uses an OP-227 as two op-amp differential amplifier. The preamp output from two opposite quadrants is subtracted and amplified by a factor of 12. There is also a simple one op-amp unity gain differential amplifier that gives the same output at a gain of one. This is used as a wide dynamic range amp for help in alignment.

§4 Performance

A rig to test the performance of the sensor consists of an x-y stage and some mechanism to level the sensor. A polished surface with the appropriate sized mask completes the setup. With the sensor properly centered, one can measure the response to translation in two perpendicular directions. The results show that there is some region where the system acts linear and then the response rolls off giving an S shaped response curve. The size of this linear region is about one quarter of a millimeter; useful information extends for a few millimeters which corresponds approximately to the size of the quadcell's active area. The position gain is roughly 280 V/cm.

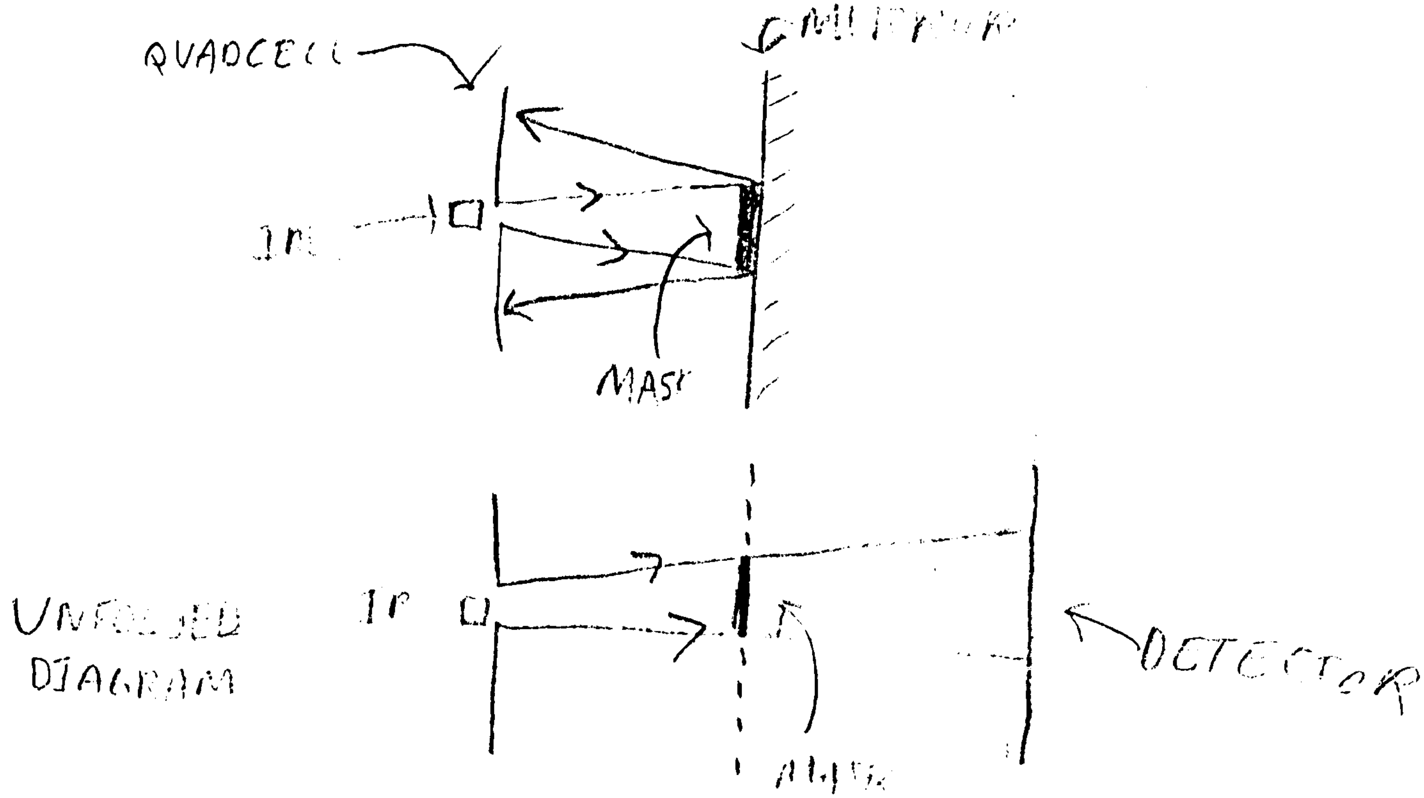
Another important test concerns the response when one axis is off center. Measurements show that the position gains changes rapidly when one axis is more than one millimeter off center. Again, this follows from the size of the mask which is about two millimeters.

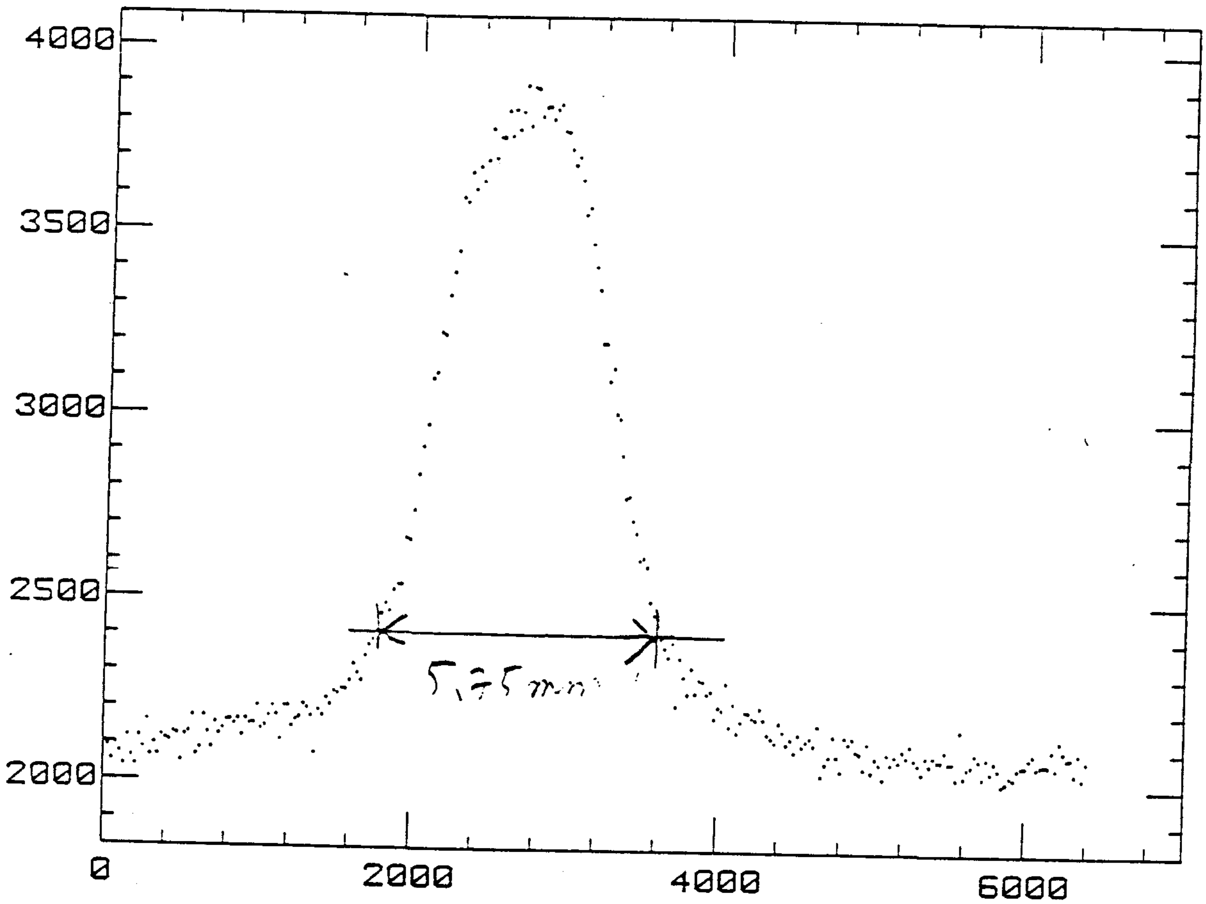
The noise measurements agree well with expected values. The 1/f knee is below 5 Hz. Above 5 Hz, the sensor is limited by shot noise. At frequencies greater than 2 kHz, the magnitude rolls off from the feedback capacitor on the preamp. At 100 Hz, the sensitivity is 4×10^{-8}cm/Hz$^{1/2}$.

The photocurrent is 1.1 μamp. Through the 1 M load resistor, this gives a shot noise of 6×10^{-7}V/Hz$^{1/2}$ or -124 dBV/Hz$^{1/2}$. Multiplying this by a gain factor of 12 acrosss the diffferential amplifier gives a noise of 7×10^{-6}V/Hz$^{1/2}$ or -103 dBV/Hz$^{1/2}$. This agrees with the measured noise. For comparison, a measurement of of the dark noise gives -114 dBV/Hz$^{1/2}$

Joe Kovalik and Peter Saulson

5 July 1988


QUADCELL
MASK
DIAGRAM
DETECTOR



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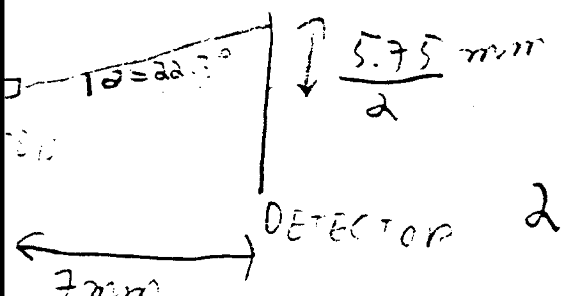
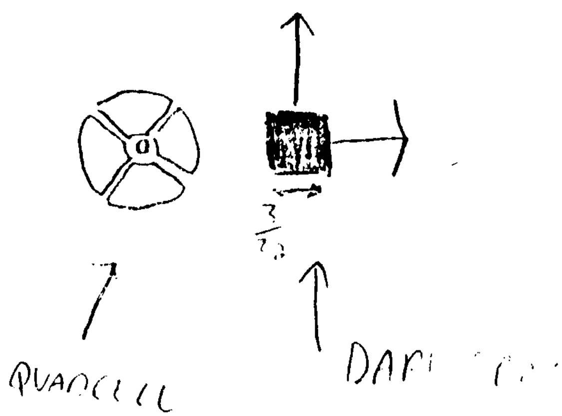
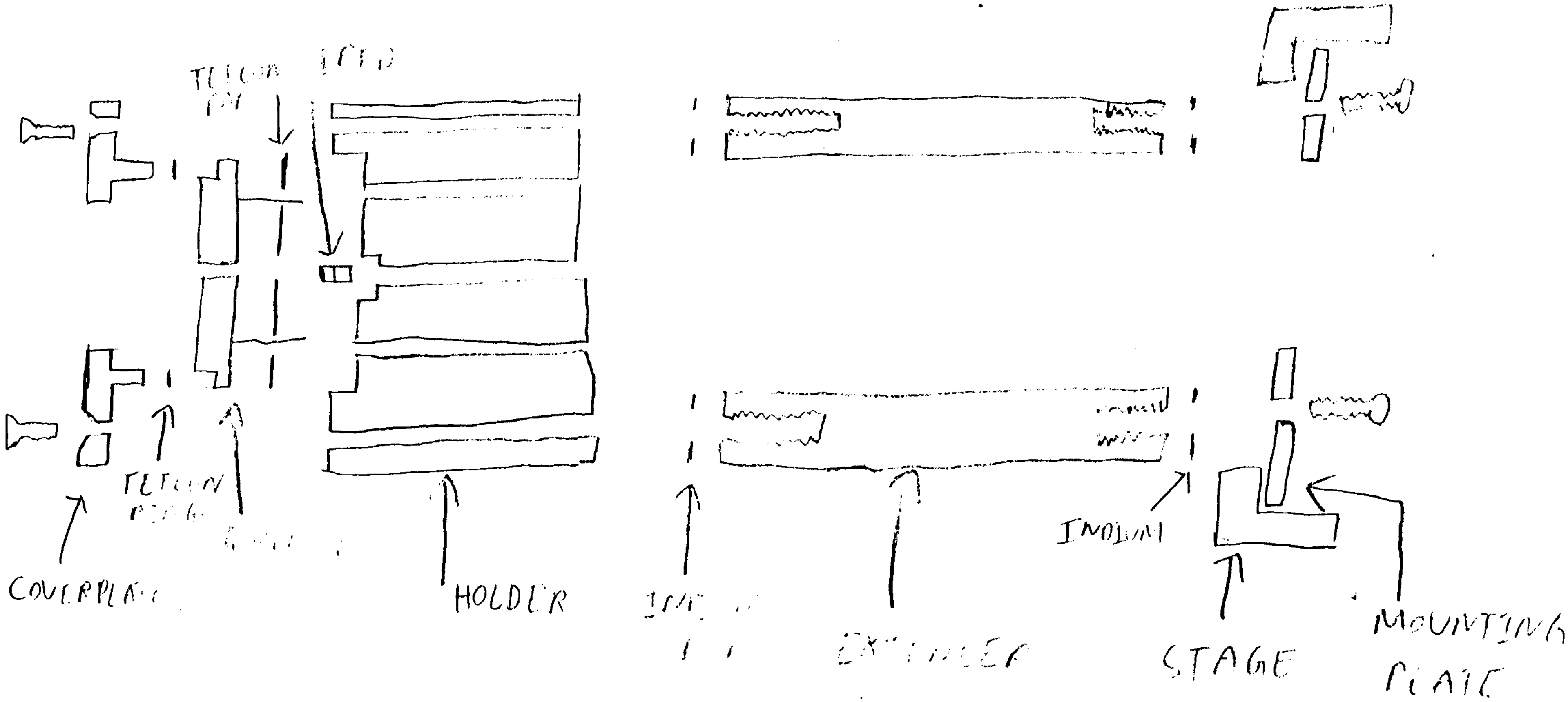


200 = 25 MILLINCH

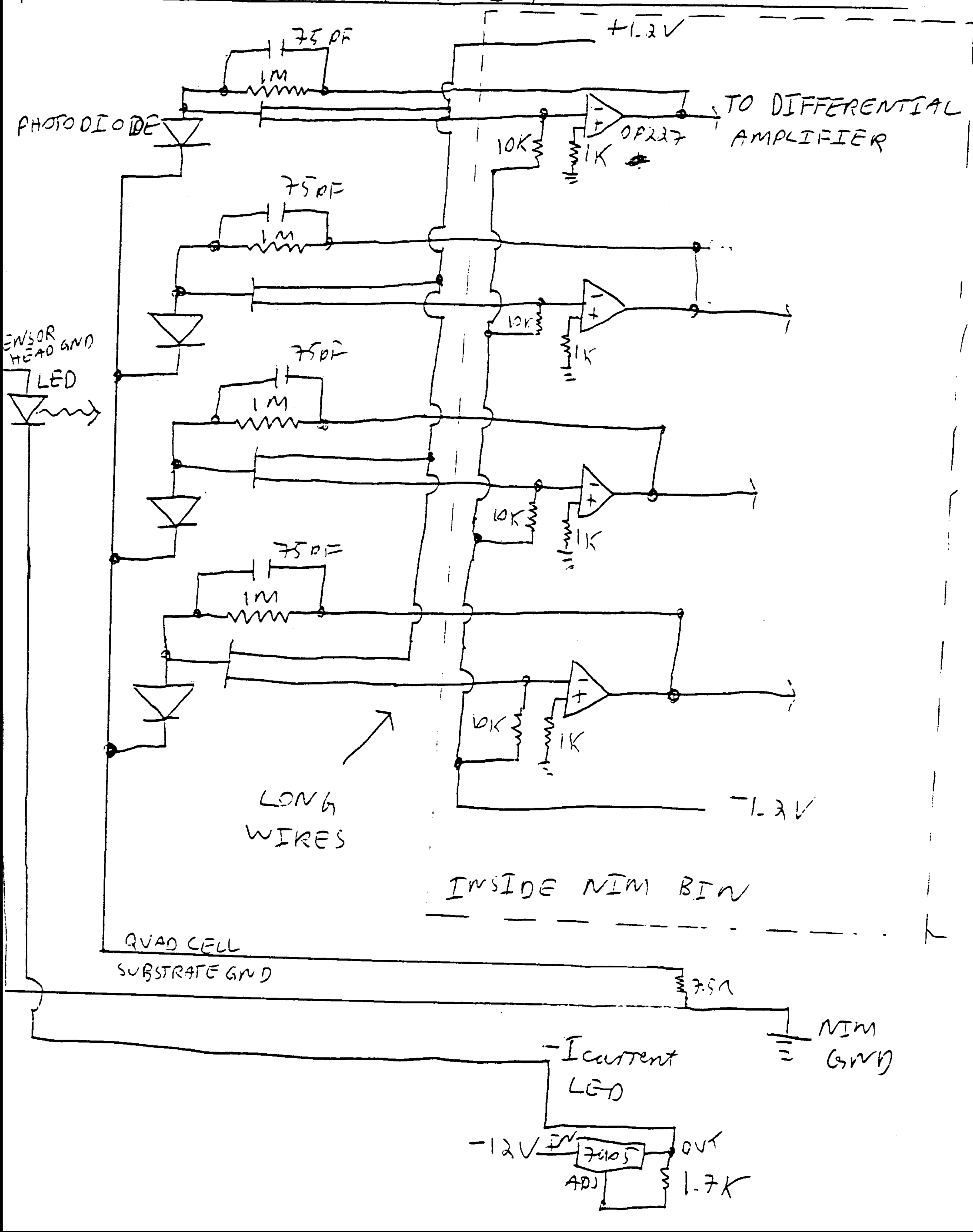
ORIENTATION OF DARK SPOT



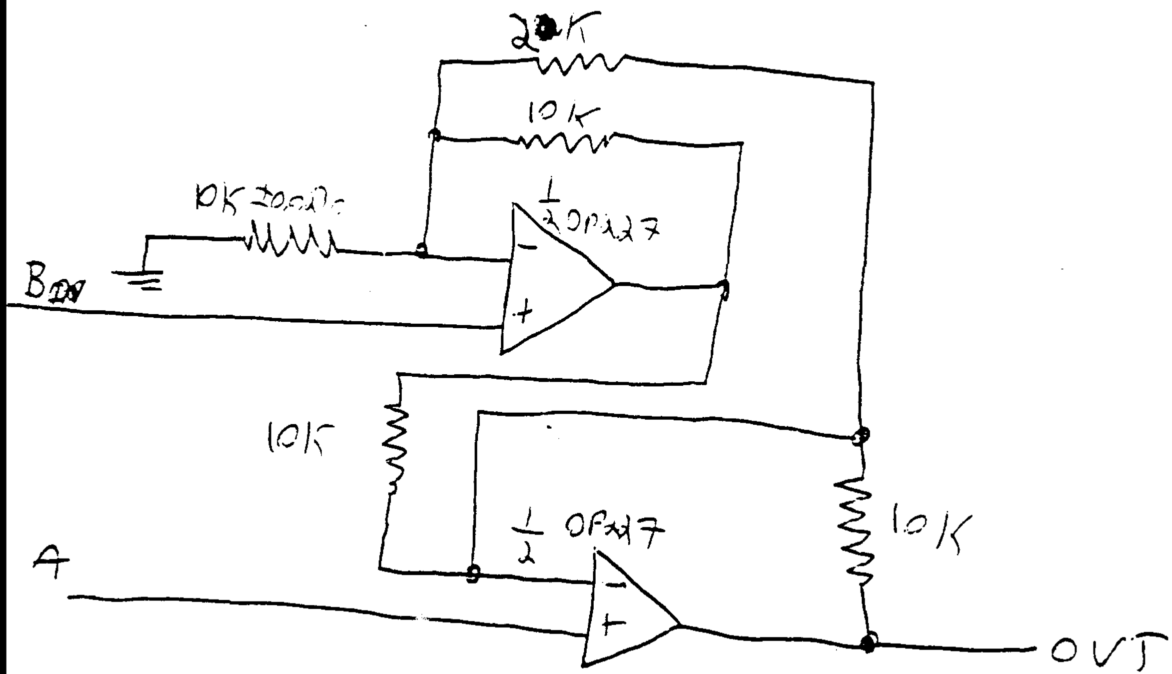


HOLDER
INDIUM
STAGE
MOUNTING
PLATE

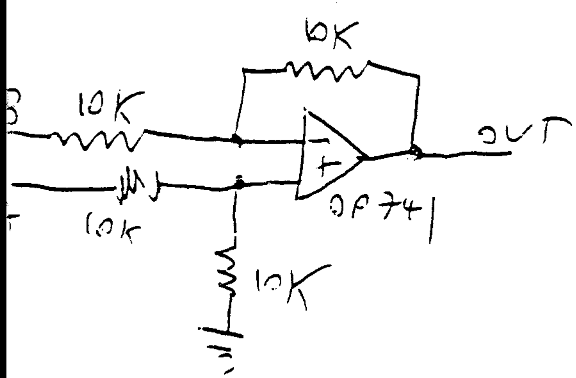
QUAD CELL SENSOR & PREAMP



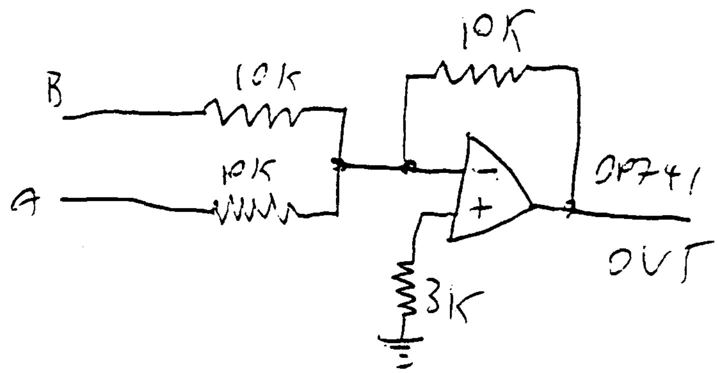
HIGH GAIN DIFFERENTIAL AMPLIFIER (OUT=12×(A−B))

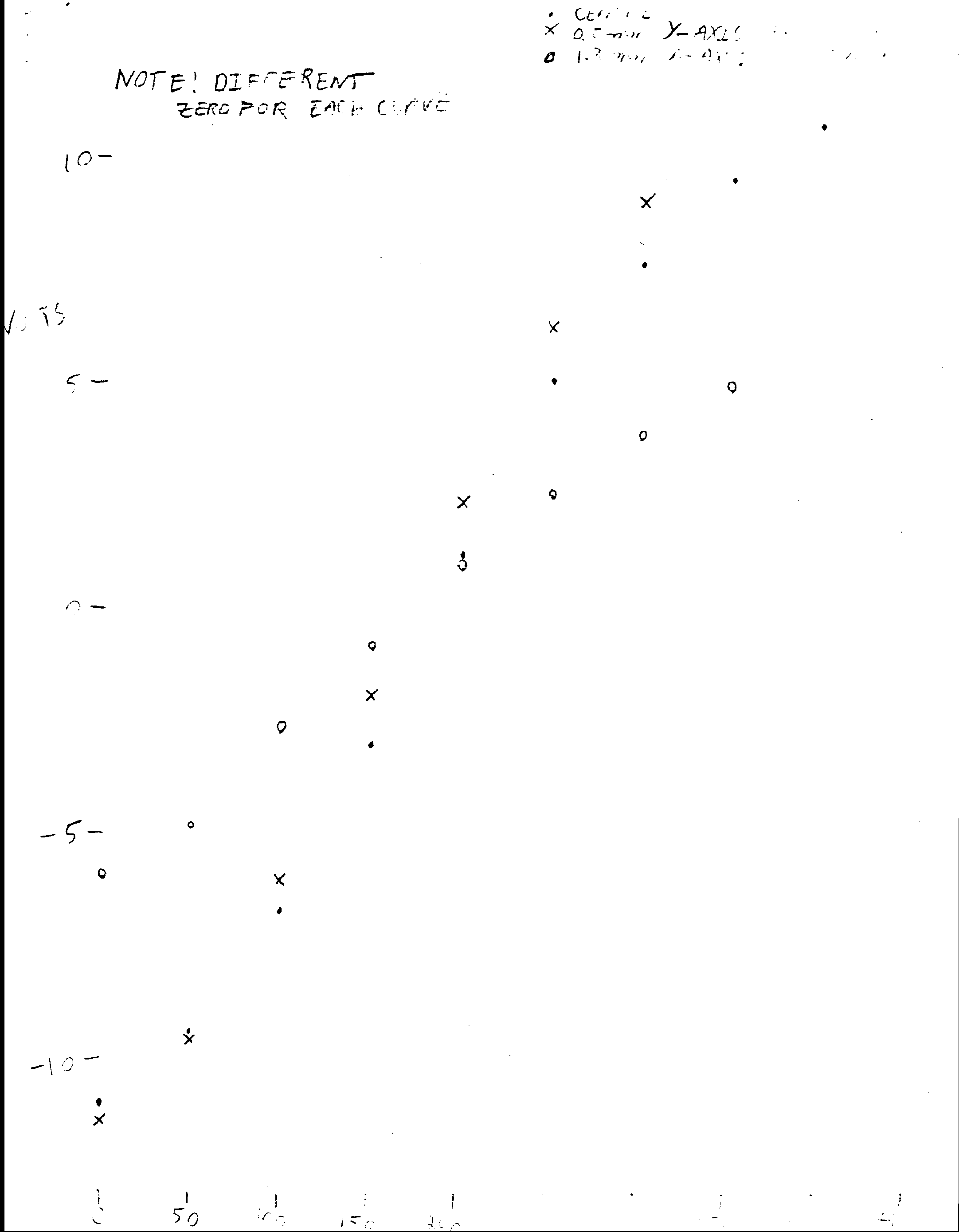


LOW GAIN (OUT=(A−B)) DIFFERENTIAL AMPLIFIER

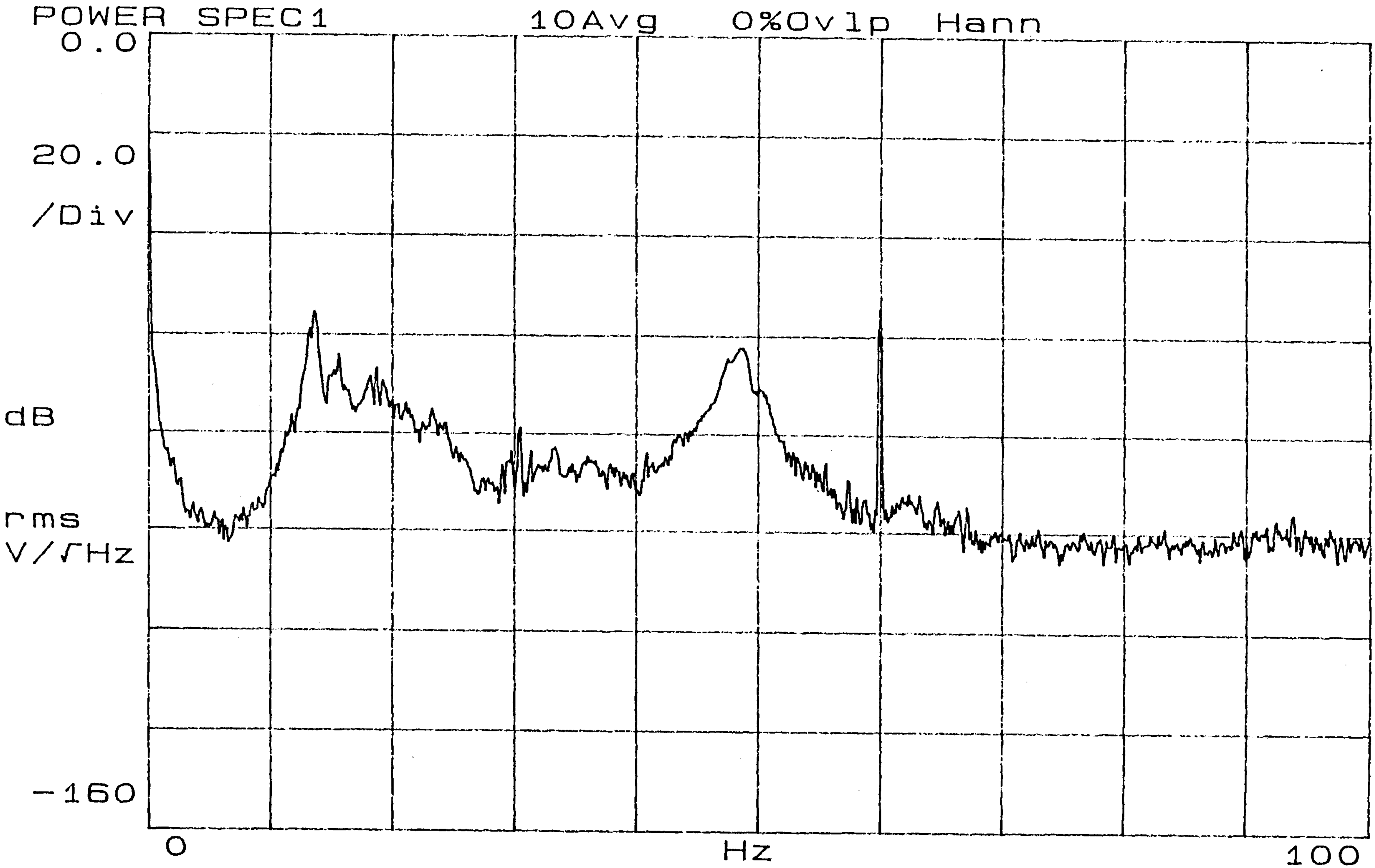


SUMMING AMPLIFIER OUT= (A+B)





NOTE! DIFFERENT
ZERO FOR EACH CURVE
Y-AXIS
10
5
0
-5
-10
50


POWER SPEC1
10Avg
0%Ovlp
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20.0
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dB
rms
V/√Hz
-160
0
Hz
100