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LSC Photodiode Bias Feedback Tuning

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1 Overview

This document describes the procedure used to modify the current version (D990454−02−B circa July, 2000) of the LIGO Length Sensing & Control Photodiode (LSCPD) to reduce/remove an observed nonlinearity in the RF response.

The LSCPD is used at the various sensing ports of the interferometer (IFO) to convert optical signals into the electronic error signals used in the various length/frequency control loops and is thereby the device which converts the gravity−wave's optical signature into an electronic signal. Various versions of the LSCPD are also used in the Input Optics (IO) and Pre−Stabilized Laser (PSL) subsystems for similar purposes. As the performance of this device is so crucial to the sensing and control of the IFO, a detailed characterization is important.

2 The Nonlinearity and its Consequences

During the characterization of a sample batch of prototype Pds (photodiodes), a nonlinearity in the RF response was noticed: the RF response has a dependence on the DC photocurrent. For typical designed power levels (~10 − 150 mW incident), the magnitude reponse at the resonant frequency of the tuned circuit on the head board may vary by as much as 40% over the range. More serious, however, is the phase lag of 10−20 deg over this range.

The current signal readout scheme requires absolute phase orthogonality between the I & Q demodulated signals of 1 deg. and stringent requirements on RF phase wander. In particular, once the relative RF/LO phase has been set, it cannot be allowed to drift by more than 5 deg. over the full range of power. The reason for this being that the error signals corresponding to various linearly independent length degrees of freedom can only be discriminated by their RF phase.

During detection mode operation, the seriousness of this effect is less, since with the entire IFO locked and the laser power stabilized, the fractional power fluctuations will be small. However, during the commissioning phase, the laser power varies due to alignment fluctuations and is also intentionally varied for diagnostic purposes. More importantly, during lock acquisition, the power at the various ports of the IFO will change by large amounts. In order to retain good discrimination of signals, the RF phase response should be a fairly flat function of power.

3 The Measurement

3.1 Required Materials/Intruments

The following is a list of the equipment necessary to conduct the measurement:

- > 500 mW Nd:YAG laser (e.g. Lightwave Electronics NPRO xxx) (1)
- ¼ wave plate (1)
- Polarizing cube beamsplitter (1)
- RF network analyzer (e.g. HP 4195A) (1)
- Broadband amplitude modulator (AM) (e.g. New Focus 4104)

In addition, the setup will require various lenses and mirrors to get the beam size correct through the AM and at the LSCPD face. A recommended accessory is a ½ wave−plate/cube polarizing beamsplitter (PBS) combo to adjust the power incident on the LSCPD in a way that does not influence the laser.

3.2 Experimental Setup

Shown below is a schematic of the setup on an optical table at MIT and which was also repeated at LHO.

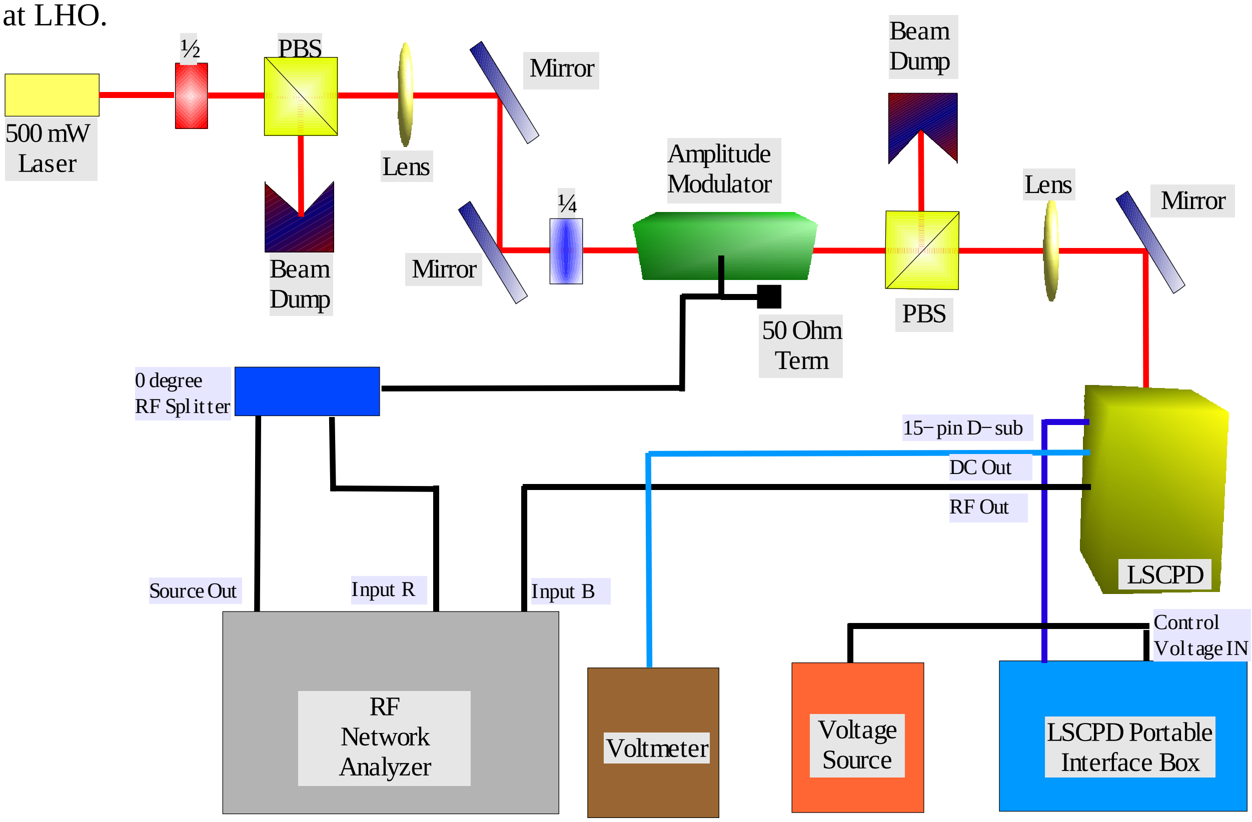


Fig. 1: Conceptual Drawing of the tabletop setup to characterize the RF Response

3.3 Measurement Procedure

The setup of the ¼ wave−plate/AM section should be such that with 0 volts on the AM, 50% of the incident power goes to the beam dump on the PBS immediately following. This is done by rotating the ¼ wave−plate so as to ’bias’ the polarization. The light incident on the PBS is now in the linear regime. So the power incident on the LSCPD has a component at the modulation frequency who’s amplitude is proportional to the level of the modulation drive. For the New Focus 4104, when coupled with a 50 Ohm terminator, a drive level of approximately −5 dBm is sufficient.

The lenses should be chosen so as to ensure a small beam size through the AM (~0.1 mm dia. is good for the 4104) and that the beam diameter on the PD is 0.6 mm +/− 0.5 mm.

The first step is to operate the Network Analyzer in the ’network’ mode and take a swept−sine response from 10−100 Mhz. With ~10 mW incident on the PD, the resulting response will allow one to calculate all useful parameters of the resonant circuit (@ 1xω) and the notch (@ 2xω), where ω is the relevant modulation frequency. The frequencies and Q’s of these should be verified to correspond to spec for that particular PD.

Next we evaluate the performance of the PD. Adjust the sweep range to a few Mhz around the resonant frequency and measure the magnitude and phase of the response. Also note the DC Out voltage.

In a typical configuration, the DC transimpedance of the circuit is 50 Ohms, so assuming a PD responsivity of 0.71 A/W, the 10 mW of power should give ~350 mV.

This measurement should be repeated with varying power, with the 3 parameters of Vdc, RF mag, and RF phase, recorded for each value of the power. The number of points which are required to get an accurate picture of the response depends on the particular PD, but typically 20 pts. is sufficient, between 10 to 150 mW or from 0.35 to 5.3 Vdc.

The following are plots of data taken in this manner from a "typical" LSCPD. The first two show data taken as explained above. The third will be explained in the section 4.

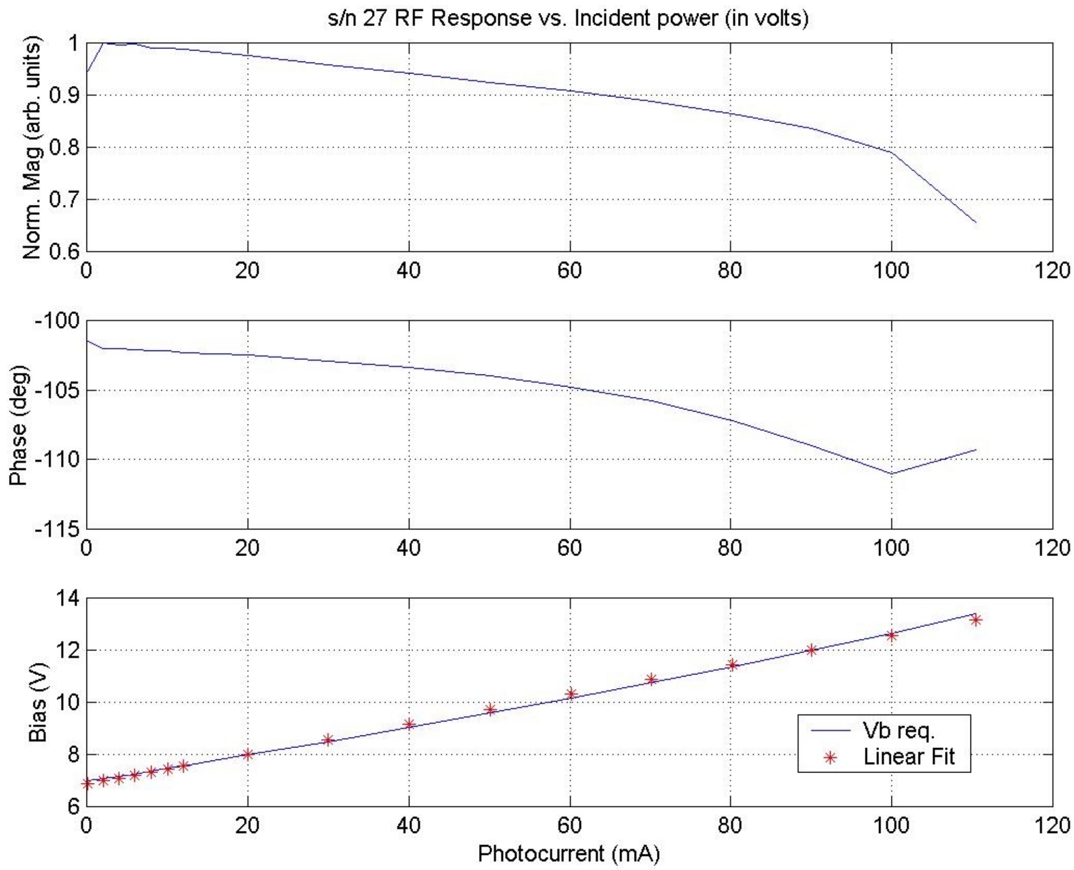


Fig. 2: Data from the initial test of LSCPD s/n #27.

4 Bias Feedback Tuning

There is an input to the LSCPD box, referred to as ’Vc Adjust’ which allows one to sum into the bias voltage (Vb) on the PD’s cathode. By adjusting this voltage *by hand* as the incident power is increased, the phase of the response can be easily kept to within a small fraction of a degree. By repeating the above measurement, but this time tweaking Vb via Vc to keep the phase flat and recording Vc, the positive feedback required can be determined.

The next step is to adjust the circuit to apply the correct positive feedback. One can see from the LSCPD schematic that a circuit has already been implemented to supply a positive feedback to Vb. In fact, the bias voltage (Vb) can be represented by the formula:

$$Vb = Vi + Idc\,(R22A + R22B)\,(R12/R21) + Vc$$

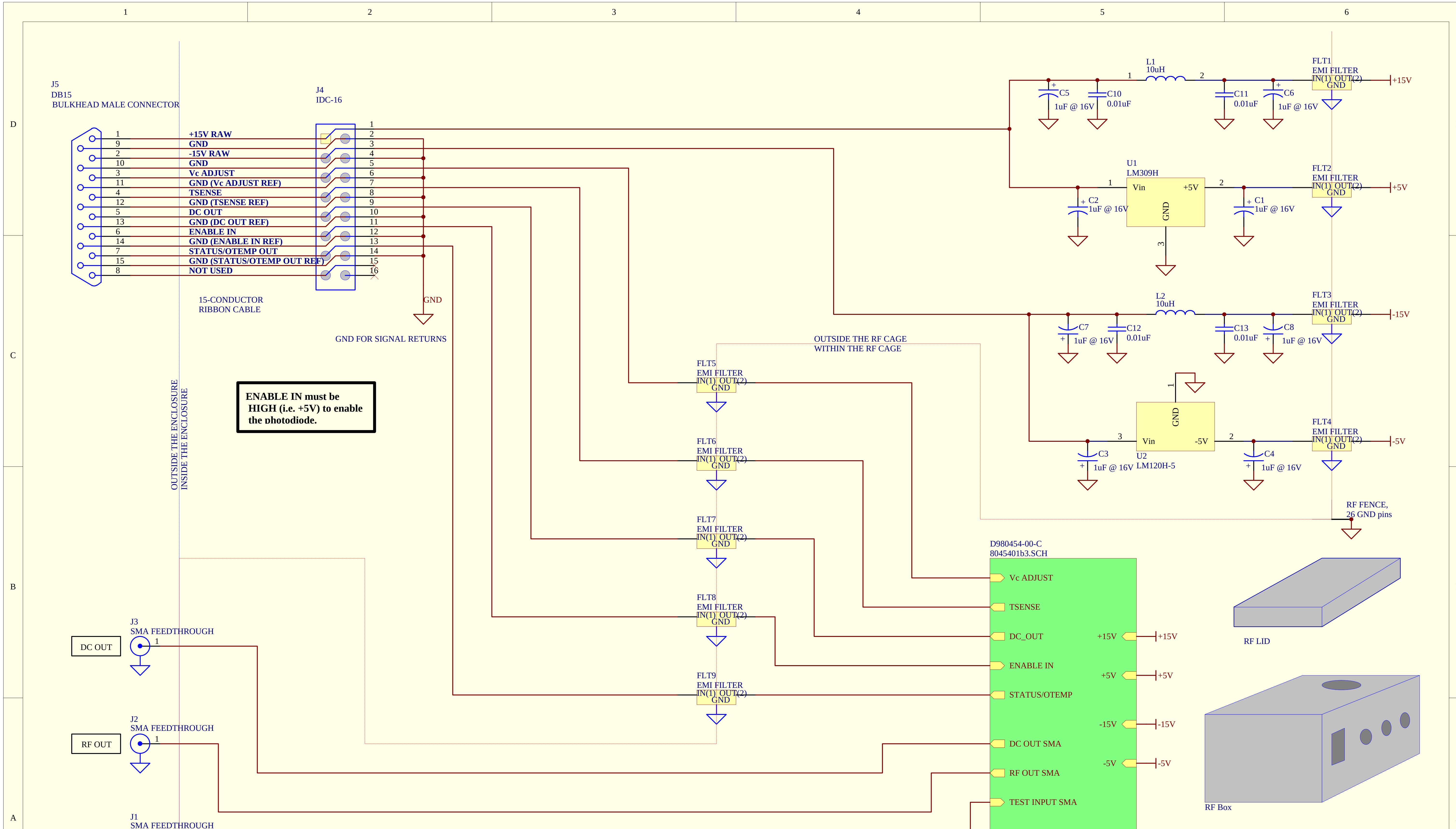
where Vi is the initial (no photocurrent) bias voltage. This can be taken to be 7V.

So the third plot in Fig. 2 shows data representing what Vb was required to correct that particular diode. A linear fit extracts from the data the additional feedback required. Then changing the value of R21, changes the gain in the feedback loop.

After doing this, the measurement of section 3 should be repeated in order to determine that:

1. Nothing is broken.
2. The required phase flatness has been achieved.
3. The final broadband frequency response MUST be recorded and archived for every single LSCPD as this will be used in detector calibration.

This last step is vital not only for the listed reason but also to ensure that there has been no significant change in the bandpass or bandstop frequencies. Changing the bias voltage across the PD may change the resonant response of the tuned circuit whether it is by changing the capacitance of the PD or through some other mechanism. Typically the phase flatness which is achieved amounts to a shallow phase lag of ~5 deg. as one ramps the power from 10−150 mW.



Date Last Modified: *7-Jan-00*

Title: ***LSC Photodiode***

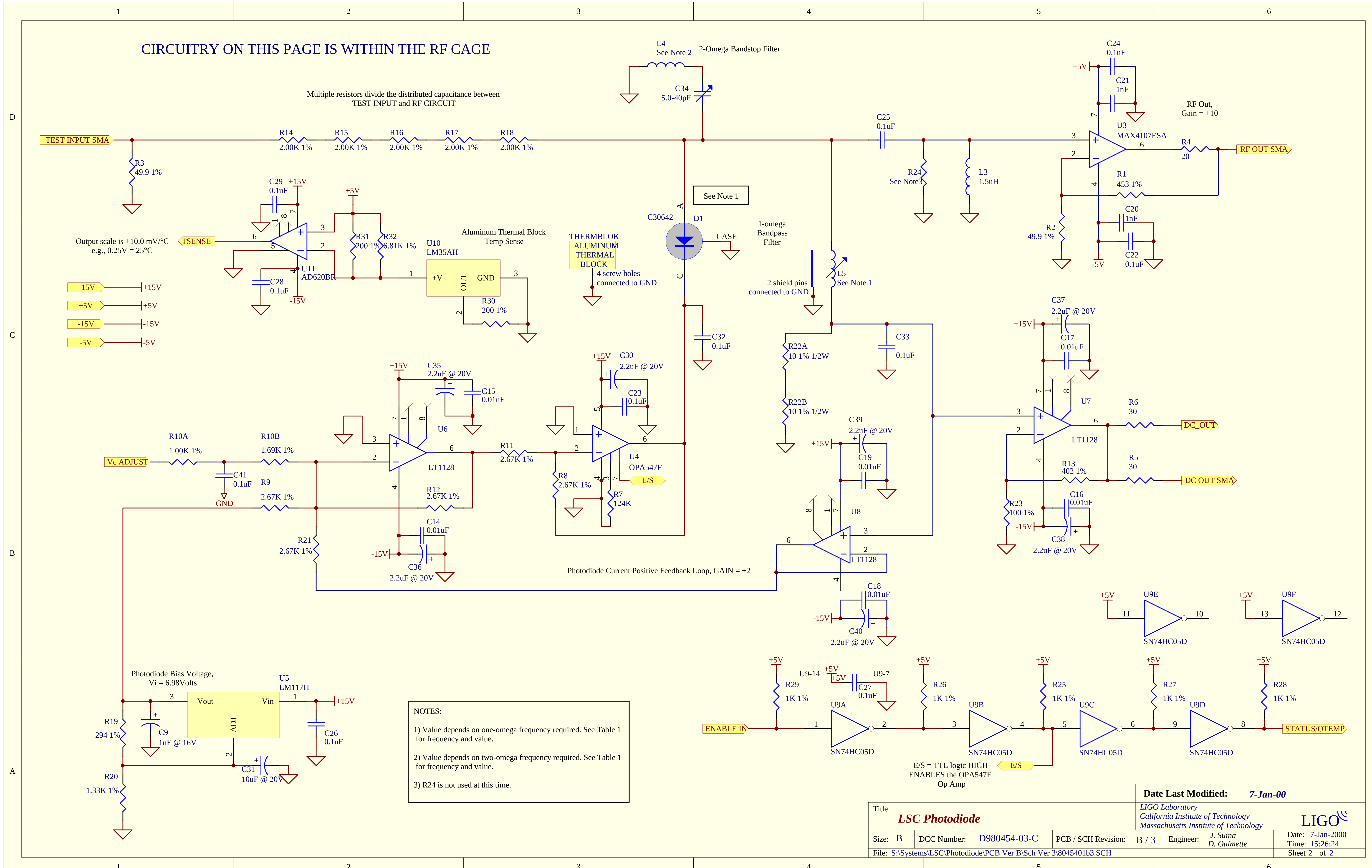
LIGO Laboratory
California Institute of Technology
Massachusetts Institute of Technology

LIGO

Size: B | DCC Number: D980454-03-C | PCB / SCH Revision: B / 3 | Engineer: *J. Suina, D. Ouimette*

Date: 7-Jan-2000
Time: 15:26:09
Sheet 1 of 2

File: S:\Systems\LSC\Photodiode\PCB Ver B\Sch Ver 3\8045400b3.prj


CIRCUITRY ON THIS PAGE IS WITHIN THE RF CAGE
Multiple resistors divide the distributed capacitance between TEST INPUT and RF CIRCUIT
TEST INPUT SMA
R3 49.9 1%
R14 2.00K 1%
R15 2.00K 1%
R16 2.00K 1%
R17 2.00K 1%
R18 2.00K 1%
L4 See Note 2
2-Omega Bandstop Filter
C34 5.0-40pF
C25 0.1uF
R24 See Note3
L3 1.5uH
C24 0.1uF
C21 1nF
+5V
U3 MAX4107ESA
RF Out, Gain = +10
R4 20
RF OUT SMA
R1 453 1%
R2 49.9 1%
C20 1nF
C22 0.1uF
-5V
See Note 1
C30642
D1
CASE
1-omega Bandpass Filter
L5 See Note 1
2 shield pins connected to GND
C32 0.1uF
C29 0.1uF
+15V
U11 AD620BR
C28 0.1uF
-15V
Output scale is +10.0 mV/°C e.g., 0.25V = 25°C
TSENSE
R31 200 1%
R32 6.81K 1%
Aluminum Thermal Block Temp Sense
U10 LM35AH
+V OUT GND
R30 200 1%
THERMBLOK
ALUMINUM THERMAL BLOCK
4 screw holes connected to GND
+15V
+5V
-15V
-5V
R22A 10 1% 1/2W
R22B 10 1% 1/2W
C33 0.1uF
C37 2.2uF @ 20V
C17 0.01uF
U7 LT1128
R6 30
DC_OUT
R13 402 1%
R5 30
DC OUT SMA
R23 100 1%
C16 0.01uF
C38 2.2uF @ 20V
C35 2.2uF @ 20V
C15 0.01uF
U6 LT1128
R10A 1.00K 1%
R10B 1.69K 1%
Vc ADJUST
C41 0.1uF
GND
R9 2.67K 1%
R12 2.67K 1%
R11 2.67K 1%
R21 2.67K 1%
C14 0.01uF
C36 2.2uF @ 20V
C30 2.2uF @ 20V
C23 0.1uF
U4 OPA547F
E/S
R8 2.67K 1%
R7 124K
C39 2.2uF @ 20V
C19 0.01uF
U8 LT1128
C18 0.01uF
C40 2.2uF @ 20V
Photodiode Current Positive Feedback Loop, GAIN = +2
U9E SN74HC05D
U9F SN74HC05D
Photodiode Bias Voltage, Vi = 6.98Volts
U5 LM117H
+Vout Vin ADJ
R19 294 1%
C9 1uF @ 16V
C31 10uF @ 20V
C26 0.1uF
R20 1.33K 1%
NOTES:
1) Value depends on one-omega frequency required. See Table 1 for frequency and value.
2) Value depends on two-omega frequency required. See Table 1 for frequency and value.
3) R24 is not used at this time.
ENABLE IN
R29 1K 1%
U9-14
U9-7
C27 0.1uF
U9A SN74HC05D
R26 1K 1%
U9B SN74HC05D
R25 1K 1%
U9C SN74HC05D
R27 1K 1%
U9D SN74HC05D
R28 1K 1%
STATUS/OTEMP
E/S = TTL logic HIGH ENABLES the OPA547F Op Amp
Date Last Modified: 7-Jan-00
Title LSC Photodiode
LIGO Laboratory
California Institute of Technology
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LIGO
Size: B
DCC Number: D980454-03-C
PCB / SCH Revision: B / 3
Engineer: J. Suina D. Ouimette
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File: S:\Systems\LSC\Photodiode\PCB Ver B\Sch Ver 3\8045401b3.SCH
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