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ISC LSC RF Photodetector Test Procedure:

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1 Introduction

This document describes the testing of the LSC RFPD photodetectors used in the aLIGO ISC subsystem. A summary of the characteristics of this detector are available in [T1100402](#). The schematics for the LSC detector can be found in [D1101124](#). A list of ISC detectors (RF & DC) can be found in [T1000264](#).

This procedure relies upon a familiarity with the complex nature of this circuit and the techniques of network analysis, modulated laser light sources, and shot noise limited sensitivity measurements. Minimal instructions are included in this procedure to avoid lengthy and complex tutorials.

All final data results are recorded in [T1200334](#)

This procedure is broken into the following sections:

- **Serial number** – Unique identification of the unit is recorded in the form of the serial number if the internal circuit board and associated schematic details
- **DC checks** – Current draw into the detector and verification of all internally regulated voltages
- **DC path transimpedance** – A measurement of the DC transimpedance of the DC path of the RFPD.
- **DC path singularities** – A measurement of the zero and pole frequencies of the whitening filter if present in the DC readout path
- **DC path output noise** – Used in conjunction with other circuit parameters to estimate the shot noise limited sensitivity of the DC readout path
- **Notch tuning** – Adjustment of RF notch frequencies
- **Notch rejection ratios** – Measurement of RF notch depths
- **RF transimpedance** – A white-light based measurement of the RF transimpedance
- **Shot noise limited input sensitivity** – Verification that the RF noise performance is within design limits
- **Test input transconductance** – A measurement of the RF transimpedance of the test input path
- **Test switch isolation** – A measurement of the isolation in dB for the ON/OFF states of the RF test switch

2 Product Perspective

As shown in Figure 1, the LSC RFPD is mounted in a metal housing with all connections on the top surface. This includes 4 SMA connectors: two for the RF outputs, one test input and one test output. Power, control lines and the DC output are on the 9-pin D-sub connector.

Figure 1



3 D-Connector Pinout

| 9 pin D Pin | Function |
|-------------|---------------------|
| 1 | DC Readout Positive |
| 6 | DC Readout Negative |
| 2 | DC Power Positive |
| 7 | Ground |
| 3 | DC Power Negative |
| 8 | Ground |
| 4 | RF Test Relay |
| 9 | Ground |
| 5 | No Connect |

4 Serial Number Data

Record the serial number and relevant schematic D-number/revision in [T1200334](#)

5 DC Checks

Record the total circuit board quiescent current draw and regulated voltages in [T1200334](#). Use caution in believing the digital readouts of laboratory triple output power supplies. Their meters are not highly accurate. When in doubt, use a multimeter on the appropriate scale in series with the supply to be measured.

6 DC Readout Path

Using a handheld current calibrator, inject 1mA DC into the anode circuit of the RFPD through a 100 Ω resistor. By observation of the DC voltages present at the BNC and differential DC readout terminals on the 9 pin D-connector, calculate the transimpedance of the DC readout chain, Z_{dc} by:

$$Z_{dc} = \frac{V_{out}}{0.001A}$$

Record each result in [T1200334](#).

Next, using an SR785 Dynamic Signal Analyzer, inject a 100mV signal into the anode circuit of the PD through a 100 ohm resistor. Measure the transfer function to the differential output at 1 Hz and 100 Hz. Compare them to Table 1

Table 1

| Frequency | Mag/Phase |
|-----------|--|
| 1 Hz | 18.7 dB +/- 0.5dB 56.1 degrees +/-5 degrees |
| 100 Hz | 27.6 dB +/- 0.5dB 1.3 degrees +/-5 degrees |

If the magnitude and phase is as indicated in Table 1, the circuit conforms to the design. Enter into [T1200334](#) the zero frequency of 0.2Hz, and the pole frequency of 2.4 Hz.

At the differential output DC readout pins, measure the differential noise voltage power spectral density with the photodiode element completely shielded from light. Calculate the inferred DC path shot noise limited sensitivity ($Ilim_{DC}$) and enter it into [T1200334](#). The factor of 2400 is the ideal gain from the PD current to the differential output. The actual gain may be slightly different.

$$Ilim_{DC} = \left[\frac{V_{rms}}{2400} \right]^2 \times \frac{1}{3.2 \times 10^{-19}}$$

7 Notch Tuning

The LSC photodetector circuit has series resonant RF notches that are tuned to allow amplification of some frequencies, while providing rejection at other frequencies. The notches are tuned by means of surface mounted RF trimmer capacitors on the photodetector PCB. Table 2 shows which capacitor to tune for each notch frequency.

Using a laser capable of RF AM modulation, and an RF network analyzer, perform a frequency sweep from the photodiode to the RF test output connector on the top surface of the photodetector housing. The RF test relay will have to be activated to connect the test path circuitry to the photodiode readout circuit. Either use the LSC RFPD interface chassis - which has a front panel test switch (D1102079) - or connect pin 4 to pin 9 on the 9 pin D-sub present on the top of the photodetector housing. This will activate the test relay.

Table 2, Notch Adjustment Frequencies

| Notch Frequency | Adjustment Capacitor |
|-------------------------|----------------------|
| F low | C38 |
| F hi | C15 |
| Notch 1 (lowest freq.) | C4 |
| Notch 2 | C10 |
| Notch 3 | C17 |
| Notch 4 (highest freq.) | C26 |

After adjusting each notch, record into [T1200334](#) the tuning frequencies as indicated.

8 Notch Rejection Ratios

With the series resonant portions of the circuit tuned to the appropriate frequencies, a measurement can be performed to establish the ratio of the gain at the desired readout frequencies to the gain at the undesired frequencies corresponding to the rejection notches.

Using a laser capable of RF, AM modulation and an RF network analyzer, perform a frequency sweep from the photodiode to the RF HI and RF LOW output connectors on the top surface of the photodetector housing. Use the delta marker function to record the difference between each notch and the relevant RF operating frequency of RF HI and RF LOW. Record the results in [T1200334](#).

9 RF Transimpedance Measurement

Illuminate the photodiode with white light (as generated by a shot noise limited source such as an incandescent bulb) to generate the photocurrent. Use an RF spectrum analyzer to measure the RF power spectral density at the readout frequency associated with the output under test. A low noise RF pre-amplifier (gain ~20dB) is useful to boost the signal to a comfortable level. Be sure the measurement is not electronically noise limited by careful attention to signal levels.

Establish a photocurrent between 6mA and 10mA. On an RF spectrum analyzer, observe the RF power spectral density present at the operating frequency of the detector, and also make note of the DC photocurrent. Using the Microsoft Excel worksheet available in the DCC as an attached document to this document, enter the data as needed to calculate the transimpedance, Z_{RF} which is derived from the following formula:

$$Z_{RF} = \sqrt{\frac{V_{rms}^2 I_{DC}}{3.2 \times 10^{-19}}}$$

Enter the transimpedance in the appropriate spot on [T1200334](#).

10 Shot Noise Limited Sensitivity

The shot noise limited sensitivity will characterize the minimum useful optical signal level below which the photodetector will be limited by electronics noise. Using the Microsoft Excel worksheet available in the DCC as an attached document to this document, enter the data as needed to calculate shot noise limited sensitivity. In general, the formula used is:

$$I_{lim_{rf}} = I_{DC} \times \frac{V_{dark}^2}{V_{light}^2}$$

Where I_{DC} is the DC photocurrent associated with the illuminated diode, and V_{light} is the RF voltage spectral density as derived from a spectrum analyzer reading at the detector fundamental operating frequency

Record the resulting shot noise limited sensitivities in [T1200334](#).

11 Test Input Transconductance and Isolation

An RF test input is provided for modulation, diagnostics, and RF notch tuning. The RF test input circuitry is implemented by use of a common-base RF transistor current source. This section measures the gain of the test input at each of the two operating frequencies, RF HI, and RF LOW.

Using an RF network analyzer, with the internal RFPD test switch enabled, take a transfer function measurement in through the test input and out of each of the two main RF outputs. Record the dB magnitude of each transfer function, Mag_{on} at the operating frequency of the respective output with the test input switch enabled. While observing the magnitude of the transfer function with the test switch on, disable the test switch and note the dB magnitude of the transfer function, Mag_{off} with the test switch disabled. Calculate the test input transconductance C_t by use of the linear magnitude of the transfer function, Mag_{on} divided by the calculated average transimpedance, Z for that RF path as recorded in section 9.

$$C_t = \frac{10^{\left(\frac{Mag_{on}}{20}\right)}}{Z}$$

$$Isolation = Mag_{on} - Mag_{off}$$

Record the resulting transconductance and test switch isolation in [T1200334](#) for each of the two RF frequencies of operation.