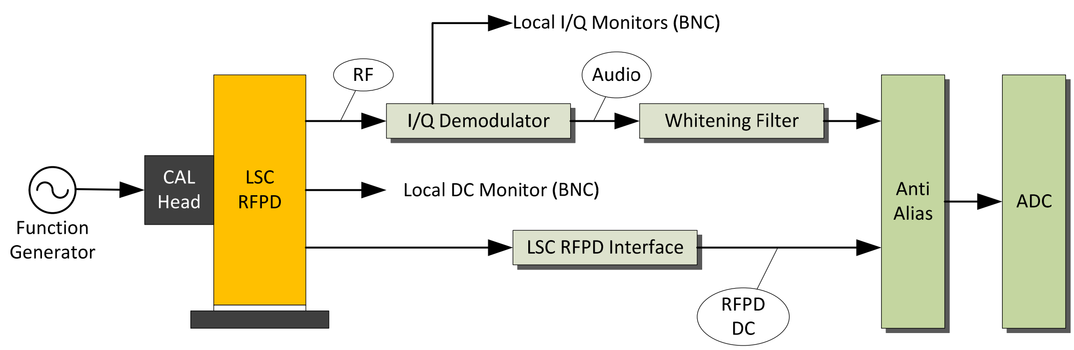
Notes on RFPD Signal Chain Measurements
R. Abbott
22 March, 2013

1. Overview

The following note aims to answer two questions as related to an RF photodetector signal chain: Is what I see in Data Viewer reasonable, and what are the expected signal levels at arbitrary points of interest in the RF signal detection chain? The example given is that of an LSC signal chain, but the same principles are applicable to ASC signal chains. A dedicated calibration head (LIGO-T1200396) is used to inject AM modulated light into the RFPD. An RF signal generator provides the modulation signal source. The RF modulation frequency is adjusted to be within a few Hz of the fixed LIGO modulation frequency associated with the signal chain under test such that the beat note is easily observed with the EPICS Data Viewer. A beat note is generated when the RF output of the RFPD is mixed with the associated local oscillator in the RF I/Q Demodulator. The ability to accurately predict the magnitude of the digitized beat note will depend on knowledge of the signal gain associated with each block in the signal path.

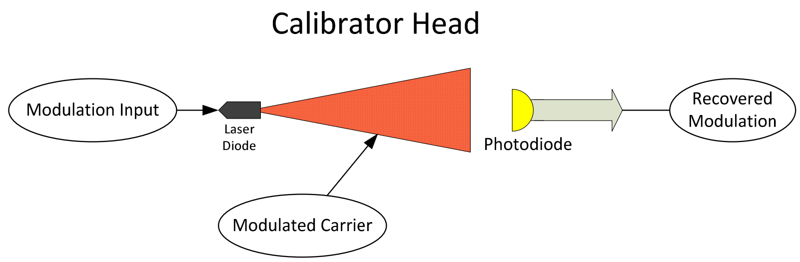
Figure 1 Measurement block diagram



2. Calibration Head –

The laser calibration head injects a 4mW, 980nm optical carrier into the photodiode of the LSC RFPD. The optical carrier is AM modulated by the function generator shown above. The laser calibrator head has a highly divergent (up to 30 degrees in one axis) optical output beam characteristic. Adjustments to calculations must be made to compensate for light spillage as the laser beam is likely to be larger than the active area of the photodiode.

Figure 2 Calibrator Head



3. Calibrating the Laser Calibration Head (LCH)

In order to calibrate the LCH, one must have an accurate measurement of the total optical power emitted by the head, and be able to quantify the AM modulation. The large aperture of typical optical power meters will capture the entire beam profile provided the measurement head is physically close to the highly divergent LCH laser diode. The laser diode current in the LCH has been adjusted to produce an optical output of 4mW at 980nm. There is no data on how stable this number is over time, so periodic re-measurement is encouraged (if you do this, please note the measured power in the e-traveler associated with the LCH serial number).

In order to measure the AM modulation transfer function, a photodetector with known AC and DC transimpedance is required. A New Focus model 1811 or a LIGO LSC RFPD can be used. The LIGO RFPD transimpedances can be obtained from the datasheet associated with the serial number on the RFPD head. The diode responsivity for the LIGO LSC RFPD is 0.67 A/W. The New Focus transimpedance data are:

Table 1 New Focus 1811

Parameter	Value
AC Transimpedance	40k Ω
DC Transimpedance	1k Ω
Diode Responsivity at 980nm	0.6 A/W

4. Example Modulation Transfer Function Calculation using LSC RFPD S1203919 test data

Table 2 Parameters for Example Calculation

Parameter	Value
Photodetector RF Transimpedance	341Ω
DC Transimpedance	100 Ω
LSC Diode Responsivity @ 980nm	0.67 A/W
Total Output Power from LCH	4mW
RF Input drive signal into LCH	0.1 Vp-p
Measured RF Output of Photodetector at the input to the RF I/Q Demodulator	180 mVp-p

Equation 1

$$K_{MOD}=\frac{0.18\,V_{pp}}{(0.67\,A/W)\cdot(341\,V/A)\cdot(0.1\,V_{pp})}=7.9\times10^{-3}\,W/V$$

Assuming 4mW of light was actually incident on this detector, we would have expected more DC output given the responsivity of the diode. This is due to the fact that the active area of the photodetector is smaller than the LCH beam spot. The correction factor can be calculated by first calculating the anticipated full light (4mW) DC output using the diode responsivity (0.67A/W) at 980nm:

Equation 2

$$V_{Full}=(0.004\,W)\cdot(0.67\,A/W)\cdot(100\,V/A)=0.268\,V$$

By taking the ratio of the anticipated DC photocurrent monitor voltage of 0.268 VDC, and the measured DC photocurrent monitor voltage of 0.165 VDC, a factor of 1.62 exists which must be applied to the previous result to account for the total power fluctuation present at the output of the LCH as a function of the input RF modulation drive. The full corrected calculation is now:

Equation 3

$$K_{MOD}=\frac{(0.18\,V_{pp})}{(0.67\,A/W)\cdot(341\,V/A)\cdot(0.1\,V_{pp})}\cdot\frac{0.268}{0.165}=12.8\times10^{-3}\,W/V$$

Given a modulation voltage of 1 Vp-p, one can expect a total power fluctuation of 12.8 x 10^{-3} watts p-p at the output of the LCH (Matt Evans and Lisa Barsotti measured 13 mW/V using an 1811 diode). To use this modulation term for a given photodetector one would have to adjust for the amount of light actually incident on the active area by correcting for the observed DC photocurrent vs. the anticipated calculated DC photocurrent.

Equation 4

$$K_{MODACTUAL}=K_{MOD}\cdot\frac{DC\,Out_{Meas}}{DC\,Out_{Calc}}\cdot\frac{0.165}{0.268}=7.9\times10^{-3}\,W/V$$

5. Signal Chain Calculations

With the modulation characteristics of the LCH known, it is now possible to use the calibrator to check out the LSC signal chain as shown in Figure 1. First the anticipated RF output can be calculated. Using the modulation gain obtained in Equation 4, we obtain the following:

Equation 5

$$V_{RFpp} = (0.1V_{pp}) \cdot \left(7.9\times10^{-3}\,W/V\right)\cdot\left(0.67A/W\right)\cdot\left(341V/A\right)=180\ \ mV_{pp}$$

This precision of this inbred result is not surprising in that it's just a restatement of the calibration shown in Equation 1, but for other applications, only the RFPD RF transimpedance would be needed for a calculation. For the signal chain shown in Figure 1, the signal at the output of the RFPD propagates down a length of cable. The RF cable loss at the operating frequency (45 MHz) of the RFPD used in this example is approximately 1.6dB (a factor of 1.2 in signal attenuation). The measured RF in this example was taken at the end of this cable, with the result that the cable attenuation has been taken into account. One can expect that an RF measurement right at the output connector of the RFPD would be a factor of 1.2 higher than the far end of the cable.

The RF I/Q Demodulator has a nominal design gain of 11 from the RF input to the base band I or Q output as measured differentially at the output. Front panel monitors are provided for ease of measurement, but the gain from the RF input to the BNC monitor is one half that of the normal differential signal.

As measured at the BNC front panel monitors of the RF I/Q Demodulator, the 180 mVp-p RF signal is down converted to a baseband audio signal of amplitude:

Equation 6

$$V_{Audio} = 180\,mV_{pp} \cdot\ 5.5 = 990\,mV_{pp}$$

An in situ measurement of 1.02Vp-p was taken on the system in question

At the differential output of the RF I/Q Demodulator, the baseband demodulated audio signal will be 1.98Vp-p. Assuming the gain of the whitening filter is set to 1; this voltage will be applied to the ADC and converted to counts according to:

Equation 7

$$Counts = 1.98\,V_{pp} \cdot\ 1638\ \ Counts\,/\,V = 3243\,Counts_{pp}$$

An in situ measurement of 3400 Counts p-p was measured on the system in this example.

The BNC DC output of the RFPD in this example was 165 mVDC. This was confirmed to result in 538 counts after application of the gain factor of two associated with the differential signal transmission.

6. Conclusions

Using the ISC Laser Calibration Head (LHC) coupled with knowledge of the RFPD transimpedance at the RF operating frequency of the signal chain in question, predictions can be made that will allow reasonable verification of signal levels at all points of interest. These verifications, while fairly crude, eliminate most common sources of gross error. While these measurements are specific to the 980nm light used in the calibrator head, a scaling factor of 1.15 can be expected based on the higher responsivity to 1064nm light for the LSC Photodetector C30642G photodiode. The primary function of this procedure is to be able to confidently ascertain whether or not the gain of a particular signal chain is correct. The procedure achieves this goal.