An analysis of aLIGO PD circuit

2023-06-24

Abstract

A numerical analysis of the noise in LIGOs photodetector demodulation circuit.

Contents

1 Introduction

This post builds on a couple of earlier posts of mine, LIGO modulation and RLC filters. In this post we will look into the Laser Interferometer Gravitational-Wave Observatory (LIGO)'s photodiode circuit and analyze its noise performance.

The actual circuit in use at the moment is shown in Fig. 1, and we will refer to it as *v5* in the following pages as it is the version number.

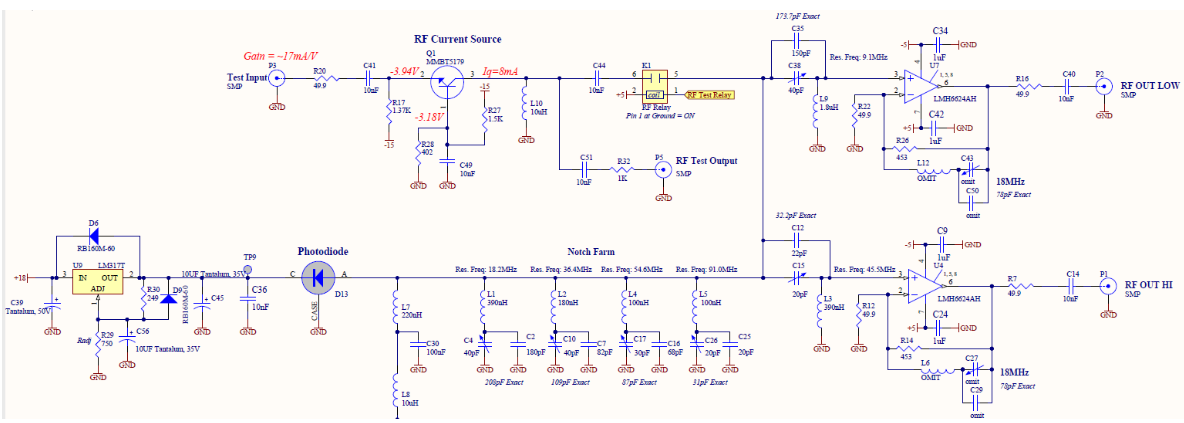

Figure 1: The actual amplifier circuit used in [the current set up.](https://dcc.ligo.org/LIGO-D1101124/public)

Let us take a closer look at the photodiode bias circuit as shown in Fig. 2. The diode is under reverse bias, and it will behave as a current source when exposed to light.

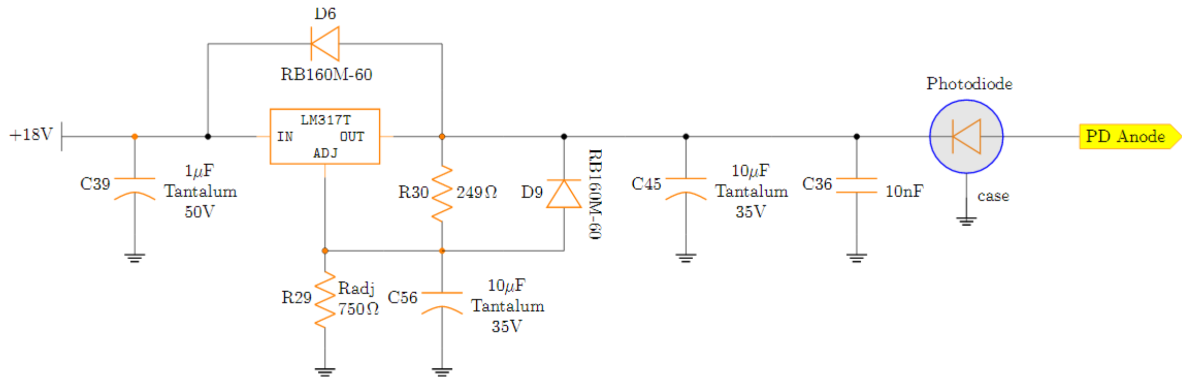

Figure 2: This voltage regulator circuit applies reverse bias to the photo diode.

The output voltage is set to 5V via every electronics hobbyist's favorite LM317T voltage regulator with some reverse bias protection. Note the two parallel capacitors in the output, 10μF and 10nF. The 10nF is a ceramic capacitor which is used to reduce to equivalent serial resistance at higher frequencies to dampen possible oscillations in the output voltage.

The anode of the phododiode is fed into a farm of fine-tuned notches as in Fig. 3.

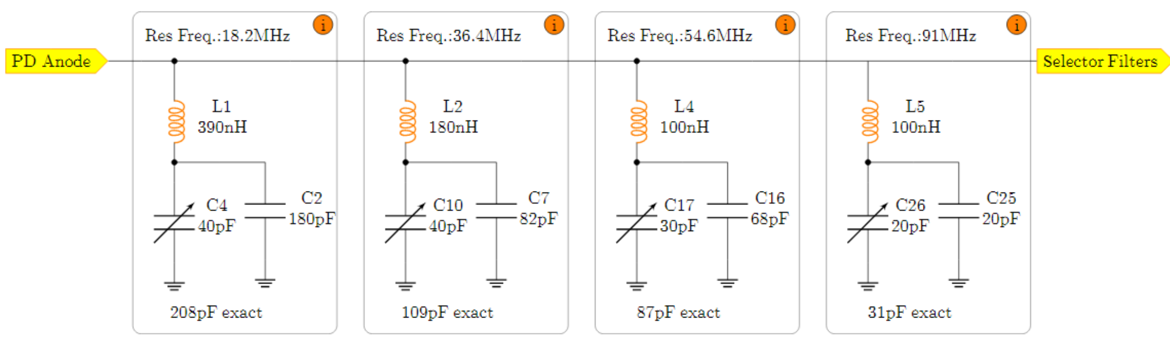

Figure 3: Notch farm to remove various harmonics.

Each block is tuned such that the natural frequency $1/\sqrt{LC}$ is around the target frequency to be carved out. Hover over the info icon, , to see the corresponding Bode plot, and the coils to see their frequency response. In the Bode plot. we just use the series resistance along with the inductance. Skin depth effects and shunt capacitance are not included in the Bode plots. We will certainly include them later.

The selectors are shown in Fig. 4.

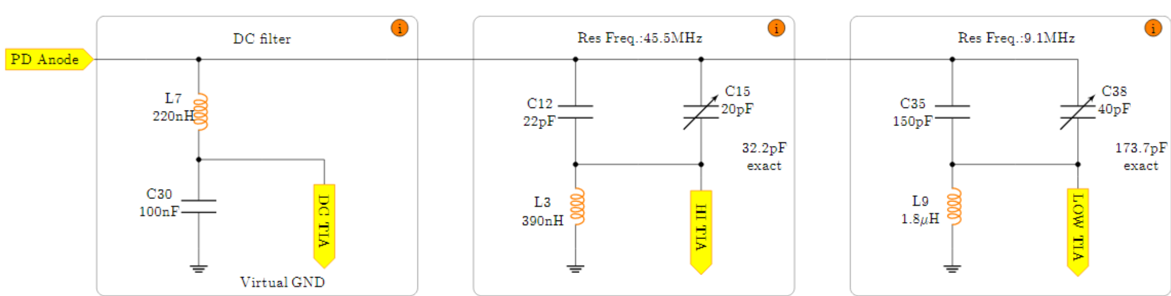

Figure 4: Selector filters.

The Trans-impedance amplifiers (TIA) are shown in Fig. 5.

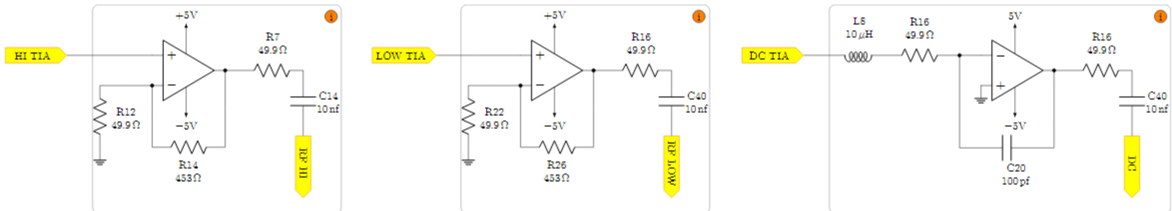

Figure 5: Basic inverting amplifiers with a gain of 10 for the RF outputs.

Table ?? shows the values of the filter elements.

We build this circuit in LTspice as shown Fig. 6 and simulate. The LTspice file can be found here.

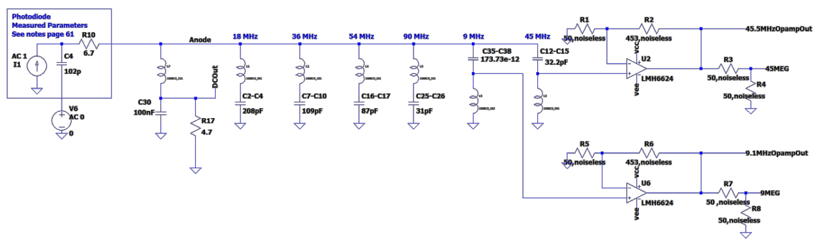

Figure 6: LTSpice circuit for simulation.

We can collect the LTspice simulation data via Python. It is convenient to measure the noise at the OPAMP output in terms its input current equivalent:

$$\text{Equivalent Current Noise} = \frac{(V/\text{gain})^2}{2e}, \tag{1}$$

where the gain is the transimpedance. We plot the noise spectrum in Fig. 7.

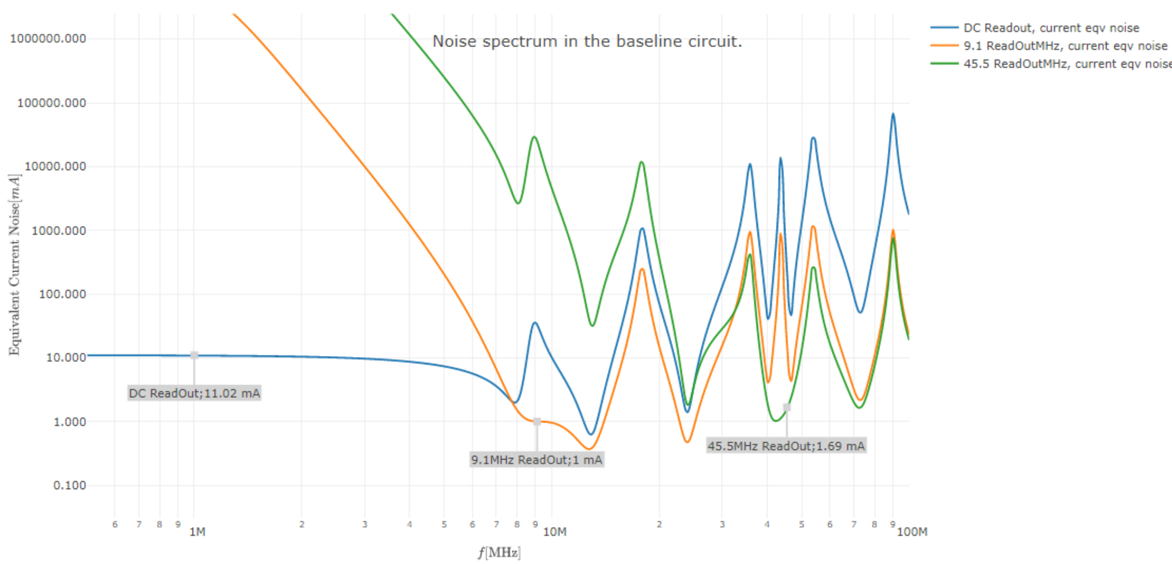

Figure 7: Baseline noise for the readout ports DC, 9.1MHz, and 45.5MHz. The critical values are marked on the plot.

The values annotated in Fig. 7 are the values we will want to reduce and they provide us with a benchmark. Can we beat these values and design a circuit with lower noise? That is exactly what we are going to do in a following post. I will include a link here when it is out.