40m RF PDs Upgrade

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Contents

1 Photodiode Noise Measurement

We want to measure the photodiode noise to check whether it is more or less than the expected shot noise. If it were more, it would mean that the electronics noise is dominating.

We need to have an estimate of the expected shot noise to compare with the measurement.

The shot noise of the photocurrent current goes like:

$$\delta i_{SN} = \sqrt{2 e i_\varphi \delta f} \tag{1}$$

where i_φ is the mean current produced at the photodiode, which is proportional to the incident power

$$i = \mathcal{R} P_{inc} \tag{2}$$

$\mathcal{R}$ is the *Responsivity* of the photodiode. The fluctuations in voltage at the DC output of the photodetector due to the shot noise are

$$\frac{\delta V_{SN}}{\sqrt{\delta f}} = \mathcal{T} \sqrt{2 e \mathcal{R} P_{inc}} \tag{3}$$

where $\mathcal{T}$ is the photodetector's *transimpedance* which is related to the photocurrent by

$$V = \mathcal{T} i. \tag{4}$$

Thus to calculate the expected shot noise level we need to know:

- Incident Power P_{inc}
- Transimpedance $\mathcal{T}$
- Responsitivity $\mathcal{R}$

INCIDENT POWER

We need a quite light source, only shot noise limited, at least at RF (our frequency range). We can use an incandescent light bulb.

The minimum power requirement can be estimated from the dark noise measurement. Th noise spectrum is composed by shot noise and dark nosie:

$$\hat{V} = \hat{V}_{SN} + \hat{V}_{DN}. \tag{5}$$

Basically, since we are going to compare $\hat{V}$ and $\hat{V}_{SN}$ we want the shot noise to be far enough from the dark noise $\hat{V}_{DN}$. How do we do it? We measure $\hat{V}_{DN}$ and we estimate I_{DC} so that $\hat{V}_{SN}(I_{DC}) \gg \hat{V}_{DN}$.

In order to guarantee that, it has to be:

$$V_{SN} = \mathcal{T}_{RF}\sqrt{2eI_{DC}} \gg V_{DN} \tag{6}$$

$$I_{DC} \gg \frac{1}{2e}\left(\frac{V_{DN}}{\mathcal{T}_{RF}}\right)^2 \tag{7}$$

$$V_{DC} \gg \frac{\mathcal{T}_{DC}}{2e}\left(\frac{V_{DN}}{\mathcal{T}_{RF}}\right)^2 \tag{8}$$

TRANSIMPEDANCE

We can estimate this looking at the schematic of the electronics of the photodetector.

Rana suggested of:

- making sure that the resistance parallel to ground in the DC path (the one just after L5 in the 40m PDs) be 10Ω
- making the opamp in the DC output path have a gain of 5

Consider the schematic in figure (1).

- Op-amp U8, after L5, is a buffer and feeds back to the photodiode the current that it produces. In this way the voltage drop at the terminations of the PD is kept constant to avoid the capacitance to change. The loop has a gain of 2 set by the ratio $R_{12}/R_{21} = 2$. The reason of the factor of 2 is purely empirical [Rana].
- Op-amp U6 is a summer. At the node between R_9, R_{12}, R_{21} the currents from the V_c *adjust*, the 15V bias supply and the feedback from U8 sum up.
- Op-amp U4 is just an amplifier with a gain of -1.
- The + connector of U8 shows infinite impedance: at DC, the current from L5 goes all through R_{22}.
- The voltage drop V at R_{22} is the same at the output of U8.
- The output of U7 is $V' = 5 \times V$ because $R_{13}/R_{23} = 5$.

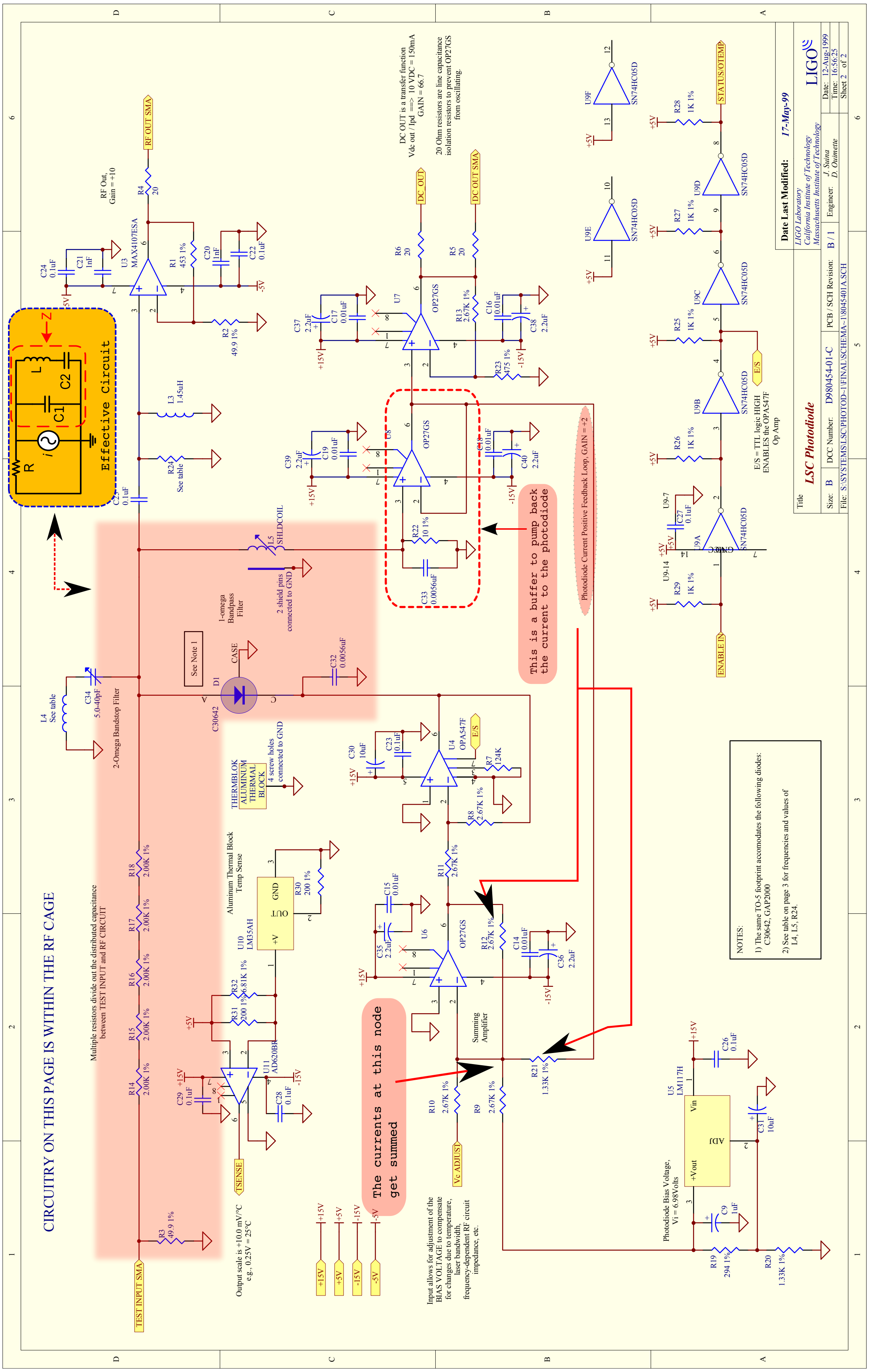

Figure 1: 40m RF PD readout electronics schematic

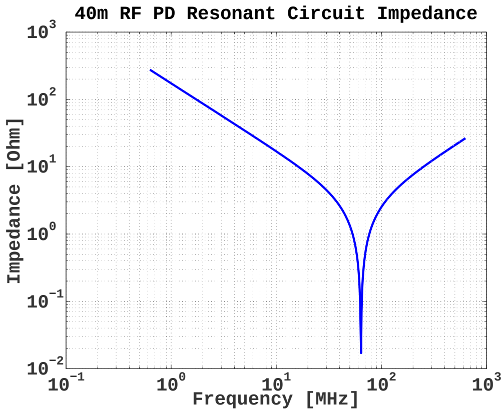

Figure 2: 40m RF PD Resonant Circuit Impedance

- The DC output $V_{out,DC}$ when measured with a scope of $R_s = 1M\Omega$ input impedance is

$$V_{out,DC} = R_s/(R_6 + R_s)V^{'} \approx V^{'} = 5 \times R_{22} i_{\varphi}.$$

- The little yellow box on top of the figure shows the effective circuit representing the parallel of the PD with L5 (the resistance of the PD is neglected). The inductance Z of the parallel $Z_{C1} \parallel (Z_L + Z_{C2})$ is

$$Z = \frac{1 - j\omega^2 LC_1}{j\omega \left[(C_1 + C_2) - \omega^2 LC_1 C_2\right]}. \tag{9}$$

and it is plotted in figure (2). The resonant frequency is at

$$\omega_{res} = \frac{1}{\sqrt{LC1}} \tag{10}$$

and depends only on the inductance and on the PD's capacitance. Whereas C2 determines the Q of the resonance.

- At the resoance $i_2 \ll i_1$: the photocurrent $i_\varphi = i_1 + i_2$ flows all toward L5.

- Including the PD's series resistance R_{PD}, the impedance would be:

$$Z^{'} = \frac{Z}{R_{PD} + Z} \tag{11}$$

- The transimpedance can be estimated by measuring the transfer function between the Test Input (see figure 1) and the RF output, as in figure 3:

$$T.F.(\omega_{res}) = \frac{R_L + R_O}{10 R_L} \frac{V_o}{V_i} \approx \frac{Z}{R_{14-18}} \tag{12}$$

where R_L,R_O are the output series impedance of the circuit and the input impedanc eof the network analyzer's port, respectively.

- $$\mathcal{T} = Z \approx T.F. \times R_{14-18} \tag{13}$$

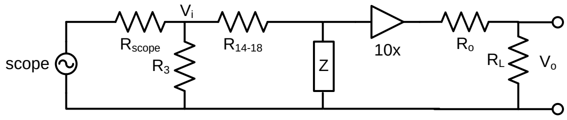

Figure 3: RF Transimpedance Measurement Setup.

RESPONSIVITY

We can measure the responsivity from the DC voltage at the output, once that we know the transimpedance:

$$\mathcal{R} = \frac{V_{DC}}{\mathcal{T} P_{inc}}. \tag{14}$$

Or we can use a reference PD as the New Focus 1611 to measure the beam power after a beam splitter.

2 RF PD Transfer Function Calibration

On the 40m PDs we can measure 3 types of tranfer functions:

- *Electronics*: between the Test In and the RF Out of the PD box
- *Optical*: between the modulation input of the AM laser and the RF Out
- *Model*: in LISO between the photocurrent from the PD and the RF Out voltage.

We would like to normalize them to the same reference input, i.e. the photocurrent from the PD.

- The Model TF does not change.
- The Optical transfer function has to be multiplied by the responsivity $\mathcal{R}$ of the PD an dby the amplitude of the power oscillations in the AM laser's beam when. The latter can be measured applying to the AM laser the same excitation provided by the network analyzer when it measures the TF.
- Electronics: we have to multiply by the transimpedence

$$T.F. = \frac{V_o}{V_i} = \frac{Z}{R_{14-18} + Z} \tag{15}$$

$$i_\varphi = \frac{V_i}{\mathcal{T}} \tag{16}$$

$$\frac{V_o}{i_\varphi} = \mathcal{T} \times T.F. \tag{17}$$