D1600314: IMC PDH Loop 200 kHz Low-pass Filter Proposal

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See Jeff Kissel's proposal (aLOG 28363) to add a 200 kHz pole to the fast path of the IMC PDH loop to improve FSS stability. The filter is intended to be used alongside a ∼2 dB reduction in gain. This daughter board is to be added in the fast path of the Common Mode Board (JP3/JP4).

Contents

1 Block Diagram

The daughter board will be integrated in the Fast Excitation path of the Common Mode Board.

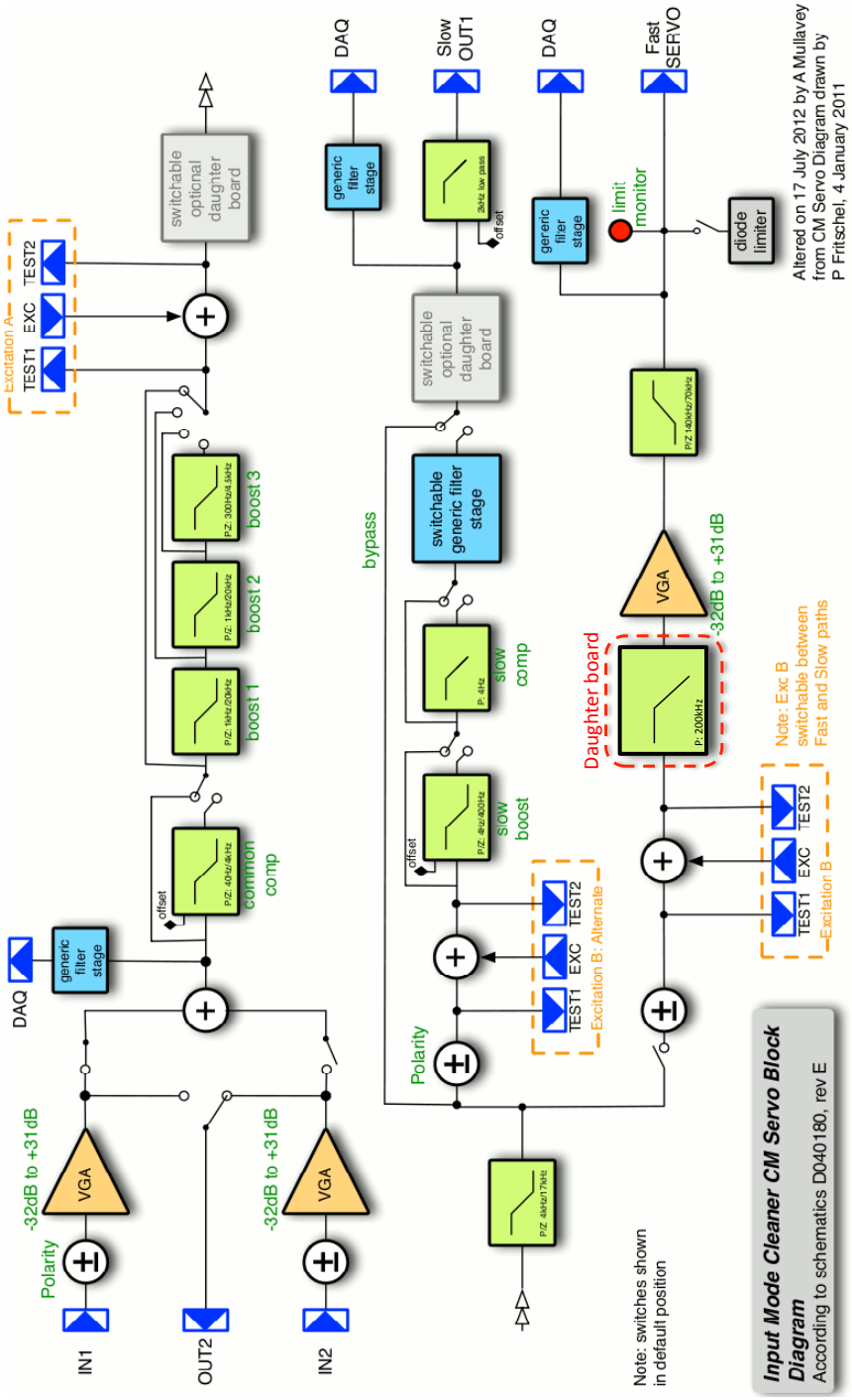

Figure 1: Block diagram of low-pass filter addition to fast path.

2 Schematics

2.1 Placement

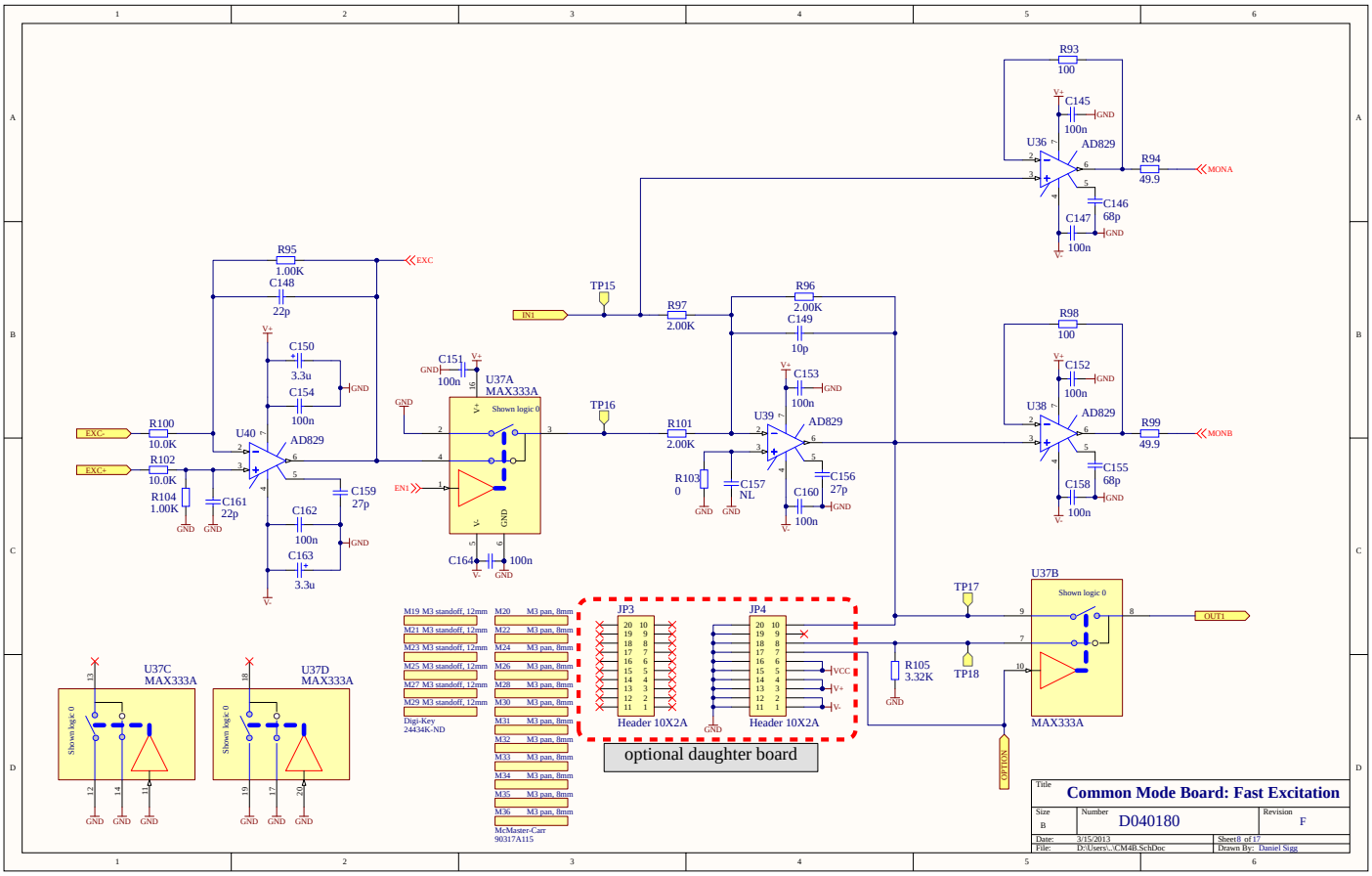

Figure 2: CM4B.SchDoc (page 8 of the Common Mode Board); location of daughter board placement.

2.2 Daughter Board Schematic

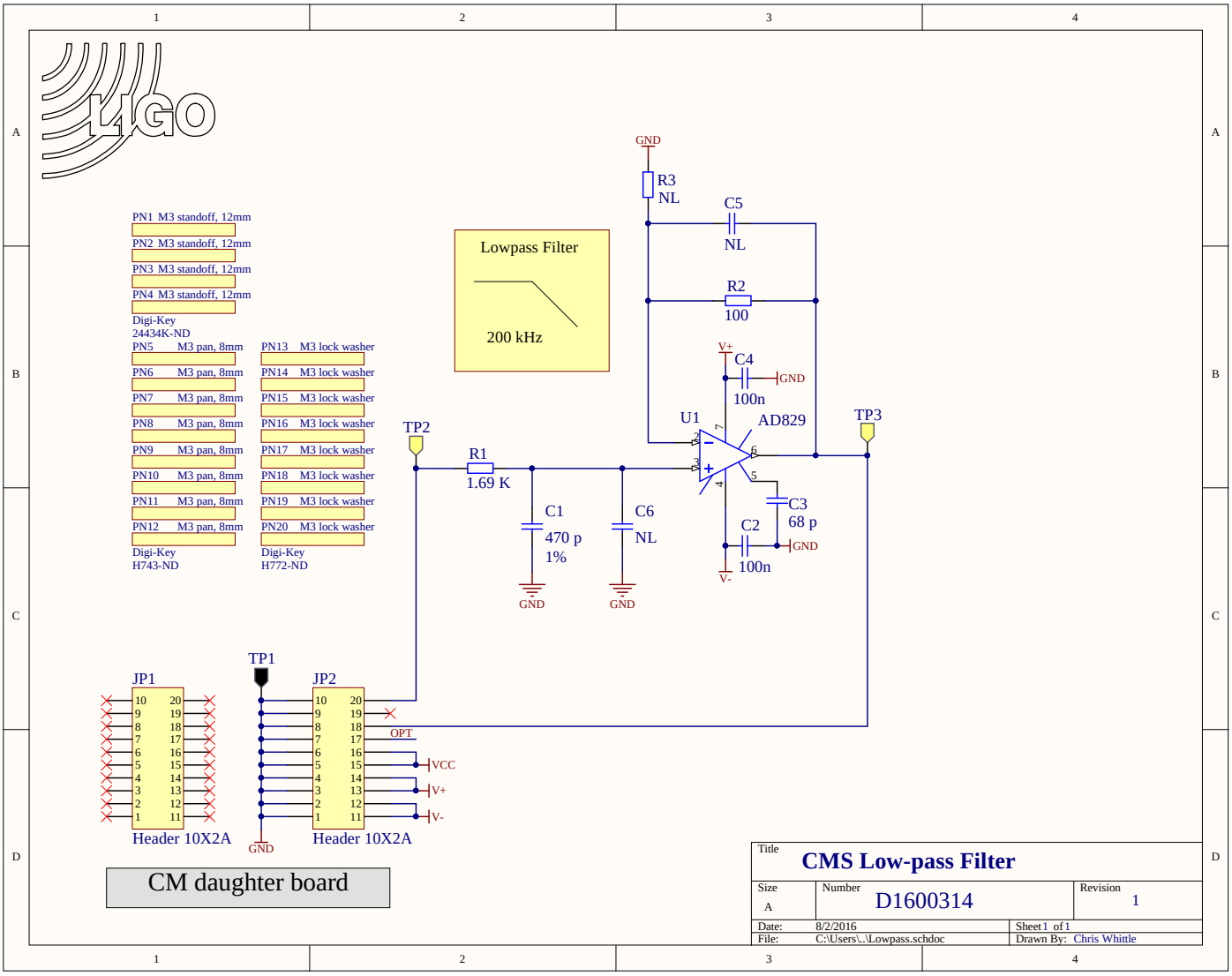

Figure 3: Schematic of daughter board low-pass filter.

3 Design

To add a single pole to the fast path, we have employed a first-order, non-inverting, low-pass filter. This was chosen over alternative active designs that invert the single or introduce additional poles. The passive RC components are buffered by the on-board unity gain amplifier and an adjacent op amp on the CMS board. A similar passive first-order design can be seen on the slow path of the CMB (4 Hz pole).

3.1 Bill of Materials

Table 1: Bill of materials for daughter board low-pass filter.

Quantity	Distributor	Part Number	Comment	Description	Designator	Footprint	Assembly Type
2	Digi-Key	5009K-ND	Testpoint	Testpoint, yellow	TP2, TP3	TP1	TH
1	Digi-Key	5006K-ND	Testpoint	Testpoint, black	TP1	TP1	TH
1	Digi-Key	RG20P1.69KBCT-ND	1.69 K	Resistor	R1	CR2012-0805	
1	Digi-Key	RG20P100BCT-ND	100	Resistor	R2	CR2012-0805	
4	Digi-Key	24434K-ND	M3 standoff, 12mm	M3 standoff, 12mm	PN1, PN2, PN3, PN4		M
8	Digi-Key	H743-ND	M3 pan, 8mm	M3 pan head screw, 8mm	PN5, PN6, PN7, PN8, PN9, PN10, PN11, PN12		M
8	Digi-Key	H772-ND	M3 lock washer	M3 split lock washer	PN13, PN14, PN15, PN16, PN17, PN18, PN19, PN20		M
1	Digi-Key	AD829ARZ-ND	AD829	Video Operational Amplifier	U1	SO-G8	
2	Digi-Key	A33165-ND	Header 10X2A	Header, 10-Pin, Dual row	JP1, JP2	HDR2X10_CEN	TH
1			NL	Film Capacitor, axial lead	C6	CA-ALL6	
2			NL	Capacitor, Resistor	C5, R3	CC2013-0805, CR	
1	Digi-Key	311-1109-1-ND	68 p	Capacitor	C3	CC2013-0805	
1	Digi-Key	399-9359-1-ND	470 p	Capacitor	C1	CC3216-1206	
2	Digi-Key	478-1395-1-ND	100n	Capacitor	C2, C4	CC2013-0805	
35	Total pieces						

The resistor ($\pm 0.1\%$ tolerance) and capacitor ($\pm 1\%$) chosen give a pole at 200.4 ± 2.2 kHz. These components were chosen in accordance with the recommendations given in T070016: Susumu Co Ltd. 0805 resistor, ceramic type NP0/C0G capacitor. The resistor is rated for 1/8 W, which should be sufficient for this circuit (up to $15/\sqrt{2}$ V RMS across resistor $\implies$ RMS power up to $(15\text{ V})^2/\sqrt{2}(1690\ \Omega) \approx 0.06$ W).

All resistors and capacitors have footprint 0805, except for the RC capacitor with a footprint of 1206 to allow replacement with bigger capacitors for lower poles. Additional pads are available for larger capacitors.

To give the op amp gain, add a resistor at R3, replace R2 and then add/replace capacitors C3 and C5 in accordance with AD829 datasheet Table 4.

Note: R2, R3, C3 and C5 must comply with the AD829 data sheet to avoid self-oscillations.

3.2 Noise Analysis

Refer to The Art of Electronics, 2nd Edition, Horowitz and Hill, p. 430.

The Johnson noise of the resistors (at room temperature) is given by

$$
\begin{aligned}
v_{n,R1} =& 4k_B T R_1 \\
\approx& 5.23 \text{ nV}/\sqrt{\text{Hz}} \\
v_{n,R2} \approx& 1.27 \text{ nV}/\sqrt{\text{Hz}}.
\end{aligned}
$$

The AD829 has 1.7 nV/$\sqrt{\text{Hz}}$ input voltage noise and 1.5 pA/$\sqrt{\text{Hz}}$ input current noise (see datasheet). The noise in the resistors due to the AD829 current noise is

$$
\begin{aligned}
v_{n,IR1} =& IR_1 \\
\approx& 2.54 \text{ nV}/\sqrt{\text{Hz}} \\
v_{n,IR2} \approx& 0.15 \text{ nV}/\sqrt{\text{Hz}}.
\end{aligned}
$$

Summing these noise sources in quadrature (along with op amp input voltage noise) gives 6.19 nV/$\sqrt{\text{Hz}}$.

As the board is being added to the Common Mode Board among other AD829 and similarly sized resistors (i.e. 2.00 K, 10.0 K), this should be comparable to existing noise.

4 Printed Circuit Board

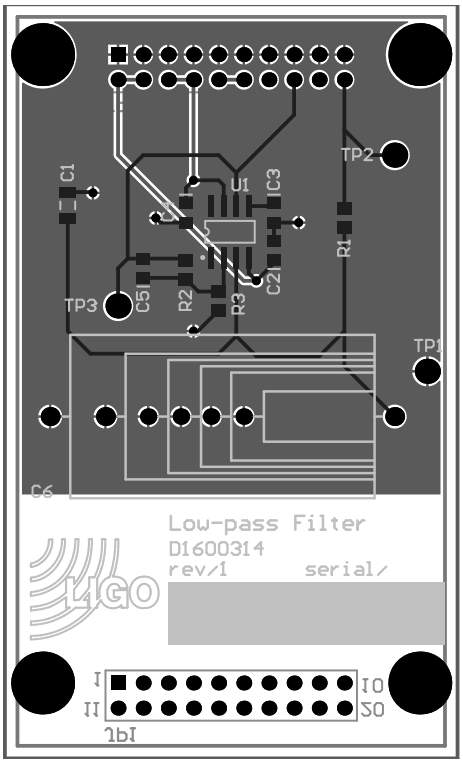

Figure 4: Printed circuit daughter board with low-pass filter.