HAM-A Coil Driver Design Study

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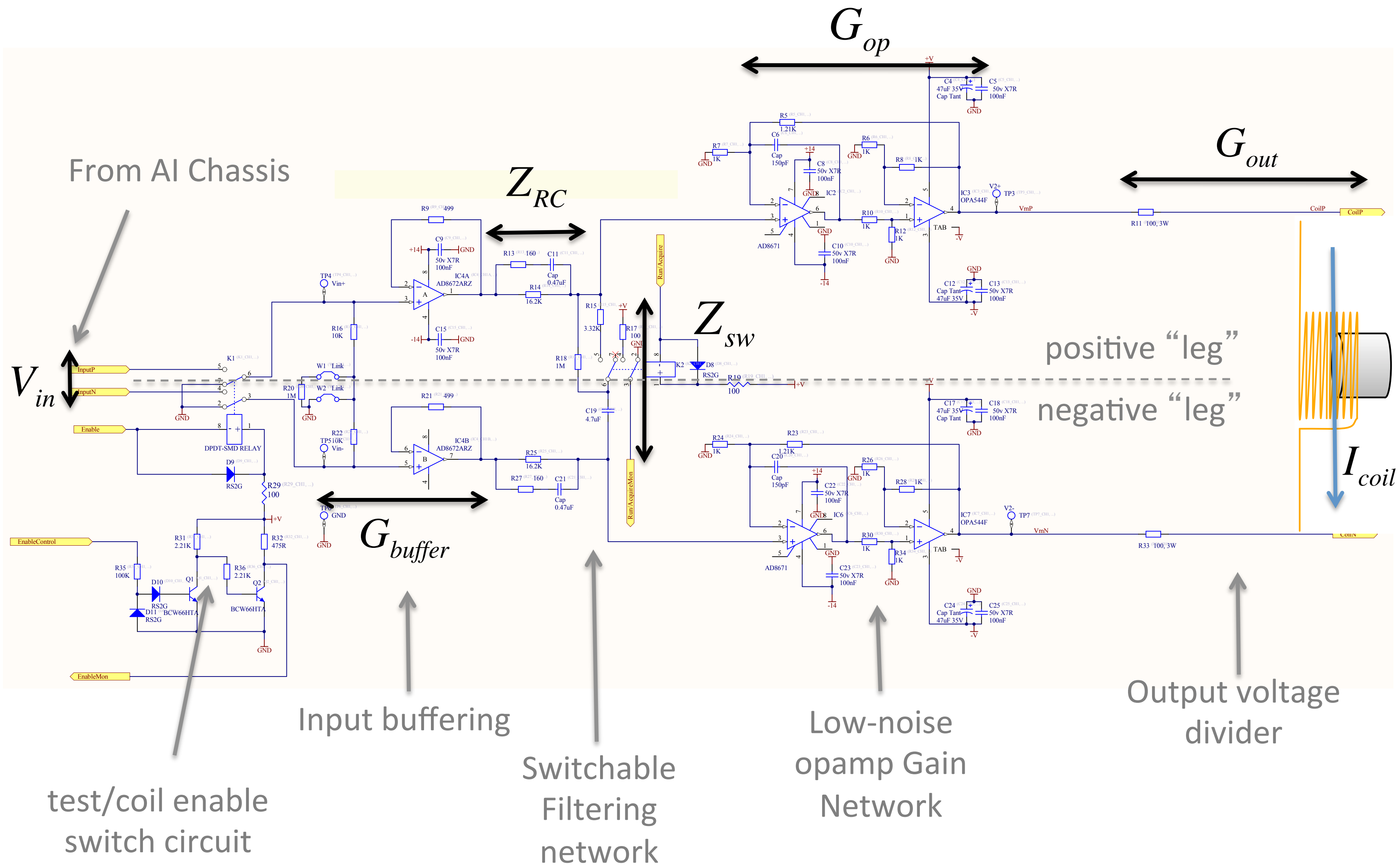
T1200264-v4

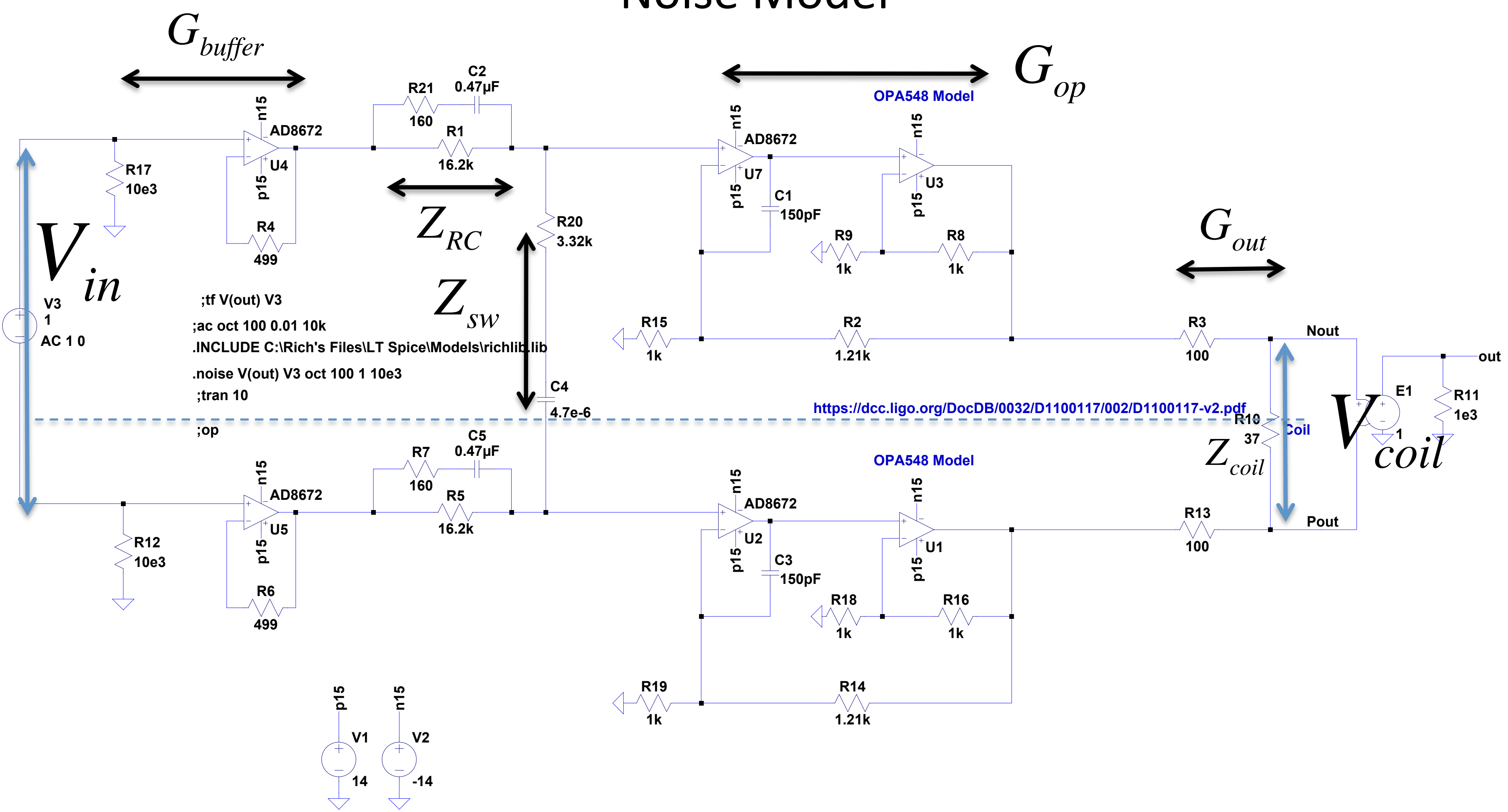
The Full Schematic

D1100117-v2



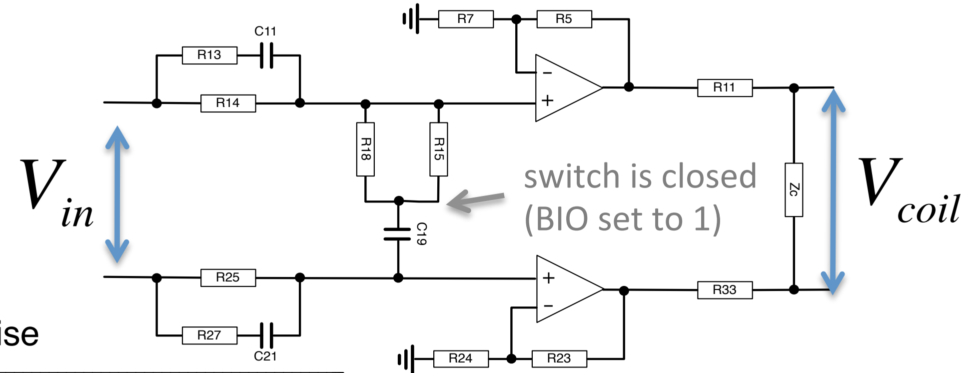
A More Simple Schematic

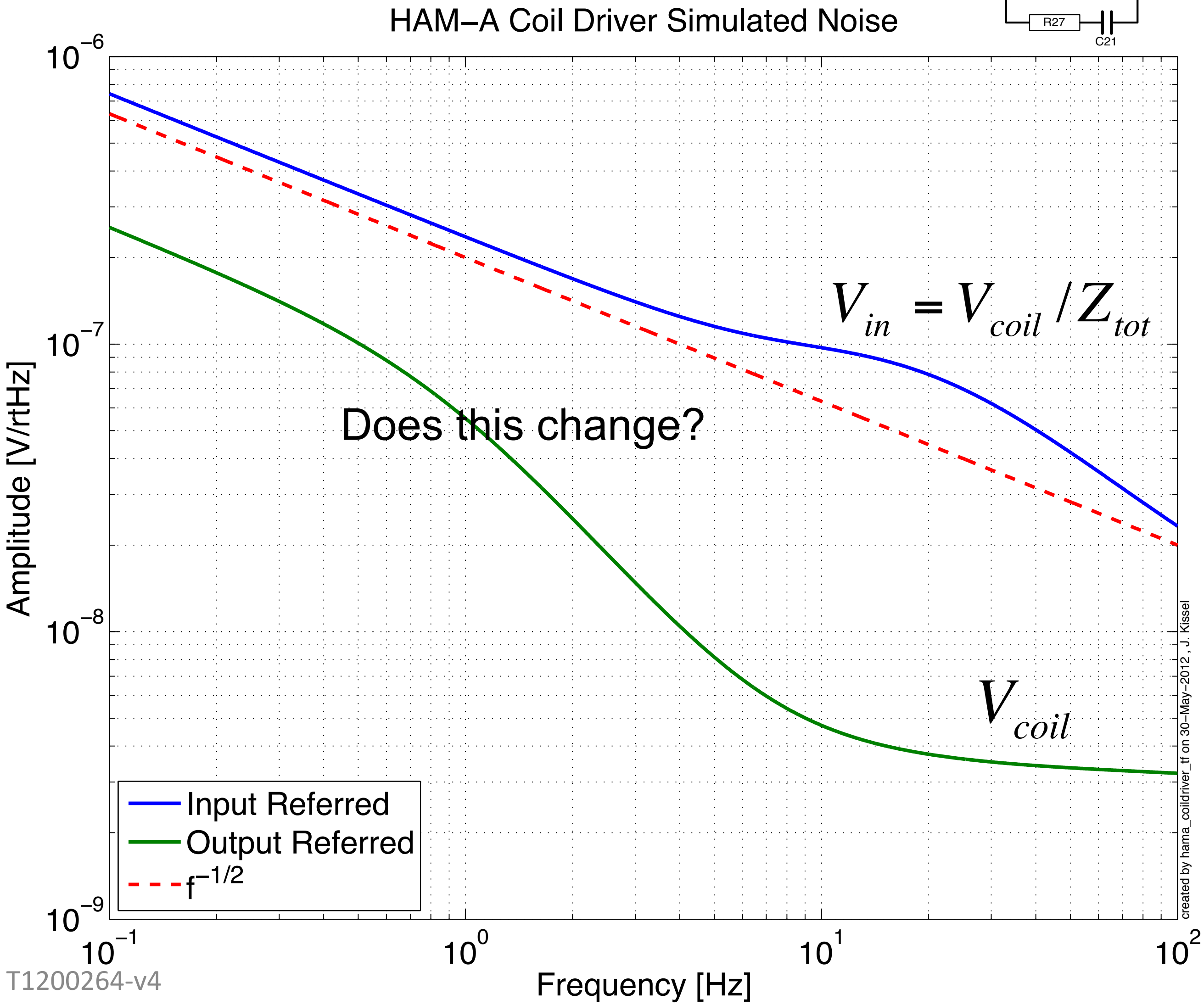
Noise Model



- Rich used Spice to model the input and output referred voltage noise of the driver
- Assumed the "low-noise" mode, where "acq/lp" switch is closed/enabled
- Assumed R18 portion of Z_{sw} is negligible
- Assumed L_{coil} and C_{cable} was negligible below 100 Hz

Noise Model
Low-Noise ("Run") Mode





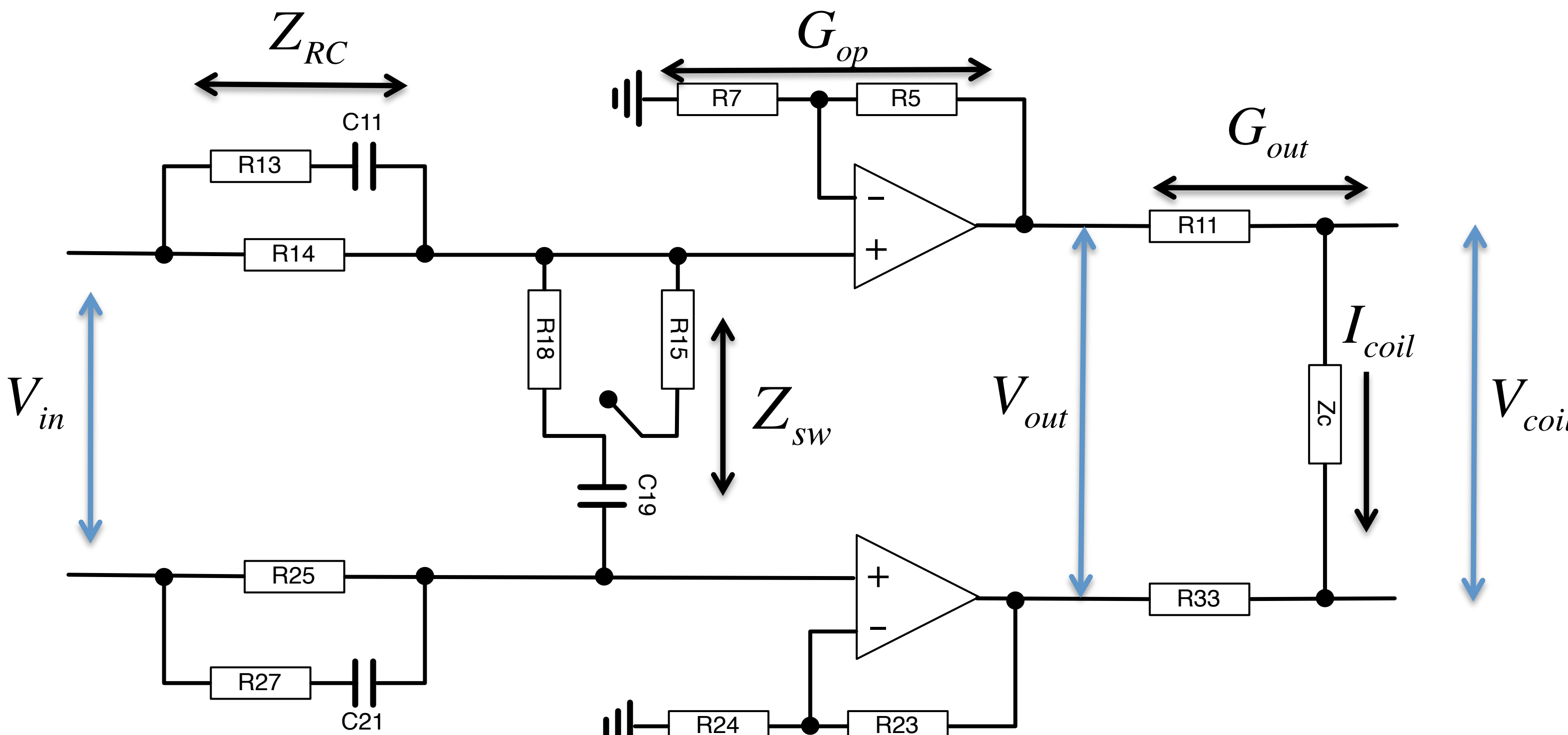
Note: The noise performance is *different/worse* in acquire mode (proportional to the change in impedance of the transfer function [see later pages]), but we're typically not worried about noise performance in high-dynamic range mode, so it's not shown

Falls as $\frac{1}{\sqrt{f}}$

Asymptotes to 2.88 nV/rtHz

An Even More Simple Schematic

Transfer Function Model



- The input buffering is designed to have a gain of 1 and no frequency response, so we ignore it.
- The complicated low-noise opamp gain network is simplified to just a non-inverting opamp, because C6 creates a high-frequency response out of the band of interest (at 10s of kHz), and the gains from R10+R12 with R6+R8 are balanced and cancel.
- Since the output resistors (R11 and R33) are usually considered tunable, and we will hook up several types of coils to the driver, we calculate the transfer function of V_{in} to V_{out} instead of to V_{coil} like Rich did for the noise calculation.
- The inductance for the OSEMs we use is non-negligible between 100 Hz and 1 kHz, so I include it in the impedance: $Z_{coil} = R_{coil} + i\omega L_{coil}$

- However, the cable capacitance [30 pF/ft * ~100 ft ~ 3nF] is neglible at frequencies < 10 kHz, so it's ignored

Transfer Function Model

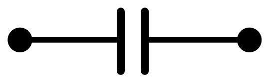
The Analysis Tools

Now it's easy; we just need a few simple equations:

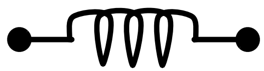
Converting to Impedance:

$$Z_R = R$$

$$Z_C = 1/i\omega C \quad (\omega = 2\pi f)$$

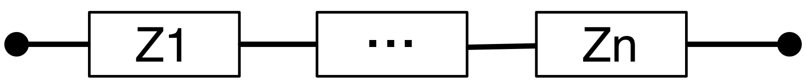


$$Z_L = i\omega L$$



Series Impedance:

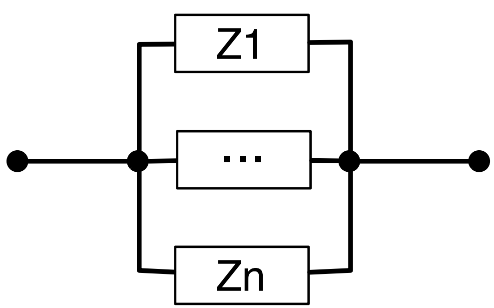
$$Z_{tot}^{S} = Z_1 + Z_2 + \ldots$$



Parallel Impedance:

$$\frac{1}{Z_{tot}^{P}} = \frac{1}{Z_1} + \frac{1}{Z_2} + \ldots$$

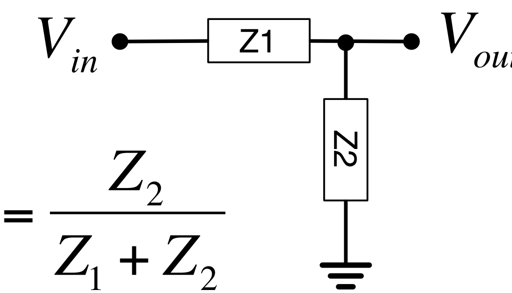
$$Z_{tot}^{P(2)} = \frac{Z_1 Z_2}{Z_1 + Z_2}$$



Ohm's Law:

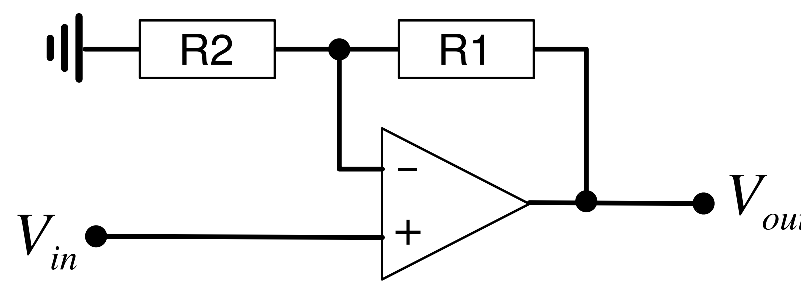
$$V = I Z$$

Voltage Divider:



$$\frac{V_{out}}{V_{in}} = \frac{Z_2}{Z_1 + Z_2}$$

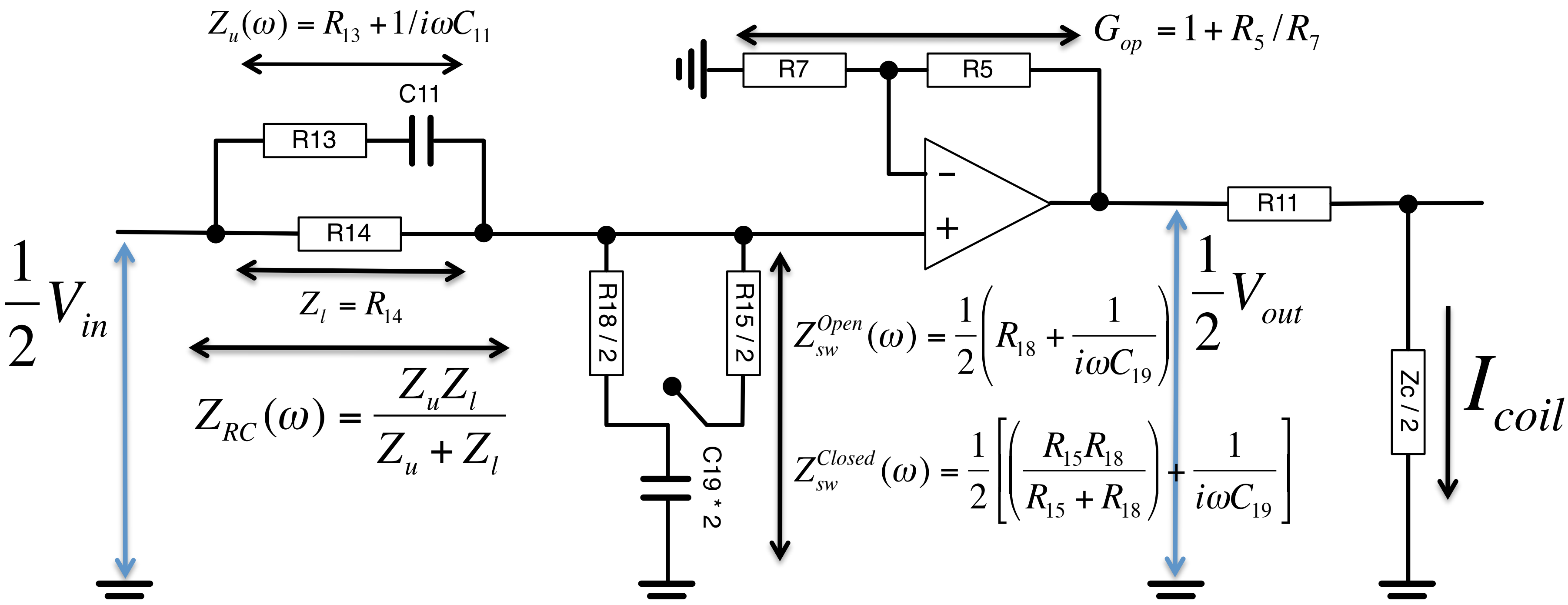
Non-inverting Op-Amp



$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_1}{R_2}$$

An Even More Simple Schematic

Transfer Function Model



• To simplify the analysis, we can split the circuit into the positive and negative leg, by removing one leg and grounding anything that's connected/measured across the legs.

• To keep the same impedance as the differential circuit, the impedance for each component connected to "ground" is halved ("Z" = Z/2 → "R" = R/2, "C" = 2C, "L"=L/2). This goes for V_{in} and V_{out} too, since we're also measuring with respect to "ground."

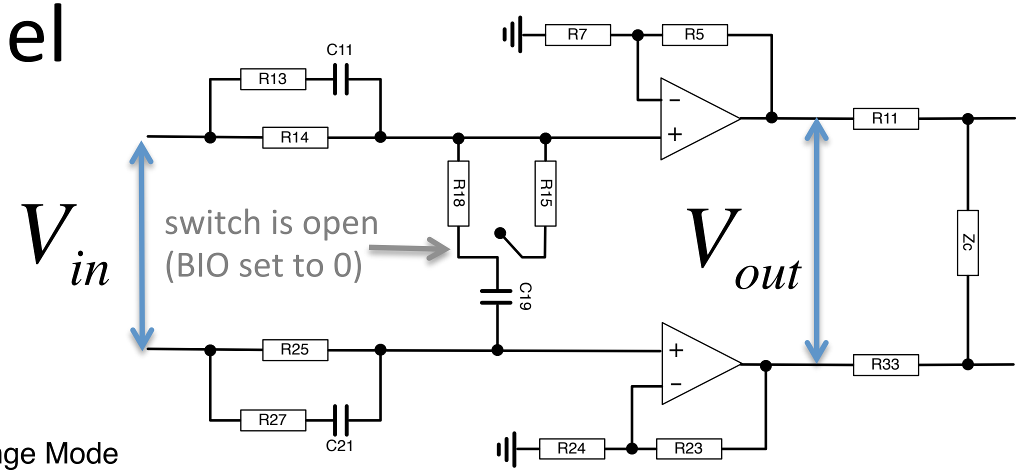
calculated as single-ended = differential

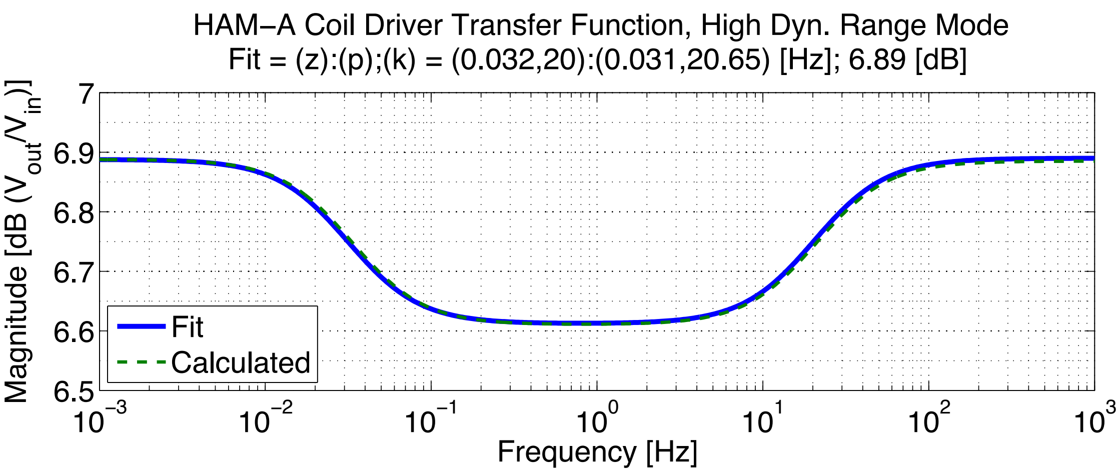
$$H = \frac{V_{out}/2}{V_{in}/2} = \frac{V_{out}}{V_{in}} = G_{op}\frac{Z_{sw}}{Z_{RC} + Z_{sw}}$$

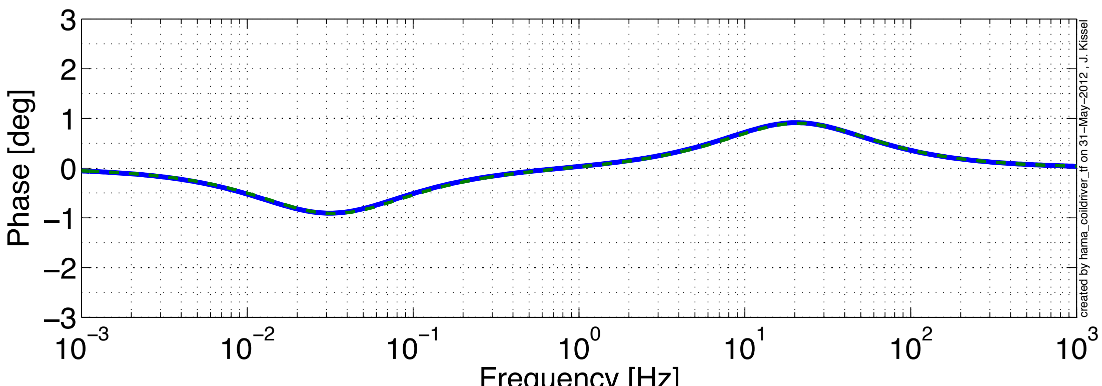
Transfer Function Model

High Dynamic Range Mode

a.k.a "Acquire" or just "Acq"







$$H = \frac{V_{out}}{V_{in}} = G_{op} \frac{Z_{sw}}{Z_{RC} + Z_{sw}}$$

Effectively Flat
(~3% drop between DC gain and ~0.1-10Hz gain)

Zeros: (0.032, 20) Hz
Poles: (0.031, 20.65) Hz

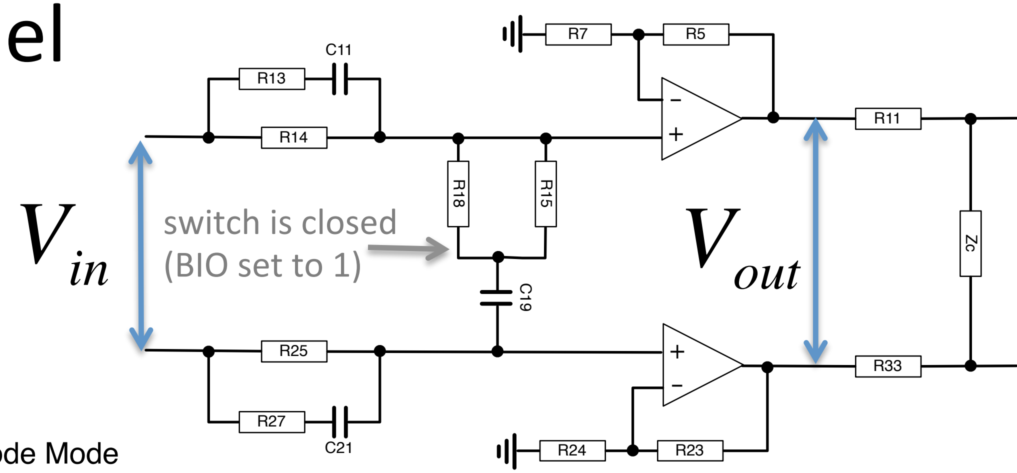
DC Gain = 6.89 dB
= 2.215 [Vout/Vin]

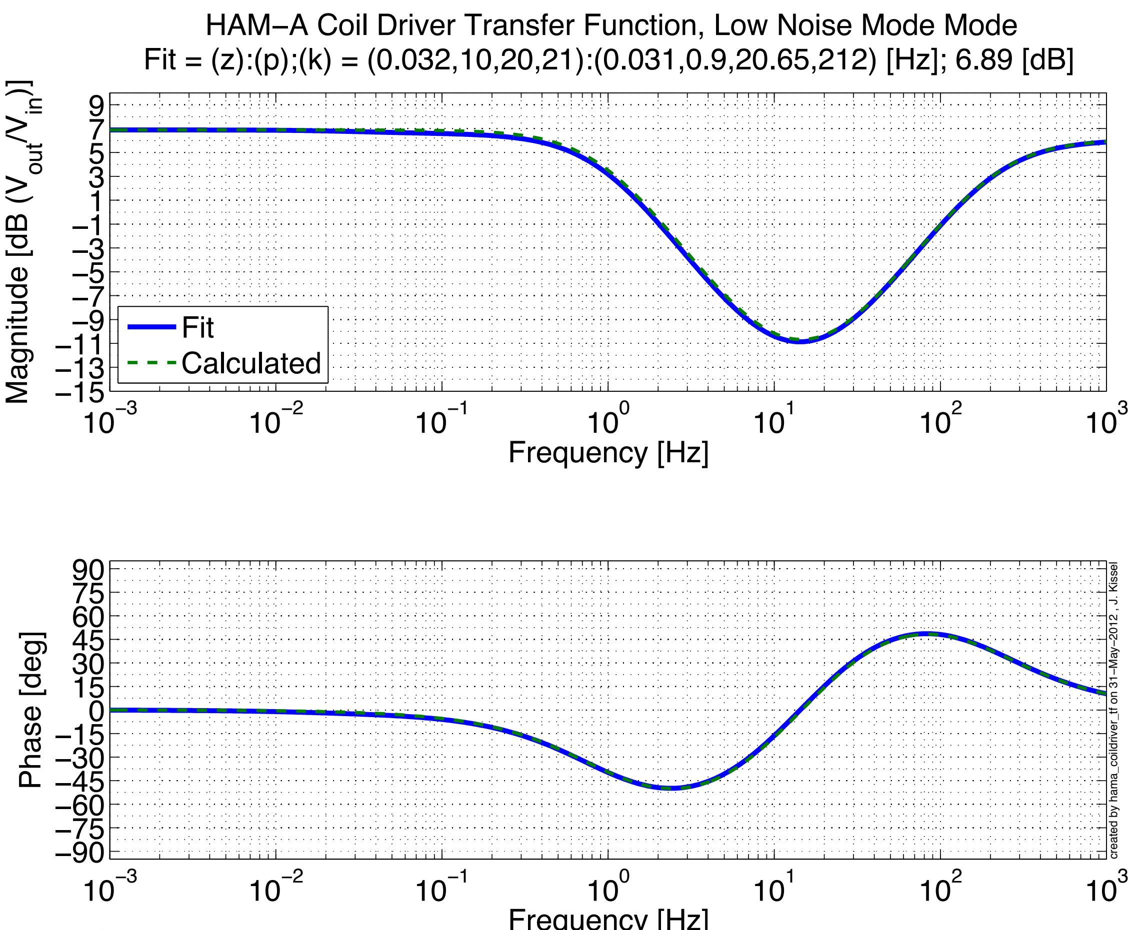
(Confirmed by Rich's Spice Model)

Transfer Function Model

Low Noise Mode

a.k.a "Run"





$$H = \frac{V_{out}}{V_{in}} = G_{op}\frac{Z_{sw}}{Z_{RC} + Z_{sw}}$$

Like "switching in" a [10,21 : 0.9,212] low pass filter

Zeros: (0.032, 10, 20, 21) Hz

Poles: (0.031, 0.9, 20.65, 212) Hz

DC Gain = 6.89 dB

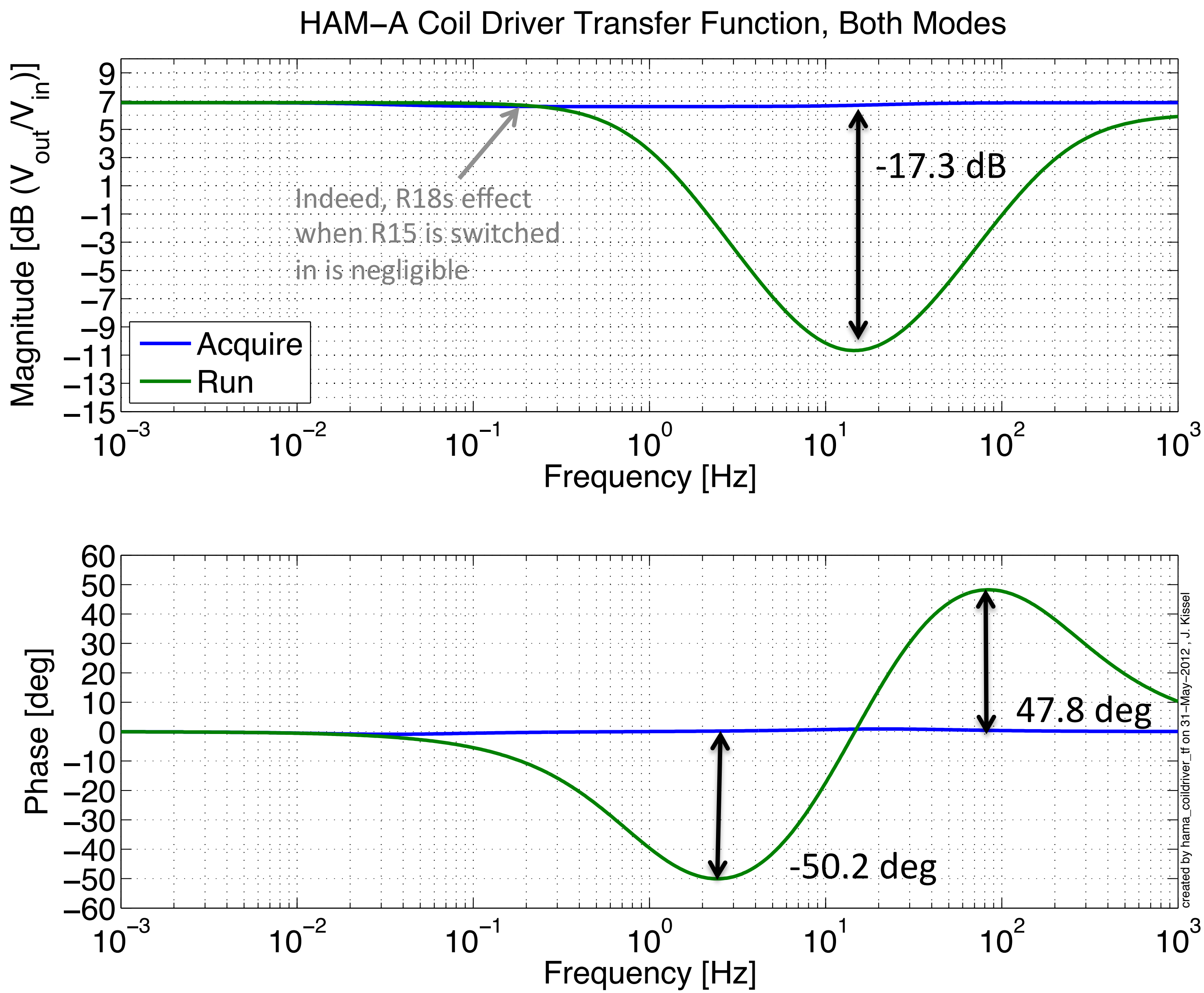
= 2.215 [Vout/Vin]

= the same as Acq.

(Confirmed by Rich's Spice Model)

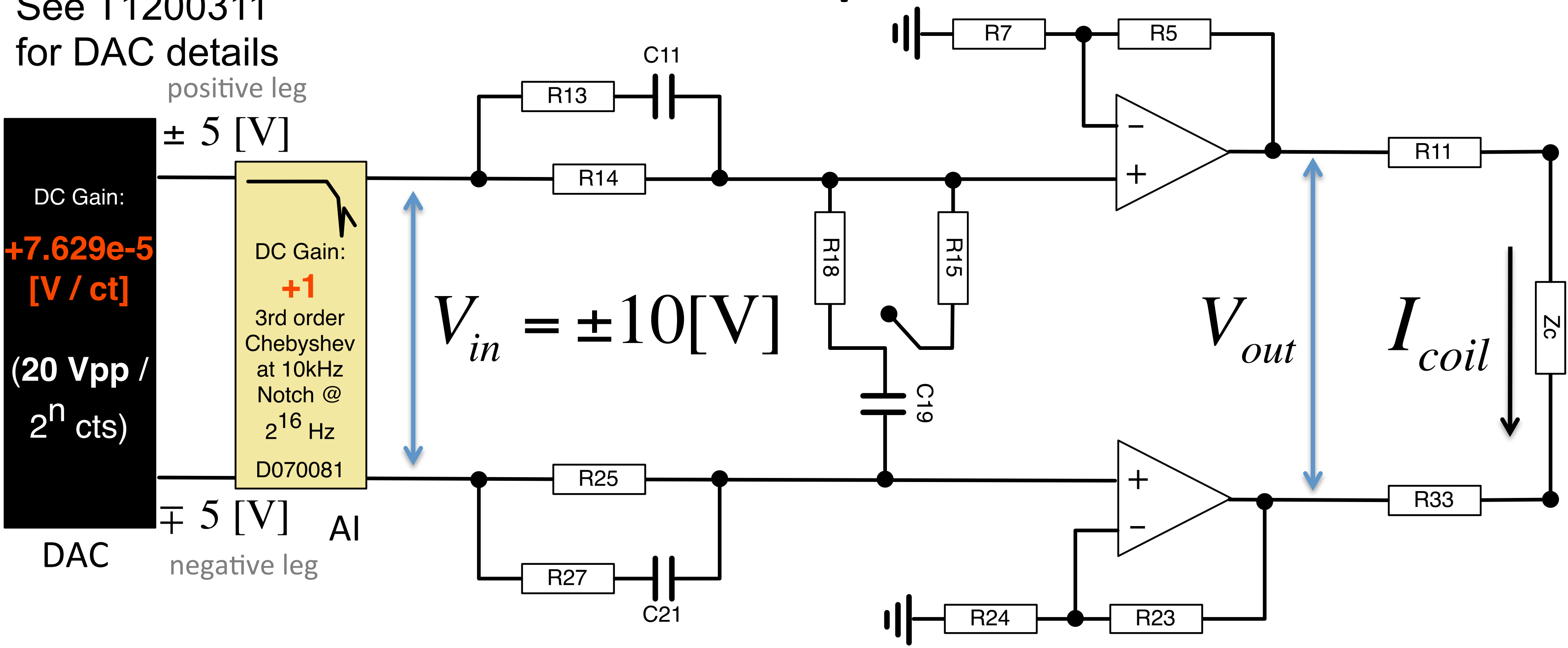
Transfer Function Model

Mode Comparison



Maximum Output Current

See T1200311 for DAC details



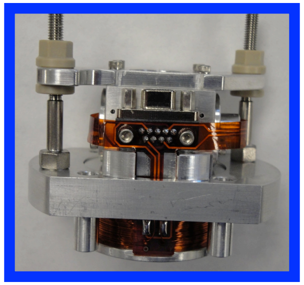
- To calculate the maximum current we assume signal chain is as shown above
- Output range = +/- (maximum current) = 2*(max current)
- We know the aLIGO DACs, as measured differentially, produce 20 Vpp (each leg can go +/- 5 [V], or +/-10 [V] across the legs). Therefore the max voltage input into this driver, V_{in} , is **10 [V] max**. Divide this by the total impedance of the coil driver and coil circuit, Z_{tot} , and we get the maximum current:

$$V_{out} = I_{coil}(R_{11} + R_{33} + Z_c) \xrightarrow[(R_{33} = R_{11})]{(V_{out} = HV_{in})} HV_{in} = I_{coil}(2R_{11} + Z_c) \longrightarrow \frac{I_{coil}}{V_{in}} = \frac{1}{Z_{tot}} = \frac{H}{(2R_{11} + Z_c)}$$

$$\Rightarrow \quad I_{coil} = \frac{V_{out}}{Z_{tot}} = \frac{HV_{in}}{(2R_{11} + Z_c)}$$

Maximum Output Current
AOSEMs vs. BOSEMs

BOSEM



$$R_{coil} = 42.7\Omega$$
$$L_{coil} = 11.9\,\mathrm{mH}$$

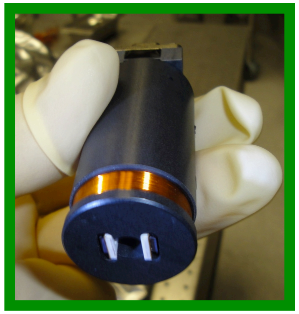
The HAM-A Driver will most likely be used for both AOSEMs (in HAUX) and BOSEMs (in HTTS)

As measured on full system by S. Aston, see LLO aLOG 3340

As measured on ATE by S. Aston

$$Z_{coil} = R_{coil} + i\omega L_{coil}$$

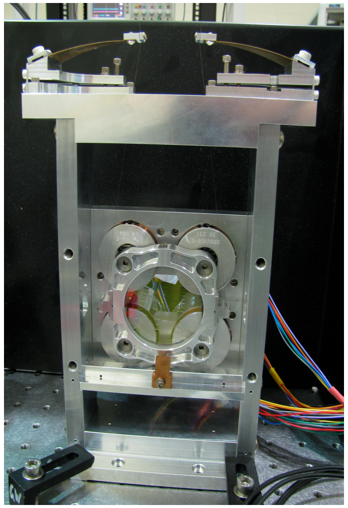
AOSEM

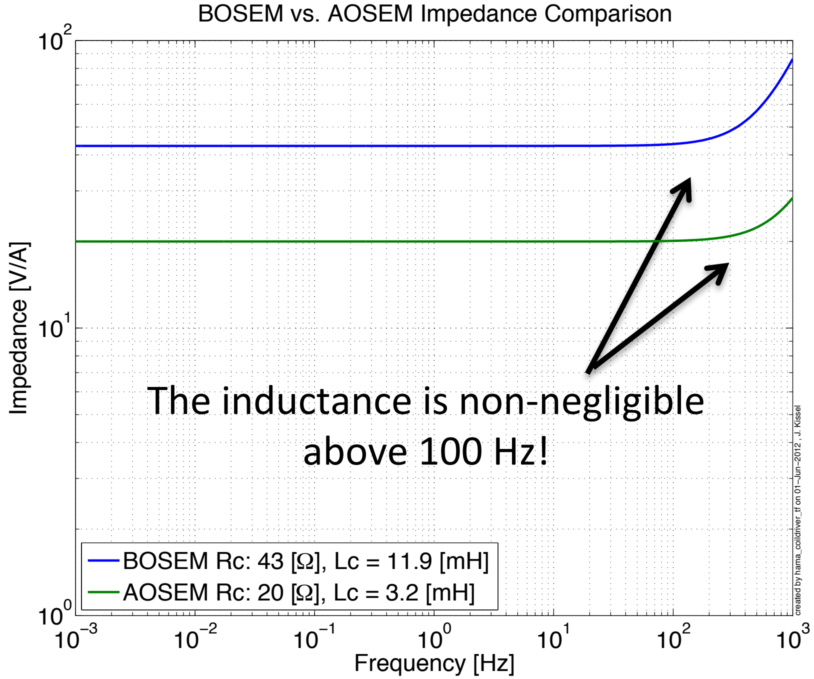


$$R_{coil} = 19.8\Omega$$
$$L_{coil} = 3.2\,\mathrm{mH}$$

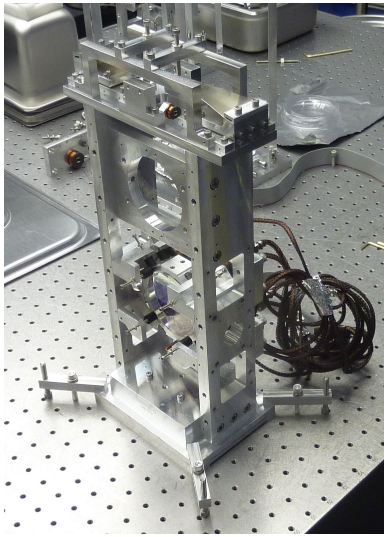
(remember parallel cable capacitance is negligible at these frequencies)

HTTS

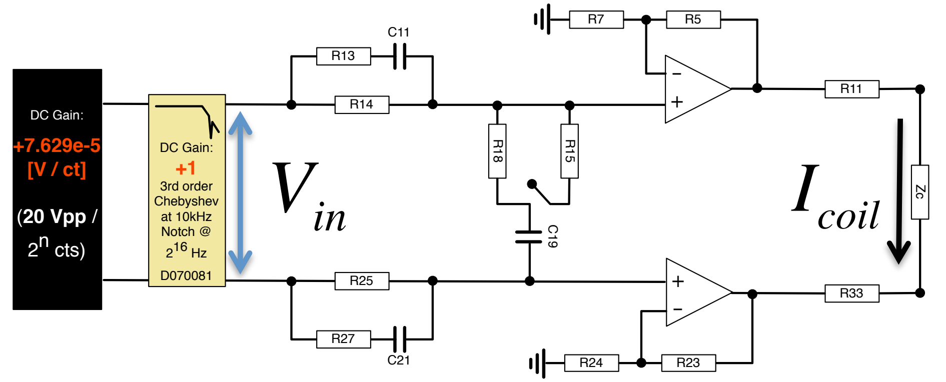




HAUX



Maximum Output Current



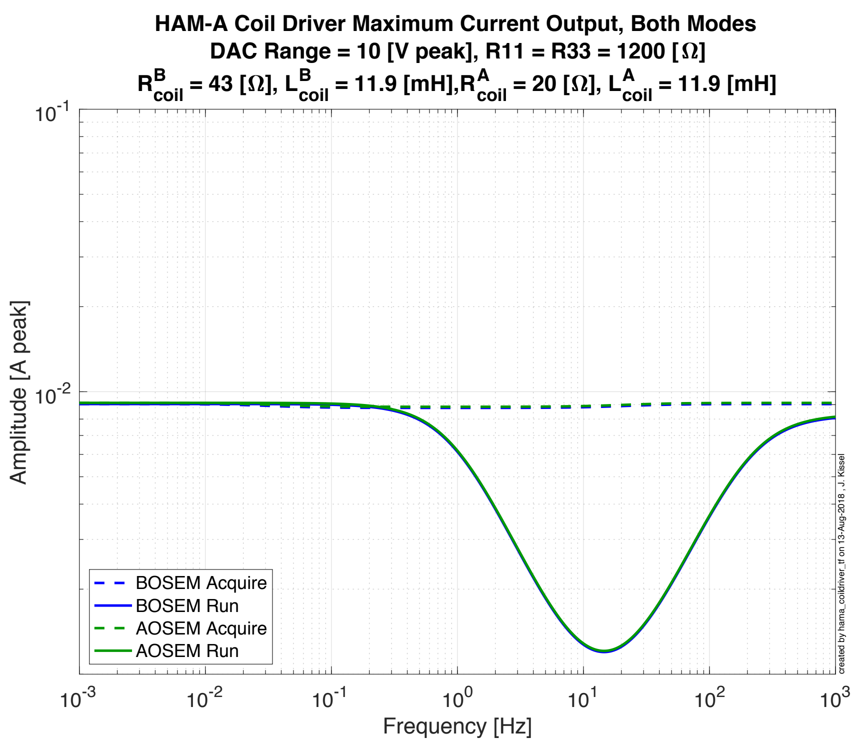
OSEM Type	Transconductance @ DC [A/V]	Maximum Output Current @ DC [A]
AOSEM	9.98e-4	9.98e-3
BOSEM	9.88e-4	9.88e-3

$$I_{coil} = \frac{V_{out}}{Z_{tot}} = \frac{HV_{in}}{(2R_{11} + Z_c)}$$

$$V_{in} = +10[\mathrm{V}]$$

~~$R_{11} = R_{33} = 100\Omega$~~

as per ECR E1201027 $R_{11} = R_{33} = 1.2k\Omega$



AOSEM

$R_{coil} = 19.8\Omega$

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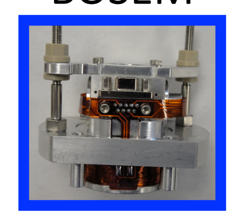
BOSEM

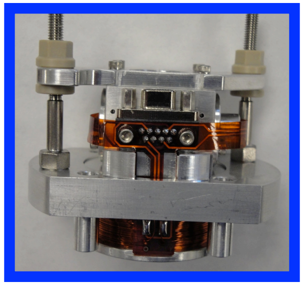


$R_{coil} = 42.7\Omega$

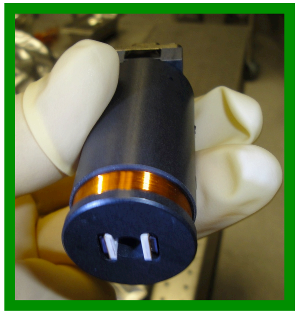
$L_{coil} = 11.9\,\mathrm{mH}$

Current & Force Noise
HAUX vs. HTTS

BOSEM



AOSEM



HAUX use HAM-A drivers with
- 18-bit DACs = 300 nV * sqrt($(50/\text{freq})^2$ + 1);
- 1.9D x 3.2T magnets = 0.0158 N/A

HTTS use HAM-A drivers with
- 16-bit DACs = 600 nV * sqrt($(25/\text{freq})^2$ + 1);
- 2D x 3T magnets = 0.021 N/A

Data shown with R11 = R33 = 1.2k, as per ECR E1201027