Power input connector	Low-noise bipolar LDO with high PSRR (to 1 MHz) and an RC input filter to suppress high-frequency noise (beyond 1 MHz), nominal output ±14.4V
Note inverted pinout to standard LIGO chassis harness!	The circuit needs at minimum ±17.0 V at input at full power draw (150 mA): – D101/D102 drops at most 0.5 V – R101/R102 drops at most 1.0 V – U101 need to drop at most 0.5 V for correct operation and the rails could be as high as ±15.0V Added benefit, reduced heat dissipation in the tiny LDO.

+18V
FB101 BLM31KN102SN1
D103 RB060M-60TR
INPR
R101 6.8
C101 10u
D105 RB060M-60TR
INP
TP102 +15V
+15V
R103 110k
C104 10n
C106 10u
R110 4.99k
R104 10k
D113 LED
U101 TPS7A3901DSCR
INP OUTP FBP BUF FBN OUTN EN NR/SS INN GND
C102 10n
R105 10k
R106 120k
C105 10n
TP103 −15V
C107 10u
R107 4.99k
−15V
D107 LED
J101 26-60-5040
D101 PESD24VL2BT,215
TP101 GND
NT101
Earth
D102 PESD24VL2BT,215
−18V
FB102 BLM31KN102SN1
D104 RB060M-60TR
INNR
R102 6.8
C103 10u
D106 RB060M-60TR
INN

Low-noise voltage reference
Expect: 48 nV/√Hz with 1/f corner at 1 Hz

+15V
C108 10u
C109 0.1u
U102 ADR441ARZ
VIN VOUT TRIM GND
TP104 REF
C110 100n
R117 1k
R118 1k
U104A OPA2202ID
TP106 +2V5

Reference buffer, 0.2 dB added noise
Expect: 49 nV/√Hz with 1/f corner at 1 Hz

R119 10k
R120 10k
U104B OPA2202ID
TP108 −2V5

Negative reference buffer, 1.1 dB added noise
Expect: 54 nV/√Hz with 1/f corner at 1 Hz
Currently unused!

+15V C111 0.1u
+15V C113 0.1u
U104C OPA2202ID
U105C OPA2202ID
C112 0.1u
C114 0.1u
−15V
−15V

Servo
COIL+
COIL−
PDA+
PDA−
INJECT
OUTPUT
INTEGRAL
File: main.kicad_sch

J102 CONBNC002
D111 PESD15VL2BT
R108 10k
R109 10k
J106 CONBNC002
GND
D112 PESD15VL2BT

COIL+
D114 PESD15VL2BT
COIL−
SLIDE+
D115 PESD15VL2BT
SLIDE−
LED+
PESD15VL2BT D116
LED−
PDA+
PESD15VL2BT D109
PDC
PESD15VL2BT D110
PDA−
NTC+
NTC−

Note:
PDA+ = anode of the first half of the bi-cell photodiode and
PDA− = anode of the other half of the bi-cell photodiode:
this is used to enable KICAD "differential pair" routing
Note 2:
NTC− is ground, no need for TVS diode
Note 3:
TVS diode order per layout & dual package pinout, see PCB

Leaf spring sensor vacuum interface:
1 & 14
continuous ±10mA ac current, typically less than 1mA
2 & 15
once a year ±7mA current pulse for a few milliseconds, normally shorted to ground
3 & 16
low-noise 35mA dc current from 3 to 16
4 & 5 & 17
4 photocurrent from cell 1 of a bi-cell photodiode
5 photocurrent from cell 2 of a bi-cell photodiode
17 low-noise +5V reverse bias for bi-cell photodiode
6 & 18
NTC thermistor with 10 kohm nominal resistance at 25°C

Leaf spring sensor output interface:
1&6 primary output monitor
2&7 integral
3&8 temperature
4&9 unused
5 ground return for coarse single-ended monitoring

J105 DB25-PL-25
J104 DB25-SL-25
NTC2+ NTC2− PDA22 PDC2 PDA21 LED2− LED2+ SLIDE2− SLIDE2+ COIL2− COIL2+

+15V
R125 1k
C118 100n
U105A OPA2202ID
R126 1k
C119 160p
R127 1k
D127 RB060M-60TR
Q101 PZT3904
R128 75
TP105 LED
R129 75
R130 75
D124 RB060M-60TR
D125 RB060M-60TR
D126 RB060M-60TR
LED+
LED−

LED current driver, 0.3 dB added noise
Expect 930 pA/√Hz with 1/f corner at 1 Hz (low-pass at 1600 Hz)
I(LED) = 2.5V / R130 = 33mA

R122 10k
R123 10k
C116 100n
U105B OPA2202ID
R121 1k
R124 51
TP109 +5V
C117 10u
D128 RB060M-60TR
D129 RB060M-60TR
PDC

Photodiode bias circuit, 0.3 dB added noise
Expect: 100 nV/√Hz with 1/f corner at 1 Hz (low-pass at 300 Hz)
OPA2202 for large capacitive load:
RO = 50 ohm (from datasheet)
RX = RO * (RG / RF) = 50 ohm
CF = (RO + RX) / RF * CL = 100 nF

SE2DIFF1
SE2DIFF2
SE2DIFF3
IN+ IN− OUT+ OUT−
GND
File: driver.kicad_sch
NTC
DRIVE NTC+ NTC−
File: ntc.kicad_sch
drive+
drive−
D119 PESD15VL2BT
D120 PESD15VL2BT
D121 PESD15VL2BT
J103 DE9 receptacle

Title: Low-frequency servo for leaf spring seismometers		
University of Birmingham		
Sheet: /		
File: servo.kicad_sch		
Size: A2	Drawing #: E00331-1	Engineer: Lari Koponen / Rev: A
KiCad E.D.A. 9.0.5	Date: 2025-11-19	Id: 1/6

The position sensor noise is approximately
12.3 pm * sqrt(1 + 3.0 Hz / f)

For TIA = 15,000 ohm and GAIN(DIFF) = 1.5, this corresponds to voltage noise at V(dPD) of
369 nV * sqrt(1 + 3.0 Hz / f)

The readout noise with OPA202 and the shown resistors is expected to be about
57 nV * sqrt(1 + 0.012 Hz / f)

We do not need a chopper amp for the photodiode readout!

First and last part form a third order low-pass filter, Bessel, nominally -3 dB at 20 Hz with Q = 0.577

TIA
gain = -15 kV/A
pole at 1 kHz
expect about 7 V at TP201 & TP202

Difference amplifier, V(dP) = gain * (V(PD1) - V(PD2))
dc gain = -1.5
pole at 1 kHz
expect +/- 10 V at TP203 for +/- 0.5 mm motion

Low-pass filter and loop-gain measurement point
dc gain -10
ideally pole at 1.3227 * 30 Hz = 40 Hz

Logarithmic gain stage
gain range from about 0.1 to 10
avoid gains below 1, they cause premature clipping

Composite filter: Sallen-Key low-pass filter and an "inverse filter"

Sallen-Key:
dc gain = -1
design: conjugate pole pair at 1.4476 * 30 Hz, Q = 0.691
components: conjugate pole pair at 29.9 Hz, Q = 0.718

Inverse filter:
dc gain = 11
pole at X Hz
zero at X Hz

Variable output gain from 1 to 310 in increments of 10

Expect to add less than 0.1 dB noise at design gain of 150
Simulation suggest maximum added noise of 0.3 dB at 100 mHz at

--

Output mixer, add in integral signal with gain 0.1

Output mixer:
3-4 for plain output
1-2 for mixed integral output

Low-noise integrator, T = 400 s

Output mixer, 1-2 & 3-4 for normal polarity, 1-3 & 2-4 for reverse polarity

Den: 470n

Den: 470n

Den: 100n

0.1%

PDA+ PDA- INJECT GND +15V -15V

R201 1k
R202 1k
R203 15k
R204 15k
R205 10k
R206 10k
R207 15k
R208 15k
R209 51
R210 20k
R211 2k
R212 20k
R213 33k
R214 20k
R215 10k
R216 100k
R217 10k
R218 10k
R219 10000k
R220 10000k
R221 10000k
R222 10000k
R223 4.99k
R224 15k
R225 1k
R226 1k
R227 1k
R228 100k
R229 10k
R230 4.99k
R231 2.49k
R232 1.24k
R233 0.62k
R234 1k
R235 10k
R236 10k
R237 100k
R238 51

C201 10n
C202 10n
C203 10n
C204 10n
C205 100n
C206 100n
C207 100n
C208 100n
C209 100n
C210 100n
C211 100n
C212 47p
C213 10u
C214 10u
C215 10u
C216 10u
C217 10u
C218 10u
C219 0.1u
C220 0.1u
C221 0.1u
C222 0.1u
C223 0.1u
C224 0.1u
C225 0.1u
C226 0.1u
C227 0.1u
C229 100n
C230 0.1u
C231 0.1u
C232 10u
C233 100n
C234 10u

RV201 20k

U201A OPA2202ID
U201B OPA2202ID
U201C OPA2202ID
U202A OPA2202ID
U202B OPA2202ID
U202C OPA2202ID
U203A OPA2202ID
U203B OPA2202ID
U203C OPA2202ID
U204A OPA2202ID
U204B OPA2202ID
U204C OPA2202ID
U205 OPA140ID
U206A OPA2202ID
U206B OPA2202ID
U206C OPA2202ID

D201 RB060M-60TR
D203 RB060M-60TR

J201
J202
J203

TP201 PD1
TP202 PD2
TP203 dPD
TP204 INJECT
TP205 GAIN
TP206 5K
TP207 NEG

OUTPUT
INTEGRAL
COIL+
COIL-

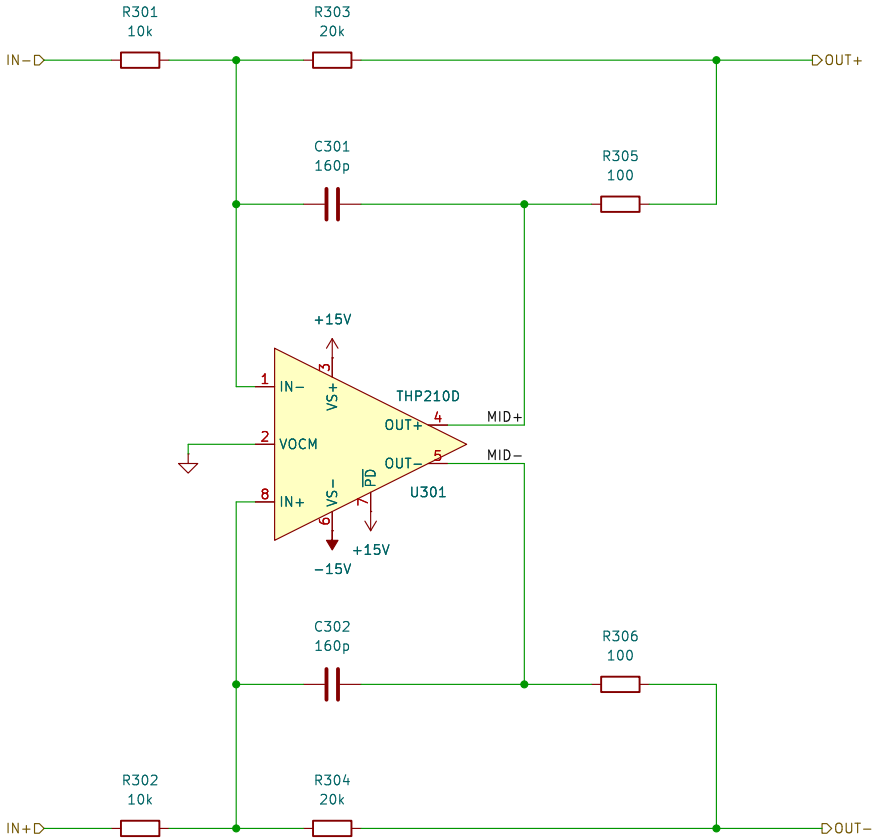
Title: Servo main signal path			
University of Birmingham			
Sheet: /Servo/			
File: main.kicad_sch			
Size: A2	Drawing #: E00331-1	Engineer: Lari Koponen	**Rev: A**
KiCad E.D.A. 9.0.5		Date: 2025-11-19	Id: 2/6

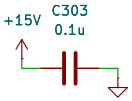
Known-good-design of a differential line driver, used either as a:

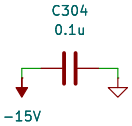
1. single-ended to differential converver, precision, low-noise, gain 2 (i.e., V(OUT+) ≈ V(IN) and V(OUT-) ≈ -V(IN))

2. differential to differential converter with a level shift, precision, low-noise, gain 2

Simulated: 3 dB bandwidth from dc to 50 kHz
Simulated: Maximum capacitive load 2500 pF = maximum value for a standard RS-232 serial cable
Simulated: Shot noise 47 nV/√Hz, flicker noise corner frequency 1.4 Hz; both well below CDS input noise floor







Title: Fully differential amplifier

University of Birmingham

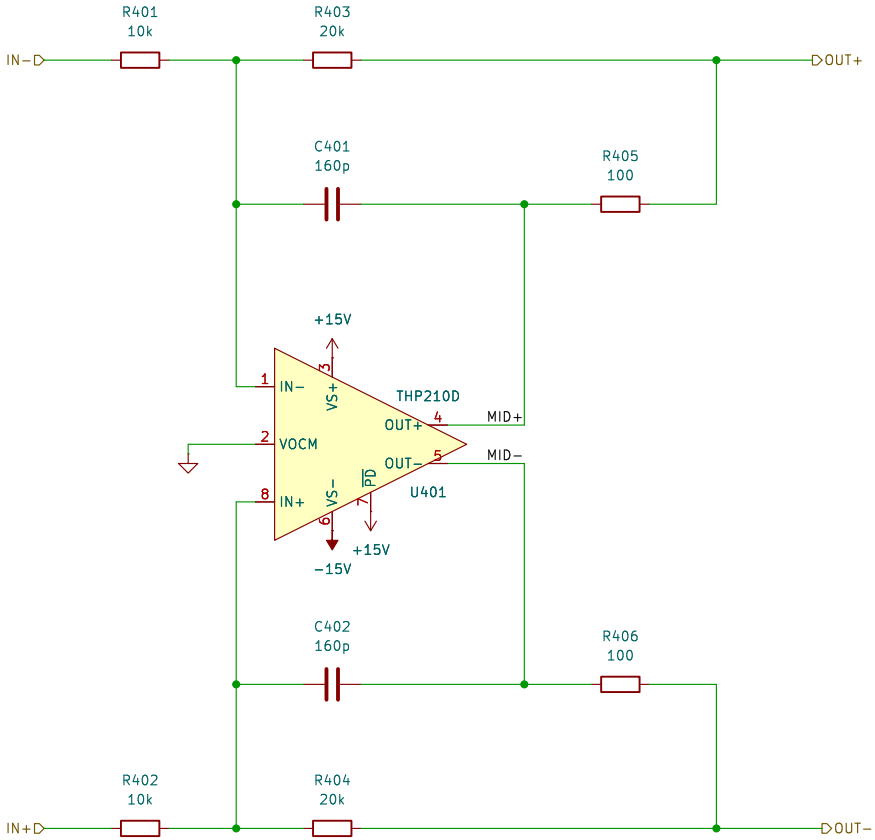
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File: driver.kicad_sch			
Size: A4	Drawing #: E00331-1	Engineer: Lari Koponen	**Rev: A**
KiCad E.D.A. 9.0.5		Date: 2025-11-19	Id: 3/6

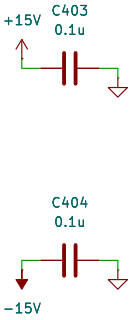
Known-good-design of a differential line driver, used either as a:

1. single-ended to differential converver, precision, low-noise, gain 2 (i.e., V(OUT+) ≈ V(IN) and V(OUT-) ≈ -V(IN))

2. differential to differential converter with a level shift, precision, low-noise, gain 2

Simulated: 3 dB bandwidth from dc to 50 kHz
Simulated: Maximum capacitive load 2500 pF = maximum value for a standard RS-232 serial cable
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Title: Fully differential amplifier

University of Birmingham

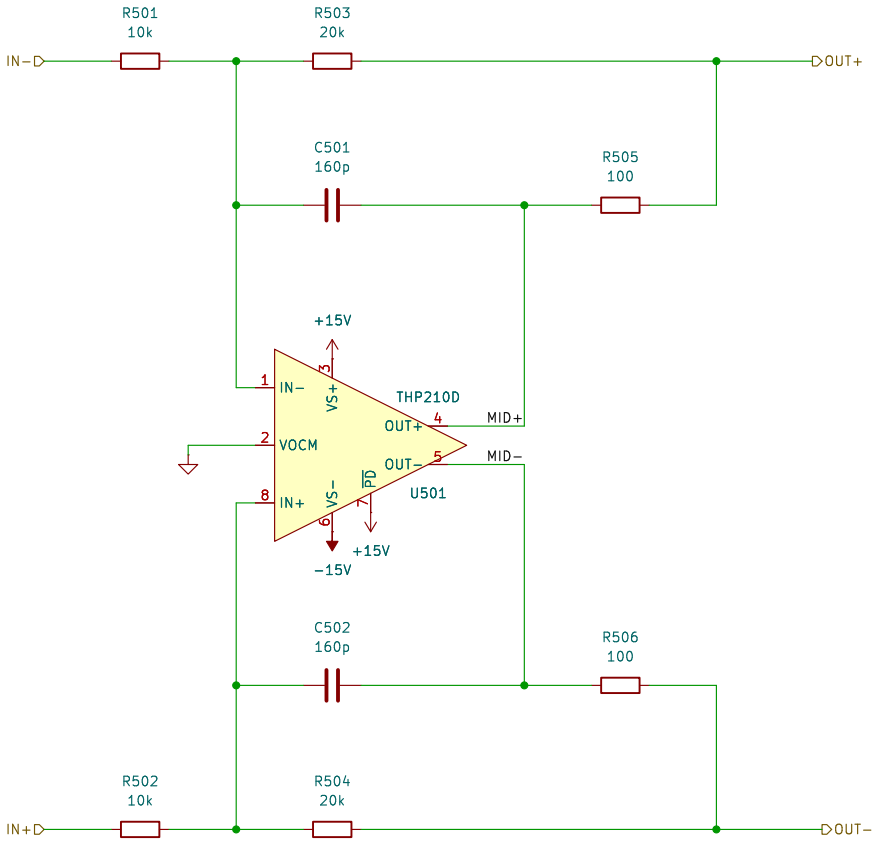
Sheet: /SE2DIFF2/			
File: driver.kicad_sch			
Size: A4	Drawing #: E00331-1	Engineer: Lari Koponen	**Rev: A**
KiCad E.D.A. 9.0.5		Date: 2025-11-19	Id: 4/6

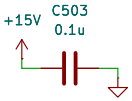
Known-good-design of a differential line driver, used either as a:

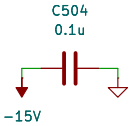
1. single-ended to differential converver, precision, low-noise, gain 2 (i.e., V(OUT+) ≈ V(IN) and V(OUT-) ≈ -V(IN))

2. differential to differential converter with a level shift, precision, low-noise, gain 2

Simulated: 3 dB bandwidth from dc to 50 kHz
Simulated: Maximum capacitive load 2500 pF = maximum value for a standard RS-232 serial cable
Simulated: Shot noise 47 nV/√Hz, flicker noise corner frequency 1.4 Hz; both well below CDS input noise floor







Title: Fully differential amplifier

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Sheet: /SE2DIFF3/			
File: driver.kicad_sch			
Size: A4	Drawing #: E00331-1	Engineer: Lari Koponen	**Rev: A**
KiCad E.D.A. 9.0.5		Date: 2025-11-19	Id: 5/6

Known-good-design of a low-noise NTC amplifier

Select R603 to set operating point at average room temperature, R603 = R0 * exp(beta * (1 / T - 1 / T0))
Select (R604||R605) to set the (approximately linear) voltage gain around this point, dV/dT = (1+(R606+R607)/(R604||R605))*V(DRIVE)*beta/(4*T0^2)

Wheatstone bridge with one NTC

R603 to set neutral point temperature, here
T=1/(log(R603/R0)/beta+1/T0])=20 °C
where
beta = 3,900 K
R0 = 10,000 ohm
T0 = 25 °C
R603 = 12,400 ohm

For even lower noise, use bridge with two NTCs

First-order low-pass filter

Input resistance from the Wheatstone bridge
Common mode LP at 32 kHz
Differential mode LP at 1.6 kHz

Fully differential in-amp, low tempco, precise gain

R605 || R604 to set voltage gain, here dV/dT = 2.8 V/°C

Note: Common mode gain 1, needs differential output stage!

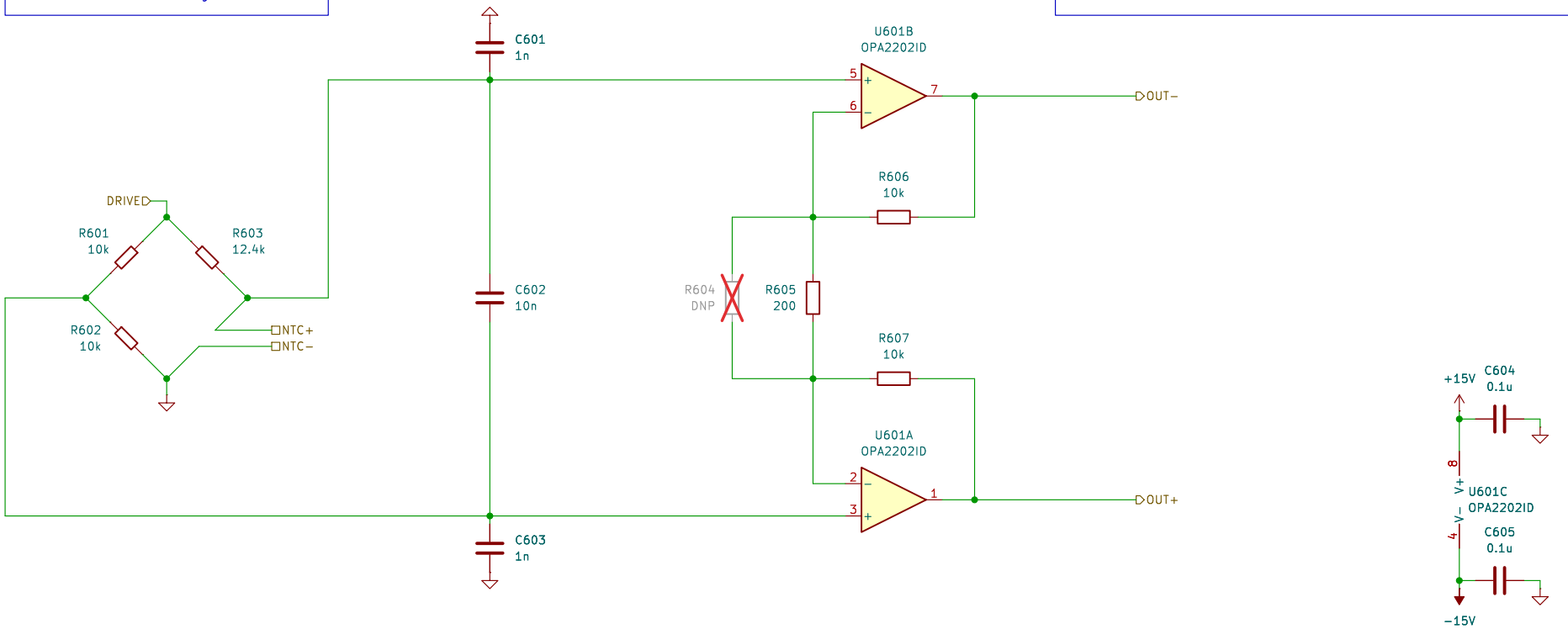
All resistors low-noise thin film resistors from a known good brand

All resistors with at most 0.5% resistance tolerance
-> The amplifier is more accurate than the uncalibrated 1% NTC

R_01-R_03 are ideally with at most 0.1% resistance tolerance
-> The amplifier is considerably more accurate than the uncalibrated 1% NTC

All resistors with low temperature coefficient, at most 25 ppm/°C
-> The amplifier temperature coefficient remains below 0.1% (1 mK/K)

For precise neutral point temperature and gain, two-point calibration is needed!



Title: Precision NTC amplifier			
University of Birmingham			
Sheet: /NTC/ File: ntc.kicad_sch			
Size: A4	Drawing #: E00331-1	Engineer: Lari Koponen	**Rev: A**
KiCad E.D.A. 9.0.5		Date: 2025-11-19	Id: 6/6