Pyrodetector

To desing amplification board of detector, some initial knowledge of principle of pyrodetector work is required.

A pyrodetector can be considered as a capasitor with a temperature dependent charge. The change of the surface charge ΔQ of ferroelectric material due to a small change ΔT of the temperature is given by:

$$\Delta Q = A\Big(\frac{dP}{dT}\Big)\Delta T = AK_p\Delta T,$$

where P is polarisation K_p-piroelectric coeficient, A - surface area of the detector element. Then, current of the detector is:

$$i_s = AK_p\frac{dT}{dt}.$$

The heat equation of the detector element when heated by the incident radiation power P is:

$$C_{th}\frac{dT}{dt} + \lambda(T - T_0) = P,$$

where T_0 is ambient temperature , P - radiative power,λ - thermal conductivity, C_{th} - thermal capacity. Let consider that an input power contain periodic component $P(1 + e^{j\omega t})$. The temperature is then described by $T = T_0 + T^* + T(\omega)e^{j\omega t}$, where $T(\omega)$ - amplitude of the oscillating temperature component and T^* is the steady state temperature increase by P. If we solve heat equation with this condition, we will get:

$$j\omega C_{th}T(\omega) + \lambda T(\omega) = P,$$

then

$$|T(\omega)| = \frac{P}{\lambda(1 + \omega^2\tau_{th}^2)^{1/2}},$$

where $\tau_{th} = C_{th}/\lambda$ is thermal time constant. Then for current:

$$|i_s| = \frac{\omega AK_P P}{\lambda(1 + \omega^2\tau_{th}^2)^{1/2}},$$

and for signale voltage

$$|v_s| = \frac{|i_s|R_L}{(1 + (\omega R_L C)^2)^{1/2}},$$

where C is the electrical capacitance and R_L the load or shunt resistnce whith is usually much smaller than the internal resistnce of the detector (in our case more than 100 times). Response ($|r| = |v_s|/P$):

$$|r| = \frac{\omega AK_P P}{\lambda(1 + \omega^2\tau_{th}^2)^{1/2}}\frac{R_L}{[1 + (\omega R_L C)^2]^{1/2}}$$

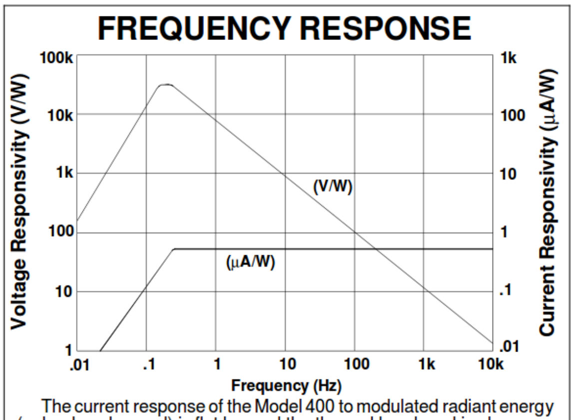
It seen that for low frequencies $\omega < 1/\tau_{th}$ the response becomes

$$r = \frac{\omega AK_P R_L}{\lambda}$$

and for high frequencies, $1/\tau_{th} < \omega < 1/R_L C$, the response is constant and given by

$$r = \frac{AK_P R_L}{C_{th}}$$

The smaller the load resistance the larger the frequecy range with constant response which is independent of both frequency and thermal conductivity.



The current response of the Model 400 to modulated radiant energy (pulsed or chopped) is flat beyond the thermal break and is shown on the designated curve with appropriate dimensioning on the right ordinate axis. Response of the Model 400 through a source follower (ELTEC Model 320 set at 5×10^{10}) is shown on the left ordinate axis.

Figure 1: Response of ELTEC 400

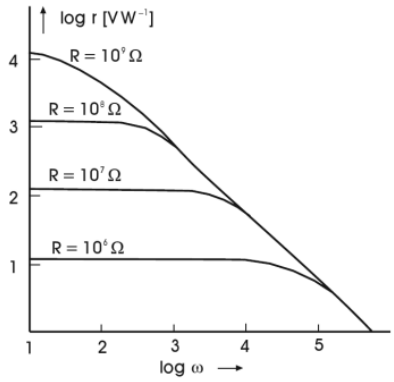


Fig. 3.5. Response for various values of load resistance. $K_p = 2 \times 10^{-4}$ [C m^{-2} K^{-1}]; $C_{th} = 1.64 \times 10^{-5}$ [JK^{-1}]; $C = 22$ pF; $A = 1$ mm^2

Figure from W.J.Wittman. Detectors and signal processing. Technical realisation.

On figure 1 You see response of our detector. Peak of volage response is moving (as shown above) and it depend from load resistance, but it ok in our case, because we also use 50 GOm load resistor.

Noise analysis

The noise is produced by the resistance (Jonson noise mainly from the shunt resistance) and by the thermal fluctuations. The mean square current fluctuations is

$$< i_n^2(\omega) >= \omega^2 A^2 K_P^2 < \Delta T^2(\omega) > .$$

For the thermal noise within the bandwidth B

$$< i_{nT}^2 >= \frac{4k\omega^2 A^2 K_P^2 T^2 B}{\lambda(1+\omega^2\tau_{th}^2)}$$

The total noise current including Johnson noise becomes

$$< i_n^2 >= \frac{4kTB}{R_L} + \frac{4k\omega^2 A^2 K_P^2 T^2 B}{\lambda(1+\omega^2\tau_{th}^2)}$$

Signal-to-noise ratio:

$$\frac{S}{N} = \frac{|i_s^2|}{< i_n^2 >} = \frac{P^2}{\frac{4kT\lambda^2(1+\omega^2\tau_{th}^2)B}{\omega^2 A^2 K_P^2 R_L} + 4kT^2\lambda B}$$

Jonson noise is much larger than the thermal noise, so Noise equivalent power

$$NEP = \frac{4kT\lambda^2(1+\omega^2\tau_{th}^2)B}{\omega^2 A^2 K_P^2 R_L}$$

When the detector element is in thermal equilibrium with its surrounding, there will be zero mean power flow between them. However, it will experience a fluctuation spectrum with an RMS value. This gives the "background limit" to the detector NEP. (*Infrared Detectors and Emitters: Materials and Devices. Peter Capper,C.T. Elliott*)

Preamplifier

Transistor

To select the input transistor pre-amp should behave responsibly. Because the noise then it will create in next amp stages will amplified more and can be perceived by the useful signal. For that I select ultra-low noise (0.8 nV/$sqrt(Hz)$) fet transistor BF862.

In datasheet to detector was proposed to make source follower. In this case we have amplification in current but not amplification in voltage. I propose replace follower by voltage amplifier. For this I use shematic as on figure 3, but without capasitor Cs. Resistance Rg is load 50 GOm resistor. Capasitor at the out of amplifier cut constant voltage. It must have big capasitance and there low resistance to ac component. Resistors Rd and Rs set working line and working point. Value of Rd+Rs=R we get from equation:

$$Vd = Vdd - IdR,$$

and value Rs, that set working point:

$$Rs = Vgs/Id.$$

It is very important to choose rigth working line and working point, in other case we will have nonlinear amplification (look at figure 7 of bf862 datasheet).

On figure 4 red is working line and blue is working point. In this amplifier Rs= 27 Om, Rd=220 Om, out capasitor 10 uF. Maximum of amplification is aproximetly 7 times, but in real life it is about 3,5 times. That may caused by that figure 3 from datasheet is not real. I will check it by simulating work of transistor in Multisim. The role of capasitor Cs is to help of amplification for ac signals, but now my experiments with it is not successful.

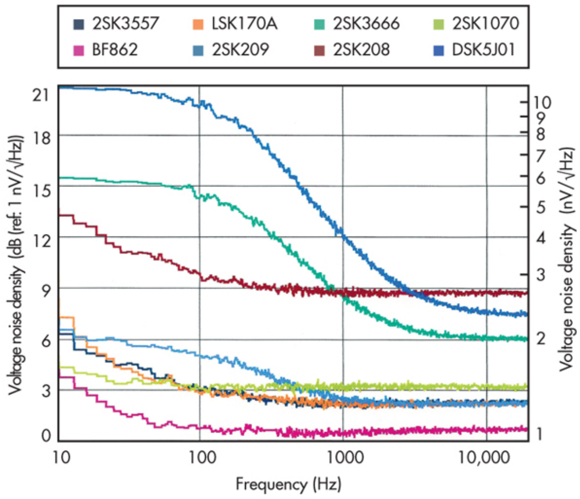


Figure 2: Noise measurements
electronicdesign.com

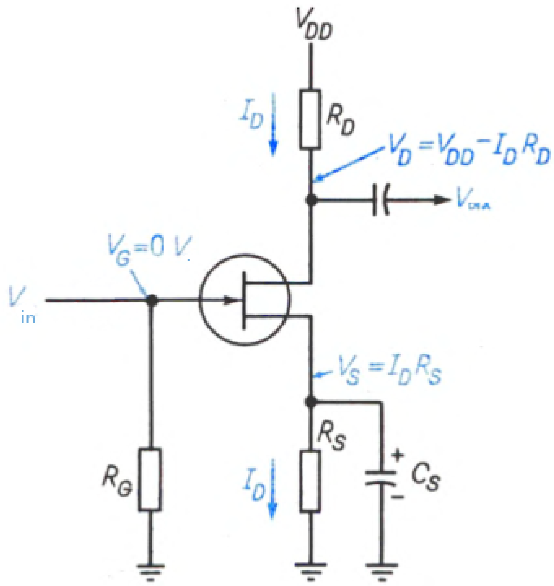


Figure 3: Typical wiring diagram
Joseph D. Greenfield. Practical Transistor and Linear Integrated Circuits

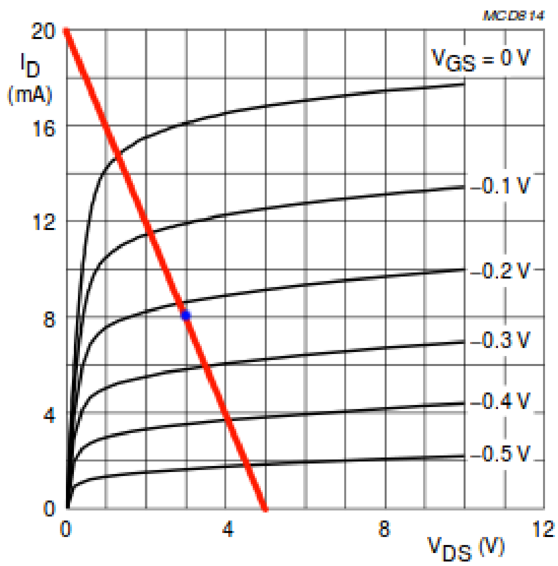
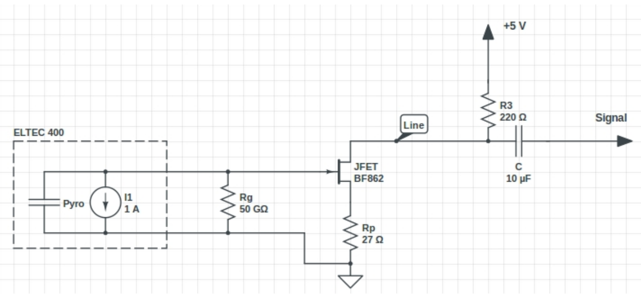


Figure 4: Drain current as a function of drain-source voltage; typical values
BF862 datasheet



(a) Shematic of preamp

(b) Preamplifier (prototype)

Other

There are some other very important things for stable work of amplifier:
1) Shielding. All parts of amp must be is shield. Very sensitive is gain of the transistor, so we must check twice if this place is shielded.
2) Power supply. I give power supply from battery and in this case sow much smaller 50 Hz component, so we must give very good and stable power for preamp.
3) Working with 50 GOm is hard. So it will be fine to wash detector from flux etc and give all condition that input resistor will respond to it nominal.
4) If we want to work with BNC connectors, we can work only with two wires. So I propose make wire from drain of transistor sligtly longer and put Rd and out capasitor on mean amp board. In this case we have only 2 wires (GND and wire from drain).

Main amplification

Since the output of pre-amplifier invert signal, it is necessary to invert it again. For this I use the negative input of the operational amplifier. Also, because the signal from the detector can be either positive or negative, and then the capacitor cut DC component, it is necessary to slightly upraised or lower signal. It is also realized through the first operational amplifier. Then second operational amplifier amplify the signal. I control two operational amplifiers by using 256 bit digital potentiometers. Then on the circuit is 12 bit ADC. For its stability measurements I use the reference source at 4.096 V, so the signal is digitized millivolts. Conection ADC is done by SPI, and communication with potentiometers for I2C.Each potentiometer has its own unique address. For the stability of the power supply I use three voltage source. One for potentiometer, ADC, operational amplifiers and reference source, and other for detectors. Last PS is for Raspberri Pi. This is for unification power of board. As shown by the test, the last PS strongly heated due to large current passing through it ($\sim$ 700 mA). Therefore, it is installed on the radiator and cooler. Temperature inside box stabilized at value of 33° what is normal. In general board use less than 1 A. The powering of board require 12V ($>$ 2 A) power supply. Communication with the external world is realised by using Raspberri (Ethernet).

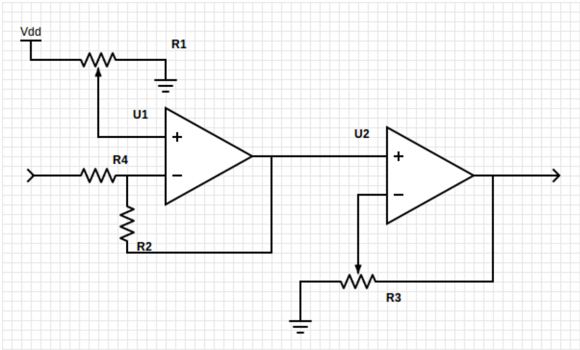


Figure 5: Block-sheme of amplification

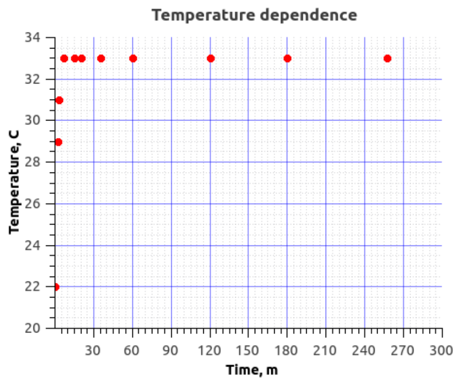


Figure 6: Temperature dependence inside board

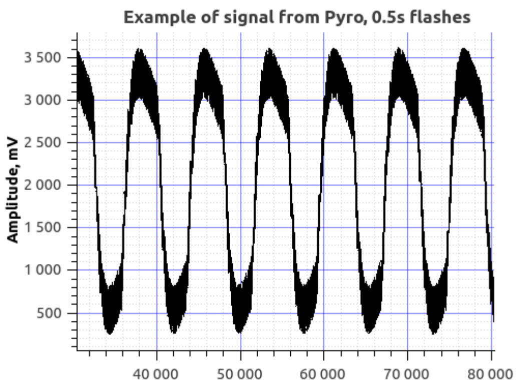


Figure 7: Typical response

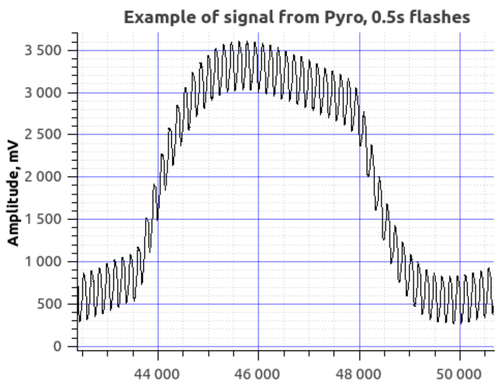


Figure 8: Typical response (zoom)

Conection with board

All connection with board is realized throw RaspberryPi. For it purpose I write programs (for RP -server and UserComp - client) to communicate. Features of the work described in ReadMe files to the programs.
...to be continued...

Install requirement

To start to work with i2c and spi on raspberry first You must activate them. Open LXTerminal and enter the following command:

sudo nano /etc/modules

and add these two lines to the end of the file:

i2c-bcm2708
i2c-dev

Then

sudo nano /etc/modprobe.d/raspi-blacklist.conf

and comment

blacklist spi-bcm2708
blacklist i2c-bcm2708

Install this tool for testing potentimeters.

sudo apt-get install i2c-tools

To avoid having to run the I2C tools at root add the 'pi' user to the I2C group:

sudo adduser pi i2c

Reboot

sudo reboot

If You type

sudo i2cdetect -y 1

You must see 8 addresses with potentiometers.

Copy program for raspberry (that I send) and type make in this folder. Follow the instructions in ReadMe file.

Testing of the board

1 Check Your Power supply. It must be 12V 1-2A, GND out, positive inside. If cooler work it mean that power of board is present. If leds on raspberry blink, than power of raspberry is also present.

2 Connect to the raspberry. Connect raspberry to the router and You computer to this router. Find IP of raspberry (on web-page of router or with ip scanner). If there is no RP in net, check connection of raspberry (Three leds near usb on RP must be on (2 green 1 yellow)). Type on Your computer:

  shh -X pi@IP

  where IP - is ip of raspberry.

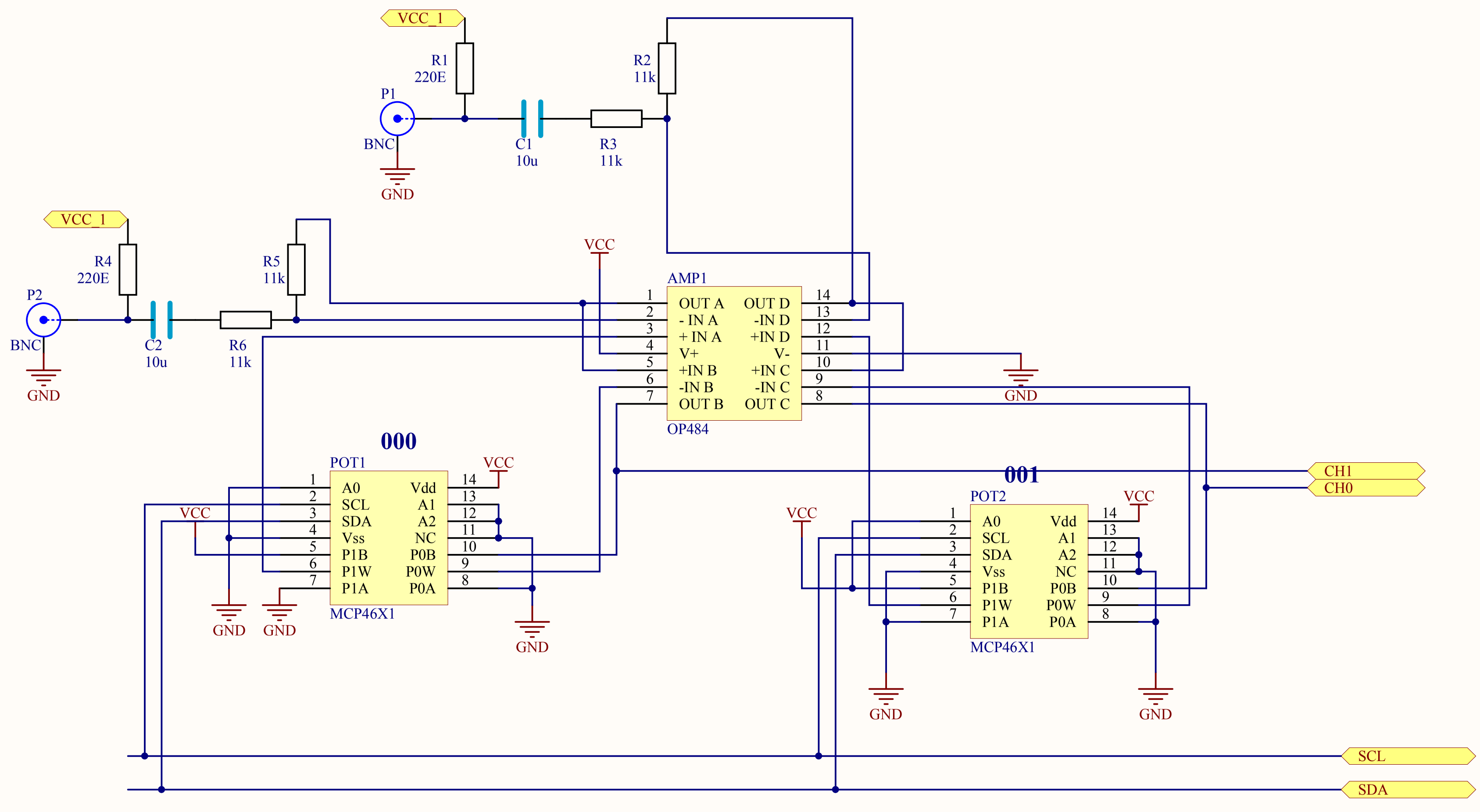
3 Check if potentiometers is ok.

  sudo i2cdetect -y 1

  There must be 8 numbers strarting from 0x28. If there ansver all addresses ask me what to do (Hodnevuch@gmail.com). If there is no addresses check bus.

4 Start Program for raspberry and then start on You computer program for user. Follow the instructions in ReadMe files.

Enjoy! =)



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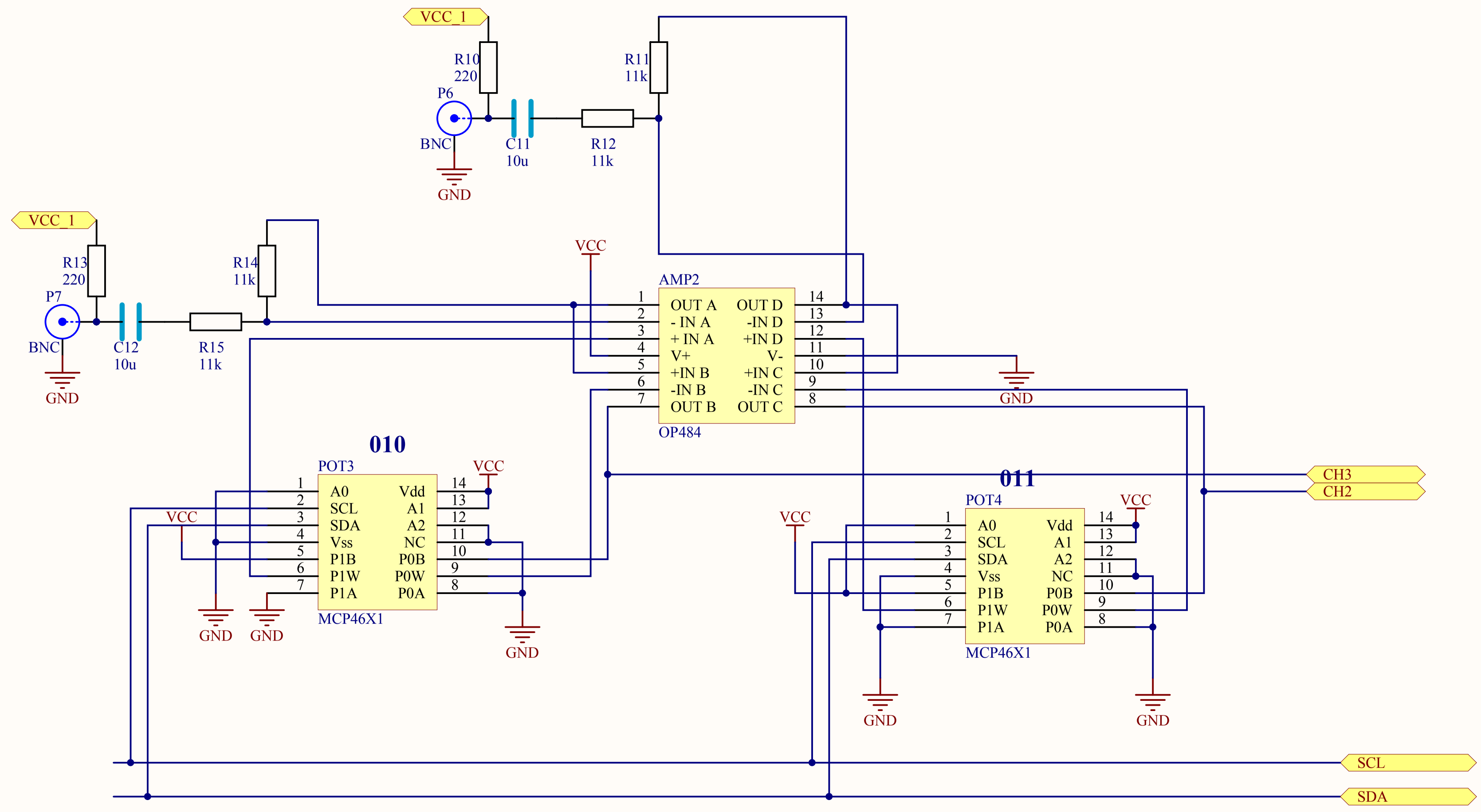

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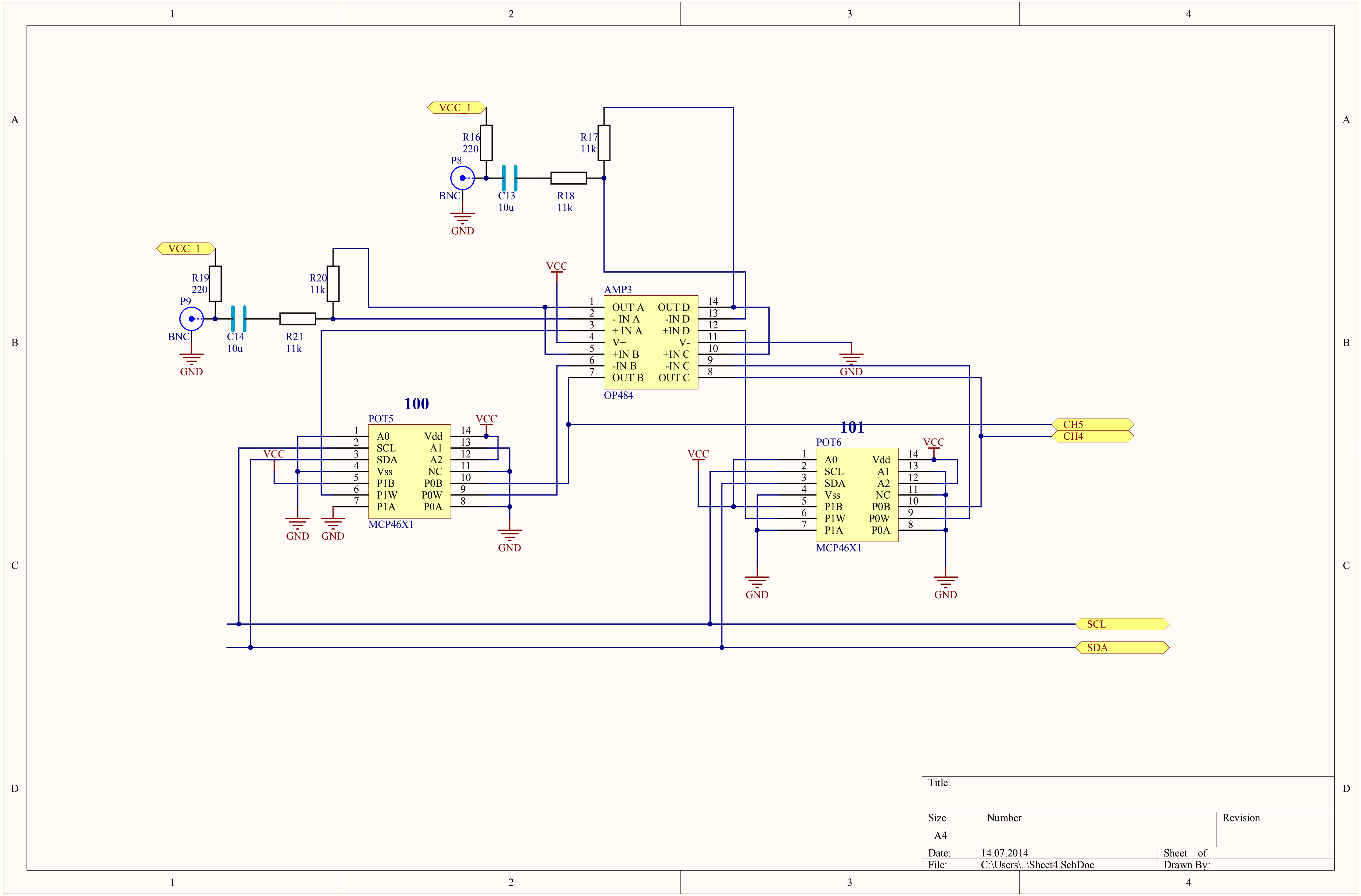

VCC_1
R16
220
P8
BNC
GND
C13
10u
R18
11k
R17
11k
VCC_1
R19
220
P9
BNC
GND
C14
10u
R21
11k
R20
11k
VCC
AMP3
OUT A
- IN A
+ IN A
V+
+IN B
-IN B
OUT B
OUT D
-IN D
+IN D
V-
+IN C
-IN C
OUT C
OP484
GND
100
POT5
A0
SCL
SDA
Vss
P1B
P1W
P1A
Vdd
A1
A2
NC
P0B
P0W
P0A
MCP46X1
101
POT6
A0
SCL
SDA
Vss
P1B
P1W
P1A
Vdd
A1
A2
NC
P0B
P0W
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MCP46X1
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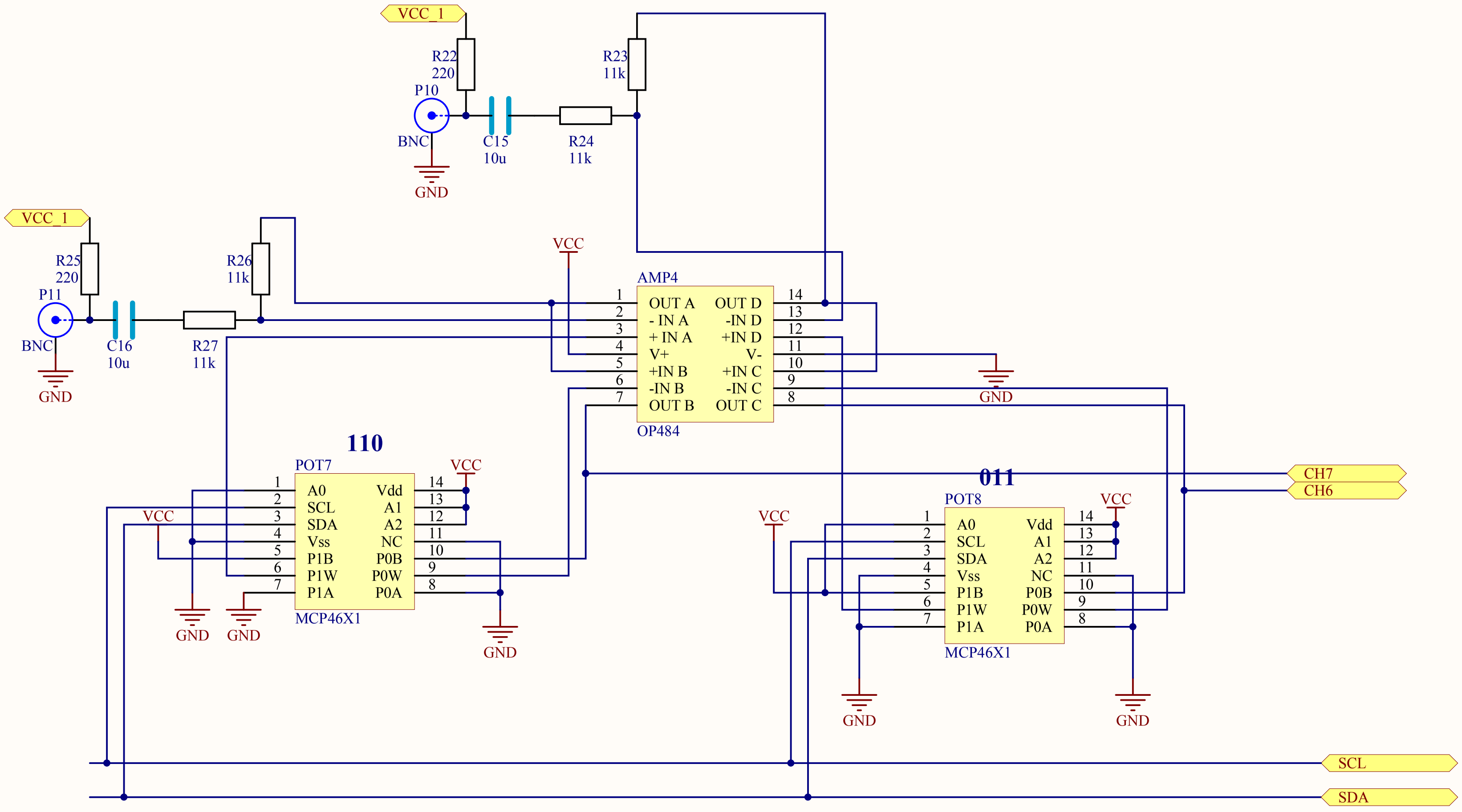

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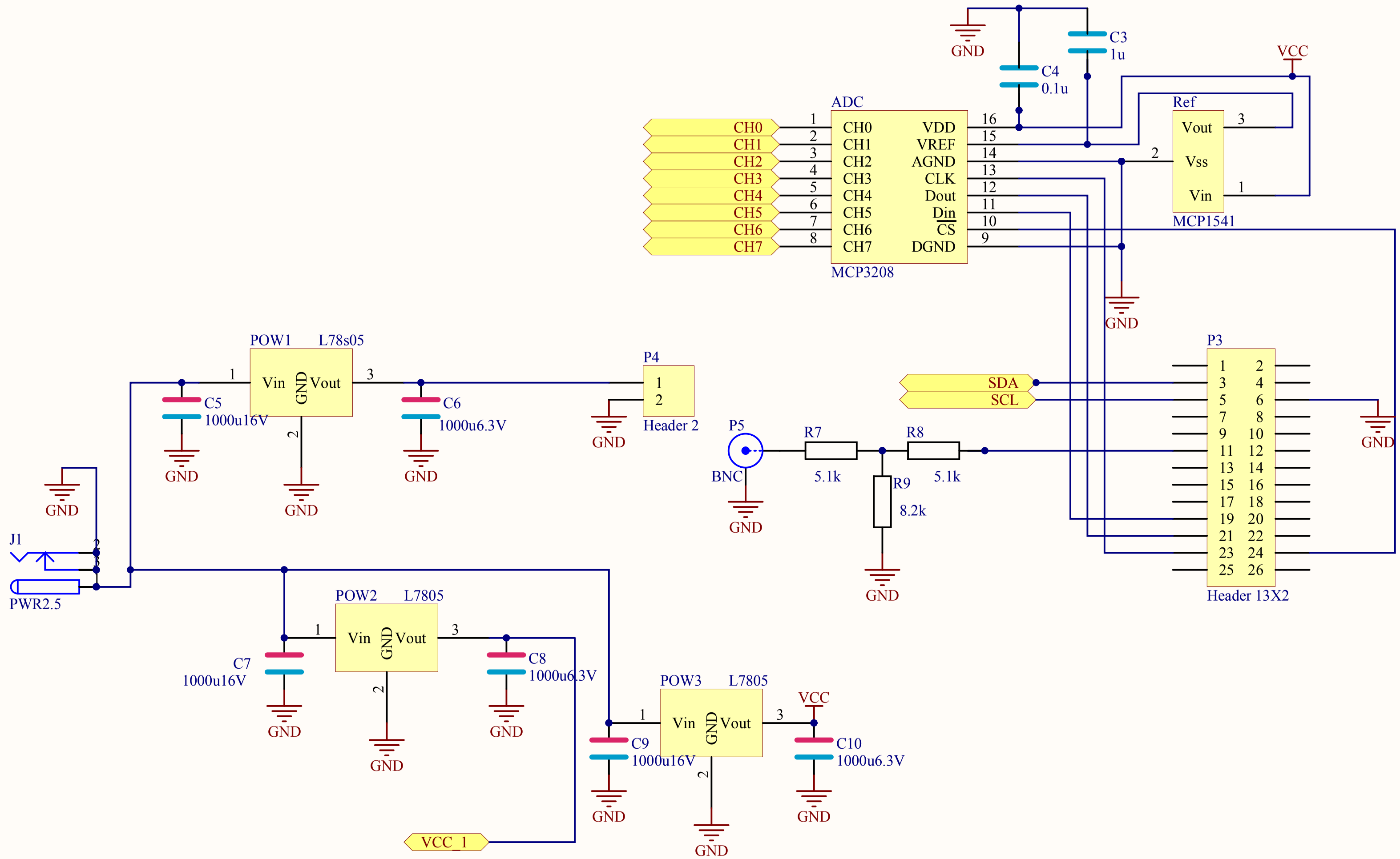

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Comment	Description	Designator	Footprint	LibRef	Quantity
MCP3208	ADC, 12bit, 8ch, SPI	ADC	MCP3208	MCP3208	1
OP484	OP. AMP., quadrus	AMP1, AMP2, AMP3, AMP4	OP484	OP484	4
Capasitor	10u	C1, C2, C11, C12, C13, C14, C15, C16	RC	Capasitor	8
1u	1u	C3	RC	Capasitor	1
0.1u	0.1u	C4	RC	Capasitor	1
1000u16V	1000u 16V	C5, C9	C_b	C1000_16V	2
1000u6.3V	1000u 6.3V	C6, C8, C10	C_s	C1000_16V	3
	1000u 16V	C7	C_b	C1000_16V	1
PWR2.5	Low Voltage Power Supply Connector	J1	KLD-0202	PWR2.5	1
BNC	BNC Elbow Connector	P1, P2, P5, P6, P7, P8, P9, P10, P11	BNC_RA CON	BNC	9
Header 13X2	Header, 13-Pin, Dual row	P3	HDR2X13	Header 13X2	1
Header 2	Header, 2-Pin	P4	HDR1X2	Header 2	1
MCP46X1	Dig. Potentiometer, 256b, i2c	POT1, POT2, POT3, POT4, POT5, POT6, POT7, POT8	MCP46X1	MCP46X1	8
L78s05	Voltage Stab.	POW1	L78s05	L78s05	1
L7805	Voltage Stab.	POW2, POW3	L7805	L7805	2
Resistor	220, 11k, 11k, 220, 11k, 11k, 5.1k, 5.1k, 8.2k, 220, 11k, 11k, 220, 11k, 11k, 220, 11k, 11k, 220, 11k, 11k, 220, 11k, 11k, 220, 11k, 11k	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13, R14, R15, R16, R17, R18, R19, R20, R21, R22, R23, R24, R25, R26, R27	RC	Resistor	27
MCP1541	Ref. Voltage Source	Ref	MCP1541	MCP1541	1