

The RDAM PCB: Why and How?

AvionicsDuino, March 2026

Introduction

The RDAM has a single PCB that manages all EMS and EFIS sensors. It is primarily designed for Rotax engines, but with some minor adaptations depending on the sensors used, it can be adapted to other engines. These notes provide information on the choices made in designing this printed circuit board, the reasons behind them, how it is organized, and how the component values were calculated.

Inputs

Ratiometric inputs for resistive sensors

- Oil temperature (150° VDO sensor)
- Cylinder head temperatures for cylinders 2 and 3 (150° VDO sensors)
- Oil pressure (VDO resistive sensor)
- Coolant temperature (120° VDO sensor)

Non-ratiometric inputs:

- 4 EGT
- 2 currents
- 1 AFR
- Keller Oil Pressure Sensor

Other inputs

1 inside air temperature sensor (One Wire)

1 intake manifold pressure sensor

1 absolute barometric pressure sensor (static pressure)

2 differential pressure sensors (Pitot probe, AOA)

ADC (Analog to Digital Converter)

Multiple tests have confirmed the limitations of the ESP32's ADCs. Therefore, external ADCs are used. We chose the ADS7828 from Texas Instruments [1], which is not too expensive. It has been extensively tested: 12-bit, 8 channels, I2C interface, with the option to use either an external reference or an internal 2.5-volt reference. We couldn't find an 8-channel, 12-bit ADC that is more efficient (with SPI connection and dual power supply) at a reasonable price. Two external ADCs are needed—one for ratiometric sensors and the other for non-ratiometric sensors, since the reference voltage differs between the two cases.

The ADS7828 are powered at 3.3 volts due to the interface with the microcontroller.

The sensors

With ratiometric resistive sensors, we measure a resistance by comparing it to a precision resistor of known value. The external reference voltage is the 3.3-volt power supply, which is not critical; it can fluctuate slightly without affecting the measurement result. In fact, only the accuracy of the resistor in series with the sensor is critical.

For non-ratiometric sensors, we measure a voltage by comparing it to the internal, very precise, 2.5-volt reference. The EGT and AFR controllers output a voltage between 0 and 5 V. The current measurement amplifiers provide an output voltage between 0 and the 3.3-volt supply voltage, with no proportional relationship to that voltage. The Keller oil pressure sensor (see below) provides a signal with a voltage between 0.4 and 1.5 V, assuming a maximum pressure of 7 bars and a series resistor of 100 ohms. The signals from all non-ratiometric sensors are conditioned by the input stage to bring them into the 0 to 2.5-volt range, allowing comparison with the ADS7828's internal 2.5-volt reference.

Power Supply 3.3 Volts

The resistive dividers of the temperature and pressure sensors are powered by 3.3 V through an LDO linear regulator LDL1117S33R [2]. A second LDL1117S33R supplies the remaining analog components, in particular the two ADS7828 ADCs.

Sampling

It is advantageous to sample the input signal as fast as possible, then filter it digitally. But this also depends on the sensors' update rate. This point is not limiting for temperature sensors. For EGT (Exhaust Gas Temperature), the response time of the thermocouple amplifier used (AD8495 [3]) is about 40 μ s, making it compatible with very fast sampling. For the AFR (Air-Fuel Ratio) controller used (PLX SM-AFR [4]), the refresh rate is unknown. The response time of the Bosch LSU4.9 O₂ sensor [5] is at best 150 ms, but the sensor's controller may update the analog output voltage faster. In fact, nothing prevents fast sampling.

What about RC filters?

Do they have any interest? We can perform very effective digital filtering. So, to avoid complicating the circuits, the RDAM PCB does not include any analog filters, neither passive RC filters nor active filters.

LTspice simulations show that a 100 μ F capacitor between the input pins of the instrumentation amplifiers (see below) significantly improves the output signal. However, such a capacitor, charged and discharged through high-value resistors, greatly delays the changes in certain voltages and clips the amplitudes. A smaller 4.7 μ F capacitor was chosen.

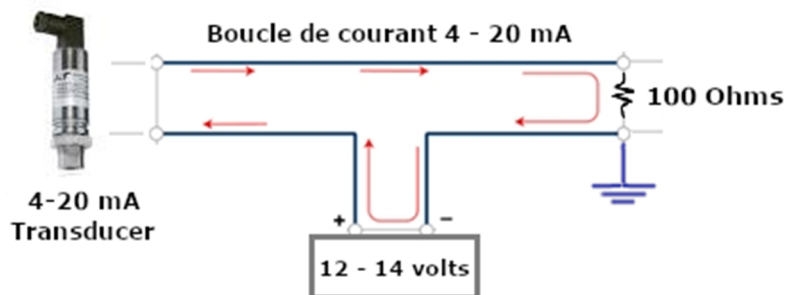
A 47-ohm resistor and a 1 μ F ceramic capacitor are placed between each input stage output and the corresponding ADC input. This is not an RC filter but a matching network [6] designed to protect the operational amplifiers from transient sampling disturbances at the ADC input, to provide a charge reservoir for recharging the ADC sampling capacitors, and to isolate the channels from each other during their scanning by the input multiplexer.

Keller oil pressure sensor

Confusion has been maintained by Rotax, notably due to errors and inaccuracies in SI-912-020R8 [7], which followed the widespread adoption of this sensor in all engines starting in 2012. The graph on page 2, section

79-00-00, of this document is incorrect. The notion of a measured pressure range extending from 0.75 bars to 10.75 bars (for 4 to 20 mA in the current loop) was, to say the least, exotic, knowing that the technical sheet of the Keller sensor used (PAA-21Y [8]) states a range from 0 to 10 bars. It's unclear why Rotax would have had Keller manufacture a sensor specifically for OEM use with a range of 0.75 to 10.75 bars. Moreover, Dynon [9] has physically tested this sensor and claims that the range indeed goes from 0 to 10 bars. MGL says the same [10]. Additionally, Keller's documentation does not specify this, but the sensor is an absolute pressure sensor, as indicated in Rotax's installation manual. In this manual, it is also specified that at ground level with the engine off, due to the "electrical configuration of this sensor," the displayed value can be 0.2 bars (3 psi) instead of zero (displayed by what? This is not specified...), depending on QNH and altitude. Therefore, it is very likely that the sensor's range is 0-10 bars, with 0 bar corresponding to absolute vacuum and 4 mA corresponding to standard atmospheric pressure of 1013 hPa. This sensor can be powered by the onboard electrical system at 12 to 14 V. To measure the current it provides, following the principle of a current loop, it must be placed in series with a fixed shunt resistor (R_{shunt}), across which a voltage is measured, which can then be converted into pressure. The maximum oil pressure of the Rotax 912 is 7 bars, so there is no need for the upper part of the range between 7 and 10 bars. The graph in the Rotax installation manual shows a current loop value of 15 mA at 7 bars.

Since an ADS7828 is used with its internal reference voltage (V_{ref}) of 2.5 V, R_{shunt} and the AD8237 instrumentation amplifier (see below) must generate a maximum voltage of 2.4 volts for a current of 15 mA. With $R_{shunt} = 100$ ohms (the value adopted by MGL [10]), the voltage across R_{shunt} will range from 0.4 to 1.5 volts for currents from 4 to 15 mA. If a negative offset of 0.3 volts is introduced on V_{in-} , and the gain is set to 2, the differential between the V_{in-} and V_{in+} pins of the AD8237 varies between 100 mV and 1.2 volts, and the output of the AD8237 ranges from 200 mV at 0 bar to 2.4 volts at 7 bars.



Input stages

Instead of individual op-amps, like in the Teensy EMS, with all their precision external resistors, we initially considered using integrated instrumentation amplifiers, such as the INA128 or INA333. But these conventional instrumentation amplifiers (in-amps), based on 3 op-amps, are not designed for such use, namely differential and common-mode voltages exceeding 1 V and a low gain between 1 and 2. Simulations show that we systematically go beyond the limits set by the common-mode voltage vs. output-voltage graph [11-13]. We then considered using a 'two-op-amp in-amp' [14, 15], but the number of external resistors would be the same as with the current system. Furthermore, with this solution, achieving a just-acceptable common-mode rejection ratio (CMRR) of only 63 dB would require many very high-precision external resistors.

Therefore, we decided to implement an in-amp based on a different technology, the AD8237 [16]. This in-amp is based on an indirect current feedback architecture that provides an excellent input common-mode range. It is perfectly suited for our specific case. Simulations in LTSpice and in Analog Devices' Diamond Plot Tool [17] confirmed this. This chip also includes anti-RFI (radio frequency interference) filters. It only requires two external resistors to set the gain, and it is not too expensive.

Input stage architecture

An example is shown in the LTSpice schematic below (Fig. 1).

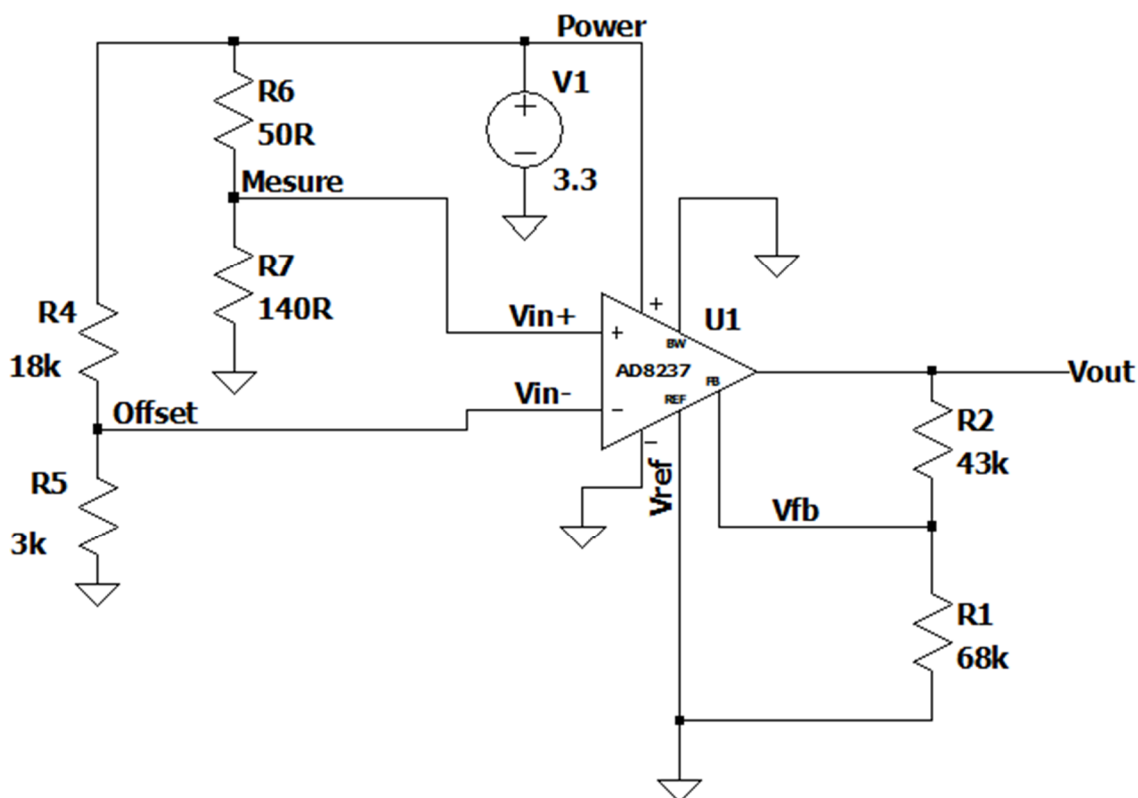


Figure 1 : Schéma LTSpice d'un étage d'entrée du RDAM

The V1 3.3 V source corresponds to the power supply voltage. The resistor values are calculated for a VDO first-generation resistive Rotax oil pressure sensor, whose resistance varies between 10 Ω (0 bars) and 140 Ω (7 bars) (see the AvionicsDuino webpage on this sensor). The sensor is represented here at its maximum value of 140 Ω by resistor R7. The optimal R6 resistor to maximize the difference between the R6/R7 voltage divider's minimum and maximum output voltages is 37 Ω (which yields a 1.90 V difference). However, the current flowing through the R6/R7 voltage divider would then be quite high. We chose an R6 value of 50 Ω , which offers a good compromise: a nearly identical difference (1.88 V) with a more acceptable current. The minimum and maximum voltages at the R6-R7 voltage divider output are then 0.55 V and 2.432 V. Resistors R4 and R5 are selected to generate an offset voltage of 0.47 V, connected to the inverting input of the AD8237 instrumentation amplifier. The R6/R7 voltage divider output is connected to the non-inverting input of the instrumentation amplifier. The current drawn by the Vin+ and Vin- inputs of the AD8237 is nearly zero (<1nA), so the output voltages of the voltage dividers are not affected (whereas this could be different with the Teensy EMS, whose input stages are designed differently). When R7 has a resistance of 10 Ω , the differential voltage

at the amplifier input is $0.55 - 0.47 = 0.08$ volts. When R7 has a value of 140Ω , the differential voltage becomes $2.432 - 0.47 = 1.962$ V. If these two differential voltages are amplified by 1.6324 (system gain = $1 + R2/R1 = 1.6324$), then Vout varies between 0.13 volts and 3.20 volts. This is perfect for a ratiometric sensor because the ADC compares this voltage to an external reference of about 3.3 volts. More precisely, the ADC actually compares the values of the two resistors R6 and R7, using a 4095-bit digital representation of the supply voltage. Hence, the need for R6, R5, and R4 to have a tolerance of 0.1% or, even better, 0.05%.

For a non-ratiometric sensor that provides an absolute voltage output to be measured, the values of the offset and gain resistors must be calculated so that the voltage output Vout does not exceed 2.4 volts, to compare it to the ADS7828's internal reference of 2.5 volts.

To avoid a complex calibration, almost all resistors used in the RDAM have a 0.05% tolerance, and some have a 0.1% tolerance. These resistances also have low temperature coefficients.

How to calculate the value of R7 knowing R6 and the digital value at the ADC output?

That is the problem with ratiometric sensors.

Let's say that the output of the R6/R7 voltage divider is directly connected, without an input stage, to a 12-bit ADC, and that the power supply voltage of this divider also serves as the external reference for the ADC. The integer digital value adcRead output by the 12-bit ADC can take any value between 0 and 4095, depending on the output voltage of the divider.

Knowing R6, we could then calculate the value of R7 without involving the supply voltage of the voltage divider, since this supply voltage is also the reference for the ADC:

We would have $R7 = \text{adcRead} * R6 / (4095 - \text{adcRead})$

But there is an input stage that introduces an offset and a gain, which must be accounted for as follows.

Let's calculate a Theoretical Numerical Value at the Output of the Voltage Divider, and call it TNVOVD.

$\text{TNVOVD} = (\text{adcRead}/\text{Gain}) + \text{digital offset}$

The digital offset dOffset is calculated as follows:

$\text{dOffset} = 4095 * R5 / (R4 + R5)$

For example, if, as shown in the LTspice schematic in Figure 1, $R5 = 3 \text{ k}\Omega$ and $R4 = 18 \text{ k}\Omega$, then $\text{dOffset} = 585$

So the value of R7 in Figure 1 becomes:

$R7 = (\text{TNVOVD} * R6) / (4095 - \text{TNVOVD})$

In the case of a ratiometric resistive sensor, the supply voltage is therefore irrelevant. This voltage can fluctuate without any issue. However, the values of resistors R4, R5, and R6 are critical. The same applies to resistors R1 and R2, which determine the gain.

Calculation of resistances for the different inputs

All the resistor numbers below (R1, R2... etc.) refer to the LTSpice schematic in Figure 1 and not to the resistor numbers in the Kicad files of the RDAM.

Ratiometric inputs

First-generation resistive oil pressure sensor

We just saw the calculation above:

$R1 = 68 \text{ k}\Omega$, $R2 = 43 \text{ k}\Omega$, $R4 = 18 \text{ k}\Omega$, $R5 = 3 \text{ k}\Omega$, $R6 = 50 \Omega$

68k, 43k, 18k, and 3k are easily available values with a tolerance of 0.05%. But for R6, a 50 Ω 250 mW 1206 resistor is used, which is only available in 0.1%. The power dissipated when $R7 = 10 \Omega$ is 150 mW, so a 0.125 W resistor would be insufficient.

The R6 divider + sensor has a minimum resistance of $50 + 10 \Omega$, totaling 60 Ω , with the engine off and zero oil pressure. During normal cruising, with a pressure of 3 bars: $50 + 70 = 120 \Omega$.

The temperature sensors for the cylinder heads and oil (150°, VDO 323-057, Rotax 965531)

Sensor resistance ranges from 23 Ω (at 140°C) to 353 Ω (at 50°C), resulting in an optimal R6 resistance of 91 Ω , with divider output voltages ranging from 2.6236V to 0.6658V.

A gain of 1.5806 and an offset of 0.5877 then yield ADC input voltages between 0.1234 and 3.2180 volts.

To obtain this offset, we use resistors R4 of 18k and R5 of 3.9k.

To achieve this gain, $R1 = 62\text{k}$ and $R2 = 36\text{k}$

These 5 resistor values are available in 0.05%

For these 3 sensors, each R6/sensor divider has a total resistance of at least $91 + 23 \Omega = 114 \Omega$, with the engine (very) hot, or 38 Ω for the resultant of the 3. When the engine is cold, $91 + 353 = 444 \Omega$, or 148 Ω for the resultant of the 3.

The coolant temperature sensor (120°, VDO 323-095, not in IPC Rotax)

Sensor resistance ranges 14 Ω (at 120°C) to 190 Ω (at 50°C), resulting in an optimal R6 resistance of 52 Ω , the closest available value being 56 Ω , with divider output voltages ranging from 2.5488V to 0.66V.

A gain of 1.5912 and an offset of 0.5395 then yield ADC input voltages ranging from 0.1917 to 3.1972 volts.

To obtain this offset, resistors R4 of 22k and R5 of 4.3k are used.

To achieve this gain, $R1 = 68\text{k}$ and $R2 = 40.2\text{k}$

Four of these 5 resistance values are available with 0.05% accuracy. But for R6, there is only a 0.1% accuracy at 250mW/0805, which is sufficient, see below.

For this sensor, the R6/sensor divider has a total resistance of at least $56 + 14 \Omega = 70 \Omega$, with the engine (very) hot, resulting in a current through the divider of 59 mA, and therefore a power dissipated by R6 of nearly 0.2W. When the engine is cold, the resistance is $56 + 190 = 246 \Omega$.

Current and power for the ratiometric sensor set

When the engine is cold, there are 5 resistances in parallel: 60 Ω , 444 Ω , 444 Ω , 444 Ω , and 246 Ω . This results in a total of 36 Ω .

When the engine is (very) hot, the 5 resistances are: 120 Ω , 114 Ω , 114 Ω , 114 Ω , and 70 Ω , resulting in a total of 20 Ω .

Let's consider the minimum value of 20 Ω : at 3.3 V, this results in a current of 0.165 A. Therefore, the LDO linear regulator LDL1117S33R provides a good safety margin, as it can supply up to 1.2 A. With a voltage drop from 5.5 V to 3.3 V (i.e., 2.2 V) and a current of 0.165 A, the power dissipated by the regulator is 0.363 W. Without a heatsink, and assuming a junction-to-ambient thermal resistance of 120°C/W with an ambient temperature of 35°C, the junction temperature could reach 35 + (0.363 \times 120) = 78.5°C. Since the maximum junction temperature is 150°C, this safe margin is maintained. There is a copper area on the PCB that enhances heat dissipation. One LDL1117S33R is dedicated solely to these five ratiometric voltage dividers, while another supplies the remaining analog circuitry, including the ADS7828, AD8237, INA296, and OPA388 (see below). The 3.3 V output from the ESP32 powers all digital components: the pull-up resistors for the I2C bus, the CAN transceiver, and the pressure sensors. This configuration ensures the best possible separation between the analog and digital parts of the PCB (see below).

Non-ratiometric inputs

Current measurement

There are no major principle changes compared to the Teensy EMS, but there is a change in the amplifiers: the two input stages are made up of an INA296A3QDGKRQ1 [18], (more precise than the LMP860x used in the Teensy EMS), with a gain of 50. This rail-to-rail amplifier is powered at 3.3 V. With a gain of 50, an output voltage of 3.3 volts corresponds to a voltage of 66 mV across a 0.0025 Ω shunt, which equals a current of 26.4 amperes.

The aircraft's electrical circuit includes two 50 mV/20 A shunts of 0.0025 Ω , allowing measurement of currents at points 2 and 3 in Figure 2, from which the current at point 1 can be deduced.

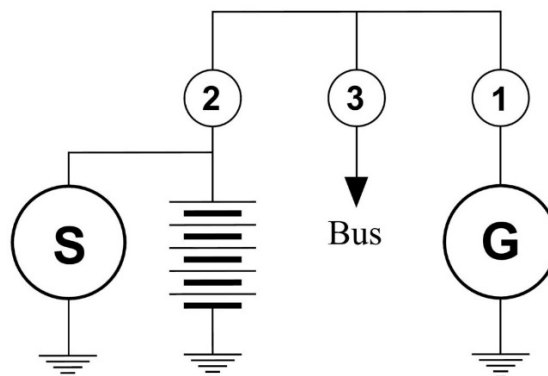


Figure 2: Simplified diagram of an aircraft power distribution system. G: Alternator and voltage regulator. S: Starter. 1,2 and 3: Locations where the current may be measured

The measurement at point 2 is bidirectional. The requirement is to be able to measure currents ranging from -10A to +10A, which is a span of 20A. The measurement at point 3 is unidirectional; the need is to measure currents from 0 to 20A, also a range of 20A. With the chosen amplifier, due to its gain of 50, the bidirectional range actually goes from -13.2A to +13.2A, and the unidirectional range from 0 to 26.4A.

At point 2, bidirectional, and for these currents, the voltage across the shunt varies between +33 mV and -33 mV, which is a measurement range of 66 mV.

At point 3, unidirectional, the voltage varies from 0 to 66 mV.

For a unidirectional measurement, the REF1 and REF2 pins of the INA296A3QDGKRQ1 must be connected to ground. The output voltage is referenced to ground.

With REF1 connected to the 3.3-volt power supply and REF2 to ground, a bidirectional measurement referenced to +1.65 volts is obtained.

The output of the amplifier that manages the unidirectional point 3 is directly connected to the ADC input, whose reference voltage is only 2.5 V. An output voltage of 2.5 volts from the amplifier is generated by a 50 mV voltage across the shunt, which corresponds to a maximum measurement current of 20 A, which is more than sufficient. Beyond 20 A, the display will remain locked at 20 A.

The output of the amplifier that manages point 2 bidirectional is connected to a voltage divider (24k and 75k) that reduces the maximum voltage from 3.3 volts to 2.5 volts, then to a precision operational amplifier (OPA388QDBVRQ1 [19]) serving as a buffer before the ADC. This results in an effective range from -13.2 A (for an ADC input at zero volts) to +13.2 A (for an ADC input at 2.5 volts), passing through 0 A at an ADC input of 1.25 V (see fig. 3).

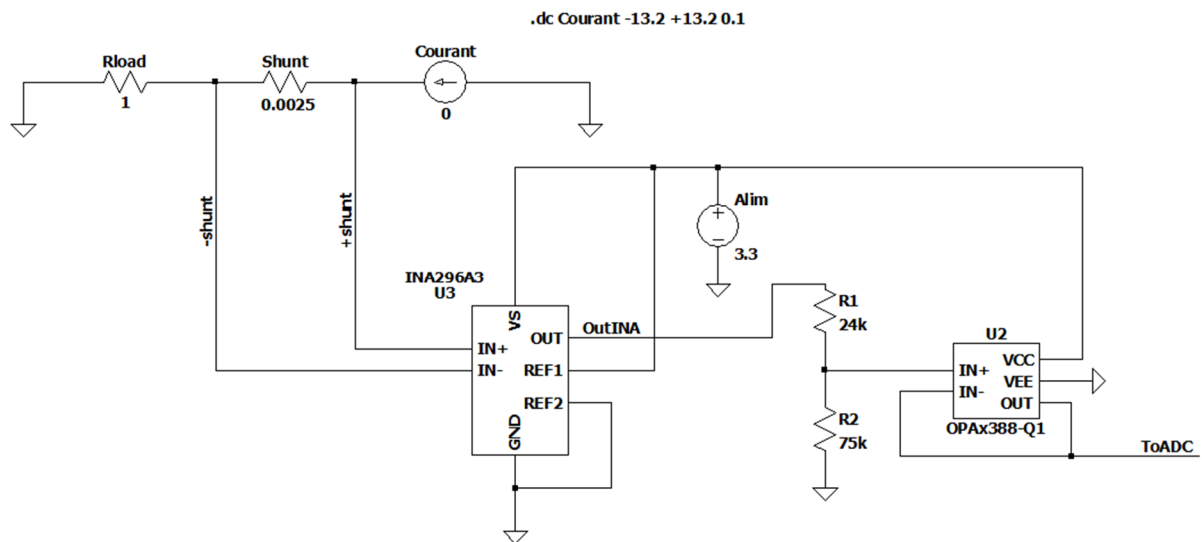


Figure 3: LTspice schematic of the input stage for bidirectional current measurement.

Keller oil pressure sensor

It is powered by 14 volts from the aircraft's electrical system. As mentioned earlier, the current loop must be closed at the EMS input with a 100 Ω shunt resistor.

The electrical diagram of the input stage is identical to that of Figure 1, but without the R6 resistor. R_{shunt} is represented by R7.

The voltage at the R_{shunt} terminals ranges from 0.4 to 1.5 V for currents between 4 and 15 mA. Vin- is biased at 0.3 V (negative offset), and with the gain set to 2, the differential between Vin- and Vin+ spans from 0.1 to 1.2 volts. Consequently, Vout varies from 0.2 volts at 0 bar to 2.4 volts at 7 bars.

For the 0.3-volt offset, R4 = 20k and R5 = 2k, and for the 2 gain, R2 = R1 = 22k

EGT and AFR

The controllers of these sensors provide a variable voltage ranging from 0 to 5 volts, linear and exactly proportional to the measured quantity. Therefore, there is no need for offset or amplification; just divide the voltage by 2 to match the 0-2.5 volt range of the ADC, along with an impedance-matching buffer. The output impedance of the AFR controller and that of the AD8495 thermocouple amplifier [3] are unknown. However, it is reasonable to assume it is low enough to directly feed a voltage divider made of two 22 k resistors without significantly dropping the signal voltage. Thus, we can omit the first operational amplifier used in the Teensy EMS input stage, which is only intended to prevent loading the output of these controllers. A single op-amp (OPA388QDBVRQ1) configured as a buffer (voltage follower) is sufficient (see fig. 4).

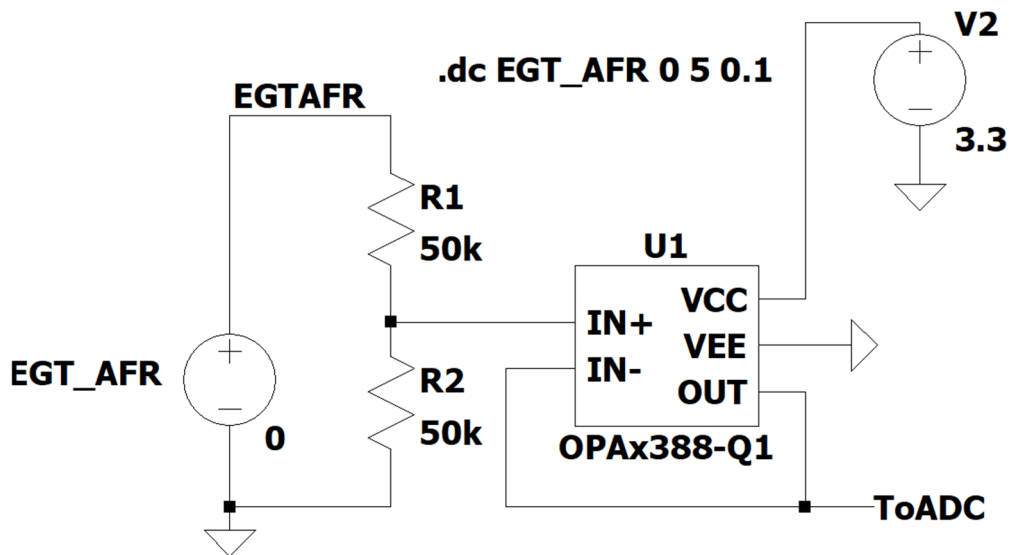


Figure 4: LTspice schematic of the EGT and AFR input stage. In the RDAM, the values of resistors R1 and R2 are actually 22 k Ω , not 50 k Ω .

Horizontal Organization of the PCB RDAM

The PCB is organized into several functional areas (Fig. 5).

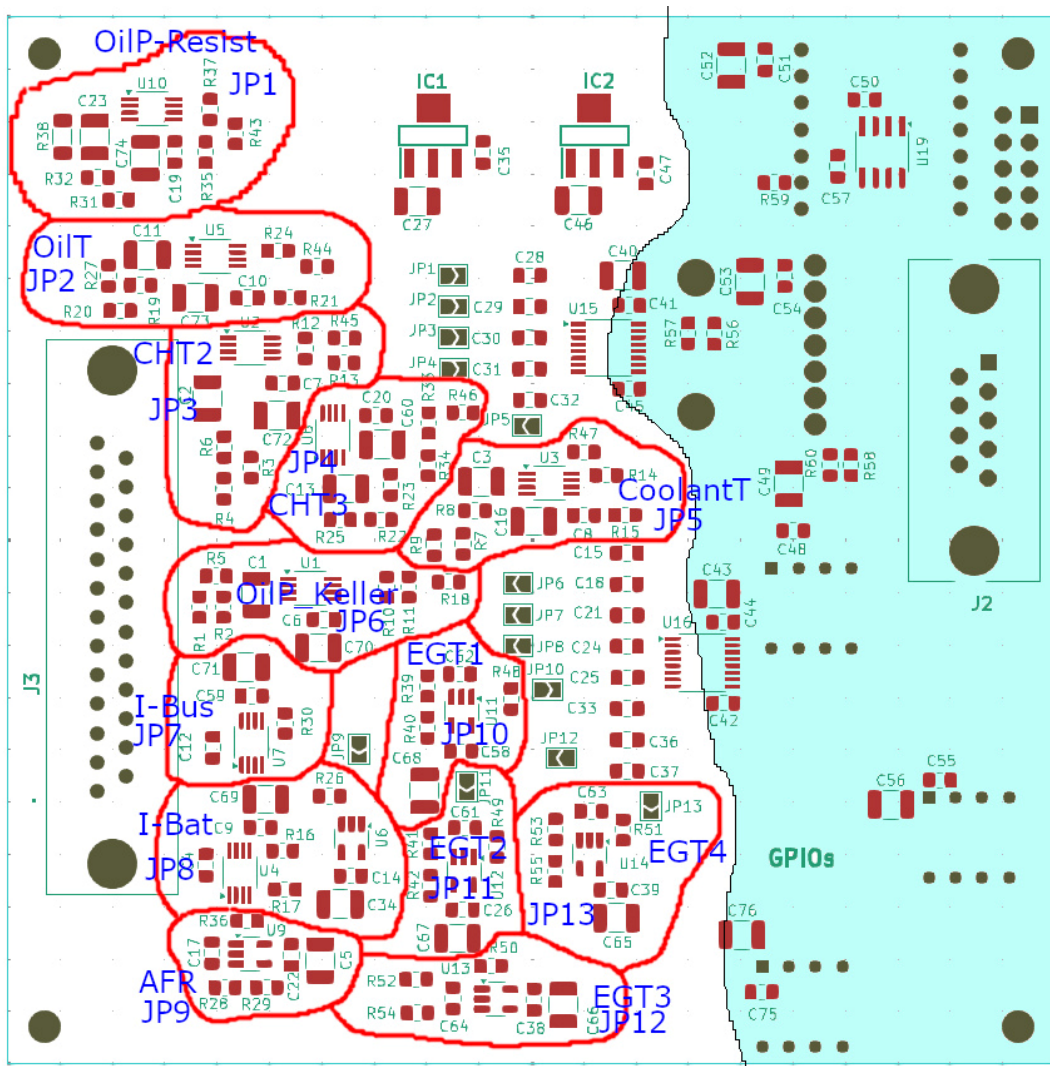


Figure 5: The areas of the RDAM PCB

In Figure 5, the bluish area on the right corresponds to the digital part, while the white area on the left corresponds to the analog part. To minimize interference, it is indeed essential to clearly separate these two areas (please see below).

The two ADS7828 analog-to-digital converters are placed at the boundary between these two main zones. As we will see later, in the last paragraph *Separate ground planes or single ground plane*, the importance of this separation and of a single, common ground plane is emphasized.

In the analog section, the components of the input stages of each sensor are grouped into well-defined areas, outlined in red in figure 5. Thus, if a function of the RDAM is not needed, it is enough not to solder the relevant components and to connect the corresponding ADC input to ground by soldering the relevant solder jumper (JP). In this case, you can also omit soldering the capacitor of the matching network located on the relevant ADC input. For example, if the OilP_Keller function is not needed, you should not solder the components in the red-circled area, solder JP6, and omit soldering C15. To prevent leaving the unused input traces floating, you can connect the relevant pins of the D-Sub 25 connector to ground. For example, in the previous case with the OilP_Keller function unused, you can connect pin 20 to ground. There will still be

some pads or small pieces of floating trace, but they will always be closely surrounded by copper surfaces connected to ground.

Vertical organization

For interference limitation, it is just as important as the horizontal organization.

We chose a 4-layer PCB partly to increase component density and reduce the size of the PCB and RDAM, but also to significantly enhance the EMI/EMC (Electromagnetic Interference / Electromagnetic Compatibility) performance of the PCB.

With a 2-layer PCB, there's no question: one layer is dedicated to the ground plane, and the other contains all components, signals, and power traces. Routing can be challenging because minimizing layer changes for signal traces (vias) is important.

With a 4-layer (or more) PCB, the first step is to determine the optimal stack-up. Which layer serves which function? A common stack-up looks like this:

Signals - GND - VCC – Signals (SIG – GND – Power – SIG)

This stack-up is increasingly criticized for a number of reasons. The first comes from the single ground plane design, which favors the closest signal face at the expense of the other. In fact, the copper layers are not uniformly distributed in height throughout the cross-section. They are arranged as depicted in Figure 6.

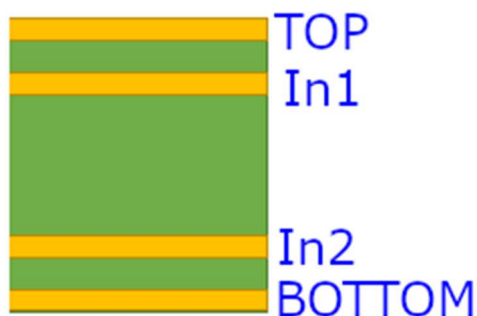


Figure 6: Cross-section of a 4-layer PCB, copper in yellow, dielectric in green

In the diagram of Figure 6, the copper layers are yellow, and the insulating layers (dielectric) are green. It can be seen that the central insulating layer (core) is significantly thicker than the outer insulating layers (prepreg).

A classic stack-up is schematized in Figure 7.



Figure 7: The classic SIG – GND – Power – SIG stack-up.

In this stack-up, the TOP/SIG layer benefits from a solid ground plane, while the BOTTOM/SIG and Power layers are at a disadvantage. However, having a ground plane nearby is crucial for EMI/EMC compliance. The return path for high-frequency currents follows the path of least impedance, not resistance. The lowest impedance is directly underneath the signal trace in the ground plane via capacitive coupling. Without a ground plane or with a poor one, high-frequency current return paths become inadequate, potentially forming large return-current loops that can lead to electromagnetic interference. Remember, a low-frequency square-wave signal produces significant high-frequency harmonics, especially due to its short rise and fall times.

For these reasons, and as it is now recommended by many experts, the RDAM stack-up is inspired by the following: SIG + Power – GND – GND – SIG + Power (Fig. 8)

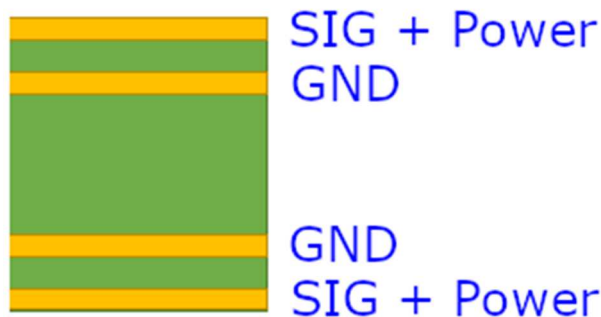


Figure 8: The SIG + Power – GND – GND – SIG + Power stack-up

This arrangement treats low-power traces as signal traces, which is fully acceptable. One could argue that having two ground planes instead of just one is a waste of layers, but on the other hand, this arrangement offers a major advantage in terms of signal integrity and EMI/EMC.

The following equivalent layout (Fig. 9) was chosen for the RDAM; it greatly facilitates routing:

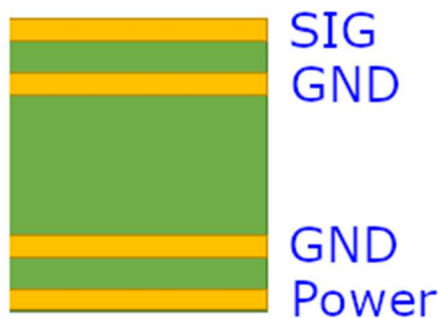


Figure 9: The SIG – GND – GND – Power stack-up of the RDAM.

For the same EMI/EMC reasons, it is crucial that whenever a signal or power trace passes through a via or a through-hole conductor to go from the TOP layer to the BOTTOM layer (or vice versa), the via or conductor is immediately surrounded nearby by one or more vias connecting the two GND layers.

It is also important to “close” the PCB outline with closely spaced ground vias along the entire edge cut of the PCB. Empirically, a spacing of 5 mm has been chosen for these edge vias.

An aspect of EMI/EMC prevention, which is often debated, involves filling all free spaces between signal and power traces on the TOP and BOTTOM layers with copper connected to ground through vias. Although its effectiveness is debated, there seems to be no downside, as long as no copper island between traces remains floating. These copper areas are connected to the internal ground planes by closely spaced vias. This method

is known as “Copper pour and via stitching.” The spacing of these stitching vias can be regular or random. A random pattern helps prevent potential high-frequency resonance phenomena. The RDAM PCB contains several hundred vias spaced randomly, which does not increase the manufacturing cost.

Separate analog and digital ground planes, or single ground plane?

For a long time, it was believed that, when designing mixed PCBs— analog and digital—it was preferable to have separate and isolated ground planes: one for the analog part, and the other for the digital part. But having two separate and isolated grounds (AGND and DGND) within the same system is not possible unless there is no physical connection or interconnection between the two systems. In the general case of a single system, the two grounds must therefore be connected at least at one point. This raises questions: where should the common point be located, and what size should it be? In other words, what shape should the mixed PCB take? For example, one can imagine the following shapes:

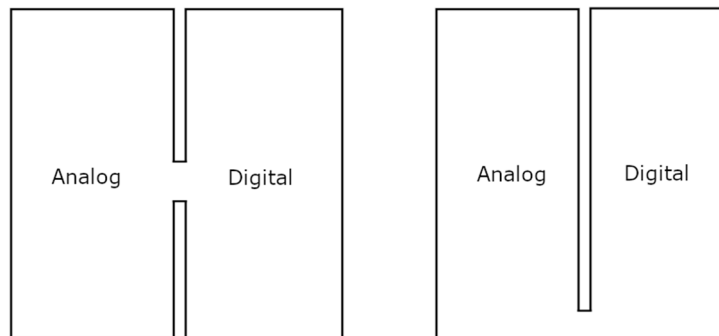


Figure 10: Mixed PCBs with separate ground planes connected at a single point.

One can also imagine a simple rectangular PCB, without a notch, but with two separate ground planes (ground plane splitting, split plane).

But then, how do you address the issue of connecting to the chassis or enclosure? At one point or two points on the PCB? How do you solve the power supply problem? How and where to route the traces connecting the digital part to the analog part? How to avoid ground loops that generate interference?

These complex issues are addressed very clearly and didactically in two articles by Sanjay Pithadia and Shridhar More [20, 21].

It is clearly demonstrated that a single partitioned ground plane should be used. The conclusion is: “So for any PCB layout, the important points are to use a single ground plane, partition it into analog and digital sections, and apply discipline in routing.”

These principles are applied in the RDAM PCB. The digital and analog parts are separated; there is only one ground plane, consisting of the two internal layers, and almost no traces cross the virtual partition of the ground plane (Fig. 11).

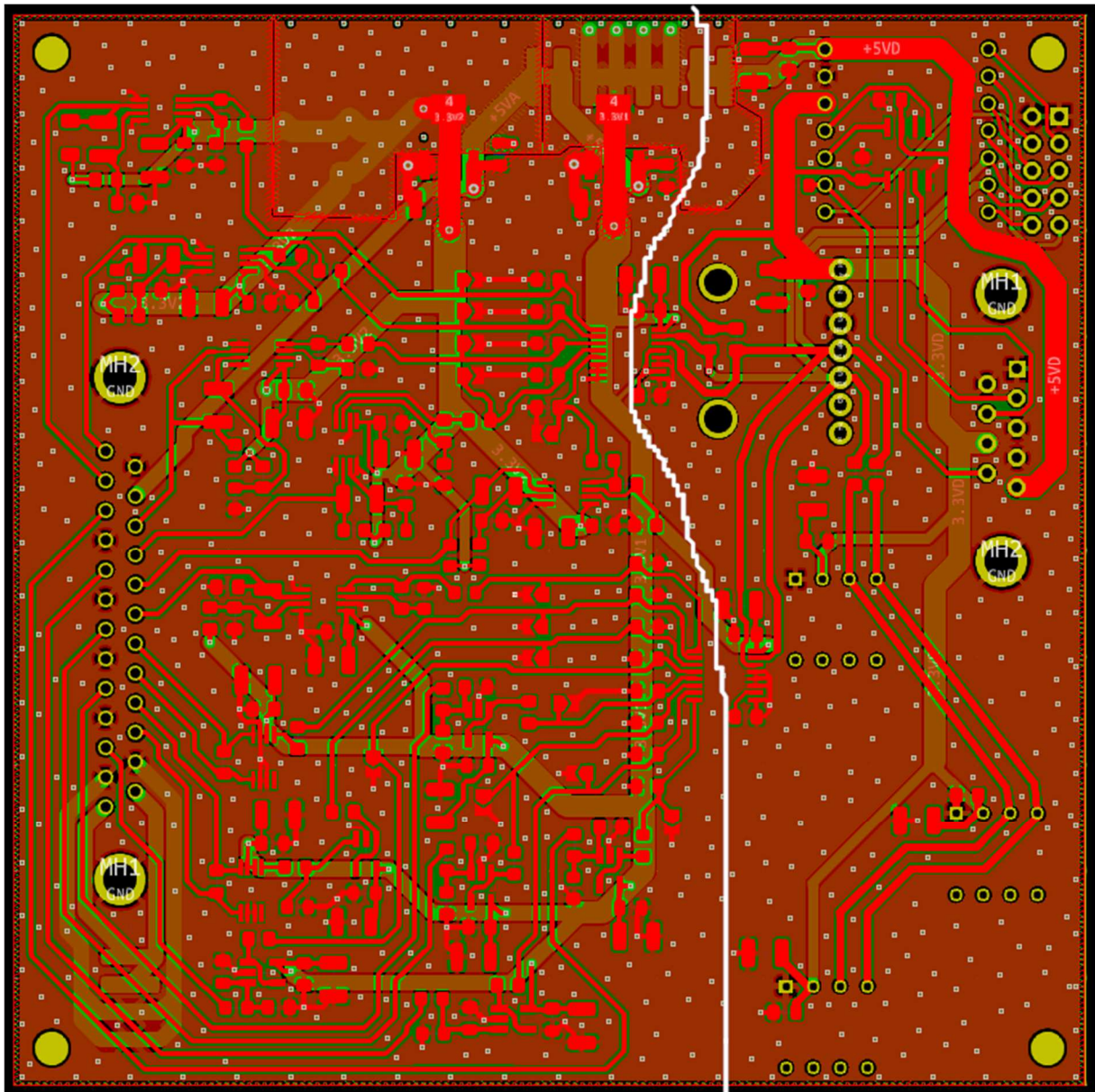


Figure 11: In white, the boundary of the partition between the analog section on the left and the digital section on the right.

References

- 1) <https://www.ti.com/lit/ds/symlink/ads7828.pdf>
- 2) <https://www.st.com/resource/en/datasheet/ld11117.pdf>
- 3) https://www.analog.com/media/en/technical-documentation/data-sheets/ad8494_8495_8496_8497.pdf
- 4) <https://www.plxdevices.com/Wideband-O2-Air-Fuel-Ratio-Sensor-Module-p/897346002726.htm>
- 5) https://www.bosch-motorsport.com/content/downloads/Raceparts/Resources/pdf/Data%20Sheet_69034379_Lambda_Sensor_LSU_4.9.pdf
- 6) <https://electronics.stackexchange.com/questions/622140/how-to-choose-the-rc-values-between-a-buffer-and-an-adc-input#:~:text=The%20RC%20filter%20is%20there,easier%20for%20it%20to%20handle>

- 7) https://legacy.rotaxowner.com/si_tb_info/serviceinfo/si-912-020-r8.pdf
- 8) <https://download.keller-pressure.com/api/download/8Ls5MtHNCdS8NgffyPLvee/en/latest.pdf>
- 9) <https://forum.flydynon.com/threads/rotax-oil-pressure-pn-456180-definition-wrong.11767/>
- 10) <https://www.mglavionics.co.za/Docs/Rotax%20Oil%20Pressure%20Sender.pdf>
- 11) <https://www.analog.com/en/resources/app-notes/an-1401.html>
- 12) <https://www.edn.com/how-instrumentation-amplifier-vcn-vs-vout-plots-change-with-supply-and-reference-voltage/>
- 13) https://www.ti.com/lit/an/slyt647/slyt647.pdf?ts=1760972702674&ref_url=https%253A%252F%252Fwww.google.com%252F
- 14) <https://freecircuitdiagram.com/427-two-op-amps-instrumentation-amplifier/>
- 15) <https://www.analog.com/media/en/training-seminars/design-handbooks/designers-guide-instrument-amps-complete.pdf>
- 16) <https://www.analog.com/media/en/technical-documentation/data-sheets/ad8237.pdf>
- 17) <https://tools.analog.com/en/diamond/#difL=0.1&difR=1.2&difSI=0.1&gain=2&l=0.3&pr=AD8237&r=0.3&sl=0.3&tab=1&ty=2&vn=0&vp=3.3&vr=0>
- 18) <https://www.ti.com/lit/ds/symlink/ina296a-q1.pdf>
- 19) <https://www.ti.com/lit/ds/symlink/opa2388-q1.pdf>
- 20) <https://www.ti.com/lit/an/slyt499/slyt499.pdf>
- 21) <https://www.ti.com/lit/an/slyt512/slyt512.pdf>