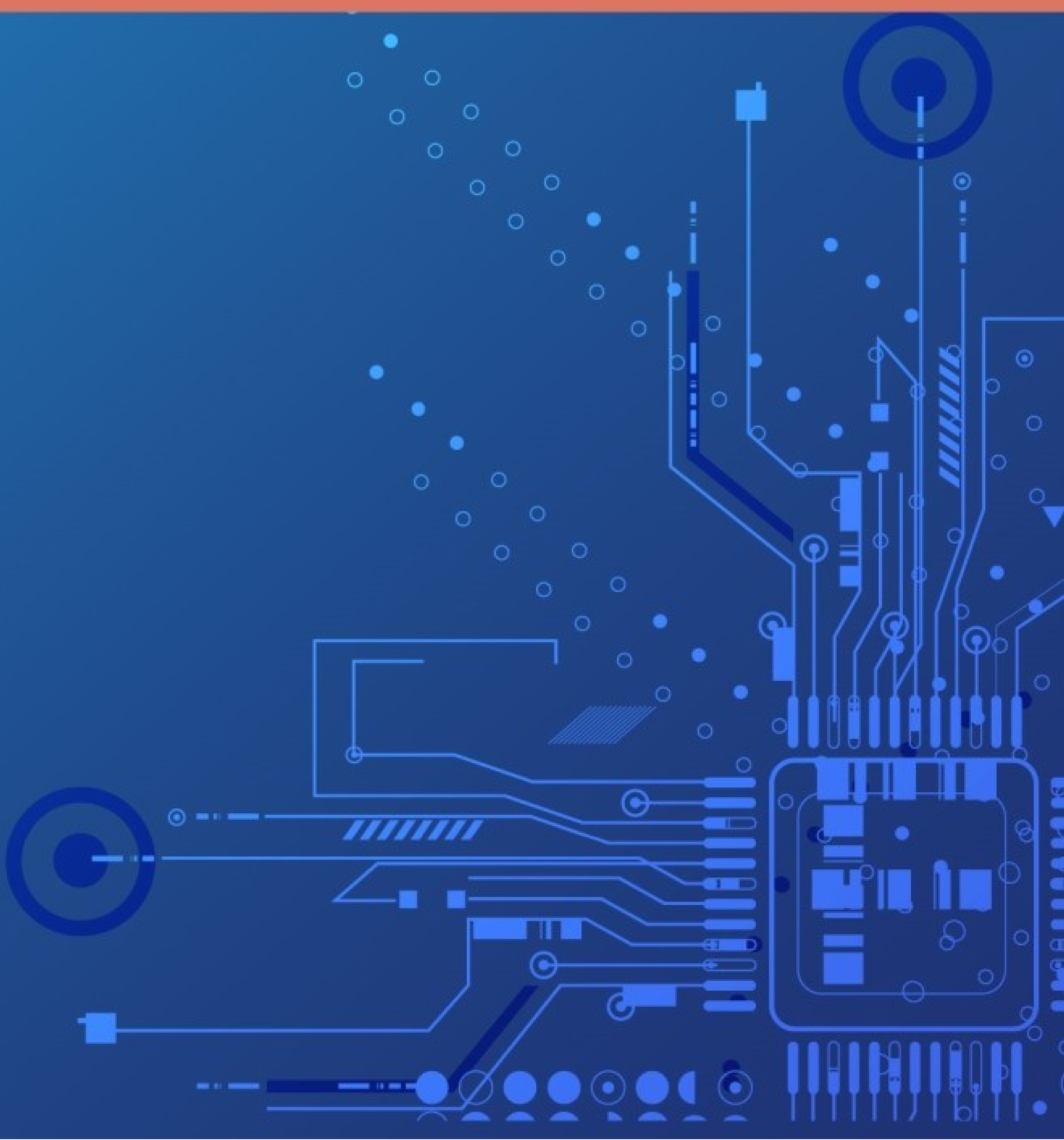
BYTESNAP

Analogue Design

12 tips for electronic product development



Analogue Design – 12 tips for Electronic Product Development

In our modern digital age, analogue design skills are often neglected.

Though analogue is rooted in Ohms Law of 1827, today's IoT driven world remains analogue and these specialist skills are more important than ever for electronics design teams.

Adding analogue circuitry to a design can be daunting for the digital engineer.

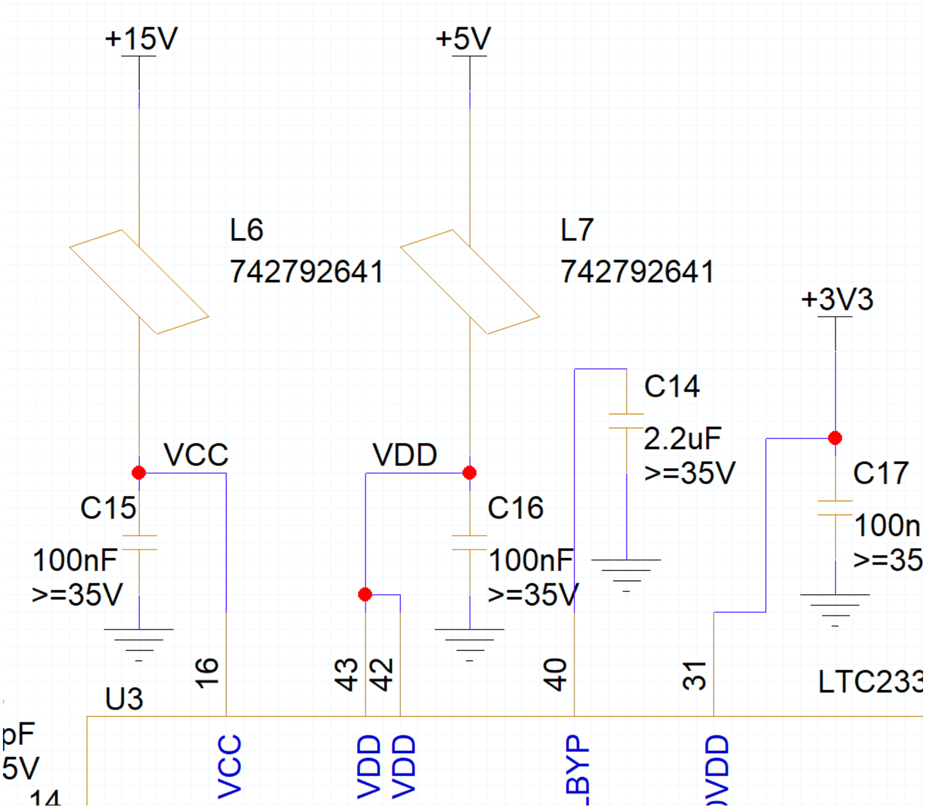
So, our engineering consultants at ByteSnap Design have pulled together a handy guide to help you avoid some common pitfalls.

Top 12 Analogue Design Design Tips
For Electronics Product Development

- Filter sensitive analogue power nets
- Filter analogue signals
- Filter digital signals on mixed-signal components
- Accuracy – use ‘root sum squared’ when calculating total error for a more representative value
- Be aware of non-ideal behaviour when conditioning analogue signals close to the power rails
- When multiple op-amps are required in a circuit, create a low current inverted power supply to allow the use of a true ground and positive and negative power rails
- Separate high-current from low-current returns
- Remember increased temperature can lead to increased noise
- Watch the input current requirements for ADCs. Be sure the signal you are measuring can drive the ADC
- Keep voltage references clean and check the output strength is sufficient
- Voltage regulators supplying power to analogue components should have a high-power supply rejection ratio (PSRR)
- When taking analogue measurements, take into account the accuracy of the measurement instrumentation

Let's go through each analogue design tip in more detail.

1 Filter sensitive analogue power nets



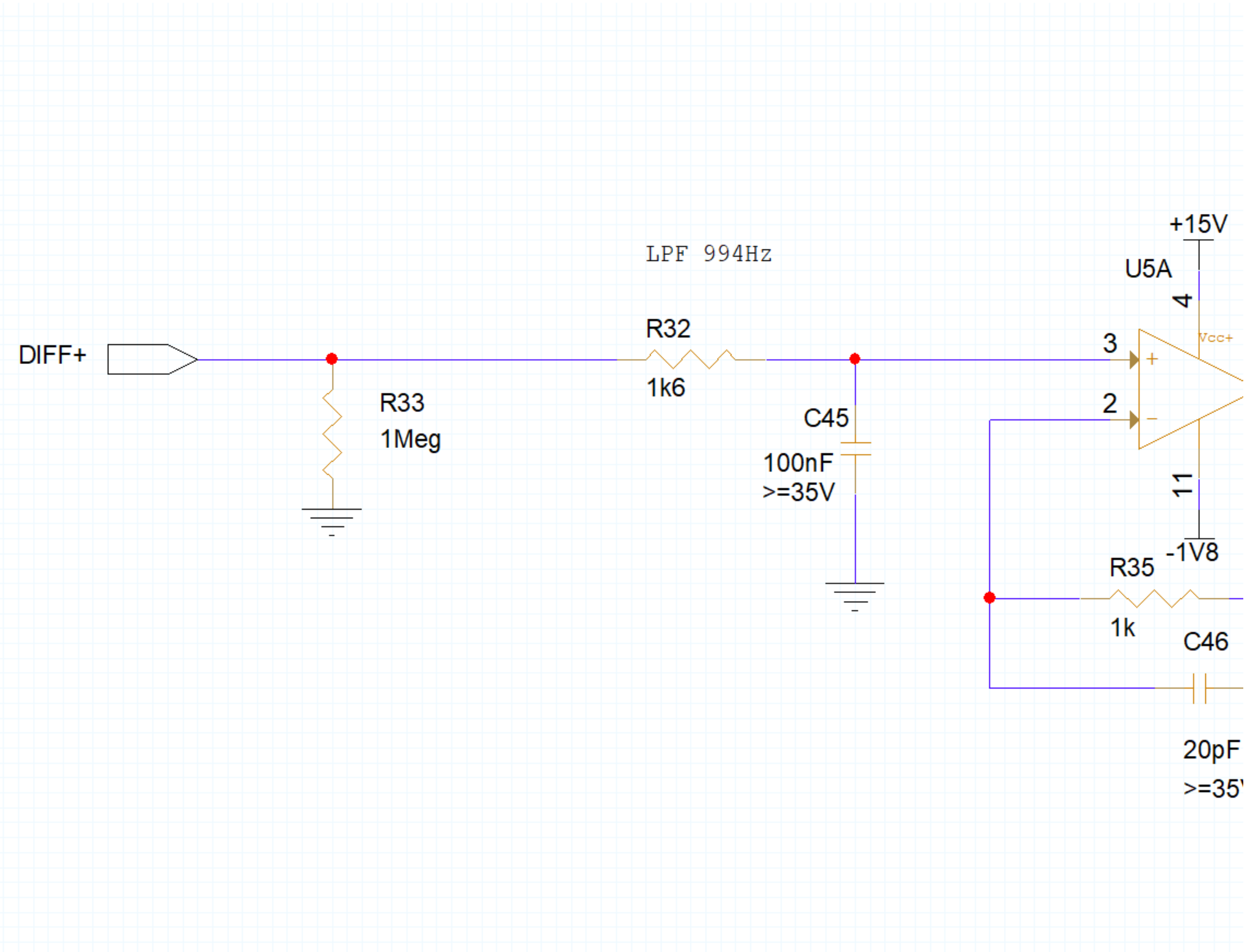
Voltage rails used for sensitive analogue circuitry should be clean and low noise. For mixed-signal PCBs, the switching of digital components and voltage regulators leads to high frequency noise on power rails. Without filtering, this can be coupled into analogue components and affect the accuracy and stability of the circuit. Using passive low-pass filtering is a simple way to reduce high-frequency noise on the analogue Vcc power rails.

If the components you are powering are low current, then a series resistor and shunt capacitor circuit may be used. Otherwise, use an inductor/ferrite and capacitor combination instead. Each of these circuits will block high-frequencies (i.e. noise) but allow low frequencies (i.e. the current to power the analog component).

A mix of capacitor values - such as 100nF, 10nF and 1nF in parallel - can be used together to create a low-pass filter which will operate effectively over a wider bandwidth.

2 Filter analogue signals

Sensitive analogue signals on mixed-signal boards should be filtered. Low-pass filters using ferrites and capacitors will remove high frequency components often caused by digital switching noise, which otherwise could be coupled into analogue integrated circuits.



It's important that the capacitor value and ferrite specification create a cut-off frequency which retains the target analogue signal whilst removing high frequency noise.

If the analogue signal goes to the input of an ADC, then the sampling frequency should be more than double the cut-off frequency of the low-pass filter. This ensures the ADC measurements do not suffer from aliasing.

3 Filter digital signals on mixed-signal components

On mixed signal boards, analogue components such as ADCs and DACs also have digital connections - communications interfaces, for instance.

Noise may be coupled from these digital signals to the analogue circuitry inside the chips. One method of reducing this is by adding ferrites or resistors on the digital lines to the ADC or DAC. This helps to slow the edges of the digital signals and reduces the high-frequency noise.

Naturally, resistor or ferrite specifications should be considered carefully with respect to the rise/fall time required by the particular digital signals. The signal edges may only be slowed so far before signal integrity and timing can become worsened.

An additional consideration for digital signals around mixed signal ICs, is that the digital PCB traces should be routed in a way as to keep them separate from analogue signals - nor should they pass underneath analogue components.

A related concept is that if using a digital component, such as a comparator in a mixed signal-design, it can be advantageous to select a part which is no faster than you require.

A very fast comparator would have a sharp rise time which would contain more high-frequency harmonics and noise (which could couple themselves into analogue tracks and components) than a part with a slower rise-time would.

4 Accuracy – using 'root sum squared' when calculating total error can offer a more representative value

```
Rshunt: 0.1%
Ref: 0.05%
INL: 0.0002%
Offset: zero (0.0012% before internal calibration)
Gain: 0.016% (0.3% before internal calibration)

Total (RSS): 0.11% (0.32% before calibration)
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When designing with analogue components such as ADCs or DACs design engineers are often required to estimate the maximum error of their system. For the example of a DAC, this means calculating the maximum error between the ideal value sent to the DAC and actual output voltage.

As with many systems the total error at the DAC output is caused by a number of separate errors, each of which can contribute to the total inaccuracy. For instance, offset error, gain error and integral non-linearity all play a part in creating error at the DAC output.

However, calculating the total error is often not simply a case of adding up the maximum value of each individual error. It is important to assess whether these individual error sources are correlated or uncorrelated and whether they are random in nature (i.e. do the error values have a normal distribution). If they are uncorrelated and random then we can use the root sum squared (RSS) of these errors to gain a truly representative worst-case error value.

Using the RSS to estimate the total error will give a lower value than if the individual errors were added together which could give a falsely large value for the total error. Using RSS means we can avoid over-designing an analogue circuit which could increase complexity and cost.

5 Be aware of non-ideal behaviour when conditioning analogue signals close to the power rails

When amplifying or filtering analogue signals using operation amplifiers, care must be taken when working with voltage levels which are close to the device power rails.

For instance, single-supply op-amp datasheets describe the ability of the op-amps to accept inputs close to Vcc and Vss, and also to drive outputs close to Vcc and Vss.

Another example: many op-amps will only be able to create a minimum output voltage of Vss+1.5V. Taking the illustration of an op-amp working as a voltage follower; if the input voltage was 0V then the output voltage would be 1.5V!

Of course, many op-amps can provide outputs much closer to Vss, but even op-amps advertised as rail-to-rail will be unable of achieving exactly 0V if Vss is system ground.

Maximum output voltage swing is greatly affected by the load. With careful design, the part could be pushed to its limit and give an acceptable performance.

While both maximum and minimum output voltage must be considered, this issue is more frequent when working on single rail designs with signals from zero volts. There are several methods of dealing with this, including:

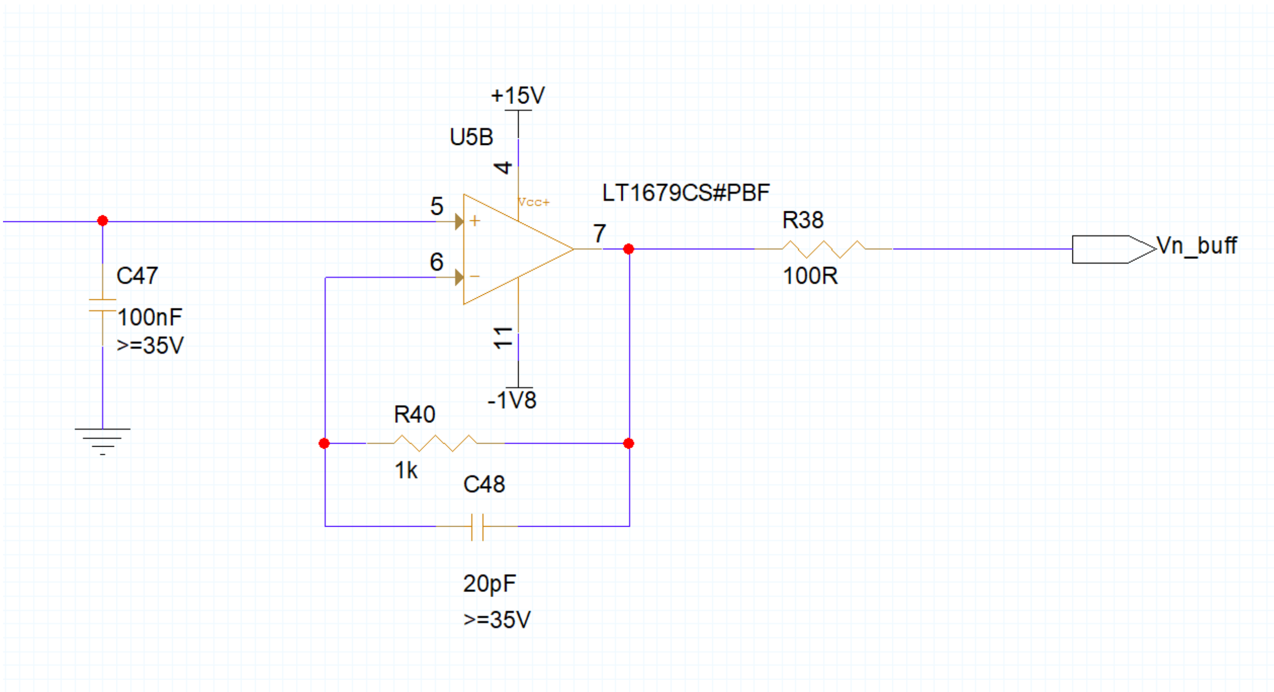
- Adding bias to the amplifier stage - just enough to keep the output away from zero volts.

- Using a dual-supply op-amp and create a low-voltage negative rail to use as the Vss connection.

This means that if 0V was input to the op-amp this would actually be above the Vss; this gives the op-amp the headroom it needs to drive 0V.

6 A better option, when multiple op-amps are required in a circuit, is to avoid single-rail op-amps and instead create a low current inverted power supply to allow the use of a true ground and positive and negative power rails

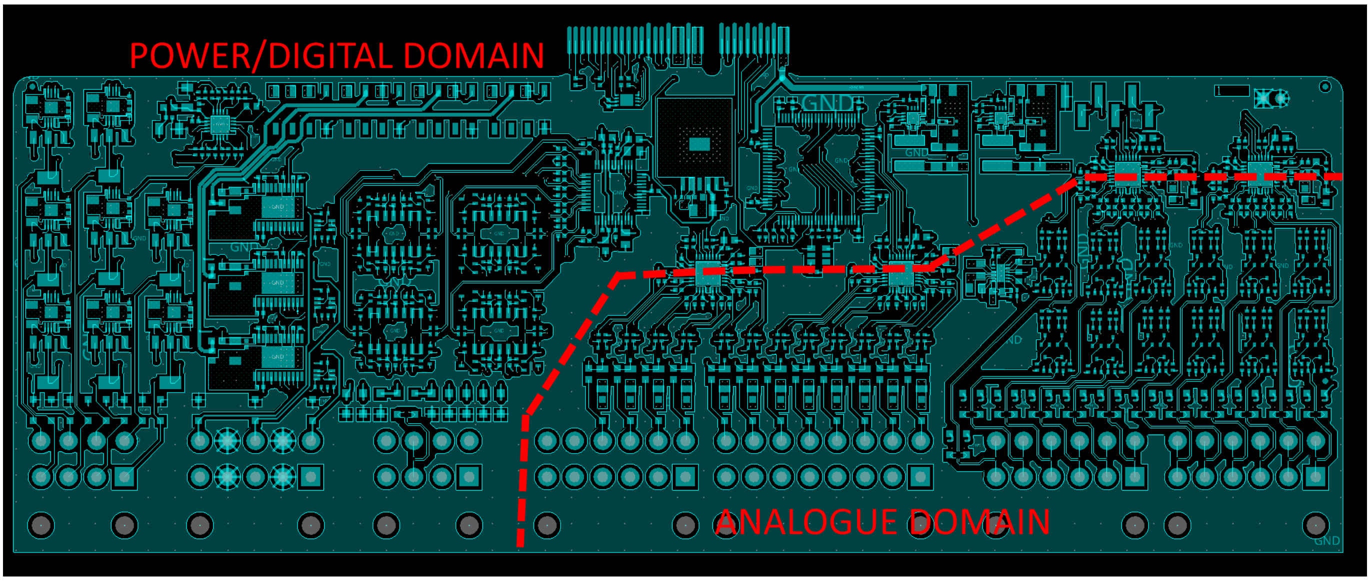
7 Separate high-current from low-current returns



PCBs often use a ground plane as the current return path for components on the PCB. Therefore, this ground plane might carry return currents from many different types of components with different ground currents.

Ground currents from low-power circuitry will be small, but ground currents from high-current and/or switching circuitry such as a motor will be large. This can cause noise and ground bounce on the ground plane due to the non-zero resistance and reactance of the ground plane PCB layer itself.

This noise on the ground plane might adversely affect sensitive analogue circuitry. Thus, the ground return paths for the high-current components and analogue circuitry should be separated.



One method to achieve this is to have analogue components in one section of the board and have the ground plane split between this section and the rest of the PCB. Be aware that this can increase the ground return path length when signals cross from the analogue side to the high-current side of the circuitry.

Having a single point of connection between the analogue ground plane and high-current plane helps to reduce this return path between the two sides of the PCB.

8 A rise in temperature can lead to increased noise

Even before considering the noise caused by the active components in an analogue system, it's important to remember that resistors themselves have thermal noise.

Thermal noise, often known as Johnson noise, is a random noise which manifests itself as voltage fluctuations. This noise increases with resistance and temperature and isn't dependent upon the accuracy or quality of the resistor.

Therefore, any analogue circuit operating at high temperatures or using large resistance values could experience noise problems due to this random voltage noise across the resistor.

This is just one example of how vital it is to be conscious of your environmental requirements and de-rate components accordingly.

9 Watch the input current requirements for ADCs. Make sure the signal you are measuring can drive the ADC

When using ADCs to measure analogue signals with high source impedance, we need to check that the ADC input will read the correct value.

Whilst ADC inputs generally have very low static leakage current, they do require a larger transient current to charge their internal hold capacitors.

If the source has a high-impedance and cannot provide this current, then the hold capacitor may not have charged to the correct voltage before it takes its reading leading to a false result.

If the source to the ADC is unable to provide this current, one method to help with this is to provide a small value capacitor (10nF) close to the ADC input pin to provide the current for the ADC hold capacitor to charge.

A more robust technique is to buffer the analog voltage before it enters the ADC.

The ADC manufacturer may recommend the use of a capacitor filter in the ADC input, with perhaps a low-value series resistor. In this case, ensure that any op-amp driving the ADC is able to handle the capacitive load, as some op-amps may oscillate with such a load.

The ADC manufacturer will often supply datasheets and application notes showing a suitable op-amp.

Some ADCs, in fact, have internal buffers on their inputs to resolve this issue.

10 Keep voltage references clean and check the output strength is sufficient

If your reference voltage is not accurate, stable and low-noise, then all components using this reference will be affected.

Care should be taken to ensure the reference is low-noise and has a large power supply rejection ratio. Even when you've selected a suitable LDO, additional filtering may be required.

It is also worth checking that the reference can provide the current required by the ICs and components it is connected to. If it cannot supply the required current, then the reference voltage may dip or become unstable. One method to combat this problem would be to use a high-accuracy buffer to maintain the precise reference voltage whilst providing a higher current capability.

11 Voltage regulators supplying power to analogue components should have a high-power supply rejection ratio (PSRR)

The voltage supplied to sensitive analogue circuitry should be as low noise as possible. Due to this, it is generally advantageous to use an LDO with a high PSRR to achieve a clean power supply. Whilst switching regulators create switching noise, LDOs typically provide much cleaner rails.

LDO datasheets should be checked in detail for their suitability to analogue supplies. An LDO's PSRR specification is one important parameter to consider and quantifies how much of the AC noise at the input is passed through to the LDO output.

PSRR values are given in dBs and an LDO with a high PSRR value will attenuate much of the noise present at its input and create a cleaner output supply rail.

Achieving a low PSRR is not always as simple as selecting a part with a high PSRR value in its datasheet, because the PSRR performance is affected by other design parameters, such as the difference between the input and output voltage.

12 When taking analogue measurements, take into account the accuracy of the measurement instrumentation

When taking measurements on high-accuracy analogue electronics, the measurement instrument must be accurate enough. Preferably, it should have an order of magnitude greater accuracy than that which your circuit is required to meet. Without checking this, you may end up debugging inaccuracies in your measuring device rather than in your circuit.

For instance, digital multimeters (DMM) will commonly have an error specification of a (% of measured signal) + a number of least significant digits (digits as shown on the DMM display). It is important to take this into account and a DMM may not be accurate enough if you are taking measurements on a circuit hoping to achieve <1% accuracy.

Also, when taking voltage measurements on a DMM always use the lowest voltage range possible.

For instance, if you were to measure a 0.5V analogue reference on the 200V setting on your DMM, the inaccuracy caused by the least significant error would be much larger than if using the 2V setting on the DMM. This is because the least significant digit is much larger for the DMMs 200V range setting than for its 2V setting.

Summary

We hope you have found this selection of tips from our analogue design engineering consultants useful. If you need specialist help with your electronics or software development, we'd love to hear from you.

Visit www.bytesnap.com to find out more!

Further reading

https://www.analogictips.com/supply-and-signal-line-filtering/

https://www.microsemi.com/document-portal/doc_download/129998-ac204-designing-clean-analog-pll-power-supply-in-a-mixed-signal-environment-application-note

https://www.analog.com/en/analog-dialogue/articles/practical-filter-design-precision-adcs.html

https://e2e.ti.com/blogs_/b/analogwire/archive/2013/10/09/dac-essentials-how-accurate-is-your-dac

https://www.analogictips.com/amplifiers-rail-to-rail-single-supply-mean/

https://www.arrow.com/en/research-and-events/articles/principles-of-grounding-for-mixed-signal-designs

https://www.allaboutcircuits.com/technical-articles/electrical-noise-what-causes-noise-in-electrical-circuits/

http://www.ti.com/lit/an/spna061/spna061.pdf

https://www.maximintegrated.com/en/design/technical-documents/app-notes/6/6650.html

https://www.designworldonline.com/how-to-determine-digital-multimeter-accuracy/

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+44 (0) 121 222 5433

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