APPLICATION NOTE

Understanding Hall sensor noise

How precise can you measure with a Hall sensor?

A question often heard: how precise can I measure? What results can I expect?

A short overview of important properties of analog components:

- Linearity
  - Influences how precise it works, the deviation from an ideal straight line
  - This can be calibrated but still non-linearities lead to other problems
  - Note: Our sensors are very linear
- Drift of properties like gain and offset
  - Due to temperature
  - This influences stability and reproducibility
  - Pressure, stress, aging and other influences can also play a role
  - Temperature drifts can sometimes be compensated
  - Note: Our sensors have a very wide temperature range with high stability
- Noise
  - This determines how deep you can measure
  - Explained in this application note
  - Note: Our sensors show low noise

Noise is important as it determines the bottom end of your measurements. Compare it to multimeters. You are measuring 1.999999 Volt.

- A cheaper multimeter has 3½ digit, it should show 1.999 V (2 V range). Due to the meter noise, the last digit is changing all the time. The noise you see is a few mV. You can read and measure 1.99 V, the last digit is undetermined.
- Now you use a 6½ digit multimeter. It should show 1.999999 V (2 V range). Due to the meter noise, the last digit is changing all the time. The noise you see now is a few µV. A factor 1000 better. You can read and measure 1.99999 V.
- If the 6½ digit multimeter would have the same noise as the 3½ digit multimeter, you could only read 1.99 V instead of 1.99999 V even if it has a good precision.

The 6½ digit multimeter is more precise because it has a lower noise (besides more resolution, less drift, better linearity). If it would have the same noise as the 3½ digit multimeter, the last 4 digits would be changing all the time and instead of measuring in the microvolt range you are measuring in the millivolt range:

Noise determines how deep you can measure.

Of course temperature drifts and other errors matter too. Also static errors and slow changes over time add to the error budget. These errors will however only influence the absolute precision, not the resolution.

Resolution gets better with lower noise.

An easy way to do Hall measurements

The noise density diagram

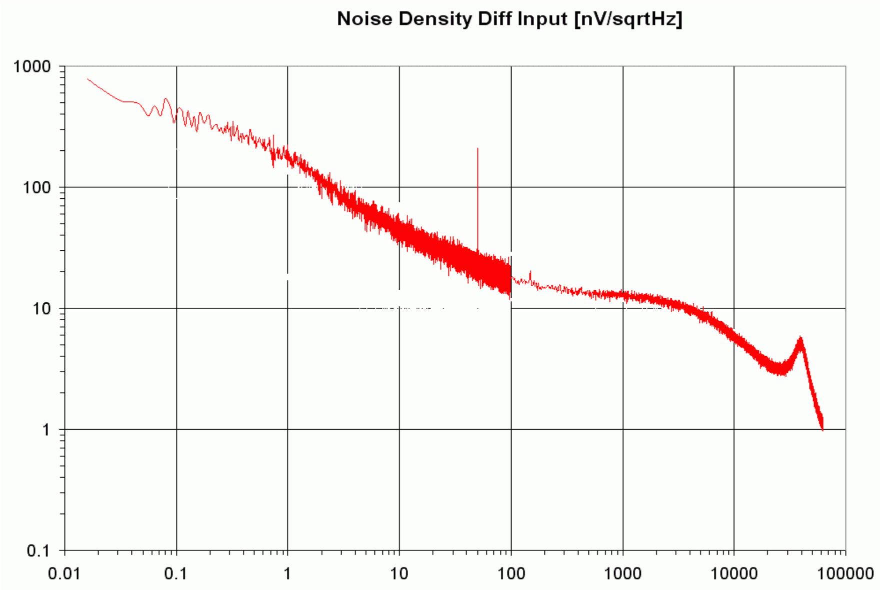


Figure 1 HE144 noise density diagram, the noise includes a pre-amplifier

We provide for our Hall sensors 2 noise diagrams, a noise density diagram and a cumulative diagram. For the electronics developer in need of a high resolution, or who builds choppers or lock-in amplifiers, noise density is important. For many end users however, the cumulative noise diagram may be more useful. If you have no knowledge about noise density, you could skip this whole chapter and move to the cumulative noise diagram. There is a good chance that supplies all information you need for your Hall sensor project.

What you see in Figure 1 is how much noise is generated at a certain frequency. Lets use an example at 1000Hz. We generate a magnetic field at 1000 Hz and we use a filter at 1000 Hz with a bandwidth of 1 Hz. Look in the diagram at 1000 Hz, you will see a noise of approximately 12 $nV_{(PeakToPeak)}$ on top of the signal you measured. Dividing this by 6.6 gives the noise in rms voltage.

What you can see is that at lower frequencies up to 100 Hz, there is more noise. This is a typical property of semiconductors called 1/f noise. Component manufacturers tend to give this as 1/f noise at 0.1 Hz (if they give it at all), what would be 400 nV_{pp} or 60 nV_{rms} for this sensor.

From 100 Hz to 1000 Hz, the curve is rather flat with a low value. This noise of approximately 15 nV_{pp} or 2.3 nV_{rms} is the sensor noise that is usually given by component manufacturers.

Noise is statistic, you cannot simply add signals, but you can follow the method below

Most applications with a Hall sensor measure from DC up to a certain frequency. Lets take another example with the same frequency of 1000 Hz. The goal is to show you how to add up noise. This time we do not perform an AC measurement but we measure with the full bandwidth from DC to 1000 Hz and use a steep filter that filters everything above 1000 Hz.

An easy way to do Hall measurements

What we need to do for the calculation is split it in 2 parts:

- The noise in the 1/f area up to 100 Hz
- The noise from 100 Hz to 1 kHz

Calculate the 1/f noise:
At 1 Hz we see a noise density of 200 nV, an important value. This value is used to determine the total noise when using a certain bandwidth. The formula to calculate the total noise from frequency f_{low} to f_{high}, 0.1 to 100Hz (the 1/f area of Figure 1). We use a formula that linearizes the graphic (assumes a straight line through the 1/f curve) but still gives good results:

$$1/f\ \text{noise} = 200\ \text{nV} * \sqrt{\ln(\frac{f_{high}}{f_{low}})}$$

You are probably expecting f_{low} to be 0 Hz, but this is not realistic. Below 0.1 Hz other factors play a role, like temperature changes, even the input of your measuring equipment changing. A realistic value for f_{low} is 0.1 Hz, maybe 0.01 Hz, the sensor will not change much below these frequencies anyway. We use in this example 0.1 Hz. Using this in the formula above, we get a noise from 0.1 to 100 Hz of **526 nV$_{rms}$.**

And the sensor noise:
We see in Figure 1 that the noise density from 100 Hz to 1000 Hz is 15 $\text{nV}/\sqrt{\text{Hz}}$. We use this formula (this assumes a flat line from 100 Hz to 1000 Hz in Formula 1):

$$\text{sensor noise} = \text{noise density} * \sqrt{\text{bandwidth}}$$

This gives 15n $* \sqrt{(1000 - 100)}$ = **450 nV$_{rms}$.**

And now about adding noise, get the total noise:
As noise is statistic, you cannot simply add it. This must be done using this formula:

$$\text{total noise} = \sqrt{(1/f\ \text{noise})^2 + (\text{sensor noise})^2}$$

This gives a total noise of **692 nV$_{rms}$.**

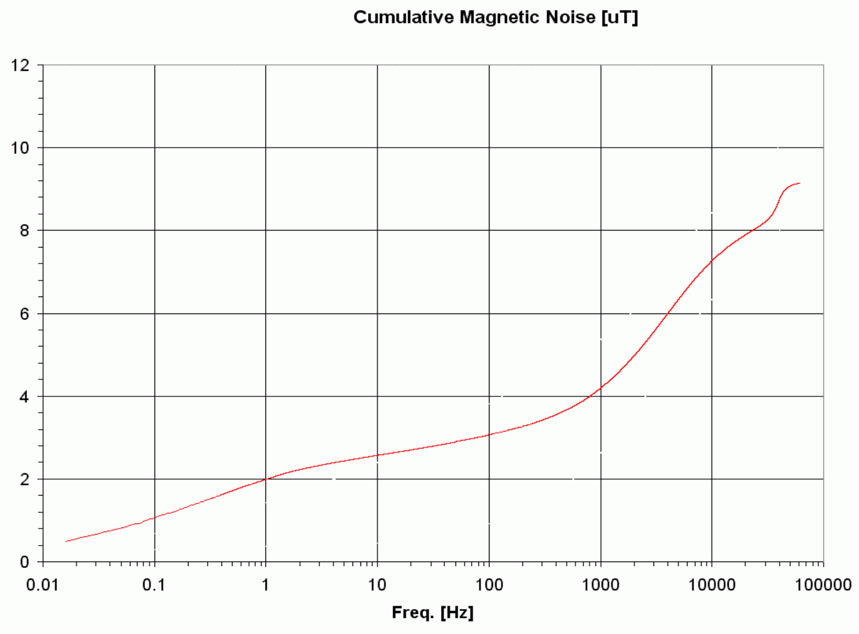
Can we improve noise?
Yes, it is possible. Some electronic components can be AC excitated where the AC signal lies above the 1/f area and where lower frequencies are filtered. In a Hall sensor it will however not remove several errors (like an offset and certain noises) and measuring the AC signal will give its own problems.

Another way often seen is chopping, where the lower frequencies (1/f) are automatically filtered. As this is time-discontinuous and therefor non-linear, this will also lead to problems like aliasing. High frequencies, noise and external signals, can be mirrored to your working range bandwidth and cannot be filtered out.

Yet another way is lock-in amplification. This is expensive, but it does work.

An easy way to do Hall measurements

The cumulative noise diagram



For many users, the cumulative noise diagram is easier to use. This diagram is assuming you measure from DC up to a certain bandwidth.

Look up horizontally the bandwidth you are using or better, filtering at. Vertically you can find the noise, that is all.

Notice that the diagrams here are indicative and not verified by calibrated measurements. The noise also includes a preamplifier as most analysers cannot measure such low noise levels.

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