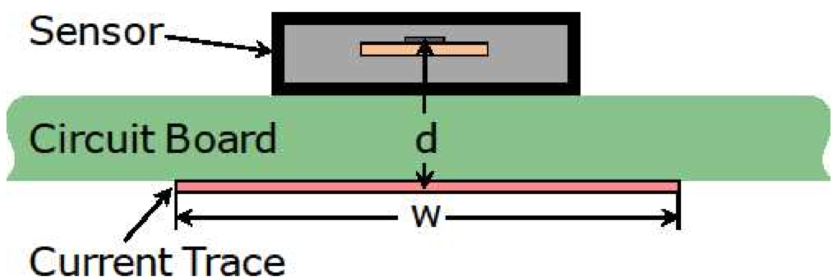
High Current PCBs for Precision High Current Sensing

World Class Current Sensing

NVE's revolutionary linear current sensors allow accurate measurements of high current. Their ultraminiature size and low power consumption make them ideal for noncontact current sensing over PCB traces. With proper design, NVE current sensors can be used to measure currents as large as traces can carry.

NVE sensors are sensitive in-plane, which is ideal for current trace sensing. A simple high-current sensing geometry is shown in the cross-section below. The current through the trace generates a magnetic field, which is read by the sensor.



$$H = \frac{0.4 \cdot I \cdot arctan\left[\frac{w}{2d}\right]}{w}$$

The sensing element is typically elevated in the package of the sensor by the leadframe, so the total distance from the current trace to the sensing element, *d*, includes the circuit board thickness and a small package dependent distance. For TDFN6 packages, this distance is approximately 0.7 mm. The equation above describes the relationship between the magnetic field H (in millitesla), the width of the trace *w* in mm, and *d* in mm. NVE sensors cover all practical magnetic fields and can detect trace currents from 10 µA to 300 A.

Other popular high current configurations, such as the AG953-07H Demonstration Board, use bus bars and NVE sensors, but for optimally cost effective and compact designs, running the sense current directly through traces can be the most practical solution. This application note details guidelines for the layout of high-current PCB traces and the use of NVE magnetometers for high-current detection.

Optimizing PCB Design for High Current

The principal concern for high current PCBs is trace heating, which may cause

- Trace fusing
- PCB deformation
- Component damage

Trace fusing is the least relevant concern because a functioning PCB trace should be designed to never fuse at steady state operation, and fusing will only occur at the most extreme temperature rises. Before this, heat from traces can raise PCB temperatures beyond the glass transition, resulting in possible deformations or mechanical failures. Additionally, heat from traces can spread to integrated circuits, leading to unexpected performance degradation or failures. All these considerations are important for maintaining lifetime reliability.

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In general, the temperature rise of a current trace and PCB is a complex question and requires thermal modeling; however, trace temperature rises can be predicted by an IPC-2221 standard in two-layer PCBs at low currents and temperatures:

$$I = KT^{0.44}A^{0.725}$$

where $K = 0.048$ is a material constant, T is the temperature rise in degrees C, A is the cross-sectional area of the trace in square mils, and I is the current in amps. This empirical formula is accurate up to 40 amps and 100 °C temperature rises; beyond these limits, the formula no longer applies and can be used as an estimate only.

Heating in PCB Traces

PCB trace heating is caused by I^2R power dissipation, so the current carrying capacity of a trace is principally determined by its cross-sectional area, which determines the resistance. This fact can be used to determine the current capacity of large traces for a given temperature rise. As an example, a 0.5″ (12.7 mm) wide, 2 oz. trace can accommodate 40 amps with a 30 °C temperature rise, as predicted by the IPC-2221 standard:

$$I = (0.048) * (30)^{0.44} * (500 * 1.37 * 2)^{0.725}$$
$$I = 40 \text{ amps}$$

A heavy-duty 6 oz. copper 1″ (25.4 mm) wide trace would have one-sixth the resistance, so it could carry

$$\sqrt{6} \cdot 40 = 100 \text{ amps}$$

with an identical 30°C temperature rise, since

$$\frac{{I_1}^2}{{I_2}^2} = \frac{R_2}{R_1}$$

For many applications, a greater temperature rise can be tolerated. Assuming the PCB trace rate of cooling does not saturate, doubling the power load will double the temperature rise. This means a maximum temperature rise of 120 °C can accommodate

$$\sqrt{4} \cdot 100 = 200 \text{ amps}$$

These calculations show how current carrying capability can be estimated in simple cases.

PCB Heat Sinking

PCB traces can withstand much larger currents than free wires because the PCB material acts as a heat sink for thermal dissipation. FR-4, a common low-cost PCB material, has 10 times higher thermal conductivity than air, which cools the trace. Trace cooling can be further improved by including an electrically isolated ground or power plane on inner PCB layers. The thermal conductivity of copper is 1000 times higher than FR-4, so these copper planes will drastically improve trace cooling if the planes are tied to a thermal sink.

Example Design: Precision Current Sensing up to 50 Amps

NVE's AG903B-07E GMR Current Sensor Evaluation Kit contains an example of on board high current sensing, optimized to sense up to 50 amps without exceeding a 50 °C temperature rise. The high current sensing board consists of an AAL024-10E sensor over a 1″ (25.4 mm) wide trace underneath a 1.6 mm thick board. For a 50 °C temperature rise, the maximum current capacity can be approximated by the IPC-2221 standard:

$$I = (0.048) * (50)^{0.44}(1000 * 1.4)^{0.725}$$

$$= 50 \text{ amps}$$

To find the magnetic field, the distance from the trace to the sensor element is calculated, in millimeters, as:

$$d = 1.6 + 0.7 = 2.3 \text{ mm}$$

The magnetic field at 50 amps is therefore:

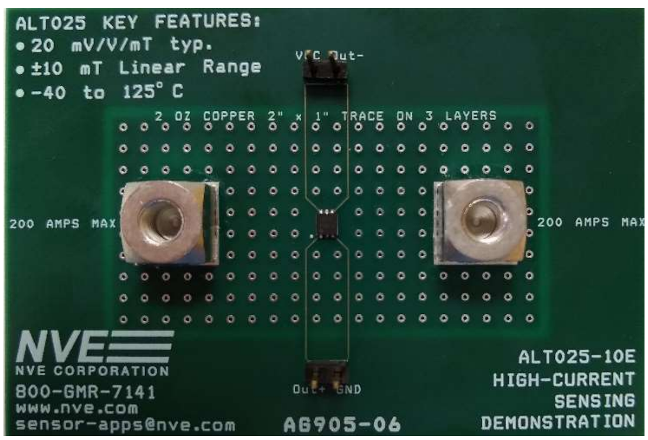
$$H = \frac{0.4 * 50 * arctan\left[\frac{25.4}{2*2.3}\right]}{25.4}$$

$$= 1.1 \text{ mT}$$

which is near the max field of the sensor's linear range. Since the sensor saturates at 1.5 mT, up to 70 amps overcurrent can be detected. Below 50 amps, the sensor output is precisely linear.

Maximum Current: ± 200 Amps with Tunneling Magnetoresistance (TMR)
NVE's ALT025-10E TMR Magnetometer is ideal for sensing high current through PCB traces. With a wide ±10 mT operating range and highly linear ±5 mT low field detection, it is capable of measuring large currents with high accuracy. The maximum current of the sensor is several hundred amps with proper PCB design. One option includes a minimum 6 oz. copper single trace; this is expensive and difficult to manufacture. A better solution is to use overlapping parallel traces on multiple layers.

The AG905-07 demonstrates this concept with a simple 4 layer PCB, where sense current flows in parallel traces on three of the layers. The 2″ x 1″ traces are connected by thermal vias, which lower the trace resistance and support cooling. Plane layers are electrically isolated and help move heat away from the traces. The PCB layout for this configuration is shown below.



Since the current runs on several layers, the joule heating easily spreads to the entire PCB, resulting in a much lower temperature rise. This also prevents localized heating and hotspots.

Assuming equal current in each array, the magnetic field can be calculated as the superposition of the field from three traces:

$$\frac{H}{I}=\frac{1}{3}\left(\frac{0.4*arctan\left[\frac{25.4}{2*(0.7+0.52)}\right]}{25.4}+\frac{0.4*arctan\left[\frac{25.4}{2*(0.7+1.04)}\right]}{25.4}+\frac{0.4*arctan\left[\frac{25.4}{2*(0.7+1.57)}\right]}{25.4}\right)$$
$$=0.023\ \mathrm{mT/Amp}.$$

This corresponds to a ±220 amps in the ±5 mT linear range. Since the ALT025 saturates gracefully up to 30 mT, the sensor can detect currents as large as the PCB can carry.

Customer Support

We have a free, Web-based application hosting these and other design calculations to assist your current sensing design: www.nve.com/spec/calculators.php#tabs-Current-Sensing

To try high current sensing yourself, order our AG903B-07E, AG905-07, and AG953-07H demonstration boards and evaluation kits: https://www.nve.com/EvaluationKits.php

For a live demonstration of high current PCB configurations and other demonstrations, check out our *YouTube* channel: www.youtube.com/c/NveCorporation

Contact Us

NVE Engineers are experts in current sensing and eager to help. Please contact sensor-apps@nve.com with questions.

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