

## *Simulation of Magnetic Field from a Current-Carrying PCB Trace*

### Relevant Crocus Devices

The concepts and examples in this application note are applicable to all of the following Crocus devices:

CTSR206V-IQ2, CTSR209V-IQ2, CTSR212V-IQ2, CTSR215V-IQ2, CTSR218V-IQ2, CTSR222V-IQ2

### Introduction

To better understand a magnitude of the generated magnetic field around a current-carrying trace and use this concept in current sensing applications simulation of magnetic field is required.

The application of current sensing without touching the wire is dependent on the details of how the magnetic flux vector forms around the current conducting material. The direction and magnitude of the flux vectors – which follow the super positioning rule - are highly dependent on the shape of the current-carrying conductor. The general formula for calculation of magnetic field and the right-hand-rule are based on the assumption of having a very long and narrow wire (single dimension). It is a simple approach and often good enough for engineering work but if more accurate data is needed then a more complex method based on 2D or 3D simulation is required.

To get a better understanding of the Crocus application notes *AN103 – General Current Sensing*, and *AN101 – Magnetic Field vs Distance*, in this note we go one step further by

presenting a 2D simulation of magnetic field around a current-carrying trace on a PCB. We start with the description of the simulation tool followed by the examples of two current-carrying traces conducting currents in opposite direction on the PCB. This is presented to better understand the differential current sensing approach.

### Simulation Tool and Parameters

The main goal of this simulation is to solve for the field vectors of the induced magnetic field around a flat, narrow and thin current-carrying trace. For this purpose, the *QuickFields 6.0 Student Edition* software was used which has the capability of having 2D analysis of induced magnetic fields. This tool allows for defining parameters based on the simulation environment, and then calculates the direction and magnitude of the magnetic field.

Magnitude of a magnetic field **B** generated by the current **I** in a straight and long wire at a distance **r** from the wire is calculated by Ampere's equation below:

$$B = \frac{\mu_0 I}{2\pi r}$$

In this equation,  $\mu_0$  is the permeability of the medium. Also, direction of field **B** vector is defined by the *right hand rule*.

Referring to application note *AN103 – General Current Sensing*, the idea is to have a current-carrying trace on the PCB which is located at a

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very short distance ( $r$ ) from the magnetic sensor.

The case described in the application note uses the PCB itself as the insulator between the sensor and the current carrying trace. In this case, the magnetic sensor is mounted on top of the PCB with the current-carrying trace located exactly under the sensor but on the other side of the PCB. The dimensions considered in this simulation are shown in Table 1.

Table 1 – Dimensions defined for simulation.

Feature	Thickness ( $\mu\text{m}$ )
Packaged Sensor	700
PCB	1600
Current-Trace	40

The permeability of the different materials is presented in Table 2.

Table 2 - Relative permeability of different materials

Parameter	Value ( $\mu/\mu_0$ )
Relative Permeability of Air	1.00000037
Relative Permeability of PCB	1
Relative Permeability of Chip	1
Relative Permeability of Copper	0.999994

The final step is to define simulation environment. The physical setup is defined as a cross-sectional view of the current-carrying trace on the bottom side of the PCB which is located exactly under the sensor chip package located on the top side of the PCB. This setup is depicted in Figure 1. Direction of current in this simulation is considered to be coming out of the page with the magnitude of 10A DC.

The second example involves two sensors and two traces as depicted in Figure 2.

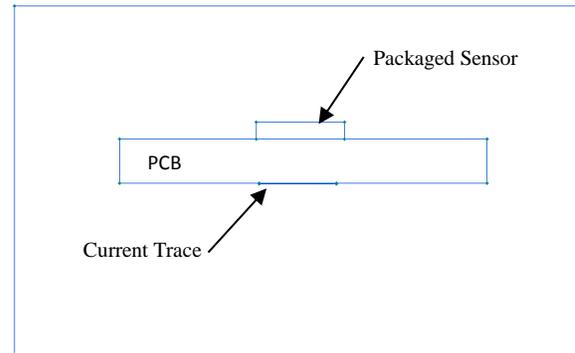


Figure 1 – The cross-section view of the PCB containing the current carrying trace and the sensor package.

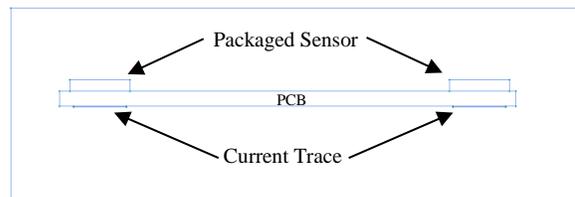


Figure 2 – Second setup. The cross-section of the PCB containing two current-carrying traces and two sensors.

The distance between the two current carrying traces in Figure 2 is 14mm from center to center and direction of currents in this simulation is considered to be coming out of the page for the current trace on the left side and into the page for the current trace on the right side, both with the magnitude of 10A DC.

For both simulation environments 4 blocks and 2 edges was defined in the simulation. Therefore if one wants to replicate the simulation, they can redefine these parameters by referring to the snapshots as shown in Figure 3 to Figure 6 included in the following pages.

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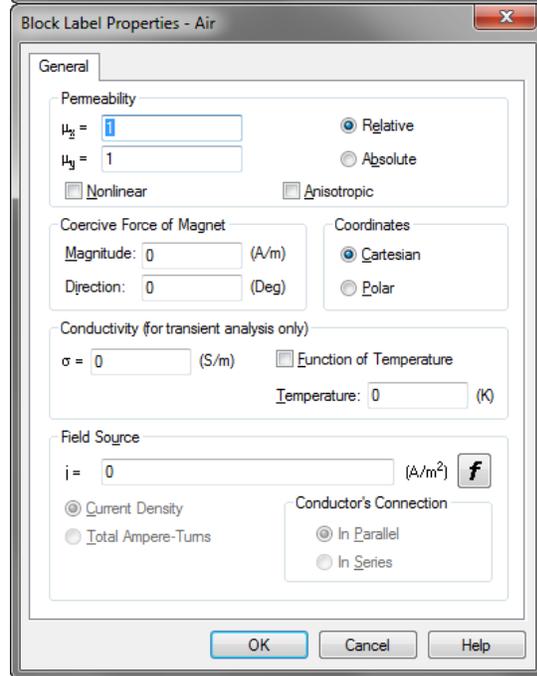
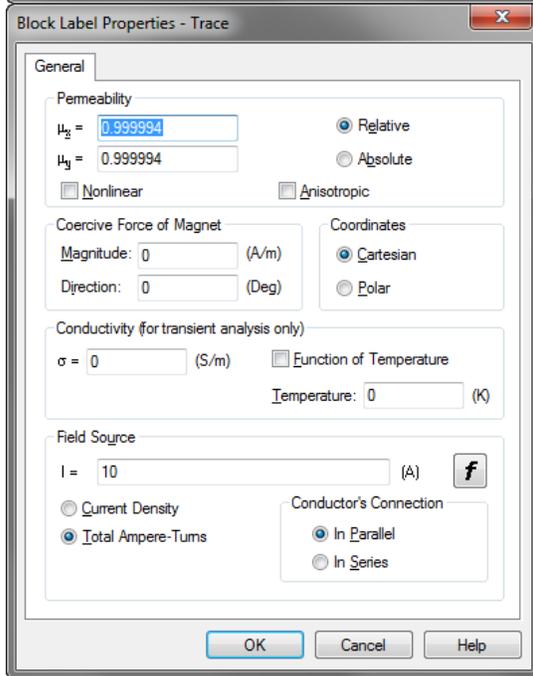
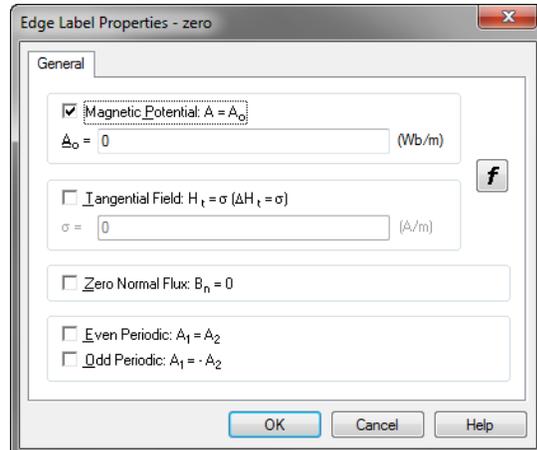
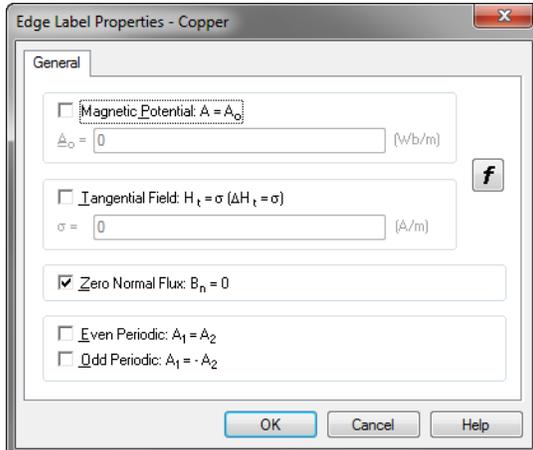


Figure 3 – “Copper” edge and “Trace” block defined in the simulation.

Figure 4 – “Zero” edge and “Air” block defined in the simulation.

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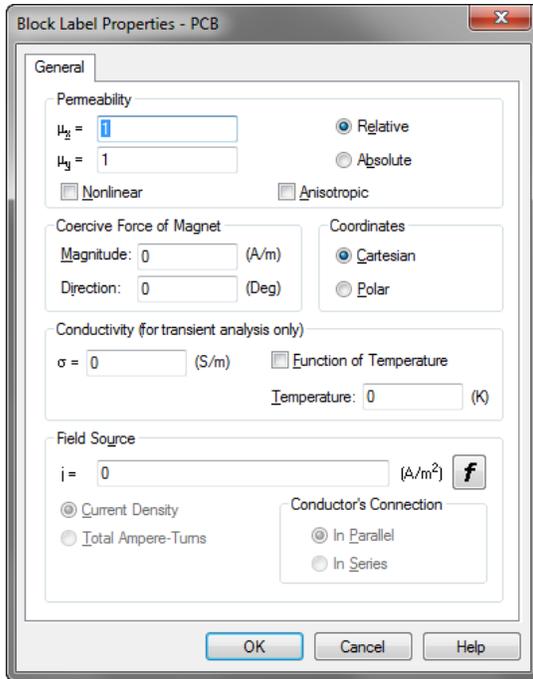


Figure 5 – “PCB” block defined in simulation.

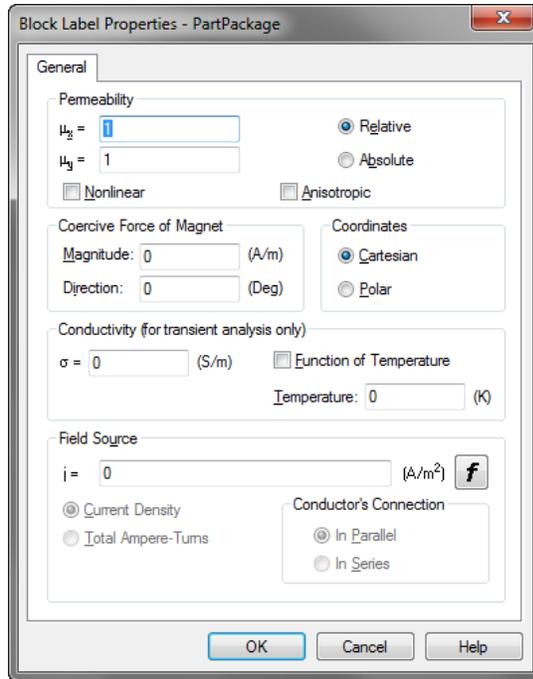


Figure 6 - "Part Package" block defined in simulation.

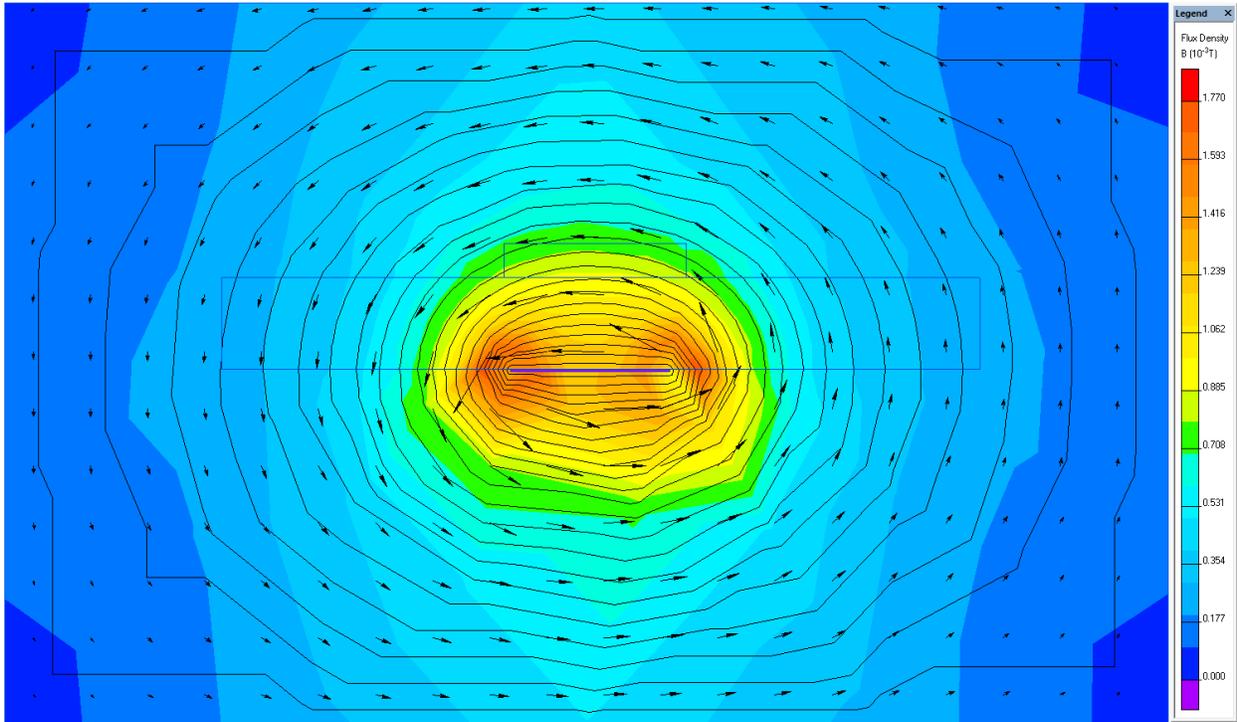


Figure 7 - Simulation result indicating the flux density and vectors of flux around a narrow and flat current carrying trace. The current of 10A is assumed to be coming out of the page.

### Simulation Results

The simulation result for the first example is provided in Figure 7. The thin blue line indicates the profile of PCB with sensor on the top and trace on the bottom. If we consider that the sensing die is located approximately in the middle of the package, then we can see that the

flux vector in the active sensing area of the chip is horizontal and ,in this case, pointing to the left. Another important insight is that magnetic lines with the same magnitude of intensity follow the shape of the trace (they are not concentric circles anymore).

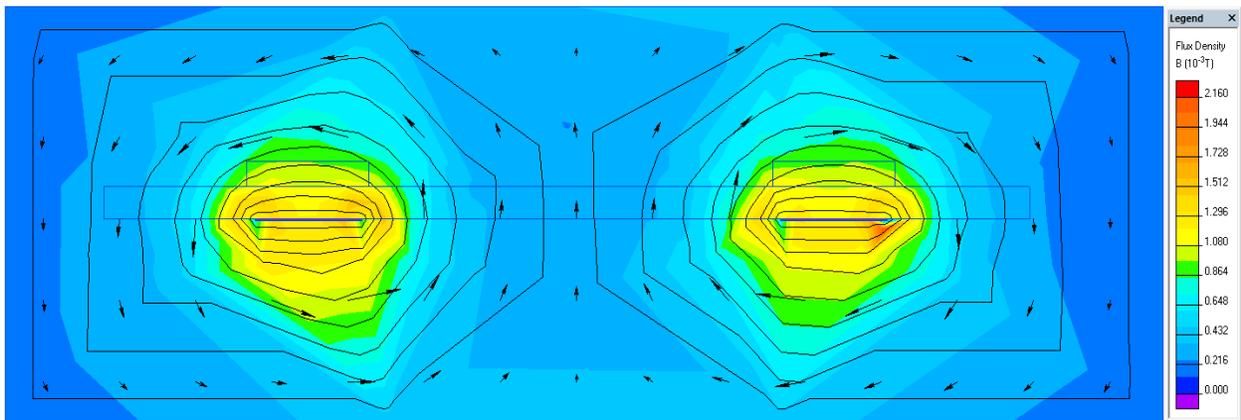


Figure 8 - Simulation result indicating the flux density and vectors of flux around two narrow and flat current carrying traces. The current of 10A is assumed to be in opposite direction on each of the current carrying traces.

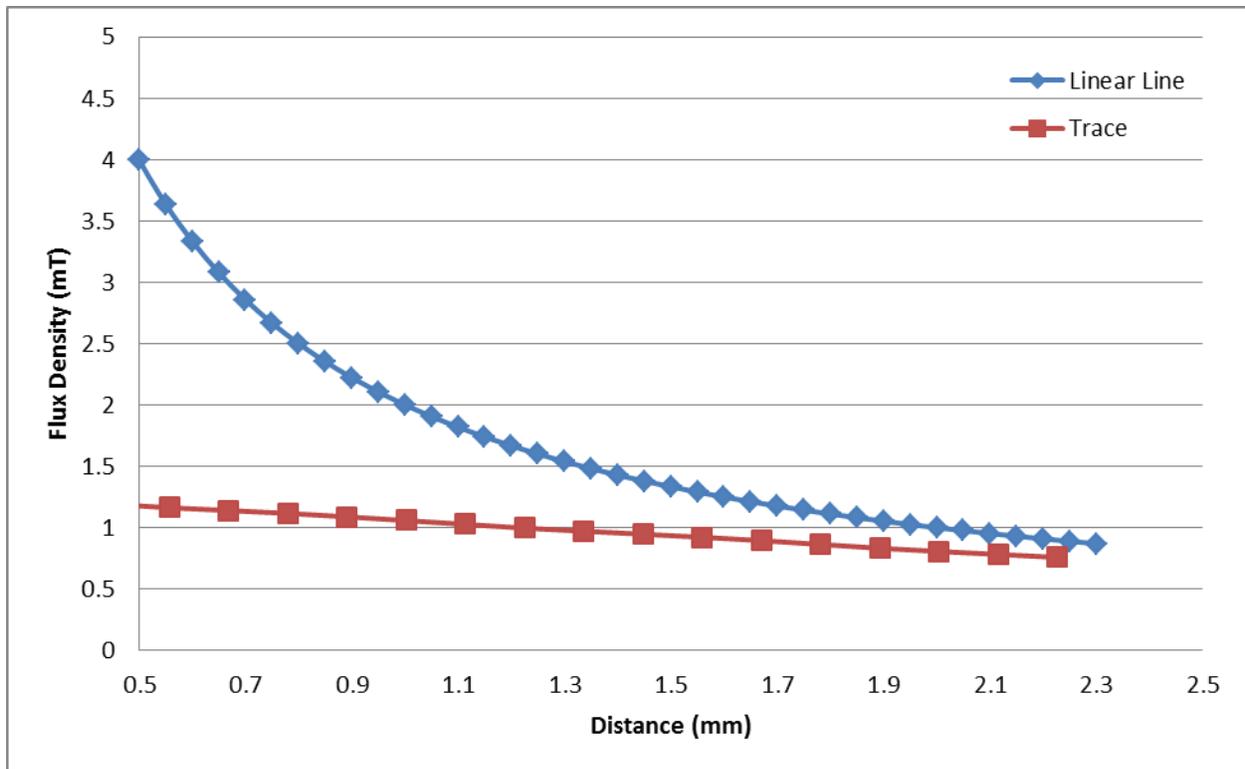


Figure 9 - The ratio of the magnitude of magnetic field for trace vs. magnetic field for linear circular conductor as a function of distance.

Result for the second example is shown in Figure 8. As one can see the direction of magnetic vector is determined by the current flow (magnetic field on the left side is in opposite direction of the magnetic field on the right side of the figure). And again, the magnetic lines with the same magnitude of magnetic field follow the shape of trace on the PCB. One can also see that magnetic flux density in the area between the two traces is very low (less than  $0.3\phi_B$ ) if the two traces are placed far away from each other. This simulation shows the two traces will have negligible effect on each other as long as there is large enough distance between them.

The interesting question is how does the magnetic field emanating from the trace on the PCB compares to the field emanating from the linear conductor carrying the same current. To

check this, the ratio of the magnitude of magnetic field for trace vs. magnetic field for linear circular conductor as a function of distance is plotted in Figure 9. As one would expect the magnetic field in both cases decreases with the distance but the magnetic field for the case of trace conductor is much lower at the very close distance to the conductor. However, the difference in the magnitude of magnetic field between the current carrying trace vs. linear conductor is negligible at the distance of  $\sim 2\text{mm}$  and beyond.

### Conclusion

Simulation results show that in the case of conducting trace the shape of the magnetic field is following the shape of the trace. Also, a wider trace makes weaker magnetic field at the distance close to the surface of the trace. This is a design challenge that needs to be taken in

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consideration when designing PCB. Clearly, the wider the trace the lower the current density, thus the weaker magnetic field. However, as one goes further away from the surface of the trace carrying the current the magnitude of magnetic field can be estimated rather accurately by using Ampere's equation for linear conductor.