CROCUS *Technology*
Blossoming FUTURE

Current Sensing

Field Strength -vs- Distance

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,

CTSR420C-IS2, CTSR440-IS2, CTSR460-IS2

Introduction

It has long been known that a conductor carrying current produces a magnetic field. The magnitude of the magnetic field and the direction of the magnetic field are determined by the magnitude and the direction of the current through the conductor as well as the distance between the conductor and the sensing device that is used to measure the field. Pioneers in the fields of electricity and magnetism such as Faraday, Ampere and Maxwell proved both empirically and mathematically that the current running through a conductor can be characterized quantitatively by measuring the magnetic field that is produced.

Applying Ampere's & Biot Savart Law

Simply stated, Ampere's Law relates the electric current passing through a conductor to a magnetic field produced around it. Without getting into the math associated with Ampere's Law, let's explore the practical application of the theory. The Law states that if we add up or integrate the magnetic field along a closed path this should equal the current enclosed by the path. Figure 1 illustrates this concept. Imagine that there is a current **I** [A] flowing through a conductor that is coming out of the page. If we add up the magnetic field along the blue circular path of radius r around the conductor, this should equal the field created by current flowing through the conductor.
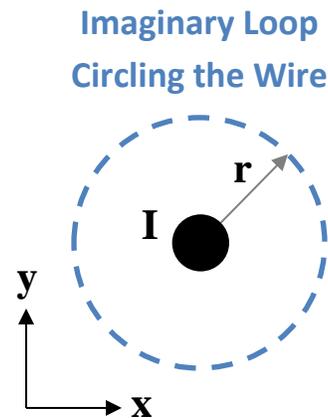
Imaginary Loop
Circling the Wire

FIGURE 1

Quantitatively Ampere's Law provides a quick, simple numerical calculation of the magnetic field strength that is proportional to the current passing through the conductor and inversely proportional to the distance from the conductor:

FIGURE 2

$$B_{long\ straight\ wire} = \frac{\mu_0 I}{2\pi R}$$

Where:

B is the flux density strength of magnetic field [T],

I is the current through the conductor [A], and

R is the distance from the center of current carrying conductor to the sensing point [meters]

μ_0 is the permeability of free space and is equal to: μ_0 = 4*PI*10^-7 [T*m/A]

Since a magnetic field is a vector quantity we must consider both the magnitude and the direction of the magnetic field in order to fully quantify it. We've already defined the equation to calculate the magnitude of the magnetic field. Now let's find the direction of the magnetic lines of flux. Again we'll not get bogged down by the math of Ampere's Law to determine the direction. Suffice it to say that the direction of the magnetic field is determined by the DOT PRODUCT of the two vectors B$^\rightarrow$ (B field vector) and the dL$^\rightarrow$ (path segment vector) along the path described in FIGURE 1. Instead of calculating the direction from the DOT PRODUCT, we'll simply use the right-hand-rule to determine the direction.
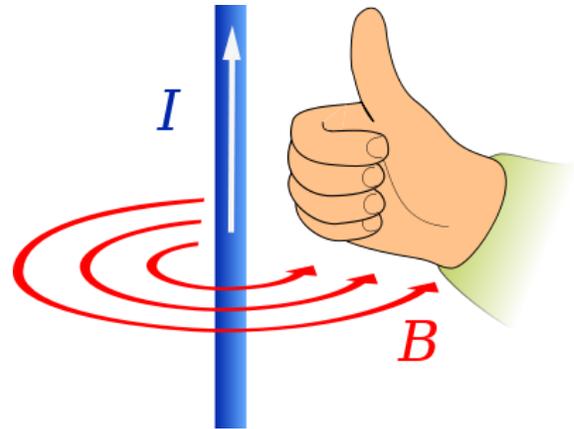

FIGURE 3

By placing your thumb of your right hand in the direction of the current through the conductor, you can determine the direction of the magnetic field by curling your fingers around the conductor. Your fingers will point in the direction of the magnetic field.

The Biot Savart Law is consistent with Ampere's Law in terms of the relationship between the current through a conductor and the magnetic field that is produced as a result. In fact, Amperes Law could be considered a special case of the Biot Savart Law where the conductor carrying the current is considered to be an infinitely long piece of straight wire. If you're a glutton for punishment and you'd like to know the details of the math behind Ampere's Law and the work that Biot and Savart did to come up with the Biot-Savart Law, you can reference any of the many books on physics that include chapters on electricity.

Enough with the theory already. Let's look at a graphical representation of what the magnetic field strength looks like as a function of the distance or R in Ampere's Law.
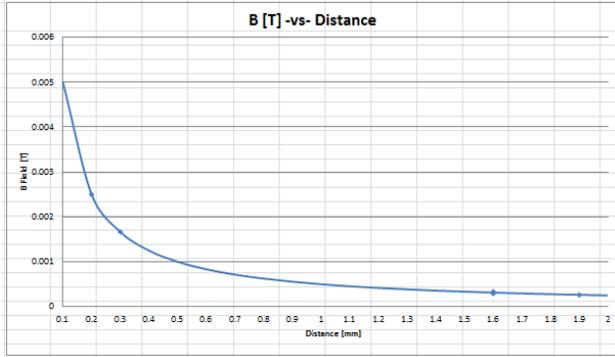
FIGURE 4

The chart in FIGURE 4 really plots the effects of the distance between the magnetic field source and the position of the point from the center of the conductor. The chart was generated using the equation of Ampere's Law stated above with a current of 10 [Amps] and the permeability of free space. Notice how the B field drops off quickly as the distance increases.

Let's use some practical numbers to calculate the relative B field strength for an actual current sensing application. For this application example, a four layer PCB with a board stackup as shown in FIGURE 5 was used to mount the sensor above a current carrying conductor. The current carrying conductor is located on an adjacent layer of the PCB. The sensor is mounted on the TOP layer of the PCB and the current carrying conductor that is generating the magnetic field can be mounted on the BOTTOM layer or either of the two INNER layers.
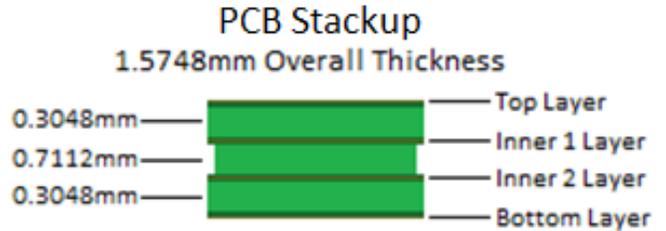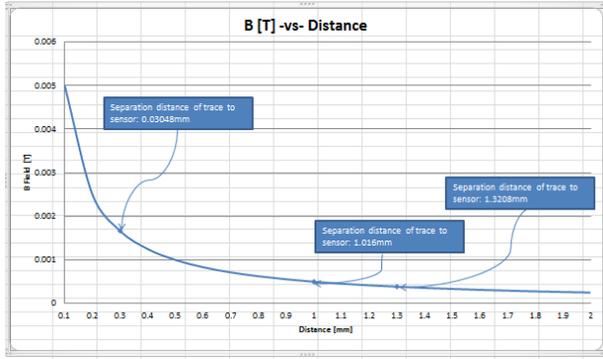

FIGURE 5

Using the chart from FIGURE 4 above or Ampere's Law to calculate the values, let's find relative B field values that the sensor will see with the current carrying trace on each of the different layers of FIGURE 5.

If the current carrying trace is placed on the FIRST INNER layer of the PCB then the sensor, which is mounted on the TOP layer, will be approximately 0.3mm away from the current carrying trace. If the current carrying trace is placed on the SECOND INNER layer then the distance between the sensor and the source of the magnetic field will be approximately 1.016mm (0.3048 + 0.7112 = 1.016mm) away from the magnetic field source. Table 1 shows the calculated B field magnitude as seen by the sensor if the current carrying trace is mounted on the three different layers:

	Distance[mm]	B Field[T]
First INNER	0.3048	0.00167
Second INNER	1.016	0.0005
BOTTOM	1.3208	0.000387

Table 1

FIGURE 6 also shows the relative B Field strengths of the three different PCB layout scenarios.

FIGURE 6

One should point out that all shown examples here are given for a single set value of the current of 10 A flowing thru the conductor. In practice the level of the current to be measured varies from mA to several hundred A. The impact of different value of the current on the magnetic field is shown in Figure 7 for currents from -50 to +50 A. It is clear that that the higher the current the distance for the same value of magnetic field is further away from the conductor of the current.
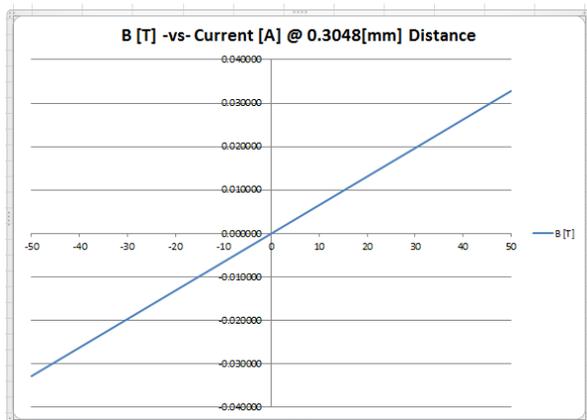

Figure 7

account several factors such as physical aspect of the setup as well as dynamic range of the current to be measured.

Summary

This application note shows the correlation of the current and magnetic field created by the current. In order to measure successfully different levels of current one has to take into