Abstract

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Poster Paper

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Applied Multiphysics in Thermoresistive and Magnetoresistive Sensor Models

Efficient, effective, functional operation of autonomous systems requires a comprehensive real-time understanding, by those systems, of the embedding environment. Autonomous systems designers can provide the required level of functional understanding to the system software through the use of environment detection sensors. This paper presents a brief overview of the multiphysics considerations involved in the development of models for thermoresistive and magnetoresistive sensors systems.

Examples of the areas of application for such sensors are: MEMS, GPS, orientation, temperature, fluid level, proximity, vehicle detection, biometrics, illumination, and numerous others.

Introduction:

The creation of an adequate, accurate sensor model requires three primary areas of consideration. First, modelers need to determine the fundamental physical stimuli that are in the sensor’s environment. Next, they need to determine the response of that particular sensor family to those stimuli. Finally, they need to understand and include the relative magnitude of the contribution of each stimulus and also the magnitude of any cross-coupled interactions.

Thermoresistive Sensing:

Consider, for example, the response of a doped silicon block to an impressed external current (see Figure 1 below).

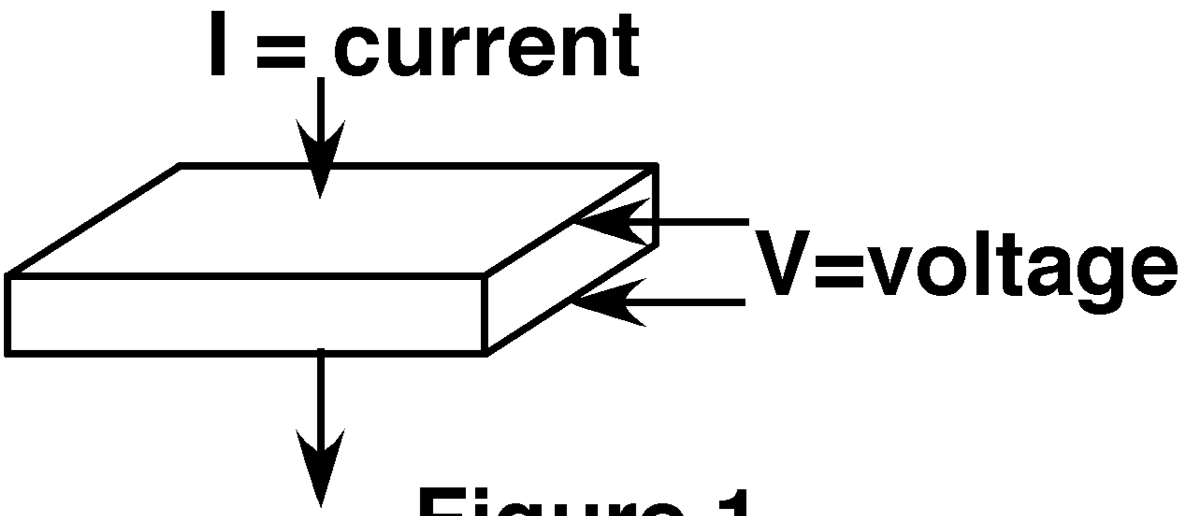


Figure 1

The resistance of a silicon block is a function of the number of carriers (N) and the temperature (T). Since this silicon is doped, it has two current carrier sources (N{total} = N{extrinsic} + N{intrinsic}). The first carrier source (N{extrinsic}) is the collection of dopant atoms that are artificially introduced into the silicon lattice during the crystal growth process. The second carrier source (N{intrinsic}) is the collection of atoms comprising the silicon host lattice. Each carrier source is thermally activated at a different rate.

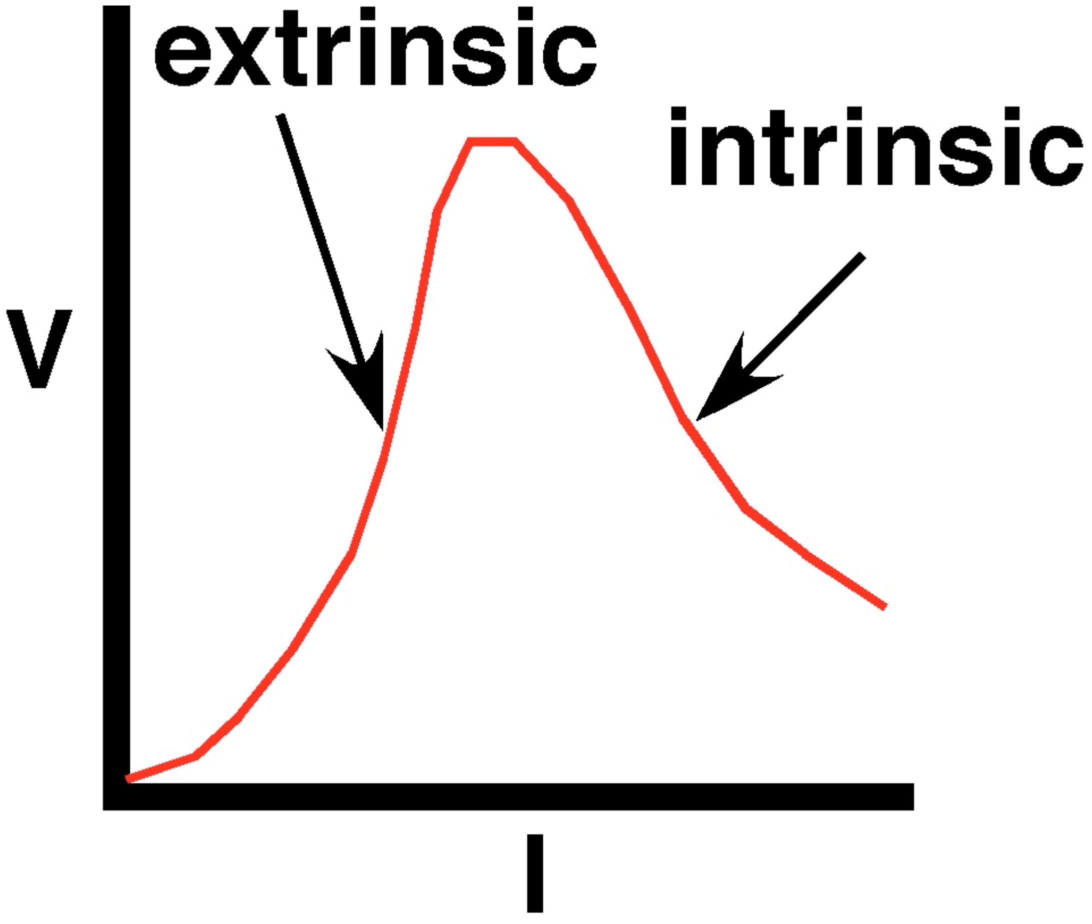


Figure 2

At a temperature around room temperature, the extrinsic carriers are fully activated and are the predominant carrier in the silicon block. Figure 2 above shows that, as the total current (I) increases, the voltage (V) dropped between the upper and lower surfaces also initially increases.

At any locality within the silicon block for any point on the characteristic curve (I-V), the power dissipated ($P = I^2 \bullet R$) within the block is the product of the square of the local current (I_l^2) and the local resistance (R_l). However, the local resistance is a function of the local temperature ($R_l = f(T)$).

The net effect of this localized heat dissipation is a non-uniform, non-linear resistance throughout the block and hence, a non-uniform power dissipation.

As the total current (I) increases, more energy is deposited locally, raising the local temperature and eventually, the intrinsic carriers, in a region, become dominant. This local temperature rise due to the local heating causes more intrinsic carriers to be activated and the local resistance falls.

This thermoresistive multiphysics example demonstrates the phenomenon called thermal runaway or thermal avalanche.

Thermoresistive Over-Temperature Sensor:

The thermoresistive response of doped silicon is easily applied as an over-temperature sensor. Consider, for example the sensor response shown in Figure 3 below.

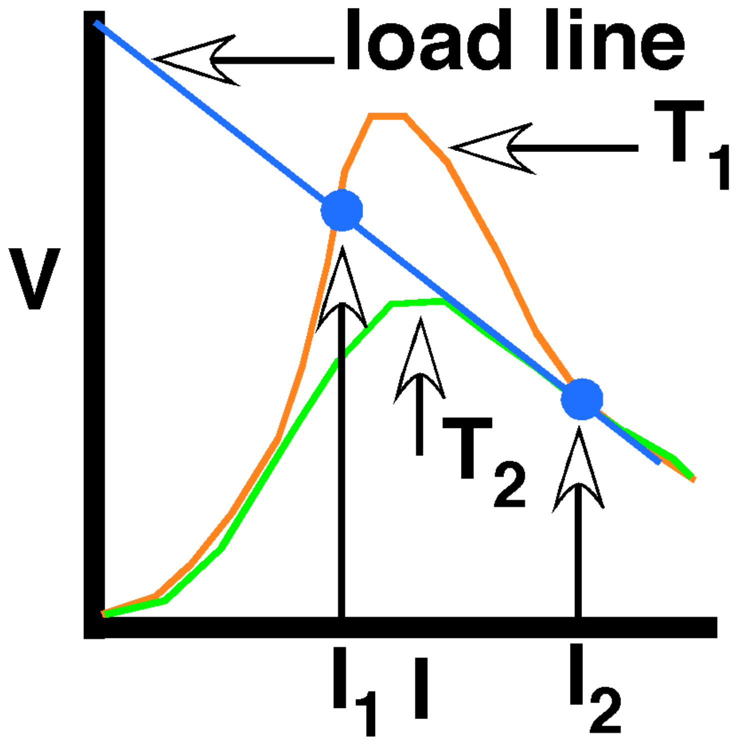
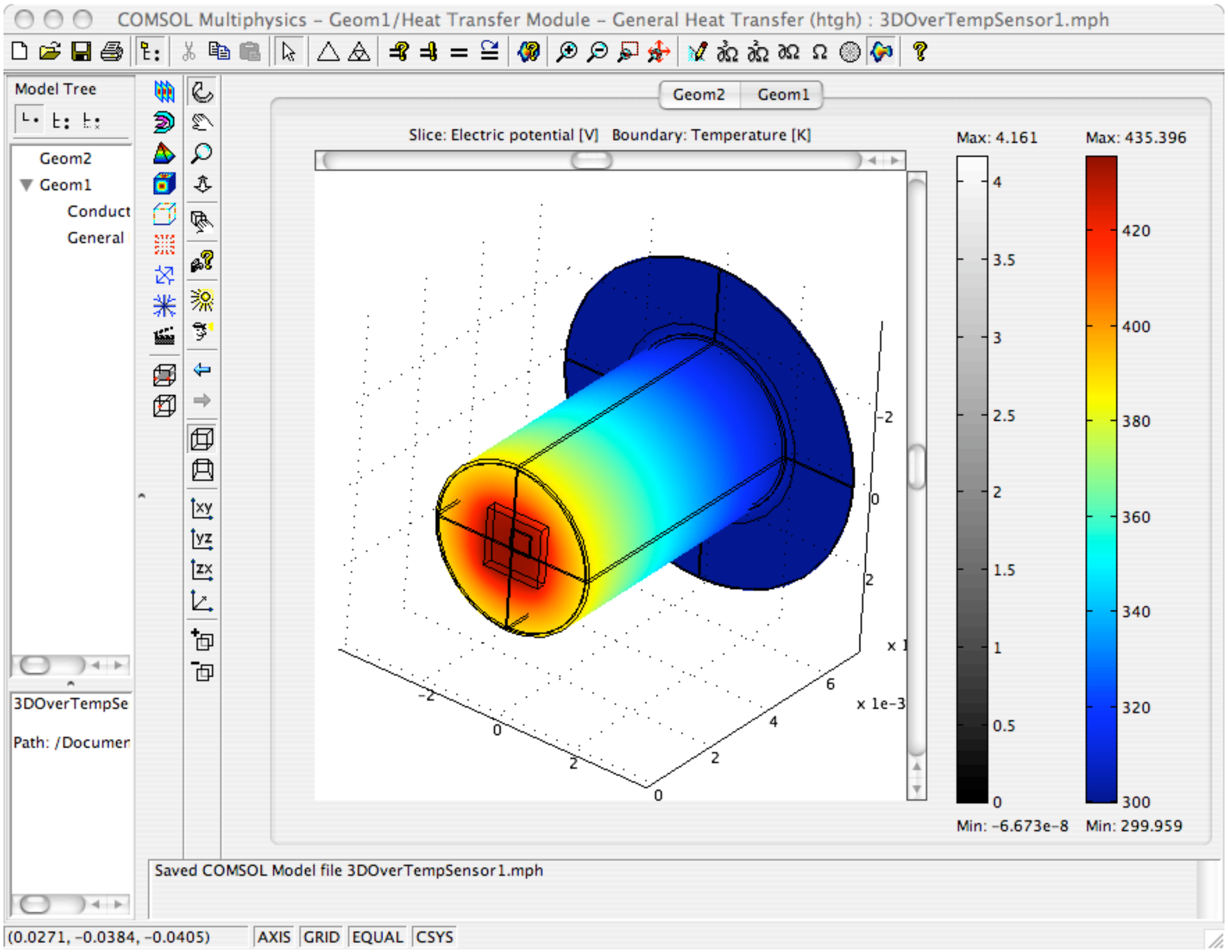


Figure 3

As the environmental temperature increases from T_1 to T_2, the I-V curve shifts to a higher current equilibrium state. If the load line imposed by the external circuit is as shown, then the current shifts from I_1 to I_2 and indicates an over temperature condition.



COMSOL Multiphysics - Geom1/Heat Transfer Module - General Heat Transfer (htgh) : 3DOverTempSensor1.mph

Saved COMSOL Model file 3DOverTempSensor1.mph

Figure 4

Figure 4 above indicates the voltage drop and shows the temperature profile as it is calculated by a COMSOL Multiphysics Model for such a silicon thermoresistive element mounted in a metallic immersion probe case for use in a liquid environment. The above model is calculated for the voltage and temperature values that would be observed when the probe is not immersed in any liquid (i.e. the probe is suspended in free air).

Magnetoresistive Sensing:

Magnetoresistive sensors are typically fabricated in a bridge configuration using a thin film, low coercivity material, such as permalloy, deposited on a silicon chip. Figure 5 below shows an example of such a bridge circuit.

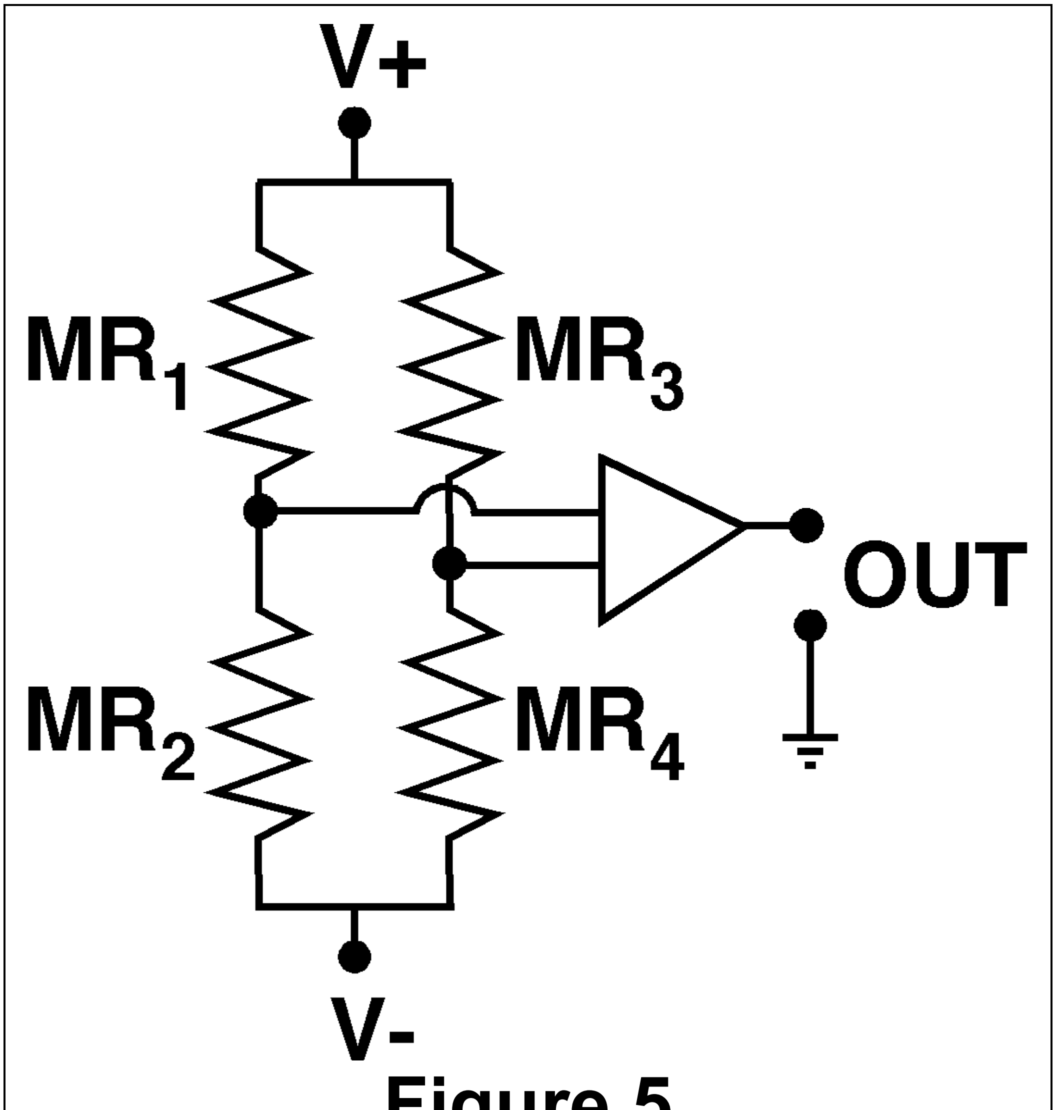


Figure 5

This bridge circuit is an example of a single axis magnetoresistive sensor configuration. If the magnetic

field to be sensed is not properly oriented, relative to the bridge elements (in the plane of and along the axis of the sensing element) or vice versa, the magnetic field will not be properly detected [1]. Resolution of this problem requires the use of a triaxial sensor, as shown in Figure 6.

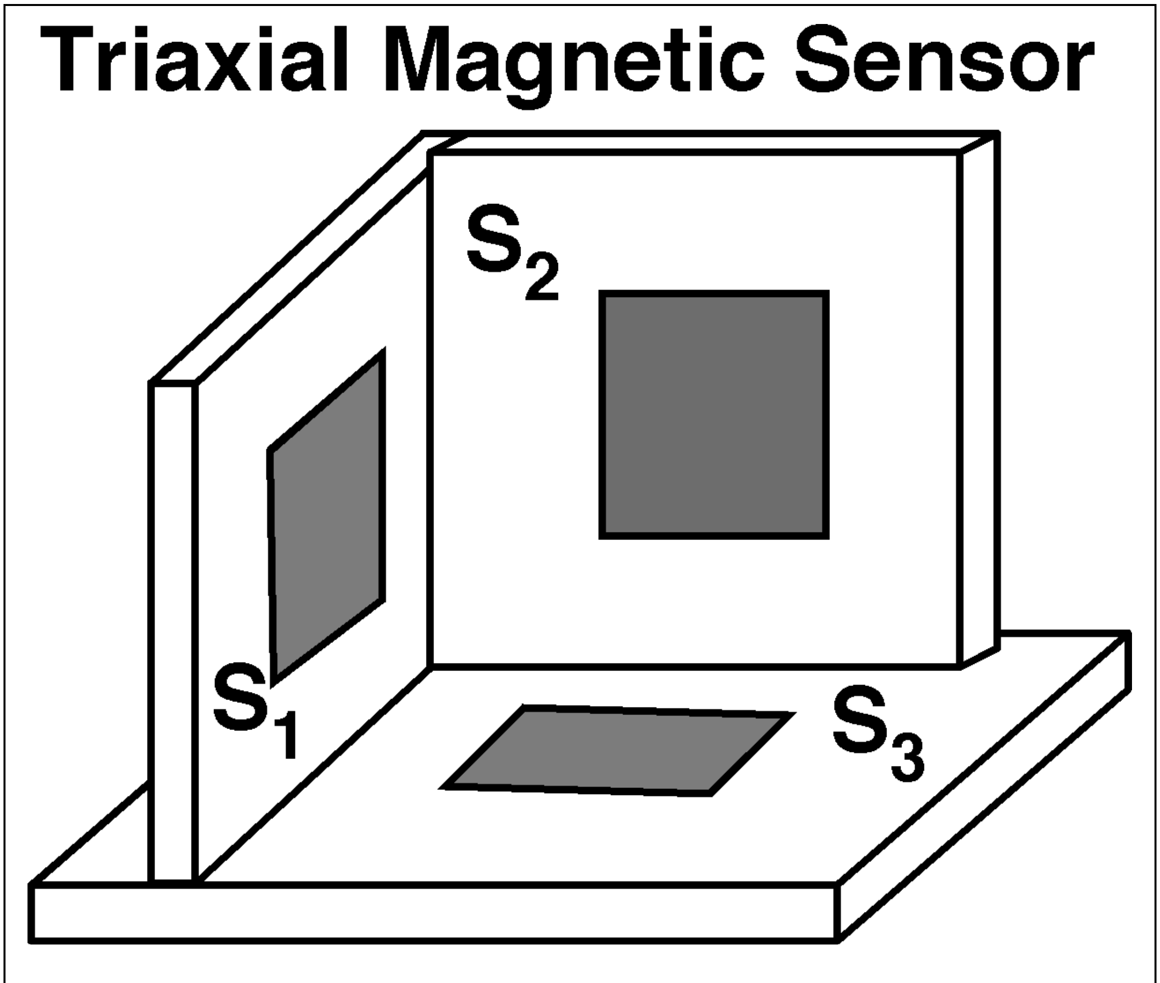


Figure 6

The planar magnetoresistive sensor modules are shown as S_1, S_2, and S_3. Such modules will include, depending upon the manufacturer, the magnetoresistive bridge, calibration coils, reset coils, a differential amplifier and possibly detection circuits.

Magnetoresistive Proximity Detection:

Consider, for example, the factors that need to be examined in the design of a 3D sensor system to determine the relative proximity of a moving arm to a moving target.

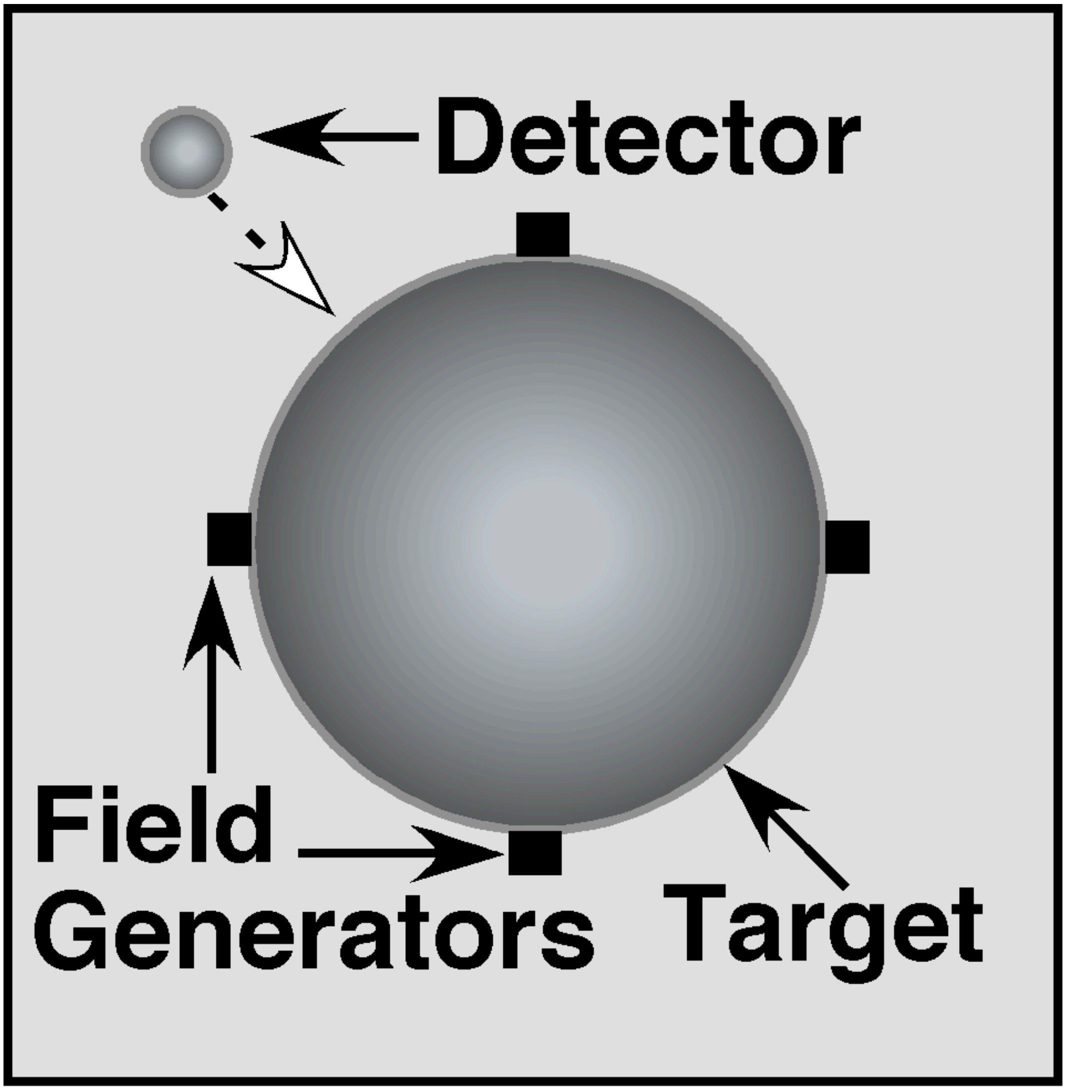


Figure 7

In the case shown in Figure 7, a triaxial magnetoresistive detector and a group of permanent magnet field generators constitute the proximity detection system. For

proximity detection applications on or close to the Earth's surface, the modeler will need to consider the Earth's natural magnetic field (0.3-0.6 gauss)[2].

For field generator designs in a range > 0.6 gauss, the contribution of the Earth's field is minor. Most other randomly encountered man-made magnetic fields from electric generators, motors and other sources will be sufficiently small so that they can either be ignored or filtered out.

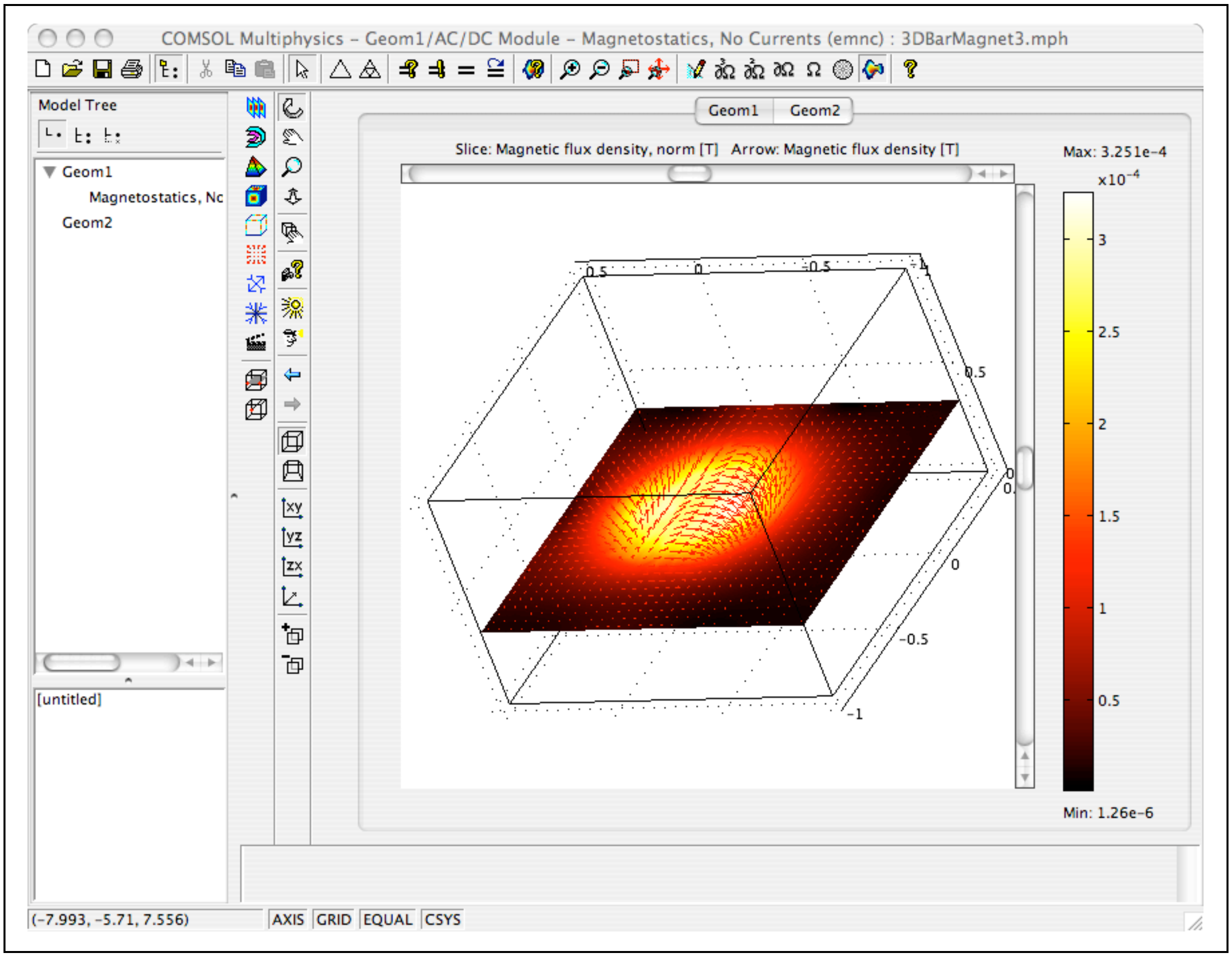


Figure 8 above shows the magnetic field configuration of a permanent magnet field generator as rendered in a slice plot using COMSOL Multiphysics. The results of this modeling

effort allow the modeler to select the desired distance/field proximity point at which to set the desired threshold values in the detection module.

Conclusions:

This paper has presented a brief overview through example of some of the multiphysics interactions that need to be considered in the development of models for thermoresistive and magnetoresistive sensor systems.

References:

1. **Honeywell Sensor Products, Application Note AN211**
2. **Wikipedia**
   http://en.wikipedia.org/wiki/Earth’s_magnetic_field