Some Notes on Magnetic Field Sensing for National Semiconductor's Natcar Race

by
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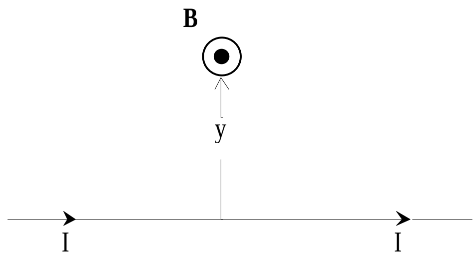
Primary Sources of Information
University Physics: Models and Applications by Crummett and Western
and
Shane Cantrell's fallible brain cells

For an infinitely long, straight wire, the magnetic field B at a point near the field is the following:



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

$$\mu_0 = 4\pi \times 10^{-7} N/A^2$$

From this we can see that the magnitude of the magnetic field induced by the current through the wire is inversely proportional to the distance the point is from the wire (when the wire is infinitely long and straight).

Using Faraday's law of induction, we can then find out how this magnetic field can be detected using inductors (solenoids).

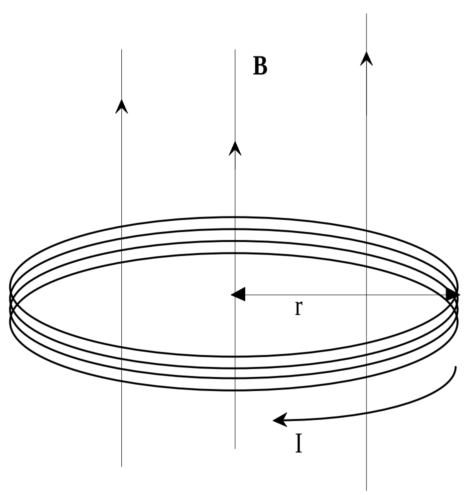
$$\xi = -\frac{d\Phi_B}{dt}$$

$$\Phi_B = \int \boldsymbol{B} \cdot d\boldsymbol{A}$$

Notice that Φ_B is the magnetic flux through a single loop and that the electromagnetic field ξ is only generated by a change in the magnetic flux over time. (This is the reason why an AC current source is used for this project instead of a DC current source.) From this formula, the current generated in a solenoid can be calculated when the magnetic flux is homogeneous over the inside loop.

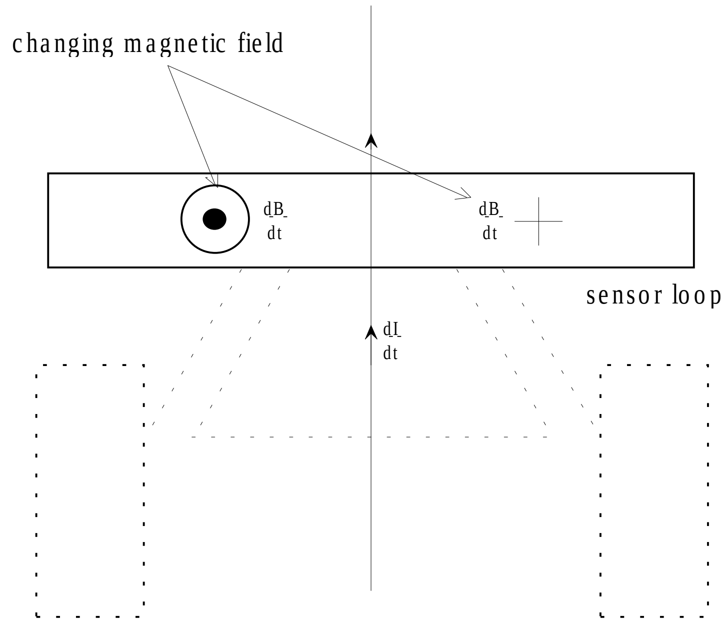
$$I = \frac{N\pi r^2 \frac{dB}{dt}}{R}$$

R is the resistance within the solenoid, and N is the number of turns.

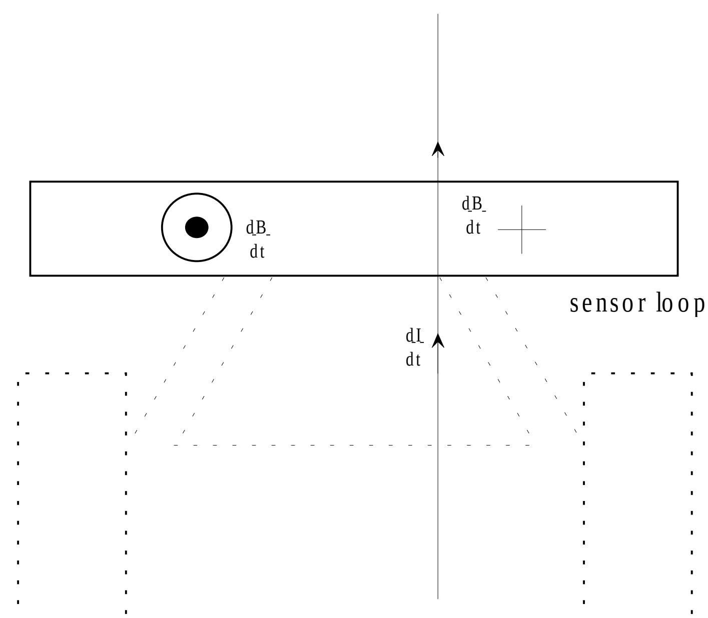


Now that you have had a really quick review, I will go over some design samples.

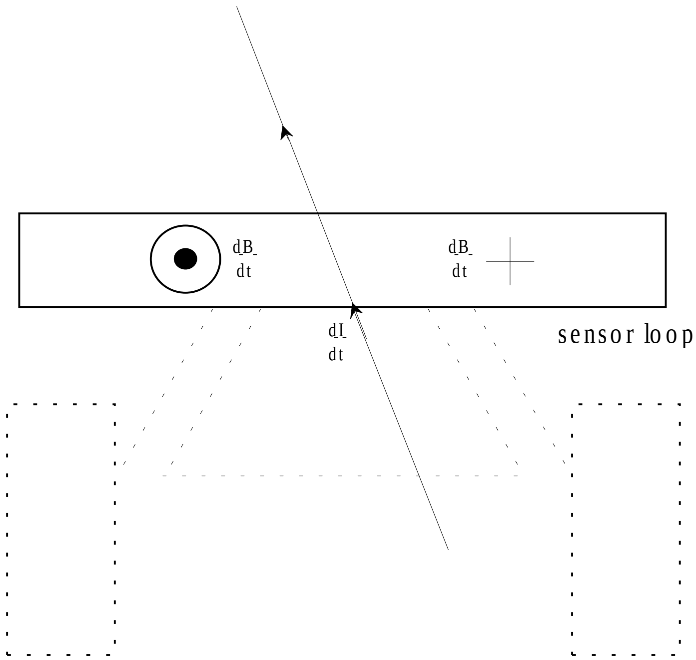
Large horizontal sensor that are close to the floor.



The first design has a long, rectangular loop of wire which rests on the ground in front of the car. When the car is centered around the line (as shown above), the amount of flux going through the loop sums to zero and the sensor sees a value of zero. If, as shown in the picture below, the car is slightly to the left of the wire, there will be more magnetic flux on one side than



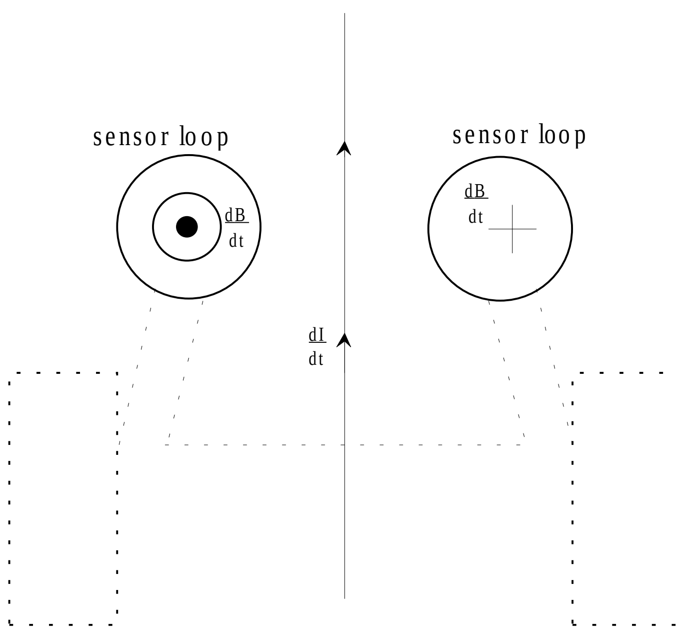
the other. Unfortunately, the track can be slanted with respect to the car such that the flux is equal on both sides. This shows that even more than one sensor is needed for detecting angle. In addition, the car will be unable to tell which way to turn even with a second, similar sensor



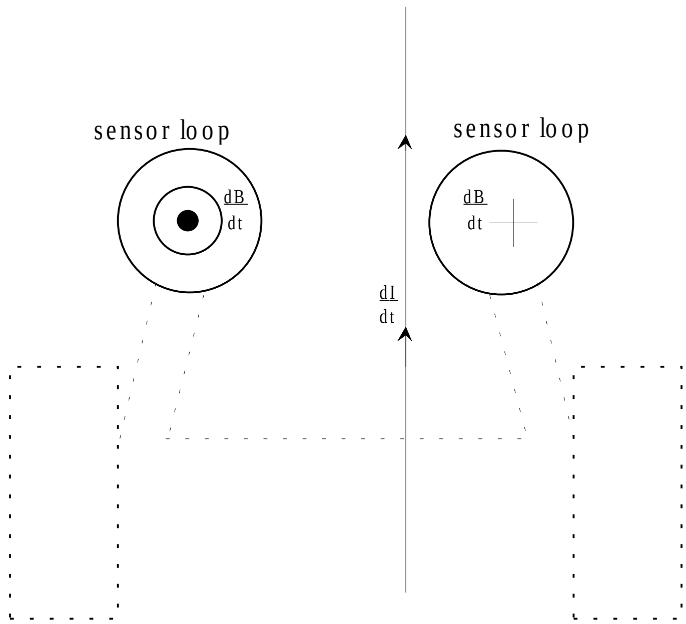
because without a third sensor to give the car a reference signal, there will be no way to distinguish the left side from the right side even though the signals produced by each side would be out of phase by π.

Circular sensors that are flat against the floor.

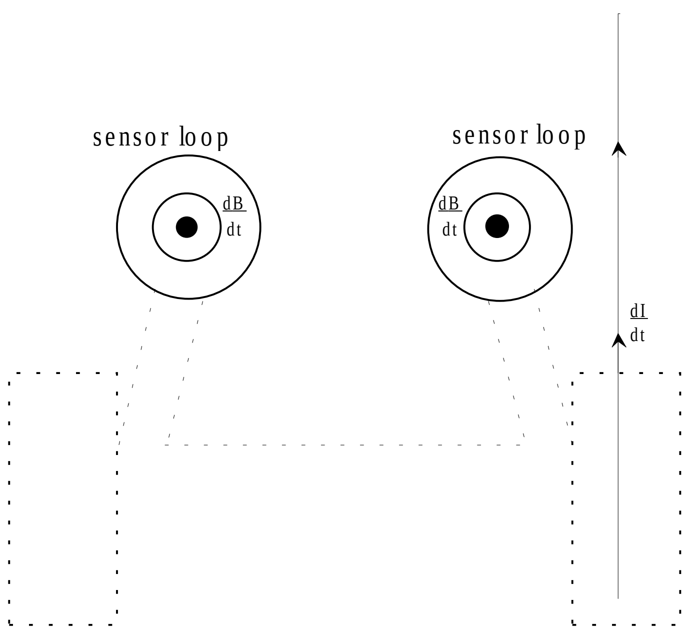
This method might be easier to implement because inductors are already circular inductors, but there are also other features that are worth mentioning. First of all, it is easier to



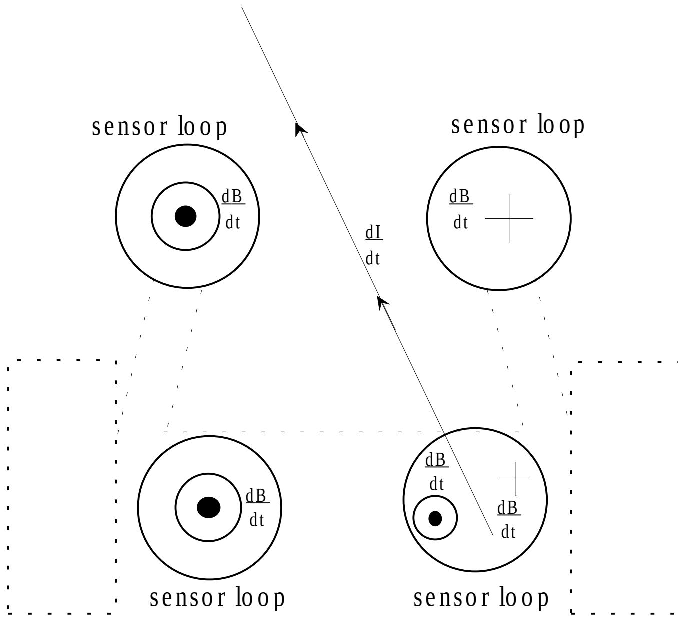
tell which side of the wire your car is on; the sensor with the largest magnetic flux will usually be closest to the wire. This, unfortunately, will not be true when the wire passes beneath the sensor because, as in the case of the previous example, the amount of flux going up, through the loop



will be canceling with the flux going down, through the loop. This will cause the total magnetic flux to drop quickly as the loop passes over the wire. Of course, once the sensor has passed over



the loop, it will be possible to determine that the car is no longer in the middle of the track because the signals will no longer be out of phase as shown in the picture above. With only a pair of these sensors, the angle of the car can not be detected, so it is probably best if two additional sensors are added as shown on the next page.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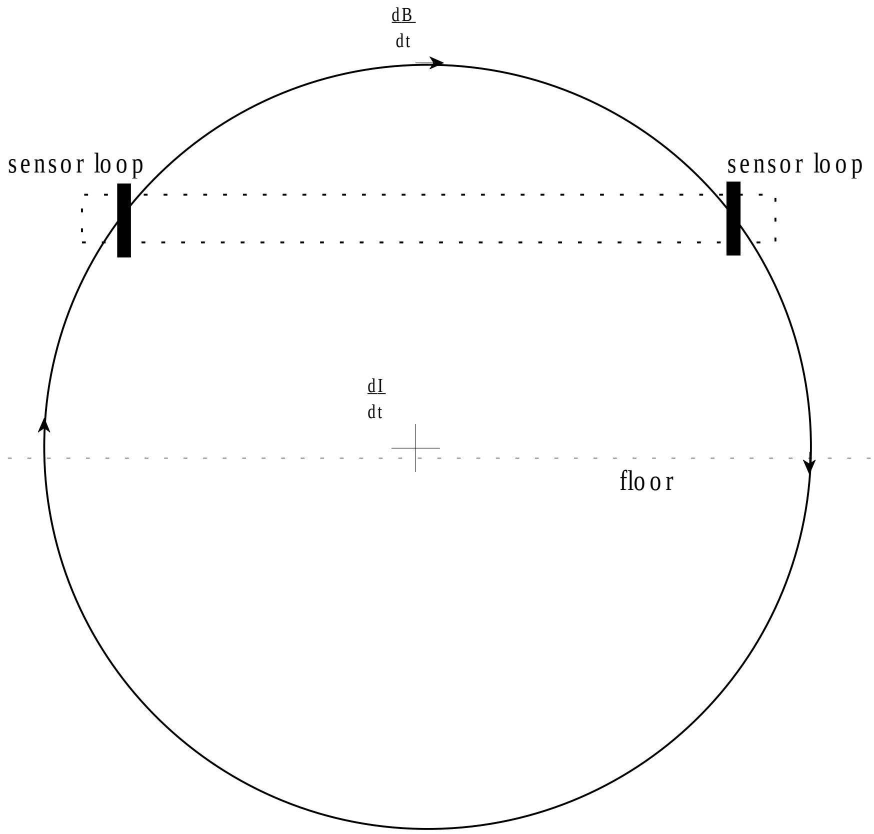
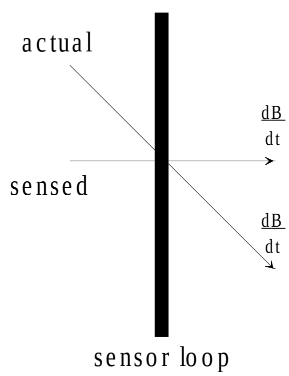
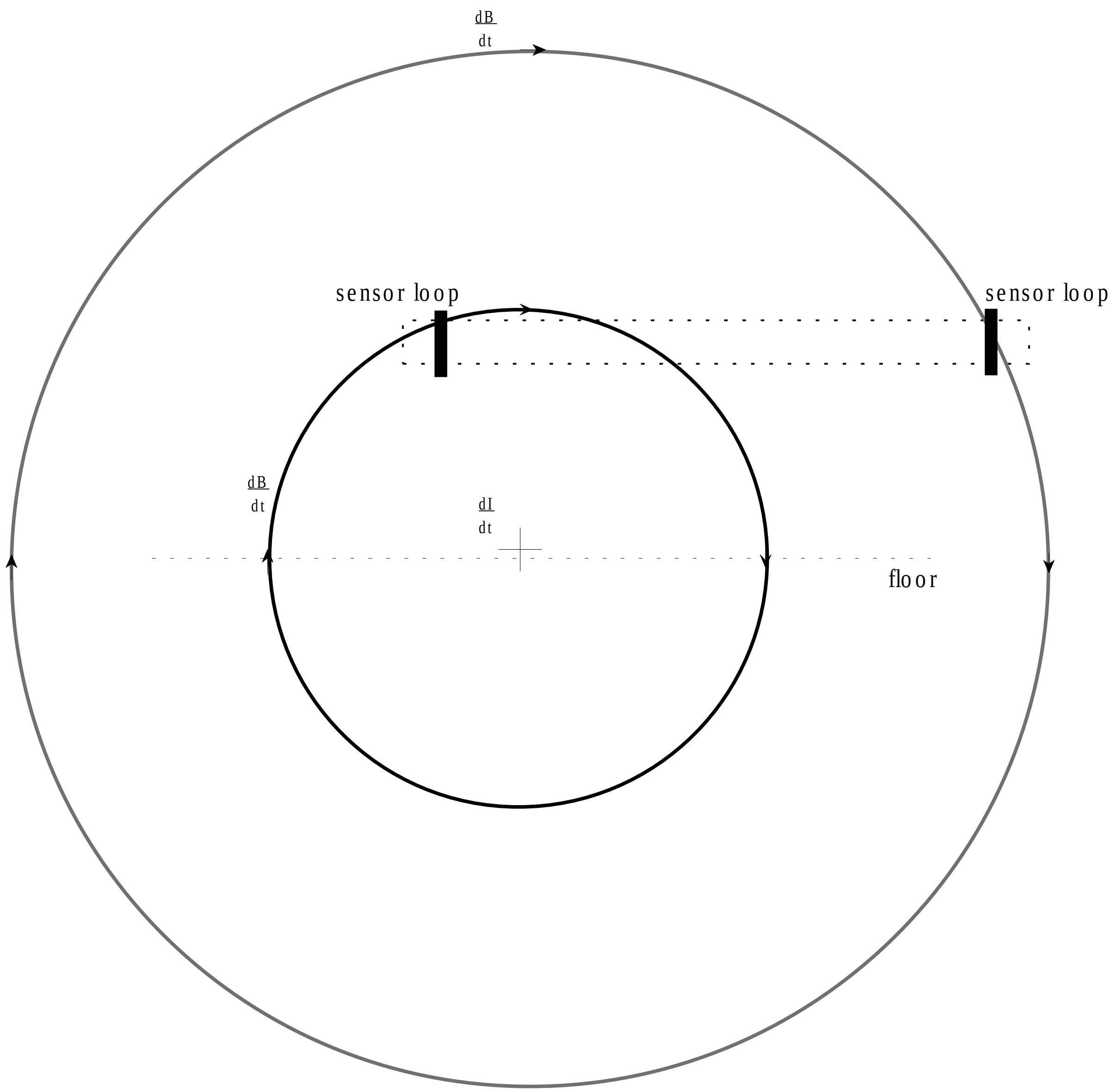
Standard, horizontally aligned sensors that are elevated.



Elevated sensors are one of the most popular orientations for the Natcar race. I think that this is because the sensors do not pass through a null area like the one I described for the previous design; at least when they are orientated as shown above, the signal will not completely die out until changing magnetic field becomes too weak to be detected. Unfortunately, this method is also less efficient because, as shown below, only the portion of the field perpendicular to each coil is actually detected and the rest is lost. If you look at the picture above and the one on the next page, it is apparent that the total field is only detected when the sensor is directly above the wire.





Notice that not only is the field reduced because of distance, but the percentage of the field is reduced when far from the wire because a smaller amount of the field is perpendicular to the loops.

Further designs.

This information should help you figure out unique locations and orientations that will maximize the stability of your car and allow you to beat those contestants with less understanding. :-)