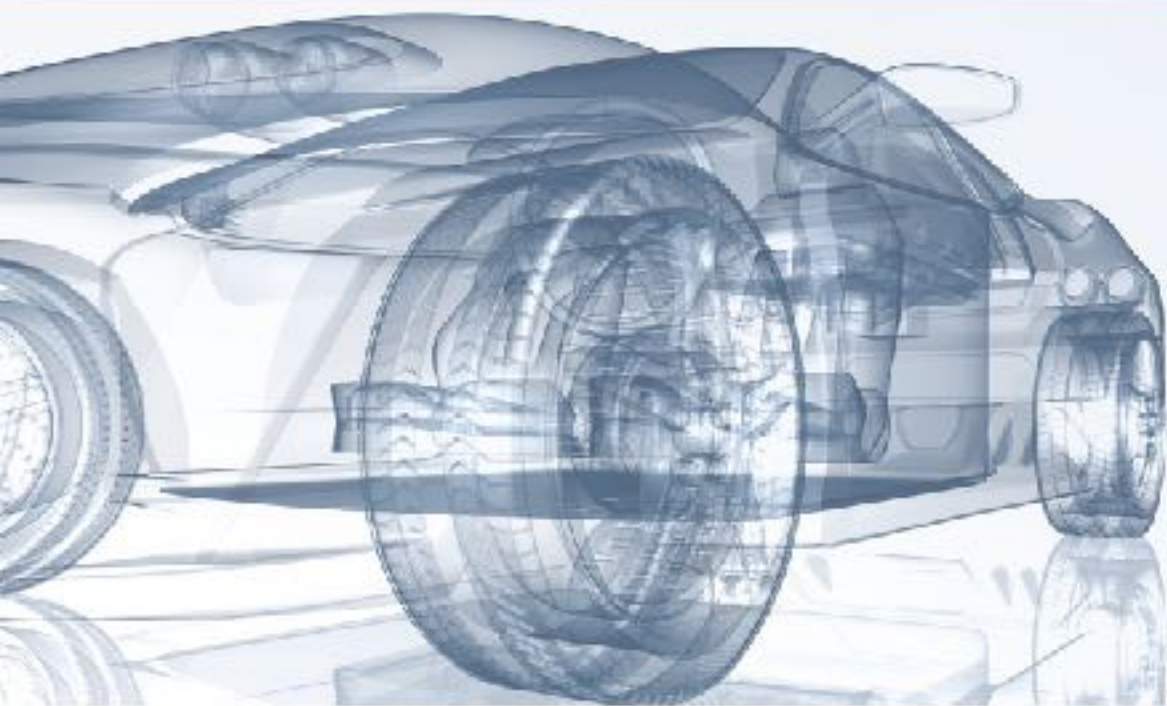


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Simple Relative Positioning 3-Axis Alignment Sensors for Wireless Power Transfer for Electric Vehicles

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Agenda

- *Alignment Requirements for Wireless Power Transfer*
- *Full Alignment System*
- *Planar Alignment Sensor Problems*
- *3-Axis Field Sensor*
- *Simplified 3-Axis Approximation Field Sensor*
- *Example Planar and 3-Axis Sensor Comparison*
- *Conclusion*

Alignment Requirements for Wireless Power Transfer

Two questions you must be able to answer:

- ***Is the system positioned in a way that power transfer is possible?***
- ***If not, how must the system be moved to improve alignment?***

First question is (relatively) easy to answer

- ***Measure the level of coupling (secondary open circuit voltage, short circuit current, etc.)***
- ***Establish a threshold above which the system will operate***

Second question is more difficult

- ***Limit the size of the problem, the vehicle can only be moved in two directions***
- ***Solving for complete spatial relationship isn't needed:***
 - ***X and Y offset – These can be controlled***
 - ***Z offset, Roll, Pitch, Yaw – These cannot***

Alignment Requirements for Wireless Power Transfer

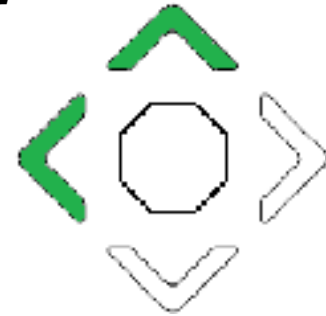
The driver can only move the vehicle relative to their current position

Since they can only move relative to their current position, relative guidance information is good enough

Relative guidance requires less information from sensors

Other Considerations

- **Fine alignment is completed in the last 1-2 feet of travel**
- **The driver will be able to get pretty close with no guidance in most parking scenarios (e.g. Garage)**
- **At a minimum, expect that they will get the ground coil between the wheels of the vehicle**
- **Expect and instruct user to use full range of control for left/right (e.g. Crank the wheel)**
 - **Anything less than this won't move the car a significant amount over the short ranges we**



Full Alignment System

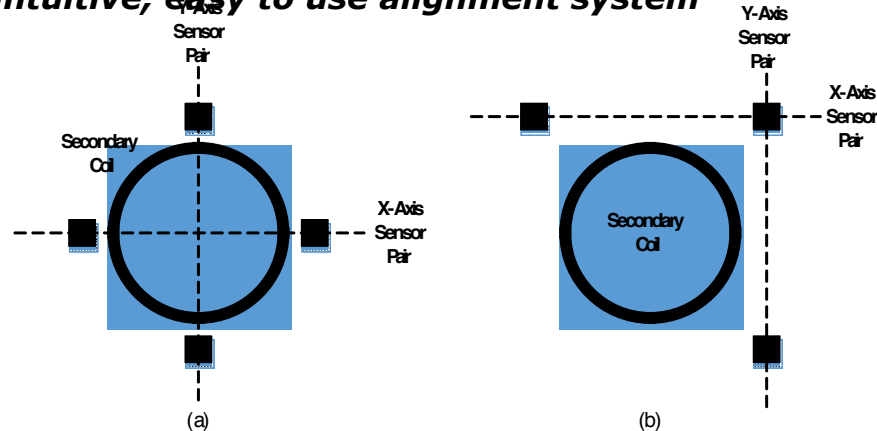
Remember: The driver can only control the vehicle in two dimensions (X and Y)

Use sensors in pairs along these two dimensions, based on which is closer, tell the driver which way to move the vehicle

Monitor the coupling between the power transfer coils to tell the driver when to stop

Build in hysteresis on the feedback signals so the driver has time to respond

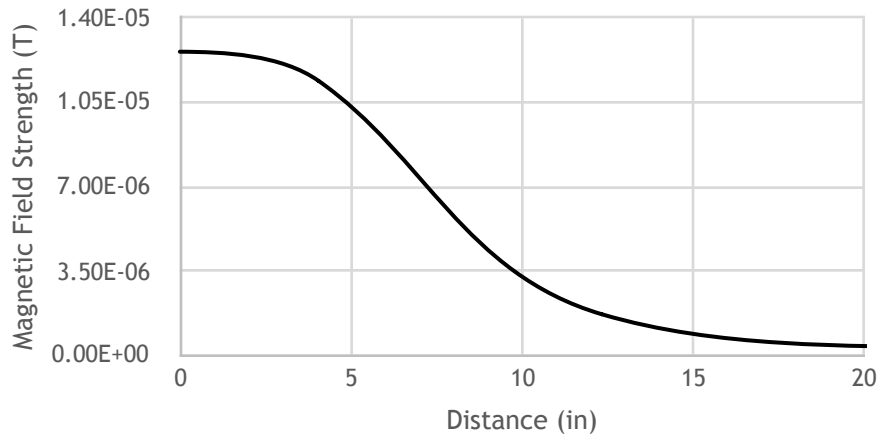
This makes an intuitive, easy to use alignment system



Full Alignment System

The primary coil is already available as a source for generating a magnetic field, so use it

Measure the magnetic field at the sensor locations to tell you which sensor is closer to the primary coil

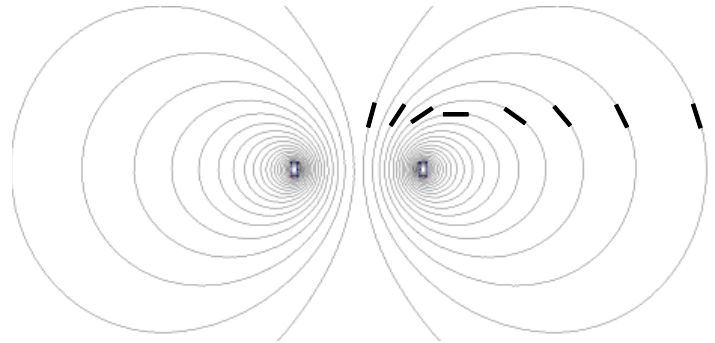
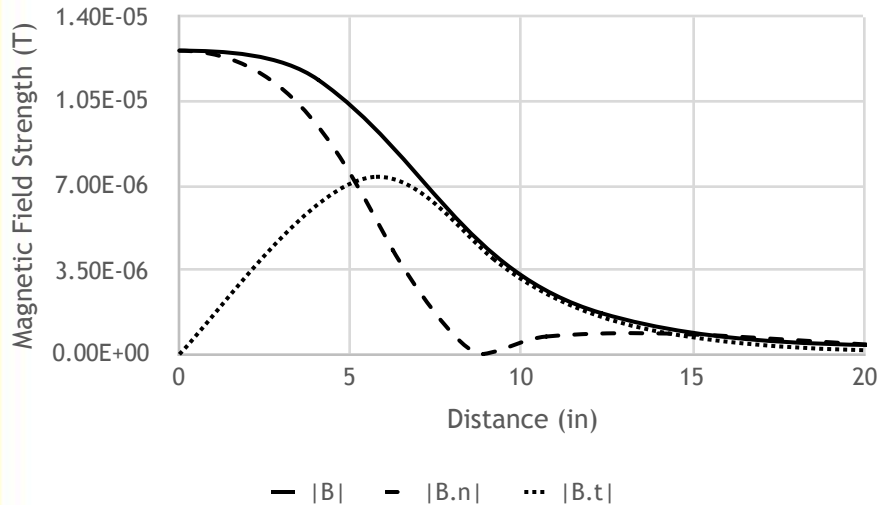


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Planar Alignment Sensor Problems

A planar sensor (or any single coil) can only detect the magnetic field in one axis

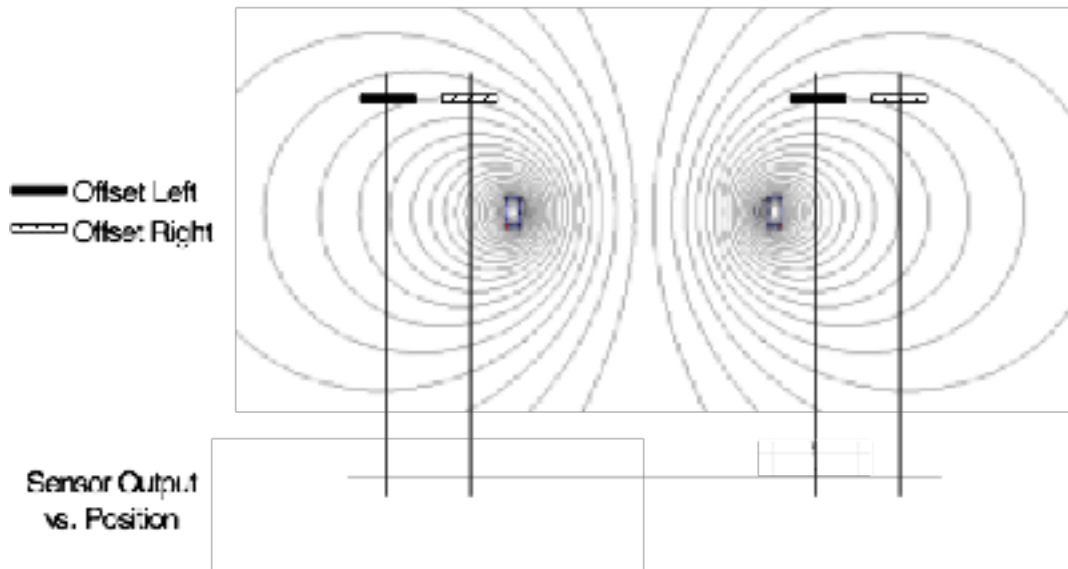
No matter how you orient this coil, you will have a dead-spot and a non-monotonic relationship between the output signal and distance



Planar Alignment Sensor Problems

You cannot just compare two sensor values to tell which is closer to the field generating coil

There will always be ambiguity between positions with direct level comparisons



3-Axis Field Sensor

What is needed is a sensor that gives the complete field strength in all 3-axis

This allows for a direct comparison of sensor outputs to tell which is closer

A high level of processing is needed to get an accurate value for the total field strength based on the three orthogonal component field strengths

This level of processing would require active components, and possibly a microcontroller, and this processing is needed for every sensor

▪ For example, if you have three sensor locations, each sensor with three separate detection coils, then you have 9 inputs that must be

processed to get 3 $|B| = \sqrt{B_x^2 + B_y^2 + B_z^2}$

Simplified 3-Axis Approximation Field Sensor

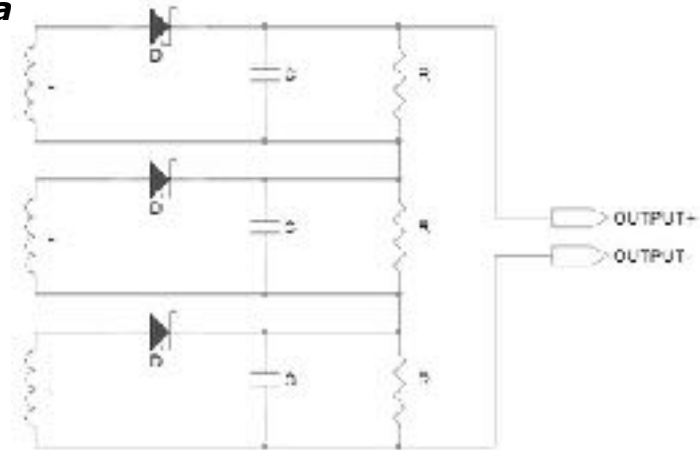
To know which of two sensors is closer to the field generating coil, you don't really need to know the exact field strength

You need a sensor with monotonic output vs distance, and no "dead spot"*

This sensor uses only passive components to get an approximation of the total field strength

These outputs can be directly compared under the right circumstances to know which sensor is closer to the field genera

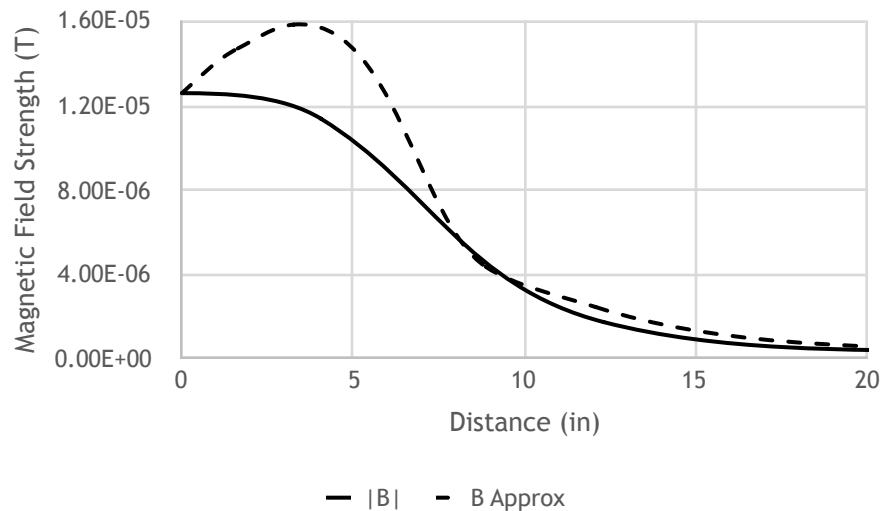
$$|B_{approx}| = |B_X| + |B_Y| + |B_Z|$$



Simplified 3-Axis Approximation Field Sensor

The output of this simplified sensor has all the properties that we need

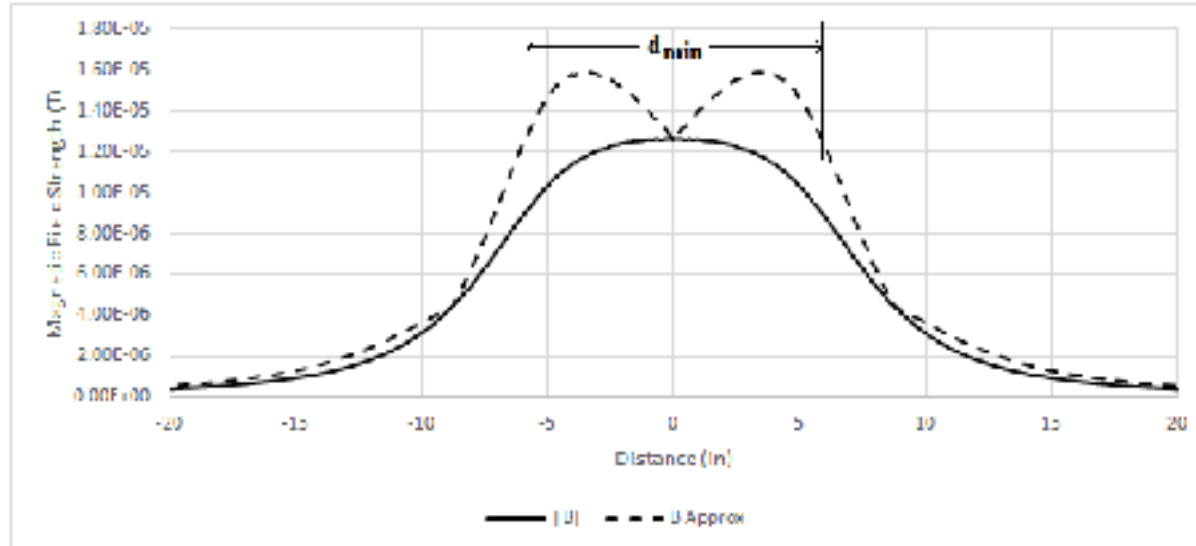
The non-monotonic area near zero must be handled



Simplified 3-Axis Approximation Field Sensor

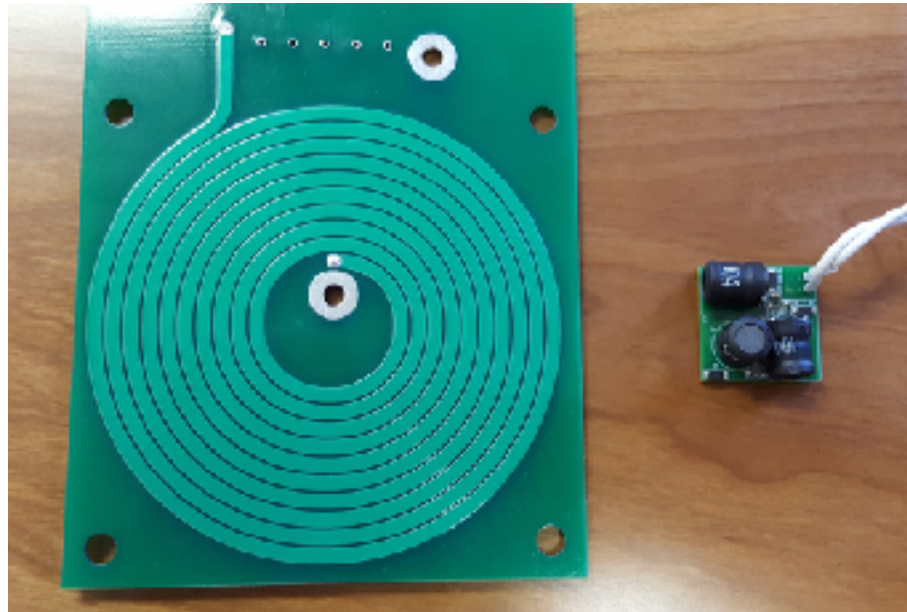
Define a minimum distance between the two coils based on how low the zero distance level drops from the maximum

As long as the space between the sensors is at least this distance a direct comparison of values is possible



Example Planar and 3-Axis Sensor Comparison

Data was captured using a 13" field generating primary coil with a 4" Z-dimension gap between the sensor and the coil



Example Planar and 3-Axis Sensor Comparison

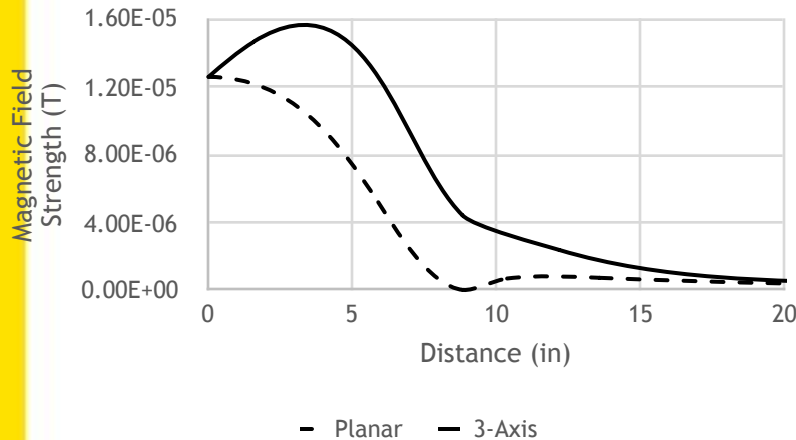
Non-ideal characteristics that come into play are:

- ***Diode forward voltage drop***
- ***Inductor and RC component tolerances***
- ***Inductors aren't perfectly orthogonal***
- ***Difficult to maintain constant plane for measurements***
- ***Difficult to maintain consistent orientation between measurements***
- ***Output voltage of planar and 3-axis sensors have a very different voltage scale, so the data was normalized to a zero offset value of 1***

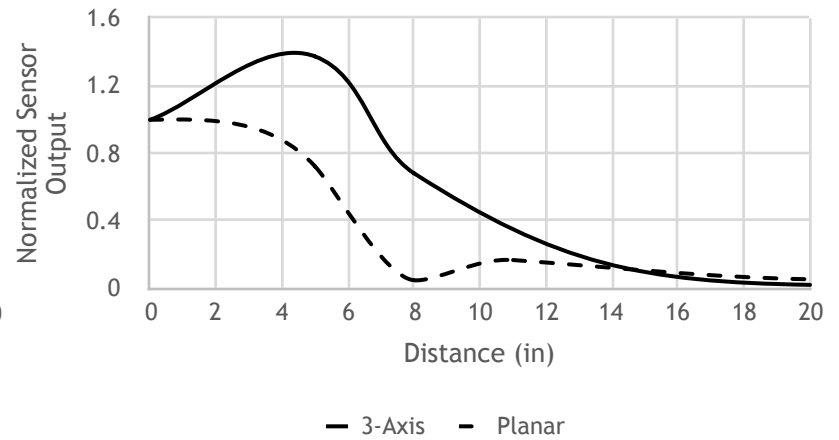
Example Planar and 3-Axis Sensor Comparison

The results show that the real world performance of this sensor very closely matches the expected performance based on computer simulations

Simulated Data



Measured Data



Conclusion

- **Relative positioning information is good enough**
 - **Don't over-complicate things**
 - **Don't give the driver more information than they can use**
- **Relative position is easy to determine with a single comparison of two sensors per axis**
 - **Only need a way to tell which sensor is closer to the field generating coil**
- **A magnetic field sensor with an approximate field strength output is simple to build**
 - **And this meets the requirements for guidance**

Thank You!