Electrical & Computer ENGINEERING

Cable Position Sensor

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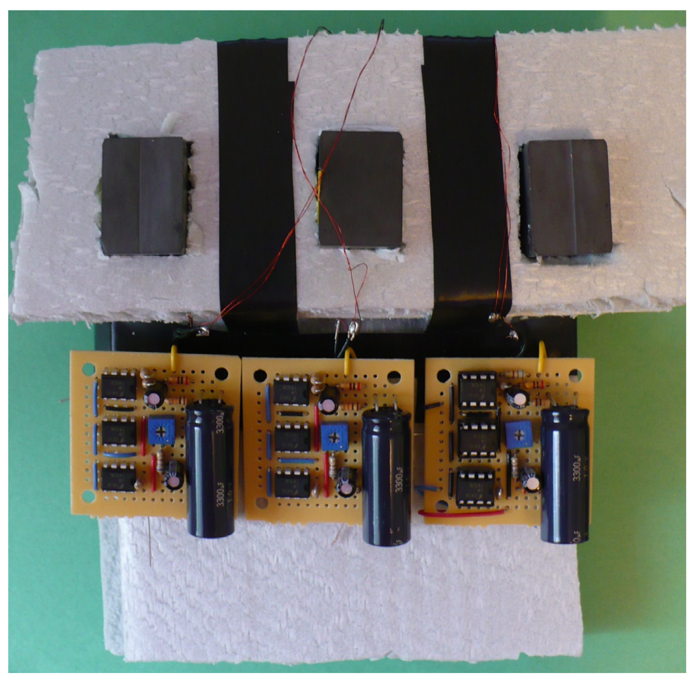
Sensor Systems Design

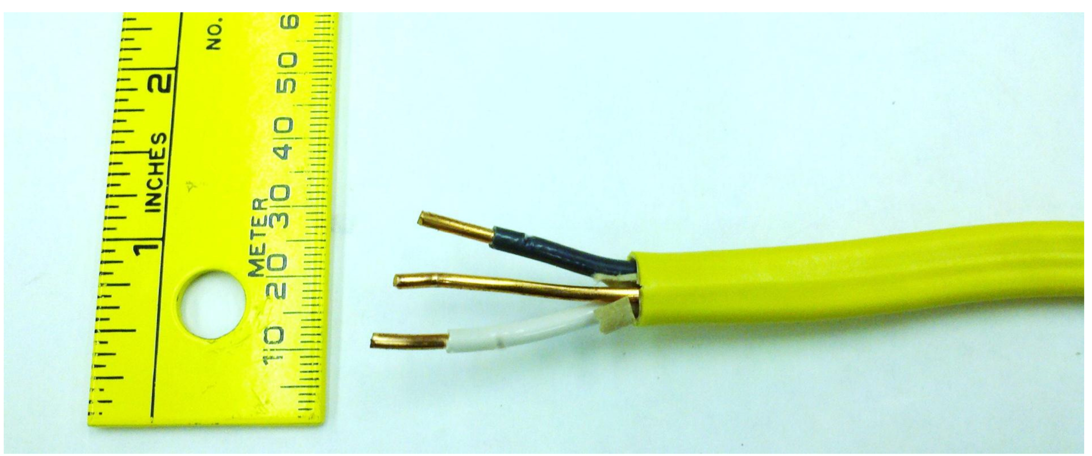


The cable position sensor.

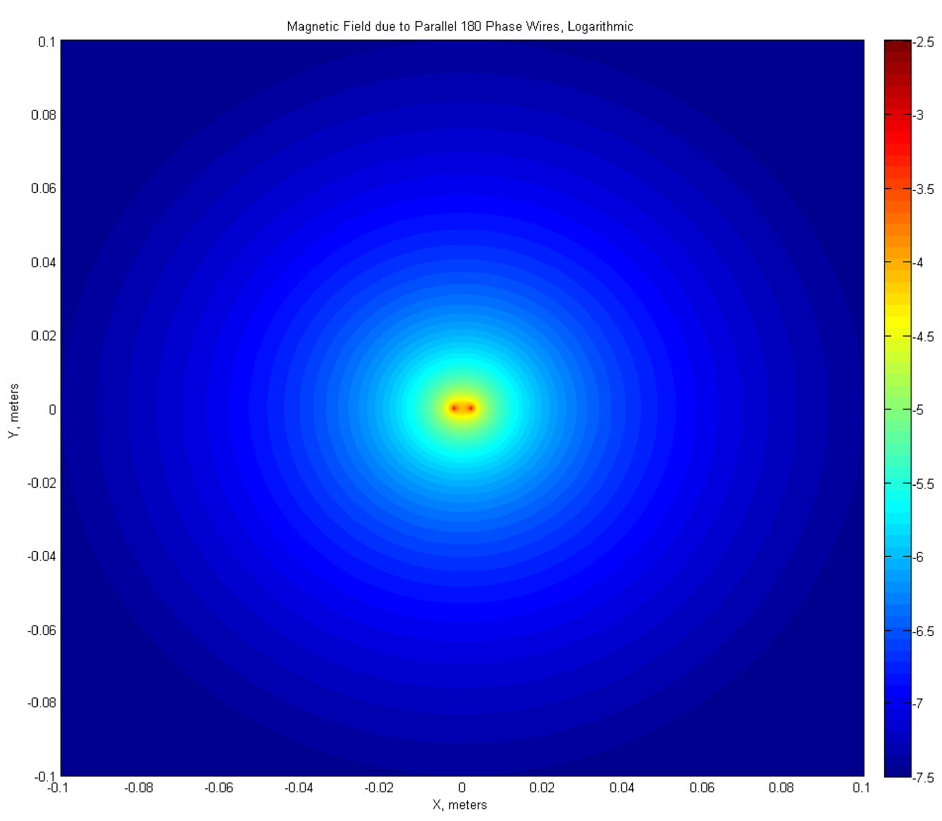
Introduction

Electrical cables are concealed behind walls and thus difficult to locate once walls have been placed. Non-invasive detection is preferred over an invasive search for reasons such as the reconstruction cost resulting from the search.

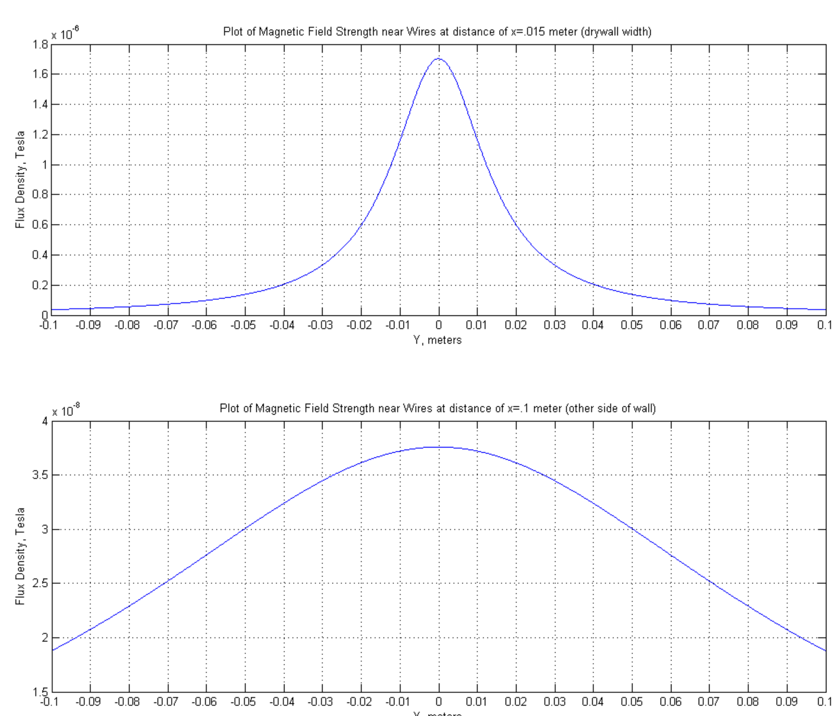
A sensor using inductive coils to measure the magnetic field induced by electrical cables is demonstrated and discussed. The sensor, with various interfacing electronics, is capable of locating cables by measuring the induced magnetic field at an array of locations, and can be used to identify a particular cable with a rectified load by reading the relative strength of each frequency present in the field.



NM-B 12/2 cable. The cable consists of “hot” (black), “ground” (copper), and “neutral” (white) wires. Alternating current flows through the hot and neutral wire, causing a magnetic field around the cable.

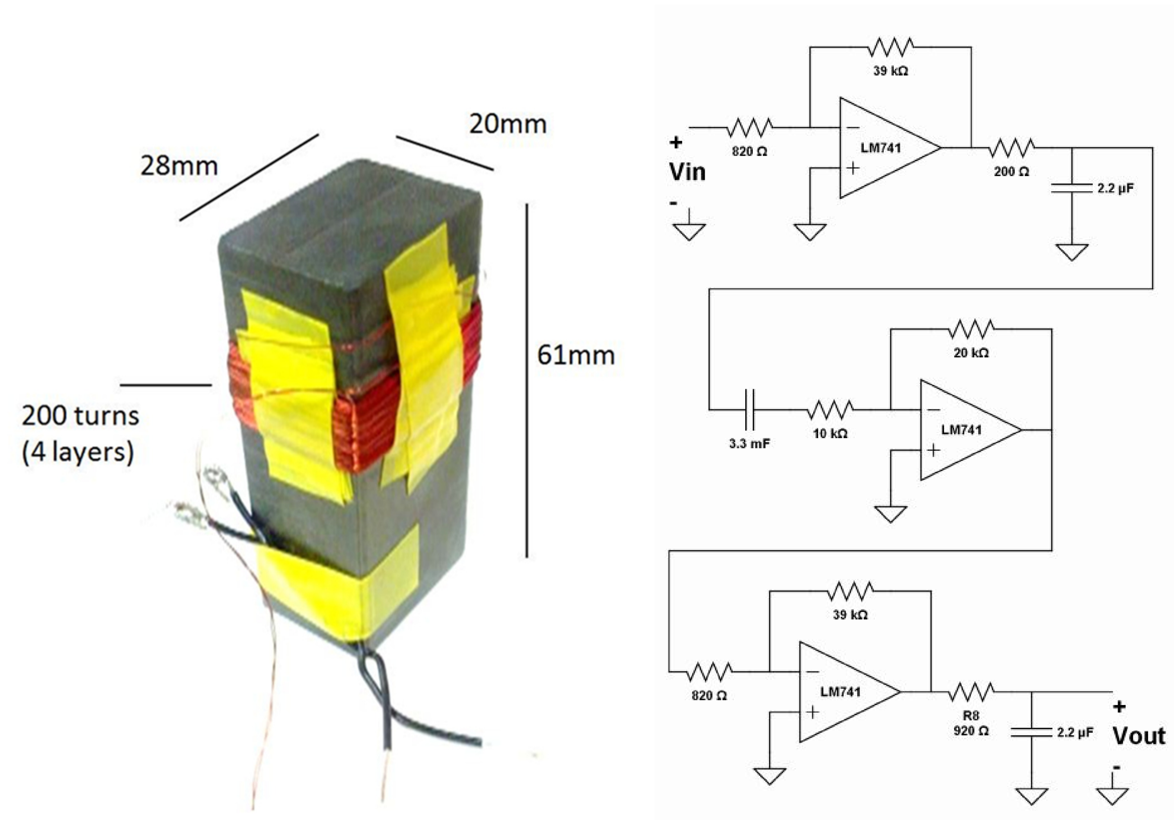


Simulated values of magnetic field due to two wires carrying 1 Amp of current, each 180˚ out of phase. Note Logarithmic Scale of Tesla.



Simulated values of magnetic fields due to 1 Ampere at cross sections of x = 0.015m, drywall width (top), and x = 0.1m, the width of a wall (bottom).

Sensor Structure and System



Individual inductive coil with ferrite core (left), interface circuit (right).

The main sensor is a ferrite core with cross-sectional area of $560mm^2$ is wound with 30 AWG magnet wire for 200 loops in 4 layers which gives an approximate coil length of 11mm.

An array of these coils gives an approximation of the relative strength of the magnetic field at various points along the wall. When the center coil gives the strongest reading, it can be said that the cable is located at the center of the array.

The interface circuit was designed to amplify the input voltage, which ranged from approximately 0.5 mV at highest proximity to a few µV at farther proximity. It also filtered out higher frequency noise by creating a bandwidth of 63 Hz.

Experimental Results

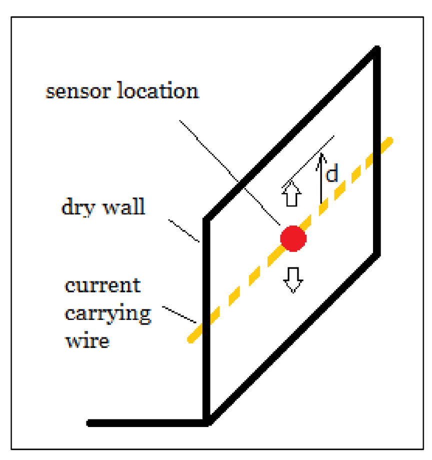
Wall section for simulation and testing, shown during test conditions.

Two main tests were conducted to gauge sensor performance. The cable was placed at 10 inch height, and lamp was plugged in to draw current.

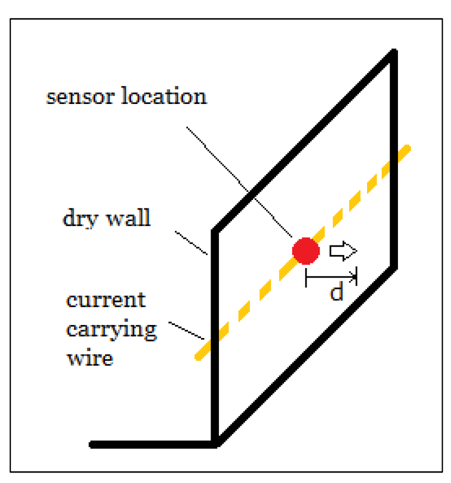
In Test 1, the sensor was moved up and down the wall, and the offset was compared to the output voltage.

In Test 2, the sensor was moved away from the wall, and the distance was compared to the output voltage.

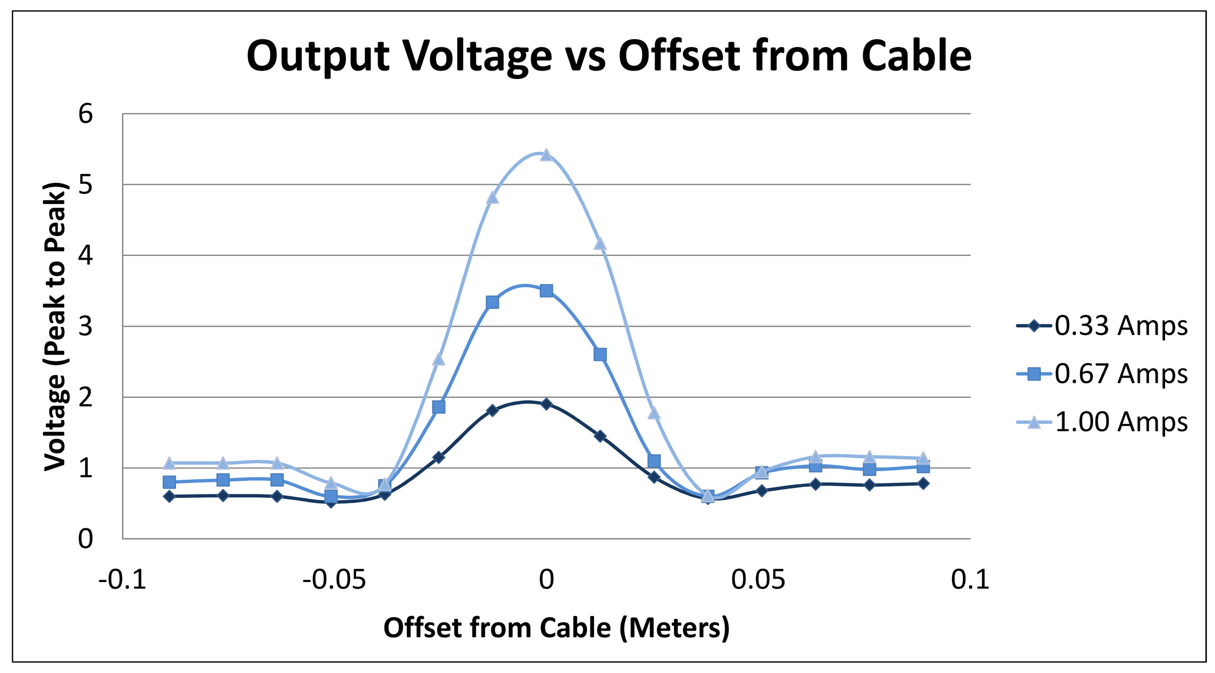
Finally, a rectifier was placed in the outlet receptacle on the hot line. This rectifier caused current to be drawn only when the voltage waveform was positive.



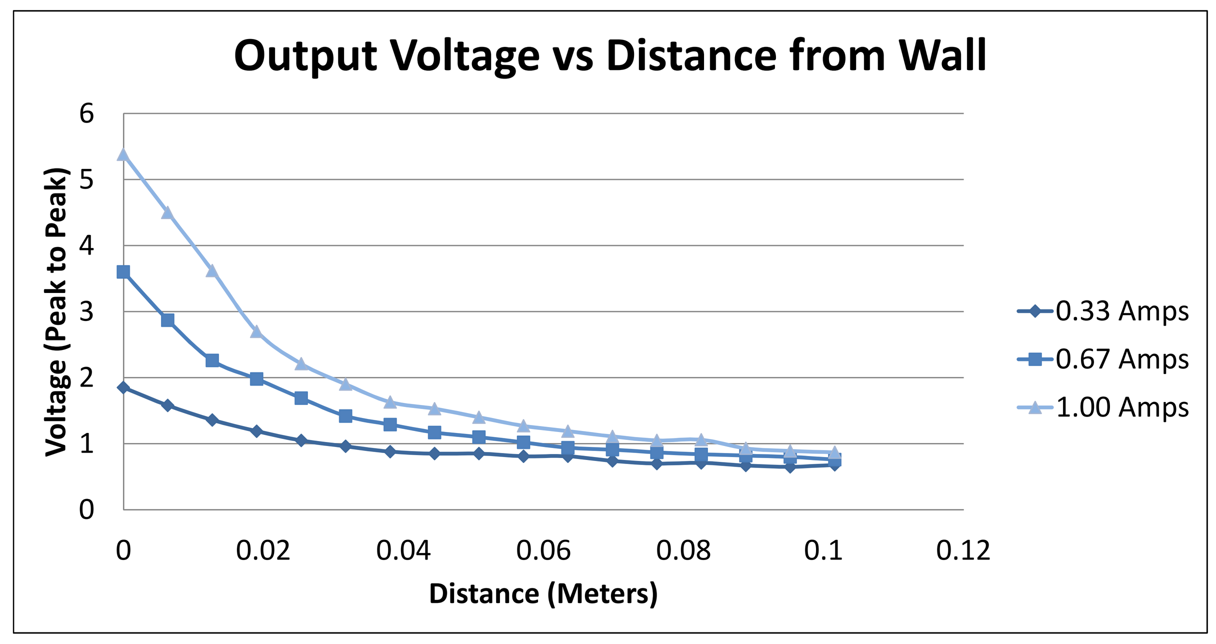
Test 1



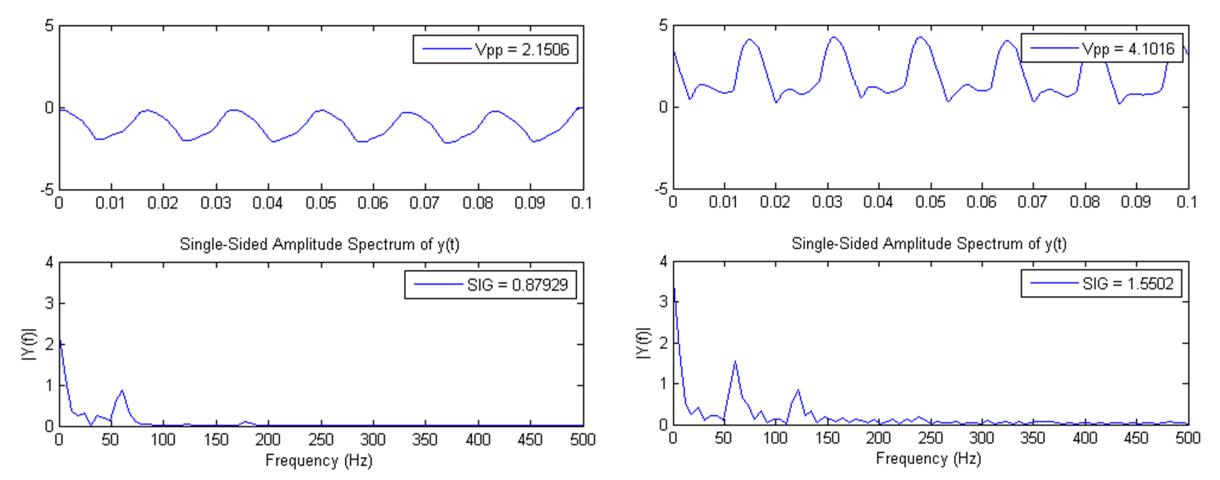
Test 2



Output Voltage vs Offset Distance. The profile suggests that the sensor can be used to find the location of cables.



Output Voltage vs Distance from Wall. The results suggest that the magnetic field strength varies with the inverse of the distance squared.



Time-varying voltages due to a normal current (left, top) and a rectified current (right, top). Note that the frequency spectrum of the rectified signal (right, bottom) shows a strong 120Hz component, relative to the 60Hz component.

Sensor Characteristics

Transfer Function (Coil)	$V_{out} = -N\frac{\Delta\phi}{\Delta t} = -N\frac{\Delta(\mu_r BA)}{\Delta t} = -1270\frac{V}{T} * \lvert\mathrm{B}\rvert$
Sensitivity (Coil)	$\frac{\partial V}{\partial\left(\frac{\Delta B}{\Delta t}\right)} = -NA\mu_r = 3.36\frac{Vs}{T}$
Span (Coil)	$39.5\ x\ 10^{-9}\ \sim 3.1\ x\ 10^{-7}\ T$
Output Range (Coil)	$133nV \sim 392uV$
Resolution (System)	$1.01 \times 10^{-7}\frac{T}{s}$
Saturation (System)	$1.04 \times 10^{-6}\ T$ (saturates Op-Amps)
Dynamic Range (System)	$20\log\left(\frac{\frac{dB}{dt}_{\mathrm{IN,MAX}} - \frac{dB}{dt}_{\mathrm{IN,MIN}}}{Resolution}\right) = 41.2dB$
Non-linearity	Variability in ferrite cores, windings, tolerance of resistors
Interference	Other electronic devices drawing 60Hz AC, AC motors
Noise	Mains noise, 1/F noise, Johnson noise, Amplifier noise

Conclusion

From experimental data, we can conclude that the output voltage varies directly with the magnetic field, and that the magnetic field varies directly with current and inversely with the square of distance. Furthermore, there is a high enough contrast in voltages that locating the cable is possible.

Additionally, experiments with rectification showed that different frequencies can be induced in the current, and the relative strength of these frequencies can be identified by the sensor system..

Future work includes creating methods of identifying field strength and frequency spectrum without use of a data acquisition unit. This work can be used to create the handheld device for personal use.