Cable Monitoring Unit

Safety Ground Detection Through Capacitive Coupling

Mattias Norman

2014

Student thesis, Bachelor, 15hp
Electronics
Electronic Engineer

Supervisor: Niklas Rothpfeffer
Examiner: Niclas Björsell
Abstract

Electronically monitoring whether or not your car block heater is connected to a mains outlet might at first seem like an arbitrary task. A device installed in the comfort of the car seating area, which tells the user at every startup whether or not his/her car is connected to a mains outlet, could have market appeal though. But in order for it to be a worthwhile idea to pursue, a certain requirement has to be met. It has to be able to be able to accurately detect whether or not the car is connected, through a single connection; the car ground. A certain part of the voltage in the phase of the mains will be capacitively coupled upon the safety ground. By exploiting the fact that the car ground will be connected to the mains safety ground when the block heater cable is in use, a device which can detect that coupled voltage could possibly be developed. In other words, a cable monitoring unit which in actuality detects a connection to the mains safety ground through capacitive coupling, hence the title of this dissertation.

This work sets out to taking appropriate measurements to find out whether or not this proposed method of safety ground detection is valid, with heavy emphasis on whether or not it is applicable to a cable monitoring unit. According to the measurement results, an appropriate device is developed. A device which can fill the function described in the previous paragraph. Development of such a device involves; proper method of supplying power which upholds a galvanically isolated floating ground, signal processing, reliable detection mechanism, and considerations to how unintentional capacitive coupling behaves.

A theoretical model of the device is put forth, as well as an actual rough prototype to in practice try to prove that the concept and method is valid. Downsides and problems with the device are discussed, such as upholding an effective detection system without making the device hard and cumbersome to use. Possible solutions to these problems are also proposed. The possible future of the concept of this device is also touched upon.
# Table of contents

Abstract ........................................................................................................................................... i

Table of contents ............................................................................................................................ ii

1 Introduction .................................................................................................................................. 1
  1.1 Background ............................................................................................................................... 1
  1.2 Purpose .................................................................................................................................... 2
  1.3 Concept .................................................................................................................................... 3
    1.3.1 Specification ....................................................................................................................... 5

2 Theory .......................................................................................................................................... 6
  2.1 Capacitive coupling ..................................................................................................................... 6
  2.2 Input impedance .......................................................................................................................... 8
  2.3 Filter design .............................................................................................................................. 9
    2.3.1 Damping and Q factor considerations ............................................................................... 11
  2.4 Detection .................................................................................................................................. 12
  2.5 Galvanic isolation ..................................................................................................................... 13

3 Process and results ....................................................................................................................... 15
  3.1 Introduction .............................................................................................................................. 15
  3.2 Mains outlet measurements ....................................................................................................... 15
  3.3 Car measurements ..................................................................................................................... 17
  3.4 Measurements with filtering ...................................................................................................... 18
  3.5 Solution prototype ................................................................................................................... 20
    3.5.1 Configuration and testing .................................................................................................... 22

4 Discussion ..................................................................................................................................... 23
  4.1 Measurements .......................................................................................................................... 23
  4.2 Threshold systems ..................................................................................................................... 25
  4.3 Single-supply vs. Split-supply .................................................................................................... 26
  4.4 Current problems ....................................................................................................................... 27
  4.5 Conclusion ................................................................................................................................. 28
References ........................................................................................................................................ 29
Appendix A ................................................................................................................................... 30
Appendix B ................................................................................................................................... 31
Appendix C ................................................................................................................................... 32
Appendix D ................................................................................................................................... 33
Appendix E ................................................................................................................................... 34
1 Introduction

1.1 Background

The safety ground in a typical household mains power line; is the connection that keeps the local power system from having a floating voltage potential. It is a connection from the neutral to the actual ground of the earth. This connection (between earth and neutral) is often located at the substation which the power is supplied from. Keeping the power system connected to the earth is important for security reasons, but there are other reasons as well. One of these is to keep the voltage stable for different systems (with their own voltage sources) that might interconnect in some way. If you want to be able to calculate relationships between these voltage sources in an easy way, you need them to have a common reference point. The earth provides this common reference [1].

As the subtitle of this dissertation inclines, it is about finding a method for detecting this earth ground, i.e. seeing if a particular object has an earth ground connection. An important caveat to this is that the detection should be as independent of the neutral and phase as possible. What exactly does that mean? It means that the system which you would like to see if it has an earth connection or not, does not have to be connected to the phase or the neutral. This limitation might seem totally arbitrary. But it is associated with a certain application that could be realized if a valid method for detecting earth ground, without phase or neutral connection, is found. The application in question is a block heater cable monitoring unit, which is explained further in following subsections.
1.2 **Purpose**

The possible application that sparked the subject of this thesis is a cable detection system. Detection of what cable exactly? The cable used for powering a car block heater. This cable connects the car to a normal mains power line, i.e. phase, neutral and safety ground. You normally want this connection to exist just ~1 hour before the car will be used; therefore it makes sense to use an outlet plug-timer in conjunction with the block heater. This makes it possible to decide beforehand when you want your block heater to be functional, so you don’t have to plug it in manually ~1 hour before the car will be used. Are there drawbacks to this system? Yes, the driver can forget to disconnect the cable before he/she drives away, which can cause cables to break. Since these cables are pretty expensive, this can definitely be seen as a problem.

An associate at Syntonic AB thought it was a problem. He gave the author of this dissertation the objective to try and solve this problem. Considerations will have to be made on not breaking possible patents that the manufacturers of the different block heater systems might have. An optimal solution would be a system that does not interfere or require modification of the actual block heater system in any way. These considerations shall be made not only in avoiding the use of proprietary connectors, but also in regard of ease of installation and maintenance of the detection system. A device which could connect to the cigarette lighter receptacles would be considered optimal. He also had the idea that this could be accomplished by detecting the safety ground. That is something that stuck, and that is what this dissertation is about. More precisely, this dissertation is about:

1. Finding out if this idea is valid, i.e. if there is a method of detecting the safety ground of a mains power line. Without direct connection to phase or neutral.
2. If there is a method of doing just that, is it practical? What would be the price, size, and overall ease of use of a device capable of applying said method?
3. Would the found method be applicable to the application proposed by Syntronic AB (i.e. detection through car). If not, why?

Point number three will guide the project along, i.e. if a valid method for detecting the earth ground is found, but it is not applicable to be used for a car block heater. The method will (if possible) be evaluated and changed to hopefully be used as a possible solution. Compromises might have to be made though, in order to accomplish a working system.
1.3 Concept

The original concept (previously touched on in Section 1.2) inclines a safety ground detection device which is sensitive and accurate enough to be able to deploy in a car. That would mean a device which would be measuring the grounding of the car, and be able to sense whether or not the car is in turn connected to a mains safety ground. Because of how the grounding scheme of a car is structured, if you connect to the car batteries ground point, you are in turn connected to both the car chassis and the safety ground of mains (if the cable connection is present).

“What is the easiest and most user friendly way to connect to the grounding of the car?”

Is a question that might arise, and the answer is most likely: The cigarette lighter receptacle. Not only is it easily accessible and user friendly. It is a universal standardized connector which is found in almost any car and it bypasses the need to use any proprietary connectors used in block heater systems. This leads to the conclusion that optimally a device which is as small as any cigarette lighter plug is desired.

Assuming that the device has a floating ground source, which is isolated from the car/safety ground (Section 2.5). AC voltages can be detected in the car ground, the safety ground, and in any other conducting material for that matter. The phenomena which facilitates this is called capacitive coupling, and it is covered in Section 2.1. Certain circumstances are required though, if detecting voltages from capacitive coupling is desirable. They are covered in Section 2.1. The essential circumstance to think about when designing a device to detect capacitive coupling, is high input impedance. Input impedance is covered in Section 2.2, and actual measurement results using differing input impedance are found in Section 3.

Most of the research specifically on capacitive coupling is done with the purpose of minimizing it for EMC-related issues. Everything from reducing capacitive coupling in thin-film transistors [2] to analyzing its effects in PWM (pulse-width modulation) driven power supplies [3].

The author found no published papers exploring this idea of using capacitive coupling as block heater cable detection. Similar techniques are used in different applications however. Such as seat occupation detection, where capacitive sensing techniques are used to distinguish whether or not a person is seated in e.g. a car seat [4]. Capacitive sensing is a technique based on capacitive coupling which measures the capacitance of an object.

This concept is not just about detecting capacitive coupling though. Since the coupled signal that is desirable to detect, is the signal that the cable from the mains to the car block heater will increase, everything else should be filtered out. The frequency of the voltage that will increase when the car is connected to mains is the mains frequency; the reasoning behind this is explained in Section 2.1. Not only do all frequency components above (and possibly below) the mains frequency needs to be substantially attenuated through filtering, the mains frequency itself needs to be amplified a substantial amount. Filtering is covered in Section 2.3. Since this dissertation is carried out in Sweden, the mains frequency specified here (50 Hz) will be assumed.
A very general illustration of the concept laid out in this subsection is shown in Figure 1, where P, N and G represent: Phase, Neutral and Safety ground. Note that the phase and neutral connection is ideally supposed to be irrelevant; all that the detection system should require to function, is that the safety ground is connected to the car.

![Diagram of cable monitoring unit](image)

Figure 1. Illustration of cable detection concept.

How will the device function from a user experience standpoint? The detection only needs to take place when someone starts the car. When the car is turned on, the car battery powers on, so that is an easy way to indicate that the car has started. When the car starts, there are only two possible scenarios this device has to handle. Either the block heater is connected to mains, or it is not. If it is connected, the device should indicate the driver with sound and/or some other indication. If it is not connected, it does nothing from the users’ point of view. The flowchart in Figure 2 illustrates the process.
1.3.1 Specification

The solution laid out in this section (1.3), will be further specified in this subsection. What guidelines will be followed when designing this device? The following list answers such questions. The device needs to follow these specifications, in order to be seen as a success.

- **Fully analog solution.**
  From the start, the idea was to design an analog device. Mostly to avoid possible software problems and unnecessary complexity. Of course would a digital solution be a possibility, but this dissertation sets out to develop a fully analog one.

- **Cheap components.**
  Expensive components should be avoided at every cost. If the device cannot be cheaply produced, it will never be a viable consumer product.

- **Small physical size.**
  The components should fit in small enough casing, to be easily usable with any cars cigarette lighter receptacle.

- **Ease of use.**
  For it to be viable as a consumer product, it needs to be extremely easy to set up and maintain. Need for calibrations and elaborative installations should be avoided.

- **Reliability.**
  The device needs to maintain consistent functionality.
2 Theory

2.1 Capacitive coupling

Electrostatic coupling or capacitive coupling is the transfer of energy through capacitance. When done intentionally, this is often achieved by placing a capacitor in series between two circuit nodes. It also occurs between conducting materials naturally, e.g. between two conducting wires. The amount of coupled voltage between a source and another circuit node though capacitance is dependent on four main factors; The voltage and frequency of the source, the capacitance between the circuit nodes, and the impedance between the receiving node and ground, i.e. input impedance.

This subject is explored in this dissertation because it is vital to the proposed method for safety ground detection. Coupling between the mains power line and a device can be substantial if the device has high input impedance and a non-shielded input stage which is relatively big (physically). The idea is that the capacitance between the safety ground conductor and the phase conductor is big enough to act as a valid way to detect a safety ground connection.

To illustrate this phenomenon and derive an expression for it, the model in Figure 3 is appropriate, where $C$ is the capacitance between the circuits and $C_{in} // R_{in}$ is the input impedance of the receiving circuit.

The voltage coupled from the source circuit to the receiving circuit can be expressed with equation (1).

$$V_c = \frac{V}{\sqrt{\left(\frac{1}{R_{in}}\right)^2 + (\omega C_{in})^2} + 1}$$

(1)

The expression can be simplified if a few assumptions are made. If the relationship in (2) is true, then the resistance $R_{in}$ will dominate the expression for the input impedance of the receiving circuit.
\[ Z_{\text{cin}} \gg R_{\text{in}} \]  \hspace{1cm} (2)

Furthermore, if the relationship in (3) is true, then the expression (1) can be simplified to (4).

\[ \frac{Z_C}{R} \gg 1 \]  \hspace{1cm} (3)

\[ V_c = \omega CRV \]  \hspace{1cm} (4)

\[ \omega = 2\pi f \]  \hspace{1cm} (5)

Where (5) is applicable.

The resistance \( R \) is the input impedance of the receiving circuit (purely resistive because of previous assumptions), \( C \) is the capacitance between the circuits, and \( V \) is the voltage source. Note that \( \omega \) and \( V \) are only dependent on the source circuit, i.e. the source of the coupled power.

Since this dissertation will primarily be concerned with the low frequency voltage from mains phase that is coupled upon the safety ground, the assumptions in (2) and (3) can be made. Since the impedance of almost any capacitance will be very big at 50 Hz.

The capacitance between the phase and the safety ground is nothing more than capacitance between two wires, which can be expressed as in (6) [9]. Where \( l \) is the lengths of the wires, \( d \) is the distance between them, \( a \) is the wire radius and \( \varepsilon \) is the permittivity of free space. Keep in mind that lengths of the wires \( l \), is the length that the wires run next to each other, i.e. when they are aligned. This capacitance will typically not exceed a few pF though. Even if a pair of 2 mm wires run perfectly aligned with each other with a constant distance of just 5mm for 100 meters, the capacitance between them is only \( \approx 30 \text{pF} \).

\[ C = \frac{\pi \varepsilon l}{\text{arcosh} \left( \frac{d}{2a} \right)} \]  \hspace{1cm} (6)

If designing a device which can detect something through capacitive coupling is desired. It would make sense to have the capacitance be very low when the device is not applied. This can then be contrasted by having a much higher \( C \) when the device is applied in a certain way, giving it the wanted properties, which will increase \( C \) and therefore also increase the coupled voltage. The value of \( R \) should be chosen so it fits well with relativity to the capacitance \( C \). In the context of safety ground detection, the input impedance \( R \) would have to be pretty big (~MΩ), since both the frequency \( \omega \) and the capacitance \( C \) will be small.
2.2 Input impedance

In the context of this dissertation, the topic of input impedance will be closely related to previous section on capacitive coupling. This is simply because the amount of capacitive coupling ‘picked up’ by a device is directly proportional to input impedance of said device (at least at low frequencies). This can be shown in (4).

The input impedance of a system is often defined as the impedance ‘seen’ by a connected source. It can be defined in different ways dependent on the subject matter, but in the scope of this dissertation it will simply mean the impedance between the input and ground. For example: The oscilloscope used for measurements in this dissertation has an input impedance consisting of a capacitor and resistor connected in parallel to ground, with the values: $R = 1\, M\Omega$, $C = 25\, pF$.

In conjunction with capacitive coupling, the input impedance of a system will basically make a high pass RC filter. This can be seen in Figure 3, where $C_{in} // R_{in}$ and $C$ make up the filter. The coupling between the circuits $C$ is normally not constant, and cannot be directly controlled, but the input impedance is and can. Figure 3 is the frequency response of the ultimately unintentional RC high pass filter with different values of $R$, $C_{in}$ and $C$ (different input impedances and coupling capacitance).

![Image](image_url)

Figure 3. Frequency response of unintentional high pass filter.

With higher values of $R$, the break frequency $F_c$ becomes smaller, and therefore the low frequencies are attenuated less, all according to (7). Also, the linearity of the curves in Figure 3 between $F = 0$ and $F = F_c$ corresponds to the linearity of the simplified low frequency expression for capacitive coupling (4).

$$F_c = \frac{1}{2\pi R C}$$

(7)

Note that in order to detect any capacitive coupling at all, the input impedance need to be relatively big. At $R = 1k\Omega$ for example, even 100 kHz signals are attenuated 50dB.

In summary, a capacitive coupling detecting device such as this dissertation is pursuing needs to have a high input impedance in order to function at all (unless its purpose is to detect very high frequencies). Also, because the input impedance in conjunction with the capacitive coupling creates a RC high pass filter, the input impedance can be matched to create a sort of pre-filtering for the device, if the frequencies that should be detected are known.
2.3 **Filter design**

A crucial part of this dissertation involves filtering. Filtering will be part of both the measuring portion (Section 3.4) as well as in the proposed solution (Section 3.5). Sufficient performance, customized for the proposed purpose, will be the prioritized first. After that, mind will be taken into cost and power consumption.

In Section 2.2, the fact that the capacitive coupling in conjunction with the input impedance of a system will act as a high pass filter was discussed. By using the model in Figure 3, tests can easily be made to see what the input impedance values should be to equalize the amount of attenuation over the frequency spectrum. Since the capacitive coupling between the source and the measurement device cannot be controlled, it is assumed to be about 0.5pF in the following example. With the resistor and capacitor having corresponding values to the Fluke 97 ($R_{in} = 1M\Omega, C_{in} = 25pF$), the low frequency signals will as previously mentioned be attenuated about 40 dB more than the high frequencies. By changing the value of $C_{in}$ from 25 pF to 4.7 nF, 50 Hz components will be attenuated 81 dB. This is a somewhat unfortunate increase, but the tradeoff is that all frequencies above 200 Hz will be attenuated 79dB.

The frequency spectrum has therefore been equalized for everything above 200 Hz, and the difference in attenuation between high frequencies and low frequencies have been decreased from 40 dB to just about 2 dB.

Since the signals processed in this dissertation will all be small, they need significant amplification to be handled properly. This leads to the choice of using active filters over passive filters. For the measuring, this principle was at least employed. An active 2nd order band pass filter cascaded with a 3rd order low pass filter was the primary filter method used in the measurements concerning filters. In the filter design process, [5] and [6] was used by the author. What follows is a quick run-through of the transfer function and frequency response of the filters used while taking measurements.

The 2nd order band pass filter has the transfer function (8), and the transfer function for the 3rd order low pass filter is (9).

$$A(s) = \frac{b_2s}{s^2+a_2s+a_3} \tag{8}$$

$$A(s) = \frac{b_3}{s+b_3} * \frac{b_3}{s^2+a_2s+a_3} \tag{9}$$

By cascading the filter, the total transfer function for the system becomes (10).

$$A(s) = \frac{b_2s}{s^2+a_2s+a_3} * \frac{b_3}{s+b_3} * \frac{b_3}{s^2+a_2s+a_3} \tag{10}$$
For the measurement circuit, the band pass filter has a 15 dB gain at the middle frequency, and the low pass filter has a gain of 20 dB. The middle frequency of the band pass filter is 50 Hz, and the break frequency of the low pass filter is 100 Hz. Since the damping ratio of either filter is not really relevant to the application (at least not for measurement purposes), it is mostly ignored (section 2.3.1 covers damping factor). The Q factor of the band pass filter is set at 15.9. The specifications of the two filters just mentioned are summarized in (11).

\begin{align*}
\text{Band pass:} & \\
& f_m = 50\text{Hz} \\
& \zeta = 0.03 \\
& Q = 16 \\
& K = -6.1 \\
\text{Low pass:} & \\
& f_c = 100\text{Hz} \\
& \zeta = 0.49 \\
& K = 10 \\
\end{align*}

Calculating the coefficient and plotting the Bode diagram for (10) with the specifications in (11) gives the resulting bode diagram magnitude plot in Figure 4. This filter is well suited for measurements. Decent amplification for the wanted 50 Hz signals at about 30 dB, very high attenuation for high frequencies, and adequate Q factor. The band pass part of the filter has very low damping factor, which could cause problems in an actual detection system, but for measuring purposes it is fine. The following subsection discusses the impact damping factor has.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{bode_plot.png}
\caption{Frequency response of the filter used for taking measurements. Derived from (10).}
\end{figure}
2.3.1 Damping and Q factor considerations

The Q factor of a band pass filter determines the narrowness of the bandwidth, i.e. how much the frequencies in close proximity to the central frequency get attenuated. A high Q factor would be desirable for the purpose of this dissertation, but with MFB (Multiple feedback) band pass filters the damping factor is inversely proportional to the Q factor of the filter. The inversely proportional relationship is seen in (12), where $\zeta$ is the damping factor.

\[
Q = \frac{1}{2\zeta}
\]  

(12)

To illustrate what effect the damping factor has on the response of a filter, two different MFB band pass filters ($f_m = 50$ Hz) are simulated with a 50 Hz input signal (this is in line with the particular application this dissertation inclines). The two different filters differ only in Q and damping factor. Figure 5 shows the resulting output signals, where it is easily seen that the output from the filter with higher Q factor (and therefore lower damping factor) takes longer time to reach its maximum amplitude. Not that Figure 5 illustrates the effect that damping factor has on a split-supplied MFB band pass filter. The effect it has on a single-supplied configuration is different; it will oscillate at startup, and the amount of time it takes for the oscillating to stop is determined by the damping factor.

As previously mentioned, low damping factor is not a problem when taking measurements. But if the final detection device is to contain a MFB band pass filter (which is likely), making sure that the damping factor is not to small will be important. If the damping factor is very low, the device will act sluggish, i.e. be unresponsive.

Figure. 5. Transient response of two different MFB BP filters, with 50 Hz input signal.
2.4 Detection

Detection inclines that the system can compare a measured value to a certain threshold value. Since the output only needs to be binary, the system only needs to keep track of two different values, the measured input value (A), and the threshold value (B). The conditions and wanted outcomes are as follows:

\[
\begin{align*}
A &> B \quad \text{Connected} \\
A &< B \quad \text{Not connected}
\end{align*}
\]

If both the measured input and the threshold are DC signals, a simple comparator can be deployed, were:

\[
\begin{align*}
A &> B \quad \text{Output} = Vcc \\
A &< B \quad \text{Output} = 0
\end{align*}
\]

Making the input signal into a DC signal, which have to be proportional to the amplitude of the original AC signal, can be achieved with a peak detector. The DC output from the peak detector will be proportional to the amplitude of the measured signal. A peak detector with amplification is seen in Appendix A, where the capacitor $C$ is chosen to suit the frequency processed, and $R_1$ and $R_2$ sets the amplification according to (13).

\[
A_v = \frac{R_2}{R_1}
\]  

(13)

The peak detector output takes about 50 ms (with a 50 Hz input) to reach its maximum value. Figure 6 shows the behavior of the peak detector in Appendix A, where the input sine wave has a frequency of 50 Hz. It is clear in Figure 6 that the resulting DC output is not a clean DC signal, it will have some fluctuation. The fluctuations can be minimized by choosing the right value for the output capacitor (‘C’ in Appendix A), but minimizing the fluctuations will also make the response more unresponsive, so some fluctuating must be tolerated.

---

**Figure 6.** Peak detector (Appendix A), Input (sine) and output (DC). Left side is without amplification, right side is with $A_v=10$.  

---
2.5 **Galvanic isolation**

In order to take a voltage measurement, a reference point has to be established (i.e. ground). Since measurements are taken on the grounding point of the car in this dissertation, it cannot be used as the reference point of the proposed device. A separate reference point has to be established. This separate reference point has to be galvanically isolated from the car ground. Galvanic isolation is when direct current flow is inhibited, and it can be achieved in multiple different ways. In Section 3, measurements are taken with a portable oscilloscope which is powered by a battery, and therefore galvanically isolated from the mains ground. So using a battery powered device is definitely a solution. The problem with using a battery as power supply is apparent; it will run out of power. Since the device should be kept small and cheap as well, small and cheap batteries should be used, which in general means short lifespan (i.e. low electric charge). A lithium button cell battery for example would be excellent from a price and size standpoint, but they have low electric charge ($\approx 50 – 150 \text{ mAh}$).

The detection device should be expected to draw around 1 mA of current. If it was powered by a button cell battery, that would mean it might only last 50 hours, which is obviously unacceptable. By exploiting the fact that the device only has to be powered for a short period of time though, the lifespan of the battery can be greatly increased. When the car is started; the device should start, do the detection, and indicate the driver if the car is connected to mains. That process only takes seconds. Even if the time the device has to be powered is exaggerated to 10 seconds, it could be used 36 thousand times with a 100 mAh battery. To realize this idea, a mechanism for starting the battery for a set period of time when the car starts, has to be constructed. An explanation of such a mechanism is what follows.

When the car is started, the car battery starts and the voltage attainable in the cigarette lighter receptacle jumps from 0 to 12V. This can be seen as a positive flank. Therefore a circuit that responds on positive flanks, and gives a corresponding DC output for a set amount of time is desired. A monostable multivibrator does just that. It can be constructed with two BJT NPN transistors, a diode, and some resistors and capacitors (Appendix B) [7]. In Appendix B; CT and RT sets the amount of time the output is ‘high’, i.e. pulse duration.

The behavior of the monostable multivibrator can be seen in Figure 7, where the pulse duration of the multivibrator can (as previously mentioned) be changed.

![Figure 7. Plot of monostable multivibrator output (1), and cigarette lighter voltage (2).](image)
This solves the problem of saving battery power, so it can last for an acceptably long time, but the whole reason a battery solution is even discussed is because of the galvanic isolation it provides. If the timing circuit is directly connected to the car battery, they share a common ground, and are not galvanically isolated. An interface between the car battery (including timing circuit) and the rest of the circuit (powered by the isolated battery) which provides galvanic isolation is wanted.

A popular way to send data over an isolating medium is through light, this method should be applicable here. Using an optocoupler (i.e. opto-isolator), a transistor can be controlled through a fully galvanically isolated medium. With the transistor, the power from the battery which can access the circuit can be controlled. An illustration of this is seen in Figure 8.

A run-through of the process follows:

When the car is turned off, the optocoupler transistor is restricting the return current of the battery with its $\approx 10^{11}\,\Omega$ resistance [8]. If the car is started, the timing circuit is activated and will give a single shot pulse output. That pulse, will activate the LED in the optocoupler, which in turn lowers the resistance of the transistor. The pulse will of a certain time, which is set in designing the timer circuit. During the time the transistor is affected by the LED, its resistance will lower significantly. In turn this will give the battery a current return path, therefore powering the device for the duration specified by the timing circuit.

![Figure 8. Illustration of optocoupler isolated power saving system.](image)

Having the monostable multivibrator timing circuit in combination with an optocoupler, solves the problem of galvanically isolating the measurement/detection device. But it is obviously not the only possible solution.

Another more obvious solution is by powering the device with the car battery, and isolating the two circuits with a transformer, a DC/DC transformer to be more specific. A DC/DC was never further explored in this dissertation though, but it could definitely be a viable option.
3 Process and results

3.1 Introduction

Can capacitive coupling (see Section 2.1) be used as a reliable way of detecting if a car is connected to the mains power grid or not? In order to find this out, measurements will have to be made.

All measurements are done with a Fluke 97 portable oscilloscope, which has an input impedance consisting of a 1 MΩ resistor parallel with a 25 pF capacitor [10]. A portable oscilloscope is necessary because it has a floating ground reference. Since the safety ground is being measured, an oscilloscope which is grounded to the safety ground cannot be used. A portable oscilloscope is also the only practical way you can take measurements in a car. An oscilloscope is chosen over a multimeter because the waveform of the measured signal is of interest.

3.2 Mains outlet measurements

Mains outlets were measured at three different locations with seven different input impedances. The input impedance was altered by simply adding a shunt resistor between the input and ground. The 1 MΩ input impedance means that the input of the oscilloscope is unaltered. During these initial tests, nothing but a Fluke 97 oscilloscope, shunt resistors, 2.5 meter long block heater cable and a 0.5 meter long coaxial cable with ‘banana connectors’ were used. The coaxial cable gets connected between the block heater cable and the oscilloscope, and the other end of the block heater cable goes into a mains wall socket. The results are shown in Table 1, where:

- All voltages are measured in RMS, according to the oscilloscope.
- ‘Cable’ indicates that the oscilloscope is connected to a block heater cable, but the cable is not connected to a mains wall socket.
- ‘Outlet’ indicates that the oscilloscope is connected to a block heater cable that is in turn connected to a mains wall socket.
- ‘Fluctuation’ meaning the values that the voltage fluctuates between.
- ‘Average’ is the average of the fluctuations.
- ‘Difference’ is the average voltage difference between when the cable is connected to a wall socket, and when it is not connected to a wall socket.
Table 1. Data from measurements on safety grounds in different locations and different input impedances.

<table>
<thead>
<tr>
<th>Input Impedance (Ω)</th>
<th>Location</th>
<th>Cable Fluctuation (mV)</th>
<th>Outlet Fluctuation (mV)</th>
<th>Cable Average (mV)</th>
<th>Outlet Average (mV)</th>
<th>Difference (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>560</td>
<td>Syntronic HIG</td>
<td>0.8 - 1.6</td>
<td>1.2 – 2.0</td>
<td>1.2</td>
<td>1.6</td>
<td>0.4 / 25%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>0.8 – 1.6</td>
<td>0.8 – 2.4</td>
<td>1.2</td>
<td>1.6</td>
<td>0.4 / 25%</td>
</tr>
<tr>
<td>5600</td>
<td>Syntronic HIG</td>
<td>1.6 – 3.2</td>
<td>2.0 – 4.0</td>
<td>2.4</td>
<td>3.0</td>
<td>0.6 / 20%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>3.5 – 4.6</td>
<td>4.8 – 6.8</td>
<td>4.0</td>
<td>5.8</td>
<td>1.8 / 31%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>0.8 – 1.6</td>
<td>1.6 – 2.4</td>
<td>1.2</td>
<td>2.0</td>
<td>0.8 / 40%</td>
</tr>
<tr>
<td>8200</td>
<td>Syntronic HIG</td>
<td>1.6 – 3.6</td>
<td>2.2 – 5.6</td>
<td>2.6</td>
<td>3.9</td>
<td>1.3 / 33%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>4.0 – 5.6</td>
<td>5.6 – 7.2</td>
<td>4.8</td>
<td>6.4</td>
<td>1.6 / 25%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>0.8 – 1.6</td>
<td>1.6 – 2.4</td>
<td>1.2</td>
<td>2.0</td>
<td>0.8 / 40%</td>
</tr>
<tr>
<td>22K</td>
<td>Syntronic HIG</td>
<td>2.0 – 3.6</td>
<td>4.0 – 7.2</td>
<td>2.8</td>
<td>5.6</td>
<td>2.8 / 50%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>4.4 – 5.6</td>
<td>6.4 – 8.8</td>
<td>5.0</td>
<td>7.6</td>
<td>2.6 / 34%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>0.8 – 1.6</td>
<td>1.6 – 2.4</td>
<td>1.2</td>
<td>2.0</td>
<td>0.8 / 40%</td>
</tr>
<tr>
<td>100K</td>
<td>Syntronic HIG</td>
<td>5.6 – 12</td>
<td>16 – 25</td>
<td>8.8</td>
<td>20</td>
<td>11.2 / 56%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>4.4 – 9.2</td>
<td>11 – 19</td>
<td>6.8</td>
<td>15</td>
<td>8.2 / 55%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>6.2 – 7.2</td>
<td>6.4 – 7.2</td>
<td>6.7</td>
<td>6.8</td>
<td>0.1 / 1.4%</td>
</tr>
<tr>
<td>560K</td>
<td>Syntronic HIG</td>
<td>16 – 32</td>
<td>64 – 95</td>
<td>24</td>
<td>79</td>
<td>55 / 70%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>10 – 18</td>
<td>48 – 74</td>
<td>14</td>
<td>61</td>
<td>47 / 77%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>70 – 78</td>
<td>156 – 160</td>
<td>74</td>
<td>158</td>
<td>84 / 53%</td>
</tr>
<tr>
<td>1M</td>
<td>Syntronic HIG</td>
<td>48 – 72</td>
<td>160 – 200</td>
<td>60</td>
<td>180</td>
<td>120 / 67%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>52 – 72</td>
<td>165 – 195</td>
<td>62</td>
<td>180</td>
<td>118 / 66%</td>
</tr>
<tr>
<td></td>
<td>Solbacka</td>
<td>70 – 78</td>
<td>156 – 160</td>
<td>74</td>
<td>158</td>
<td>84 / 53%</td>
</tr>
</tbody>
</table>

As table 1 show; bigger input impedance will on average give a bigger difference in voltage between a non-connected cable and a connected cable, which is consistent with the previously outlined theory surrounding capacitive coupling.
3.3 Car measurements

In cars the measurements were taken from the cigarette lighter receptacle ground, i.e. the ground of the car battery, which is connected to the chassis and the safety ground of the block heater. This was done with a generic cigarette lighter connector, which was through a 0.5 meter coaxial cable connected to the oscilloscope. Measurements were taken when the block heater cable either was connected between the car and a wall socket, or it was not. A 2.5 meter block heater cable was used. The different cars used were: Mitsubishi Colt (2013) and Mitsubishi L200 (2013), both with block heater systems from DEFA. All these initial measurements without filtering were taken in a medium populated suburban area.

The results are shown in Table 2, where:

- All voltages are measured in RMS, according to the oscilloscope.
- ‘Car’ indicates that the oscilloscope is connected to the car, but the car is not connected to a mains wall socket through the block heater.
- ‘Outlet’ indicates that the oscilloscope is connected to the car that is in turn connected to a mains wall socket through the block heater.
- ‘Fluctuation’ meaning the values that the voltage fluctuates between.
- ‘Average’ is the average of the fluctuations.
- ‘Difference’ is the average voltage difference between when the car is connected to a wall socket, and when it is not connected to a wall socket. Negative difference indicates that the voltage measured was actually bigger when the car was not connected to the mains.

### Table 2. Data from measurements on safety grounds in different cars and different input impedances.

<table>
<thead>
<tr>
<th>Input Impedance (Ω)</th>
<th>Car used</th>
<th>Car Fluctuation (mV)</th>
<th>Outlet Fluctuation (mV)</th>
<th>Car Average (mV)</th>
<th>Outlet Average (mV)</th>
<th>Difference (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>560</td>
<td>Colt</td>
<td>0.2 – 0.8</td>
<td>0.4 – 1.0</td>
<td>0.5</td>
<td>0.7</td>
<td>0.3 / 43%</td>
</tr>
<tr>
<td>5600</td>
<td>Colt</td>
<td>0.4 – 1.2</td>
<td>0.6 – 1.4</td>
<td>0.8</td>
<td>1.0</td>
<td>0.2 / 20%</td>
</tr>
<tr>
<td>8200</td>
<td>Colt</td>
<td>0.4 – 1.2</td>
<td>0.6 – 1.4</td>
<td>0.8</td>
<td>1.0</td>
<td>0.2 / 20%</td>
</tr>
<tr>
<td>22K</td>
<td>Colt</td>
<td>0.8 – 1.6</td>
<td>0.8 – 1.6</td>
<td>1.2</td>
<td>1.2</td>
<td>0 / 0%</td>
</tr>
<tr>
<td>100K</td>
<td>Colt</td>
<td>4.0 – 5.6</td>
<td>3.2 – 4.8</td>
<td>4.8</td>
<td>4.0</td>
<td>-0.8 / -20%</td>
</tr>
<tr>
<td>560K</td>
<td>Colt</td>
<td>18 – 24</td>
<td>18 – 22</td>
<td>21</td>
<td>20</td>
<td>-1.0 / -5%</td>
</tr>
<tr>
<td>1M</td>
<td>Colt</td>
<td>48 – 56</td>
<td>40 – 44</td>
<td>52</td>
<td>42</td>
<td>-10 / -24%</td>
</tr>
<tr>
<td></td>
<td>L200</td>
<td>50 – 58</td>
<td>32 – 50</td>
<td>54</td>
<td>41</td>
<td>-15 / -37%</td>
</tr>
</tbody>
</table>

Because of the very noisy nature of the signal measured in the car ground, these unfiltered measurements (Table 2) are inconsequential. No real conclusions can be drawn from the results, except that filtering is desperately needed in order realize the CMU idea.
3.4 Measurements with filtering

Using an active filter with fairly high gain, the wanted 50 Hz signal can be amplified without amplifying other unwanted frequency components. The theory behind the filter used for these measurements is explained in Section 2.3. In practice it is a band pass filter cascaded with a low pass filter. Both are constructed with op amps (MCP6021), using MFB topology. The circuit is powered by a 9 V alkaline battery (single supplied) and biased to have a middle voltage of 4.5 V. It does also have a buffer stage at the input, with an input impedance (Section 2.1, 2.2) consisting of a capacitor and resistor in parallel (22 pF, 1 MΩ). Figure 4 (Section 2.3) depicts the frequency response of the circuit used in the follow measurements. The measurements were taken in the same way as described in Section 3.3, with slight differences to incorporate the filter. The input of the filter-circuit was connected to the grounding of the car through the cigarette lighter receptacle, and the oscilloscope was connected to the output of the filter-circuit. Measurements were taken with two different filter configurations, one with just the BP filter, and another with both the LP and the BP filter cascaded. The exact filter circuit can be found in Appendix C.

The different cars used were: Mitsubishi Colt (2013), Mitsubishi L200 (2013), Renault Clio (2000), and a Renault Trafic (2013) minibus. Measurements were taken at eight different locations. A short description of these locations follows:

- **Solbacka** – Moderately populated suburban area
- **Låsarpåsen** – Highly populated suburban area
- **Ljusne Square** – Very small town square
- **Gammelsågen** – Forest
- **Gävle City** – Moderately populated city area
- **Stugsund** – Moderately populated suburban area
- **E-Center** – Moderately sized shopping mall
- **HIG** – Parking lot at the University of Gävle.

All the measurements were not taken at areas with a mains outlet nearby (due to lack of access to appropriate areas), therefore there is more data collected for when the car is not connected to an outlet, rather than when it is.

The results are shown in Table 3, where:

- All voltages are measured in RMS, according to the oscilloscope.
- ‘Car’ indicates that the oscilloscope is connected to the car, but the car is not connected to a mains wall socket through the block heater.
- ‘Outlet’ indicates that the oscilloscope is connected to the car that is in turn connected to a mains wall socket through the block heater.
- ‘Difference’ is the voltage difference between when the car is connected to a wall socket, and when it is not connected to a wall socket.
- The boxes with missing values are measurements which were not taken.
Table 3. Data from measurements on safety grounds in different cars at different locations, employing filtering.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Car</th>
<th>Location</th>
<th>Car (mV)</th>
<th>Outlet (mV)</th>
<th>Difference (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP 15dB</td>
<td>Colt</td>
<td>Solbacka</td>
<td>0.2</td>
<td>8.0</td>
<td>7.8 / 98%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Läsarvägen</td>
<td>0.16</td>
<td>0.6</td>
<td>0.44 / 73%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ljusne square</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gammelsågen</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gävle City</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Clio</td>
<td>Solbacka</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Stugsund</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>E-Center</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Trafic</td>
<td>HIG</td>
<td>0.4</td>
<td>3.5</td>
<td>3.1</td>
<td>3.1 / 86%</td>
</tr>
<tr>
<td>L200</td>
<td>Solbacka</td>
<td>0.4</td>
<td>1.6</td>
<td>1.2</td>
<td>1.2 / 75%</td>
</tr>
<tr>
<td>LP+BP 30dB</td>
<td>Colt</td>
<td>Solbacka</td>
<td>0.6</td>
<td>80</td>
<td>79.4 / 99%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Läsarvägen</td>
<td>1.0</td>
<td>7.0</td>
<td>6.0 / 86%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ljusne square</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gammelsågen</td>
<td>0.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central Gävle</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Clio</td>
<td>Solbacka</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Stugsund</td>
<td>0.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>E-Center</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Trafic</td>
<td>HIG</td>
<td>2.0</td>
<td>30</td>
<td>28</td>
<td>28 / 93%</td>
</tr>
<tr>
<td>L200</td>
<td>Solbacka</td>
<td>5.0</td>
<td>18</td>
<td>13</td>
<td>13 / 72%</td>
</tr>
</tbody>
</table>

As seen in Table 3, the unconnected results (labeled ‘Car’) are not very dependent on location, but rather on what type of car is used. When it comes to connected results (labeled ‘Outlet’) though, location is a huge factor. This makes sense, since there are properties of every specific mains outlet which will affect how it interacts with the car and the measurement device.
3.5 **Solution prototype**

This section goes through the device that was constructed as a prototype at the end of the dissertation. The prototype was constructed as a proof of concept, without much emphasis on size or ease of use. As previously specified (in Section 1.3.1), the solution is fully analog. It can be split up into three parts, each related to different parts of the theory section. They are:

- Filter part \((\text{Section 2.3})\)
- Detection part \((\text{Section 2.4})\)
- Power supply/saving part \((\text{Section 2.5})\)

An overview of how the device is structured can be seen in Figure 9. On the left side of the image, the three connectors of the mains are illustrated by the vertical lines, and a connection between the car and safety ground is drawn. Different sources of capacitive coupling (Section 2.1) are illustrated. The actual device starts with a buffer stage; the buffer stage is there so the input impedance of the device can be set in a controlled fashion. A band-pass and low-pass filter with high amplification, peak detector and comparator follows. The threshold of the comparator is in the prototype set to a static value. Different threshold systems are discussed in Section 4.2. Using the measurement results from 3.4, the static threshold is set to an appropriate value. Since the filter used when taking the measurements is not the same as the filter in this prototype, the results will have to be slightly reassessed in order to be used as a basis for threshold configuration. Indication in this prototype consists of just a LED. The basic design of the filters in this prototype is exactly the same as the ones used in the measurements (Section 3.4) though, but the specifications of the filters are different.

![Figure 9. Overview of prototype functionality.](image)

The power supply/saving part of the device is not represented in Figure 9. In the prototype a battery solution with a power saving system is deployed rather than a DC/DC transformer (Section 2.5). Appendix D has the schematics of two different prototype devices, single-supplied and split-supplied (discussed in section 4.3), not including the just mentioned power saving system. Appendix E are schematics of the power saving system used in the prototype (both single-supply and split-supply versions).
Indication is in the prototype done with just a LED. In a consumer version, some sort of audio indication would be used. The indication part of the circuit is powered by the car battery, and to keep the circuit galvanically isolated, an optocoupler is put at the output of the device. Choosing to power the indicator with the car battery instead of the device battery, will extend the lifetime of the device battery.

The prototype was constructed on nothing more than a breadboard. Making an actual circuit board prototype would be preferred, but because of time restraint it was not achieved. This brings with it practical issues, mostly regarding interference. For example could the prototype never be connected directly to the cigarette lighter receptacle, rather it got connected through a 0.5 meter coaxial cable, which increase interference and makes the input to the device less stable than it would optimally be. Because the device process low frequency signals though, the negative impact of breadboard construction is not as big as it could have been with higher frequency signal processing.

Another important fact to bring up regarding the tested prototype, is that the part of the device that are supposed to be powered by the car battery (power saving and indication), was never actually powered by the car battery. Why? An appropriate connector was not available to the author. Instead a 9 V battery was used as a substitute, which should have no effect on the actual functionality of the device, but it bears mentioning.

There were initially tests done with a single filter solution, i.e. only the low pass filter. It was tried to see if the problems associated with the MFB band pass filter (Section 2.3.1) could be avoided, it would also decrease the cost of the device. But this left the device susceptible to low frequency interference, so the band pass filter was reintroduced. Note that the low pass interference in question might be a product of the fact that the prototype is constructed on a breadboard, and connects to the car via cables. If a proper device (PCB, shielded enclosure, direct connection to car) was constructed, using only a low pass filter might be an option.
3.5.1 Configuration and testing

Setting appropriate amplification for the peak detector (Section 2.4) and the right threshold, is not as straight forward as it might seem. First of all, the filters used in the prototype are not the same as the once used in when taking the measurements in Section 3.4. So therefore the exact measurement results cannot be used as a direct guideline for setting the threshold. Also, more importantly, when taking any measurements on the device with for example an oscilloscope, the device is affected by said oscilloscope. When the oscilloscope is connected to the device, the floating ground characteristics of the device will change, and in the example of the oscilloscope, signals picked up by the device will be significantly stronger. This means that all the results from the measurements in Section 3.4 are affected by the method of measurement, i.e. the oscilloscope.

The theoretical way to get around this, is to first take the difference in gain between the circuits into account (35dB measurement circuit Appendix C vs. 51dB prototype Appendix D), which is 16 dB. After that, a magnitude relationship between when the oscilloscope is connected, and when it is not, has to be established. This can be done by setting a 50 Hz signal of known amplitude at the input of the prototype, measure the output of the filter stage, disconnect the oscilloscope, and change the threshold of the comparator until the output is borderline positive. As long as the change in signal magnitude between when the oscilloscope is connected and not connected is linear, a magnitude change coefficient can be established. Note that this coefficient will be dependent on the type of battery used.

Going by the measurements in Section 3.4, a threshold at 6.5 mV would seem reasonable. To get a 6.5 mV output from the measurement circuit (35dB gain), the input signal needs to be 106 μV\text{RMS}. Using for example a signal generator, a 50 Hz, 106 μV\text{RMS} sine wave can be fed into the input of the prototype, and without having the oscilloscope connected the threshold of the comparator can be tuned until it is at the breaking point between giving a positive and negative output, as previously explained. Going through this process, an appropriate threshold corresponding to a 6.5 mV output with the measurement circuit can be established for the used battery.

Two 1.5 V AA alkaline batteries were used to power the prototype. With that power source, a threshold of 30 mV was set, which roughly corresponds to a 6.5 mV reading from the measurement circuit (Section 3.4). Note that the threshold would have to be reconfigured if a different power source would to be used.

A single test was conducted at with the prototype device, with successful results i.e. the device worked as it is set out to do. A turned off outlet timer was used, along with the following parameters:

*(some of them previously defined in Section 3.4)*

- **Car:** Colt
- **Location:** Solbacka
- **Threshold:** 30 mV
- **Power source:** Two 1.5 V alkaline batteries
4 Discussion

4.1 Measurements

Regarding the measurements, they were taken to get an understanding of what magnitude of capacitive coupling that can be detected in different environments. Parts of the measurements were very crucial to the design of the detection device, but other parts turned out to be mostly insignificant, at least from a practical point of view. The measurements can be categorized into three different subgroups; the mains measurements, the car measurements, and the car measurements including filtering. All the results from these measurements can be found in Section 3. This subsection discuss the importance of these measurements, and how the results were later applied in designing a prototype device which is conceptually laid out in Section 1.3 and realized in Section 3.5.

Different input impedances were used in the initial mains measurements. This was in large to verify that the measured voltage was in fact caused by capacitive coupling. The connection between input impedance and capacitive coupling is explained in Section 2.1. As the results show, when small input impedances were used, very small voltages were measured, therefore verifying the theory. The other thing that was gained from these measurements is the fact that inside a building with mains wiring, pretty large 50 Hz signal can be picked up, assuming the measurements device has high input impedance and an input stage of somewhat big physical size. Also as theorized in Section 2.1, when connected to the mains ground, the coupled voltage increases significantly. This is definitely a good sign, if the cable monitoring unit concept is to come to fruition.

The next set of measurements, which were the car measurements without filtering, was not very numerous. There is a perfectly logical reasoning behind this; the results were very ‘bad’ from the start. Bad in the sense that whether or not the cable was connected, no correlating voltage change was found. If the results are as bad as they were, there is really no reason to spend time taking measurements with different cars at different locations. The device cannot be based on a premise which only works on a set number of locations; it needs to be as universally applicable as possible. After these measurements were taken, there was definitely some doubt on the validity of the concept itself, if a method of capacitive coupling detection could be used as a cable monitoring device. In hindsight was the inclusion of differing input impedance not necessary in these set of measurements, but it was included to further verify that the measured voltage was from coupling.

When it comes to the measurements done with filtering, they were a really important asset in later development of a detection device, much more so than the other measurements. A 2nd order active band pass filter with about 15 dB amplification (Section 2.3) was at first constructed to see if the discouraging results from previous car measurements could be improved with filtering. As the results show, they could.
A thing to point out is that non-connected measurement results in Table 3 are not very exact. All the 0.4 mV measurements for example were not in fact all 0.4 mV, the oscilloscope was just not correctly set for each measurement, i.e. the voltage scale was not made appropriately small to make such small measurements.

The reason why this does not really matter is that if you have the oscilloscope set as such, the RMS measurement will be overshot, and not the other way around. Therefore those 0.4 mV measurements really mean that they are at a maximum 0.4 mV. 0.4 mV is well under the maximum measurement taken when the cable was not connected to the car. Therefore whether or not those measurements were actually 0.1 mV or 0.2 mV is really inconsequential when they are applied in designing the device. The important measurements to look out for are the resulting maximum non-connected voltage and the minimum connected voltage. Those two in tandem makes the smallest voltage difference between the two states (cable connected vs cable not connected). It is desirable for the difference to be as high as possible for every possible situation, so the device is never confused whether or not the cable is in fact connected to the car.

A big criticism of these filter measurements is that sample size is very small. Especially when it comes to measurements the cable was connected. The reason there is significantly more non-connected is simple; to make a measurement with connected cable, a mains connection needs to be established. Finding locations were there was an accessible mains socket for use with a car, was definitely a problem for the author.

All the available non-connected results are somewhat promising though. Most of them are kept at a minimum level, and the environment does not seem to have a very big impact. If a totally static threshold system is to be implemented though, problems will arise if this particular filter circuit is used. This is due to the fact that the maximum 35 dB filter ‘non-connected’ measurement result is at 5.0 mV RMS. While the minimum ‘connected’ result with the same circuit, is at 7.0 mV. That is a very small difference, and if more measurements were made, with different cars and locations. It is safe to assume that there would be results from the ‘non-connected’ measurements that would overlap the ‘connected’ measurements, which would make detection unreliable. There is a possibility that through better filtering, the results could be convincingly better, and therefore a static threshold system might still be useful. From a pure performance point of view, a dynamic threshold system would be preferred. But a dynamic threshold system would most probably compromise the ease of use of the device, and add cost. There might well be a way to implement a dynamic threshold system that would not mean a too significant cost increase, and that would not make the user experience a hassle. But the author of this dissertation could not think of such a system. He does have some proposal for dynamic threshold systems though, but they all have significant weaknesses. The next section explores possible threshold systems (Section 4.2).

Something that was initially overlooked by the author, is the effect that current going through the cable and block heater has on the results. All the measurements were done without obstructing the phase and neutral connection between the mains and the block heater. The repercussions of this are covered in the concluding section of the dissertation (Section 4.4). Some tests were done with a mains timer though, and whether or not the timer was turned off or on did not affect the results, which is positive. More tests should be made with different types of timers though, to see if they possibly could have an effect on the results. The device should be compatible with almost any outlet timer, in order to be successful as a consumer product.
4.2 Threshold systems

In the prototype (Section 3.5) a purely static threshold system was used, setting a simple comparator. Nothing other than a static threshold system was never in practice tried during this project, even though the problem with a static system is apparent. This is something discussed in the previous section. By looking at the results from the filter measurements (Section 3.4, Table 3) it is easy to see that there will most likely at some point be overlap between connected and non-connected measurements, if the pool of cars and locations tested was bigger.

To reliably use a static threshold, you need to be sure that the non-connected result will never exceed the threshold, and that the connected result will never lower than the threshold. Since that assurance cannot be made here, some other solution would be optimal. Here are two options that could fulfill the requirement of a reliable threshold:

1. **Digital solution with memory.**
   If the device had some sort of passive memory, a threshold could be situationally set by the user, which means the threshold would be set with location and car used in mind.

2. **Dynamic threshold.**
   An analog solution, which dynamically sets a threshold according to the surrounding mains electric field intensity. By basically using the same filtering and AC/DC conversion as in the main part of the device (Section 2.3 and 2.4), a dynamic threshold could be set. Instead of having the car as input of this ‘threshold setting’ part, a sort of antenna would be used. A relationship between how good this ‘antenna’ and a car would be at picking up a mains electric field would be calculated. From the calculated relationship, adequate amplification of the ‘antenna’ signal could be set, and used as a dynamic threshold. Figure 10 illustrates how such a device could be constructed.

The problem with solution one is that it breaks the requirements laid out in the start of the dissertation (Section 1.3.1). It severely compromises the ease of use of the device, and it is not a fully analog solution.

There are glaring issues with solution two as well. Since most cars are different and have different electrical properties (which are seen in Section 3.4), the relationship between the ‘antenna’ and the car will not be static. Solution two does therefore only solve the problem of differing locations, not the problem of differing cars. Other problems with solution two are; extra component cost, possibly bigger size for ‘antenna’, slightly higher power consumption, and the fact that is based on an untested/unproven concept.

In all reality, the author does not have a clear solution to the threshold problem. With more testing a static threshold system might turn out to be sufficient, but the author is doubtful.
4.3 **Single-supply vs. Split-supply**

At first the focus was on a single supplied circuit with appropriate biasing. The biasing in the single supply prototype (Appendix D) is handled by adding a 1 MΩ resistor from the input of the buffer to $V_{cc}$, and setting the reference point of the filters at $V_{cc}/2$. At a maximum, this biasing just adds an operational amplifier, three resistors, and possibly a capacitor to the circuit. The cost of those extra components is definitely lower than the extra cost of having a split power source (two batteries). So the choice would seem obvious at this point. But the nature of the peak detector circuit used in the prototype (Section 2.4 and 3.5), makes the choice between whether or not to single or split-supply the circuit somewhat unclear.

First of all, the peak detector does not handle DC input signals well. So having a DC offset in the output of the filter will skew the results, the peak detector will give a DC output even if no AC signal is processed through the filter. This means that AC coupling will have to be done on the filter output, which is easily done with a RC high-pass filter.

With the extra cost from the RC filter, it is still much cheaper to use the single-supply design. But there is another problem associated with a single-supplied solution. At startup, the single supplied filters will not function properly for a certain amount of time. A MFB band-pass filter which is single-supplied for example, will oscillate at startup. The amount of time it takes before the oscillating stops, is determined by the damping factor of the filter (damping factor is discussed in 2.3.1). The prototype (Section 3.5, Appendix D) has a damping factor of 0.1, which makes the filter output oscillate at startup for $\approx 200$ ms.

Since the device always starts up right before it determines whether or not the block heater cable is connected, having the device give false readings for 200 ms after startup is unacceptable. The way this is solved in the prototype, is by prohibiting the output of the filter to be read by the peak detector for the first $\approx 200$ ms after startup. This is done by the circuitry labeled ‘Delay circuit’ in Appendix D, which is basically just a transistor which is activated at...
startup, and after \( \approx 200 \text{ ms} \) it gets deactivated. The filter output will therefore be grounded while the startup oscillation occurs, effectively drowning out the oscillation. Therefore the circuit functionality is delayed by \( \approx 200 \text{ ms} \).

A 200 ms delay should not be too detrimental. The extra component cost is of concern though, but it should still be cheaper with a single-supply solution, rather than a split-supply one. But some power consumption and size will be added.

### 4.4 Current problems

In this section, the author would like to bring up present problems that still exist in the current design and possible improvements that could fix said problems.

The problems that are associated with the prototype (Section 3.5) that was finalized in the very concluding part of the dissertation timeline are numerous. But the author is confident that most of them could be fixed.

**Minor concerns:**

First of all, the fact that the prototype is constructed on a breadboard brings certain unstable characteristics to the table. Since the device is made to be sensitive enough to pick up small coupled signals, it is susceptible to interference. This is mostly a problem when handling the device indoors though (because of the present of a much stronger 50 Hz electric field), which is obviously not were the device should be deployed. But even when handling the device in a car, certain movements can skew the results in an unwanted way. The good news is that if the same device is constructed on a PCB, and put in a shielded casing, these interference problems should not be a problem.

Hysteresis is not addressed in the current prototype. If the input of the device alternates between being higher than the threshold, to being lower than the threshold again, the output of the comparator will also alternate from negative to positive, at the same rate. This can cause an unstable output if the measurement is bordering the threshold. Hysteresis can be added to the circuit in a few different ways. A retriggable multivibrator added to the comparator output is an option, prolonging every positive output. If the output is switching between positive and negative at a fast rate, the multivibrator would ‘link’ together the positive outputs, giving a constant output value.

An alternative method of adding hysteresis to the system is by using a schmitt trigger as a comparator, instead of a basic comparator circuit. With a relatively small gap between the higher and lower threshold.
Major concerns:

The problems that ultimately could be a deal breaker for the whole concept to be realized, is how a proper threshold system could be established. This is a subject already covered in Section 4.1 and 4.2. But to summarize: The author is not sure he was successful in constructing a fully reliable threshold system within the parameters of the dissertation (analog solution, user friendly design) (Section 1.3.1). A lot more of tests would have to be conducted to see if the currently employed threshold system (static) could be considered reliable.

4.5 Conclusion

To conclude this dissertation, whether or not the goals laid out in the introduction have been met needs to be finalized (Section 1.2). If the goals are reframed as questions, they can be summarized as:

1. Is there a way to detect mains safety ground without direct connection to phase or neutral?
2. If so, can it be done in a cost effective and practical way?
3. Most importantly. Is the method applicable for a block heater cable monitoring unit?

Yes, there is a way to detect a mains safety ground without having direct connection to either the neutral or the phase. It can be done with capacitive coupling, which is the method used throughout this dissertation.

Yes, it can be done with a somewhat cheap solution. It can also be done in a practical way, depending on the circumstances and applications, which leads to the last question. Using the method for a cable monitoring unit solution is possible, but there are some problems associated with the detection mechanism of the system, i.e. the threshold system.

Moving forward with this project, a PCB prototype with grounded shield should be made and tested thoroughly. Overall, more testing is needed, with a vast amount of differing cars and locations. There is a possibility that the static threshold system used in the prototype developed in this dissertation might be viable. If it is proven to not be viable, digital solutions with memory and possible calibration systems have to be explored, if this idea is to be fully realized in a consumer product. 
References


Appendix A

A peak-detector can be used for AC-DC conversion. The output of the peak-detector will give a (close to) DC signal which will be proportional to the amplitude of the AC input. A peak detector containing active components can be used if amplification is desired. The schematic in Figure 11 is for an active peak detector where the gain is set by $R_1$ and $R_2$.

![Figure 11. Peak detector with amplification.](image-url)
Appendix B

Monostable multivibrators are useful for creating timers. The schematic in Figure 12 is for a Monostable multivibrator with positive trigger. The amount of time the circuit will be unstable is set by $R_T$ and $C_T$.

![Monostable Multivibrator Schematic]

*Figure. 12. Monostable multivibrator with positive trigger*
Appendix C

A circuit containing a buffer stage with high input impedance and filters with amplification can be used for detecting capacitively coupled voltage. The schematic in Figure 13 is for such a device. 2nd order band pass filter cascaded with a 3rd order low pass filter is used for the filtering. The device got outputs for both the filters cascaded (35dB gain) and for just the band pass filter (15dB gain).

Figure. 13. Filter circuit with buffer and active BP and LP filters.
Appendix D

The schematic in Figure 14 and Figure 15 is for a device combining a capacitive coupling measurement system with a detection system. The difference between the schematics in the two different figures is the type of power-supply solution they are using.

*Figure 14: Single-supply, Figure 15: Split-supply*
Appendix E

Schematic of a galvanically isolated power saving system constructed with a monostable multivibrator and an optocoupler is seen in Figure 16 and Figure 17. The difference between the schematics in the two different figures is the type of power-supply solution they are using. *Figure 16: Single-supply, Figure 17: Split-supply*

*Figure 16. Power-saving system for single-supplied device.*

*Figure 17. Power-saving system for split-supplied device.*