

# The properties of E-field sheets

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## Abstract

In this report the properties of the E-field sheet have been measured. Also the connection between the E-field sheet and the pc has been developed. For visualisation of the data a GUI has been made in Matlab which also reads out the data from the DAQ card. Before a measurement on the clinical equipment can be done the E-field sheet needs to be calibrated. The calibration process was developed in this report. The relative calibration was done by correcting of an offset and correcting for a variation in the sensitivity of the diode. To calculate the sensitivity of the diode an antenna was place on top of a diode and the voltage difference was calculated that was created with the E-field that the antenna was emitting. The calibration process has an uncertainty that was build up from several parts. These uncertainty parts where the noise in the signal, the position uncertainty of the antenna, a rotation uncertainty of the antenna in relation to the E-field sheet and an uncertainty in the temperature. The properties of the special made agar phantoms have been measured. The phantoms are specially made for the E-field sheets, because the agar phantoms are more homogenous then the superstuff phantom already available at the lab. The properties that have been measured from the agar phantom are the heat capacity and the dielectric properties have been measured by an outside lab. The uncertainty in the position sensitivity (1mm variation) was an error of 0.45% in the voltage. The rotation sensitivity gives an error of 0.8% in the voltage for an error of  $5^\circ$ . A variation of 1 Celsius gives a voltage difference of 9mV per Celsius. This all give an uncertainty in the calibration process of 2.5% when it is calibrated with a E-field that give 3V. When the temperature comes above 35 Celsius some of the diodes do not behave linear anymore. Besides to the properties for the E-field sheet the possibility of resolution increase has been looked at, which was found possible because the diodes do not influence each other. Also a calibration routine has been made to calibrate the E-field sheet before use. The calibration needs to be done every day, because the diodes change in time. For now the calibration in relative which means the it can accurately give the distribution of the E-field that its in but not the absolute value of the E-field.

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# 1 Introduction

In the world there are a lot of diseases known to men. Dozens of these are fatal. Cancer is one of those diseases that can be fatal. With cancer, cells divide and grow uncontrollably, forming malignant tumors, and invade nearby parts of the body. The cancer may also spread to more distant parts of the body through the lymphatic system or through the bloodstream. Not all tumors are cancerous. Tumors in their early stages do not grow uncontrollably, do not invade neighbouring tissues, and do not spread throughout the body.

Cancer can be detected in a number of ways, including the presence of certain signs and symptoms, screening test, or medical imaging. Once a possible cancer is detected it is diagnosed by microscopic examination of a tissue sample. Cancer is usually treated with chemotherapy, radiation therapy and surgery. The chances of surviving the disease vary greatly by the type and location of the cancer and the extent of disease at the start of treatment. While cancer can affect people of all ages and a few types of cancer are more common in children, the risk of developing cancer generally increases with age. In 2007, cancer caused about 13% of all human deaths worldwide (7.9 million). Rates are increasing as more people live to an old age and as mass lifestyle changes occur in the developing world. One of the new ways of treatment is radio- or chemotherapy in combination with hyperthermia. Hyperthermia is heating of a region of the body to temperatures around 41 to 43 C. When combined with radiation, hyperthermia is particularly effective at increasing the damage to acidic, poorly oxygenated parts of a tumor and to cells that are preparing to divide. Hyperthermia treatment is most effective when provided at the same time, or within an hour, of the radiation.<sup>[1]</sup> In the Daniel den Hoed clinic there are two types of hyperthermia, the deep and the superficial hyperthermia.

## **Deep hyperthermia.**

This type of hyperthermia is used for the pelvis or abdomen, i.e. deep-seated tumors. The tumorous area is heated by arrays of antennas. The sigma-60 applicator is a widely spread applicator, which consists of four dipole antenna pairs arranged in a ring around the patient. Planning systems describe correctly to some extent the power-density and temperature distribution given depending on various treatment variables. Even though each antenna pair can be controlled in phase and amplitude, there are restrictions in terms of the generated SAR (Specific Adsorption Rate) distribution.<sup>[2]</sup> The frequency used for deep hyperthermia is from 77MHz to 100MHz.

## **Superficial hyperthermia**

Superficial tumors can be heated by means of antennas or applicators emitting mostly microwaves or radio waves placed on their surfaces with a contacting medium. Several types of applicators have been used clinically, such as waveguide applicators, horn, spiral, current sheet, and compact applicators. The electromagnetic coupling of the applicator to the tissue is ensured by a water bolus (preceding water path). Intratumoral temperature can be controlled by the output of the power generator or by positioning the applicator. The resulting SAR distribution is subject to strong physical curtailment resulting in a therapeutic depth of only a few centimetres and is even further limited in regions with an irregular surface.<sup>[2]</sup> The superficial hyperthermia is preformed at 433 MHz frequency.

## **Goal of the report**

Both methods to heat the tumors use applicators that emit electromagnetic fields (E-fields) and need to be checked periodically to meet the current standards. A way to do this quality check fast and accurately is not yet available, but there are E-field sheets with the ability to do a fast check on the electric field distribution. An E-field sheet is basically a flexible print board with 64 dipole antennas with Schottky diodes on it. Only there is no existing equipment to use the E-field sheets. This goal of the internship is first to make the hardware connection from the E-field sheets to the computer. In the PC the data will be measured by a data acquisition (DAQ) card. The software needed to read out the E-field sheet needs to be programmed in Matlab. After the hardware connection and the software readout are finished the properties of the E-field sheet under various conditions need to be investigated. The end goal is to have a way to calibrate the E-field sheets and to know its measuring errors.

## 2 Theory

Hyperthermia is a medical condition where the body has an elevated body temperature. This condition can be used to improve the cancer treatment by heating the cancer after a radiation session. The hyperthermia can kill cells when temperatures above 43°C are reached. At lower temperatures (i.e. 40 to 43°C) it will prevent cells from repairing the damage induced during the radiation session. There are multiple ways to increase the temperature of the body; whole-body hyperthermia where the entire body is heated, superficial hyperthermia, where a tumor that is close to the surface gets heated and deep hyperthermia, where the target tumor gets heated that lies deep in the body. To get the target area to warm up, different methods can be used. Two that are commonly used are ultra sound and electric fields. In the hyperthermia department of the Daniel den Hoed clinic in Rotterdam, electric fields are used to heat up the target area. The electric fields are created by antennas.

### 2.1 Antennas

An antenna is an electrical device which converts electric currents into electromagnetic waves and vice versa. In hyperthermia dipole antennas are used to create an electromagnetic field distribution within the target area to heat it up. Dipole antennas consist of two metallic conductors with a small gap in between them, see Figure 2-1.

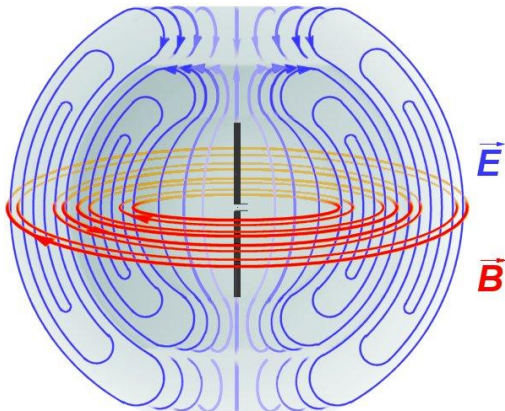
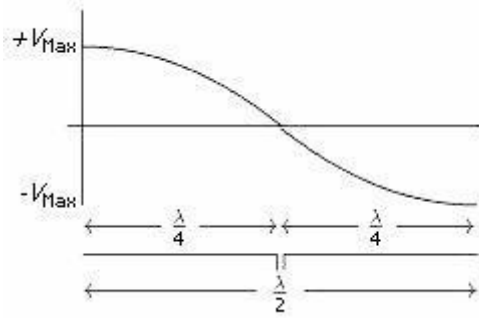


Figure 2-1 – Electromagnetic field from a dipole antenna.<sup>[3]</sup>

A high frequency electric signal will be put on the two metallic conductors to generate a electromagnetic field. The metallic conductors are designed to have a length of  $\frac{1}{4}$  of the wavelength. This makes the whole dipole antenna  $\frac{1}{2} \lambda$ , which gives the greatest voltage difference as one end of the metallic conductor is at a node while the other is at an antinode of the wave.



**Figure 2-2 – Voltage distribution over the dipole antenna.** <sup>[3]</sup>

This sets the required dipole length for a specified frequency by:

$$L = \frac{\lambda}{2} \quad 2-1$$

Where:

$L$	= length of the dipole	$[m]$
$\lambda$	= wavelength	$[m]$

The wavelength can be calculated by:

$$\lambda = \frac{v}{f} \quad 2-2$$

$v$	= speed of the wave	$[m/s]$
$f$	= frequency of the wave.	$[1/s]$

If the formulas (2-1) and (2-2) get combined it will result in:

$$L = \frac{v}{2 \cdot f} \quad 2-3$$

In hyperthermia 2 types of antennas are used, the WGA (Waveguide Applicator) for superficial treatment and the sigma 60 applicator for deep treatment.

## **2.2 Specific Absorption Rate**

The Specific Absorption Rate (SAR) is a measure of the rate at which energy is absorbed by the body when exposed to an electromagnetic field. It can also refer to absorption of other energy by tissue including ultrasound. The SAR is defined as the power absorbed per unit mass tissue. The energy is transferred from the antenna into the tissue is by polarizing the dipole molecules and through drift of electrons and ions. The average power that is transferred from the antenna into the tissue is:

$$\frac{P}{V} = \frac{\sigma \cdot |E|^2}{2} \quad 2-4$$

Where

$P$	= power transferred into the tissue	$[W]$
$V$	= volume	$[m^3]$
$\sigma$	= electrical conductivity	$[S/m]$
$E$	= RMS electric field	$[V/m]$

Because the SAR is defined as the power absorbed per mass tissue the SAR can be written as:

$$SAR = \frac{P}{m} = \frac{P}{V} \cdot \frac{1}{\rho} = \frac{\sigma \cdot |E|^2}{2 \cdot \rho} \quad 2-5$$

Where

$SAR$	= Specific Absorption Rate	$[W/kg]$
$\rho$	= density	$[kg/m^3]$

A different way to calculate the SAR is by using thermodynamics, where the heat added to the system is given by:

$$\dot{Q} = \int_{T_0}^{T_f} c \cdot dT \quad 2-6$$

Where

$\dot{Q}$	= heat needed to raise one kg of material from temperature $T_0$ to $T_f$	$[J/kg]$
$c$	= heat capacity	$[J/kg \cdot ^\circ C]$

This equation can only be used when there is no heat transfer to the surroundings, so all the heat is used to warm up the system. Equation 2-6 can be rewritten to:

$$dQ = m \cdot c \cdot dT \quad 2-7$$

Where

$m$	= mass	$[kg]$
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Combining equation 2-4 and 2-7 the SAR can be calculated.

$$SAR = \frac{P}{m} = \frac{1}{m} \cdot \frac{dQ}{dt} = \frac{1}{m} \cdot m \cdot c \cdot \frac{dT}{dt} = c \cdot \frac{dT}{dt} \quad 2-8$$



This can be used to calculate an unknown electric field by combining formula 2-5 and 2-8.

$$c \cdot \frac{dT}{dt} = SAR = \frac{\sigma \cdot |E|^2}{2 \cdot \rho} \quad 2-9$$

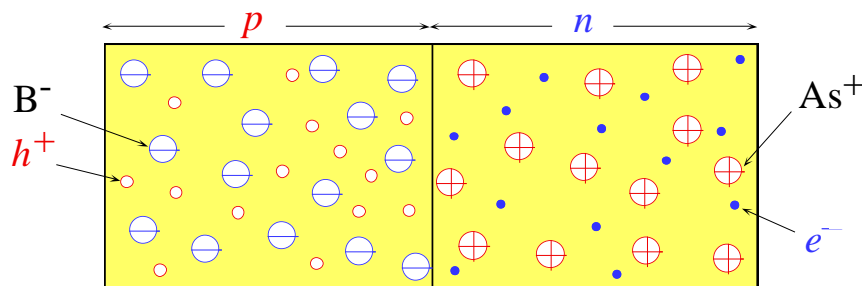
This can be rewritten to:

$$|E| = \sqrt{\frac{2 \cdot \rho \cdot c \cdot dT}{\sigma \cdot dt}} \quad 2-10$$

Equation 2-10 can only be used when there is no heat transfer to the surroundings.

## 2.3 Diodes

A diode is a two-terminal electronic component with asymmetric transfer characteristic, with low (ideally zero) resistance to current flow in one direction, and high (ideally infinite) resistance in the other direction. The kind of diode mostly used is a semiconductor diode. This is a crystalline piece of semiconductor material with a p-n junction connected to two electrical terminals. A p-n junction is formed at the boundary between a p-type and n-type semiconductor created in a single crystal of semiconductor by doping, or by epitaxy. P-type is obtained by carrying out a process of doping by adding a certain type of atoms (acceptors) to the semiconductor in order to increase the number of free charge carries (in this case positive holes). At the n-type region the number of free electrons is increased. In a p-n diode is displayed from p-type B<sup>-</sup> and n-type As<sup>+</sup>.



Metallurgical Junction

Figure 2-3 – p-n junction of a diode.<sup>[5]</sup>

In Figure 2-3 the holes and electrons do not move, but in the p-n junctions this is not the case. Some holes will travel into the n-type part and some electron in the p-type part. When an electron and a hole meet each other the hole will recombine with the electron and create a neutral particle. Then the p-n junction will be like as displayed in the figure below.

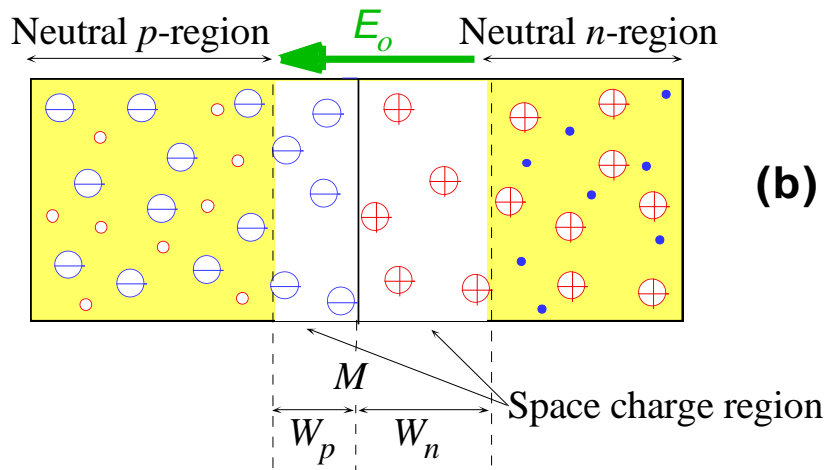


Figure 2-4- p-n junction of a diode with a neutral region. <sup>[5]</sup>

Because of the holes recombined with the electrons a positively charged region will be created in the n-type region and a negative at the p-type region. The middle region is called a depletion region, because of this an E-field is created inside the depletion region, with is strongest at the junction between the p and n region.

The positive terminal of a battery is connected to the p-type side of the diode and the negative terminal on the n-type side a counter electric field is created. When a low voltage is supplied the electric field of the diode is greater than the electric field the battery can produce. This will cause the diode to be “closed” (does not conduct electricity), but when the battery can produce a stronger electric field than the diode it will start conducting. Normally this will occur when around 0.7V. When the poles of the battery are switched so the negative pole is on the p-type region the electric field that is created by the battery in the diode will be in the same direction as the diodes own field. This causes the diode to keep being “closed” and will not conduct electricity until the voltage will be above  $V_{br}$  (breaking point) then it will start conducting. In Figure 2-5 the I-V graph is shown of a diode.

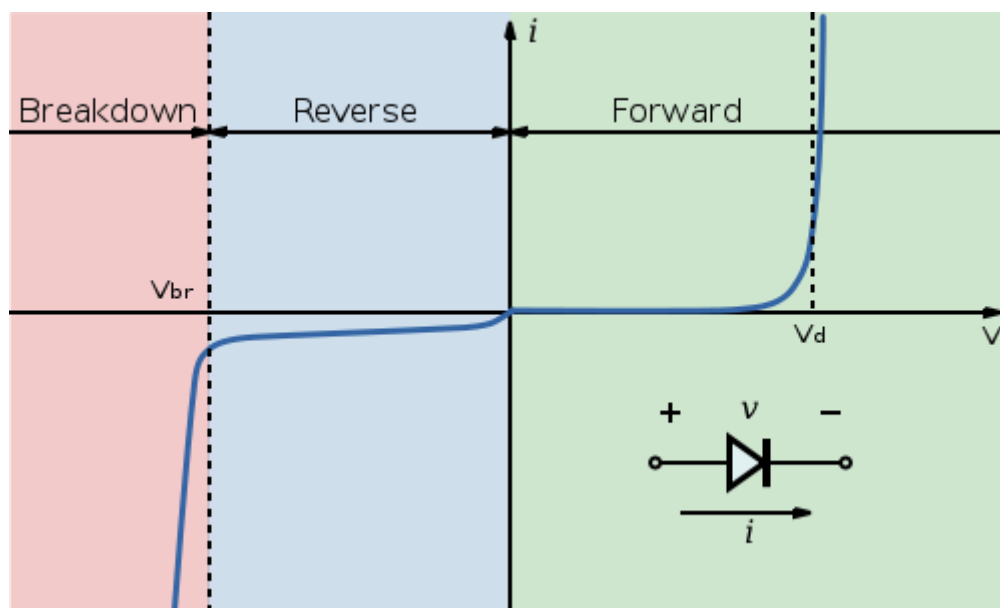


Figure 2-5 - I-V characteristics of a p-n junction diode (not to scale – the current in the reverse region is magnified compared to the forward region, resulting in the apparent slope discontinuity at the origin; the actual I-V curve is smooth across the origin).<sup>[7]</sup>

The diode can change fast between sparring and conducting but it has limits, for the E-field that are used in hyperthermia (50 MHz – 450MHz) the normal diode is not fast enough. For this purpose the Schottky diode is used. The Schottky diode has a metal-semiconductor junction in stead of two semiconductors, the semiconductor is the n-type area see .

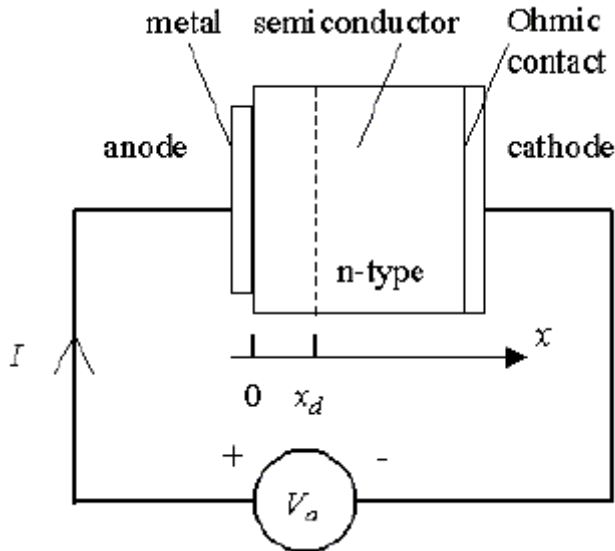


Figure 2-6 – Schematic overview of the Schottky diode.<sup>[6]</sup>

When the Schottky diode is not in equilibrium lets say too much electrons in the n-type area, the electrons move to the metal and when they enter the metal they are immediately moved out of the diode and a positively charged atom is left behind in the n-type material and lowering the difference between the metal and the semiconductor. This metal-semiconductor junction has a lower junction voltage and a decreased (almost nonexistent) depletion width in the metal, making the recovery time (time it takes to switch between conducting and non conducting) a lot faster than the normal diode. This makes it better suited for high frequency use.

## 2.4 Thermal conductivity

In one of the experiments a heat source is place inside an isolated box. The heat transferred from inside the box to the surroundings will occur through thermal conductivity. The rate at which the heat is transported can be calculated with Newton's law of cooling.

$$\frac{dQ}{dt} = h \cdot A \cdot (T_{env} - T_s) \quad 2-11$$

Where

$Q$	= heat transferred in a period $dt$	$[J]$
$T_s$	= Temperature of the source	$[^{\circ}C]$
$T_{env}$	= Temperature of the surroundings	$[^{\circ}C]$
$A$	= area	$[m^2]$

$h$	= heat transfer coefficient	$[W/m^2 \cdot K]$
$t$	= time	$[s]$

### 3 Material and methods

In this report, multiple experiments are described to investigate the properties of the E-field sheet. In all experiments the general setup for the measurement of the E-fields has been done with an E-field sheet connected to a computer. The E-field sheet measures the E-field by using Schottky diodes in an 8x8 configuration. The diodes are 2.5 cm apart and are connected with carbon high resistive wires. See Figure 3-1 for an overview of the E-field sheet.

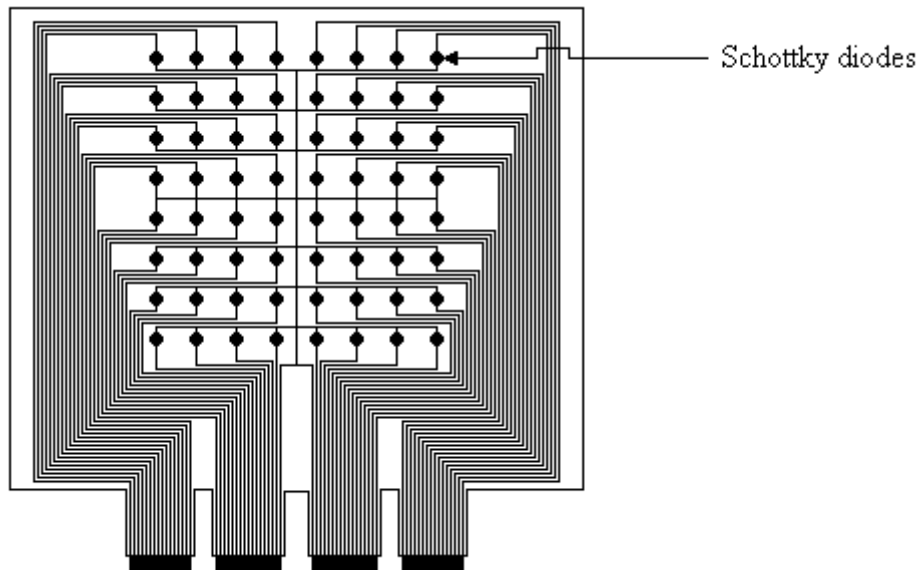


Figure 3-1– Schematic overview of the E-field sheet

The connectors from the E-field sheet are connected to a shielded connector box where they are converted to Dsub connectors. This box can be connected to a second connector box with a shielded Dsub cable. With the cable it's possible to measure in a different room than the pc is in. The second connector box transforms the Dsub to a SCSI connector, used to connect to the DAQ card used to connect to the DAQ card, DAQ2208 from ADlink. See Figure 3-2 for a schematic overview of the measurement setup.

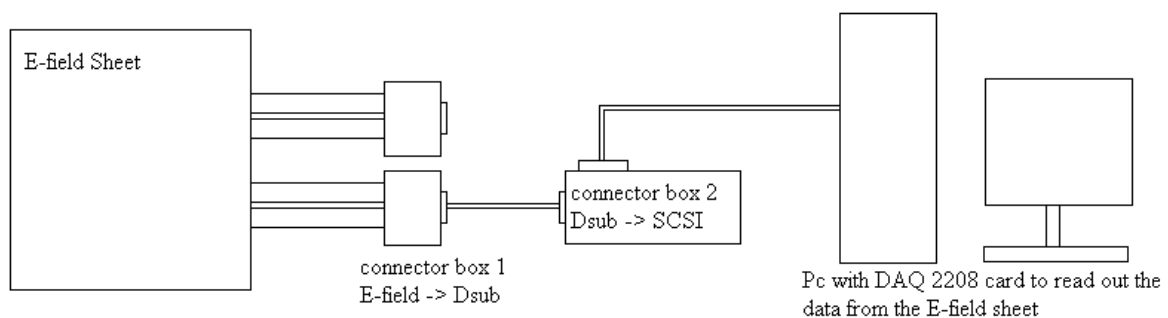


Figure 3-2 – Schematic overview of the measurement setup, left the E-field sheet connected to box 1 which converts it to Dsub (only half a sheet connected per connector). Connector box 2 converts the Dsub to SCSI that is used by the DAQ card for read out.

First the E-field sheet will be characterized by calibration and thereafter experiments have been done to examine the properties of the E-field sheet and the measurement setup. The first experiment is to measure the influence of the temperature on the output voltage. The next experiment is to look at the sensitivity of the cables/converter boxes for noise from different equipment. The third is the sensitivity of the diodes for E-fields that are not in the optimal angle. In the last experiment the possibility to increase the resolution of the E-field sheets will be examined.

After the experiments and calibration, the measurement system will be tested on clinical equipment to measure the E-field. The clinical equipment that is available at the Daniel den Hoed clinic are the antennas for the surface hyperthermia and the applicator of the deep hyperthermia. In the next paragraphs, the materials and methods are explained per measurement setting.

### 3.1 Phantoms

The solid phantoms that will be used in all the experiments are agar phantoms. The ingredients are listed in the Table 3-1.

**Table 3-1– Ingredients of the agar phantom.**

<b>Ingredient</b>	<b>quantity</b>
demineralized water	1 liter
Agar Agar	40 grams
Salt	2,1 grams
Formaldehyde	20ml

This phantom is used in the calibration setup and the experiment to measure the rotation sensitivity of the diodes. The properties of this phantom at 434 MHz signal are listed in the Table 3-2.

**Table 3-2 – Properties of the agar phantom.**

<b>Property</b>	<b>Value</b>
Relative permittivity ( $\epsilon_r$ )	78,37
Conductivity ( $\sigma$ )	0,5380 s/m

The phantoms are made by heating up a fixed amount of water to the boiling point, then agar is put into the water and thereafter salt and formaldehyde. The product has to be stirred well to guaranty a homogeneous phantom. After mixing the liquid phantom, it has to be put into a plastic bag and sealed for preservation and to prevent dehydration.

For the calibration two different phantoms have been made, one thick phantom approximately 6 cm thick and one thin phantom of 1 cm thickness. For the temperature measurements the thin phantom has three catheters placed inside the phantom, these catheters are glued to the plastic bag to ensure they are just below the surface of the phantom. Temperature probes can be placed inside the catheters to measure the temperature directly above a diode. Earlier studies

<sup>[8]</sup> have shown that temperature crystals that are placed directly above or below the diodes influence the E-field the least if the catheters are placed perpendicular to the E-field. The 3 catheters are placed 2.5 cm apart so the temperature of 3 different rows of diodes can be measured without repositioning the phantom.

## 3.2 Calibration setup

The diodes on the E-field sheet do not give the same voltage response when the same signal is applied. The formula that relates the E-field to the voltage is:

$$V_{diode} = k \cdot E + b \quad 3-1$$

where

$V_{diode}$	= Voltage over the diode	[V]
$k$	= slope constant	[-]
$b$	= offset	[V]

Every diode has its own  $k$  and  $b$ , which can be determined with a calibration setup. The constant  $b$  can be measured by connecting the E-field sheet to the computer and read out the voltage without applying any E-field from the antenna. The constant  $k$  can be rewritten to:

$$k = r \cdot a \quad 3-2$$

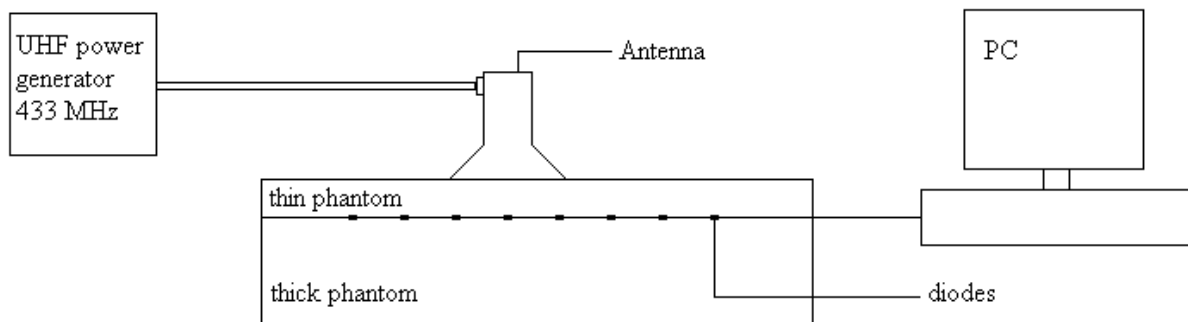
where

$r$	= relative slope constant.	[V]
$a$	= absolute slope constant.	[-]

The relative constant  $r$  is different for every diode because by fabrication a small and different error is introduced in every single diode, however the absolute slope constant  $a$  is the same for all diodes. Also  $r$  can be easily determined by using the relative calibration setup (see chapter 3.2.1), this will allow a correct E-field distribution. With this calibration other measurements can be done to further characterize the E-field sheet. After the relative calibration the absolute calibration can be done to calculate the exact E-field on a given point. The absolute calibration will be explained in the second part of this paragraph.

### 3.2.1 Relative Calibration

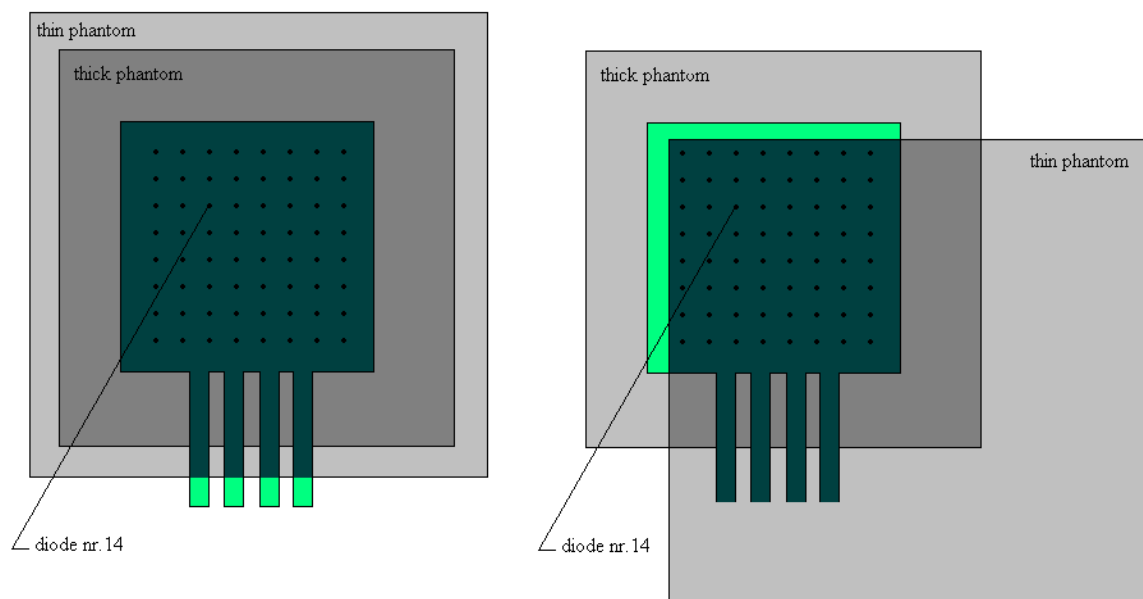
The relative calibration will be used to calculate  $r$  for every diode. This will remove the independency between every diode, so that the E-field sheet will give the correct distribution when an E-field is introduced. This will not give the exact E-field but when the  $a$  is calculated this can easily be transformed to an absolute E-field. To do the relative calibration the E-field sheet will be placed on the thick phantom, on top of the E-field sheet lies a one cm phantom. The centre of the antenna will be placed directly above the centre of the diode. See Figure 3-3 for a small cross section of the calibration setup.



**Figure 3-3 – Cross section of the calibration setup below is the thick phantom to absorb the E-field that comes out of the antenna so that it will not be reflected back. On top of the thick phantom an E-field sheet is placed to measure the E-field. A 1cm phantom is placed on top of the E-field sheet to enclose the diodes in phantom material to reduce reflection on material boundaries.**

### Homogeneity of the phantom

To do a calibration with a phantom, it is necessary that the phantom is homogeneous. Therefore an experiment has been done to see if the phantom meets the requirements. The E-field sheet has been secured on the thick phantom to prevent it from moving. On top of the E-field sheet a one cm phantom has been placed. On this phantom an 8x8 raster has been drawn to mark the positions of every diode on the E-field sheet. For the first measurement the 1cm phantom was placed normal to the E-field sheet. The antenna has been placed on top of the one cm phantom with its center on position 14, that is directly above diode 14. An UHF power generator has been connected to the antenna and it has been set to an output power of 5W. The measurement duration was five min, after which the second measurement has been done with the one cm phantom moved such that position four (upper left corner) was on diode 14. Also, the antenna was moved so that the center of the antenna was on position four on the phantom (directly above diode 14) and a measurement of five min will be done on five W power output see for a schematic overview. This will be done for several diodes and several locations.



**Figure 3-4 – Schematic overview of the measurement setup used for checking the homogeneity of the phantom.**



When the voltage measured in both positions of the phantom are the same for the diode measured. This has to be the same for every diode measured than the phantom is found to be homogenous, the calibration can proceed.

### **Calibration measurement**

To calibrate a diode, the antenna is placed directly above it. When the antenna is positioned the power generator is set to produce a 20 watt forward signal. Because the power generator has a very inaccurate read out of the forward and reflected power a bidirectional coupler is used to measure the exact forward and reflected power. The power tapped by the bidirectional coupler can be measured exactly with a network analyzer. For every diode a 60 sec measurement will be done to measure the voltage; at  $t = 0$ s the power generator is switched on and at  $t = 45$ s the power generator is turned off. The first 40 seconds will be used to calculate the average voltage when the antenna is on. The last 10 seconds when the power is off will be used to calculate the offset of the diode. The voltage difference between power off and on the  $r$  can be calculated for every diode.

### **3.2.2 Absolute calibration**

To do an absolute calibration the electric field emitted by the antenna has to be known. This is going to be done with the use of thermometry, with thermometry the amount of heat induced by RF can be measured, which will give the power of the antenna. With the power of the antenna the E-field can be calculated. The E-field can be calculated directly from the temperature by using equation 2-10.

$$|E| = \sqrt{\frac{2 \cdot \rho \cdot c \cdot dT}{\sigma \cdot dt}} \quad 2-10$$

The temperature change over time can be measured by using the calibration setup used by the relative calibration setup, and use the 1 cm phantom with the catheters to measure the temperature on the diode. The constants  $\rho$ ,  $\sigma$  and  $c$  have to be measured/calculated, which can be done in the lab except for  $\sigma$ , this will be sent to an other lab where it will be measured.

### **Power pulse**

The equation 2-10 can only be used when there is no heat transfer to the surroundings, this can be done by giving the phantom a power pulse, i.e. a high power signal for only a several seconds. The use of the power pulse will make the heat loss very small compared to the heat putted in the phantom.

The measurement setup for measuring the temperature change in time is shown in Figure 3-5.

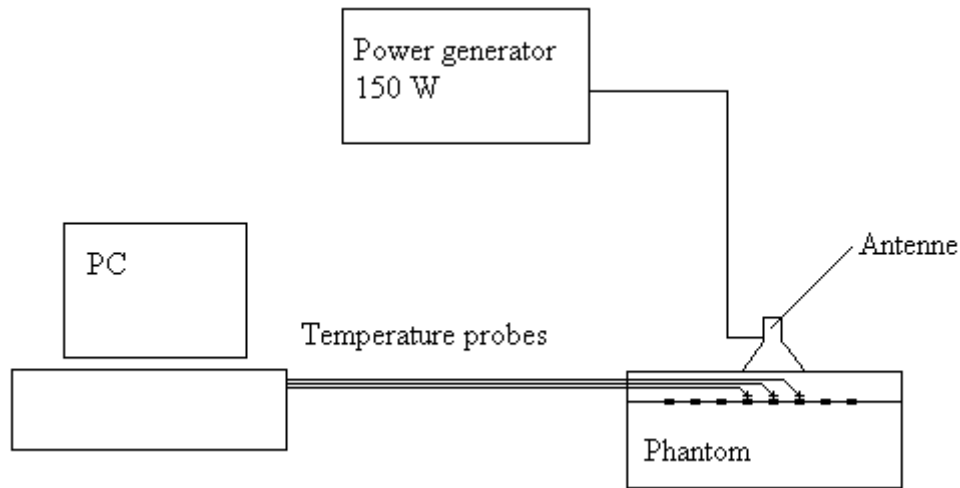


Figure 3-5 – Schematic overview to measure the temperature change over time.

The power pull will be 150 W and 30 seconds long. The temperature will be measured every three seconds.

### 3.3 The heat capacity

The heat capacity  $c$  will be measured by using an isolated box. The box has been made of expanded polystyrene (EPS) with inner dimensions of 10cm x 10cm x 12cm the walls have a width of 6 cm. A water volume of one liter at room temperature has been put inside. In the water a piece of phantom with initial temperature of 50°C will be put inside. The temperature change will be measured by placing a probe inside the box of water. The heat capacity can be calculated by using equation 3-3.

$$(T_{wf} - T_{wb}) \cdot c_w \cdot m_w = (T_{phb} - T_{phf}) \cdot c_{ph} \cdot m_{ph} \quad 3-3$$

Where

$T_{wf}$	= Water final temperature	[°C]
$T_{wb}$	= Water begin temperature	[°C]
$T_{phf}$	= Phantom final temperature	[°C]
$T_{phb}$	= Phantom begin temperature	[°C]
$c_w$	= heat capacity of the water	[J/kg·°C]
$c_{ph}$	= heat capacity of the phantom	[J/kg·°C]
$m_w$	= mass of the water	[kg]
$m_{ph}$	= mass of the phantom	[kg]

This equation can be rewritten to:

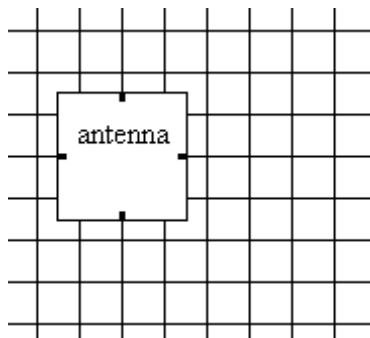
$$c_{ph} = \frac{(T_{wf} - T_{wb})}{(T_{phb} - T_{phf})} \cdot c_w \cdot \frac{m_w}{m_{ph}} \quad 3-4$$

Before an accurate  $T_{wf}$  can be found the heat transfer coefficient ( $h$ ) needs to be measured. This needs to be done because with this coefficient  $h$  the heat loss through the box can be calculated, which is needed to correct the  $T_{wf}$ . This has been done with the following experiment.

The insulated box has been filled with 1kg of water at a certain temperature. With the probe in the insulated box the temperature will be measured every three seconds for a period of 30minutes. Also a temperature probe will be placed just outside the box to measure the surrounding temperature from the cooling of the water a heat transfer coefficient can be found. With the heat transfer coefficient the  $T_{wf}$  can be found by using the formula 2-11.

### 3.4 Position sensitivity

When an E-field sheet is calibrated there can be a small error in the centre position of the antenna with respect to the centre of the diode. To measure the error made by a slight variation in the position the voltage from the diode will be compared between when the antenna is placed directly on top of the diode and when the centre of the antenna is moved away from the diode. The 0.0 position of the antenna will be when the centre of the antenna is on top of the centre of the diode. Then the antenna will be shifted five mm with steps of one mm to either side of the diode (from -5.0 to 5.0). From this measurement the uncertainty of misplacing the antenna can be calculated. To accurately measure the steps a raster will be placed on the diode. The raster will have lines every 1mm in both the x as the y direction, the antenna has marks on every side of the antenna, this will allow the antenna to be placed within 0.5mm of the desired position. See Figure 3-6 for a schematic overview of the position system with a raster.

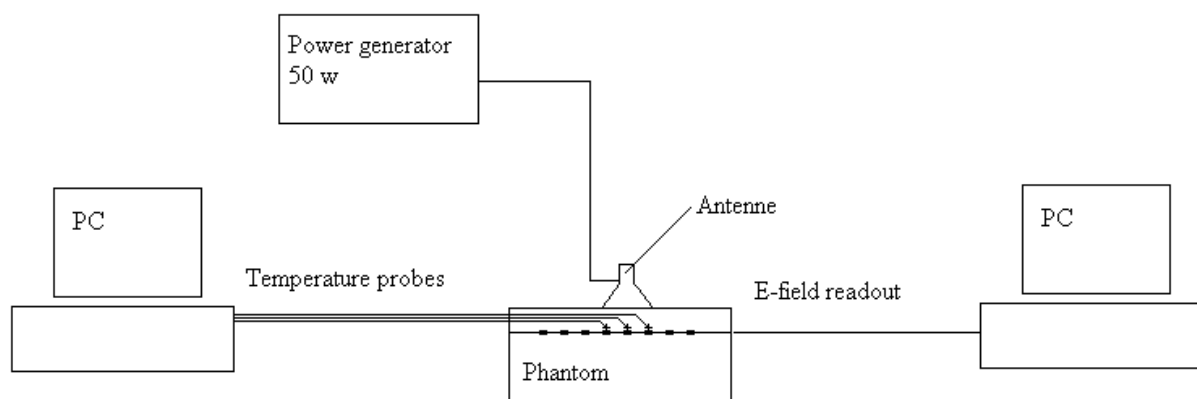


**Figure 3-6 – A raster to accurately position an antenna on a phantom, every side of the antenna is a middle point marked. This way the antenna can be accurately positioned (not on scale).**

The antenna is powered by 20 watt to ensure that the phantom does not get too warm during the measurements, every step is measured for 60 seconds. During the measurement the temperature of the diodes is measured to correct the data for the temperature change. The temperature is measured with an optical temperature probe. The average voltage and temperature for a position is taken from the 60 second measurement.

### 3.5 Temperature sensitivity

To measure the voltage change due to a change in temperature, caused by different room temperatures or by heating from the E-field, a special phantom has been made with catheters. The E-field is placed in between the thick phantom and the thin phantom with catheters and connected to the pc through the converter boxes. The thin phantom with the catheters allows temperature probes to be placed directly above a diode. For the readout of the temperature a different measurement / computer system is used. The computer will measure the temperature from the crystals in the tip of the probe. In order to correctly measure the temperature the probes have to be calibrated. This is done inside a water bath that is temperature regulated. The probes are put in the water bath of 30°C and measured, whereafter the water is heated in steps of 5°C to 50°C this gives a five points calibration. After the calibration the probes are fitted inside the catheters of the thin phantom directly above a diode. The centre of the big antenna (10cm x 10cm waveguide antenna) is placed directly above the centre of the diode. The power supply is set to 50 W forward power, and then the measurement starts on both pc's the first is connected to the E-field sheet to read out the voltage from the diodes and the other measures the temperature of the diodes. The phantom is heated for five min. The measurement data is plotted in a V-P diagram and fitted with a linear curve. A schematic overview of the measurement setup can be seen in Figure 3-7.



**Figure 3-7 – schematic overview of the temperature measurement setup, temperature probes are positioned directly above the diode to measure the temperature. The catheters are placed perpendicular on the E-field so they won't disturb the E-field.**

The temperature of the probes is measured every three seconds. The voltage over the diodes is measured with 400 samples per second. In most cases the voltages data get averaged over one sec but in this case it's averaged over three seconds to match the temperature data.

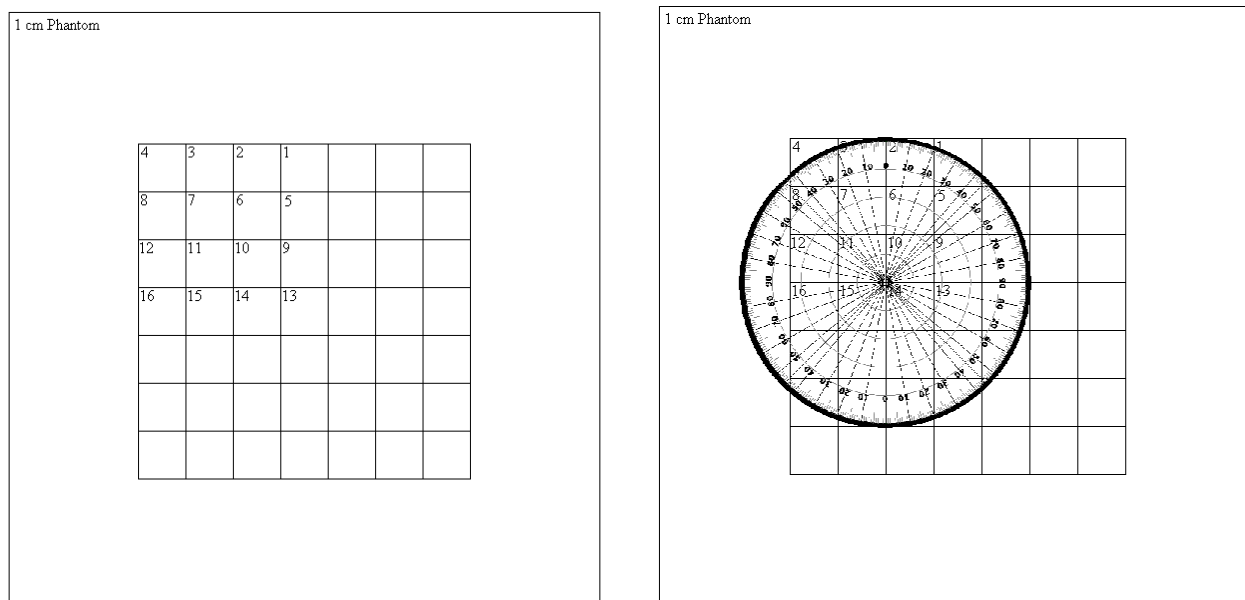
### 3.6 Noise from the cables and converter boxes.

The measurement system will be placed inside the deep hyperthermia chamber which is inside a Cage of Faraday to shield the measurement equipment from outside noise. The E-field sheet will be connected to the pc, but the E-field sheet itself will be shielded from the E-field so the noise that comes in to the system through the cables or connector boxes will be measured. The pc has to be outside the cage to make sure that the whole system is shielded from influences from outside. The split phantom that has been used for the temperature measurements will be

used to absorb the power from the applicator. The deep field applicator is a Sigma-60 applicator of the BSD Medical Corporation.

### 3.7 Rotation sensitivity

To see what the rotation sensitivity of the Schottky diodes on the E-field sheet are, the E-field sheet will be secured on the thick phantom. On top of the E-field sheet a one cm phantom will be placed and secured on the thick phantom below with tape. On top of the one cm phantom a raster is drawn to mark every location of the diodes, this is done to help placing the protractor, see figures below.



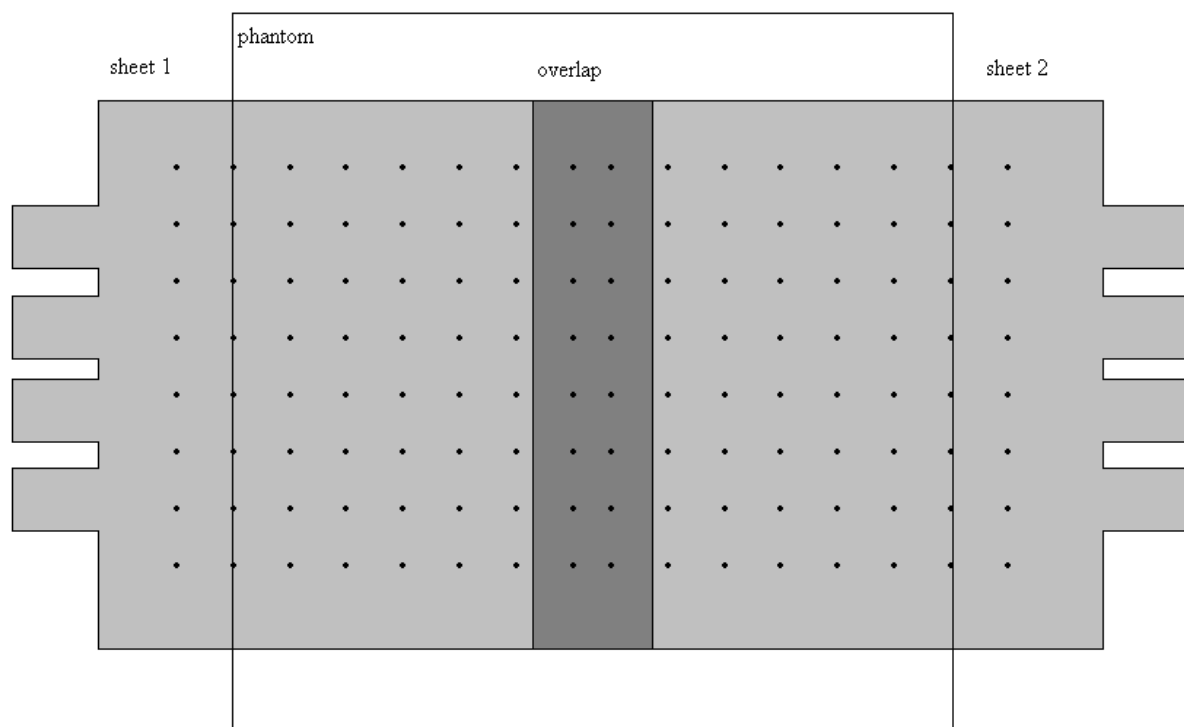
**Figure 3-8 – The picture on the left shows a grid that has been drawn on the phantom to mark every diode. On the right a protractor has been placed on a diode marking every 10 degrees.**

On top of this one cm phantom an antenna will be placed. This antenna will be rotated with 10 degree per step the full 360 degrees. To prevent temperature to disturb the measurement, two diodes are measured at the same time. The first diode will be measured from 0 till 80 degrees then the second diode will be measured from 0 till 80 degrees allowing the phantom around the first diode to dissipate the small amount of heat from the antenna. After the range of 0 to 80 has been measured on both the diodes the next quadrant can be measured. To align the middle of the antenna on the centre of the diode a protractor has been used. The middle of the sided of the antenna has been marked to accurately place the antenna on the diode under the correct angle. The power output of the UHF power generator has been set to 10 W forward

power. A low power output has been chosen because it will induce a low heat change in the phantom.

### **3.8 Resolution increase**

Two E-field sheets are placed inside the calibration setup, instead of connection one sheet, two half sheets will be connected to see the influence of placing two diodes closer together. The two diodes will be placed from two cm to 0.5 cm with steps of one mm the change of the “fixed” diode will be used to see if it’s getting disturbed by the second diode. See Figure 3-9 below for the experimental setup. The sheets are placed on top of each other in order to get the diodes on the different sheets close enough to each other.



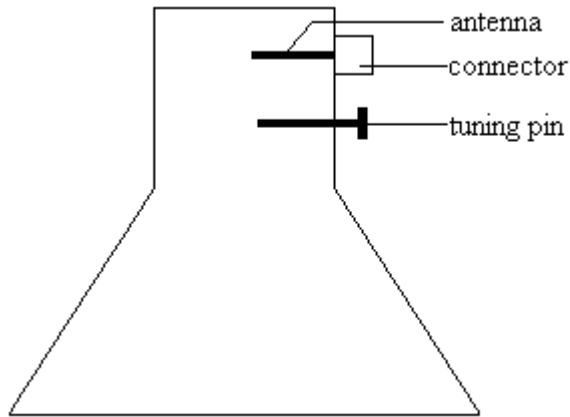
**Figure 3-9 – Schematic overview of the resolution increase measurement. Left is sheet 1 and right sheet 2, in the middle the overlap each other in order to get the diodes that are on the right column of sheet 1 and left column of sheet 2 closer together.**

### **3.9 Applicators used by hyperthermia**

There are several applicators used in hyperthermia for the superficial hyperthermia Wave guide Applicators (WGA's) were used and have been changed for Lucid Cone Applicators (LCA's). For the measurements WGA are used to generate fields. Deep hyperthermia uses the sigma 60 applicator and the sigma eye applicator the last one is actually the same as the sigma 60 only it has an ellipse shape instead of the circle.

### 3.9.1 WGA

The WGA is a waveguide filled with water. The first part is a 3.0 by 5.0 cm (W × H). The second part starts approximately  $\frac{1}{2}$  lambda from the dipole. From this level, the wave-guide cross-section diverges to the radiating aperture of  $10 \times 10 \text{ cm}^2$ . The sidewalls of the WGA are made of brass, as in the first part of the antenna.

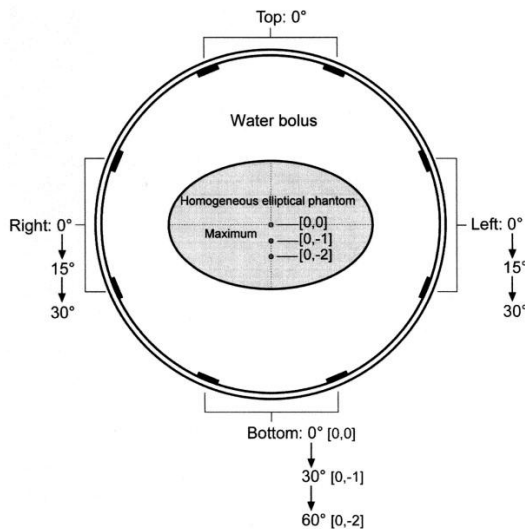


**Figure 3-10 – schematic overview of the WGA antenna, the inside is filled with water.**

There are several WGA available. They all have different dimensions but the general layout is the same. The connectors used are mostly coax cables, and the antennas used are all designed for 433MHz signals. The tuning pin is used to tweak the impedance to 50W in order to get the maximum forward power with the lowest reflected power.

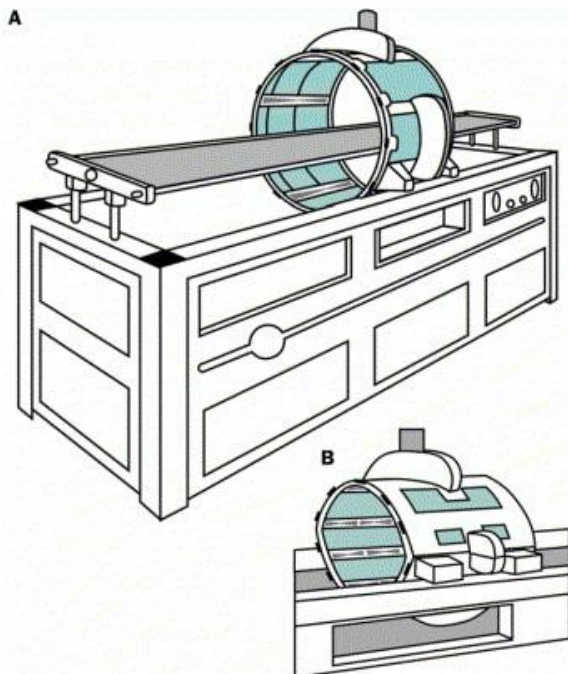
### 3.9.2 Sigma 60

The Sigma 60 applicator is ring with 4 dipole antenna pairs around the target area. See Figure 3-11 and see Figure 3-12 for a full overview of the deep hyperthermia treatment unit. The Sigma 60 operates at  $f = 77...90 \text{ MHz}$ .



**Figure 3-11 – Schematics of the SIGMA-60 applicator (with diameter 60 cm). The maximum of the power deposition patterns can be shifted to the bottom by phase delays as shown. The first selection (0, -1) of a target point shifts the maximum from the center (0, 0) 3 cm downward, the next step (0, -2) about 6 cm downward.<sup>[4]</sup>**

The area between the patient and the antennas is filled with water, this is done for three reasons, first the length of the antenna needs to be in water is a lot smaller than in air which would be 3meters instead if 30cm. second because humans have a lot of water in them so the transition from an aqueous environment to the human body gives almost no reflection, where as most power would be reflected back when there was no water in between. Third, provides cooling at the skin of the patient.



**Figure 3-12 – (a) Sigma-60 applicator (four dipole pairs) with treatment couch of the BSD-2000 system for regional hyperthermia. Dipole antennas are schematically shown. (b) A novel Multi antenna applicator Sigma-Eye (12 dipole pairs) mounted on the same treatment unit as shown in (a). the elliptical form is more comfortable for the patient.<sup>[2]</sup>**

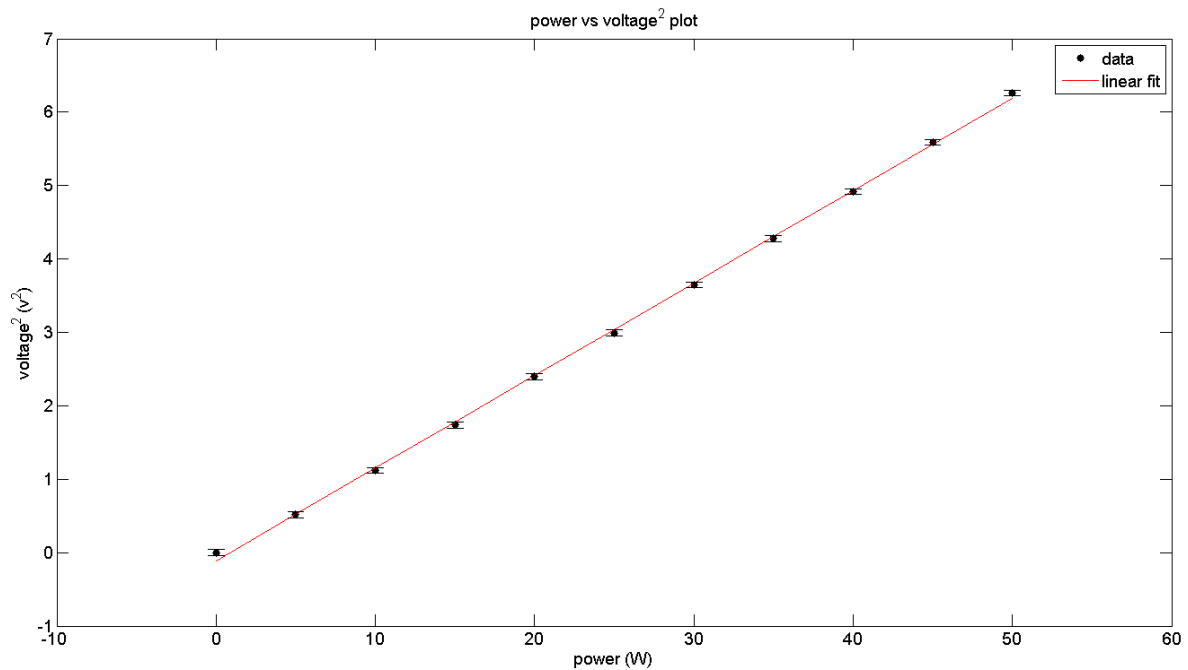
Figure 3-12 shows the full overview of the treatment unit and b shows a different applicator the sigma-eye, it works on the same principals only a different shape.



## 4 Results

### 4.1 Calibration

The calibration process took two steps, first a relative calibration and subsequently an absolute calibration. The relative calibration has been done to get a correct E-field distribution, so that the other experiments could be done. The absolute calibration is process is more time consuming; therefore it has been done separately from the relative calibration. To verify equation 3-1 a power vs. voltage measurement has been done, in which the power was changed from 0 to 50 watt with steps of five watt, for every step the voltage has been measured see Figure 4-1.

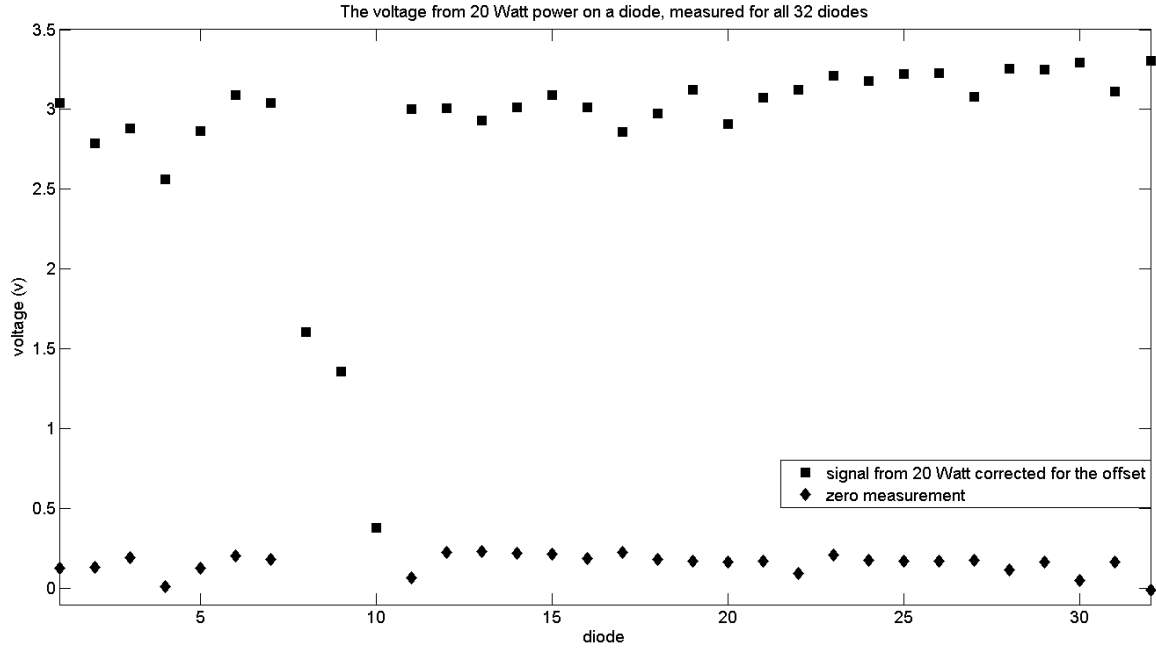


**Figure 4-1 – Power vs. voltage<sup>2</sup> plot, blue line is measurement data and red line in a linear fit with formula  $V^2=0.126 \cdot \text{Power} + 0.11$ . The norm of residuals is 0.15**

The linear fit represents the measurement data well; the formula of the linear fit is  $V^2=0.126 \cdot \text{Power} + 0.11$  with a  $R^2 = 0.9995$

#### 4.1.1 Relative calibration

The relative calibration is to calibrate every diode so that they will give the same voltage when the same E-field is applied to them. In the calibration method the voltage when there was no E-field has been measured and the voltage when a 20W signal was applied. The results of this measurement are present in Figure 4-2.



**Figure 4-2 – Calibration graph, for every diode the power difference between 0 Watt and 20 Watt have been plotted. The diamonds are the voltage when no E-field is applied on the E-field sheet (zero measurement), and the squares are the voltage when a E-field of 20 Watt from the small antenna is placed on top of the measured diode corrected by the offset.**

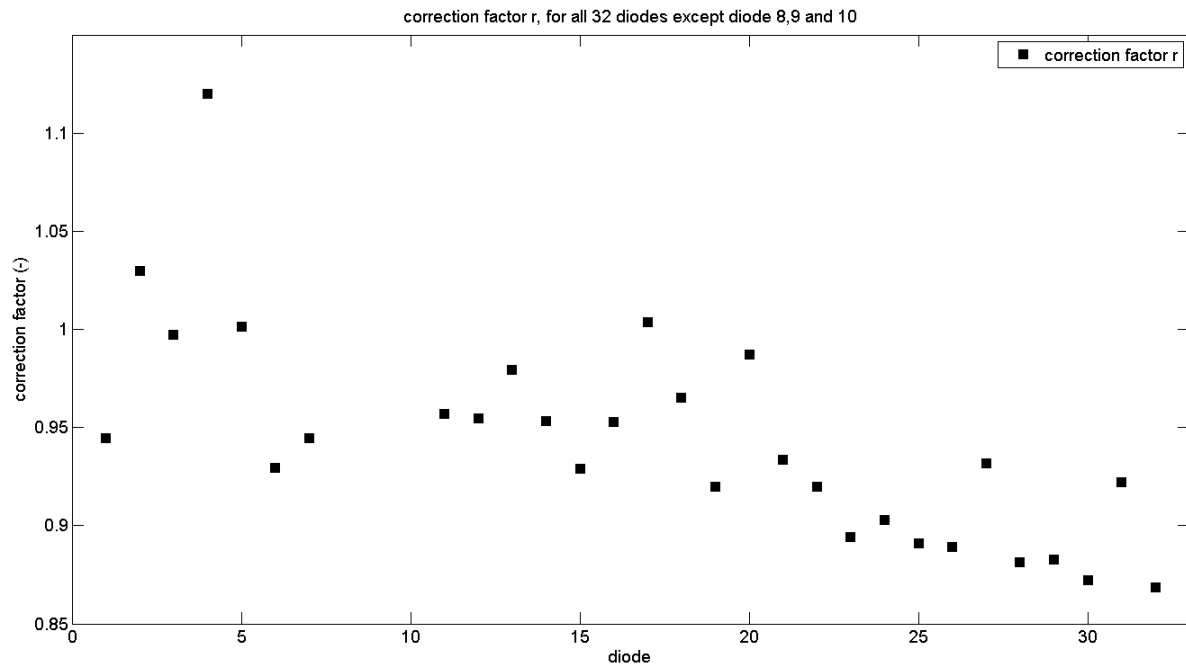
In Figure 4-2, a calibration measurement has been done. The diamonds show the zero measurement (no power on the antenna) to correct for the offset. The squares show the voltage when the small antenna is used with a power of 20 watt. The voltage due to the 20 watt has been corrected for the offset. The diodes on channel eight, nine and 10 give an abnormal low power increase due to the E-field, and the zero measurement points are below 0 V (not shown in the graph). These diodes are broken and cannot be used for measurements. The  $r$  and the  $b$  in equation 3-1 can now be calculated. Where  $b$  will be the offset (zero measurement) and  $r$  will be calculated with the next formula:

$$r_{diode} = \frac{\text{Mean\_voltage\_over\_all\_diodes}}{\text{Voltage\_from\_the\_diode}} \quad 4-1$$

Where:

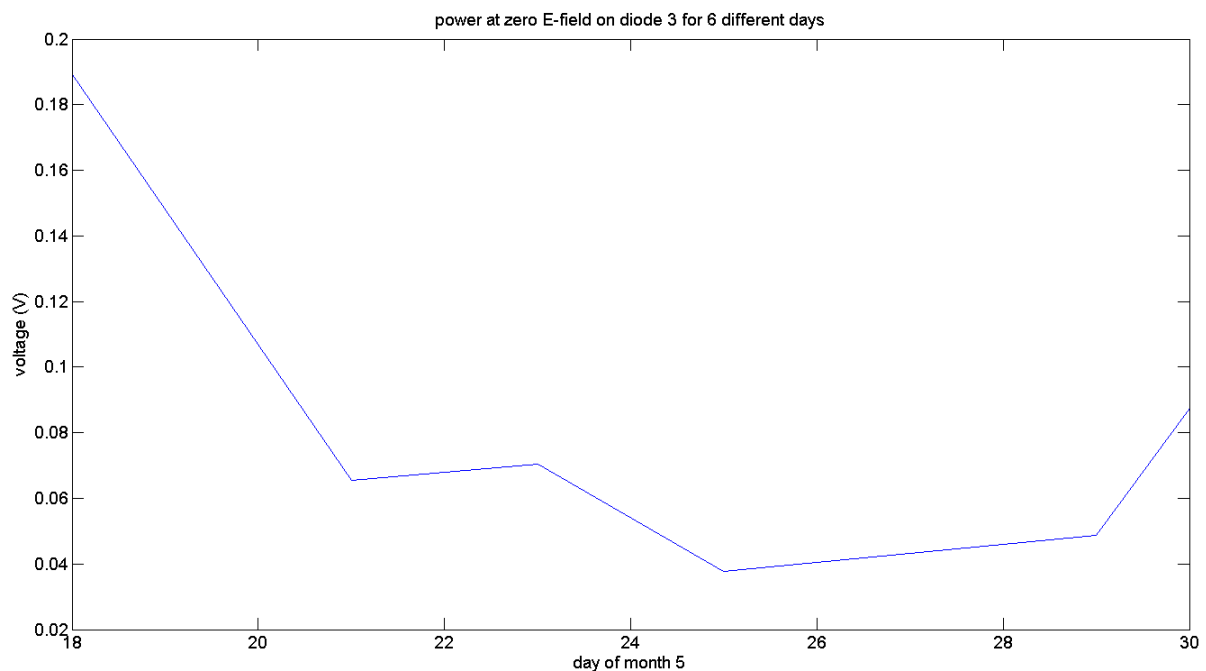
$r_{diode}$  = correction factor for the measured diode [-]

With this formula the  $r$  for every diode has been calculated and shown in Figure 4-3.



**Figure 4-3 – The correction factor  $r$  has been calculated for every diode except diode 8, 9 and 10 because they are broken. The correction factor  $r$  is needed for the relative calibration of the E-field sheet.**

To see if the relative calibration is valid for a long period of time, zero measurements have been done. These results are shown in Figure 4-4.



**Figure 4-4 – The voltage when no E-field was applied on the E-field sheets, measured over time.**

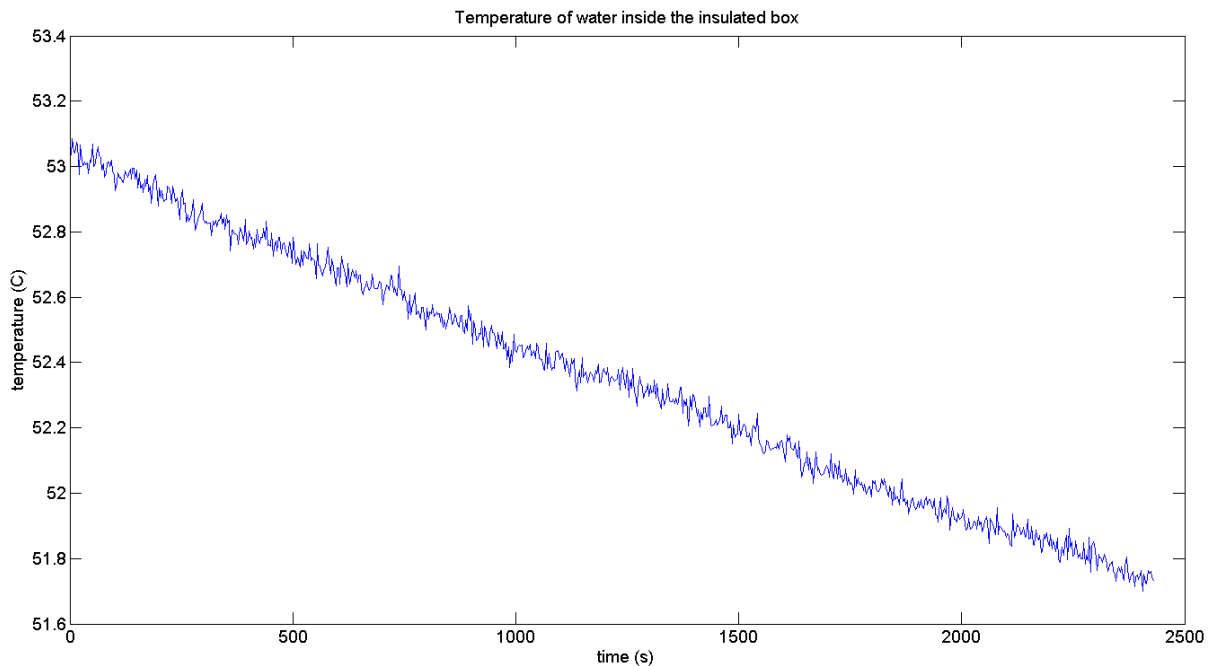
The zero measurements show that the zero power (offset) varies over time. This means that at least very day a new offset calibration needs to be done. In the future there needs to be research done to find out if the slope changes over time. If the slope changes than the relative calibration needs to be done very day, if not it can be done with longer intervals in between.

### 4.1.2 Absolute calibration

To do the absolute calibration the heat capacity, information about the dielectric properties are of the phantom are required. The heat capacity is determined on site, but the dielectric properties needed to be measured in an outside lab because there is no equipment available in the Erasmus MC to measure this. Besides the phantom properties the temperature change due to a Power pulse needs to be measured in the futur. With these measurements and a simulation of the antenna with the phantom beneath it the absolute E-field on the spot where the diode is located can be calculated. With this the whole sheet can be calibrated, because the relation between the diodes is already known.

## 4.2 Heat capacity

The heat capacity of the phantom material has been measured in the isolated box. The first experiment is to see how well the box is insulated. One liter water with a begin temperature around 55°C has been place inside the box (see Figure 4-5).



**Figure 4-5 – Temperature of the water inside the insulated box, used to calculate the heat transfer coefficient.**

To calculate the  $\Delta T$  the first 20 samples have been averaged to give the begin temperature and the last 20 samples for the end temperature.  $Q$  in this case was:

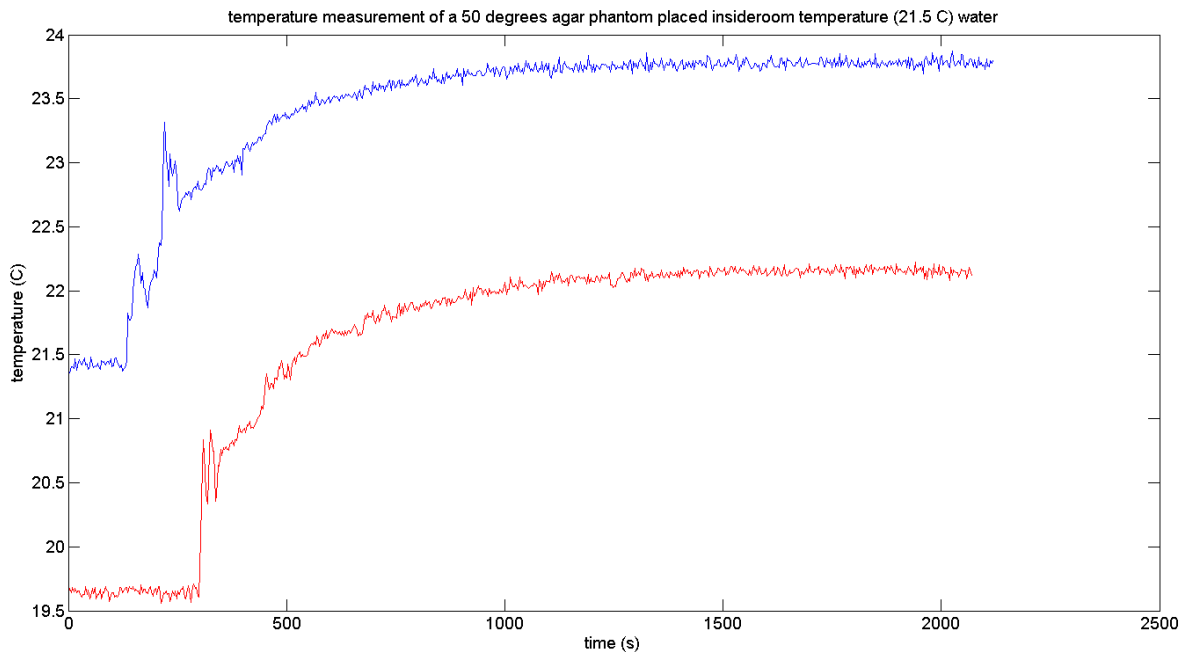
$$Q = \Delta T \cdot c_w \cdot m_w = 1.2852 \cdot 4180 \cdot 1 = 5372 \quad 4-2$$

The ambient temperature was 21.25°C and for  $T_s$  the average water temperature has been taken. Now the  $A \cdot h$  can be calculated by using formula 2-11.

$$\frac{dQ}{dt} = h \cdot A \cdot (T_{env} - T_s)$$

$$\Rightarrow h \cdot A = \frac{dQ}{dt} \cdot \frac{1}{(T_{env} - T_s)} = 0.0728$$

To measure the heat capacity a piece of phantom with a certain temperature has been placed inside the isolated box with one liter of room temperature water. In the first measurement (blue line in Figure 4-6) a total weight of 1.0000 kg water at 21.43°C +- 0.03°C was inside the box. The phantom was heated in a water bath of 49.75 +- 0.03°C for 30 min. For the second measurement (red line in Figure 4-6) the water in the box was 19.65°C +- 0.03°C and the phantom was on a temperature of 50.21°C. The phantom material with the plastic bag had a total weight of 97.6 grams and a volume of 97 ml this makes the density of the agar phantom less than 1% higher than water. The weight of the agar itself was 96.5 grams.



**Figure 4-6 – Temperature measurement for the heat capacity, a 96.5 gram agar phantom was heated to 50 degrees where after it was placed in an isolated box with 1 litre room temperature water. The temperature plotted is from a probe placed inside the water. Blue plot is 1<sup>st</sup> measurement and red one is the 2<sup>nd</sup> measurement. The agar and water initial temperatures are slightly different.**

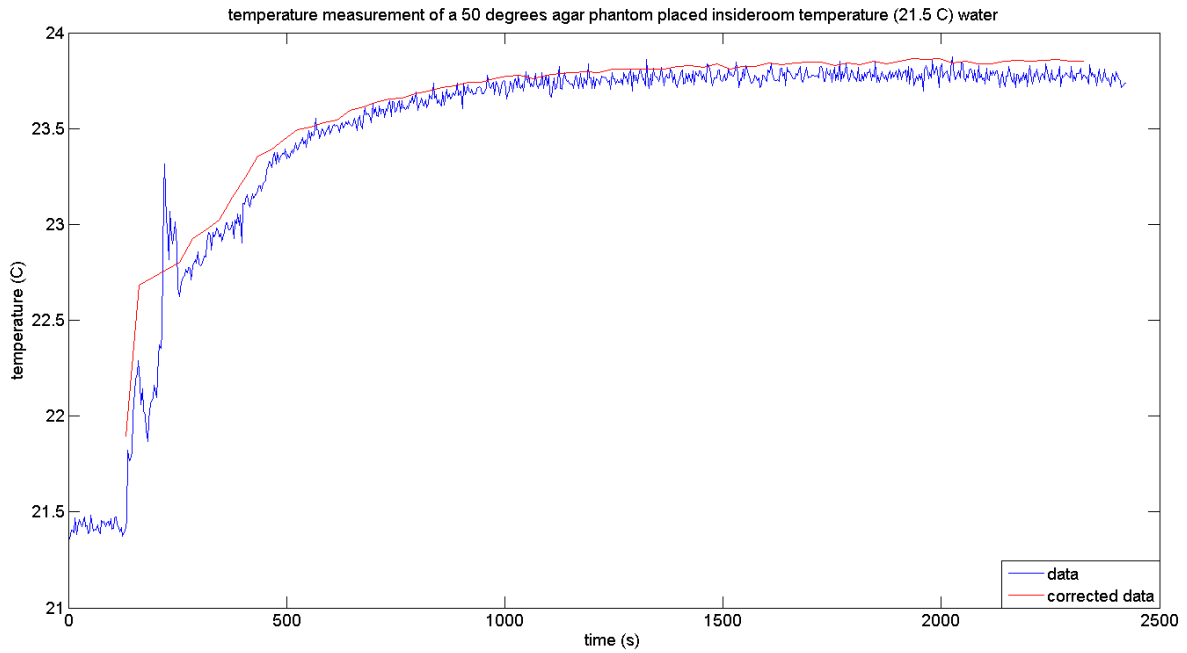
The first measurement showed an increase water temperature increase of 2.35°C. This is not the correct temperature difference because some heat has been leaking trough the walls of the insulated box. To calculate the heat loss the graph has been divided into parts of 10 measurement points each, for every period of time the heat loss has been calculated. To know the heat loss at period i the formula 4-3 has been used.

$$Q_i = \sum_{n=1}^i \left( \frac{\left( \sum_{m=-5}^5 T_{w-5(n-1)+m} \right)}{11} - T_{env} \right) \cdot h \cdot A \cdot dt \cdot c_w \quad 4-3$$

Where

$i$  = time period number  $i$  [-]  
 $dt$  = time period = 30 [s]

The result of the correction is shown in Figure 4-7



**Figure 4-7 – Temperature measurement of a 50 degree agar phantom placed inside room temperature water (blue line) and corrected for the heat loss (red line).**

The heat loss due to conduction through the walls of the box have been calculated to be 0.0844°C when the measurement stopped. After 25 minutes the temperature stabilized at 23.78°C to correct for the heat loss through the walls the new temperature is 23.78°C + 0.0844°C that is 23.86°C. The heat capacity of the phantom material in the first measurement is calculated with formula 3-4.

$$c_{ph} = \frac{(T_{wf} - T_{wb})}{(T_{phb} - T_{phf})} \cdot c_w \cdot \frac{m_w}{m_{ph}} \quad 4-4$$

$$c_{ph} = \frac{(23.86 - 21.43)}{(49.75 - 23.86)} \cdot 4180 \cdot \frac{1}{0.0965} = 4080$$

The uncertainty of  $c_{ph}$  can be calculated with the uncertainty analysis shown in formula 4-5.

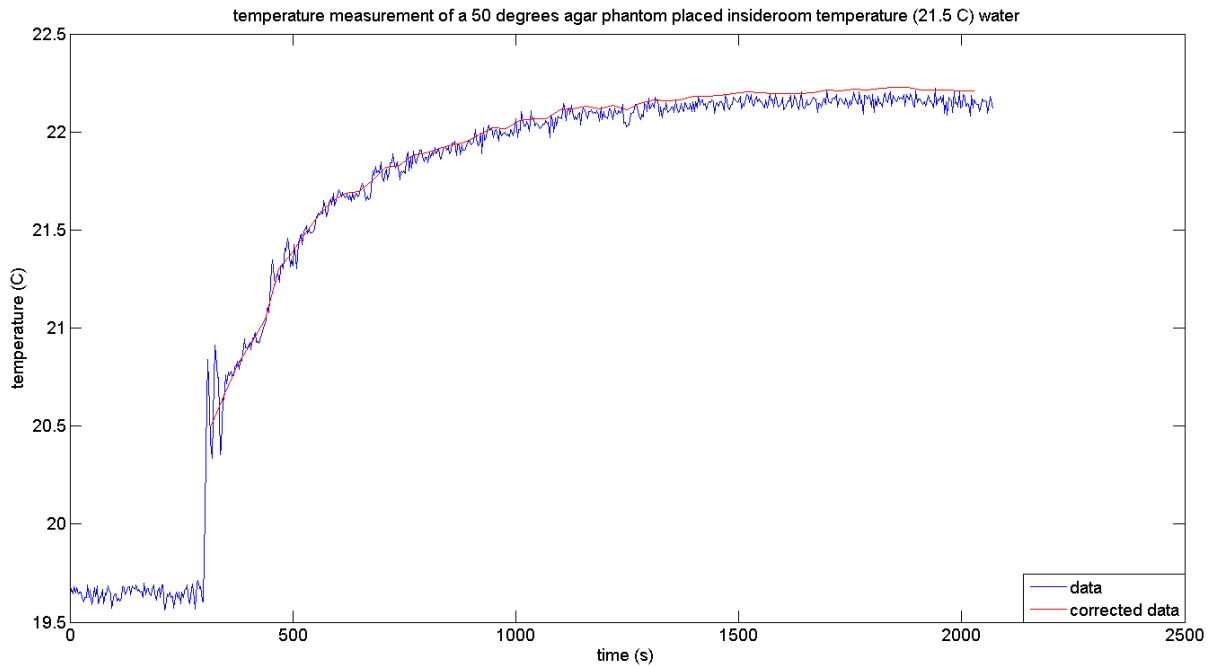
$$\begin{aligned}
\Delta c_{ph} &= \frac{dc_{ph}}{dT_{wf}} \cdot \Delta T_{wf} + \frac{dc_{ph}}{dT_{wb}} \cdot \Delta T_{wb} + \frac{dc_{ph}}{dT_{phf}} \cdot \Delta T_{phf} + \frac{dc_{ph}}{dT_{phb}} \cdot \Delta T_{phb} + \\
&\frac{dc_{ph}}{dc_w} \cdot \Delta c_w + \frac{dc_{ph}}{dm_w} \cdot \Delta m_w + \frac{dc_{ph}}{dm_{ph}} \cdot \Delta m_{ph} \\
&= c_{ph} \cdot \left( \frac{\Delta T_{wf} + \Delta T_{wb}}{(T_{phb} - T_{phf})} + 2 \cdot \frac{\Delta T_{phb} + \Delta T_{phf}}{(T_{phb} - T_{phf})} + \frac{\Delta c_w}{c_w} + \frac{\Delta m_w}{m_w} + 2 \cdot \frac{\Delta m_{ph}}{m_{ph}} \right) \\
&= 4.0801 \cdot \left( \frac{0.03 + 0.03}{25.8902} + 2 \cdot \frac{0.03 + 0.03}{25.8902} + \frac{0}{4.18} + \frac{0.00005}{1} + 2 \cdot \frac{0.00005}{0.0965} \right) \\
&= 0.0328 \text{ kJ/kg} \cdot \text{K}
\end{aligned} \tag{4-5}$$

Where

$\Delta c_{ph}$	= uncertainty in $c_{ph}$	[J/kg·K]
$\Delta T_{wf}$	= uncertainty in $T_{wf}$	[C]
$\Delta T_{wb}$	= uncertainty in $T_{wb}$	[C]
$\Delta T_{phf}$	= uncertainty in $T_{phf}$	[C]
$\Delta T_{phb}$	= uncertainty in $T_{phb}$	[C]
$\Delta c_w$	= uncertainty in $c_w$	[J/kg·K]
$\Delta m_w$	= uncertainty in $m_w$	[kg]
$\Delta m_{ph}$	= uncertainty in $m_{ph}$	[kg]

This gives a makes the  $c_{ph} = 4.08 \pm 0.033 \text{ kJ/kg} \cdot \text{K}$ .

For the 2<sup>nd</sup> measurement the same correction can be calculated and is shown



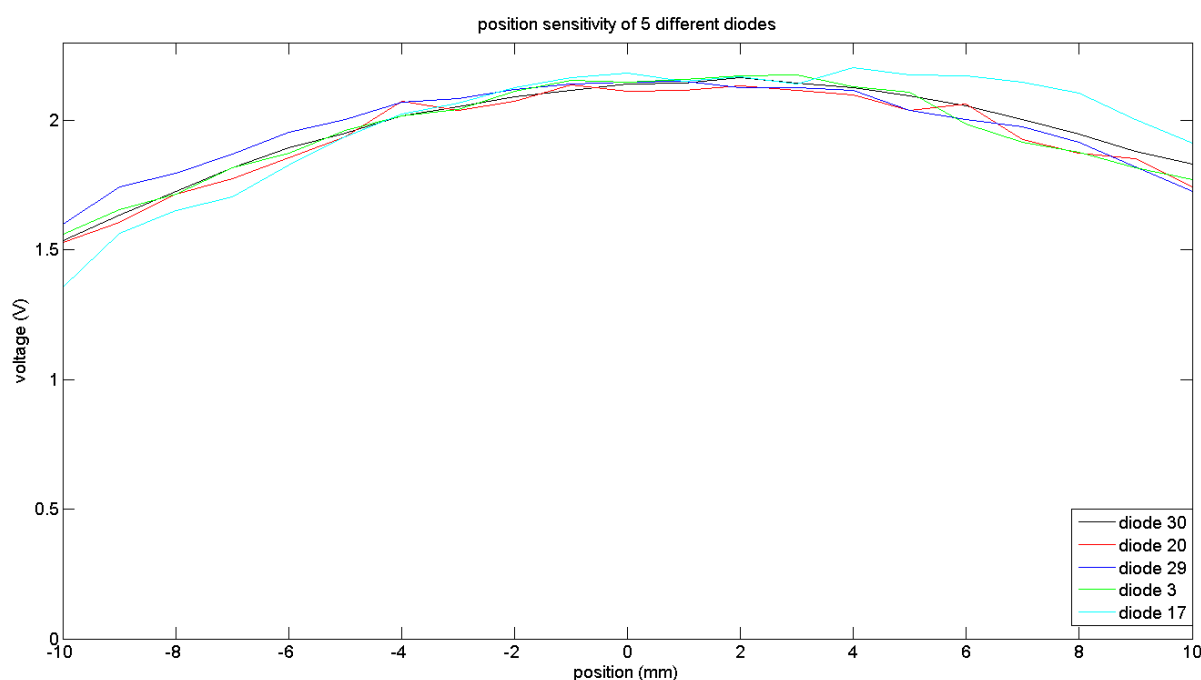
**Figure 4-8 – Temperature measurement of a 50 degree agar phantom placed inside room temperature water (blue line) and corrected for the heat loss (red line).**

The 2<sup>nd</sup> measurement showed corrected final temperature of 22.224°C a heat capacity of  $3.99 \pm 0.030 \text{ kJ/kg} \cdot \text{K}$ .

The average  $c_{ph}$  is now  $4.036 \pm 0.031$  kJ/kg·K.

### 4.3 Position sensitivity

The position sensitivity has been measured for multiple diodes to see what the error is when the antenna is misplaced by a few millimeters. In Figure 4-9 the diodes are plotted (see Appendix A for all the other diodes). The measurement points are shown for an error of -10 mm trough 10 mm with steps of one mm. The measurement error is 20 mvolts in the voltage and 0.5mm in the positioning.



**Figure 4-9 – position sensitivity measurement for one diode from -10mm to 10 mm in steps of 1mm, positioning error of 0.5 mm and a voltage error of 0.02 volts. The red line is a cubic fit though the measurement data.**

In Figure 4-9 the diodes show an expected behavior, this is that the power decreases as the antenna gets further away from the diodes. The Table 4-1 show the uncertainty when the antenna is displaced by one mm and two mm.

**Table 4-1 – position sensitivity of the measured diodes.**

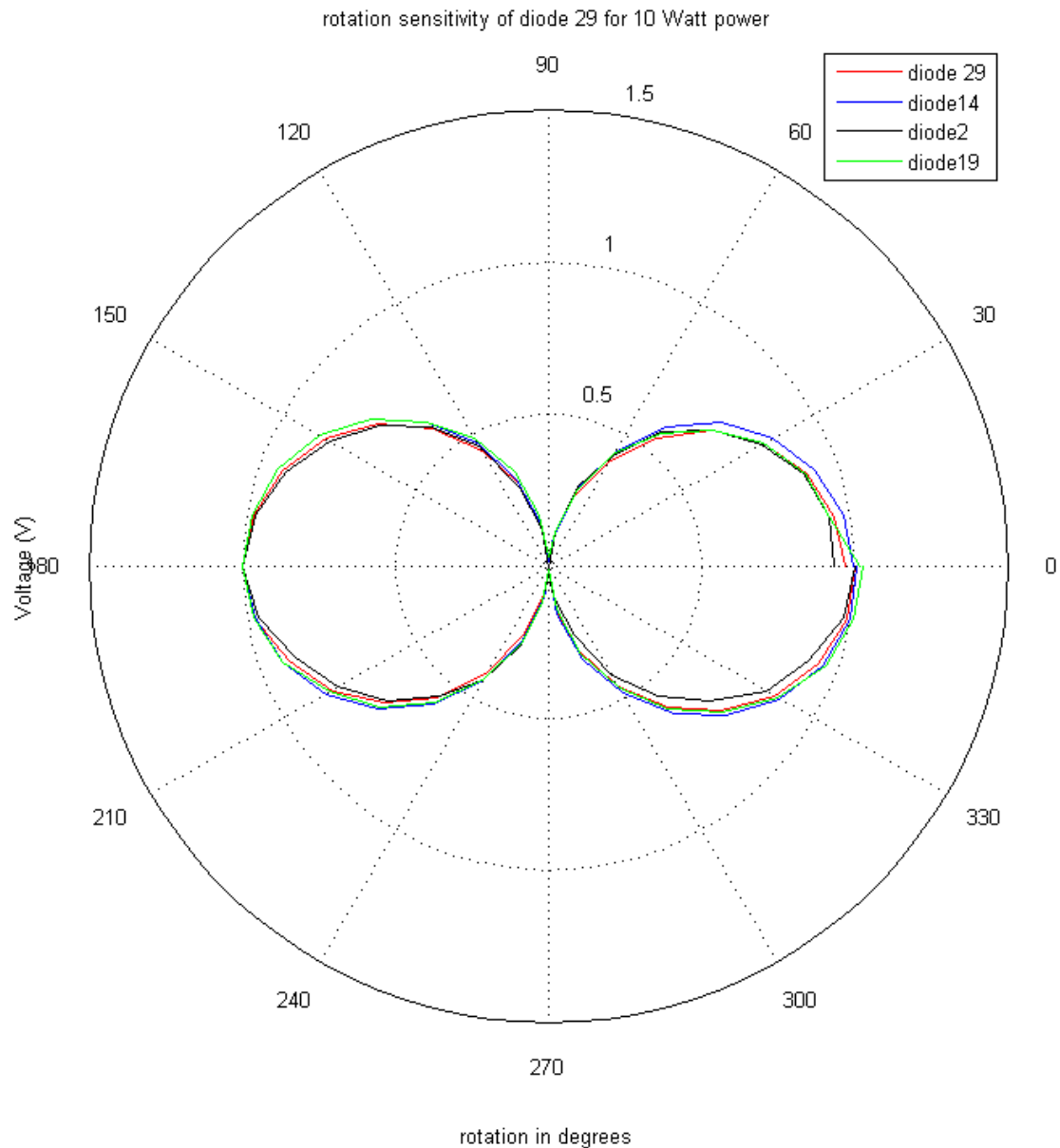
Diode	1mm variation	2mm variation
30	0.45%	1.3%
20	0.33%	1.09%
29	0.37%	1.19%
3	0.23%	0.97%
17	0.36%	1.21%

These results show that the one mm variation is within 0.45% and the two mm variation is within 1.3%.



#### 4.4 Rotation sensitivity

The rotation sensitivity has been measured on 4 different diodes. These diodes were 29, 14, 2 and 19. The measured voltages have been plotted in Figure 4-10.

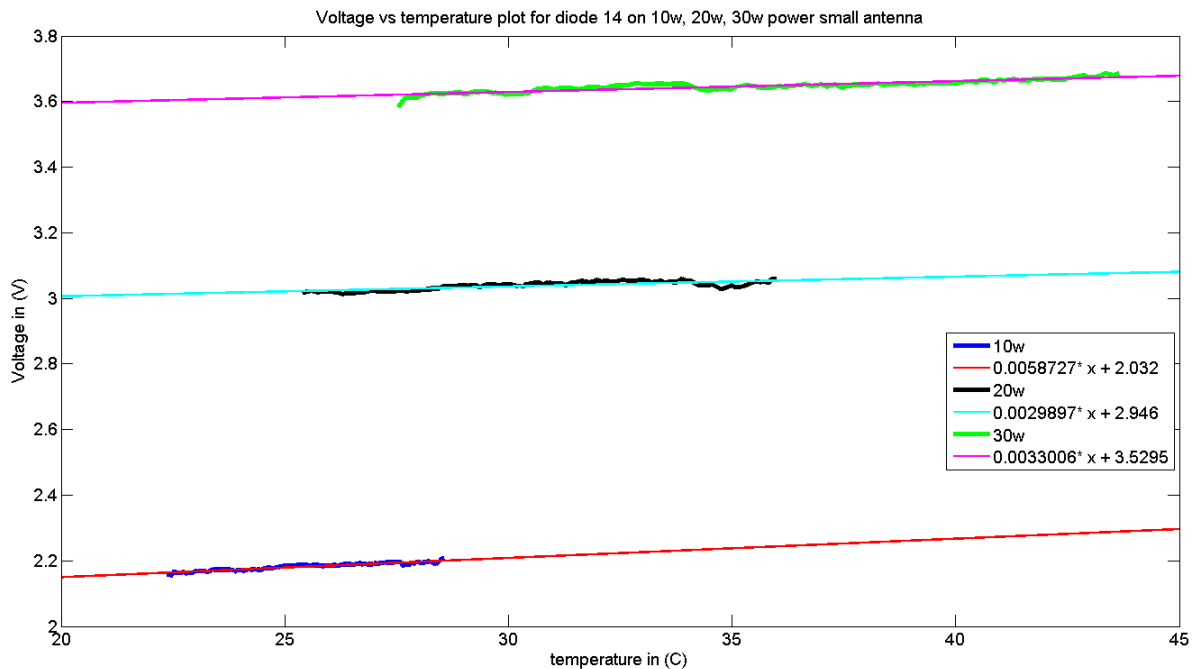


**Figure 4-10 – rotation sensitivity for 4 diodes, the voltage has been set to 1 V when the antenna was on 180°. This has been done so the all the diodes could be compared.**

As expected the maximum voltage due to the E-field is when the antenna is at 0° or 180°, and zero at 90° and 270°. The error caused by a misplacing of 5° will result in an error of 0.8%.

## 4.5 Temperature sensitivity

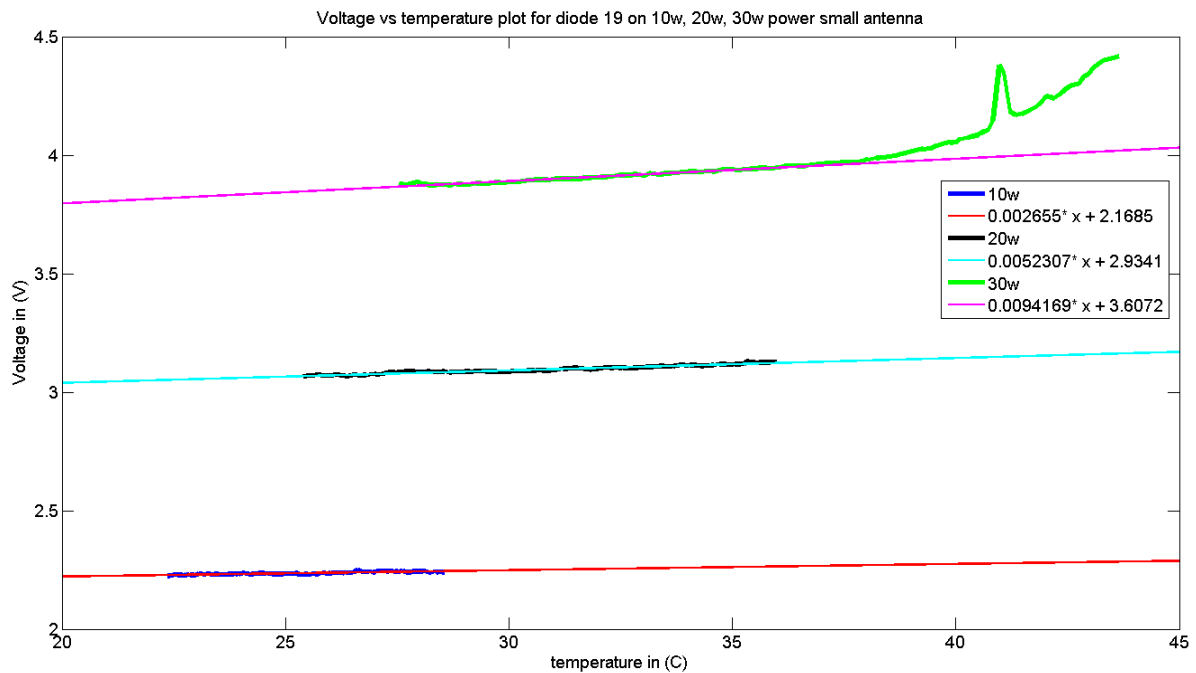
The temperature sensitivity has been measured for 3 different diodes and each diode for 10, 20, 30 watt. The antenna used was the 5x5 cm one. The results from the diode 14 for 10, 20, 30 watt power (small antenna) is shown in Figure 4-11.



**Figure 4-11 – Temperature vs. voltage measurements for 3 different power settings (10, 20, 30 watt), and a linear fit has been plotted through every data set.**

Figure 4-11 shows the temperature vs. voltage measurements for 3 different power settings (10, 20, 30 Watt). The linear fits have been plotted to show the slope. The slopes are not the same for every power setting, but are all close to each other.

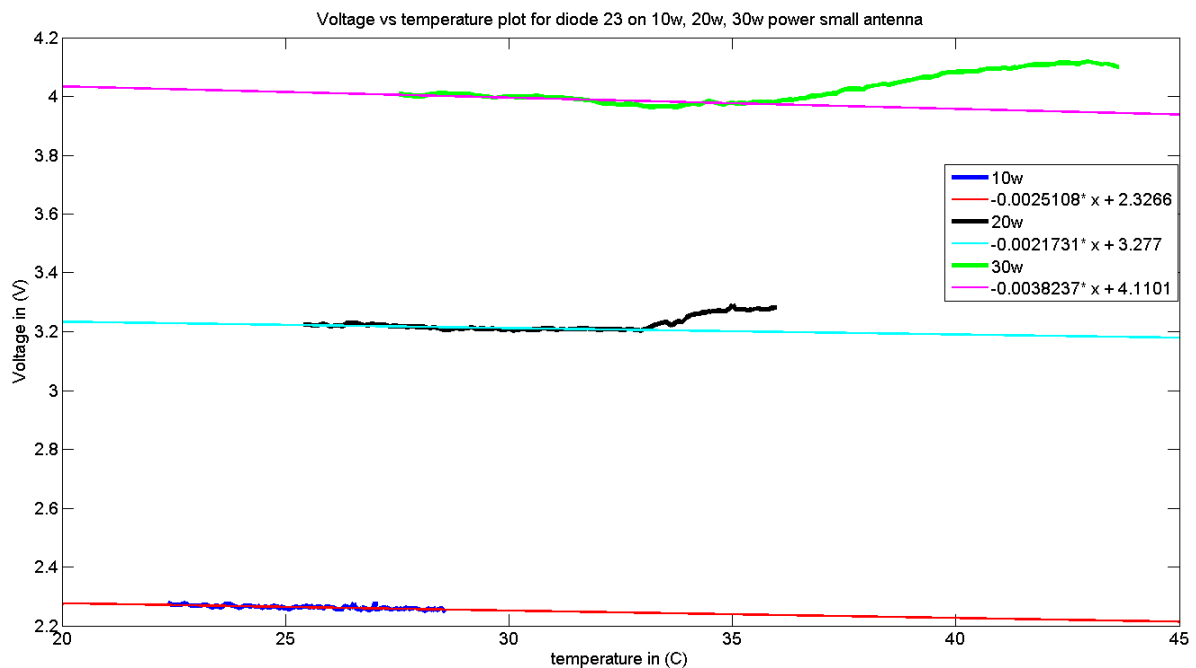
The results from the diode 19 for 10, 20, 30 watt power (small antenna) is shown in Figure 4-12.



**Figure 4-12 – Temperature vs. voltage measurements for 3 different power settings (10, 20, 30 watt), and a linear fit has been plotted through every data set.**

In Figure 4-12 the temperature vs. voltage measurements for three different power settings are shown with a linear fit through them to show the slope. The spike at the green (30 Watt) signal is a disturbance in at the antenna and should be ignored. Diode 19 shows a linear temperature dependence for temperatures below 37 degrees Celsius. Above this value the temperature shows a cubic relation.

The results from the diode 19 for 10, 20, 30 watt power (small antenna) is shown in Figure 4-13



**Figure 4-13 – Temperature vs. voltage measurements for 3 different power settings (10, 20, 30 watt), and a linear fit has been plotted through every data set.**

Figure 4-13 shows the temperature vs. voltage measurement for three power settings, the lower range of temperatures show a negative slope, which changes when the temperature comes above 33°C. After that point the slope is positive, the 3 different diodes show completely different temperature dependence. One thing that they have in common is that on the lower temperature range (around 25°C) they all show a small temperature dependence.

Although the diodes show completely different behavior they all have a linear domain in the lower temperature ranges. This makes it important that the measurements being done with the sheet are around room temperature, and are also calibrated at this temperature. The steepest slope shown by the four diodes was 9mv V/°C this results of a max error of 0.3% per °C.

#### ***4.6 Noise from the connection to the pc***

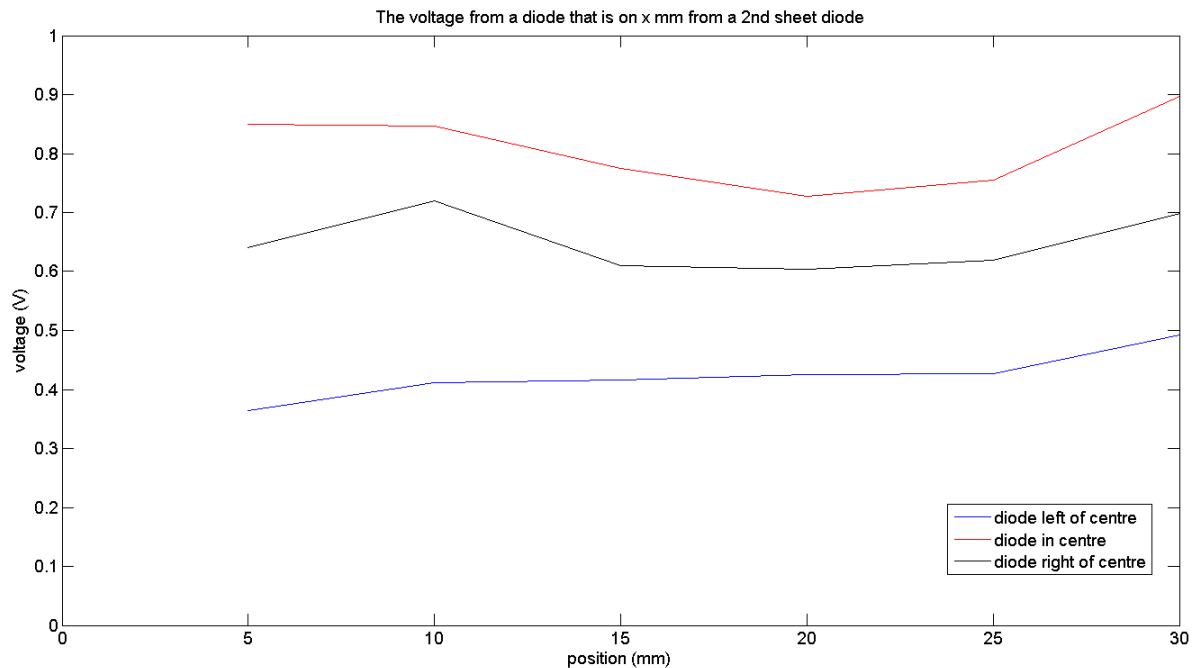
After the E-field sheet was shielded, which was done by encasing the E-field sheet in a grounded copper net which, an antenna was placed on various parts of the connection from the E-field sheet to the pc. This was done on the connector boxes and the cables between them. All the measurements showed no disturbance of the signal. This makes the connection from the E-field sheet to the pc protected from 433 MHz noise. After the antenna was placed on various parts of the connection a 50Hz noise source was introduced to the system. The 50 Hz noise was not visible on the signal from the E-field sheet.

The conclusion can be made that the connection from the E-field sheet to the pc doesn't add measurable noise to the signal. This means that all the noise on the signal is comes in the system at the E-field sheet.

To get the least noise in the signal the E-field measurement should be done in a shielded room and connected to a pc that is outside the room. The deep hyperthermia room is best suited for this purpose because it is a big Cage of Faraday.

#### ***4.7 Resolution increase***

The resolution increase has been measured by placing a sheet between 2 phantoms (thick on the bottom and the thin on top. Then a 2<sup>nd</sup> sheet was placed so that a diode was on a distance of x mm to a diode of the 1<sup>st</sup> sheet. In Figure 4-14 the results are shown.



**Figure 4-14 – The voltage from a 3 diode that are on a E-field sheet, on x mm from this row of diodes is a 2<sup>nd</sup> sheet with diodes placed. The antenna was on the diode in the centre, and the voltage from when de distance is 30 mm is the voltage when no 2<sup>nd</sup> E-field sheet was present.**

The red line is the voltage of the diode that is positioned in the center of the antenna, the blue line is the diode left of the centre diode and the black is right of the centre diode. The 30 mm position is actually the measurement when the 2<sup>nd</sup> sheet is completely removed. What is expected is that the 25 mm position is the same as the 30mm because on a sheet the diodes are 2.5 cm from each other. This is not the case; one of the possible reasons is because there is space between the overlapping sheets creating a small pocket of air. This pocket of air will disturb the E-field; to verify this in the future the 2<sup>nd</sup> E-field sheet can be replaced by a piece of plastic with the same flexibility. If the plastic gives the same change in voltage than placing the diodes do not influence each other. The limit of distance between 2 diodes needs to be at least 10 mm because otherwise the antennas will overlap.

## 5 Discussion

The ultimate goal of the internship was to develop software and a connection box to use the E-field sheets including a calibration routine. This goal has not been reached entirely, but only a few steps are needed to get to this goal. What has been finished is the relative calibration so the relative E-field can be measured. Also the steps to get the absolute E-field are researched and partly taken.

### **The creation of the measurement setup**

The first part of the internship was to make the hardware for the measurement set-up, this needed to be done before any measurement could be done. The first priority was the connection from the E-field sheet to the DAQ card. Because the E-field sheet needed to be working as fast as possible the choice has been made to only connect one half of the E-field sheet, which was the fastest option. Once one half of the E-field sheet was connected to the DAQ card, the software that needed to be written could be tested. After the first half of the E-field sheet was connected a GUI (Graphical User Interface) could be made. After a basic version of the GUI was made and the output diodes could be made visible the connection from the E-field sheet to the DAQ card was tested. This was done by using a power supply to make a voltage difference between the channel and the common ground. The voltage measured by the DAQ card was the same as was applied with the power source. This confirms that the connection and readout is correct. The data acquisition was done with Matlab. Every channel was measured 400 times per second. The signal measured with the E-field sheets had so much noise that the signal was “drowned” in the noise, typically the noise was from -8V to 10V, where it clipped. After a long search where the noise came from, the biggest noise source was found. This source was also the UHF power generator, after an extra ground cable was placed from the power generators’ casing the measured noise was reduced to 0.5V above and below the signal. After the noise problem was reduced, another problem became visible; the averaged signal was negative and in the range of 0 to -5V depending on what diode was measured. Because the correct voltage was measured when an external power source was connected to the DAQ card. It was believed that the data acquisition was correctly done. To begin the measurements for the report, phantoms needed to be made. First a small phantom was made to see how the process of making a phantom worked, after the small phantom a 30x30x1 cm and the thick 30x30x7 phantom were made. The 30x30x7 phantom was made thinner and wider than was planned because when the agar is warm it is a liquid that is poured into a plastic bag. This plastic bag was placed on top of a table and pushed down with a wooden plate to create two big flat surfaces, this had as consequence that the phantom became thinner and wider. The wider thick phantom was not a problem because it gave a bigger flat surface now and was only needed to absorb the power transmitted from the antennas. The power of the antennas needs to be absorbed so that they can not disturb the measurement when they reflect back from an object. After the creation of the phantoms the power vs. voltage<sup>2</sup> has been measured. The data that came back from the E-field sheet was strange such a way that when no E-field was applied a negative voltage was measured. A choice has been made to compensate this with an offset.

### **Data acquisition**

The first method used to read out the data from the DAQ card was done by taking 400 samples per second for every channel available. This means every 1/400 sec 1 measuring

point for every diode was done. The strange part of the data that was measured was that it was negative. It was decided to compensate this with an offset. When the data was corrected a power vs. voltage<sup>2</sup> graph could be made see Figure 4-1. The plot showed that a linear fit is a good fit, this concludes that the relation between the voltage and the electric field is linear. This means that equation 3-1 can be used to characterize the diodes. The linear fit has the equation of  $V^2 = 0.12601 \cdot \text{Power} + 0.10851$  with a norm of residuals of 0.15V. Next the rotation sensitivity was measured; the voltage difference between with power and zero power measurement was used to find the correct voltage. The rotation sensitivity was in the as expected 100% at the 0° and 180° and low at 90° and 270°, what was surprising was that at 90° and 270° the voltage did not went to 0% but was 20%. After the rotation sensitivity the position sensitivity was measured to know the error that will be made when calibrating the E-field sheet. Here it went wrong, the voltage on the different places from -1cm to 1cm showed that sometimes the left side had a higher voltage difference between power on and power off, than the right side. Often the 0 position (where the diode should be) was one of the lowest points on the graph. Also it was not possible to repeat the measurements so that the same values came appeared. After a long search, the problem was found to be the AD converter in the DAQ card. The data was acquired by scanning all 64 diodes at the same time and that 400 times per second. To do this the AD converter had to switch 64x400 times per second, it appear that the AD convert was not able to switch so fast between all the channels and measure the correct value of that channel. When the sampling frequency was increased the voltage measured was more negatively than before. And when the sampling frequency was lowered the signal was less negative. To solve this problem a new way of data acquisition was developed. To readout the data out of the DAQ card first a channel is selected and 8 samples with 400 samples per second have been measured where after a new channel was selected and another 8 samples were measured. This was done for every channel. The 8 samples were averaged to make 1 measurement point every cycle. 8 samples at 400 Hz where chosen because this would measure 1 period of the dominant 50 Hz noise. This way of measuring provided a correct voltage from the E-field sheet, only has as disadvantage that one measurement cycle along all the channels takes around three seconds. After the new measurement method was implemented into the GUI the experiments needed to be repeated.

## **The measurement results**

The results of these measurements are shown in the chapter Results. The rotation sensitivity now showed 100% at 0° and 180° and 0% at 90° and 270° as expected, the error of 0.8% in the voltage when the antenna is misplaced by  $\pm 5^\circ$  is acceptable. The error in the position has been measured to be 0.45% if the antenna is place within 1mm of the centre of the diode, which can be done in the manual calibration. When the calibration is done with help of a robot the error can become even smaller. The automation of the calibration process is also recommended to speed up the process and reduce the errors. Automation can be done with the 3d scanner that is available in the laboratory. The 3d scanner is basically a robot arm that can position an object anywhere in a 3d.

To see what influence the temperature has on the voltage, the temperature sensitivity has been measured for 3 diodes. The temperature sensitivity around room temperature is linear and relative to the measured voltage small maximal 9 mV per C. Because of this it is recommended to calibrate the sheet on the temperature where the measurement will be preformed. For the higher temperatures they do not all show a linear dependency, but to confirm this, a study has to be done to look to the temperature dependency of the diodes in the higher temperature range. To see where the noise in the signal is generated the E-field sheet was shielded with copper netting that was grounded, to make a little cage of Faraday. When

the signal was measured it showed 0V for every channel with little noise that was not bigger than a few mV, this is because the cage of Faraday was not completely closed around the connectors. Trying to produce noise in the cables or in the connector boxes an antenna was placed on them, this resulted in no extra noise in the signal. Also a 50 Hz noise source was placed near the cables and boxes like the antenna this also did not create any extra noise. So there may be concluded that the cables and connector boxes will not pick up any noise. The calibration setup is now complete and a calibration measurement has been done. This resulted in a set of calibration constants for every diode. The calibration constants can only be used for a short period of time because the diodes properties change over time. This will make a calibration before every measurement necessarily. Because the E-field sheet has only 64 diodes on a big surface area, a test was done to see if the diodes could be placed together allowing more diodes on the same surface area. This will increase the resolution with which the E-field can be measured. The results showed that placing diodes closer together doesn't influence each other. Further research need to be done to confirm that the differences do come from the plastic and not the diode, but as far as the measurements have shown now the diodes can be placed closer together. The difference that was seen was most likely due to the plastic above the first diode. This extra sheet of plastic on top of a diode will create a little pocket of air between the 2 sheets which will influence the E-field present at the diode. To confirm this a new measurement needs to be done with a plastic sheet instead of the 2<sup>nd</sup> E-field sheet. At the moment the diodes can be placed closer together, and more on a sheet. Only extra diodes will increase the time it takes to measure 1 cycle, and the connection from the E-field sheet to the PC might need to be altered because the current cables can only allow 2x36 channels. More diodes are recommended for a better image of the E-field at higher frequencies but this will require a whole new setup. To do an absolute calibration the properties of the agar phantom needs to be known therefore the heat capacity has been measured. This has been done in a Styrofoam box with walls of 6cm thick. To measure how well this box isolates, water of 55° has been placed inside and the temperature has been measured for a period of time. With this the heat lost during the heat capacity measurement could be calculated. The heat capacity of agar has been measured to be 4.04 kJ/kg·K with an error of 0.03 kJ/kg·K. this is slightly lower than water but still close to water as expected because it is almost completely consists of water. One to lack off equipment, the dielectric properties need to be measured in another laboratory. With these properties of the agar phantom a model of the calibration setup can be made in SEMCAD (a simulation software program specially created to solve EM problems) so the absolute E-field can be calculated. With the E-field known the voltage can be circumscribed to an E-field. The error in the E-field is the percentage error in the voltage + the error in conductivity. The error in the voltage is known and is 1.25% + 0.038V.



## 6 Conclusion

With the calibration setup the E-field sheet can be relatively calibrated. The error that will be seen in the voltage is 0.8% for the rotation error of 5 degrees. An error of 0.45% when the antenna is positioned within 1 mm. The temperature variation of 2 degree Celsius will give an error of 18mV. The voltage measurement error is 0.02V. This gives a total of 0.0755V when the signal is 3V (3V is what will be measured in the clinical equipment) which is an error of 2.55%. After the calibration is done it is only valid for one day at the most, because the diodes are not stable in time. At the moment the calibration can only be done by hand, this is a time consuming process of a few hours. This can be speeded up by using an automatic scanner which is available in the lab, but there was no time to automate the calibration process. For the absolute calibration only a simulation needs to be made to calculate the E-field, all the parameters for this simulation have been measured. The goal to get the E-field sheet working has almost been reached, the hardware connection between the E-field sheet and the pc has been made. Also a calibration setup has been made and all the sensitivities have been measured, the last step to make an absolute calibration has almost been completed. In the future it is recommended to do the last simulation and calculation to finish the absolute calibration. Also the calibration routine needs to be made automatically, and in the case that the E-field sheet needs to be used for temperatures above 35 degrees Celsius, the temperature sensitivity of the diodes needs to be studied.

## 7 References

- 1 [http://en.wikipedia.org/wiki/Hyperthermia\\_therapy#cite\\_note-Dollinger08-2#cite\\_note-Dollinger08-2](http://en.wikipedia.org/wiki/Hyperthermia_therapy#cite_note-Dollinger08-2#cite_note-Dollinger08-2)
- 2 Wust P, Hildebrandt B, Sreenivasa G, Rau B, Gellermann J, Riess H, Felix R, Schlag PM. Hyperthermia in combined treatment of cancer. The Lancet 2002; **3**: 487-497
- 3 [http://en.wikipedia.org/wiki/Dipole\\_antenna](http://en.wikipedia.org/wiki/Dipole_antenna)
- 4 Geetha Sreenivasa, Johanna Gellermann, Beate Rau, Jacek Nadobny, Peter Schlag, Peter Deuflhard, Roland Felix, Peter Wust. Clinical use of the hyperthermia treatment planning system HyperPlan to predict effectiveness and toxicity. International Journal of Radiation Oncology\*Biophysics 2003; 44.1: 407-419.
- 5 Kasap S.O., 2001, Optoelectronics and Photonics. Prentice-Hall Inc. 340p;
- 6 [http://www.tmi.vu.lt/legacy/pfk/funkc\\_dariniai/diod/schottky.htm](http://www.tmi.vu.lt/legacy/pfk/funkc_dariniai/diod/schottky.htm)
- 7 <http://en.wikipedia.org/wiki/Diode>
- 8 Jurriaan Bakker. Effecten van waterbolus groote en vorm op de SAR verdeling in spier equivalent weefsel. Erasmus MC 2003; 51p.

## 8 List of symbols

$\lambda$	= wavelength	[m]
$\sigma$	= electrical conductivity	[S/m]
$c$	= heat capacity	[J/kg · °C]
$C_{ph}$	= heat capacity of the phantom	[J/kg · °C]
$c_w$	= heat capacity of the water	[J/kg · °C]
$dt$	= time period = 30	[s]
$E$	= RMS electric field	[V/m]
$f$	= frequency of the wave.	[1/s]
$i$	= time period number i	[-]
$L$	= length of the dipole	[m]
$m$	= mass	kg
$m_{ph}$	= mass of the phantom	[kg]
$m_w$	= mass of the water	[kg]
$P$	= power transferred into the tissue	[W]
$Q$	= heat needed to raise one kg of material from temperature $T_0$ to $T_f$	[J]
$T_{phb}$	= Phantom begin temperature	[°C]
$T_{phf}$	= Phantom final temperature	[°C]
$T_{wb}$	= Water begin temperature	[°C]
$T_{wf}$	= Water final temperature	[°C]
$v$	= speed of the wave	[m/s]
$V$	= volume	[m <sup>3</sup> ]
$\Delta c_{ph}$	= uncertainty in $c_{ph}$	[J/kg · K]
$\Delta c_w$	= uncertainty in $c_w$	[J/kg · K]
$\Delta m_{ph}$	= uncertainty in $m_{ph}$	[kg]
$\Delta m_w$	= uncertainty in $m_w$	[kg]
$\Delta T_{phb}$	= uncertainty in $T_{phb}$	[C]
$\Delta T_{phf}$	= uncertainty in $T_{phf}$	[C]
$\Delta T_{wb}$	= uncertainty in $T_{wb}$	[C]
$\Delta T_{wf}$	= uncertainty in $T_{wf}$	[C]
$\rho$	= density	[kg/m <sup>3</sup> ]

## Appendix A: Figures

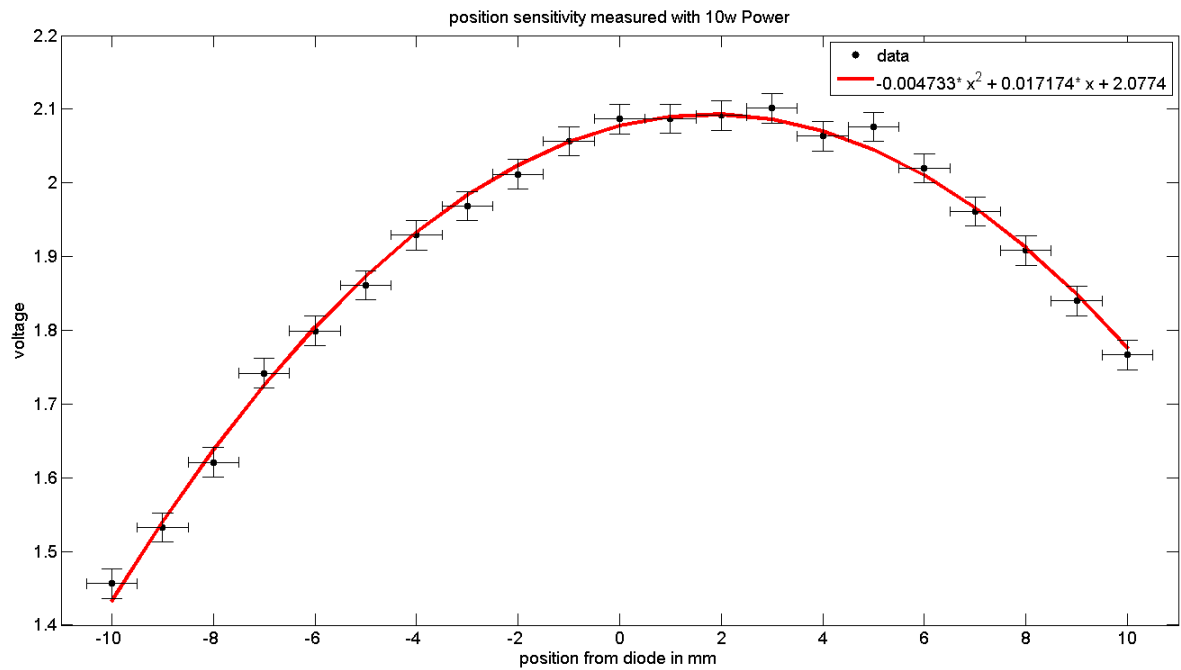


Figure A-1 – position sensitivity of diode 19.

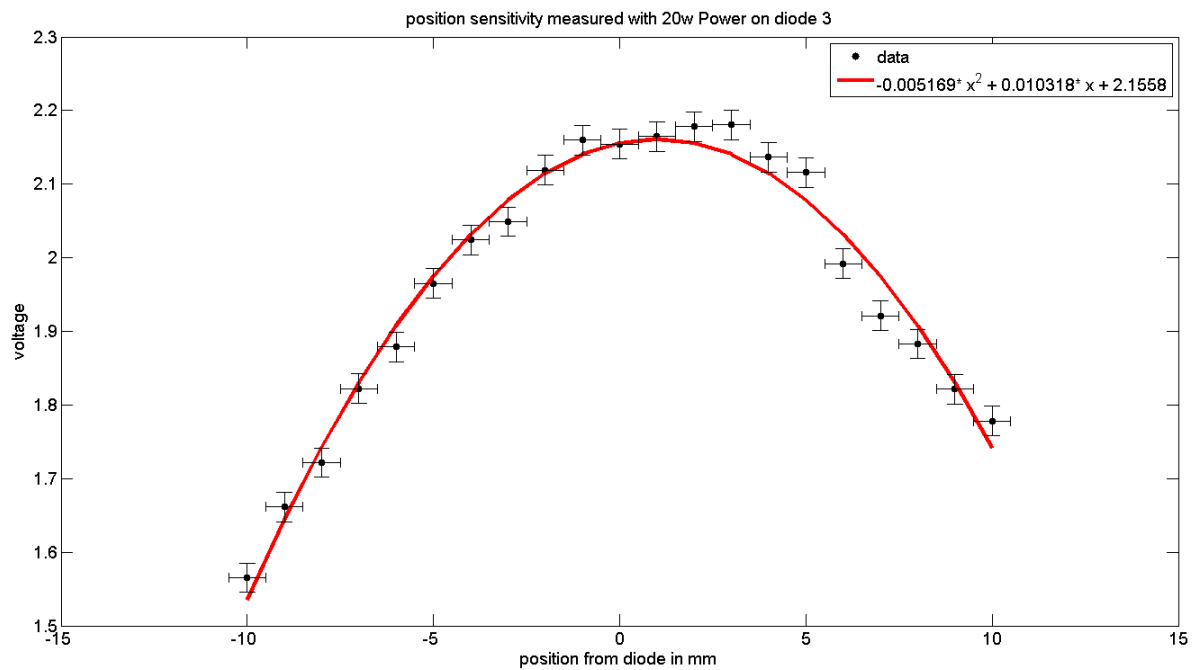


Figure A-2 – position sensitivity of diode 3.

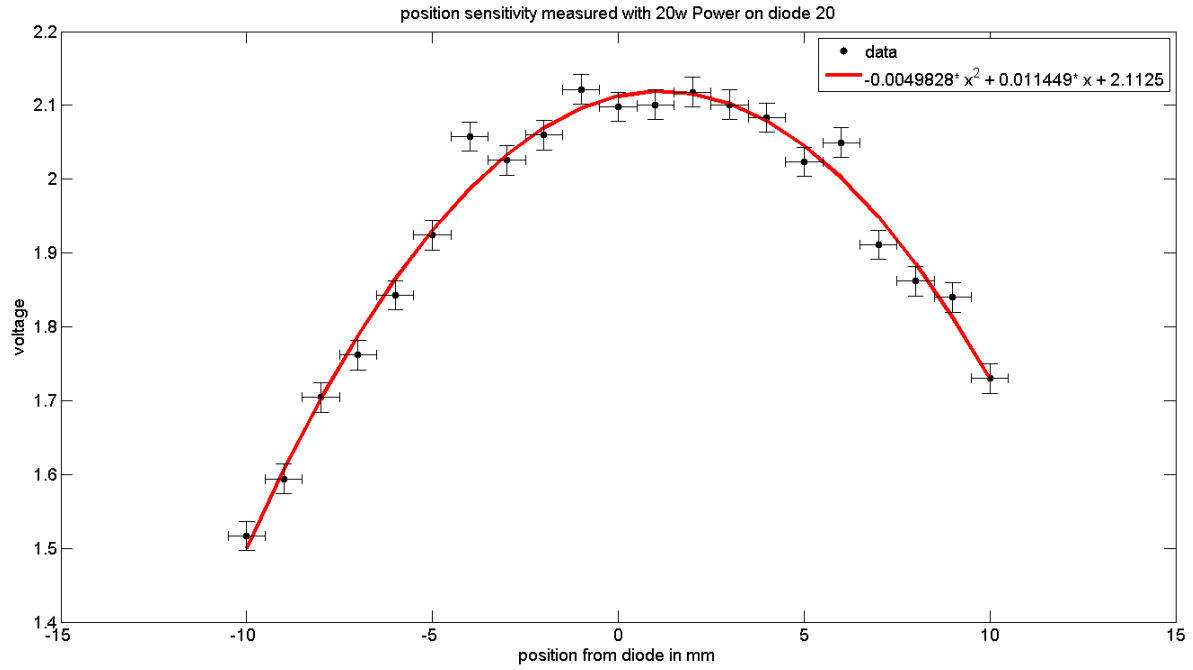


Figure A-3 – position sensitivity of diode 20.

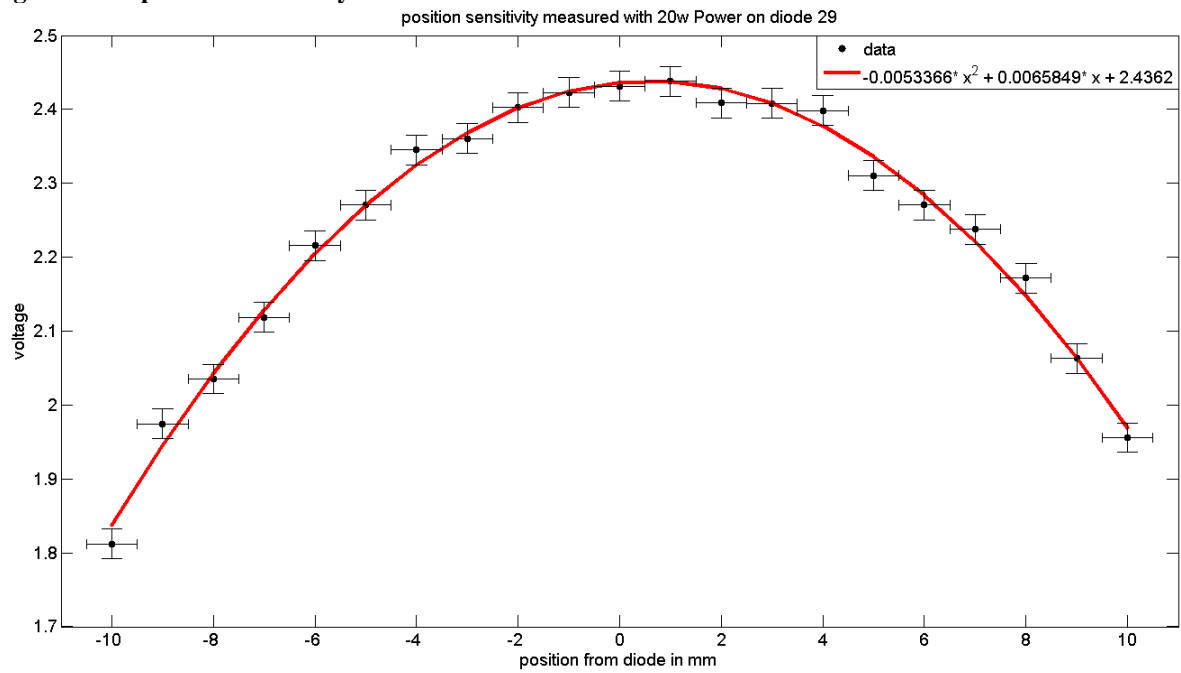


Figure A-4 – position sensitivity of diode 29.

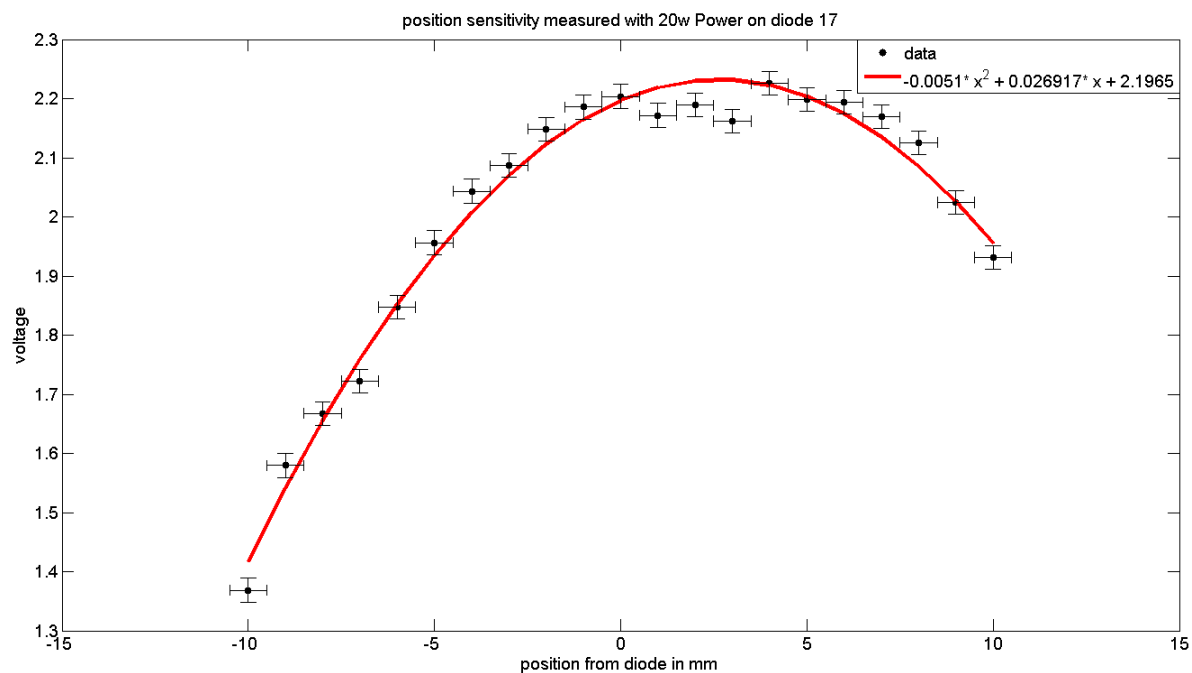


Figure A-5 – position sensitivity of diode 17.

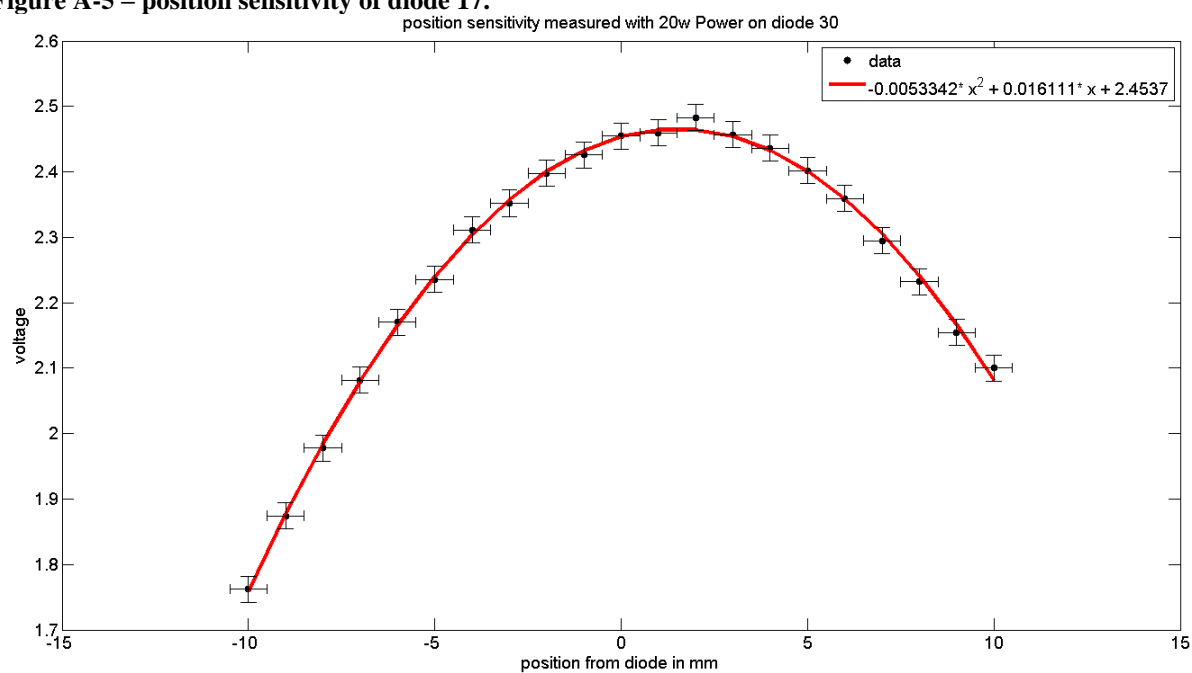


Figure A-6 – position sensitivity of diode 30.

## **Appendix B:     The initial assignment**

### **The E-field sheet, a fast way of measuring E-fields in hyperthermia applicators.**

Goal: To adapt the current E-field sheet system to current standards and to develop a calibration setup.

Background: In hyperthermia, phased array applicators are used to heat tumors in the range of 40 to 43°C. For heating quality it is very important that the E-field in the applicator is known well. Therefore, in the past, an E-field sheet was developed. This sheet enables us to measure the field in a plane inside a cylindrical phantom.

Assignment: After studying relevant literature and getting used to the equipment, the student will reconstruct the connection of the sheet to an AD-card and test the currently available sheet. At the same time, the student will get used to using Matlab and programming a GUI. Subsequently, the student will start updating the software for reading out, displaying and storing data. After finishing the sheet setup, currently available applicators will be characterized using the sheet.

Finally, a calibration setup will be designed and tested, to be able to quantify the results obtained from the sheets.

## Appendix C: The Matlab Code.

```
% GUI created for E-field measurement and visualisation.  
% created by Stefan Timmers as graduation internship at Erasmus MC Daniel  
den Hood clinic.
```

```
function GUIEsheet08
```

```
    % GUI voor het uitlezen van een E-field sheet.  
  
    clc;  
    close all;  
    clear all;  
  
    f = figure('Visible','off','Units','normalized','Position',[0,0,1,1]);  
  
    %%      constanten  
    c = clock;  
    current_file = ['data_resolution_ch3_ch35_0mm_' num2str(c(2)) '_'   
num2str(c(3)) '.mat']; % '_' num2str(c(4)) '-' num2str(c(5)) '  
    current_data = zeros(8);  
    current_location = [pwd '\Data']; %default folder where the data is  
stored and or loaded  
    speriod = '';  
    datac = [];  
    begin = 1000;  
    datafull = [];  
    T = 0;  
    timemes = '60';  
    t = 0;  
    t2 = 0;  
    data = [];  
    period = inf;  
    fsamplerate = 400;  
    samples = 8;  
    q = 0;  
    ii = 1;  
    iii = 1;  
    n = 1;  
    channel = 3;  
    channels = '';  
    ch = [1:64];  
    contfix = 1;  
    gem = 0;  
    calibrationslope_data = ones(1,90);  
    %calibrationslope_data(4) = (.8412/.7914);  
    calibration_data = zeros(90,1);  
    current_datacali = [];  
    %load([current_location '\' 'calibration_data'],'calibration_data');  
%load the calibration data.  
    cali_matrix = zeros(8);  
    dt = 1.5*length(ch)*samples/fsamplerate;  
    datam = [];  
    time = [];  
    pasttime = [];  
    dpasttime = [];  
    data_matrix = zeros(8,8);  
    rt = ones(1,4);
```



```

for i = 1:8
    r(((i-1)*4+1):i*4) = i.*rt;
end

%%      componenten
hcp = uipanel('Parent',f,'Title','',...
    'Position',[.75 .89 .25 .1]); %first panel with the start
and stop button and the elapsed time.
hstart = uicontrol('parent',hcp,'Style','pushbutton',... to start
the measurement.

'String','Start','Units','normalized','Position',[.05,.25,.25,.5],...
    'Callback',{@startbutton_Callback}); %#ok<NASGU>
hstop = uicontrol('parent',hcp,'Style','pushbutton',... to stop the
measurment in case of a continues time measurement.

'String','Stop','Units','normalized','Position',[.40,.25,.25,.5],...
    'Callback',{@stopbutton_Callback}); %#ok<NASGU>
htimer = uicontrol('parent',hcp,'Style','text',... the elapsed
time of the measurement.

'string',0,'Units','normalized','Position',[.7,.1,.25,.5]);
hbg = uibuttongroup('Parent',f,'Title','Timesettings',... panel to
choose between continues time and fix time measurement.
    'Position',[.75 .79 .15 .1]);
hcontmes = uicontrol('parent',hbg,'Style','radiobutton',...
continues time measurement
    'Units','normalized','String','Continues
measurement','Position',[.1,.7,.9,.3],...
    'Callback',{@contmesbutton_Callback});
hfixedtime = uicontrol('parent',hbg,'Style','radiobutton',... fix
time measurement
    'Units','normalized','String','Fixed time
measurement','Position',[.1,.4,.9,.3],...
    'Callback',{@fixedtimebutton_Callback});
hftime = uicontrol('parent',hbg,'Style','edit',... to set the fix
time in seconds.

'string',timemes,'Units','normalized','Position',[.2,.1,.6,.3],...
    'Callback',{@ftimetbutton_Callback});
hdp = uipanel('Parent',f,'Title','Data',... panel for saving and
loading of the data.
    'Position',[.75 .59 .25 .2]);
hsavedatat = uicontrol('parent',hdp,'Style','text',... text in the
GUI
    'Units','normalized',...
    'string','Save data to:','Position',[.025 .6 .2
.3]); %#ok<NASGU>
hsavedatato = uicontrol('parent',hdp,'Style','edit',... box to
enter the file name in.
    'Units','normalized',...
    'string',current_file,'Position',[.25 .6 .45 .3],...
    'Callback',{@currentfile_callback});
hchangeopath = uicontrol('parent',hdp,'Style','pushbutton',...
button to select the path where to store or load the data
    'Units','normalized','String','file...',...
    'Position',[.75 .5 .2 .3],...
    'Callback',{@changeopathbutton_callback}); %#ok<NASGU>
hsave = uicontrol('parent',hdp,'Style','pushbutton',... saving the
data to a predefined path
    'Units','normalized',...

```

```

        'String','Save','Position',[.025 .2 .2 .3],...
        'Callback',{@savebutton_callback});%#ok<NASGU>
    hload = uicontrol('parent',hdp,'Style','pushbutton',... loading the
data to a predefined path
        'Units','normalized',...
        'String','Load','Position',[0.25 .2 .2 .3],...
        'Callback',{@loadbutton_callback});%#ok<NASGU>
    hcleardata = uicontrol('parent',hdp,'Style','pushbutton',... clear
the current data
        'Units','normalized',...
        'String','clear data','Position',[0.475 .2 .2 .3],...
        'Callback',{@cleardatabutton_Callback});%#ok<NASGU>
    hcap = uipanel('Parent',f,'Title','Calibration data',... pannel for
calibration settings
        'Position',[.75 .49 .25 .1]);
    hshowtable = uicontrol('parent',hcap,'Style','pushbutton',... to
show the current calibration table
        'String','Show
table','Units','normalized','Position',[.1,.25,.25,.5],...
        'Callback',{@showtablebutton_Callback});%#ok<NASGU>
    hnewtable = uicontrol('parent',hcap,'Style','pushbutton',... a new
calibration table will be made based on the last measurement.
        'String','new
table','Units','normalized','Position',[.4,.25,.25,.5],...
        'Callback',{@newtablebutton_Callback});%#ok<NASGU>
    hloadtable = uicontrol('parent',hcap,'Style','pushbutton',... to
load a calibration table from disk.
        'String','load
table','Units','normalized','Position',[.7,.25,.25,.5],...
        'Callback',{@showtablebutton_Callback});%#ok<NASGU>
    hchs = uipanel('Parent',f,'Title','Chanel selection',... to select the
channel that is shown in the history graphs
        'Position',[.75 .19 .25 .1]);
    hchannelselect =
uicontrol('parent',hchs,'Style','popupmenu','Value',(channel),... dropdown
menu to select the desired channel

    'String',num2str(ch'),...%{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,
20,21,22,23,24,25,26,27,28,29,30,31,32,...

...%33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56
,57,58,59,60},...

        'Units','normalized','Position',[.1,.25,.25,.5],...
        'Callback',{@channelselectbutton_Callback});
    hgemtext = uicontrol('parent',hchs,'Style','text',... text in the
GUI
        'Units','normalized',...
        'string','gemiddelde :','Position',[.4 .25 .25
.5]);%#ok<NASGU>
    hgem = uicontrol('parent',hchs,'Style','text',... the avarage value
of the channel.
        'Units','normalized',...
        'string',gem,'Position',[.7 .25 .25 .5]);

%%      figuren
%      ha =
axes('Parent',f,'Units','pixels','Units','normalized','Position',[.5,.55,.2
4,.44]); %the axis are created here.
    hb =
axes('Parent',f,'Units','pixels','Units','normalized','Position',[.5,.05,.2
4,.44]);

```

```

        hc =
axes('Parent',f,'Units','pixels','Units','normalized','Position',[.05,.55,.
67,.44]);
        hd =
axes('Parent',f,'Units','pixels','Units','normalized','Position',[.05,.05,.
40,.44]);
        th =
uitable(f,'Data',current_data,'Units','normalized','Position',[.75,.29,.25,
.19],'ColumnWidth',{40});

%%      opstarten GUI

        set(f,'Visible','on');

%%      DAQ kaart configuratie

        AI.aiobj = analoginput('mwadlink');
        AI.aiobj.InputType = 'Ref SE';
%      addchannel(AI.aiobj,[20]);
        set(AI.aiobj, 'SampleRate', fsamplerate); % sample rate might be
changeble in a new version of the GUI.
        set(AI.aiobj, 'TriggerRepeat', 0);
        set(AI.aiobj, 'SamplesPerTrigger', samples);
        set(AI.aiobj, 'LoggingMode','Memory');
%      LogFileName = [pwd '\ ' 'temp.daq']; % to temperally store the
data
%      set(AI.aiobj, 'LogFileName',LogFileName);
%      set(AI.aiobj, 'LogToDiskMode','Index');

%%      Callback functies

        function startbutton_Callback(source,eventdata) %#ok<INUSD>
            clear ('T','t','data');
            if (get(hfixedtime,'Value') == get(hfixedtime,'Max'))% if fixed
time is selected this will run
                contfix = 2;
                ftimetbutton_Callback
            elseif (get(hcontmes,'Value') == get(hcontmes,'Max'))% if continues
time is selected this will run
                contfix = 1;
                period = inf;
            end
            tic
            T = timer('TimerFcn',@timer_callback, 'Period',
0.1*samples/fsamplerate, 'ExecutionMode','fixedRate'); %timer function used
to display the elapsed time and refresh rate of the graphs.
            ii = 1;
            iii = 1;
            t = 1;
            n = 1;
            data = [];
            datam = [];
            time = [];
            pasttime = [];
            addchannel(AI.aiobj,[ch(n)]);
            start(AI.aiobj);
            start(T);
        end

```

```

function stopbutton_Callback(source,eventdata) %#ok<INUSD>
    t = ii;
    iii = 0;
    stop(T);

end

function timer_callback(source,eventdata)%#ok<INUSD>
    if AI.aiobj.samplesavailable >7
        try
            dataTemp = peekdata(AI.aiobj,samples);
            data(samples*(ii-1)+1:samples*ii,ch(n))=dataTemp(1:end,1);
            datam(ii,ch(n))=mean(data(samples*(ii-
1)+1:samples*ii,ch(n)));
        catch ME
            disp(['Error ch ',num2str(ch(n)),' : ',ME.message])
        end
        if n < 17
            data_matrix(r(n),(4*r(n))+1-n) = datam(ii,ch(n));
        elseif n > 16 && n < 33
            data_matrix(r(n),(n-4*r(n))+4) = datam(ii,ch(n));
        elseif n > 32 && n < 49
            data_matrix(r(n-32),(n-4*r(n-32))-24) = datam(ii,ch(n));
        elseif n > 48
            data_matrix(r(n-32),(4*r(n-32)+37-n)) = datam(ii,ch(n));
        end
        delete(AI.aiobj.channel(1));
        time(ii,ch(n)) = toc;
        if n == length(ch)
            n = 1;
            pasttime(ii) = toc;
            if ii > 1
                dpasttime = pasttime(ii) -pasttime(ii-1);
            else
                dpasttime = pasttime;
            end
            disp(['time past is : ',num2str(pasttime(ii)),' and dt
:',num2str(dpasttime)])
            plot(hc,time(:,channel),datam(:,channel))
            [X,Y] = meshgrid(0:7, 7:-1:0);
            surf('parent',hb,X,Y,data_matrix);
            htimer = uicontrol('parent',hcp,'Style','text',...
                'string',ii
                , 'Units','normalized','Position',[.7,.1,.25,.5]); %#ok<SETNU>
            t = ii;
            if period < pasttime(ii)
                stop(T);
            end
            ii = ii + 1;
        else
            n = n + 1;
        end
        addchannel(AI.aiobj,[ch(n)]);
        start(AI.aiobj);

    end

end

```

```

function currentfile_callback(source,eventdata)%#ok<INUSD>
    current_file = get(hsavedatato,'string'); %reading out the file
name where to save to.
end

function changepathbutton_callback(source,eventdata)%#ok<INUSD>
    current_location = uigetdir('C:\Documents and Settings\835005\My
Documents\E-Sheet project\MATLAB'); % setting the path to save the data to
end

function savebutton_callback(source,eventdata)%#ok<INUSD>
    save([current_location '\\'
current_file'],'pasttime','datam','data','dpasttime','time','ch','samples','
fsamplerate')%'data','period','datafull'); %saving the data to the
predetermend folder and file, or uses the default settings.
end

function ftimetbutton_Callback(source,eventdata)%#ok<INUSD>
    speriod = get(hftime,'string'); % to read out the fix period time
    period = str2num(speriod); %#ok<ST2NM> % convert the string to
nummeriek value.
end

function loadbutton_callback(source,eventdata)%#ok<INUSD>
    load([current_location '\\' current_file]); %load data into the GUI

    showdata
end

function cleardatabutton_Callback(source,eventdata)%#ok<INUSD>
    current_data = zeros(8); %clear the current data from memory
    data = [];
    showdata
end

function showtablebutton_Callback(source,eventdata)%#ok<INUSD> % this
will open a new figure with the calibration table in it
    ft =
figure('Visible','off','Units','normalized','Position',[.25,.25,.5,.5]);
    for i = 1:4 % to set the calibration data into the calibration
matrix
        for ii = 1:4 % the configuration of the first 4 rows of diods
are different from the last 4 rows. this will set the correct diodes on the
correct positions
            cali_matrix(ii,i) = calibration_data(-i+2+ii*4);
        end
        for ii = 5:8
            cali_matrix(ii,i) = calibration_data(i-3+ii*4) ;
        end
    end
    cali_matrix(8,4) = calibration_data(48); % the last diode is on
channel 48 instead of 32 because channel 32 is unavailible on the first
cable connection.

uitable(ft,'Data',cali_matrix,'Units','normalized','Position',[0,0,1,1],'Co
lumnWidth',{40});
    set(ft,'Visible','on');
end

```

```

function channelselectbutton_Callback(source,eventdata)%#ok<INUSD> %
this will make the desired channel visible in the graphs.
    channels = get(hchannelselect,'Value');
    channel = ch(channels);
    if t == 0;
    else
        plot(hc,time(:,channel),datam(:,channel));
        gem = mean(datam(:,channel));
        hgem = uicontrol('parent',hchs,'Style','text',...
            'Units','normalized',...
            'string',gem,'Position',[.7 .25 .25 .5]); %#ok<SETNU>
    end
end

function newtablebutton_Callback(source,eventdata)%#ok<INUSD> % will
set the new calibration table into the default calibration table.
    calibration_data = current_datacali;
    save([current_location '\ 'calibration_data'],'calibration_data');
end
%%      other functions

function showdata(source,eventdata)%#ok<INUSD> to make the data visible
    q11 = zeros(fsamplerate*period-20,1); % software filter data
    q = data(1:(fsamplerate*period),channel);
    for i = 21:(fsamplerate*period-20) % the data gets averaged over
the last 21 samples.
        q11(i) = (q(i-20)+q(i-19)+q(i-18)+q(i-17)+q(i-16)+q(i-15)...
            +q(i-14)+q(i-13)+q(i-12)+q(i-11)+q(i-10)+q(i-9)+q(i-8)+q(i-
7)+q(i-6)+q(i-5)...
            +q(i-4)+q(i-3)+q(i-2)+q(i-1)+q(i-0))/21;
    end
    x = 1:(fsamplerate*period);
    x11 = 1:(fsamplerate*period-20);
    plot(hc,x,(q-
calibration_data(channel))*calibrationslope_data(channel)); %plotting the
data in graph c
    plot(hd,x11,(q11-
calibration_data(channel))*calibrationslope_data(channel)); %plotting the
data in graph d
    gem = (mean(data(begin:fsamplerate*period,channel))-
calibration_data(channel))*calibrationslope_data(channel); % calculating
the avarage value of the channel, the avaraging will start after 'begin'
amout of time to take out the starting up of the DAQ card.
    hgem = uicontrol('parent',hchs,'Style','text',...
        'Units','normalized',...
        'string',gem,'Position',[.7 .25 .25 .5]); %#ok<SETNU>
%      showsurfandcontour
    th =
uitable(f,'Data',current_data,'Units','normalized','Position',[.75,.29,.25,
.19],'ColumnWidth',{40}); %#ok<SETNU>
end

%      function calibration(source,eventdata)%#ok<INUSD> % to correct the
data with a calibration offset
%      for i = 1:90
%          data((1:fsample*period),i) = data((1:fsample*period),i) -
calibration_data(i);
%      end
%      end

```

```

function matrixdata(source,eventdata)%#ok<INUSD> % this will calculate
the mean of every channel and put it in a matrix for easy plotting of the
E-field distribution.
    for i = 1:4
        for ii = 1:4
            current_data(ii,i) = (mean(data(begin:fsamplerate*period,(-
i+2+ii*4)))- calibration_data(-i+2+ii*4))*calibrationslope_data(-i+2+ii*4)
;
            end
        end
    end
    for i = 1:4
        for ii = 5:8
            current_data(ii,i) =
(mean(data(begin:fsamplerate*period,(i-3+ii*4)))- calibration_data(i-
3+ii*4))*calibrationslope_data(i-3+ii*4) ;
            end
        end
    end
    for i = 4
        for ii = 8
            current_data(ii,i) =
(mean(data(begin:fsamplerate*period,(48)))-
calibration_data(48))*calibrationslope_data(48);
            end
        end
    end

function showsurfandcontour(source,eventdata)%#ok<INUSD> %plotting the
surface and contour plots in graph a and b
[X,Y] = meshgrid(0:7, 7:-1:0);
surf('parent',ha,X,Y,current_data);
rotate3d on
contour('parent',hb,X,Y,current_data,7,'ShowText','on');
end

function avarage(source,eventdata)%#ok
gem = (mean(data(begin:fsamplerate*period,channel))-
calibration_data(channel))*calibrationslope_data(channel);
hgem = uicontrol('parent',hchs,'Style','text',...
'Units','normalized',...
'string',gem,'Position',[.7 .25 .25 .5]); %#ok<SETNU>
end
end

```