ACCURATE SIMULATION OF HEATING PROPERTIES OF METTLER 27 MHZ DIATHERMY SYSTEM USING FINITE ELEMENT METHODS

Sateesh Kumar Nagulapally
B.Tech, Jawaharlal Nehru Technological University, India, 2007

Ravi Kiran Chappa
B.Tech, Jawaharlal Nehru Technological University, India, 2007

PROJECT

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

in

ELECTRICAL AND ELECTRONIC ENGINEERING

at

CALIFORNIA STATE UNIVERSITY, SACRAMENTO

SUMMER 2010
ACCURATE SIMULATION OF HEATING PROPERTIES OF METTLER 27 MHZ DIATHERMY SYSTEM USING FINITE ELEMENT METHODS

A Project

by

Sateesh Kumar Nagulapally

Ravi Kiran Chappa

Approved by:

__________________________________, Committee Chair
Suresh Vadhva, Ph.D.

__________________________________, Second Reader
Russ Tatro, M.S.

___________________________________
Date
Students: Sateesh Kumar Nagulapally
Ravi Kiran Chappa

I certify that these students have met the requirements for format contained in the University format manual, and that this Project is suitable for shelving in the Library and credit is to be awarded to this Project.

____________________________, Graduate Coordinator
Suresh Vadhva, Ph.D. Date

Department of Electrical and Electronic Engineering
Abstract

of

ACCURATE SIMULATION OF HEATING PROPERTIES OF METTLER 27 MHZ DIATHERMY SYSTEM USING FINITE ELEMENT METHODS

by

Sateesh Kumar Nagulapally

Ravi Kiran Chappa

This project will focus on the practical simulation of the focusing properties of the 27 MHz Mettler diathermy system that is potentially used as a heating tool in the treatment of tumors by hyperthermia. The simulation is carried out using the advanced 4NEC2 Finite Element Method software. The goal is the accurately model the focusing properties of the diathermy system with a view to improve the efficiency of the system by possibly using conductive reflectors to enhance the focusing property. In this project, it was possible to accurately model the diathermy system, and generate the 3-dimensional electric field patterns of the system. These results will be compared with experimental results that are being generated presently as part of another student project.

Suresh Vadhva, Ph.D.

, Committee Chair

Date
ACKNOWLEDGEMENTS

Any student’s success is not solely his hard work and intelligence and we must say we are no exception. Every step we took, every risk we took, every experiment we did, every result we achieved is all because of Dr. Kumar. We take this opportunity to thank him for being with us all the time and guide us to reach the result. It would not be exaggerating to say that, without Dr. Kumar, this project would never have been so successful. It was his excellent coursework which gave us a thought to work on this project and we sincerely thank him for the support and his continuous supervision.

We would also like to thank Professor Russ Tatro, who had so much of faith in us and helped us in making this project better. It would have been impossible without his excellent guidance to complete this project with such perfection. We would like to thank him for being a part of the review committee and extending his help.

And, it would be incomplete if we do not acknowledge the support and love of our family and friends who were supporting us from a long time. Their support in terms of Academic knowledge and personal strength is invaluable to us.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>v</td>
</tr>
<tr>
<td>List of Tables</td>
<td>viii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>ix</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. HYPERThERMIA: MICROWAVES AS CANCER TREATMENT</td>
<td>3</td>
</tr>
<tr>
<td>2.1 Mechanism of Hyperthermia Treatment</td>
<td>3</td>
</tr>
<tr>
<td>2.1.1 Mechanisms for Hyperthermia Treatment</td>
<td>5</td>
</tr>
<tr>
<td>2.2 Application and Methods in Hyperthermia Treatment</td>
<td>8</td>
</tr>
<tr>
<td>2.2.1 Local Hyperthermia</td>
<td>8</td>
</tr>
<tr>
<td>a. External Approach</td>
<td>9</td>
</tr>
<tr>
<td>b. Intra-luminal or Endocavitary</td>
<td>9</td>
</tr>
<tr>
<td>c. Interstitial</td>
<td>9</td>
</tr>
<tr>
<td>2.2.2 Regional Hyperthermia</td>
<td>9</td>
</tr>
<tr>
<td>a. Deep Tissue Approach</td>
<td>10</td>
</tr>
<tr>
<td>b. Regional Perfusion Technique</td>
<td>10</td>
</tr>
<tr>
<td>c. Continuous Hyperthermic Peritoneal Perfusion(CHPP) Perfusion Technique</td>
<td>10</td>
</tr>
<tr>
<td>2.2.3 Whole-body Hyperthermia</td>
<td>11</td>
</tr>
<tr>
<td>2.3 Risks in Hyperthermia</td>
<td>11</td>
</tr>
<tr>
<td>2.4 Benefits of Hyperthermia</td>
<td>13</td>
</tr>
<tr>
<td>3. TECHNICAL DETAILS OF METTLER AUTOThERM EQUIPMENT</td>
<td>15</td>
</tr>
<tr>
<td>3.1 Introduction to Mettler Autotherm Equipment</td>
<td>15</td>
</tr>
<tr>
<td>3.1.1 Features Mettler Autotherm Equipment</td>
<td>15</td>
</tr>
<tr>
<td>3.2 Indications for Medical Diathermy</td>
<td>17</td>
</tr>
<tr>
<td>3.3 Mettler Autotherm Equipment</td>
<td>17</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Page

1. Table 3.3 Selecting the Best Therapy .......................................................... 21
2. Table 3.7 Electromagnetic Heating Comparison ........................................... 24
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Figure 2.1a: Typical Hyperthermia System</td>
<td>4</td>
</tr>
<tr>
<td>2.</td>
<td>Figure 2.1b: Hyperthermia Ranges</td>
<td>5</td>
</tr>
<tr>
<td>3.</td>
<td>Figure 2.1c: Radiation Hyperthermia</td>
<td>5</td>
</tr>
<tr>
<td>4.</td>
<td>Figure 2.1d: Denaturation of a Normal Protein</td>
<td>6</td>
</tr>
<tr>
<td>5.</td>
<td>Figure 2.1e: Microwave Hyperthermia System</td>
<td>7</td>
</tr>
<tr>
<td>6.</td>
<td>Figure 2.2.1: Local Hyperthermia System</td>
<td>8</td>
</tr>
<tr>
<td>7.</td>
<td>Figure 2.3: Hyperthermia at Different Temperatures</td>
<td>12</td>
</tr>
<tr>
<td>8.</td>
<td>Figure 3.1.1: Mettler Autotherm 300 Equipment</td>
<td>16</td>
</tr>
<tr>
<td>9.</td>
<td>Figure 3.3.1: Timer Switch and Intensity Control Knob</td>
<td>18</td>
</tr>
<tr>
<td>10.</td>
<td>Figure 3.3.2: Power Meter on Mettler diathermy unit</td>
<td>18</td>
</tr>
<tr>
<td>11.</td>
<td>Figure 4.4: Main Window</td>
<td>28</td>
</tr>
<tr>
<td>12.</td>
<td>Figure 4.4.1a: Geometry Builder</td>
<td>30</td>
</tr>
<tr>
<td>13.</td>
<td>Figure 4.4.1b: Generate Window</td>
<td>31</td>
</tr>
<tr>
<td>14.</td>
<td>Figure 4.4.1c: Generate and Pattern Windows</td>
<td>32</td>
</tr>
<tr>
<td>15.</td>
<td>Figure 5.1a: Photograph of Mettler Diathermy System</td>
<td>34</td>
</tr>
<tr>
<td>16.</td>
<td>Figure 5.1b: Geometry Builder</td>
<td>35</td>
</tr>
<tr>
<td>17.</td>
<td>Figure 5.1c: Wire-Grid Model of Diathermy Applicator</td>
<td>36</td>
</tr>
<tr>
<td>18.</td>
<td>Figure 5.2: Geometry Table Values</td>
<td>37</td>
</tr>
<tr>
<td>19.</td>
<td>Figure 5.3.1a: 4NEC2 Edit Window</td>
<td>38</td>
</tr>
<tr>
<td>20.</td>
<td>Figure 5.3.1b: Near Field Pattern at Half Power</td>
<td>39</td>
</tr>
<tr>
<td>21.</td>
<td>Figure 5.3.1c: Generate Window for Near Field Pattern at Peak Value</td>
<td>40</td>
</tr>
<tr>
<td>22.</td>
<td>Figure 5.3.1d: Near Field Pattern at Peak Value</td>
<td>41</td>
</tr>
<tr>
<td>23.</td>
<td>Figure 5.3.2a: 4NEC2 Edit Window</td>
<td>42</td>
</tr>
<tr>
<td>24.</td>
<td>Figure 5.3.2b: Near Field Pattern at Normal Power</td>
<td>43</td>
</tr>
<tr>
<td>25.</td>
<td>Figure 5.3.2c: Generate Window for Near Field Pattern at Peak Value</td>
<td>44</td>
</tr>
</tbody>
</table>
26. Figure 5.3.2d: Near Field Pattern at Peak Value ........................................... 44
27. Figure 5.3.3a: 4NEC2 Edit Window .............................................................. 45
28. Figure 5.3.3b: Near Field Pattern at Full Power .......................................... 46
29. Figure 5.3.3c: Generate Window for Near Field Pattern at Peak Value ....... 47
30. Figure 5.3.3d: Near Field Pattern at Peak Value .......................................... 47
Chapter 1

INTRODUCTION

Microwaves and radio-frequency (RF) find a number of applications not only in far-range communications and radar, but also in near-range devices like the commonly used microwave oven at home, and medical applications such as hyperthermia or heat treatment of tumors. There are several RF and microwave frequency bands which are considered as “windows” into biological tissue: 27 MHz, 900 MHz and 2450 MHz. This frequency range in the 27 MHz frequency falls in the ISM (Industrial Scientific and Medical) band, which includes applications such as hyperthermia or heat treatment of cancer in humans and animals [1]. Unlike the past times, hyperthermia is not usually used as a stand-alone treatment, but is often used as an adjuvant to conventional cancer fighting tools such as radiation and chemotherapy [1-4]. The reason for this transition in modality was due to the fact that when hyperthermia was used as an independent form of cancer treatment; the tumors seemed to recede, however recurred soon after the treatment. It is more efficient as an adjuvant treatment, with the heat dilating the blood vessels to get more oxygen into the tumor, and thereby making the latter more responsive to following radiation or chemotherapy.

In this project, our goal is to focus on the accurate simulation of the 27 MHz Mettler diathermy system so that these can predict measured data, and help to
characterize the equipment for practical use. Specifically, the aim of the project is to generate the 3-dimensional electric field distribution of the diathermy source, and study the possible control of focus points within the near-field area. There is a simultaneous student project currently underway which is focused on the measurement of the electric field in the volumetric space around the Mettler system. The latter project will compare the simulation results generated in our current project with the measured results. Accurate characterization of the electric field distribution is very essential for ultimately obtaining precise focusing of the energy on the tumor volume, with minimal energy leakage to neighboring healthy tissue.

The first chapter of this report is an introduction to the main goal of the project which is the accurate characterization of the Mettler diathermy system, with a view to accurate tumor targeting in the future. Chapter II gives background knowledge and research on hyperthermia for the treatment of cancer. We will also be discussing the benefits and applications of microwave hypothermia. Chapter III looks at the details of Mettler Diathermy equipment. Chapter IV explains about the working of 4NEC2 simulation software and its details. Finally Chapter V details the simulated results that were obtained using the 4NEC2 simulation software, followed by the conclusions.
Chapter 2

HYPERTHERMIA: MICROWAVES AS CANCER TREATMENT

2.1 Mechanism of Hyperthermia Treatment

Hyperthermia therapy (or thermotherapy) is a procedure where the tumor volume in the human or animal body is raised to a maximum temperature of 42 degrees C or 108 degrees F. This temperature must be maintained for a period of time for about 30 min so that the body tissue such as a tumor is weakened or made more susceptible to following radiation or chemotherapy. A typical hyperthermia system is shown in figure 2.1a below. If too much heat misses the tumor target, the skin or other healthy tissues could be burned. At the same time, causing minimal injury to normal tissues by not allowing rise in temperature around surrounding healthy tissues thereby avoiding damaging levels. Figure 2.1b shows different ranges of hyperthermia [1, 2]. The success of the treatment lies in the capability of confining heat to the tumor volume. Research has shown that that by killing cancer cells and damaging proteins and structures within the cells, hyperthermia may shrink tumors, or make the tumors more responsive to following radiation or chemotherapy [2].
Hyperthermia may make some cancer cells more sensitive to radiation or harm other cancer cells that radiation cannot damage. When hyperthermia and radiation therapy are combined, they are often given within an hour of each other. Hyperthermia temperature levels and a typical equipment schematic are shown in figures 2.1b and 2.1c respectively. Hyperthermia can also enhance the effects of certain anticancer drugs. Numerous clinical trials have studied hyperthermia in combination with radiation therapy, biological/immunotherapy and/or chemotherapy [3].
2.1.1 Mechanisms for Hyperthermia Treatment

A tumor is a solid lesion formed by an abnormal growth of cells (termed neoplastic) which looks like a swelling [4]. Hyperthermia may kill or weaken tumor cells by intense heating which will cause denaturation (a process in which proteins lose their tertiary structure and secondary structure by application of some external stress or compound, such as a strong acid or base, a concentrated inorganic salt, an organic solvent, or heat). Figure 2.1d shows the denaturation of a normal protein. It increases blood flow to the warmed area, perhaps doubling perfusion in tumors, while increasing perfusion in normal tissue by ten times or even more. This enhances the delivery of medications [6]. Hyperthermia also increases oxygen delivery to the area, which may make radiation more likely to damage and kill
cells, as well as preventing cells from repairing the damage induced during the radiation session [7].

![Figure 2.1d: Denaturation of a Normal Protein [5]](image)

Additionally, to explain the hyperthermia mechanism, Microwave energy is very effective in heating cancerous tumors, because tumors typically have high-water content. Such tissue heats very rapidly when exposed to high-power microwaves. Furthermore, microwaves can be delivered to tissue by special-purpose antennas that are located adjacent to the patient’s body. A clinical adaptive microwave hyperthermia system for treating cancer deep in the body is show in figure 2.1e below [8].
Depending on the tumor size and location in the body, one or more microwave antennas can be used to treat the tumor. When a microwave thermotherapy antenna is turned “on” body tissues with high-water content that are irradiated with significant amounts of microwave energy are heated. As the microwave energy (oscillating about a billion times a second) passes through the tissue, water molecules are vibrated. Frictional forces between the water molecules in the tissue result in the heating of the tissue. By concentrating the microwave energy, it is possible to selectively heat tumors and protect healthy tissues. This process of concentrating or focusing microwaves at a tumor is somewhat analogous to a group of orchestral instruments being played in synchronization when played together, a bunch of individual instruments make a big sound. In the same way, synchronized radiating antennas produce concentrated microwaves [8].
2.2 Application and Methods in Hyperthermia Treatment

Several methods of hyperthermia are currently under study: local, regional, and whole-body hyperthermia.

2.2.1 Local Hyperthermia:

Heat is applied to a small area, such as a tumor, usually using an applicator such as the Mettler diathermy system that is being studied in this project. The cells affected with cancer are heated to a maximum temperature of 108° F by using heating elements such as microwave, antennas, heating rods, ultra sound. Local hyperthermia system is show in figure 2.2.1 below.
Depending on the tumor location, there are several approaches to local hyperthermia such as external, intra-luminal and interstitial [9].

a. **External Approach:** Used to treat tumors that are in or just below the skin. External applicators are positioned around or near the appropriate region, and energy is focused on the tumor to raise its temperature.

b. **Intra-luminal or Endocavitary:** Used to treat tumors within or near body cavities, such as the esophagus or rectum. Probes are placed inside the cavity and inserted into the tumor to deliver energy and heat the area directly.

c. **Interstitial:** Used to treat tumors deep within the body, such as brain tumors. This technique allows the tumor to be heated to higher temperatures than external techniques. Under anesthesia, probes or needles are inserted into the tumor. Imaging techniques, such as ultrasound, may be used to make sure the probe is properly positioned within the tumor. The heat source is then inserted into the probe. Radiofrequency ablation (RFA) is a type of interstitial hyperthermia that to heat and kill cancer cells.

### 2.2.2 Regional Hyperthermia:

Heat is applied to a larger part of the body, such as an entire organ or limb. Usually, the goal is to weaken cancer cells so that they are more likely to be killed by radiation and chemotherapeutic medications. This may use the same techniques as local hyperthermia treatment, or it may rely on blood perfusion in which the patient's blood is
removed from the body, heated up, and returned to blood vessels that lead directly through the desired body part. Various approaches used to heat large areas of tissue, such as a body cavity, organ, or limb are deep tissue, regional perfusion and continuous hyperthermic peritoneal perfusion (CHPP) [10].

a. **Deep Tissue Approach:**

It may be used to treat cancers within the body, such as cervical or bladder cancer. External applicators are positioned around the body cavity or organ to be treated, and microwave or radiofrequency energy is focused on the area to raise its temperature.

b. **Regional Perfusion Technique:**

It can be used to treat cancers in the arms and legs, such as melanoma, or cancer in some organs, such as the liver or lung. In this procedure, some of the patient’s blood is removed, heated, and then pumped back into the limb or organ. Anticancer drugs are commonly given during this treatment.

c. **Continuous Hyperthermic Peritoneal Perfusion (CHPP) Technique:**

It is used to treat cancers within the peritoneal cavity (the space within the abdomen that contains the intestines, stomach, and liver), including primary peritoneal mesothelioma (a cancer of the lining of the abdominal cavity) and stomach cancer. During surgery, heated anticancer drugs flow from a warming
device through the peritoneal cavity. The peritoneal cavity temperature reaches 106–108°F.

2.2.3 Whole-body Hyperthermia:

Heat is applied to the entire body to temperatures of about 107–108°F. It is typically used to treat metastatic cancer (cancer that spreads in many parts of the body). Techniques include infrared hyperthermia domes which include the whole body apart from the head, putting the patient in a very hot room, or wrapping the patient in hot, wet blankets.

2.3 Risks in Hyperthermia

Hyperthermia side effects for the external methods include pain, unpleasant sensations and burns in a small percentage of patients. In the case of the internal pyrogens (a substance inducing fever), which are sometimes bacterial toxins, the situation is more complicated, as bacterial toxins can induce serious, even fatal reactions in humans, depending on dosage [2]. Ultrasound hyperthermia in areas where the tumor is over a bone will cause bone pain. Whole body hyperthermia is a more radical form of heat treatment, and has not been approved in the FDA as yet, since it has increased potential for side effects due to large-volume heating.
Figure 2.3: Hyperthermia at Different Temperatures [11]

Extracorporeal systemic hyperthermia is another mode, where the blood is routed from the body as in dialysis, for example, and is heated before returning to the body [2]. It has two advantages, higher possible temperatures and more homogeneous heating. The figure 2.3 above shows different temperature conditions. The side effects, however, have been considerable frequent persistent peripheral neuropathies, abnormal (and sometimes lethal) blood coagulation, some damage to liver and kidneys, and brain hemorrhaging and seizures. Hyperthermia should be administered to patients who are awake and can report any problems as they experience them. Analgesics can be administered if a patient has difficulty lying still for the duration of the session. Patient’s vital signs must be monitored frequently during the session. Cardiovascular disease and sometimes pace
makers (depending on the heat delivery method) are a contraindication for the treatment [14].

2.4 Benefits of Hyperthermia

Hyperthermia, when used alone, leads to impressive results, eradicating 10-15% of tumors. These results usually do not last, and the tumors grow again. Hyperthermia raises the body temperature above normal to a maximum of 108 °F as this reduces the foreign organism presence and the impurities in the body. When compared to the body tissues, the invading foreign organisms cannot survive in the high temperatures. This is a certain benefit as the temperature can be increased above certain level which kill the unwanted organisms, bacteria and virus, and thereby killing the cancer cells [15].

Hyperthermia and radiation combined together in the treatment has been reported to yield higher and durable responses than radiation alone. In deep seated tumors, the effect of this combined treatment is under research for deep seated tumors. Though it is difficult to increase human tumor temperature, recent clinical trials has shown that radiation with hyperthermia is far more successful in controlling many human tumors radiation alone. Hyperthermia may also provide additional advantage in drug delivery. Several studies have shown that the delivery of monoclonal antibodies is enhanced by using hyperthermia, particularly to the tumors with resultant improvement in anti tumor effects. The spread of carried chemo drugs into the tissues of liposome is increased considerably with higher temperature when compared to that under normal temperature. Much of the
information and research has emerged from hyperthermia studies in several other treatments that may become valuable in the future [15].
3.1 Introduction to Mettler Autotherm Equipment

Mettler Electronics has produced an affordable shortwave diathermy (SWD) unit that produces comforting deep heat in muscle tissues. Shortwave diathermy is used when the clinician needs to provide deep heat to a larger area than normally covered by ultrasound. [16]. SWD is the therapeutic elevation of temperature in the tissue by means of an oscillating electric current. The tissue and body organs are overheated, which increases local metabolism, supports absorption of chronic inflammatory, post-injury and post-operation infiltrates, improves tissue elasticity and has analgesic effects [17]. The Autotherm unique induction field circuitry produces a short wave frequency of 27.12 MHz that penetrates into muscle tissue with negligible heating in the fatty layer or bone [18]. The equipment that we are characterizing in this project is the Mettler Autotherm 300, which is also being experimentally studied in a parallel student project. The equipment is shown in the Figure 3.1.1.

3.1.1 Features Mettler Autotherm Equipment

1. Easy to use and offers the clinician maximum treatment flexibility.
2. Provides deep heat within each patient’s tolerable limits.
3. Features timer switch (0 to 30 minutes) and a roller coaster base (rolling base).
When deep heat therapy is indicated, the Mettler system turns it on with shortwave diathermy. The economical Autotherm provides safer, more comfortable heating of subcutaneous body tissues. Its exclusive circuitry generates an electro-magnetic field that penetrates deep into muscle tissue, bringing soothing relief. Back pain or spasm, bursitis (inflammation of small sacs of synovial fluid in the body), chronic arthritis and other muscular-skeletal conditions can be treated effectively and comfortably.
Short-wave diathermy is used in medical therapy to produce local heating in tissue through the conversion of electromagnetic energy into thermal energy. This therapeutic modality has been in use since the mid-thirties, and since 1947 has been almost exclusively conducted at 27 MHz, one of the frequencies allocated for industrial, scientific and medical uses [19]. Clinicians also feel comfortable with Autotherm. It's simple to use: Two dials control all treatment settings and the lightweight, portable unit travels easily between treatment rooms or offices.

3.2 Indications for Medical Diathermy

Shortwave Diathermy is effective when deep heating of body tissues is desired. Beneficial effects include decreased joint stiffness, increased vasodilation (widening of blood vessels), muscle spasm relief and reduced pain from ligamentous sprains and strains. Often, a regimen of manipulation and exercise is prescribed with medical diathermy to produce optimal therapeutic benefits. [20]

3.3 Mettler Autotherm Equipment

The Autotherm 300 is a continuous shortwave diathermy unit which is designed to be economical and light weight. It is portable with a roller coaster base and is flexible. The arm is made adjustable, so that it can reach different parts of the body and can heat accordingly. This equipment is mainly used where deep heat is required such as the low back, shoulder, neck and hip. This equipment is economical and is easy to operate since it
only has two controls, a timer knob and an intensity control knob as shown in figure 3.3.1 below.

![Timer Switch and Intensity Control Knob](image)

**Figure 3.3.1 Timer Switch and Intensity Control Knob**

The Autotherm has a timer which is designed such that we can have a wider variation of 0 to 30 minutes. The timer helps to know the timing of treatment. The power meter, as shown in Figure 3.3.2, displays the energy levels absorbed by body surface. We can measure the current from the power supply and it has the capability to display the energy absorbed.

![Power Meter on Mettler diathermy unit](image)

**Figure 3.3.2 Power Meter on Mettler diathermy unit**
3.3.1 Technical Specifications of Mettler Autotherm Equipment

Input: 100–240 VAC, 50-60Hz

Frequency: 27.12 MHz (Wavelength $\lambda = 11.06$ meters)

RF output: Continuous mode 100 W Average Power, Pulsed mode 200 W Peak Power

Continuous mode: 100 Watts Average Power

Pulsed Mode: 200 Watts Peak Power

Pulse frequency: 10 Hz, 20 Hz, 50 Hz, 100 Hz, 400 Hz

Pulse duration: 65 $\mu$s, 100 $\mu$s, 200 $\mu$s, 300 $\mu$s and 400 $\mu$s

Treatment time: 1–30 minutes [24]

Weight: Unit: 30 pounds

Dimensions: 40 in (H) x 18 in (W) x 18 in (D), (100 cm (H) x 46 cm (W) x 46cm (D)) [21]

3.3.2 Advantages of Mettler Autotherm 300

1. Induction drum electrode can be easily applied to any body area

2. Lightweight all metal treatment arm is spring balanced for precise positioning and easy access to all body areas

3. Patented self tuning circuitry ensures that the unit is always in tune. A single dosage intensity control regulates patient power demand.

4. Timer Switch turns the unit on and off. Treatment lengths from 1 to 30 minutes may be selected.
5. No damages are done to the adjacent tissues and bones.

6. Lightweight unit design and roller coaster base provide maximum portability [22].

Mettler Autotherm is used when deep heat therapy has to be done for any part of the body. It operates with short wave diathermy and is a safe for subcutaneous body tissues. The electro-magnetic field is generated between the equipment and the body. The heat penetrates deep into muscle tissue and eases the tensions and brings relief. This therapy is mainly used for back pain, chronic arthritis, bursitis and other muscular-skeletal conditions. The table 3.3 helps us to find which type of radiation is necessary for different kinds of body parts. As we observe, Most of the heat from shortwave induction field is created in muscle tissue where it has a great therapeutic effect.

The output intensity controls the percentage of maximum power transferred to the patient circuit. The tuning control adjusts the output circuit for maximum energy transfer from the radio frequency oscillator. The power output meter monitors only the current that is drawn from the power supply and not the energy being delivered to the patient.

The power output produces sufficient energy to raise the tissue temperature into a therapeutic range. The Specific absorption rate (SAR) represents the rate of energy absorbed per unit area of tissue mass [24]. The Table 3.3 shows the table for selecting which therapy to be used for the appropriate body part.
3.4 Care of Equipment

1. Short-wave diathermy devices should be thoroughly examined at least yearly to ensure that all the parts are in good working order. Particular care should be taken to ensure that cables and electrodes are not cracked or burned, and the hinges of the applicator (electrode) support are working properly.

2. The operation of electrodes should only be tested when they are placed over a tissue phantom such as a plastic container with physiological solution. Power must not be switched to the electrodes unless they are properly applied to a patient or the tissue phantom.
3.5 Precautions Using the Equipment

To avoid fire hazard, cables and electrodes should be kept away from flammable materials, as stray RF fields can heat such synthetic materials as nylon, polyvinyl chloride (PVC), polyethylene terephthalate (PET) and combinations of cotton with synthetics. Operators of short-wave diathermy devices should minimize potential exposure to RF radiation. To maintain exposures within the recommendations of the Federal government:

a. Short-wave diathermy devices should be used only for treatments prescribed by a physician.

b. The electrodes should be carefully placed over the treatment area. Minimizing the gaps between the electrodes and patient or towels helps to limit stray RF radiation.

c. The RF power should be turned on only after the electrodes are in place.

d. The operator should remain at least 1 m from the electrodes and 0.5 m from the cables during the treatment. Short duration excursions closer to the electrodes or cables are permitted, but only when necessary.

Care must be taken to ensure that the patient does not receive any unnecessary exposure to tissues other than those prescribed for treatment. To minimize such exposure:
a. The applicator should be carefully placed to conform to the treated area as closely as possible.

b. The cables leading to the applicator should not be placed in the vicinity of the patient's non prescribed tissue.

c. A patient-operated safety switch should always be operational, so that the patient can terminate the treatment.

d. The patient should remove all metal objects.

3.6 Contraindications of Shortwave Diathermy

Shortwave diathermy has the following precautions or contraindications:

1. Malignancy (Tendency of a medical condition to become progressively worse and to potentially result in death)

2. Sensory loss

3. Tuberculosis

4. Metallic implants or foreign bodies

5. Pregnancy

6. Application over moist dressings

7. Ischemic areas or arteriosclerosis (stiffening of arteries)

8. Cardiac pacemakers

9. Contact lenses

10. Metal-containing intrauterine contraceptive devices
11. Metal in contact with skin (e.g., watches, belt buckles, jewelry)

12. Active menses[24]

3.7 Heating Effect in Autotherm Equipment

Microwave diathermy units have well-shielded leads within the equipment between the generator and head of the applicator. The generator and applicator head are integrated, and there is normally very little radiation from other source except that of the applicator. There is very little or no heating of the air surrounding the cables since it absorbs little energy from the radio-frequency fields. Table 3.7 shows the variation pattern of electric and magnetic fields in the diathermy unit as a function of distance within the treatment volume.

<table>
<thead>
<tr>
<th>Height (cm)$^2$</th>
<th>Front site</th>
<th>Back site</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E-field (V/m)</td>
<td>H-field (A/m)</td>
</tr>
<tr>
<td>30</td>
<td>53.73 (3.08)$^3$</td>
<td>0.87 (0.020)</td>
</tr>
<tr>
<td>100</td>
<td>19.24 (2.04)</td>
<td>0.22 (0.004)</td>
</tr>
<tr>
<td>150</td>
<td>15.96 (1.15)</td>
<td>0.34 (0.007)</td>
</tr>
<tr>
<td>Spatial averaging</td>
<td>34.21</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Table 3.7: Electromagnetic Heating Comparison [15]

Heating occurs only when conductive or partially conductive material is located within the electric or magnetic field produced by the cables or applicator. The Canadian Bureau of Medical Devices mentions in its data that certain plastics and synthetics such as nylon, polyvinyl chloride, and polyethylene terephthalate and some fabric blends which are
usually regarded as good insulators, can also be heated certain temperatures by shortwave and microwave diathermy units [25]. However, two other synthetics widely used in medical practice for several applications, silicone and polytetrafluoroethylene usually called Teflon are relatively very less affected by electromagnetic fields.
Chapter 4

INTRODUCTION TO 4NEC2 ELECTROMAGNETIC MODELING SOFTWARE

4.1 Introduction to 4NEC2

We used 4NEC2 software for modeling of the Mettler Autotherm system. 4NEC2 is a completely free Windows based tool for creating, viewing and optimizing 2D and 3D style antenna geometry structures and generate, display and/or compare near/far-field radiation patterns for both the starting and experienced antenna modeler [26]. The Numerical Electromagnetic Code (NEC) has been developed at the Lawrence Livermore Laboratory, Livermore, California, under the sponsorship of the Naval Ocean Systems Center and the Air Force Weapons Laboratory. The Numerical Electromagnetic code (NEC-2) is a computer code for analyzing the electromagnetic response of an arbitrary structure consisting of wires and surfaces in free space or over a ground plane. It is built around the numerical solution of integral equations for the currents induced on the structure by sources or incident fields. This approach avoids many of the simplifying assumptions required by other solution methods and provides a highly accurate and versatile tool for electromagnetic analysis.

The new 5.1 4NEC2X version also enables real-life structure-geometry and far- or near-field pattern visualization. The use of DirectX based hardware graphics-acceleration delivers you fast rotating, zooming and moving of the more complex structures or patterns. [27]
4.2 Capabilities of 4NEC2

1. Graphical 2D and 3D visualization of Far- and Near-field data and Geometry structures (including circular polarization view).
2. Capable of running up to 11000 wires and/or segments (limited by the max of 2Gb of windows on-board memory)
3. Screen grabber for easy cut/paste, print or save parts of the screen, window or form.
4. Geometry builder to create cylindrical, patch, plane, box, helix and parabola shaped structures using auto-segmentation and/or equal-area rules.

4.3 Modeling Structures Using 4NEC2

The basic devices for modeling structures with the NEC code are short, straight segments for modeling wires and flat patches for modeling surfaces. There are two types of modeling, wire modeling and surface modeling.

4.3.1 Wire Modeling

A wire segment is defined by the coordinates of its two end points and its radius. Modeling a wire structure with segments involves both geometrical and electrical factors. Geometrically, the segments should follow the paths of conductors as closely as possible, using a piece-wise linear fit on curves [28].
4.3.2 Surface Modeling

A conducting surface is modeled by means of multiple, small flat surface patches corresponding to the segments used to model wires. The patches are chosen to cover completely the surface to be modeled, conforming as close as possible to curved surfaces. The parameters defining a surface patch are the Cartesian coordinates of the patch center, the components of the outward-directed, unit normal vector and the patch area.

4.4 Working of 4NEC2 tool

We used 4NEC2 5.8.1 version for this project. After setting the executable file, we need to open the 4NEC2 application file. The first thing that pops up is the main file with the version number. The Figure 4.4 for the main window is shown below.

![Main Window](image)

**Figure 4.4: Main Window**
The geometry window is the main antenna. In this window we can see the name of the file, frequency used and other parameters (which are out of scope for the current project). We can generate the near field and far field patterns using the generate option in the tool. When we use Ctrl+F4 on this Generate window, we can see a new window popping up with options to construct wires, arc, Helix under Geometry tab. In this project we inserted a wire to apply the current source. We will need to provide the tag, segment number, wire radius in order to construct a wire. In the same window we will have a tab for inserting a Current/voltage source under Source/load tab. We will need to provide the magnitude and tag value for the source as well.

4.4.1 Using Geometric Builder

One of the major advantages of using 4NEC2 tool is using the Build tool. We directly created a cylinder using the specifications of the project i.e., the dimensions of the head of the Autotherm equipment. The figure 4.4.1a shown below is the geometry builder used in the tool.
Length field indicates the length of the cylinder in meters and Radius R1 is the radius on the top and Radius 2 is the radius for the low end of the cylinder in centimeters. When we say create, a separate window pops up with the desired Geometry.

When selected as near-field pattern we can simulate the electric field pattern in either Z-direction or X-Y plane. We select X and Y coordinates as 0 and select the Z-axis for radiation along the Z-direction. For the X-Y plane, we will have the same Z value for start and stop and X and Y ranges from -0.1 to +0.1 m with a step value of 0.01 m. The Z-value selected is usually the position of the peak electric field, and when we click on “Generate” we can observe the pattern in the Pattern window. The Pattern window has
a 2-d graph, and depending upon the option selected (either the radiation long Z direction or X-Y plane) we can see the radiation pattern and their peak values accordingly.

When calculations are done, the Pattern window is displayed with the 'Near-field' lay-out. Initially you mostly will see a blue plane with on the left a color-bar telling on the left, telling you what field-strength is represented by a certain color. The maximum value will be in the range > 1e+4 volts/m. This is due to the fact that one or more of the calculation points will be very close (or maybe on) a geometry wire with high RF-voltage/current. Initially the field-strength on the XY plane for a certain Z value is displayed. To change the Z-value uses the cursor-left or -right keys. To change between XY, YZ and XZ plane, use the spacebar. The Generate window is shown in the below figure 4.4.1b.

![Generate Window](image_url)
A sample Z-axis plot and a sample X-Y plot is shown in Figure 4.4.1b. The left figure in Figure 4.4.1c shows the 1-dimensional z-plot, and the right figure shows the 2-dimensional X-Y plot.

![Figure 4.4.1c: Generate and Pattern Windows](image-url)

### 4.5 Creating an Antenna Using 4NEC2

The following are the steps to be followed to construct an antenna and see the near field patterns.

1) Create an antenna model using 'Geometry Edit'.

2) Show structure; generate data and view currents and phase distribution.

3) Generate near-field data and view 2D polar and 3D near field patterns and construct a linear graph for the 3d near filed patterns data. [29]
Chapter 5

SIMULATION RESULTS OF METTLER DIATHERMY USING THE 4NEC2 SOFTWARE

In this chapter we outline the simulation study on the 27 MHz Mettler diathermy system. The entire simulation process consists of the following three steps, and will be explained in detail in the sections below:

- Creation of the wire-grid model of the actual diathermy system
- Generation of the geometry file of the model obtained in the previous step
- Creation of the electric field simulation coordinates and generation of the near-field in both linear and planar axes

5.1 Creation of the Wire-Grid Model of the Actual Diathermy System

The system, which was outlined in Chapter 2, is shown below in Figure 5.1a again as a reference to start the modeling process. As can be seen from the figure, the main applicator module is at the top left end of the photograph, and essentially has the shape of a rhombic circular cylinder, with the outer radius smaller than the inner radius.
We build a cylinder using geometry builder in 4NEC2 software tool. A NEC file was created and created its geometry. Figure 5.1a shows the geometry values (in meters). Using the Build tool in the 4NEC2 software, we created sections based upon the specifications. We took straight circular, radial sections as 10 for a clear view of the pattern. The frequency used in this project is 27.12 MHz and hence used in the build section. The Build window is shown in Figure 5.1b, and wire-grid model of the diathermy applicator is shown below in Figure 5.1c.
Figure 5.1b: Geometry Builder

The dimensions of the rhombic circular cylinder are as follows:

Radius R1 of smaller side: 12 cm

Radius R2 of bigger side: 11 cm

Length of cylinder: 15.6 cm
5.2 Generation of the Geometry File of the Model Obtained in the Previous Step

The geometry window that was created by the Build tool is shown below. Each line represents the location and dimensions of each wire in the model. The software tool can handle a maximum of 11000 wire elements in the free-source version. Higher wire element numbers require the much more power version which is available at cost.
Figure 5.2: Geometry Table Values

5.3 Creation of the Electric Field Simulation Coordinates and Generation of the Near-Field in Both Linear and Planar Axes

5.3.1 Measurements of Cylindrical Antenna at Half Power

Measurements are taken from the cylindrical antenna and then derived the length as 15.6 cm, outside and inside radius of cylinder as 12 cm and 11 cm respectively. The
values such as source current and magnitude is included under the source/load tab as shown in figure 5.3.1a below.

![Figure 5.3.1a: 4NEC2 Edit Window](image)

We then operated the 4NEC2 software at 27.12 MHz frequency. Simulation was carried out using three different source current values. In the first phase of our simulation, we simulated the cylindrical antenna at a half power of 50 Watts. We calculated the current at a voltage of 110 Volts and power of 50 Watts using the equation below.

\[ P = V \cdot I \]

Where, \( P \) is Power, \( V \) is voltage and \( I \) is current. The resulting current at half power is 0.45 Amperes. The resulting current at half power is 0.45 Amperes. We then calculate the NEC output data for the given geometry of measured values.
In the first plot, the x and y coordinate values are given both start and stop values as zero. We then generate the graph showing total electromagnetic field along the z-axis at every step of 0.01 meters from 0.156 m to 0.60 m; the start value of 0.156 meters corresponds to the first point outside the metallic structure shown in Figure 4.4.2 geometry. The graph shows the near field pattern for the cylindrical antenna at different distances as in the figure 5.3.1b below. The axis on the left shows the scale range of the value electric field distribution, with a maximum value of 20000V/m right at the point closest to the diathermy applicator.

Figure 5.3.1b: Near Field Pattern at Half Power

However, the peak of interest for hyperthermia application is the clear maximum lobe formed at a distance of 0.346 m where the electromagnetic field can be used to focus on the tumor area. For the planar x-y plot, the z-axis value is fixed at the latter peak
value: This value is taken as the z start and stop values. The x and y axes are given values as start value -0.1m and stop value 0.1m., and the field is calculated in steps of 0.01m. The figure 5.3.1c below shows the generate window for the planar field calculation.

![Generate Window for Near Field Pattern at Peak Value](image)

**Figure 5.3.1c: Generate Window for Near Field Pattern at Peak Value**

Then we generate a two-dimensional x-y graph, as shown in Figure 5.3.1d below which shows the planar near field pattern at peak value z-distance of 0.346 meters.
The linear graph is plotted using the 3D plot from the plot tab. We get the linear values stating the total electromagnetic field corresponding to each distance at the steps of 0.01. Graph shown above in figure 5.3.1d above shows the peak value as 7037.133 V/m.

5.3.2 Measurements of Cylindrical Antenna at Normal Power

In this second phase of our simulation, we simulated the diathermy system at a normal power of 100 Watts. We calculated the current as 0.909 Amperes at a voltage of 110 Volts and power of 100 Watts. The values such as source current 0.909 Amperes and current magnitude is included under the source/load tab as shown in figure 5.3.2a below.
We then calculated the NEC output data for the given geometry of measured values. As in the case of the half-power simulation described earlier, the x and y axes are given both start and stop values as 0 meters, to generate the 1-dimensional electric field distribution along the Z-axis. We then generate the z-axis graph showing total electromagnetic field in steps of 0.01 meters from 0.156 m to 0.60 m. The graph in the figure 5.3.2b below shows the near field pattern for the diathermy system at different distances along the Z-axis.

As before, the peak of interest for hyperthermia application is the clear maximum lobe formed at a distance of 0.35 m where the electromagnetic field can be used to focus on the tumor area. For the planar x-y plot, the z-axis value is fixed at the latter peak value: This value is taken as the z start and stop values. The x and y axes are given values as
start value -0.1m and stop value 0.1m, and the field is calculated in steps of 0.01m. The figure 5.3.2c below shows the generate window for the planar field calculation.

**Figure 5.3.2b: Near Field Pattern at Normal Power**

From the generated near field pattern, we calculate the peak value again where the electromagnetic field is the highest. This value for z which is 0.346 is taken as the z start and stop values. The x and y axes are given values as start value -0.1 and stop value 0.1. And the field is calculated at a distance in steps of 0.01. The figure 5.3.2c shows the generate window.
Then we generate a two-dimensional x-y graph, as shown in Figure 5.3.2d below which shows the planar near field pattern at peak value z-distance of 0.346 meters.
5.3.3 Measurements of Cylindrical Antenna at Peak Power

In this third phase of our simulation, we simulated the cylindrical antenna at full power of 200 Watts. We calculated the current as 1.81 Amperes at a voltage of 110 Volts and power of 200 Watts. The values such as source current 1.81 Amperes and current magnitude is included under the source/load tab as shown in figure 5.3.3a below.

We then calculated the NEC output data for the given geometry of measured values. As in the case of the half-power simulation described earlier, the x and y axes are given both start and stop values as 0 meters, to generate the 1-dimensional electric field distribution along the Z-axis. We then generate the z-axis graph showing total electromagnetic field in steps of 0.01 meters from 0.156 m to 0.60 m. The graph in the figure 5.3.3b below shows the near field pattern for the diathermy system at different distances along the Z-axis.

As before, the peak of interest for hyperthermia application is the clear maximum lobe formed at a distance of 0.4 m where the electromagnetic field can be used to focus on the
tumor area. For the planar x-y plot, the z-axis value is fixed at the latter peak value: This value is taken as the z start and stop values. The x and y axes are given values as start value -0.1m and stop value 0.1m., and the field is calculated in steps of 0.01m. The figure 5.3.3c below shows the generate window for the planar field calculation.

![Figure 5.3.3b: Near Field Pattern at Full Power](image)

From the generated near field pattern, we calculate the peak value again where the electromagnetic field is the highest. This value for z which is 0.4m is taken as the start and stop values. The x and y axes are given values as start value -0.1 and stop value 0.1. And the field is calculated at a distance in steps of 0.01. The figure 5.3.3c shows the generate window.
Figure 5.3.3c: Generate Window for Near Field Pattern at Peak Value

Then we generate a two-dimensional x-y graph, as shown in Figure 5.3.3d below which shows the planar near field pattern at peak value z-distance of 0.4 meters.

Figure 5.3.3d: Near Field Pattern at Peak Value
Chapter 6

CONCLUSIONS AND SCOPE FOR FUTURE WORK

This project was aimed at the simulation of the electromagnetic field distribution of the Mettler 27 MHz Diathermy system using the 4NEC2 software to simulate the results. We used the statistics and experimental results of a previous project who directly worked on Mettler Autotherm equipment. The Mettler diathermy system has application in clinical treatment of cancer by hyperthermia or heat treatment.

We used the freely available 4NEC2 finite element software to simulate these results. We built the diathermy system using the Build tool in 4NEC2 with the given dimensions of the Mettler Autotherm equipment. After placing a wire and a current load across it (1.1 amps with a power of 110W), we calculated the near field values using the Generate option and along the Z axis. We also checked the pattern for the XY plane using the generate option at the position of peak electric field along the Z-axis.

We then changed the power to 50W and repeated the same process. We simulated and acquired the results for this current source value as well. Finally we changed the power to the peak value (200W) and repeated the steps. We noted the peak value and compared the results with the earlier results. We could see that the values didn’t have too much of deflection with the change in current source value.
This project gave us a good exposure towards the cancer treatment system. This project gave us an opportunity to work on new software, “4NEC2” for simulation. We could explore the features of the software for various options. We faced few difficulties in achieving the results. The near field patterns were not showing up as expected due to the incorrect alignment of the current source and giving appropriate values to the wire and current source will give good results. We tried with different values initially and tried to achieve the results. We initially tried using different software for simulation but we ended up using 4NEC2 as it is easy to use and it has all the features required for the present project.

The simulated data will be compared with measured results are being generated currently on another student project. The comparison will validate the accuracy of simulation, and improvements in the model, if required, will be affected at that point. Ultimately, accurate modeling of the electric field properties of the diathermy system will contribute directly to successful treatment planning of the hyperthermia therapy.
REFERENCES


25. http://www.cancer.org/docroot/ETO/content/ETO_1_2x_Hyperthermia.asp, Hyperthermia, 06/20/2010


27. http://www.si-list.net/swindex2.html, Changes with version 5.1, 06/15/2010
