School of Engineering Science
Burnaby, BC, V5A 1S6

November 12, 2007

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Project Design Specification for Trans Dental Monitoring Solution.

Dear Dr. Rawicz,
Please find attached the *Design Specification for Trans Dental Monitoring Solution* (TDMS) document which defines the different attributes of the project idea for ENSC 440: Capstone Project.

We are in the process of designing and implementing a device that can be used by the dentists to monitor the anesthesia status of a numbed tooth at the beginning and during a dental operation. This will alarm the dentist to stop working or reapply anesthesia when the numbing effect is wearing off. The dentist will be able to set the current by communicating with the device through the carefully designed interface unit; a seven segment display circuit will be used to display the output to the dentist. TDMS will also include safety circuitries such as overload detection and a fault detection circuitry. This document will outline and discuss the functionality of TDMS in terms of design specifications and implementation of its subsystems.

Innovative Dental Technologies consists of four enthusiastic and innovative final-year engineering science students: Isabella Taba, Petar Ivaz, Bahman Sotoodian and Mohammadali Khorasani. Please feel free to contact me at skhorasa@sfu.ca with any questions or concerns regarding the design specification.

Sincerely,

Mohammadali Khorasani
Chief Executive Officer
Trans Dental Technologies

Enclosure: *Functional Specification for Trans Dental Monitoring Solution*

Functional Specification for

TRANS DENTAL MONITORING SOLUTION

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Submitted to Dr. Andrew Rawicz – ENSC 440
Mike Sjoerdsma – ENSC 305

Issued date November 12, 2007

Revision 1.0

Executive Summary

The thought of a drill digging into a tooth is enough to send a chill down anyone's spine. The vast majority of us will be subject to it at some point in our lives. Anaesthesia is a very powerful numbing tool and when used properly, completely shuts down the local nerves. The downside is that the effectiveness of the anesthesia has more to do with the dentist's skill and experience, rather than the product itself.

There is a significant minority of people who cannot feel if their teeth have been numbed properly. On one end of the spectrum are people with immense fear of needles, and on the other, people with immense fear of pain. The former suffers from too little anesthesia, while the latter from too much.

Our device, TDMS (Trans Dental Monitoring Solution), will assist the dentist in determining when the proper level of anesthesia has been administered. It will also serve to monitor the effects of anesthesia during a dental procedure. When a specific amount of current is applied to a tooth, the patient experiences a touch sensation. It is important to note that this sensation is painless.

This document outlines how we intend to implement and test our product. When a dentist works on a patients tooth, they use a clamp around it. This clamp isolates the tooth from the rest of the mouth, and forms a very tight seal. The electrical contact point between the tooth and TDMS is on the inside of the clamp. The inward pressure produced by the clamp will push the positive end of our circuit into the tooth, isolating it from water. The ground will be attached to the opposite side of the mouth by a simple hook. The patient will feel a touch sensation every 2 seconds. Our device will stay on the tooth and apply the pre-determined current. Once the patient has stopped feeling the rhythmic pulses, they will alert the dentist. The device is very small, and only a small wire is applied to the area. This is important, as we want to keep the area around the tooth non-cluttered.

The design of the various electrical components of the circuit, in addition to the methods of testing the functionality of the device will be outlined in this document. Trans Dental Technologies completed the research phase, and has recently fully transitioned into the development stage. The preliminary circuits for the power supply and the current generation have been developed and are being tested and modified to fit the requirements and expectations of the Trans Dental Technologies engineers. We aim to have a full prototype developed by mid December of 2007.

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List of Figures and Equations

Introduction

The Trans Dental Monitoring Solution (TDMS) is a device that can be placed on the tooth and monitors the activity of the tooth nerve. It is proposed that a tooth that is anaesthetized will show no nerve activity. Furthermore, a tooth that is "awake" or "waking up" will show nerve activity and the dentist can administer anaesthetic to achieve profound anaesthesia. TDMS will send consecutive pulses at predefined intervals and amplitude which is below the patient perception threshold. As soon as the amount of the anaesthetic drops the patient will feel the signal and gives the feedback to the dentist. The design specifications are listed in the following document.

1.1 Scope

This document describes the design requirements that must be met by a functioning TDMS. These set of requirements fully describe the proof-of-concept device and partially describes the production device.

1.2 Intended Audience

The design specification is intended for use by all members of Trans Dental Technologies. TDT will use this document as a guideline in building the product.
The project manager will refer to the functional specifications and requirements as a concrete measure of progress throughout the development phase. Test Engineers will use this document to implement the test plan and confirm proper behaviour of the Trans Dental Monitoring Solution

2 System Overview

The overall requirements for Trans Dental Monitoring Solution (TDMS) have been described in the following section. The general implementation of our product is seen in Figure 2.1.

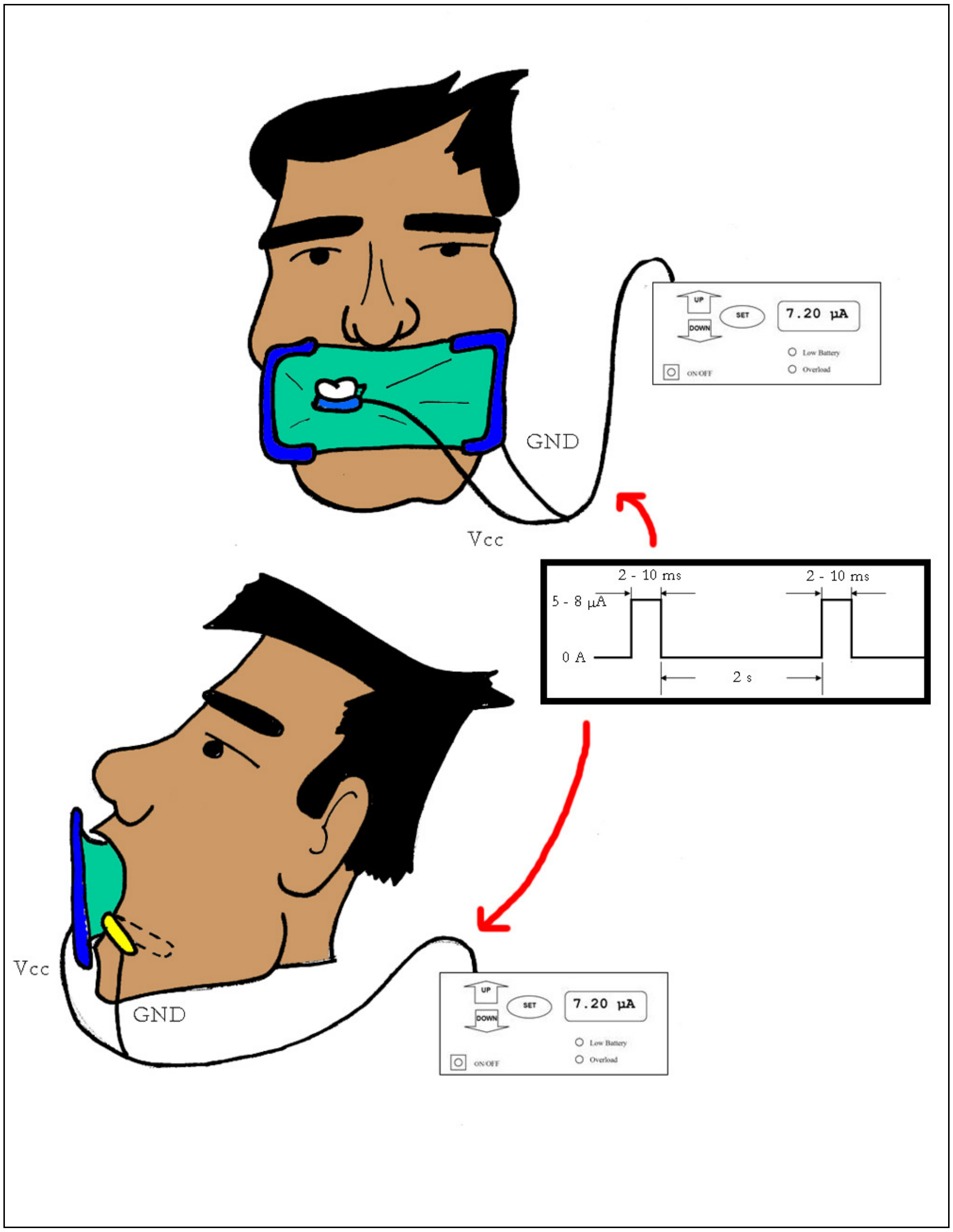

Figure 2.1 - Trans Dental Monitoring Solution[1]

[1] Drawn by Petar Ivaz, October 12, 2007

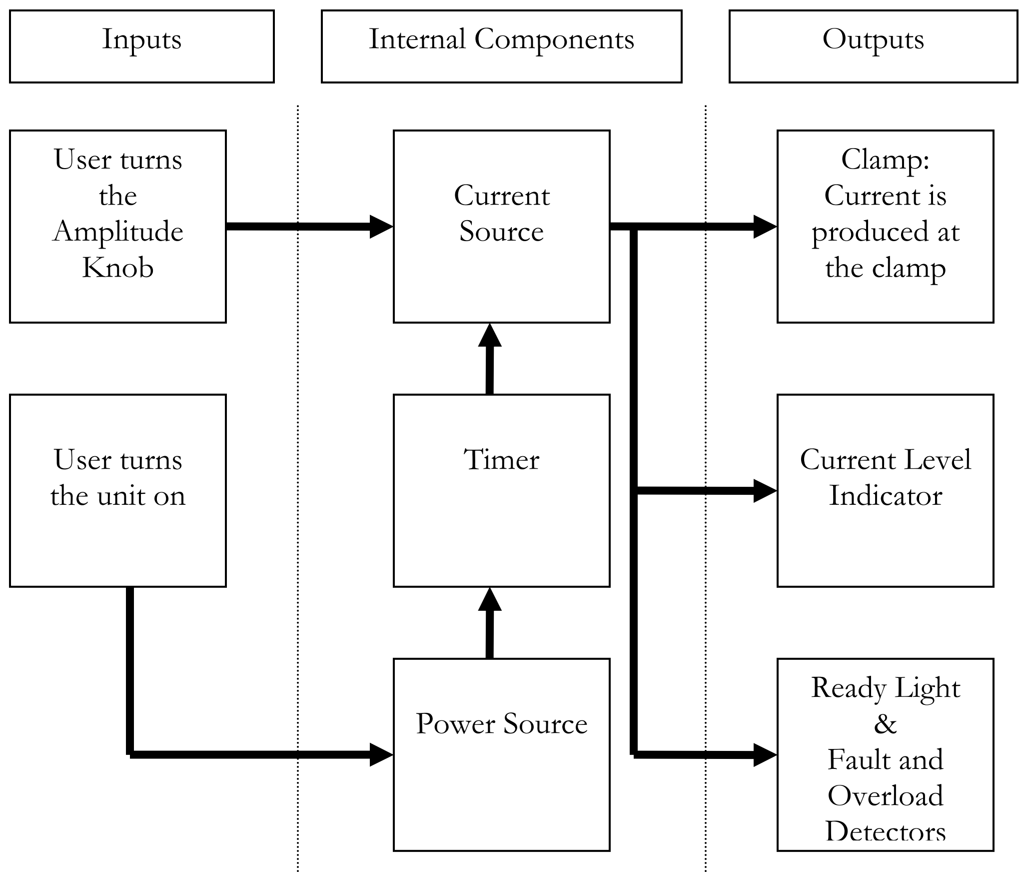

Figure 2.2 – High Level Overview of TDMS[2]

Figure 2.2 shows the high level system overview of the Trans Dental Monitoring Solution.

The inputs consist of an amplitude knob which controls the amplitude of the current, as well as an ON/OFF switch that powers the device.

The internal components are: the power source which steps up 1.5V DC to 300V DC, the timer which produces the 10 ms-0.5 Hz pulse and the current source which produces the constant current.

The outputs are the current supplied to the tooth at the clamp, the current level indicator as well as various indicators for the dentist.

[2] Block Diagram created by Petar Ivaz, in Microsoft Word, November 12, 2007

3 Current Source and Control

The circuit for the current pulse generator and magnitude control is given in Figure 3.1

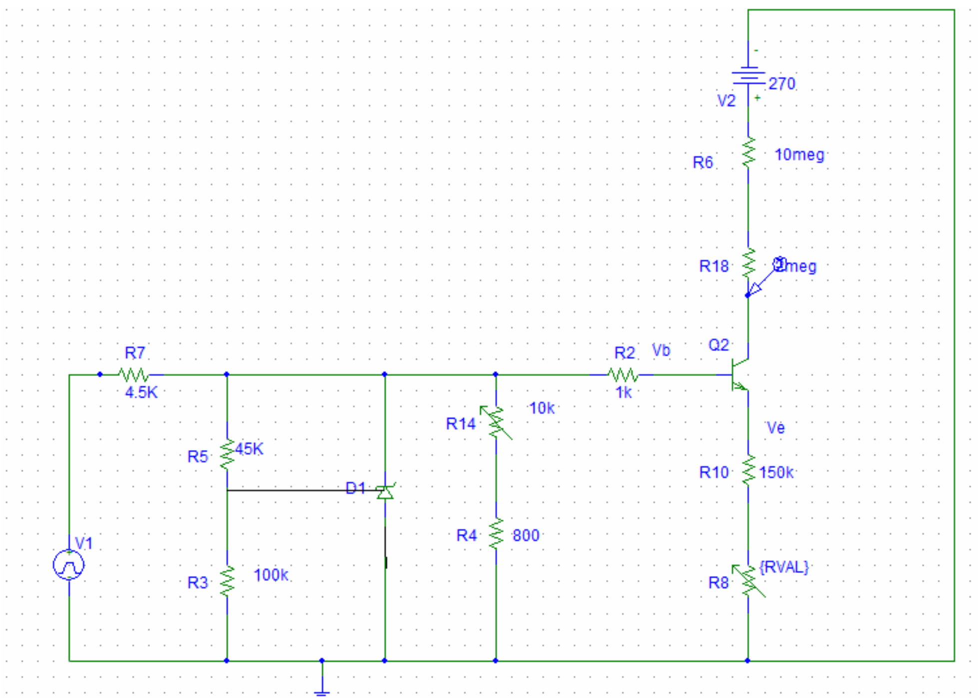

Figure 3.1 - The overall schematic of our current source and control circuitry[3]

3.1 Current Source and Magnitude Control

We chose a transistor, BF259, which can tolerate high voltage at its collector, maximum 300V. The pulses, which are sent from our timer would turn on the transistor. The pulses would go under regulation and attenuation to provide a constant voltage at the base of transistor. This constant voltage will be changed by varying the variable resistor, R14, which subsequently would vary the collector current of transistor. It is assumed that $I_e \approx I_c$ and that I_c is given by

$I_c \approx \frac{V_e}{R_e} = \frac{V_b - V_{be}}{R_e}$, where R_e = emitter resistor and V_{be} = 0.5 V. The V_{be} will be constant with a good approximation. Hence, we can say that $I_c = I_e \approx \frac{V_b}{R_e} -$ constant.

[3]Pepper M and Smith D. *An electric tooth pulp vitality tester.* 1981. Medical & Biological Engineering & Computing

So, As mentioned before, the base voltage will be controlled by 10 kΩ potentiometer, which consequently would provide a linear control for the collector current of our transistor. Hence, we can linearly control our output current by appropriate changed of 10 kΩ potentiometer.

The 800Ω resistor in series with the 10kΩ potentiometer would enable us to bias the transistor at ($I_c \approx 2\mu A$), which is our minimum required current. With the 10kΩ potentiometer in the emitter, we can vary our collector current precisely with steps as small as 1 μA .

3.2 Current Regulation

The programmable Zener diode will provide us with constant 3 voltage which is insensitive to fluctuation of 9 volt battery. The pulse will be provided to the 10kΩ potentiometer in the base of transistor to set the voltage to the desired value. The programmable zener diode will provide us with much lower slope resistance at low currents in compare with the low power Zener diodes. This characteristic will enhance our voltage regulation.

3.3 Output Pulse

The final pulse at the output of collector has gone under 180 ° phase shift with respect to the input pulse. Hence, in order to restore the original phase of our pulse, we have to label the collector side of our output pulse as negative and the high voltage supply side as positive output socket.

4 Overload Indicator[4]

As the current pulse is usually applied to teeth of high impedance there is always the possibility that the voltage necessary to drive that current is greater than that available, it is therefore essential that the operator is made aware of the occurrence of an overload condition because increasing the current setting will not increase the actual current passed. If this is not done the likelihood of obtaining false negative readings is greatly increased as, for example, in the case where the cause might be a high impedance contact between the electrode and the tooth. An alarm has been incorporated to indicate the occurrence of an overload condition. The circuit used is given in Figure 4.1.

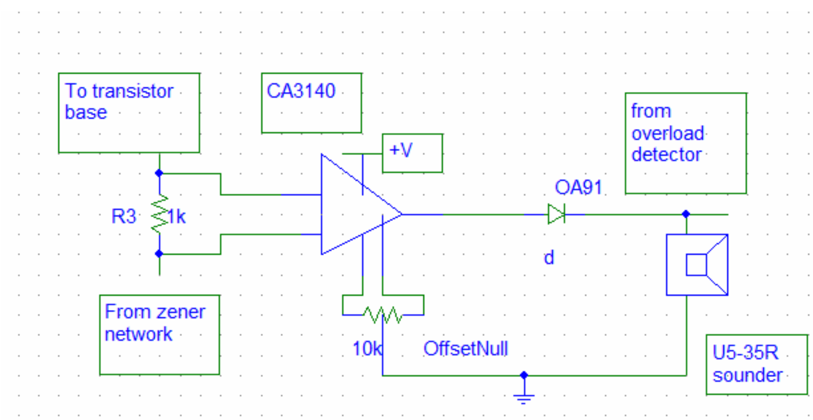

Figure 4.1 - The Overload Indicator Circuitry[4]

When overload occurs, and the base voltage is increased in an attempt to increase the collector current, the base current will increase much more rapidly than under normal conditions as the current gain of the transistor is now reduced to unity. The presence of an overload will be indicated by an excessive increase in base current. For this instrument, under normal conditions, the maximum collector current is 20μA, which gives, for a current gain of 25, a base current of 0.8 μA. This will develop a maximum 0.8 mV across the 1 kΩ sensing resistor in series with the base of the transistor. Thus, even for low current settings, the onset of overload could be detected within a setting of 0.8 μA of that onset. This voltage is sensed by a CA3140 BiMos operational amplifier, which can operate from a single supply rail. The offset null facility is used to bias the amplifier off until the 0.8 mV level is exceeded. The output of the amplifier is fed to a 6mA, 3.3 kHz sounder (ITT U5-35R) which will, if an overload occurs, be switched on and off for 10ms at the pulse repetition rate to give a bleep alarm. The OA91 diode D1 is incorporated to permit the sounder to be operated by the fault detection, which will be shortly explained, without the interaction of either circuit.

[4] This previous art is borrowed from "Pepper M and Smith D. *An electric tooth pulp vitality tester.* 1981. Medical & Biological Engineering & Computing". It is considered optional at this moment

5 Fault Detection[5]

Because this instrument is able to place up to 270 V across the patient's tooth, it is desirable, for patient comfort, to ensure that this will not be caused by an instrument fault, and that any such fault should be indicated to the operator before application to the patient. The circuit of Figure 5.1 combined with that of the overload detector should enable the operator to detect any fault condition.

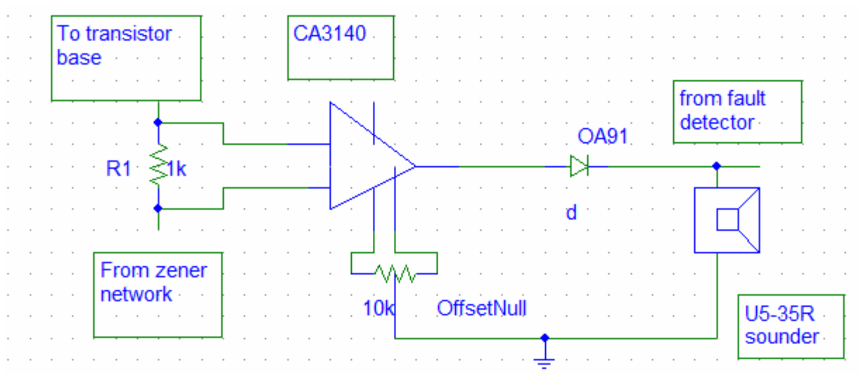

Figure 5.1 - The Fault Detection Circuitry[5]

The circuit of Figure 5.1 is designed to detect a short-circuit fault in the base-collector junction. This fault will, when a load is connected between the collector and the high voltage rail, cause a voltage to be developed across the 1 kΩ current sensing resistor in the base circuit. The triggering level of the CA3140 amplifier is set by use of the offset null. It should be noted that this amplifier detects voltages of a reverse polarity to that of the overload amplifier. The 6-2 V Zener gives some measure of protection to the amplifier inputs at initial breakdown after which the direct current capacity of the high voltage supply is not sufficient to raise the voltage across the amplifier to a damaging level. The OA91 diode D2 gives isolation between the two alarm circuits. If this fault occurs then a continuous alarm will sound.

[5] This previous art is borrowed from "Pepper M and Smith D. *An electric tooth pulp vitality tester.* 1981. Medical & Biological Engineering & Computing". It is considered optional at this moment

6 Power Supply

The constant current generator will be implemented with a BJT; producing currents in the range of 7 to 10µA[6], across a purely resistive load of 2 to 10 MΩ. The load is attached to the emitter of an NPN transistor. In order to keep the BJT within the linear operating region it is necessary to provide a V_{CC} that is higher than the maximum voltage drop possible across the load.

$$10\mu A * 10\ M\Omega = 150\ V$$

Equation 1

We decided to give our selves some wiggle room, and decided to allow a maximum drop of 300V across the load.

Our device is meant to be portable and will be run by three 1.5V AA batteries. To step-up the voltage from 1.5 Vto 300 V, we needed a circuit with a transformer. We initially attempted to build the entire circuit on our own, but found acquiring the necessary parts difficult. The transformers found in most electronics stores were for application of high power, and were far too bulky for our design. The low power transformers we required were expensive and would have taken weeks to order. After consulting with Dr. Ash Parameswaran we concluded that the best solution would be to modify the internal circuitry of a Disposable Kodak Flash Camera™. These cameras are available for free from the majority of photo processing laboratories; solving both the problem of cost and availability.

The circuit of the disposable camera is pictured in Figure 6.1.

[6] Suggested by Dr. Bawa Parveen, September 2007

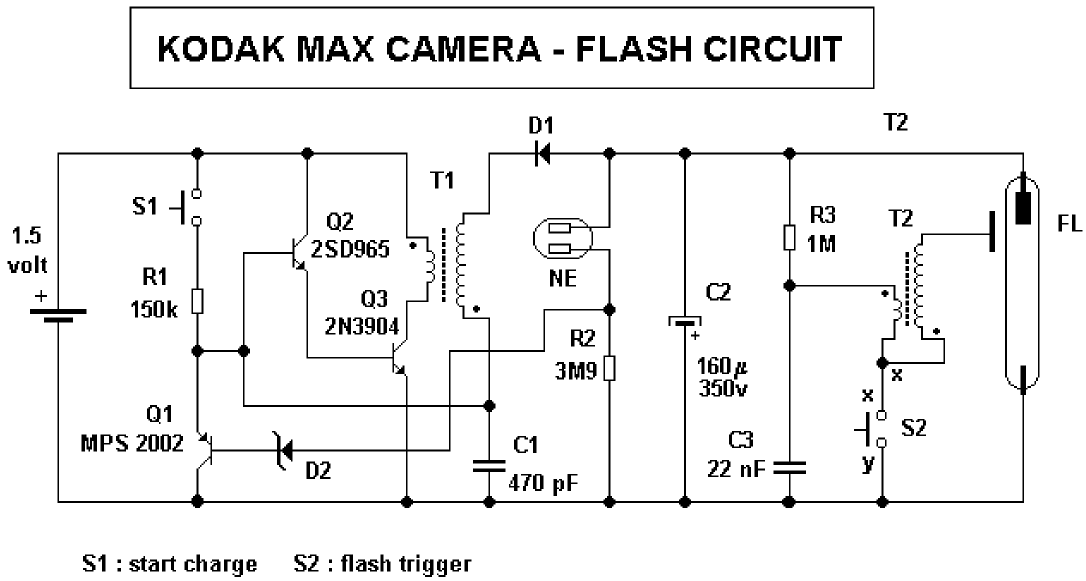

Figure 6.1 - Kodak Disposable Camera Circuit[7]

6.1 Brief Overview of Kodak Camera Circuit

When the user presses switch 1, it initiates Q1, Q2 and Q3 to switch on and off in a rapid manner. This creates a frequency across transformer T1, which allows for an extremely efficient voltage gain. On the other side of the transformer is a rectifying circuit, which creates a DC voltage of 300 V across C2. When C2 is properly charged the neon light NE will turn on; indicating to the user the flash is ready. When the user shorts switch 2, it creates an immense burst of energy across T2, that results in the extremely bright flash of light associated with cameras.[8]

6.2 Power Supply Modifications

6.2.1 Constant Voltage Modification

Our design requires for a steady voltage of 300V to be produced. When the capacitor is charged using the camera circuit, it reaches 300V and then slowly begins to lose charge at an initial rate of 1V/sec. To correct this loss, we took out switch 1 by creating a short across

[7] Le Magicien. (2005). *1.5 Volt Strobo with a.* Available: http://www.geocities.com/lemagicien_2000/elecpage/maxflash/maxflash.html. Last accessed November 1, 2007.

[8] Explained by Dr. Ash M. Parameswaran, School of Engineering Science, Simon Fraser University

these two nodes. This renders the circuit in a constant recharging mode, and results in a steady voltage across our capacitor.

6.2.2 On/Off Modification

When we turn the device off, we want to remove the battery from the circuit. We have therefore placed a switch on the positive end of the battery.

6.2.3 Safe Discharge Modification

The capacitor holds a great deal of charge. When our device is turned off enough this charge will still remain, and can cause an immense amount of pain; just ask Mohammadali Khorasani about it, he has many first hand experiences.

The peak current that is produced by this capacitor can go as high as 40 Amps. To make sure it discharges safely we have placed a 10 kΩ resistor in parallel. One end of this resistor is floating and attached to a switch. When the device is turned off, this resistor is connected and the capacitor discharges though it at a very fast rate of 0.16s, as given by Equation 2.

$$\tau = RC = (1k\Omega)(160\mu F) = 0.16s$$

Equation 2

This switch appears as a totally separate switch from that used in the On/Off modification, but will be directly related. We do not expect the user to turn the device off, and then also discharge the capacitor. Therefore, when the user turns the unit off, he will also discharge the capacitor by changing switch 2 to its second state.

All of our modifications can be seen in Figure 6.2.

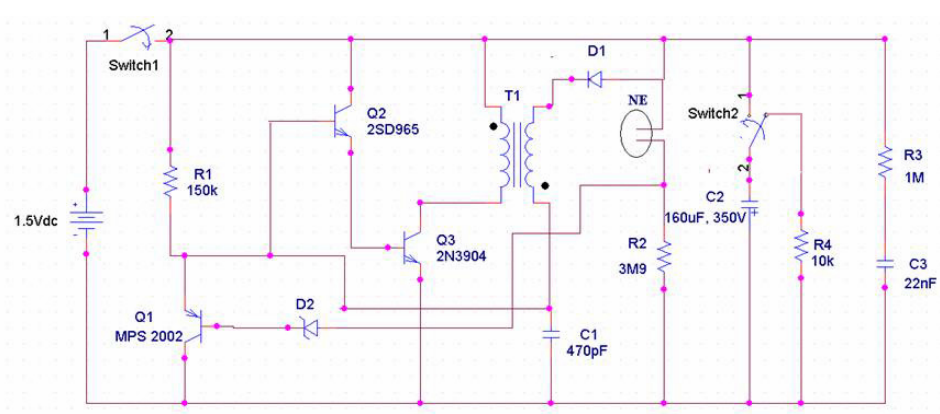

Figure 6.2 – TMDS Power Supply[9]

9 Created by Mohammadali Khorasani, November 10, 2007

7 Pulse Generator

We want to generate a 10 ms pulse every 2 seconds. The constant current generator is switched on and off by feeding a timing voltage into the BJT's base. This timing circuit is implemented using an LM555 timer.

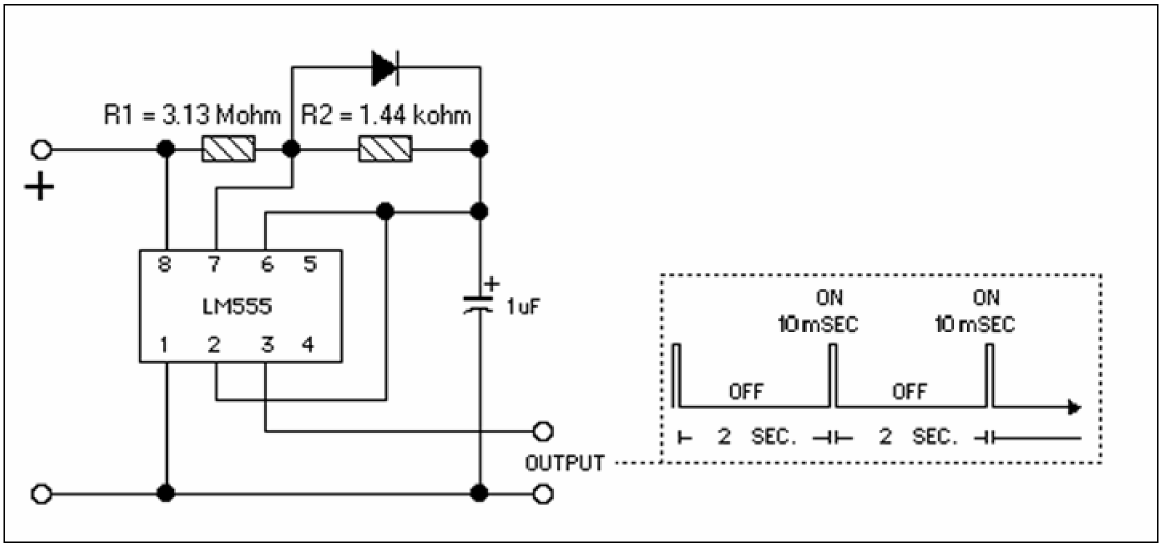

Figure 7.1 - LM555 Timer Circuit[10]

The equations that dictate the circuit are:

$$T_{ON} = 0.693CR_1 = 0.693(1\mu F)(1.44k\Omega) = 10ms$$

Equation 3

$$T_{OFF} = 0.693CR_2 = 0.693(1\mu F)(3.13M\Omega) = 2s$$

Equation 4

When in the OFF mode, the timer outputs 0 V, and when the timer is in the ON state it delivers an output of 3V.

Currently we connect two 1.5 AA batteries in series to power our circuit, but we are considering powering this circuit through the same circuitry as the BJT, by simply using a voltage divider; this configuration is preferable because it allows us to run the device using only 1 battery as opposed to needing different batteries for each component of the device.

[10] R. Paisley. (2007). *LM555 Timer Circuits.* Available: http://home.cogeco.ca/~rpaisley4/LM555.html. Last accessed November 1, 2007.

8 Clamp

The rubber dam clamp is a device made of stainless steel with that is used to retain a rubber dam in place and improve the operating field by isolating it from the oral environment. The shape of the clamp and the gauge of the stainless steel give the clamp spring like properties and allow it to slide upon the tooth and grip the tooth actively.

The clamp we designed is a stainless material with a spring attach to it. The spring is connected to a stainless rod which is placed in an angle with respect to the spring as is shown in the picture. The rod will be pushed onto the middle of the tooth by the force exerted by the spring. The rod and the spring are made of stainless steel and their surfaces are coated with rubber for isolation and safety purpose. The only two spots on the spring and rod without isolation are the tip of the rod and the portion attached to the TDMS. The clamp will therefore serve as a mechanism that isolates the tooth for work by the dentist and as a support platform for the attachment of the TDMS to the tooth.

When designing the clamp several parameters were considered. No fundamental changes in clamp design were made in order to insure acceptance by the dental profession and minimization of the need to educate staff members on the proper method of clamp placement. The addition of the spring and rod assembly to an existing platform should keep the clamp construction cost low. The clamp was designed in stainless with autoclavable spring components and plastic coatings in order to insure patient safety and avoid cross contamination.[11] The spring assembly and attachment rod were designed to be durable and withstand many autoclave cycles as well as repeated use. The clamp is pictured in Figure 8.1 through Figure 8.3.

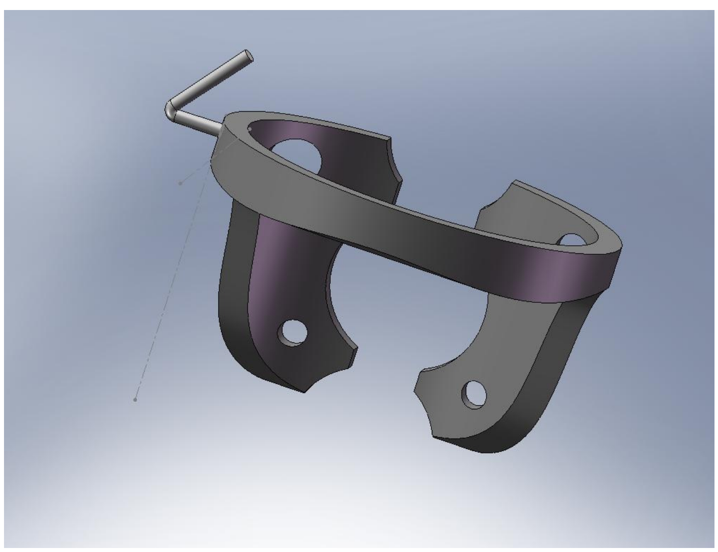

Figure 8.1 – Clamp View 1

[11] As suggested by Dr. Kevin Aminzadeh, November 5, 2007

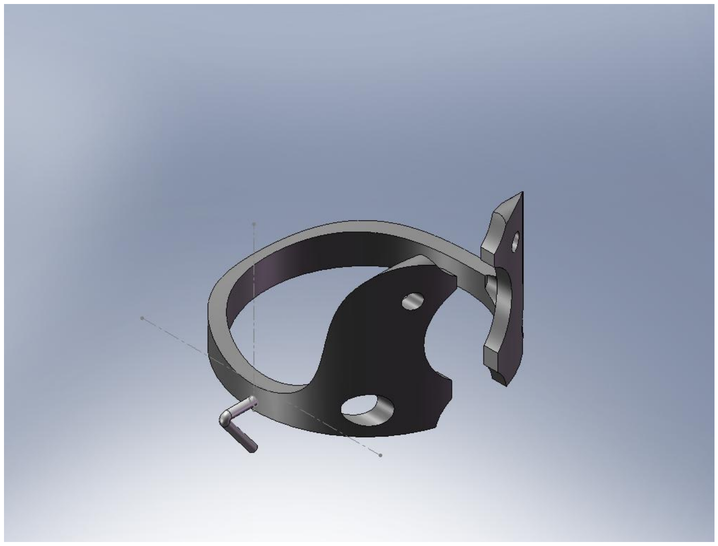

Figure 8.2 - Clamp View 2

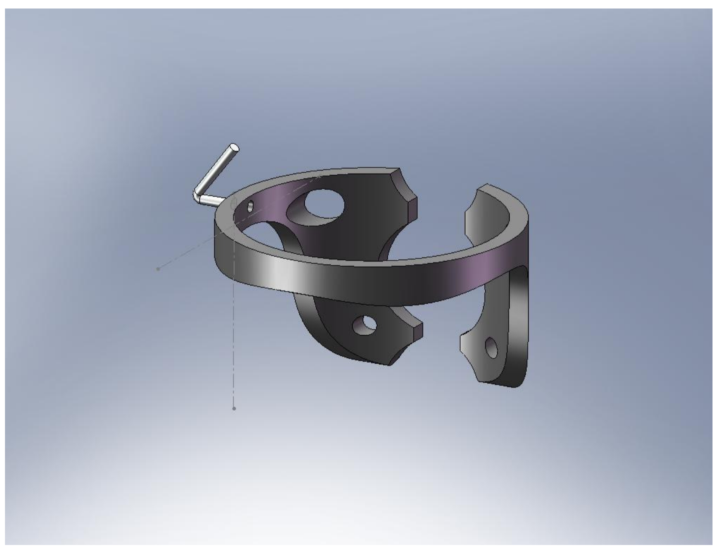

Figure 8.3 - Clamp View 3[12]

[12] Figure 8.1, Figure 8.2 & Figure 8.3 were created by Isabella Taba in Solidworks, November 12, 2007

9 User Interface Unit

The user interface panel will contain buttons and/or knobs as inputs from the operator and a screen as the output which shall display the current that the device is operating at. In addition, small warning lights will also alarm the user about conditions such as low battery and overload and fault.

A design of the user interface panel is shown below:

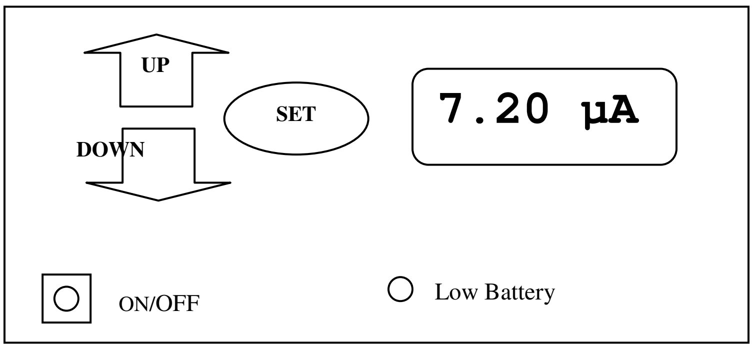

Figure 9.1 - A design for the user interface panel[13]

9.1 Inputs

9.1.1 Current Adjustment:

UP and DOWN buttons are used to, respectively, increase and decrease the current by the dentist and another button, SET, to choose the amplitude of the current pulses that are outputted. The SET button is intended to be included aside form the up and down buttons so that the operator will have a chance to see the current to be outputted first on the display and then choose the appropriate output by pushing the SET button. This will reduce the chance of cranking up the current unintentionally. The decrease/increase of current in very small steps by the DOWN or UP buttons also contributes to this cautionary design consideration. Please note that the UP and DOWN buttons might be replaced by a standard knob, upon further design considerations, that will increase the current when turned clockwise and decrease the current when turned in the opposite direction.

Using intuitive conventions for the buttons responsible for increasing/decreasing the current (e.g. arrows pointing up and down or +/-, or turning the knob clockwise/counter clockwise for indicating increase/decrease action) shall reduce errors by the users. In addition, appropriate spacing between input buttons and their location on the user interface panel shall reduce the chance of unintentionally pressing the wrong button by the operator.

[13] Created by Mohammadali Khorasani in Microsoft Word, October 2007

9.1.2 Power Control:

There will be a button for turning the power of the device on and off, labelled ON/OFF; this is another input from the user. A small LED will light-up to indicate when the device is on; this light is an output.

Locating the ON/OFF button on the bottom left corner of the panel and its smaller size, relative to the current adjustment buttons, appropriately fits its less frequent usage. However, by locating it at one of the corners of the panel, it is made in the reach of the operator and easy to find in case the user needs to promptly turn the device off.

9.2 Outputs

There will be a display screen that will inform the dentist of the output current. A seven segment display unit will be used to either display the value of the output current or an integer that corresponds to this value. Careful spacing of the display unit on the top right hand corner is consistent wit usability standards.

There will be warning lights to inform the operator about low condition. Also, as mentioned before, an LED on the ON/OFF button is another output of the device to the user. Using standard colors for output lights (orange for warning outputs and green for the ON state of the device) shall make the communication between the device and the operator more effective.

In addition, sound and bleep alarms are used as an output to inform the operator of warnings conditions of overload and fault detection. Using sound as opposed to visual warning will ensure that these conditions are noticed by the dentist as he/she is operating on the patient and lacks visual communication with the interface panel.

10 System Test Plan

The separate components of the device will be implemented first. After completing individual part testing, we will test the entire unit under normal as well as extreme circumstances.

10.1 Unit Testing

1. The power supply will be left charged for a maximum of one week, to verify that one battery can power the unit for a significant time.

2. The timer will be connected to two 1.5 V AA batteries, and we will verify that it produces the proper waveform; we will check for the right pulse duration, frequency and amplitude.

3. The BJT constant current generator will be hooked up to a function generator instead of the timer, and the powered by 30V lab generator. We will verify that the right currents are produced, and that it can produce the currents to a suitable accuracy.

4. The clamp will be tested for electric conductivity.

10.2 Varying Resistances

Scenario: Varying resistive loads applied to the device.

Conditions: The circuit will be hooked up to the bread board, and we will measure the current across varying values of resistors, from 1-10 MΩ.

Expected Results: We do not expect the current to vary greatly with various loads, but rather it will be determined by the input value entered by the user.

10.3 Testing Reaction on Nerve

Scenario: The current generator will be connected to the lips of a patient.

Conditions: After applying the device to the lips of a patient without the clamp, we will increase the current until the patient feels something. This test will be conducted by just the engineers.

Expected Results: We aim to cause a touch like sensation in the lips of the patient.

10.4 Nerve Stimulation

Scenario: The device is mounted on the patients tooth, using a clamp.

Conditions: The patient will be lying on their back, and we will apply the clamp. The clamp will not be applied by any of the engineering students, but rather by Dr. Kevin Aminzadeh. After successful application of the clamp, we will turn on our device.

Expected Observations: The current will slowly be increased until the patient gives a signal that they can feel a rhythmic touch sensation; our aim is for this feeling to be comfortable and in no way painful.

10.5 Shorting of the Circuit

Scenario: The device is mounted incorrectly, and the dentist touches the positive and negative terminals of the device together.

Conditions: We will connect the device across a very small resistance, in the range of a few ohms, and see if the current generated is still constant.

Expected Observations: We do not expect the amount of current to be changed by shorting the device.

11 Conclusion

We are very positive that our innovative product can substantially reduce patients' pains and help dentists to enhance their productivity. There is a huge market demand for our innovation in dentistry and medicine and can provide vast financial outcome in near future. With its safety features and accurate performance, our innovative product would shorten the dentists' performance time and greatly enhance the safety of the patient during the dentist operations

12 References

1. Canadian Centre for Occupational Health and Safety, "What is meant by thermal comfort?", *OSH Answers: Thermal Comfort for Office Work*, August 23, 2005. [Online]. Available at: http://www.ccohs.ca/oshanswers/phys_agents/thermal_comfort.html. [Accessed: October 11, 2007].

2. Martins De Araujo MT, Vieira SB, Vasquez EC, Fleury B. Heated humidification or face mask to prevent upper airway dryness during continuous positive airway pressure therapy. Chest 2000;117(1):142-147. [Online]. Available at: http://www.talkaboutsleep.com/sleep-disorders/archives/Snoring_apnea_abstract79.htm [Accessed: October 11, 2007]

3. Virtanen A. Electrical Stimulation of Pulp Nerves-Comparison of Monopolar and Bipolar Electrode Coupling. 1985. Elsevier.

4. Dr.Kevin Aminzadeh, Dentist

5. Dr. Ash M. Parameswaran, Professor of the School of Engineering Science, SFU

6. Dr. Parveen N.S. Bawa, Professor of the School of Kinesiology, SFU

7. Pepper M and Smith D. *An electric tooth pulp vitality tester.* 1981. Medical & Biological Engineering & Computing

8. Le Magicien. (2005). *1.5 Volt Strobo with a.* Available: http://www.geocities.com/lemagicien_2000/elecpage/maxflash/maxflash.html. Last accessed November 1, 2007.

9. R. Paisley. (2007). *LM555 Timer Circuits.* Available: http://home.cogeco.ca/~rpaisley4/LM555.html. Last accessed November 1, 2007.

