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Compatibility of CMOS Detectors in Production Line Image Testing

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The purpose of this thesis work was to prove that an image testing section of an intraoral dental machine production line could function with a CMOS detector. The pre-existing style of imaging used was a photostimulable phosphor plate and a separate reader for the plate, which was very time consuming. The detector was much quicker in the process of getting the image to the software for further analyzing. To be eligible for use in the production line the detector had to be active to obtain the radiation data at the same moment as the intraoral machine made the exposure.

To achieve this an external circuit was used, which consisted of a timer circuit and an opto-coupler. The external circuit obtained a signal from the intraoral machine when the exposure was started and modified the signal length to be fit for the i2000 circuit board that controlled the detector. The i2000 board was connected to a computer, which was running a script that allowed the tester to control the image testing procedure. At the end of the exposure the i2000 board saved the image data to the computer for further image analyzing on a computer software.

The test results were at a satisfying level for the system to be implemented into the production line in the foreseeable future. The images obtained were clear and quick to get into the software used for viewing and analyzing.

Keywords	Dental, Imaging, Intraoral, Radiation

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Opinnäytetyön päätarkoituksena oli todistaa, että suunsisäisen hammaslääkärilaitteen kokoonpanolinjan kuvan testauspiste voi toimia CMOS-sensorin kanssa. Edeltävä kuvantamisen tyyli oli kuvastimuloitu fosforilevy ja erillinen lukija levylle, mikä oli erittäin aikaavievää. Sensori oli paljon nopeampi saaman kuvan otettua ja siirrettyä tietokoneohjelmistoon analysointia varten. Sensorin piti pystyä olemaan valmis vastaanottamaan valoitusta silloin kun laite aloitti valoituksen, jotta sensoria pystyisi käyttää kokoonpanolinjan kuvan testauspisteessä.

Tämä tavoitettiin käyttämällä ulkoistapiiriä, johon kuului ajastinpiiri ja optinen kytkin. Ulkoinenpiiri vastaanotti signaalin suunsisäiseltä laitteelta ja muutti signaalin pituutta niin, että se oli sopiva i2000 piirikortille, joka ohjasi sensoria. i2000 piirikortti oli yhdistettynä tietokoneeseen, joka pyöritti komentosarjaa, minkä avulla testaaja pystyi kontrolloimaan kuvan testaustoimenpidettä. Valoituksen päätyttyä i2000 piirikortti tallensi kuvan tiedoston tietokoneelle, josta sen pystyi avata analysointia varten tietokoneohjelmalla.

Testaustulokset olivat tyydyttävällä tasolla, jotta järjestelmä voidaan implementoida kokoonpanolinjalle lähitulevaisuudessa. Testikuvat mitä otettiin testien aikana olivat selviä ja nopeita saada tietokoneohjelmaan analysointia varten.

Avainsanat	Hammaslääkäri, Kuvantaminen, Suunsisäinen, Säteily

Contents

List of Abbreviations

PSP — Photostimulable phosphor. A material that stores absorbed energy within excited electrons and release it in the form of light on exposed to X-rays.

CMOS — Complementary metal oxide semiconductor. Technology used to produce integrated circuits.

LVDS — Low-voltage differential signaling. A technical standard that specifies electrical characteristics of a differential, serial signaling standard. Used in many data communication standards and applications.

USB — Universal serial bus. An industry standard that establishes specifications for cables, connectors and protocols for connection.

UART — Universal asynchronous receiver-transmitter. A computer hardware device for asynchronous serial communication in which the data format and transmission speeds are configurable.

CPU — Central processing unit. An electronic circuitry within a computer that executes instructions that make up a computer program.

IP address — Internet protocol address. A numerical label assigned to each device connected to a computer network that uses the internet protocol for communication.

TTL — Tera Term language. It is a simple language like BASIC. Check Tera Term website for more info.

CAN — Controlled area network. Allows microcontrollers and devices to communicate with each other's application without a host computer.

TIF — Tag image file. It is a computer file format for storing raster graphics images.

1 Introduction

This thesis work was devised for a company that manufactures Dental radiography equipment called KaVo Kerr, more specifically for an intraoral Focus unit manufacturing line. In the production line the thesis work was aimed at the image quality testing section, with a purpose of making the image quality testing faster and the equipment used easier to repair in case of a malfunction. The equipment used at the time were old and not manufactured anymore, making them difficult to repair in the worst-case scenario of a malfunction. The end result was estimated to increase productivity in the manufacturing line as well as the reliability of the equipment used. To achieve the goal, parts from another manufacturing line were used. Getting the new parts to work in the testing point with the intraoral Focus X-ray machine in harmony, required an external circuit and a Tera Term script to control the testing process.

2 Oral Radiology

2.1 X-ray machine

An X-ray machine is a medical appliance that provides X-rays that pass through a patient's body and hit a digital receptor or film to produce a radiographic image. For intraoral X-ray units, the tube head is usually connected to a support arm that is mounted either to a wall or a dentist's chair as figure 1 illustrates.

Figure 1. Example of an intraoral wall-mounted X-ray unit, KaVo FOCUS.

A control panel is used to adjust the duration of the exposure, exposure rate and the energy, of the X-ray beam. For electrical insulation often oil is used to surround the tube and transformers. To increase the source-to-object distance and minimize distortion the tube is usually enclosed within a tube head. (Mallya and Lam, 2019).

2.1.1 X-ray tube

An X-ray tube consists of an anode and a cathode placed within vacuum of a glass envelope or a tube as can be seen in figure 2.

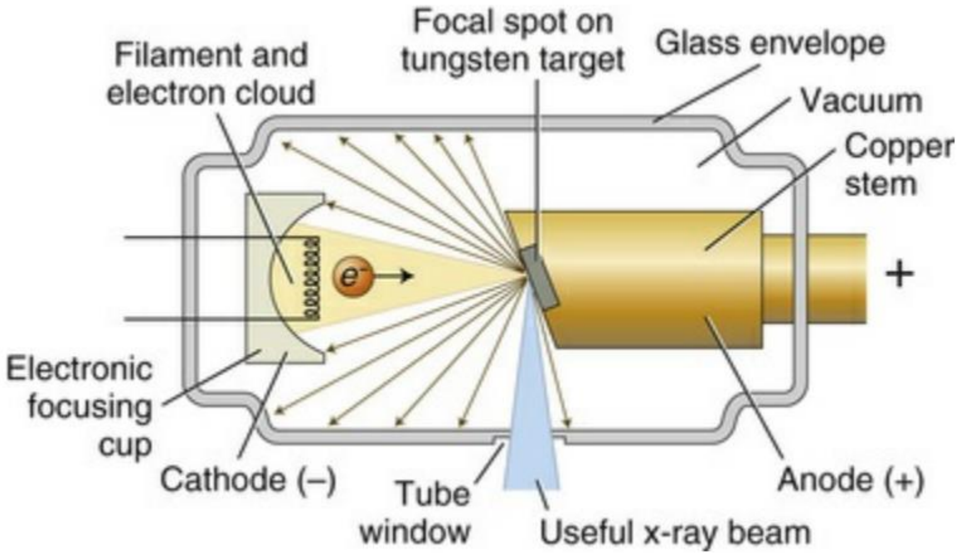


Figure 2. X-ray tube with the major components labeled (Mallya and Lam, 2019, p.47).

The X-ray is produced with the electron's stream from the filament in the cathode that is focused with an electronic focusing cup to the target in the anode. The cathode of an X-ray tube includes a filament and a focusing cup. The filament is the source of electrons in the X-ray tube. It is a coil of tungsten wire and usually include approximately 1% thorium, which greatly increases the release of electrons from the heated wire. The rate of electrons emitted is proportional to the temperature of the filament and it is heated with a low-voltage source. The anode in an X-ray tube includes a tungsten target embedded in a copper stem. The target has a purpose to convert kinetic energy from the colliding electrons into X-ray photons. The conversion is inefficient, since more than 99% of the electron kinetic energy is converted to heat. The target is made of tungsten, an element with many characteristics of an ideal target material, including the following:

- High melting point (3422°C) allowing it to withstand the heat coming from the x-ray production.
- High atomic number allowing efficient X-ray production.
- Low vapor pressure at the working temperatures of an X-ray tube, helping to maintain the vacuum in the tube at high temperatures.
- High thermal conductivity (173 $W\,m^{-1}\,K^{-1}$) helps to dissipate the heat away from the target.

The target has a focal point to which the focusing cup directs the electrons and from which X-rays are produced. The X-ray tube and two transformers are housed withing an electrically grounded metal housing, which is called the tube head of the X-ray machine. The power supply transformers have two primary functions, to provide a low-voltage current to heat the X-ray tube filament and to accelerate the electrons by generating a high potential difference from the cathode to the focal spot on the anode. (Mallya and Lam, 2019).

2.2 Sources of radiation exposure

The primary exposure to radiation for the general population comes from natural background and medical sources. The background radiation sources can be divided to four different parts consisting of

- radon
- terrestrial
- internal radionuclides
- space.

Global average annual effective dose of background radiation is 2.4 mSv per year. Most of it comes from radon, but the other three sources have a significant contribution to the total dose as can be seen in figure 3.

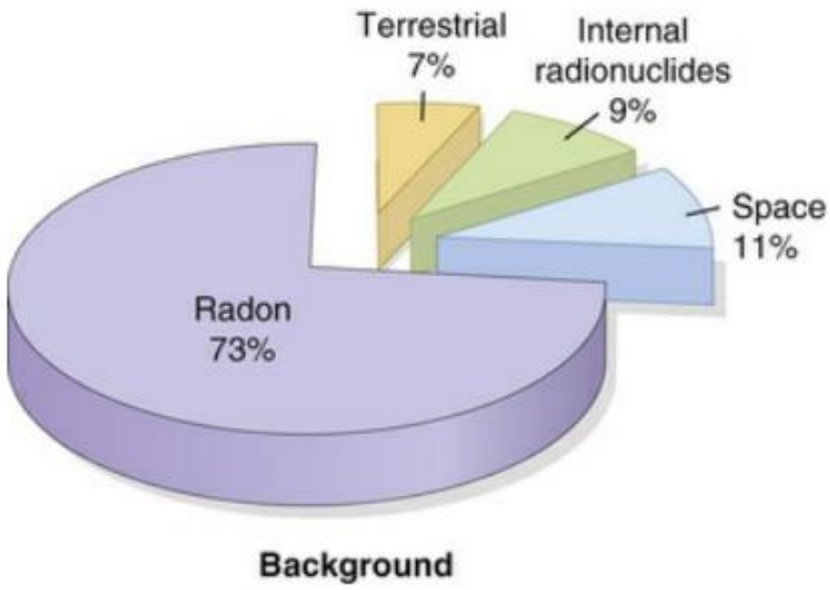


Figure 3. Pie chart of the background radiation sources (Mallya and Lam, 2019, p.104).

Radon-222 is a decay product from uranium-238. Radon-222 with its decay product polonium-218 emit α particles, that can be attached to dust particles and inhaled. Radiation that comes from the space is from the sun and cosmic rays. The amount of radiation from space almost doubles every 2000 meters increase in elevation. This happens because the earth’s atmosphere is less present to attenuate the radiation. Terrestrial radiation comes from radioactive nuclides in the soil. The top 20 cm of the soil contain most of the γ-radiation from radioactive nuclide potassium-40 and the radioactive decay products of uranium-238 and thorium-232. Internal radionuclides are a source of radiation that are ingested. Food containing uranium and thorium and their decay products, primarily potassium-40 are the sources of the greatest internal exposure.

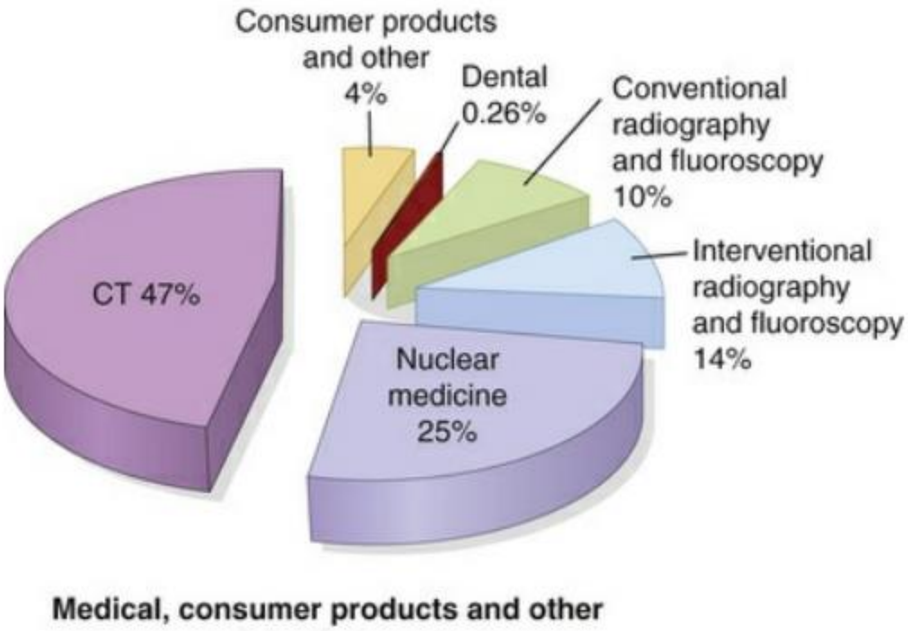


Figure 4. Pie chart of the human contributed additional sources of radiation (Mallya and Lam, 2019, p.105).

Medical exposure covers most of the human made additional radiation, however even though dental X-ray examinations are done relatively frequently it only contributes a small percentage of the medical total exposure as figure 4 illustrates. Some consumer products that are sources of radiation are mining and agriculture, cigarette smoking, combustion of fossil fuels and air travel. (Mallya and Lam, 2019).

2.2.1 Protection from radiation exposure

The three guiding principles in radiation protection are justification, optimization, and dose limitation. These are used to eliminate as much unnecessary radiation as possible. The principle of justification in practice influences what examination a dentist chooses for a patient, and which patients are selected for radiographic examinations. The principle of optimization withstands that dentists should reduce unnecessary exposure with every reasonable mean available to protect patients and the working staff. Some of these reasonable means include:

- Only making radiographs when they are likely to contribute to diagnosis and treatment plans.
- Optimizing exposure settings to fit with the patient’s size and the area to be imaged.
- Standing at least 2 meters away from the patient and from the X-ray machine when making the exposure.

The principle of dose limitation determines safe limits for radiation doses in occupational and public exposures to confirm that no one is exposed to unacceptably high doses. The principle only applies to dentists and their staff who are exposed occupationally. It does not apply to patients, because there are no dose limits when it comes to individuals exposed for diagnostic purposes. When it comes to protecting patients there are several things to consider. Radiographs should only be made when they are likely to provide additional information. Historical or clinical findings help to identify patients with a high probability, that a radiographic examination would provide information affecting their prognosis or treatment. When a radiograph is decided to be obtained, the dentist should always choose the lowest dose image that would still provide the necessary diagnostic information. Good radiologic practice is to use the fastest image receiver that is compatible with the diagnostic task. When a faster receiver is in use the needed exposure decreases. The distance between the exposure source and the patient skin has an impact on the exposed tissue volume. Two standard distances are used in intraoral radiography 20 cm and 40 cm. With longer distance the X-ray beam is less divergent. (Mallya and Lam, 2019).

2.3 Digital imaging in dental imaging

Digital imaging differs from analog in the numeric format of the image content and its discreteness. Conventional film imaging can be considered an analog medium in which differences in the size and distribution of black metallic silver result in a continuous density spectrum. While in the digital medium the spatial distribution of the pixels and the different shades of gray of each of the pixels make digital images numeric and discrete. The pixels are placed in a matrix with a location coordinate containing the row and column of each pixel. An analog process is required in the beginning of forming a digital image. X-rays generate a small voltage at each of the pixels, the voltage increases with the intensity of X-rays. The voltage can fluctuate between a maximum and minimum value at each pixel, thus it is an analog signal. The signal then goes through an analog-to-digital conversion (ADC). (Mallya and Lam, 2019).

There are numerous digital image receptors of different shapes and sizes, that utilize different technologies. Two main technologies are solid-state technology and photostimulable phosphor (PSP) technology. Even though there are many subdivisions of solid-state detectors, they have certain physical properties and the ability to generate a digital image in the computer without any other external device in common. Intraoral solid-state detectors are often called sensors in dentistry. A type of solid-state detector is a complementary metal oxide semiconductor (CMOS) detector. These detectors have pixels that are read individually, each pixel is isolated from its neighboring pixels and connected directly to a transistor. Within a pixel electron-hole pairs are generated in proportion to the amount of absorbed X-ray energy, this charge is transferred to the transistor as a small voltage. The voltage in each transistor can be addressed separately, read by a frame grabber, and stored and displayed as a digital gray value. CMOS technology is widely used for intraoral imaging applications by most manufacturers. Photostimulable phosphor (PSP) technology uses PSP plates that absorb and store energy from X-rays. The stored energy can be released as light (phosphorescence) when another light of an appropriate wavelength stimulates the plate. When the phosphorescent light and the stimulating light differ in wavelengths, the two can be distinguished, and the phosphorescence can be quantified as a measurement of the amount of X-ray energy that the material has absorbed. In one of the ways to read the PSP plates, a rapidly rotating multifaceted mirror is used to reflect a beam of red laser light. The laser sweeps across the plate as the mirror revolves. As the plate advances, an adjacent line of phosphor is scanned. The direction of plate advancement is termed the slow scan direction and the direction of the laser scanning is termed the fast scan direction. (Mallya and Lam, 2019).

3 The Focus manufacturing line image quality test

3.1 PSP plate version

The test consisted of several small steps. There were two small dental radiation doses from an intraoral Focus device, which were radiated to a PSP plate and then a PSP reader read them and provided an image to the computer software as can be seen in figure 5.

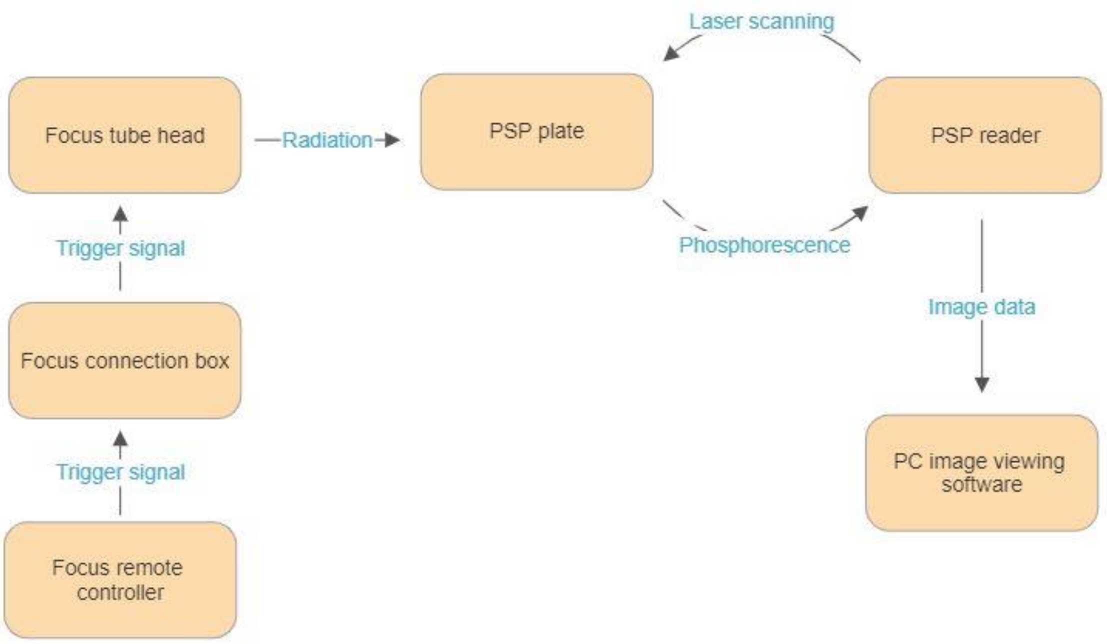


Figure 5. Block diagram of the image acquiring process using a PSP plate.

The procedure to acquire an image took over a minute when the PSP reader was scanning the PSP plate. Since the procedure had to be carried out twice for a single intraoral Focus unit, the scanning part was clearly a loss of time. A time that could be spent more efficiently. When the image was in the computer software, the area of radiation was measured by measuring the diameter of a circular radiated area or measuring the width and height of a rectangular radiated area, depending on whether a circular or a rectangular variation of the collimator was attached. After the images were observed and measured, two voltage tests were to be carried out.

3.2 CMOS detector version

In the new version the test steps were the same, but the radiation target was changed from a PSP plate to a CMOS flat detector as figure 6 illustrates.

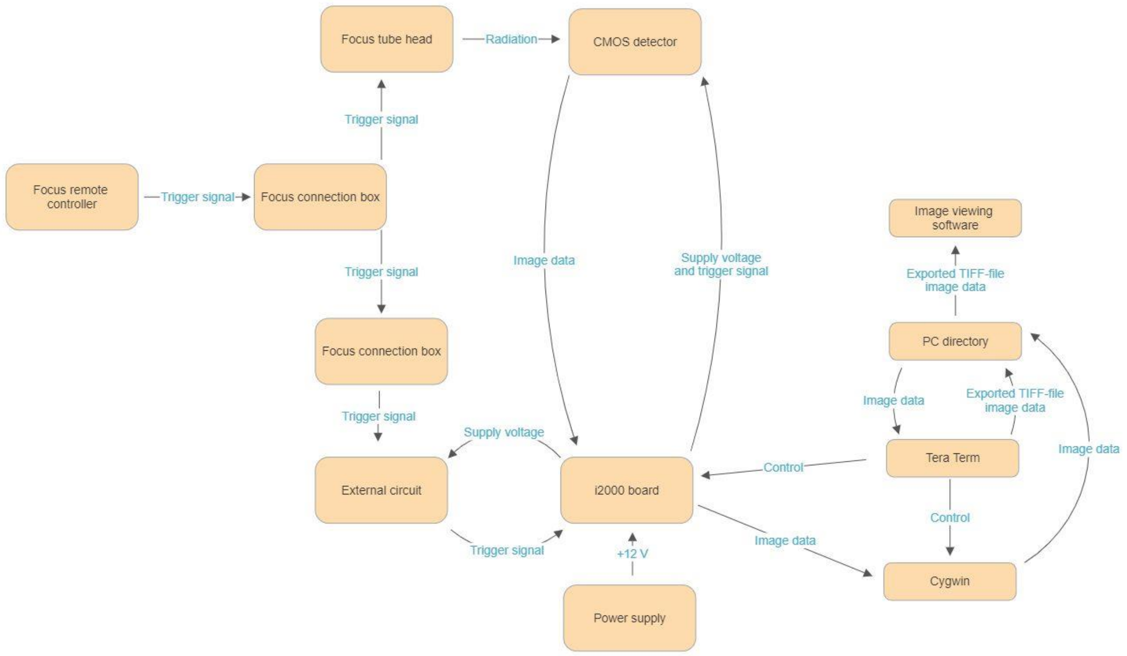


Figure 6. Block diagram of the image acquiring process using CMOS detector.

This implementation meant that other parts had to be added in the process to make it work. In the CMOS version the two small dental radiation doses were radiated to the CMOS detector, that was controlled by the i2000 board, which received instructions from the computer through a script running in Tera Term program and got the trigger signal from the Focus connection box through an external circuit. The whole procedure of acquiring an image to be viewed in the computer software with CMOS version was more time efficient than in the PSP plate version, since the time to get the image data from the CMOS detector to the computer directory was from 2 seconds to 5 seconds depending on the file size. A significant improvement compared to the time it took with the PSP plate version.

4 Connection and control of acquiring an image

4.1 Acquiring an image with CMOS detector

The main factor to acquire an image with the CMOS detector version was figuring out a way to arrange the Focus tube head and the CMOS detector to operate simultaneously. This arrangement can be seen presented as a block diagram in figure 6. The way used was to get the CMOS detector triggered by the same button that triggers the Focus tube head radiation. With some manipulation of the signal that appeared when the exposure button was pressed, this was achieved.

4.2 Connection points in the CMOS detector version

4.2.1 Focus unit

In the beginning, the first idea that came to mind to get the trigger signal for further usage from the remote controller was to use an ethernet grabber to get the information signal from the ethernet cable that connects the remote controller and the connection box. This idea was quickly discarded as the knowledge of the signal variety that was transported through the ethernet cable came clear. Originally thought to be a kind of binary signal of multiple bits, turned out to be a single change in voltage when the exposure button was pressed. This knowledge helped tremendously to come up with a new idea to obtain the trigger signal for further usage. This meant that there was no need for any overly complicated ethernet grabber system.

After all the schematics of the Focus unit were examined, it was discovered that the best point to take the trigger signal coming from the remote controller, was the connection box as it was originally considered to be. The signal ended up being taken from the connection box's row connector which in more detail had two pins that were needed, ground pin and the trigger voltage pin.

4.2.2 The i2000 board and CMOS detector

The connection between the i2000 board and the CMOS detector consisted of four wire set for triggering and power, with a LVDS connector for data transport. This led into attempts to insert the trigger signal from the Focus connection box into the i2000 boards trigger signal line that controls the CMOS detector. However, this led to the i2000 board to run into errors in its own programming. With the help of a previous Thesis work done in the same company, that also used the i2000 board in it, it was found that there were many commands in the i2000 boards program, that return nothing if false and a message "ok" if true. One of these commands connected to a connector that was used to let the i2000 board know, that the exposure button has been pressed. The CMOS detectors datasheet revealed that there were three different synchronization modes that determined how the trigger signal operated the detector to obtain data from the incoming radiation. With that information the concept of the external circuit that connects the Focus and the i2000 board was able to be completed.

4.2.3 External circuit

With the Focus units and the i2000 boards connection points known, what was needed was a way to connect them together while using the trigger signal to inform the i2000 board that the exposure button has been pressed. The trigger signal on the Focus connection box was tested to be active only for a short while when the exposure button was pressed. This was an inefficient time to get the i2000 board to read it and give the signal to the CMOS detector to start detecting radiation. So, the solution was to make the signal last longer. This was achieved with a monostable 555 circuit, that would make the trigger signals voltage change last for one second, which was reassuringly more than enough time to have a script to notice that a change has happened. The monostable 555 circuit alone was not enough. From the schematic of the i2000 board was found that the pins that could be checked by a command were located in connector J2001 of the i2000 board. The result of the command was triggered by an optocoupler. So, the signal that came from the monostable 555 circuit was connected to an optocoupler as the emitting diode and the pins on the i2000 board were connected to the phototransistor side of the optocoupler. This external circuit was powered with +5 V voltage from the i2000 board, the power was taken from a +5 V line and the common ground of the i2000 board.

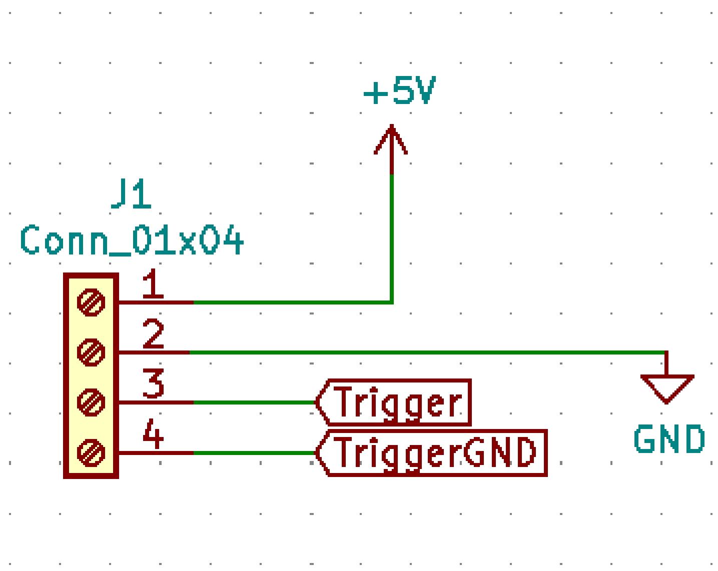


Figure 7. First part of the schematic of the external circuit that connects the Focus connection box and the i2000 board.

As can be seen in figure 7, the first part of the schematic displays one of the connectors. This connector was used to connect two pins to the Focus connection box pins containing the trigger signal voltage. These pins were labelled in the connection box as X61-2 and X61-7, the X61-2 was ground, and the X61-7 was the trigger signal. The other two pins came from the i2000 board to supply the monostable 555 circuit.

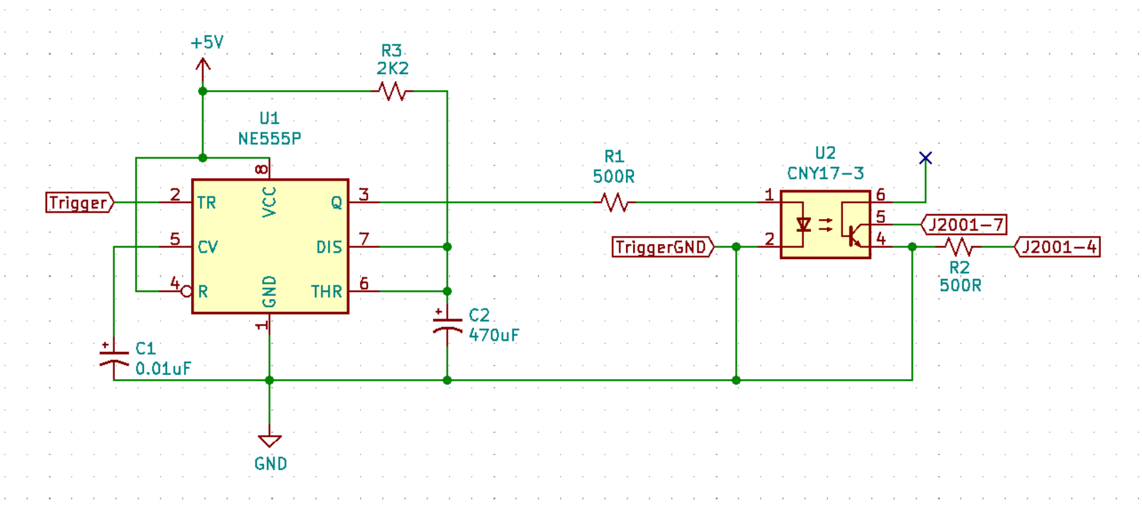


Figure 8. Second part of the schematic of the external circuit that connects the Focus connection box and the i2000 board.

The important part of the external circuit was formed as figure 8 illustrates. In the monostable 555 circuit, the NE555P precision timer was used to extend the trigger active time (Texas Instruments, 2014, p. 10). The trigger coming from the Focus connection box acted as a trigger for the monostable circuit. To achieve an approximate one second active time in the output, following resistor and capacitor values were used. For the capacitor, a value of 470 microfarads was decided and the resistor value was 2200 Ohms to get the approximate one second output active time with the formula 1.

$$t = 1.1RC \qquad (1)$$

The output from the monostable was connected to the input of the emitting side on the CNY17-3 optocoupler through a 500 Ohm resistor. The output of the emitting side was connected to the trigger ground (Vishay, 2014, p. 4). All grounds were connected in the end. On the phototransistor side of the optocoupler, pin 6 was left unconnected as there was no need for it to be connected to anything. Pin 4 and 5 were connected to a connector named J2001 on the i2000 board, which had the ability to check connectivity with a command in the script.

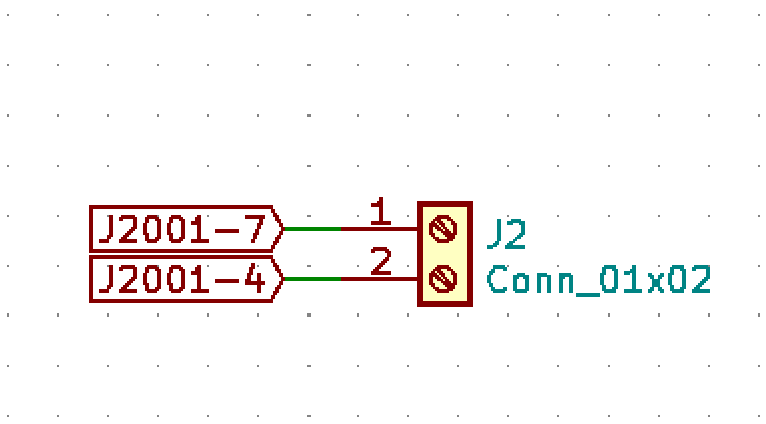


Figure 9. Third part of the schematic of the external circuit that connects the Focus connection box and the i2000 board.

The two wires that were connected to the i2000 boards connector J2001 had their separate connector as figure 9 illustrates. The external circuit was soldered on a stripboard.

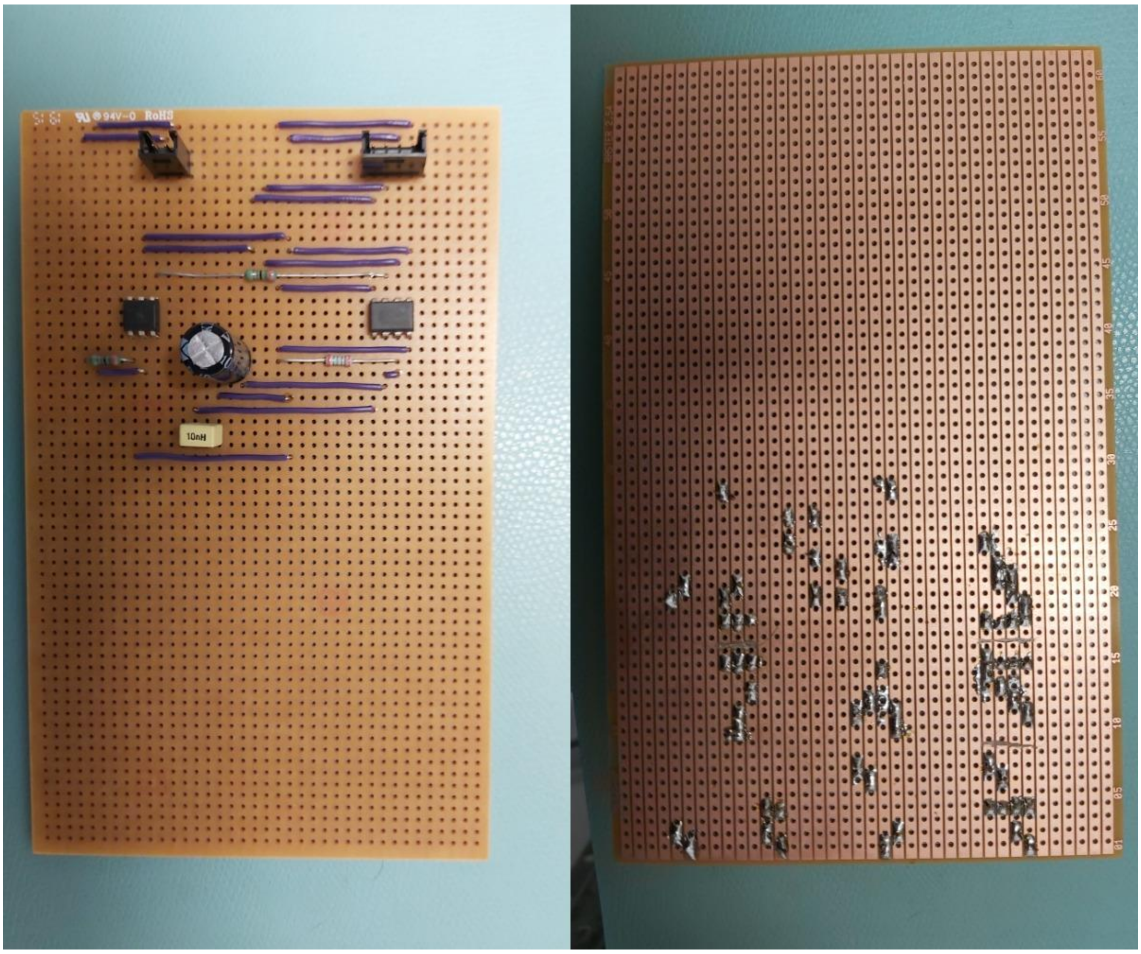


Figure 10. The circuit soldered on a stripboard.

The circuit was soldered in such a way on to the stripboard, that it included multiple jump cables, which allowed it to stay orderly and easy to follow as figure 10 illustrates.

4.3 Controlling the image acquiring processs

4.3.1 Computer configuration

There were two connection types used from the computer to the i2000 board in order to control the board and receive the image data from the board. For the control, an USB connector was used for an UART connection and for the data transfer an ethernet connection was used. To get the UART connection working between the computer and the i2000 board, a specific driver provided by the company was installed to the computer.

There was also an important thing that had to be done for the computer to ensure that everything works. The IP-address of the computer had to be changed.

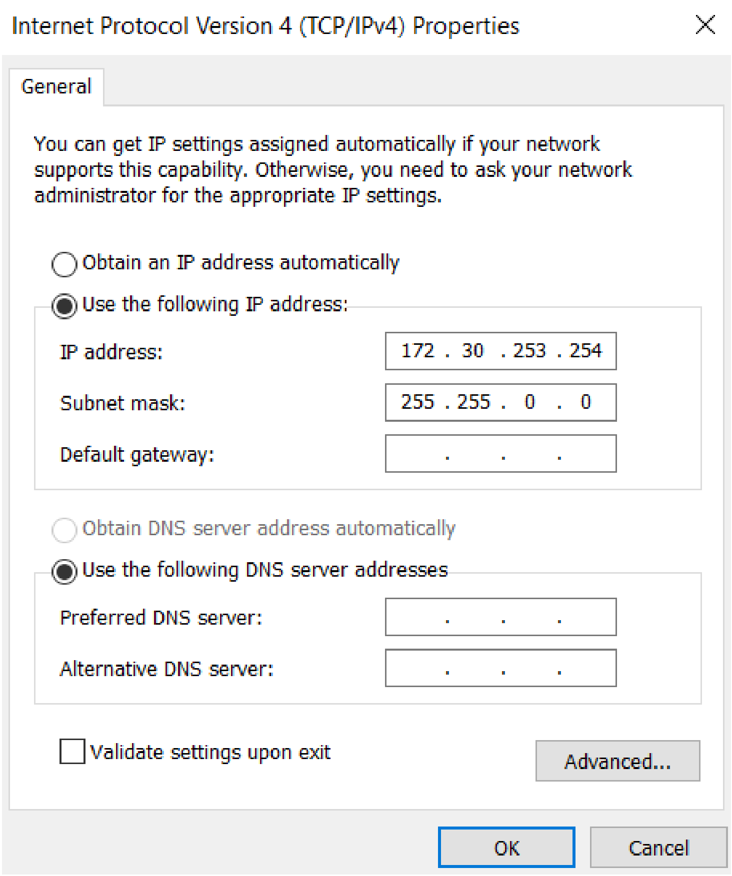


Figure 11. IP configuration of the computer.

The IP address of the ethernet connection between the computer and the i2000 board was changed to somewhere between 172.30.253.0 and 172.30.253.254 to get them in to the same network as can be seen in figure 11. Since the i2000 boards IP address was set to a static 172.30.253.253, and the automatic IP address setting did not get the correct network for the computer, the IP address had to be set manually. Two programs were used to setup the i2000 board correctly and to control it with a script. The programs were called Cygwin and Tera Term.

4.3.2 Cygwin setup

The program Cygwin was used to test that the i2000 board is working properly by running a stress test, provided by the company. This stress test also reprogrammed the i2000 boards CPU and tested the connection between the computer and the board.

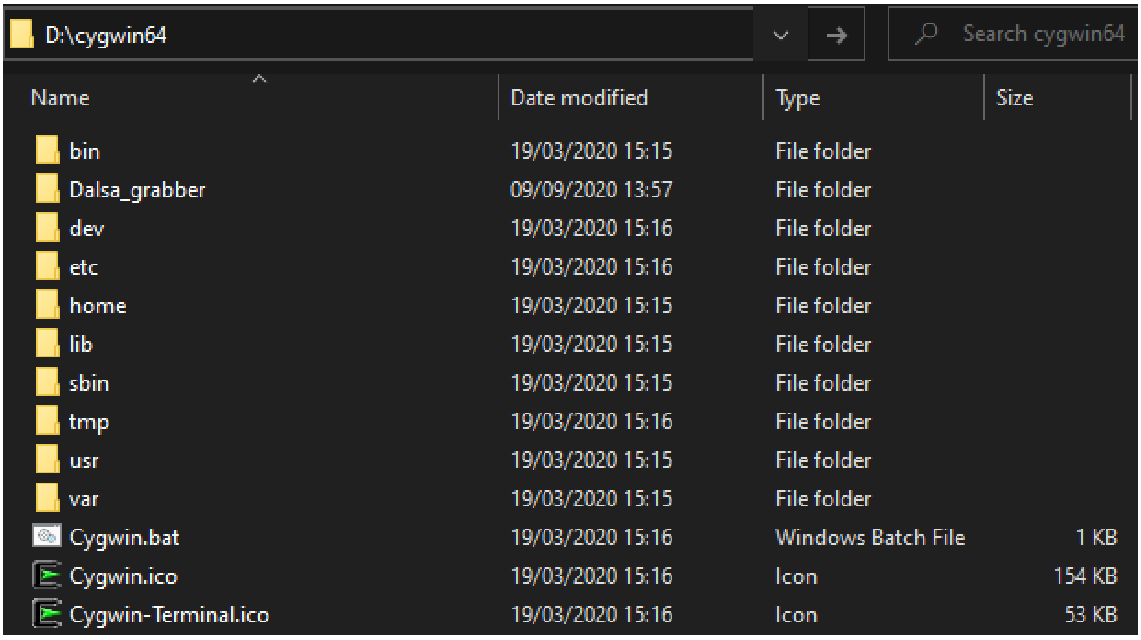


Figure 12. Inside of the Cygwin directory.

A folder called Dalsa_grabber was installed into the Cygwin directory as figure 12 illustrates. Inside the Dalsa_grabber folder was the i2000 stress test and socket client file. The socket client file was used in the Tera Term script to connect to the i2000 through ethernet and get the image data from the i2000 board to the computer. The i2000 stress test, which is inside the Dalsa_grabber folder was named i2000_stress.sh as figure 13 illustrates.

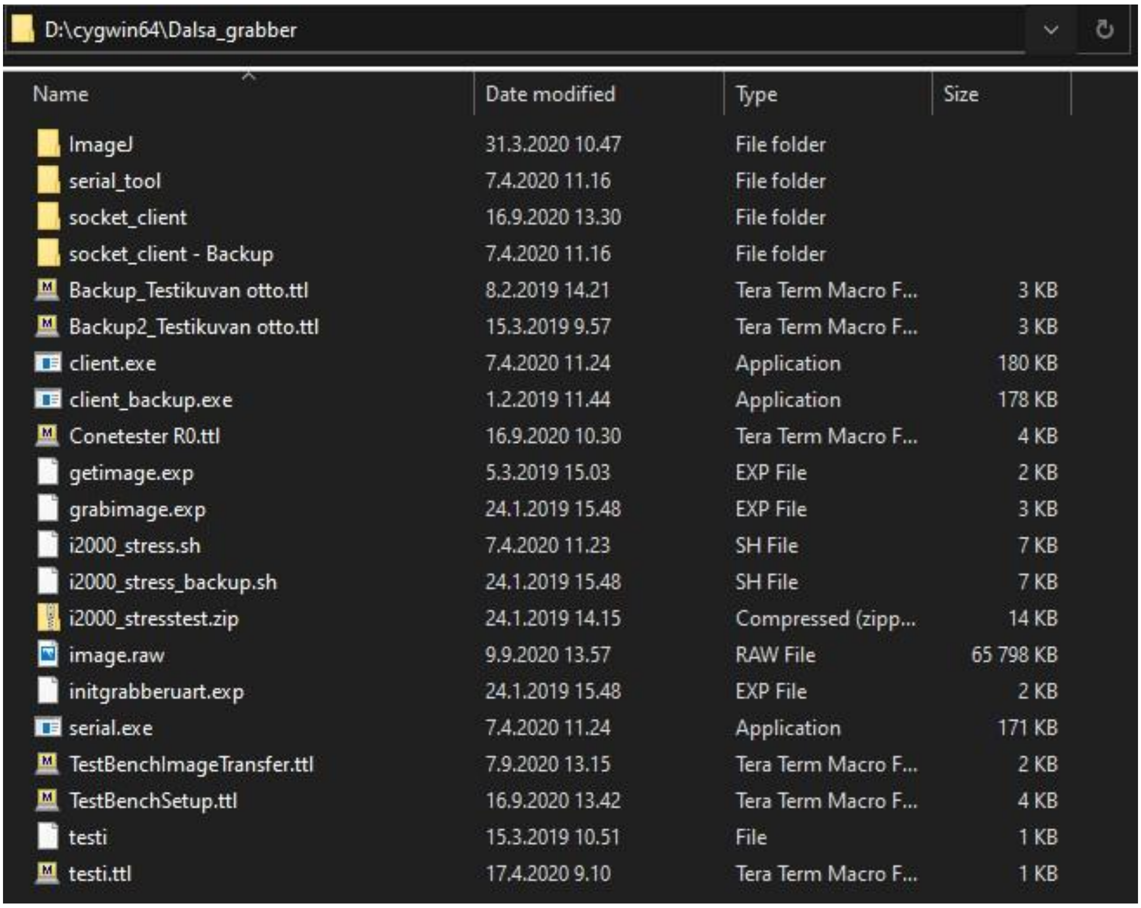


Figure 13. Inside of the Dalsa_grabber directory.

To start the stress test with Cygwin, first when Cygwin was started, the working directory was set to the target directory where the stress test was allocated. By writing a command, that would start the stress test into the Cygwin terminal the stress test returns a small template, that shows what command to use depending on what kind of Dalsa product was connected at the time. The template, that was returned, and the command that was used to start the stress test was highlighted as can be seen in figure 14.

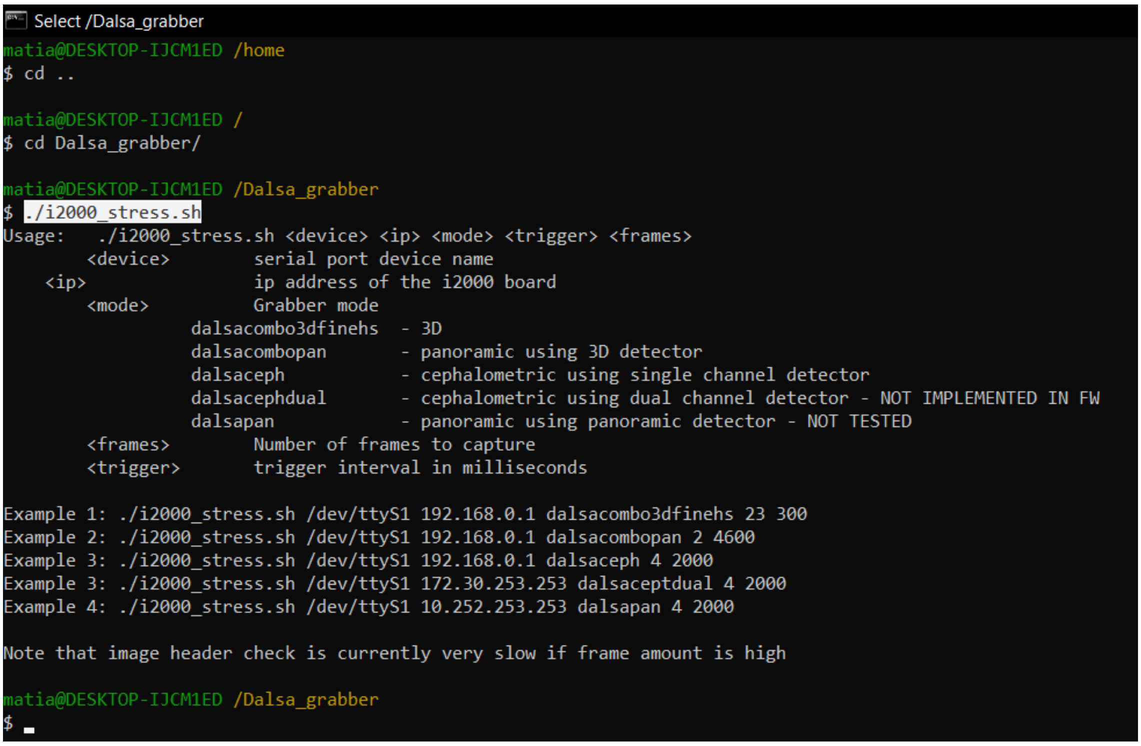


Figure 14. The Cygwin terminal showing the start of the i2000 stress test.

The template that the stress test returned had four different example commands to choose from, however with the used components the command line had to be modified. The command to start the stress test consisted of

- device
- IP-address
- mode
- frames
- triggers.

After using a suitable command line that was appropriate for all the parts, the stress test started by looking for an executable file named serial, if such file would have not existed the stress test would have compiled and named the compiled file as serial and execute it.

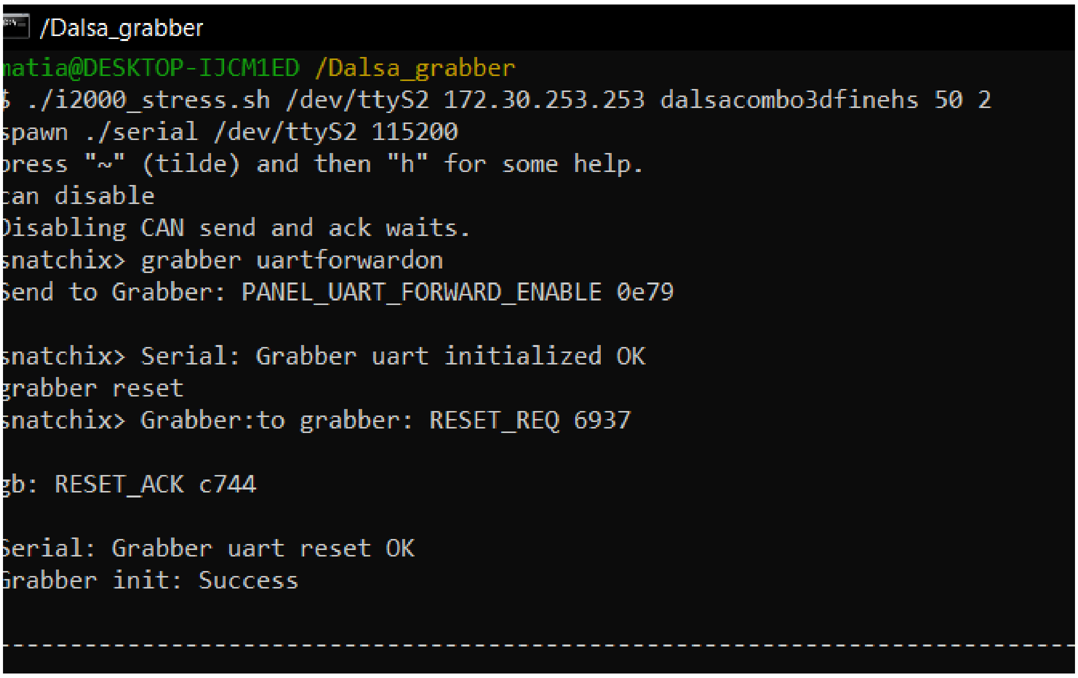


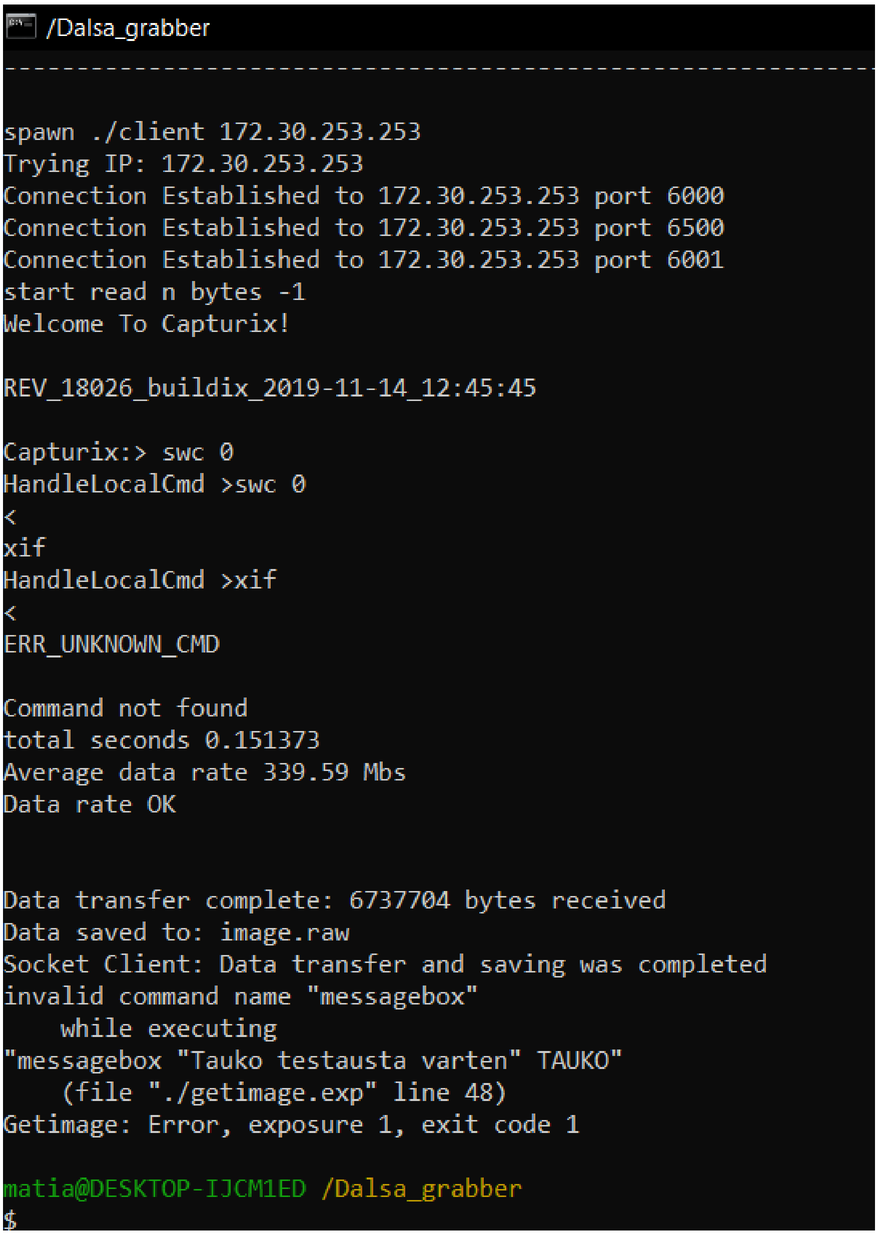
Figure 15. Start of the i2000 stress test.

When the serial file was executed, it opened a serial connection between the computer and the i2000 board with a baudrate of 115200. It started by disabling CAN, enabling UART and finally resetting the grabber, as can be seen in figure 15. With the grabber reset, a new serial connection was opened, and the stress test gave commands to the grabber to start preparing for the trigger events. After a confirmation from the grabber the stress test gave a command to trigger. When triggering was done a confirmation message from the serial port told that the grabber has finished the triggering as figure 16 illustrates.

```
/Dalsa_grabber

--------------------------------------------------------------------------------

spawn ./serial /dev/ttyS2 115200
press "~" (tilde) and then "h" for some help.
Serial port opened
grabber prepare 2 dalsacombo3dfinehs
snatchix> Grabber:to grabber: PREPARE_REQ 2 dalsacombo3dfinehs 377c

gb:

gb: Bootloader Apr 12 2016, 11:13:00

gb:

gb: CD41M1151: Command Line Interpreter

gb:

gb: USER>

gb: USER>

gb: USER>

R>PREPARE_ACK bf0c

grabber trig 50 2
start trigger timer for panel testing, period = 50 (ms) ntriggers=2
snatchix> gb: IMAGE_COUNT 1 c95b

ticks done 2
gb: IMAGE_COUNT 2 c81b

gb: READY ee2b

Serial: Grabber finished OK
Grabimage: Success, exposure 1

--------------------------------------------------------------------------------
```

Figure 16. Triggering part of the i2000 stress test.

With the triggering done, the stress test connected through ethernet to the i2000 board and started to transfer the image data from the i2000 board to the computer as can be seen in figure 17.



```
/Dalsa_grabber
---------------------------------------------------------------

spawn ./client 172.30.253.253
Trying IP: 172.30.253.253
Connection Established to 172.30.253.253 port 6000
Connection Established to 172.30.253.253 port 6500
Connection Established to 172.30.253.253 port 6001
start read n bytes -1
Welcome To Capturix!

REV_18026_buildix_2019-11-14_12:45:45

Capturix:> swc 0
HandleLocalCmd >swc 0
<
xif
HandleLocalCmd >xif
<
ERR_UNKNOWN_CMD

Command not found
total seconds 0.151373
Average data rate 339.59 Mbs
Data rate OK


Data transfer complete: 6737704 bytes received
Data saved to: image.raw
Socket Client: Data transfer and saving was completed
invalid command name "messagebox"
    while executing
"messagebox "Tauko testausta varten" TAUKO"
    (file "./getimage.exp" line 48)
Getimage: Error, exposure 1, exit code 1

matia@DESKTOP-IJCM1ED /Dalsa_grabber
$
```

Figure 17. Image data transfer part of the stress test.

The stress test gave an error as it finished, but the error was not anything noteworthy. It was only a message box error and had nothing to do with the i2000 boards or the Dalsa detectors functionality. A great number of information and commands were learned from the stress test and they were utilized in the Tera Term script.

4.3.3 Tera Term script

The program Tera Term was used to make the script that controls the i2000 board and the flow of the timing between the tube head radiation and the CMOS detectors active receiving time. This was accomplished by writing the script in TTL for Tera Term. All commands used were very straight forward, which made the process of writing the script much more pleasant.

```
; Tera Term macro for getting 3d fast image with external trigger from Dalsa
combo3D sensor
; SETTINGS ARE: BAUDRATE:115200, DATA: 8-BIT, PARITY: NONE, STOP BITS: 1, FLOW
CONTROL: NONE

:Start
     connect "/C=3"
     timeout = 10

;Disable CAN for rejecting error messages
     timeout = 2
     sendln "candisable"
     wait "Disabling CAN"
     if result = 0 goto exit_macro0

;Enable UART to panel
     timeout = 2
     sendln "grabber uartforwardon"
     sendln "grabber pw 1 svs 0 0"
     wait "PANEL_UART_FORWARD_ENABLE"
     timeout = 5
     if result = 0 goto exit_macro0

;Reset the grabber
     sendln "grabber reset"
     wait "RESET_ACK"
     timeout = 5

;Switch power ON for panel and prepare the grabber for image capturing and
check that the correct Dalsa sensor is connected (if any).

     sendln "grabber prepare 2 dalsacombo3dfinehs"
     timeout = 5
     wait "Bootloader"
     if result = 0 goto exit_macro1
     wait "CD41M1151"
     if result = 0 goto exit_macro2
     wait "PREPARE_ACK"
     of result = 0 goto exit_macro1
     pause 3

;Set panel to external trigger mode
     sendln "grabber pw 1 stm 1"
     wait ">"
     sendln "grabber pw 1 sbn 0"
     wait ">"
     sendln "grabber pw 1 svm 0"
     mpause 100

:Start_MENU
     yesnobox "Take test image?"  "Focus Image Capture PRO"
```

```
     if result goto Exp
     goto exit_macro4

:Exp
     statusbox "PRESS EXPOSURE BUTTON!"  "Start Exposure"
     sendln "M2M:IO:2000?"
     wait "M2M:IO:2000:on"
     mpause 200
     timeout = 1
     if result goto Exp
     goto Trig

:Trig
     closebox
     sendln "grabber trig 100 2"
     wait "READY"

     mpause 2000
     timeout = 5
     closett
     flushrecv
     sendln "echo using Cygwin"
     wait "$"
     sendln "cd.."
     sendln "cd.."
     sendln "cd Dalsa_grabber/socket_client"
     sendln "./client.exe 172.30.253.253"
     wait "REV_18026"
     if result goto XIF

:XIF
     sendln "xif"
     timeout = 10
     wait "image.raw"
     if result goto DISCONN
     goto NOETH

:NOETH
     messagebox "No ethernet connection! Check the cables and/or that the test
     setup is powered up!"  "EthFail"
     disconnect = 0
     unlink
     connect "/C=3"
     goto exit_macro4

:DISCONN
     disconnect 0
     unlink
     connect "/C=3"
     exec "D:\cygwin64\Dalsa_grabber\socket_client\grabraw2tif.exe
     D:\cygwin64\Dalsa_grabber\socket_client\image.raw"
     messagebox "image.raw has been exported to a tif-file."  "Focus Image
     Capture PRO"
     goto exit_macro3

:exit_macro0
     Messagebox "No connection to the i2000 board!!!"  "Check the USB connec-
     tion."
     sendln
     goto exit_macro4

:exit_macro1
     messagebox "No connection to any Dalsa detector!!!"  "Dalsa Fault"
     sendln
     goto exit_macro4
```

```
:exit_macro2
     messagebox "No connection to Xineos1511 detector!!!"  "Xineos Fault"
     sendln
     goto exit_macro4

:exit_macro3
     yesnobox "Take a new test image?"  "Focus Image Capture PRO"
     if result goto Start
     goto exit_macro4

:exit_macro4
     yesnobox "Close application?"  "Focus Image Capture PRO"
     if result goto exit_macro5
     goto exit_macro3

:exit_macro5
     sendln
     closett
     end
```

Listing 1. The whole script for controlling the detector and getting the image data.

The full Tera Term script was as listing 1 illustrates. In the script whenever a semicolon was used, it meant that the text after the semicolon was a comment and Tera Term could just skip it. When a colon was used it signified a point in the script where the program can jump to when using a command called goto.

```
; Tera Term macro for getting 3d fast image with external trigger from Dalsa
combo3D sensor
; SETTINGS ARE: BAUDRATE:115200, DATA: 8-BIT, PARITY: NONE, STOP BITS: 1, FLOW
CONTROL: NONE

:Start
     connect "/C=3"
     timeout = 10

;Disable CAN for rejecting error messages
     timeout = 2
     sendln "candisable"
     wait "Disabling CAN"
     if result = 0 goto exit_macro0

;Enable UART to panel
     timeout = 2
     sendln "grabber uartforwardon"
     sendln "grabber pw 1 svs 0 0"
     wait "PANEL_UART_FORWARD_ENABLE"
     timeout = 5
     if result = 0 goto exit_macro0

;Reset the grabber
     sendln "grabber reset"
     wait "RESET_ACK"
     timeout = 5

;Switch power ON for panel and prepare the grabber for image capturing and
check that the correct Dalsa sensor is connected (if any).

     sendln "grabber prepare 2 dalsacombo3dfinehs"
```

```
      timeout = 5
      wait "Bootloader"
      if result = 0 goto exit_macro1
      wait "CD41M1151"
      if result = 0 goto exit_macro2
      wait "PREPARE_ACK"
      of result = 0 goto exit_macro1
      pause 3

;Set panel to external trigger mode
      sendln "grabber pw 1 stm 1"
      wait ">"
      sendln "grabber pw 1 sbn 0"
      wait ">"
      sendln "grabber pw 1 svm 0"
      mpause 100
```

Listing 2. The Start point of the script.

The start of the script handles all the preparations that had to be done to the i2000 board and the detector as listing 2 illustrates. In the start the computer was connected to the communication port COM3, which was the port that the USB connector was connected between the computer and the i2000 board. After the connection was established, the i2000 board started sending error messages which had to be rejected. This was done by disabling the CAN. With the CAN disabled, the UART was able to be turned on and the grabber was reset. Whenever a sendln command was used the next command line had a command wait. If the wait commands expected character string would have not appeared the result would have been 0, which was used multiple times in the whole script to jump to different sections of the script. After the grabber was reset, the power for the detector was turned on with a single sendln command, which also checked that the detector was attached and that it was the specific detector. Using that command returned three different character strings in order, which were checked with the wait command. With the knowledge that the detector was attached and was the correct type, the detector was ready to be put in one of the three modes that it had. The mode was called external trigger mode, which was the only one to work with the used setup out of the three options.

```
:Start_MENU
     yesnobox "Take test image?"  "Focus Image Capture PRO"
     if result goto Exp
     goto exit_macro4

:Exp
     statusbox "PRESS EXPOSURE BUTTON!"  "Start Exposure"
     sendln "M2M:IO:2000?"
     wait "M2M:IO:2000:on"
     mpause 200
     timeout = 1
     if result goto Exp
     goto Trig
```

Listing 3. The START_MENU and EXP point of the script.

With the setup done, the next part of the script asked the user to start taking the test photo as listing 3 illustrates. If the user selected the yes button, which was the expected result, a status box appeared to the computer screen telling the user to press the exposure button. At the same time the script started sending out a command that kept getting a wrong character string back and kept looping until the exposure button was pressed on the Focus remote controller. Then the script continued to the Trig point.

```
:Trig
     closebox
     sendln "grabber trig 100 2"
     wait "READY"

     mpause 2000
     timeout = 5
     closett
     flushrecv
     sendln "echo using Cygwin"
     wait "$"
     sendln "cd.."
     sendln "cd.."
     sendln "cd Dalsa_grabber/socket_client"
     sendln "./client.exe 172.30.253.253"
     wait "REV_18026"
     if result goto XIF

:XIF
     sendln "xif"
     timeout = 10
     wait "image.raw"
     if result goto DISCONN
     goto NOETH
```

Listing 4. The Trig and XIF point of the script.

When the exposure button was pressed the script could continue to the Trig point of the script as can be seen in listing 4. In the Trig point, the grabber was told to trigger two times with a one hundred millisecond delay. After the two triggers had occurred the grabber returned a character string confirming that it was ready. This was followed by the closing of the UART connection between the computer and the i2000 board. With the connection closed, the script started using Cygwin and echoing the Cygwin commands to the Tera Term window. In Cygwin, the starting directory was two directories too deep, so a command to move up a directory was used two times following a command to go to a specified directory, which had an executable file in it. This file was used to connect to the i2000 board through ethernet. After getting a character string that ensured that the program was working correctly the script moved onto the XIF point of the script. The XIF point sent a command to transfer the image data to the computer. Depending on if there were any problems in the ethernet connection the script would jump to either NOETH point or DISCONN point.

```
:NOETH
      messagebox "No ethernet connection! Check the cables and/or that the test
      setup is powered up!"  "EthFail"
      disconnect = 0
      unlink
      connect "/C=3"
      goto exit_macro4

:DISCONN
      disconnect 0
      unlink
      connect "/C=3"
      exec "D:\cygwin64\Dalsa_grabber\socket_client\grabraw2tif.exe
      D:\cygwin64\Dalsa_grabber\socket_client\image.raw"
      messagebox "image.raw has been exported to a tif-file."  "Focus Image
      Capture PRO"
      goto exit_macro3
```

Listing 5. NOETH point and DISCONN point of the script.

The last points of the script before the exit macros were NOETH and DISCONN as can be seen in listing 5. In NOETH point a message box appeared and told the user to check all the cables and that the setup was powered on. Then the script disconnected and unlinked from Cygwin and connected to the communication port 3 and jumped to the exit_macro4 point. The DISCONN point was jumped to if the image data was acquired successfully. In DISCONN point the script disconnected and unlinked from Cygwin and connected to the communication port 3. Afterwards the script executed an application that exported the raw image data to a .tif file type and then gave a message box to the user telling that the file has been exported and jumped to the exit_macro3 point.

```
:exit_macro0
      Messagebox "No connection to the i2000 board!!!"  "Check the USB connec-
      tion."
```

```
     sendln
     goto exit_macro4

:exit_macro1
     messagebox "No connection to any Dalsa detector!!!"  "Dalsa Fault"
     sendln
     goto exit_macro4

:exit_macro2
     messagebox "No connection to Xineos1511 detector!!!"  "Xineos Fault"
     sendln
     goto exit_macro4

:exit_macro3
     yesnobox "Take a new test image?"  "Focus Image Capture PRO"
     if result goto Start
     goto exit_macro4

:exit_macro4
     yesnobox "Close application?"  "Focus Image Capture PRO"
     if result goto exit_macro5
     goto exit_macro3

:exit_macro5
     sendln
     closett
     end
```

Listing 6. The exit_macro points of the script.

In the end of the script all exit_macro points were allocated as listing 6 illustrates. The first three exit macros showed a message box with a message that corresponded to the reason why the script jumped to that specific exit macro. In exit_macro4 where there first three exit macros jumped to, a box showed up asking if the user wanted to close the application. Depending on the result the script would have either jumped to exit_macro5, which would have closed the whole script or to the exit_macro3 that would have asked the user if they wanted to take another image. If the answer was positive then the script jumped to the Start point, which was in the beginning of the script.

5 Testing of the CMOS detector version

5.1 Test environment

The test environment had to be inside of an area with lead coated walls, to keep the tester safe from the radiation that occurred during testing periods. Fortunately, there was an old testing booth that had been used in radiation testing in the past. So, that was used to carry out all the necessary testing, that occurred during the process of getting all the required parts to work with each other. The tests that were run consisted of running Tera Term script in the test environment with the Focus tube head powered on to get an image that could be observed in its clarity.

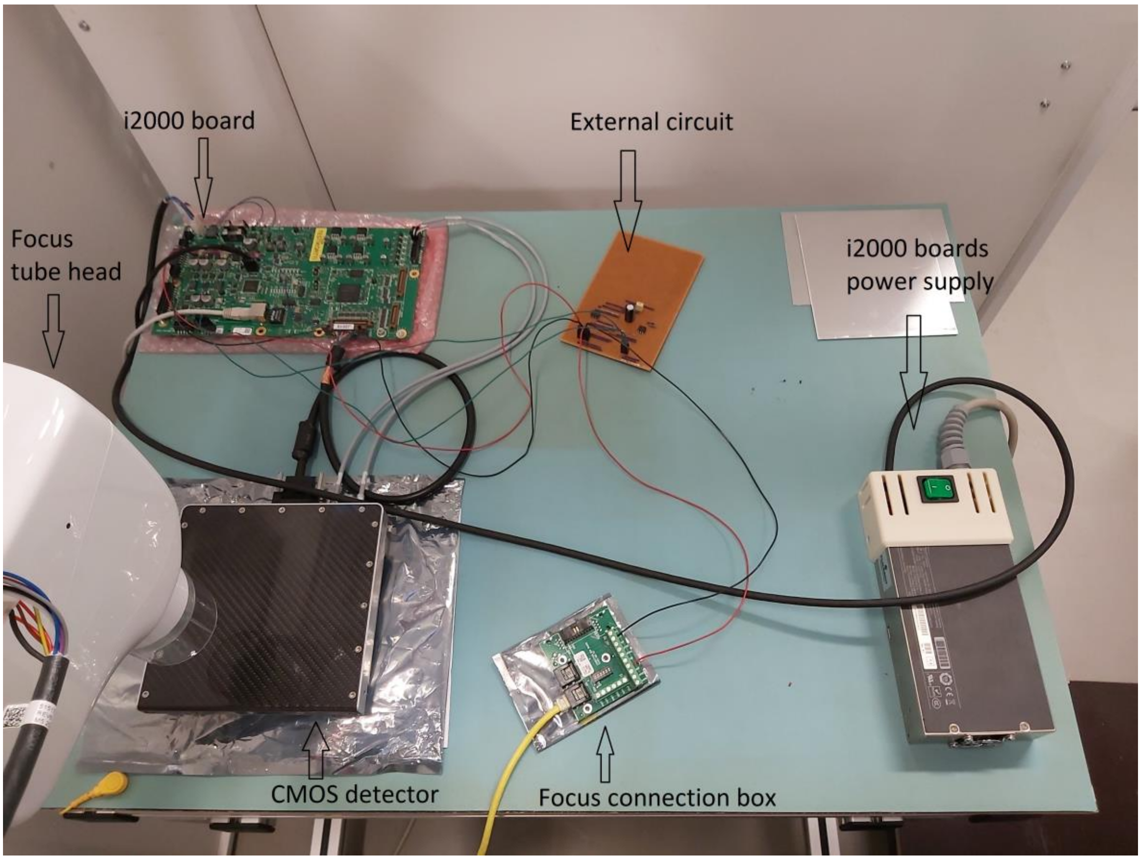


Figure 18. Layout of the testing table and all parts involved.

All the parts were arranged on the testing table as can be seen in figure 18. The parts were connected to each other in the same way as figure 6 illustrates with the block diagram. The cables between the parts were placed so, that they would not run right next to the detector, since that was the focal spot where the radiation was occurring and targeted to.

5.2 Test results

Multiple tests were carried out successfully with results that improved after each test, with the help of changes that were made.

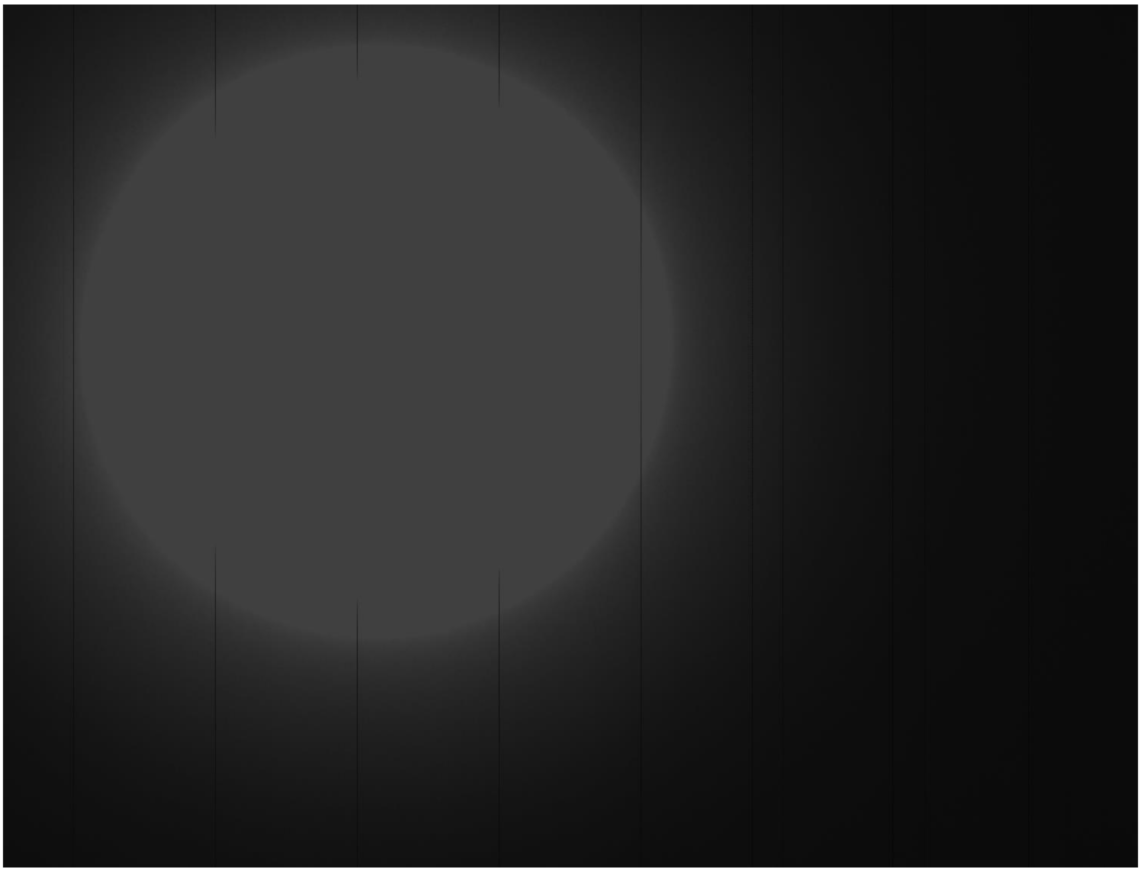


Figure 19. Test image with 0,1 second exposure time.

In the first test image the outlines of the collimated area that was radiated were extremely blurry as figure 19 illustrates. This was caused by the 0,1 second exposure time, which was used when the target for the radiation was a PSP plate. Due to the detector being more responsive and fragile when it came to the amount of radiation it was able to withstand before the radiation spread to pixels that were not in the collimated area.

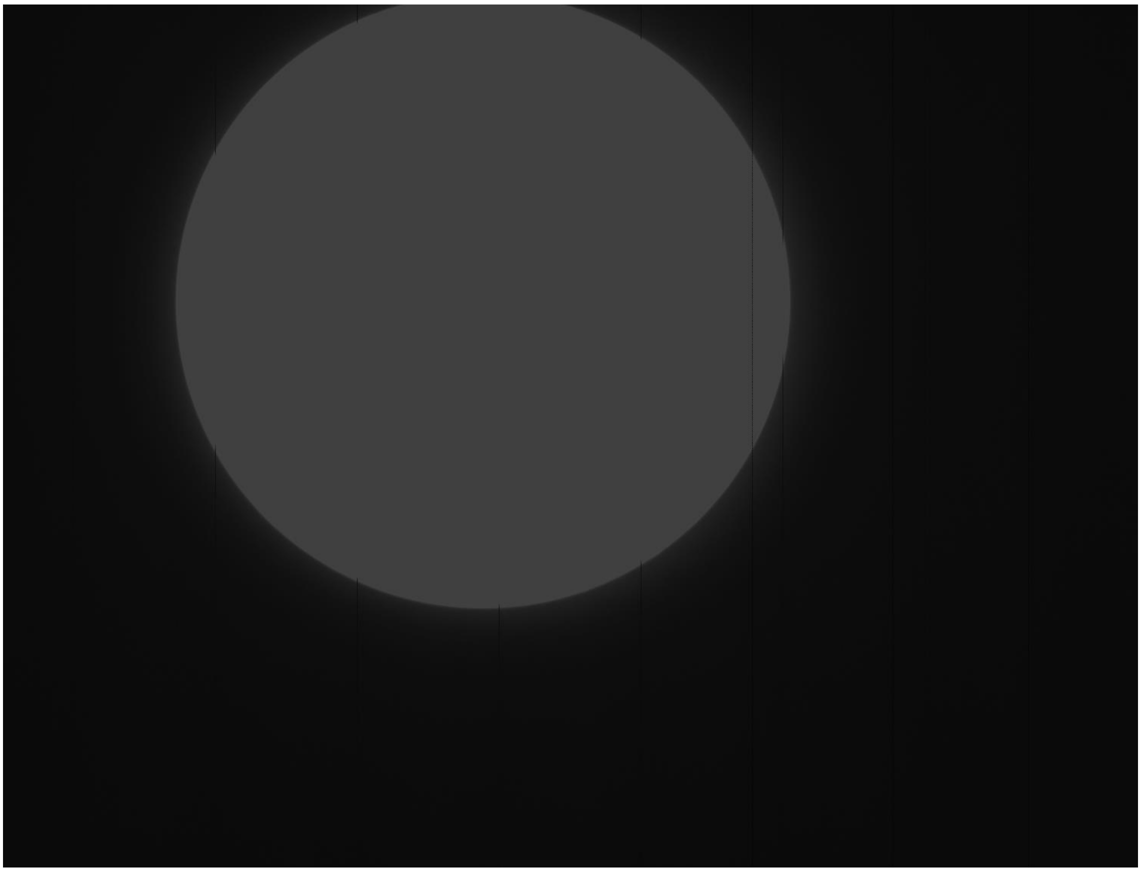


Figure 20. Test image with 0,02 second exposure time.

After dialing down on the exposure time, the edges of the collimated area were much more refined as can be seen in figure 20. When the image was examined closely there was still a very slight blurriness on the edges of the collimated area. This was easily removed with a software that was used to view and analyze the test images, regardless a better image quality was still strived towards.

Figure 21. Test image with 0,02 second exposure time and a 2mm thick aluminum plate.

The last image did get rid of the black line inside of the collimated area as can be seen in figure 21. In the final test image that had the shortened exposure time of 0,02 seconds and a 2 millimeters thick aluminum plate shielding the detector, the image quality stayed relatively same as when there was not an aluminum plate on top of the detector.

6 Conclusion

This thesis work was set out to prove that a CMOS detector could be made compatible in the intraoral Focus production line image quality testing and could replace the PSP plate procedure that was used at the time for image quality testing. This was achieved by utilizing the trigger signal that the Focus X-ray unit used to start the radiation exposure and making that signal trigger the CMOS detector to start recording radiation levels at the same time as the radiation exposure was happening. The trigger signal was modified to be in an active state for a prolonged period of time with a monostable 555 circuit, that used the prolonged signal to power an optocouplers emitting side in order to make the optocouplers photosensor conduct. When the optocouplers photosensor was conducting the i2000 board was able to give an answer to a command used in the Tera Term script to then proceed to trigger the CMOS detector to start recording the radiation. The Tera Term script was made to handle the timing between the radiation exposure and the CMOS detectors radiation receiving so they happened simultaneously. The script was made to be very user friendly and easy to use. Based on the test result, it was concluded that the detector system could be implemented into the production line in the foreseeable future. All testing was successful, and the results were on a level that was acceptable for the purpose that the detector system was aimed for. The used external circuit to get the timing correctly clearly worked, but it did raise the question of how else the timing could have been done. The Tera Term script could be delved into more deeply to modify it for further optimization. It can be concluded that this thesis work has proven the CMOS detector to be compatible for use in the intraoral Focus production line with an appropriate mounting system for the detector.

References

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