October 19, 2015

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

RE: ENSC 305W/440 Functional Specification for a **Portable Magnetic Resonance Imaging Scanner**

Dear Dr. Rawicz,

The attached document contains the functional specifications for Portable Magnetic Resonance Imaging Scanner. Our goal is to design a cost effective and portable MRI Scanner using simplified hardware and a project-based imaging technique.

The document gives an overview of the functionality of the prototype. It lists the requirements and standards from proof-of-concept to the final production for the system as a whole, as well as the all the subsystems. This document will be used as a principle guideline throughout the project.

MRI Solutions consists of 5 determined, brilliant and compassionate senior engineering students: Anterpal Singh Sandhu, Barry Yim, Evangeline Yee, Gagandeep Kaur, and Robin Wisniewski. If you have any questions or concerns regarding this document, please do not hesitate to contact our Chief Communication Officer Gagandeep Kaur by email at gkaur@sfu.ca.

Sincerely,

Evangeline Yee
CEO
MRI Solutions Inc.

Enclosure: Functional specifications for a Portable Magnetic Resonance Imaging Scanner

Executive Summary

MRI is widely used in the diagnosis of bone and soft tissue conditions but a conventional MRI scanner is very expensive. MRI Solutions has devised a cost-effective solution which utilizes the inherent inhomogeneity of permanent magnets for spatial encoding. This unique approach also allows the proposed scanner to be portable. The design will be centered around cost-effectiveness, portability, safety and scalability.

The major development stages for this project are listed below:

I. 2D proof-of-concept
II. 3D proof-of-concept
III. Production

We are moving forward with stage I, 2D proof-of-concept. We aim to reach the requirements set for stage I. If time permits, we will attempt to complete the requirements for stage II. However, stage II and III are beyond the scope of this project.

The development cycle for stage I includes the following:

- Assembly of magnet system
- Construction of radio frequency transmitter
- Construction of radio frequency receiver
- Development of signal processing system

In this document, we describe the functions of the systems listed above and the various requirements set for each system for the different development stages. Along with the safety and sustainability considerations, we also discuss the engineering standards that our scanner must meet.

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Glossary

MRI	:	Magnetic Resonance Imaging
RF	:	Radio Frequency
Halbach	:	An arrangement of permanent magnets which produces uniform magnetic field inside, with no magnetic field outside
Spin Echo Pulse	:	In magnetic resonance, a spin echo is the refocusing of spin magnetisation by a pulse of resonant electromagnetic radiation. Modern nuclear magnetic resonance and magnetic resonance imaging make use of this effect.
DDS	:	Direct Digital Synthesizer
DAC	:	Digital to Analog Converter
ADC	:	Analog to Digital Converter
Larmor Frequency	:	Rate of precession of the magnetic moment of the protons around the external magnetic field
FPGA	:	Field programmable gate array; An integrated circuit designed to be programmed by the user
LNA	:	Low Noise Amplifier; An amplifier used to amplify weak signals without adding noise

1. Introduction

Our MRI scanner is an innovative solution to provide tissue and bone imaging. Designed to be cost-effective and portable, our MRI scanner will provide greater access to MRI scans and allow for remote imaging.

1.1 Background

Conventional MRI machines use strong magnetic fields to magnetize hydrogen protons in the human body. Radio frequency pulse is then used to excite the protons. When the radio frequency pulse is turned off, hydrogen protons emit a response. This signal can be encoded to produce high quality images. To encode the spatial location of the signal, the magnetic field of the magnets must be very homogenous and a linear gradient field must be superimposed on it. However, it is extremely challenging to produce a field that has both a good field homogeneity and a reasonable field strength. This is why conventional MRI uses superconducting magnets. This design is very expensive and ultimately leads to limited number of MRI scanners and long MRI wait lists.

The proposed design uses the rotation of the magnet's inhomogeneous field and a projection-based imaging technique to reconstruct the spatial location and frequency of detected signals. Our design relaxes the homogeneity constraints and removes the need for heavy gradient coils, thereby allowing our scanner to be cost-effective and lightweight.

1.2 Scope

The scope of this document is to outline the functional specifications for the magnet system, radio frequency module, and software throughout all development cycles. Additionally, the related engineering standards, sustainability issues and safety issues are discussed in details.

1.3 Intended Audience

The intended audience for this document is all the engineers at MRI Solutions. This document will be referred by engineers to ensure that the product meets the required functional capabilities. Design and production issues can be avoided by following the requirements listed in this document. This document will also be used to compare the functionality of our final product with the targeted functionality by the engineering team. This document provides the marketing team with an overview of the capabilities of the product. It can be used to bring in funding for the prototype.

1.4 Classification

Throughout this document, the following convention will be used to specify the requirements of different phases of development:

[ST-##-DP]

where ST denotes the section title, ## specifies the requirement number and DP denotes the development phase.

The requirements are intended to be met at the following phases of development:

I 2D proof of concept
II 3D proof of concept
III Production

2. System Requirements

The general requirements and specifications for the complete Portable MRI Scanner are outlined in this section.

2.1 System Overview

The Portable MRI Scanner is a prototype medical diagnostic device designed for soft tissue and bone imaging. The system block diagram shown in *Figure 1* provides a high-level overview of the interaction and communication between each system.

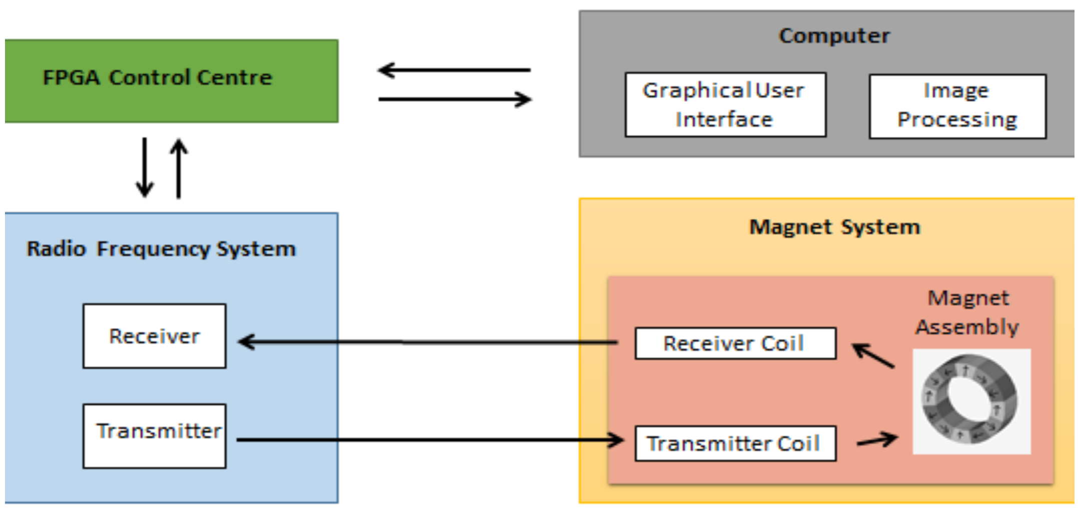

Figure 1: High Level System Block Diagram

<u>Field Programmable Gate Array (FPGA) Control Centre</u>

The FPGA is the "brain" of the prototype. It is the key element in coordinating the communication between different systems. The FPGA retrieves instructions from the user, decodes the instructions and sends appropriate commands to the radio frequency system. Its interaction with the radio frequency system includes crucial functions of programming pulse sequence, executing sampling, programming control signals and managing data flow.

<u>Magnet System</u>

The main function of the magnet system is to provide a strong external magnetic field such that hydrogen protons in the imaging sample precess or spins about an axis in the direction of the external magnetic field. The frequency of the precession is directly proportional to the strength of the magnetic field and this frequency is called the Larmor frequency. In order to transmit energy to the hydrogen protons, the RF coils must be tuned to the Larmor frequency.

Radio Frequency (RF) System
The RF system consists of a transmitter and receiver. The transmitter performs the essential function of transmitting RF energy to hydrogen protons within the imaging sample. The hydrogen protons absorb the transmitted energy and the additional energy causes a net magnetization in the transverse direction. As this net magnetization decays with time, a RF signal is emitted and the receiver is responsible for detecting this signal. This signal can be used to create tissue contrast images.

Computer System
The computer system provides a graphical user interface, allowing user to design and visually inspect pulse sequence. This instruction is passed to the FPGA. The computer system also streams data from the FPGA and performs signal processing to create tissue contrast images.

2.2 General Requirements

[SR-2.2.1-I] The prototype shall be able to image soft tissue and bone.
[SR-2.2.2-I] The prototype shall be scalable.
[SR-2.2.3-I] The prototype shall be portable.
[SR-2.2.4-I] The prototype shall cost less than US$ 2000.
[SR-2.2.5-III] The final product shall cost less than US$ 20,000.

2.3 Performance Requirements

[SR-2.3.1-I] The 2D prototype shall create high resolution 2D images.
[SR-2.3.2-II] The 3D prototype shall create high resolution 3D images.
[SR-2.3.3-III] The final product shall have spatial resolution of at least 5 mm.
[SR-2.3.4-III] The final product shall provide fast imaging.

2.4 Physical Requirements

[SR-2.4.1-I] The prototype shall weigh less than 15 kg.
[SR-2.4.1-I] The prototype shall have the physical dimensions listed in Table 1 to enable 2D imaging of a 2 cm diameter circular area.
[SR-2.4.2-III] The magnet system shall be enclosed in a Faraday cage to reduce RF interference.

Table 1: Specifications for 2 cm radius circular imaging area.

Specifications	Values
Minimum inner diameter	7 cm
Minimum length of magnet	7 cm
Minimum coil diameter	2.5 cm

2.5 Electronic Requirements

[SR-2.5.1-I] The prototype shall consume less than 100 Wh.
[SR-2.5.2-I] All components shall be able to handle up to 2A.
[SR-2.5.3-I] The RF circuitry shall be isolated from the magnet system and imaging sample.
[SR-2.5.4-I] The RF components shall be shielded to reduce RF interference.
[SR-2.5.5-I] The power amplifier shall have power rating that is at least two times higher than the power required.
[SR-2.5.6-III] The final product shall consume less than 1000 Wh.

2.6 Reliability and Durability

[SR-2.6.1-I] The prototype shall be fully operational within 10 °C to 30 °C temperature.
[SR-2.6.2-I] The prototype shall withstand at least 10 hours of imaging per day.
[SR-2.6.3-I] The prototype shall withstand at least 5 years of usage.
[SR-2.6.4-III] The final product shall withstand at least 18 hours of imaging per day.
[SR-2.6.5-III] The final product shall withstand at least 15 years of usage.
[SR-2.6.6-III] The final product shall routinely check for component failure.
[SR-2.6.7-III] The final product shall generate error messages in the case of component failure.
[SR-2.6.8-III] The final product shall prevent usage in the case of component failure.

2.7 Safety Requirements

[SR-2.7.1-I] The magnet housing shall be stable and secured.
[SR-2.7.2-I] The magnet system shall be properly labelled.
[SR-2.7.3-I] The magnet system shall be isolated from electronic and magnetic devices.
[SR-2.7.4-I] The electronic components shall be enclosed and isolated from the user.
[SR-2.7.5-I] The electronic components shall be properly labelled.
[SR-2.7.6-I] The electronic circuit shall be properly grounded.
[SR-2.7.7-III] The RF exposure shall be limited to 1W/kg over one gram of tissue.
[SR-2.7.8-III] Subject shall be screened for magnetic materials prior to imaging.
[SR-2.7.9-III] The magnet system shall be enclosed and isolated from subject.

2.8 Usability Requirements

[SR-2.8.1-III] The final product shall be easy to operate.
[SR-2.8.2-III] The final product shall store data in a standardized format.
[SR-2.8.3-III] The final product shall include intuitive software for pulse sequence design.
[SR-2.8.4-III] The final product shall include intuitive software for image processing.
[SR-2.8.5-III] The final product shall be compact and easily transported.
[SR-2.8.6-III] A full instruction manual shall be provided.

2.9 Environmental Requirements

[SR-2.9.1-III] The enclosure materials shall be recyclable.
[SR-2.9.2-III] The production process shall be designed to minimize waste.

3. Magnet System Requirements

3.1 Overview:

As shown in Figure 2, the magnet system consists of a bar magnet assembly which produces a uniform static magnetic field. A strong magnetic field is required such that when an imaging sample is placed within the magnet assembly, the hydrogen protons will precess or spin about an axis in the direction of the magnetic field. Due to the strength of the magnets, a strong housing is required to hold the assembly of magnets in place. The housing material needs to be non-magnetic to prevent distortion in the magnetic field. The magnet system also includes rotational hardware which rotates the magnet assembly. This changes the magnetic field experienced by the imaging sample and provides information for spatial encoding. In order to reconstruct an image, prior information of the field map is required. Thus, the magnet system includes magnetic field sensors that measure the magnetic field of the entire imaging region. These functions justify the following requirements.

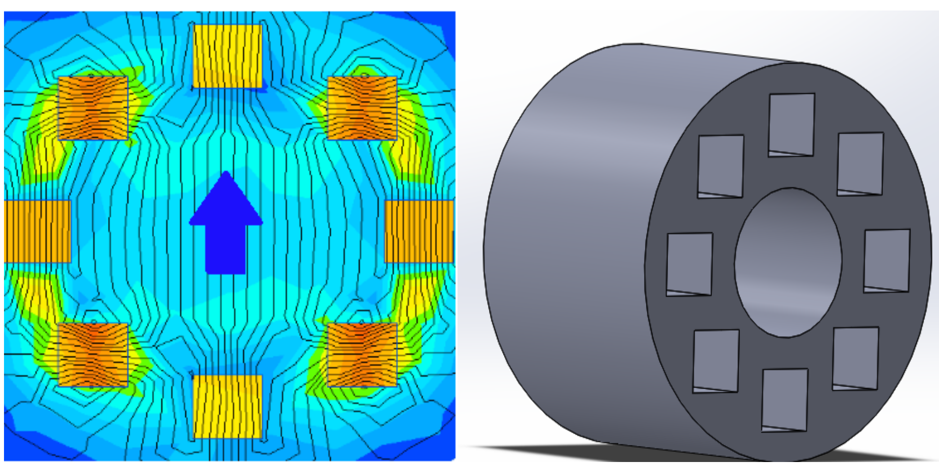

Figure 2: Simulated Field Map of the Magnet System

3.2 Magnet Design and Housing Requirements

[MSR-3.2.1-I] Magnet assembly shall produce a homogenous magnetic field strength of at least 0.1 T.
[MSR-3.3.2-I] Inhomogeneity of magnetic field shall be less than 1% to ensure uniform excitation.
[MSR-3.2.3-I] Magnet assembly shall be oriented to produce magnetic field in one direction.
[MSR-3.2.4-I] Magnet assembly shall have zero stray magnetic field.
[MSR-3.2.5-I] Magnet housing shall stabilize and hold bar magnets in fixed geometry.
[MSR-3.2.6-I] Magnet housing material shall be non-magnetic.
[MSR-3.2.7-I] Magnet housing material shall be lightweight and strong enough to withstand magnetic repulsive forces.
[MSR-3.2.8-I] Magnet housing shall have minimum adhesive strength of 3000 psi.

3.3 Field Mapping Requirements

[MSR-3.3.1-I] Magnetic field sensors shall have a dynamic range of at least 0.1 T to 0.2 T.

[MSR-3.3.2-I] Magnetic field sensors shall have a linear gain profile.

[MSR-3.3.3-I] Magnetic field measurement shall be reproducible.

[MSR-3.3.4-I] The 2D prototype shall produce accurate 2D field maps for 2D image reconstruction.

[MSR-3.3.5-II] The 3D prototype shall produce accurate 3D field maps for 3D image reconstruction.

3.4 Rotation Hardware Requirements

[MSR-3.4.1-I] Rotation steps shall be no larger than 1.8^{o} per step.

[MSR-3.4.2-I] Stepper motor shall operate at 1^{o} per second.

[MSR-3.4.3-III] System shall be stable with each rotation.

[MSR-3.4.4-III] Rotation hardware shall generate minimum friction.

[MSR-3.4.5-III] Rotation hardware shall generate zero vibrations.

4. Radio Frequency Module Requirements

4.1 Overview:

The radio frequency (RF) module shown in Figure 3 serves two important functions:

- To excite hydrogen protons by transmitting a radio frequency pulse
- To receive a response from protons

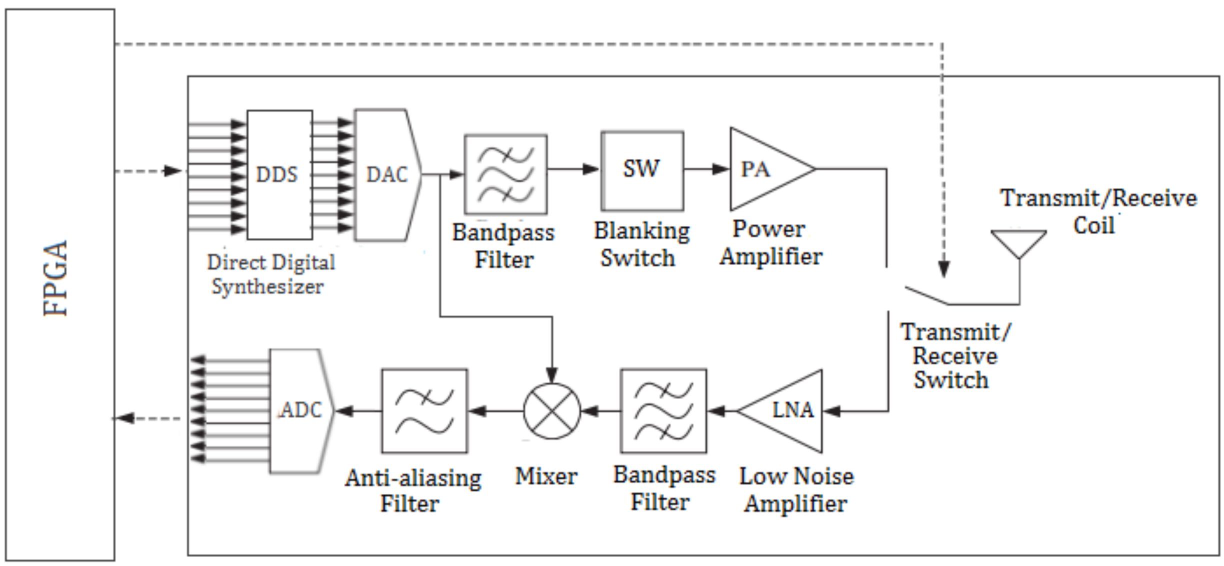

Figure 3: Radio Frequency System Overview

By exciting protons and recording the response, tissue contrast images can be created. In order to excite protons, the Direct Digital Synthesizer (DDS) needs to generate a sinusoidal signal oscillating at the Larmor frequency. Based on the estimated range of 0.1T to 0.2T static magnetic field strength, the following equation is used to determine the range of Larmor frequency,

$$f = \frac{\gamma}{2\pi} \cdot B$$

where B is the static magnetic field strength and $\frac{\gamma}{2\pi}$ is the gyromagnetic ratio in MHz/ T (42.5 MHz/T for hydrogen protons). Figure 4 shows the plot of the Larmor frequency range.

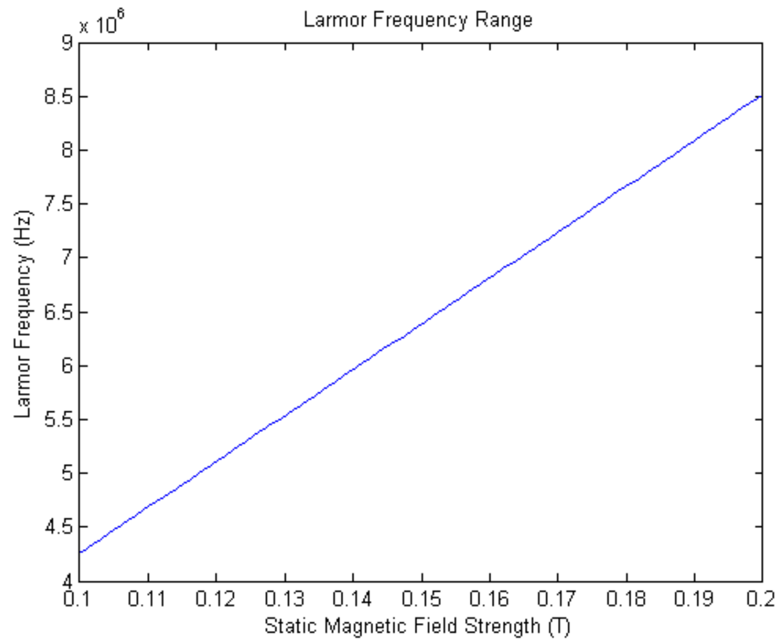

Figure 4: Larmor Frequency Range

The Digital-to-Analog Converter (DAC) needs to convert this digital signal to an analog signal. To remove unwanted harmonics from the DAC, the bandpass filter needs to selectively pass desired frequencies centered at the Larmor frequency. The power amplifier then needs to provide a large enough gain such that the transmitting coil will generate sufficient magnetic field. The magnetic field strength required to tip the net magnetization by an angle can be calculated using the following equation,

$$B_1 = \frac{\phi}{2\pi\gamma T}$$

where B_1 is the required magnetic field strength, ϕ is the angle, γ is the gyromagnetic ratio and T is the pulse length. The calculated B_1 values are used to estimate the current required to drive the tightly wound (no spacing between turns) transmit/receive coil as follows

$$I = \frac{d}{\mu} \cdot B_1$$

where I is current required, d is the wire diameter and $\mu$is the permeability of free space. The estimated current required is shown in Figure 5.

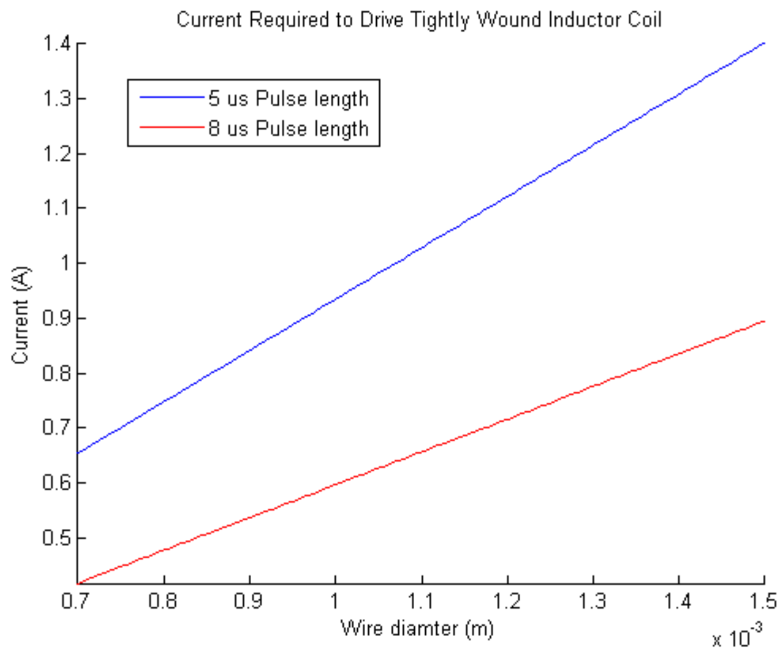

Figure 5: Current Required to Drive Transmit/Receive Coil

Considering a 8μs pulse length and the current required, the power amplifier needs to provide the power shown in Figure 5.

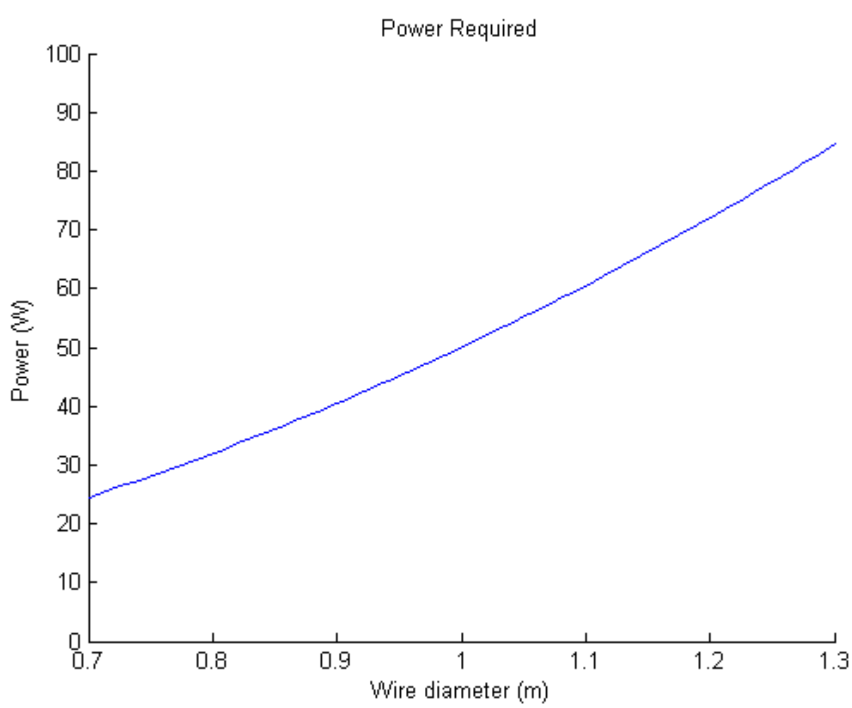

Figure 6: Power Requirement for Power Amplifier

To prevent high current from entering the receiving end and damaging the components, the blanking switch needs to turn off the power amplifier between RF pulses. Since the response from protons will be of small magnitude, the received signal needs to be amplified using a low noise amplifier (LNA) and the bandpass filter needs to remove any noise due to the environment. The mixer then needs to down convert the high frequency signal and the anti-aliasing filter needs to remove any aliasing effect due to the mixer. This allows the Analog-to-Digital Converter (ADC) to properly process the analog signal into a digital signal that can be used by computer for image processing. The following requirements address these needs.

4.2 Requirements for 2D proof of concept

[RFR-4.2.1-I] The DDS shall generate a sinusoidal output within the range shown in Figure 4.
[RFR-4.2.2-I] The DAC shall provide 14-bit resolution.
[RFR-4.2.3-I] The bandpass filter shall selectively pass the Larmor frequency bandwidth.
[RFR-4.2.4-I] The power amplifier shall provide power within the range shown in Figure 6.
[RFR-4.2.5-I] The blanking switch shall allow fast switching.
[RFR-4.2.6-I] The blanking switch shall provide low insertion loss.
[RFR-4.2.7-I] The RF module shall provide 1 transmit/receive coil.
[RFR-4.2.8-I] The transmit/receive switch shall provide fast switching of at least 5 μs.
[RFR-4.2.9-I] The LNA shall provide at least 60 dB gain at maximum 1.4 dB noise figure.
[RFR-4.2.10-I] The mixer shall downconvert signal to 0 Hz at maximum 12 dB noise figure.
[RFR-4.2.11-I] The anti-aliasing filter shall remove frequencies higher than Nyquist frequency.
[RFR-4.2.12-I] The ADC shall provide at least 14 bit resolution.
[RFR-4.2.13-I] The ADC shall provide at least 40 MSPS throughput rate.
[RFR-4.2.14-I] The transmit/receive coil shall withstand the range of current shown in Figure 5.
[RFR-4.2.15-III] The power amplifier shall provide up to 1000 W to image larger volume.
[RFR-4.2.16-III] The transmit/receive coil shall be able to handle at least 5 A.
[RFR-4.2.17-III] The ADC shall provide at least 100 MSPS throughput rate to handle higher signal volume.

4.3 Additional requirements for 3D proof of concept

3D imaging will be based on Bloch Siegert Spatial Encoding Technique (BSSET). This technique uses an additional RF coil to produce a spatially varying B_1 magnitude and spatially dependent phase shift [1]. The additional requirements are listed below.

[RFR-4.3.1-II] The RF module shall provide 2 transmit coils: one for excitation and one for 3D encoding.
[RFR-4.3.2-II] The DDS shall be able to output 2 sinusoidal waves of different frequencies.

5. Software Requirements

5.1 Overview:

The primary function for the software component is to process data stream from FPGA to produce medical images. User will have access to an image processing suite that performs fast and accurate image reconstruction. The software component also includes a Graphical User Interface (GUI) to allow user to design and inspect the pulse sequence signals transmitted. The GUI further allows user to monitor the imaging progress. Note that software component is part of stage III development. Pending successful 2D and 3D proof-of-concept, the software component may be required to perform additional functions. However, the requirements based on the primary functions are listed below.

5.2 Software Requirements

[SWR-5.2.1-III] Software shall be compatible with current Windows and Mac operating systems.
[SWR-5.2.2-III] The GUI shall be intuitive.
[SWR-5.2.3-III] Software shall provide pulse sequence programming.
[SWR-5.2.4-III] Software shall include an image processing suite for 3D image reconstruction.
[SWR-5.2.5-III] Software components shall be modular and easily upgradable.

6. FPGA Requirements

6.1 Overview:

The "Portable MRI Scanner" will consist of multiple modular parts interconnected to form the complete scanner. The prototype will contain an Altera DE-1 field programmable gate array. The FPGA will be the main hardware controller for all the modular components. Using FPGA inherent logic blocks and programmable routing resources, we will configure these chips to implement the necessary hardware functionality. Figure 7 illustrates all the modules relating to FPGA hardware inputs and outputs.

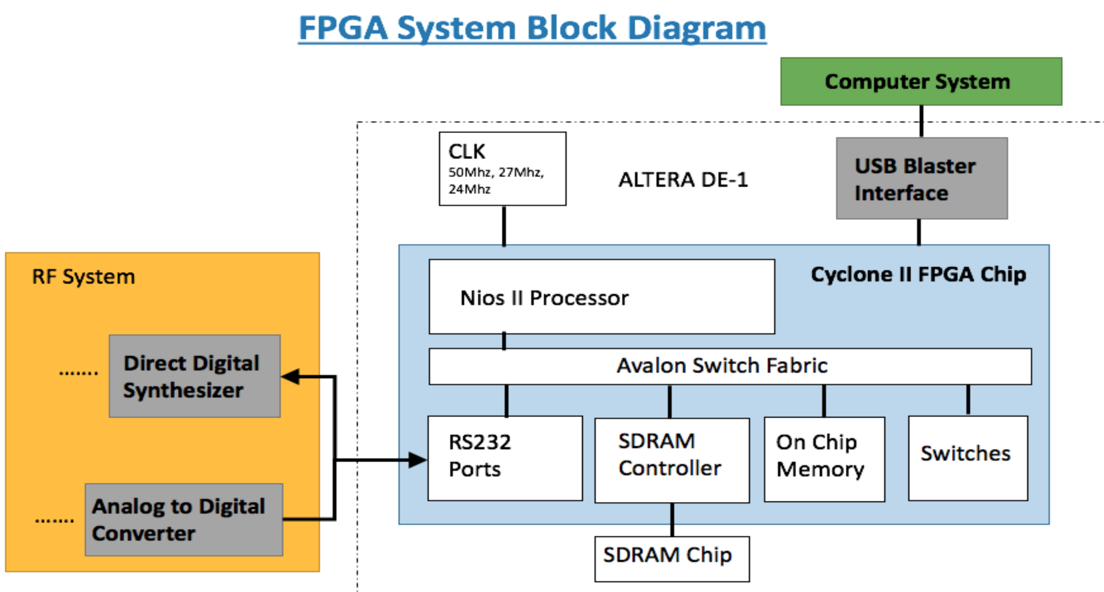

Figure 7: Simple FPGA System Block Diagram

6.2 FPGA Requirements

[FP-6.2.1-I] Must serve as connection bridge between radiofrequency system and magnet system
[FP-6.2.2-I] The FPGA clock oscillator must be at least 40 Mhz
[FP-6.2.3-I] The FPGA must have programmable input/output pins
[FP-6.2.4-I] The FPGA shall be compact enough to be portable
[FP-6.2.5-I] The FPGA shall operate normally for 0°C to 45°C
[FP-6.2.6-I] The FPGA shall have short setup time
[FP-6.2.7-I] The FPGA must have switches to control the magnetic assembly rotation device
[FP-6.2.8-III] The FPGA must be able to stream data towards computer system via USB
[FP-6.2.9-II] The SDRAM shall provide dynamic memory access
[FP-6.2.10-I] The RS232 Ports must be used for radiofrequency system connection bridge

7. Standards

There are many health, medical, engineering and safety standards that our MRI scanner will need to meet. The following associations and government bodies have established standards for MRI scanners:

1. American college of radiology (ACR)
2. American National Standards Institute (ANSI)
3. American Society for Testing and Materials (ASTM)
4. Canadian Association of Radiologists (CAR)
5. Food and Drug Administration (FDA)
6. Health Canada
7. International Electrotechnical Commission (IEC)
8. International Standards Organization (ISO)
9. National Electrical Manufacturers Association (NEMA)

Some of the medical safety and electrical standards are listed below:

1. **ACR** Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging [2]
2. **ACR** Site Safety Guidelines [3]
3. **ANSI S3.19-1974 and S12.6-1997** Hearing protection for the patient [4]
4. **ANSI/IEEE C95.1** Exposure levels for controlled areas recommended [5, 6]
5. **ASTM F04.15.11** MR Standards [7]
6. **ASTM F2052-00** Standard Test Method for Measurement of Magnetically Induced Displacement Force on Passive Implants in the Magnetic Resonance Environment [8]
7. **ASTM F2119-01** Standard Test Method for Evaluation of MR Image Artifacts From Passive Implants [9]
8. **ASTM F2182** Test Method for Measurement of Radio Frequency Induced Heating On or Near Passive Implants During Magnetic Resonance Imaging [10]
9. **ASTM F2503 - 13** Standard Practice for Marking Medical Devices and Other Items for Safety in the Magnetic Resonance Environment [11]
10. **DIN 6876:2014-05** Operation of medical magnetic resonance systems [12]
11. **FDA** CFR Title 21 Parts 1000 to 1005 [13]
12. **IEC 601-2-33** Medical Electrical Equipment - Part 2: Particular requirements for the safety of magnetic resonance equipment for medical diagnosis [14]
13. **IEC/FDA** Requirements for static magnetic fields [15]
14. **ICS 11.040.01** Medical equipment in general [16]
15. **ISO 14971** Medical Devices Application of Risk Management to Medical Devices [17]
16. **ISO-ICS 11.040.40** Implants for surgery, prosthetics and orthotics [18]
17. I**SO/IEC Guide 51** Safety Aspects [19]
18. **ISO/TS 10974** Assessment of the Safety of Magnetic Resonance Imaging for Patients with an Active Implantable Medical Device [20]

19. **Health Canada-Safety Code 26** Guidelines on Exposure to Electromagnetic Fields from Magnetic Resonance Clinical Systems [21]
20. **HIMSS/NEMA HN 1-2013** Manufacturer Disclosure Statement for Medical Device Security [22]
21. **NEMA MS 1-9** – Safety and Performance Standards [23]
22. **UNSPSC Code 42201600** Medical magnetic resonance imaging MRI products [24]

8. Sustainability and Safety

MRI solutions is an environmentally conscious company and strives to create a better world for everyone. From the beginning of the project, we keep the Cradle to Cradle design philosophy in our minds. Using Cradle to Cradle, we aim to minimize our design's negative impact on the world. Our portable MRI design will not contribute waste, as all components are either recyclable or reusable.

The magnets we chose for our design are Neodymium magnets which are part of the Rare Earth metal magnet family. The metal alloy that forms these magnets is composed of Neodymium, Boron and Iron. Methods are being developed to recycle Neodymium magnets as throwing them out would be a waste of resources and energy [25]. The assembly for the magnet is composed of fibreglass and plywood. Plywood is recyclable and recent breakthroughs have allowed for the future recycling of fibreglass as well [26].

All our electronic components are RoHS compliant, which ensures that the electronics are lead (Pb), mercury (Hg), cadmium (Cd), hexavalent chromium (CrVI), polybrominated biphenyls (PBB), polybrominated diphenyl ethers (PBDE), and four different phthalates (DEHP, BBP, BBP, DIBP) free [27]. By ensuring all electronic components are RoHS compliant, we are reducing people from exposure to hazardous chemicals from the manufacturing stage to the recycling stage.

The safety of everyone who may potentially come in contact with the device is paramount to us. As the current we are driving into the RF coils exceeds levels that would be considered safe to touch (<1mA [28]), we will isolate the entire RF system and enclose the magnet assembly to ensure nothing comes into direct contact with the RF and the magnet system. Another safety concern is the radiation energy from the RF system. Since RF energy can cause tissue to heat and potentially burn, the RF exposure will be limited to 1W/kg over one gram of tissue as per the FDA guideline [29]. Stray magnetic field is also taken into account as there can be potential risks for patients with pacemakers and other electronic implants. The Halbach magnet array was chosen for our design as there is negligible magnetic field outside the magnet assembly. We will also ensure that no other electronic and magnetic devices come in close proximity to our magnet system.

9. Conclusion

In this report, we described the functions of every system in our Portable MRI Scanner. Specifically, we have 4 major systems. First, we have a magnet system that aligns the precession of hydrogen protons. The magnet system also includes rotational hardware and field mapping sensors which together provide 2D spatial information. Second, there is a radio frequency system which excites the protons and records the emitted response. Third, we use an FPGA as a control centre to coordinate the communication between different systems. Lastly, our software component allows the user to interact with our scanner.

To ensure that each system performs the specified functions, we defined a set of requirements for each system at each development stage. The 3 development stages for this project are 2D proof-of-concept, 3D proof-of-concept and production. Our objective is to complete the first development stage and these requirements will serve as a road map as we move forward. We have also discussed the standards, safety concerns and sustainability issues related to our proof-of-concept model and the final product that we envision.

References

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[6] IEEE Standards Interpretations for IEEE Std C95.1™-2005 IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, ANSI/IEEE C95.1, 2005

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