Gradient Amplifier Software

Software development of thermal and electrical model for MRI gradient amplifiers

ELECOMP Capstone Design Project 2019-2020

Sponsoring Company:

Analogic Corporation

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https://www.analogic.com/

Analogic Engineering Center

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https://www.analogic.com/products/magnetic-resonance-imaging/gradient-power-amplifiers/

Company Overview:

Analogic creates innovative technology that improves the practice of medicine and saves lives. For over 50 years, Analogic has created markets by anticipating and solving some of the world's most complex medical and engineering challenges. Today, our specific areas of expertise include developing technologies used in computed tomography (CT), digital mammography (DM), and magnetic resonance imaging (MRI). We also develop state-of-the-art threat detection systems for airport checked-baggage screening and checkpoint screening - as well as motion controls.

At Analogic, we create life-changing technology. For decades our customers have manufactured products that have advanced the practice of medicine and saved lives. They repeatedly turn to Analogic to foresee market trends before the rest of the industry does. As a result, our customers are often a step or two ahead of their nearest competitor.
Our engineering and manufacturing expertise are unmatched, and our products are used extensively around the world in medical imaging and airport security.

Solid-State, Water-Cooled Amplifier Designs for All MRI Applications:

Analogic MRI power solutions include high-power gradient amplifiers (GA). Today, our high-precision power systems are employed in MRI systems worldwide. Our gradient amplifier technology solves demanding system needs that require precision current control with the highest levels of stability and repeatability. This technology can also support other applications that require the use of magnetic power coils, including:

- Nuclear magnetic resonance
- Particle analysis in accelerators
- Semiconductor processing
- Dynamic scanning
- Material analysis

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Project Motivation:

Background:

Magnetic resonance imaging (MRI) is an imaging technique that provides a means of obtaining detailed, high-contrast images for medical diagnostic purposes. Analogic MRI power solutions provide high-power gradient amplifiers (GA) that are widely used in MRI systems all over the world. A gradient system generates position and time dependent magnetic fields on three orthogonal axes (X, Y and Z axis). The GA is the power stage of the MRI system that delivers electrical power to a gradient coil for the generation of these magnetic gradient fields. GAs are ultimately used in technical rooms of hospitals and mobile MR-systems.

The capstone design project (hereafter referred to as "Project") is to develop a software package that predicts key parameters inside the GA.

Challenges to GA:

Highest voltage compliance, precise control and repeatability, and outstanding noise performance allow our customers to meet the latest challenges in today's most advanced MRI applications. Each axis in the GA can provide to its respective load coils:

- Peak current up to 900A
- RMS current up to 360A
- Peak voltage up to 2000V

The amplifier should be able to generate any waveform within the limitations of these ratings and should not be damaged if given a request for any waveform beyond these limitations.

The challenge is that it takes time and sometimes trial and error to determine the feasibility of a specific input waveform. The MRI operator needs to know the answers to questions such as: 'Is this input waveform beyond the limit of the GA', or 'How long can the GA operate, given a specified time-series waveform?' Since catastrophic failure is definitively unacceptable, and even automated GA shutdowns, which could interrupt patients' MRI tests, are highly undesirable, these operational events must be mitigated, or prevented completely.

Objectives of the project:

One important intended deliverable to the customers consists of a user-friendly, accurate, compact software package (hereafter referred to as "software") that contains the thermal model, electrical limitations, power-loss modeling, and the cooling model of the entire GA unit. Such a software would be designed and implemented for Windows OS.

Before applying a current waveform to actual patients in the MRI system, an MRI installer/developer should be able to run predefined test waveforms that check the feasibility of the intended input waveforms as well as the present capability of the GA. The software would guide and assist an MRI installer/developer to finish this task, safely and quickly.

Given a current waveform command, MRI coil parameters and user-defined operating parameters as time-series input data, the software would estimate several key parameters inside the GA over time, providing a real-time dynamic visual interface, such as a plot window which provides instantaneous operational data. Such information is crucial to performance, safety, and reliability of the GA.

The software would also make use of decision-making algorithms to predict whether the GA can maintain the output current. After each run, a report would be generated to summarize the performance estimates, with time stamps and highlights of any suspicious or abnormal data points.

Anticipated Best Outcome:

- Complete deliverable of a fully functional, user-friendly, accurate, and compact software package for various configurations of Windows OS (7/10; 32/64-bit).
- Development of models for thermal, electrical limitations, power loss, and cooling, among other mathematical models of the GA unit systems.
- Development of an intuitive graphical user interface (GUI) which is designed with a minimal learning curve such that it is accessible to a mass market.
- Robust development is applied such that the software remains easy to maintain and modify, including use of a widely used programming language and a free of charge integrated development environment (IDE) and compiler.
- Best industry practices are used, including well organized and commented code.
- Software is encrypted, such that the models and other developments may remain secure and proprietary.
- Development of first draft of a software user manual.

Project Details:

Overall system concept (background/global picture):

Magnetic resonance imaging (MRI) is an imaging technique that provides a means of obtaining detailed, high-contrast images for medical diagnostic purposes. As shown in Fig. 1, a complete gradient system has coils mounted along the inner bore of the scanner driven by a powerful gradient amplifier and cooled by water chillers in the adjacent MRI equipment room.

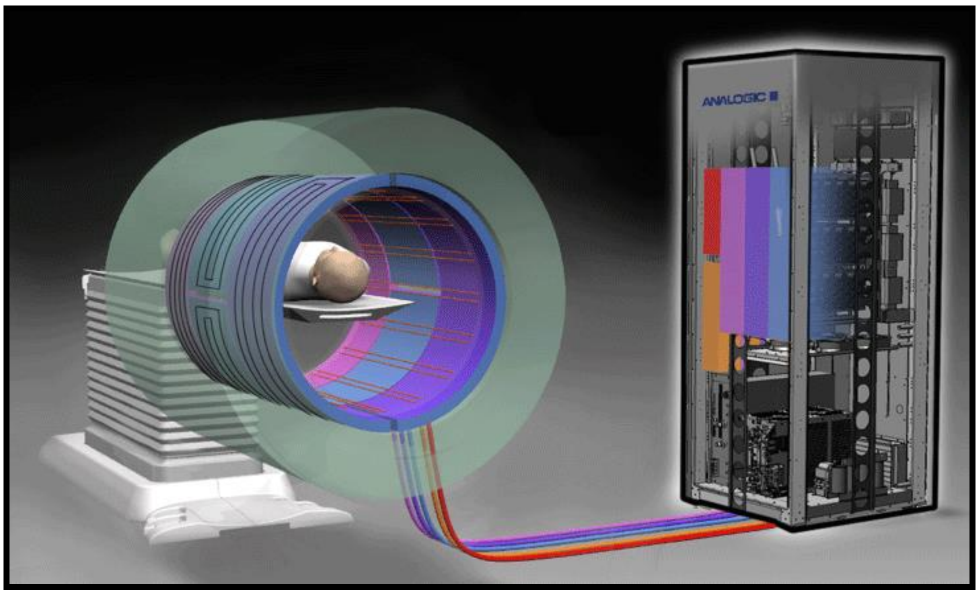

Fig. 1 Illustration of a complete MRI gradient system

Analogic MRI power solutions provide high-power gradient amplifiers (GA) that are widely used in MRI systems all over the world, which is shown as the large cabinet in Fig. 1. The gradient system generates position and time dependent magnetic fields on three orthogonal axes (X, Y and Z axis). The GA is the power stage of the MRI system that delivers electrical power to a gradient coil for the generation of these magnetic gradient fields. The GA is used in a technical room of a hospital or a mobile MR-system.

A simplified block diagram of the GA system is given in Fig. 2.

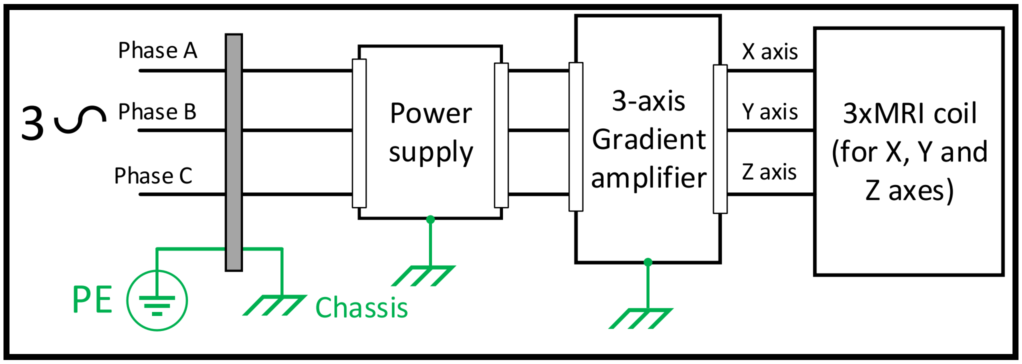

Fig. 2 Block diagram of MRI Gradient Amplifier (GA) system

Software development (specific deliverable):

The proposed software is a separate tool that runs on Windows OS. It serves as a digital toolbox that can help an MRI installer/developer run predefined test waveforms to check the feasibility of intended input waveforms as well as limit the capability of the GA if such waveforms could put the device in a dangerous or undesirable state. The software will take several input parameters, such as MRI coil parameters, time-series input current waveforms, and user-defined unit operating conditions to perform its intended functions.

Two present and major limitations of the GA are given as follows:

- The junction temperature of insulated-gate bipolar transistor (IGBT) should never surpass its threshold temperature. (If so, the controller of GA will trigger a fault and shut down automatically, interrupting operation, which is undesirable).
- The high-voltage capacitor bank voltage inside GA should never deplete to the point that the output current waveform's fidelity could become compromised. This could distort the output waveform and potentially interfere with the results of the test or even possibly disturb the patient under test.

Flow chart:

A basic flow chart is given in Fig. 3 as an illustration example.

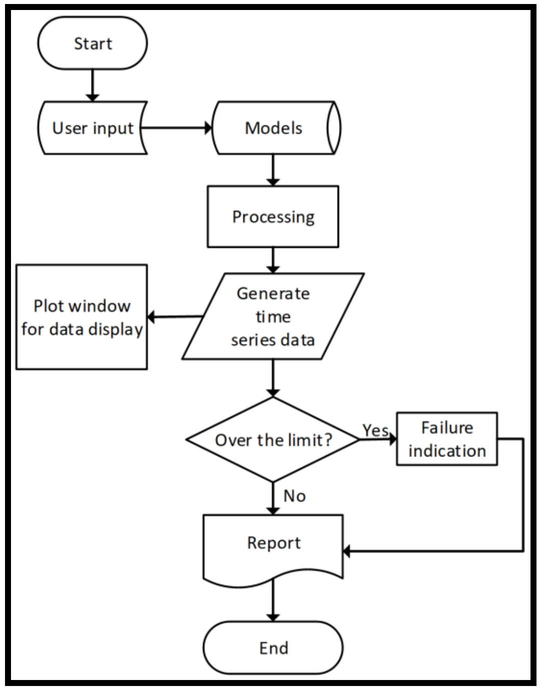

Fig. 3 Flow chart of the software (for illustration purposes only)

Hardware/Electrical Tasks:

The students in this project will be given necessary training and guidance regarding the electrical and hardware side of the GA, including the thermal and electrical models of the GA, based on the mathematic equations and measurement datasets. The students are expected to become familiar with these models such that they can ultimately be interpreted into programming language.

Firmware/Software/Computer Tasks:

Most of the tasks in this project are related to computer engineering field. The 2 students will collaborate and be responsible to develop the entire software from scratch.

Examples tasks include (but are not limited to)

- Project scheduling
- Architecture of the software
- Selection of programming language and IDE
- Study of the existing (rudimentary) software that was developed a few years ago
- Development of intuitive graphical user interface (GUI)
- Documentation
- Testing and debugging in different versions of Windows OS, such as:
  - Windows 10 as well as legacy versions.
  - 32-bit, 64-bit
- Draft of the software user manual

Composition of the Team:

1 Computer Engineer and 1 Electrical Engineer

Preference towards electrical engineers will be given to those with coursework and/or extracurricular experience in both CPE and MTH disciplines

Skills Required:

Electrical Engineering Skills Required:

- Basic understanding of electrical circuits
- Basic understanding of mathematic modeling
- Basic understanding of thermal modeling

Computer Engineering Skills Required:

- Willing to learn and become a full-stack developer and understand concepts of software engineering.
- Programming language: C++, C#, Python, etc.
- Database: SQL
- Network server

Anticipated Best Outcome's Economic Impact on Company's Business:

The anticipated best outcome will help MRI installers, developers and operators better use the Analogic gradient amplifiers (GA). This will reduce the unit failures rate during real operation and increase the overall system reliability and safety. More importantly, the proposed software would be beneficial to both operators and patients because it can minimize the operation risks including unit shut down, failures and any unexpected interruptions.

Broader Implications of the Best Outcome on the Company's Industry:

There is a great need of the proposed software in the community of MRI GA users. Currently, Analogic only has a preliminary version with very limited features that barely meets the user requirement. If this software is developed and becomes available for users, it will bring several benefits to the MRI gradient amplifier industry:

(1) Improved user experience and satisfaction

(2) Improved safety and reliability

(3) Proactive prevention of any unexpected results or failures

(4) Augmented customer loyalty and relations.