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Design and safety considerations of I/O modules

Eric Aderhold [a,*] · Liana Mirzojan [a,b,*] · Jan-Philipp Scheel [a,b,*] · Jonas Schuhmacher [a] · Florian Sevecke [a,b] · Mandy Ahlborg [a] · Matthias Graeser [a,c]

[a] Fraunhofer IMTE, Fraunhofer Research Institution for Individualized and Cell-Based Medical Engineering, Lübeck, Germany
[b] Institute of Medical Engineering, University of Lübeck, Lübeck, Germany
[c] Chair of Measurement Technology, Universität Rostock, Rostock, Germany
[*] Corresponding author, email: {eric.aderhold;jan-philipp.scheel;liana.mirzojan}@imte.fraunhofer.de

Abstract

In Magnetic Particle Imaging, numerous data inputs and outputs are required to receive and process signals from the feedback and receive coils, and to control the output associated with the drive and selection field coils. Previously used conventional input/output (I/O) boards have shown limitations in regard to the initial start-up procedures, safety assurance and usability. To address these issues, a more sophisticated I/O unit was designed, incorporating and expanding the functionality of twelve measurement cards. These cards are housed within the I/O unit as shielded, interchangeable modules and built up as synchronised multi-channel I/O system.

I. Introduction

A magnetic particle imaging scanner for bed-side stroke monitoring is being developed. To enable a flexible and adaptable imaging sequence, a field generator consisting of $2\times(3\times3)$ coil arrays is currently constructed [1]. This generator needs to be controlled in addition to the drive field and receive coils. To manage this complexity, twelve DAQ Cards (RPs) (STEMLab 125-14, Red Pitaya d.o.o, SI) are integrated into one I/O unit for capturing and transmitting signals effectively. Those modules have the advantage of being tuneable and operational with the open source software `MPIMeasurements.jl` [1] and have two input and two output channels. Despite the considerable potential of the RPs, its implementation in a complex scanner configuration requires a robust and dependable performance. This is particularly important in clinical settings, where patient safety is of paramount importance. This paper shows the development of an I/O unit which ensures this reliability and safety.

[1] `https://github.com/MagneticParticleImaging/MPIMeasurements.jl`

II. Methods and materials

The planned drive field consist of two coils, while the selection field generator features a total of 18 core coil modules.

This leads to a demand of at least 20 separately controllable output channels to create the desired signals. A minimum of five input channels with a high sampling rate and a high demand for signal quality is needed. Two channels for the feedback coils, which are required for the control of excitation field coil currents and three additional channels for 3-dimensional receiving. Considering the separation of receive and transmit channels to minimize crosstalk, a minimum of twelve RPs is needed in the I/O unit.

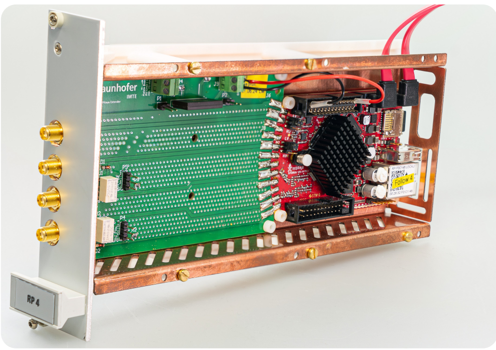

Figure 1: Open I/O module with a Red Pitaya and its extender board.

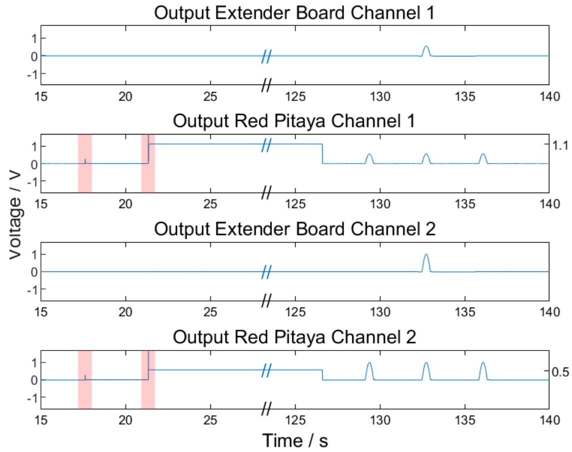

Figure 2: Measurement of the voltage over time for the booting sequence and a sinussoidal sequence.

For the I/O unit twelve I/O modules (cf. Figure 1) are housed in a 19-inch chassis, which also includes the needed Low Noise Power Supplys [2] and a control PCB with a corresponding microcontroller. To minimize cross talk and external interferences each I/O module is shielded by a copper box, featuring the necessary cutouts for the routing of cables. Each I/O module is dimensioned in the eurocard specification for the mounting inside the rack chassis. Internally, each RP is extended with a PCB which enables the blanking of the output channels. To guarantee a fully synchronized operation of the RPs they are configured in a cluster. A start up sequence, where the main module is fully operational before the secondary boards start up, is used. The microcontoller on the control PCB initiates this boot sequence for all I/O modules.
During the boot-up of a RP the output shows unpredictable offset behaviour (cf. Figure 2, red area), which can pose as a safety problem to the patients, users and the system. Therefore, robust safety measures must be taken to guarantee not only system integrity but also safe and reliable operation. For this, another crucial function of the microcontroller inside the I/O unit is to enforce the blanking of RP outputs. Relays on the RP extension boards first verifies the correct boot up of the full system before letting any signal pass towards the output. In order to demonstrate the security and safety feature of the I/O unit an experiment was conducted. A boot sequence is initiated on the microcontroller concurrently with a voltage measurement. This is performed at both the unmodified RP outputs and simultaneously at the extender board outputs. In the initial stage of the procedure, the microcontroller disconnects the power supply, effectively switching off all boards. Subsequently, the booting process is initiated by re-establishing the power to the RPs. Once fully operational, the RP is ready to transmit three successive voltage pulses, with the output towards the system authorised exclusively during the second pulse.

III. Results and discussion

The timeline provided in Figure 2 demonstrates that the output post-extender remains at 0 V, even when the voltage at the RPs peaks during the supply of power or during the internal boot up process. During this phase, the output voltage is set to a random value between ±1.1 V. The successful connection results in a zero-voltage transition at the RP outputs. Subsequently, three half-sine impulses are transmitted on both channels, with only the second pulse being purposely transmitted through the extender output when the activation of the extender is enabled.

IV. Conclusion

The integration of twelve I/O modules into an I/O unit, together with the implementation of robust performance management for complex multichannel scanner configurations, has demonstrated the significant potential of the I/O unit as a crucial component for enhancing efficiency and safety in magnetic particle imaging systems.

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Author's statement

Authors state no conflict of interest.

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