REAL-TIME ENVIRONMENTAL MONITORING FOR MRI-ADJACENT DEVICES

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In recent years, the deployment of additional devices near MRI scanners, such as EEG readers, motion trackers, and field sensors, has increased. While proximity to the bore offers benefits like reduced losses and shorter cabling, it also presents challenges due to stray magnetic fields and vibrations. High electron mobility semiconductors and crystal oscillators are particularly affected. To address these issues, devices are often aligned parallel to the magnetic field. However, this is not feasible in fringe fields. This work proposes equipping devices with sensors to monitor environmental conditions in real-time, ensuring optimal operation and alerting operators when necessary.

Environmental monitoring helps operating devices in the vicinity of MRI safely and predictably. Using sensor information, influence of the electro-magnetic field or vibrations can be corrected for or the user can be informed about potential problems and ways to mitigate.

Introduction

In recent years, there was a constant trend to deploying more devices at the magnet. Besides primary scanner functions, also devices for EEG reading, audio/video, elastography, motion trackers and radars or field sensors are deployed.

While locating these devices close to the bore offers many benefits such as lower losses and shorter cabling, it also imposes additional challenges for operating electronics in the stray magnetic fields and vibrations induced by the system. For instance, certain high electron mobility semiconductors can show a distinct field dependence [1]. Also, modulation due to gradient induction and vibrations are reported [2] and crystal oscillators for high quality clocking are susceptible to vibration [3].

For devices that are designed to reside close to the imaging area (e.g. preamplifiers), the problem of field dependence is typically tackled by aligning the devices parallel to the field. In this way, induction of Hall voltages and similar effects is largely suppressed.

This however can not be applied if devices are located in the fringe field of the magnet and/or are freely placed by the user where the direction of the magnetic field permeating the device becomes strongly location dependent (Figure 1). Also, exposure to vibrations and sound pressure becomes highly positioning dependent.

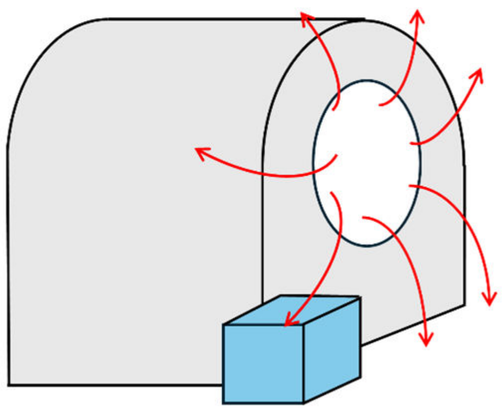

Figure 1: Schematic view of the field lines a device positioned next to the bore may be subject to. While devices positioned in the bore are permeated by the magnetic field in very defined direction, the direction depends strongly on the location outside the bore.

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In this work we propose therefore to equip the device with additional sensors whose readings are employed to estimate if the environment conditions are within tolerated levels in real time and employ this information in real-time to flag the data, stop operation or warn the operator.

Methods

The approach was applied to a low-noise, high dynamic range, 16-channel RF receiver. It is designed to operate at the magnet and consist (Figure 2) of second stage amplification, digitization as well as the required low-phase-noise clocking circuitry. It is equipped with Hall sensors measuring primarily the field components perpendicular to the micro devices. Furthermore, MEMS accelerometers are detecting the motional state of the electronics. The output of all these sensor are fed to a controller and evaluated. If a predetermined threshold level for the magnetic field or the acceleration is exceeded, the output data is flagged as potentially invalid for further processing.

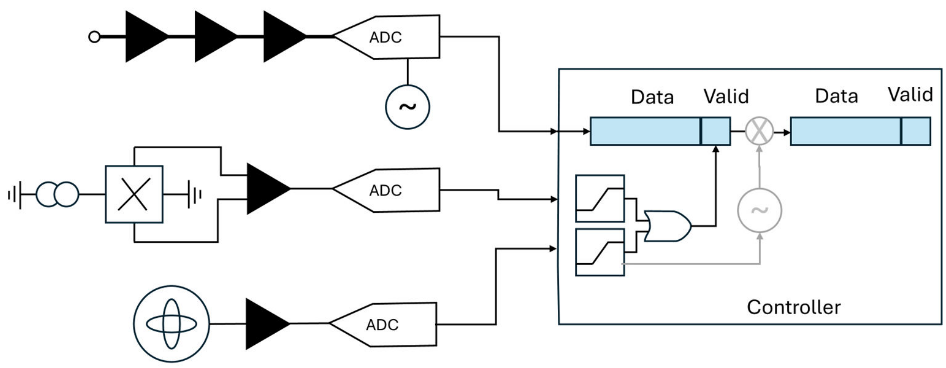

Figure 2: The presented system entails magnetometers (Hall sensors) and an accelerometer. The measurements are used to by the controller to decide if the data is received in valid conditions. Additionally, the data could be used to correct the acquired data as well as indicate to the user, how to better locate the device.

Furthermore, the Hall sensors are employed to direct the user to correctly position the device at the scanner.
To determine the thresholds, the field dependence of the involved circuitry was measured in a 3T system. The tolerance towards the perpendicular magnetic field is estimated by tilting the device in isocenter location while measuring its electrical properties. The measurements entailed determination of the transfer function using a network analyzer as well determination of the noise figure.
Threshold levels with respect to vibrations were derived on an electrodynamic shaker table.

Results

Figure 3 shows an example of static field exposure measurements of the second-stage amplification block. This block consisted of 3 cascaded monolithic microwave integrated circuit amplifiers (MMIC, MiniCircuits, TSY-13LNB+). As seen, the gain starts to degrade by almost 3 dB for 0.7T of perpendicular field strength. Furthermore, the amplification chain was seen to oscillate for higher values.
As example for distortions induced by vibrations, the quality of the electro-optical conversion of the fiber optical clock transmission to the receiver was tested on the shaker. As seen in Figure 4, a 200 Hz sine wave acceleration can already induced substantial modulation spurs on the received clock signal. Similarly, oscillators, particularly crystals are affected [4]. Since the clocking spurs translate directly onto the received signal phase, there threshold could be set by the spur level and total in-band jitter values.

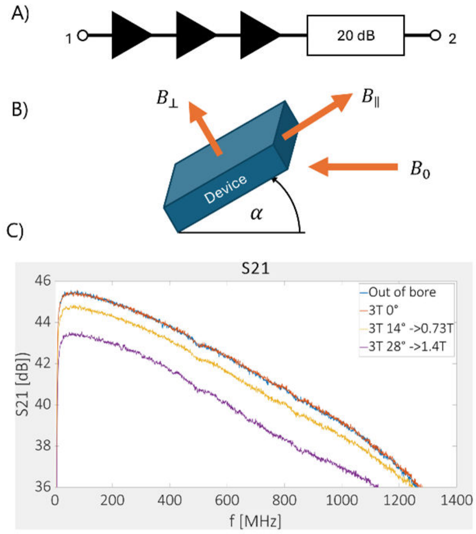

Figure 3: A) Example circuit tested consisting of 3 cascaded GaAs FET amplifiers deliver a total gain of about 45 dB. For stabilizing the VNA measurement an attenuation of 20 dB was entered in the circuit and subtracted from the results. B) The circuit was inclined relative to main field axes in the bore of a 3T magnet. C) Results of the gain in the bore showing a drop in gain at higher perpendicular field strengths.

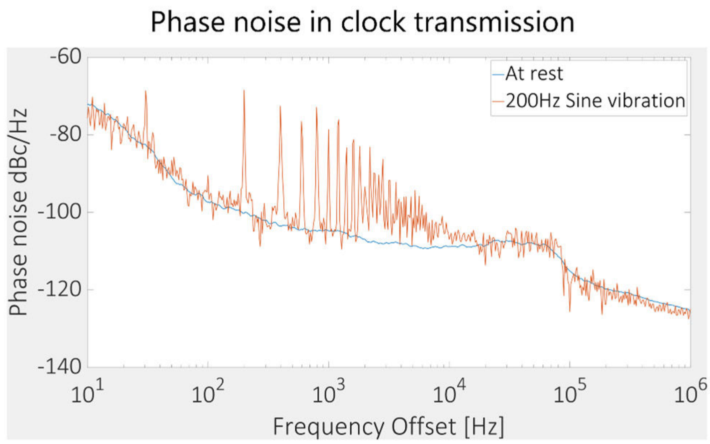

Figure 4: Results from optical RF clock transmission where the receiver is placed on a shaker table. If the shaker is actuated at 200Hz with a sine wave, spurs in the phase noise are induced. Depending on the amplitude of the shaking, these spurs can reach significant levels.

Discussion

The performance and fidelity of device operating close to MR magnets can be significantly affected by the scanner. Particularly vibrations and static magnetic fields can impair the operation of electronics.

While system components that are built into the scanner or operated at fixed locations in the scanner can be designed and tested to withstand these immissions, proper operation of devices that can be located freely in and around the bore is much harder to control. Embedding corresponding sensors can be employed to flag the data to thereby ensure correct operation.

Furthermore, the sensors can be employed to guide the user in finding an appropriate location with respect to the B0 field, similarly as it is well established in certain infusion pumps and life sustaining equipment [5].

Finally, the sensor data may of course also be used to correct the induced distortions in real-time or in post-processing as for instance as demonstrated in [4] or in analogous digital implementations.

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