A Patient Isolation System for Invasive MRI

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Introduction:

In order to safely use active MR devices inside of human subjects it is necessary to provide electrical isolation between the patient and the MR imaging system while permitting high SNR MR signal detection from coils inside the body. A custom-built patient isolation module for use with an MR tracking system is presented here.

The circuit is designed to prevent leakage currents from the system entering the device and has been designed to specifications used to build ultrasonic catheters for coronary arteries. The barrier must hold even if full line voltage appears at the scanner-side of the isolation module. In particular, the system must feature a total leakage current less than 10μA at 50 Hz when 120 volts AC applied, and must be Hi-Pot tested to 4000 volts.

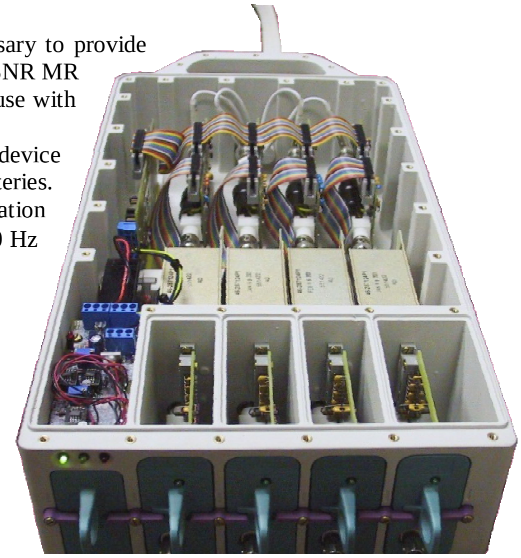

Figure 1

Methods:

As shown in Figures 1 and 3, each signal path in the isolation module contains:

- a capacitively matched air-core transformer to provide isolation
- a preamplifier placed before the isolation stage to reduce the SNR decrease due to the air-core transformer
- an adapter module enabling the user to customize the signal path for a specific application.

Logic and power voltages are provided by a non-magnetic 12 volt 2.0Ah lead-acid gel cell battery through a voltage regulator. These voltages are distributed to a control board and then daisy-chained to the isolation boards. An opto-isolated switch routes the 12 volt power to the isolation modules and the preamplifiers only when a bias is present on the cables from the scanner. The state of the power switch is indicated for each channel by a diode on the front panel of the adaptor modules (see Figures 1 and 2). Three additional diodes connected to the power board indicate the battery status. For future design flexibility the device adaptor modules also receive logic and switched 12 volt power. Furthermore, the design contains spare filtered digital signal lines originating from the control board, daisy-chained via the isolation boards and passed on to the adaptor boards.

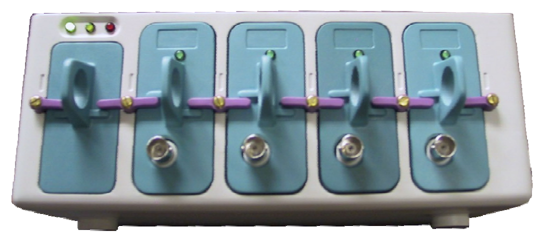

Figure 2

The case of the module was designed using a CAD system. The computer model was then used to create a mold from which plastic castings of the box were made.

Discussion:

The overall system performs according to the required specifications, with the isolation transformer itself displaying a leakage current less than 2μA at 50 Hz when 120 volts is AC applied. The isolation is maintained even with one of the blocking capacitors is shorted and the winding insulation is compromised.

Compared to our previous version of the isolation module, moving the preamplifiers to the patient side of the isolation transformer significantly reduced the insertion loss and cross-talk between channels. This enabled us to reliably perform MR point source tracking with smaller devices, such as guide-wires.

The device adapter modules are easily changed and made unique for each device. For example, device adapters modules for BNC and SMA connectors have been constructed. Device adapter modules with tuning and matching circuitry, and baluns have also been constructed to maximize the SNR of the tracked device.

Since battery depletion results in the loss of preamplifier bias, it was necessary to include low voltage indicators in the design. With the current adaptor modules the charge lasts for more than 6 hours of continuous operation (1.05 W per preamp and 0.07 W per indicator diode). The yellow warning diode was set to light at about 10% charge remaining, thus leaving the interventional staff sufficient time to insert a fully charged battery.

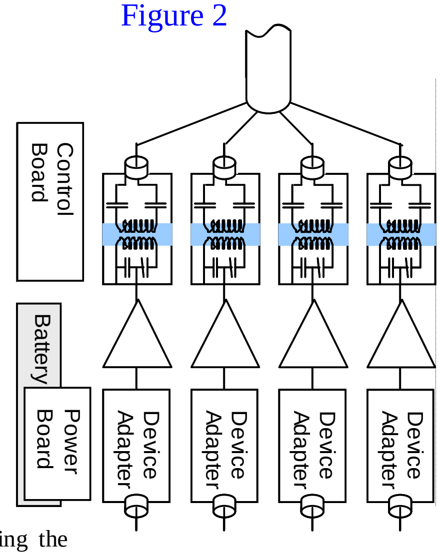

Figure 3

Conclusions:

The isolation module meets the required safety standards and provides the user sufficient flexibility without the need to modify (and possibly compromise) the other safety-critical components of the system. It should be noted, however, that while the isolation box protects the patient from harmful currents and voltages originating from the MR system, it does not eliminate the dangers from voltages induced on the shields of the tracking coil cables. This and similar remaining issues, are currently being addressed by our group.