HIGH POWER SWITCHING UNIT FOR THE MRI RF SYSTEM

David Bělohrad† (david.belohrad@cern.ch)
Daniel Valúch (daniel.valuch@cern.ch)

Abstract:

The switching unit of a Magnetic Resonance Imaging (MRI) RF system with the universal RX/TX coil is one of the main causes of quality degradation of the resulting image. The difficulties of the design of such switch have the origin in very different signal levels in the RX and TX mode, and complicated timing of the switching. In this paper the 1kW CW mode switching unit is shown with all major aspects of its design.

1. PROBLEM DESCRIPTION

In the MRI system the signal is usually processed in two separate paths. To obtain the magnetic resonance (MR) response from the sample (biological tissue), it is excited by an RF signal of defined parameters properties first. After switching off the excitation, the sample response is detected. Due to the common coil for RX and TX used, the correct signal path must be set by the switching unit.

The switching unit must have a high power handling capability, low insertion loss, very high isolation between RX and TX ports and finally high switching speed. Main difficulties are caused by a very different signal levels of the transmitter (+60dBm) and the receiver (-50dBm). Very important is also a precise switching synchronization. The switching synchronization is linked to the signal to noise ratio of the response signal, which is exponentially decaying with respect to time. Bad switch timing, or very long transient periods between the TX and RX modes can yield to poor signal to noise ratio of the experiment.

In this article we are presenting the construction of the switching unit for MRI system built at the Institute of Scientific Instruments of Czech Academy of Sciences in Brno, Czech Republic. For excitation, a 1kW CW linear power amplifier is used. The received response is amplified by a low-noise pre-amplifier. Due to a very long recovery time of the pre-amplifier after input overload, the crosstalk between the transmitter and the receiver is the critical parameter. The pre-amplifier's input power must be kept within its linear operating region. For our particular case, the power level of -50dBm is tolerated.

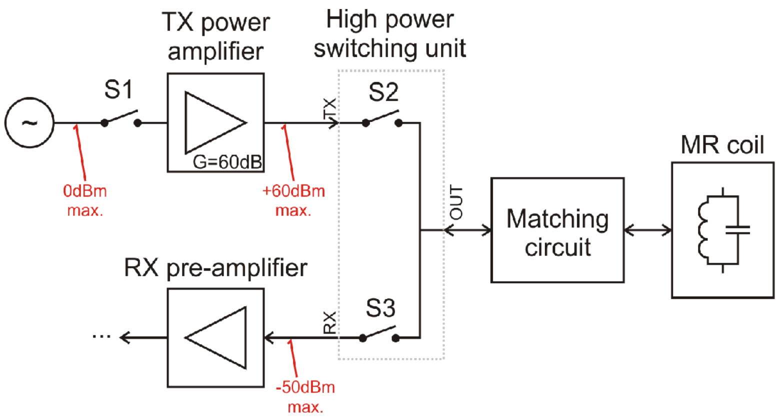

Figure 1: Proposed system solution

Figure 1 shows the discussed solution. The exciting signal of 0dBm from the generator is fed via switch S1 to the power amplifier. Switch S1 serves as protection of the pre-amplifier against accidental excitation during reception. The output of the amplifier

† Contact address: CERN, Geneva 23, CH-1211 Geneva, Switzerland

(maximum power of 60dBm) is connected to the TX port of the switching unit. To improve the signal to noise ratio of the measured response, switch S2 is blocking the output of the power amplifier while the apparatus is in the RX mode. Switch S3 is connected between the MRI coil and the receiver. Its role is to isolate the very sensitive input of the receiver from the high power exciting signal while the apparatus is in the TX mode.

The technical requirements are very different for each of the switches mentioned. Switch S1, processing the low power signal, can be commercially available. Switches S2 and S3 are high power ones, which must withstand 1kW CW RF power without damage. These switches are not commercially available, and must be designed and built in house. For the switch S1, the MiniCircuits ZASWA-2-50DR type is proposed. It has an attenuation better than 80dB at 200MHz and very fast switching time (hundreds of nanoseconds). The insertion loss of typically 1.7dB is not critical.

The switching speed and power handling capabilities are critical for the switches S2 and S3. S2 is suppressing the power amplifier's output noise and has to be opened (high isolation state) as soon as the excitation pulse finishes. S3 is connecting the receiver to the coil, and has to be closed immediately after the end of the excitation. Any delay between the end of the excitation pulse and the start of the response acquisition yields to a degradation of the signal to noise ratio of the MR image. In addition, switch S3 must have very low signal distortion and very high isolation exceeding 120dB as well.

As the parameters of the switch S3 are the most critical, we are going to describe the design of the high power part of this switch. For S2 we can suppose the same solution as for S3, as the parameters are common, but less restrictive.

2. THE SWITCH DESIGN

In the modern MRI switching units the PIN diode solutions are preferred, rather than the anti-parallel diode pair solutions ([1]) due to smaller non-linear distortion. Another advantages lie in higher isolation, better RF power handling capability and non-magnetic properties. In contrast to the anti-parallel diode solution, the process of switching is not automatic and requires a pulsed current generator providing DC current for the PIN diodes.

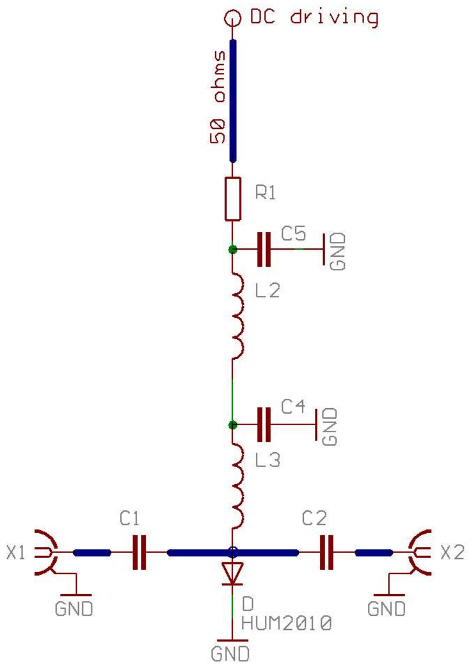

Figure 2: The schematic diagram of high power PIN diode stage.

From the previous section one can summarize the needs for the switch S3: isolation bigger than 120dB, insertion losses smaller than 2dB, minimization of transition effects and high power handling capability. For the excitation, the narrowband MRI signal with a centre frequency of 197MHz is used.

It is clear, that the high power part of the switch must be reflective, and contain multiple stages. With a single stage the maximum isolation of about 20dB is achievable. The desired isolation must be higher than 40dB. For the low power part, the MiniCircuits absorptive ZASW250DR switch is proposed. The cascade connection of high and low power switches gives desired total isolation at reasonable cost.

The high power stage of the switch is

depicted in Fig. 2. To drive several PIN diodes by one common driver, a small resistor (R1), equalling the forward PIN diodes currents, must be used. The fourth order Tschebyschev filter isolates the driver circuitry from the main RF path. To suppress the RF leakage, the filter attenuation must be at least 80dB. The Microsemi's HUM2010 PIN diode is used, which has currently state-of-art electrical properties. The switch stage is AC coupled by high quality capacitors C1, C2 (Johanson Dielectrics, 1nF, type 302S48N102KV4).

The RF part of the switching unit is shown in Figure 3. To achieve an isolation of the high power part better than 40dB, two cascaded stages must be used. The stages are connected by the a low loss λ/4 (diode-to-diode plane) transmission line. The last stage represents absorptive, TTL driven, PIN diode switch from MiniCircuits.

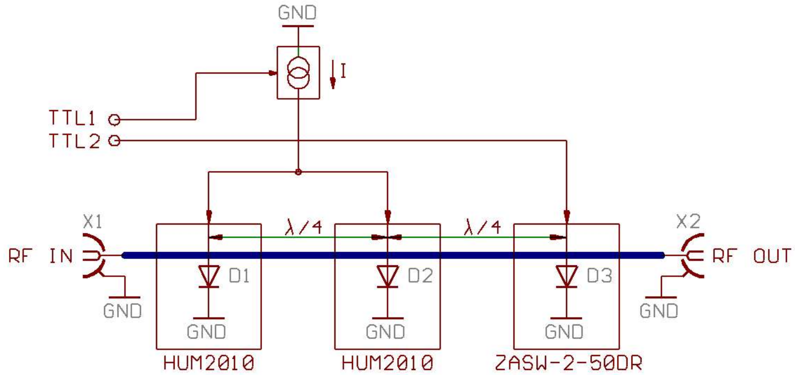

Figure 3: The RF part of the switching unit

The current generator, depicted in Fig. 3 as a current source, provides the pulsed current of 1A for each stage. PIN diodes, biased by 1A, represent the short circuit for RF signal (0.2Ω). To switch off the diodes, a reverse voltage of -48V is applied. When switched off, RF sees impedance of 10kΩ || 4pF. The fast switching times are achieved by using push-pull driver, 10ns into a resistive load were measured.

3. REALIZATION

The two high power switching unit stages were built (Fig. 4) and tested. During the realization the HUM2010 PIN diodes were found mechanically extremely fragile. This is caused by the absence of robust diode package. The cathode is screwed into the massive aluminium box for better diode cooling (expected power dissipation 10W).

The input stage of the driver is realized using BFG541 transistors, forming a differential amplifier. The push-pull stage is realized by a complementary pair of MOSFET transistors (type ZVP4424G/ZVN4424G). To obtain the desired current several transistors are connected in parallel.

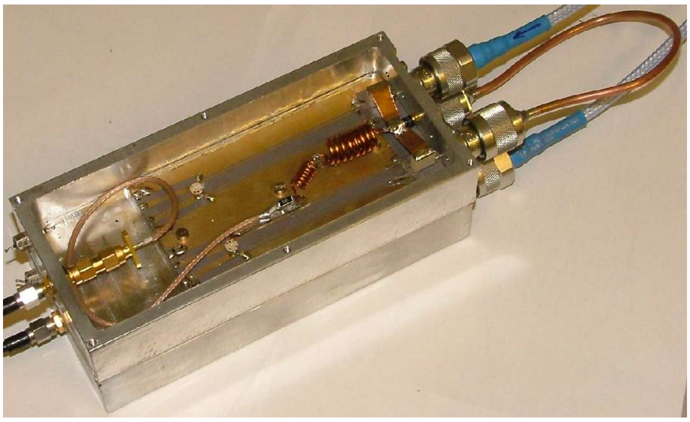

Figure 4: The built prototype of two high power switch stages

4. MEASUREMENTS

Figure 5 shows the two PIN diode stages in the open state. Achieved isolation is exceeding 47dB. A value of S_{11} gives a rough idea how much RF power is dissipated in the diodes. Figure 6 shows the insertion loss of the closed switch. A value lower than 0.23dB was measured, which fully satisfies initial requirements. A very good return loss (S_{11} = -37dB) was achieved as well. The switching speed and the transition effects (while switching) are shown in Figure 7. Top trace displays driver's output voltage. The bottom trace shows the keyed RF signal passing through the switch. The turn-on time (t_{on})was measured to be 1.8us and the turn-off (t_{off}) time 55ns respectively. In case of insufficient turn-on switching time, the possibility of shortening it might be further studied.

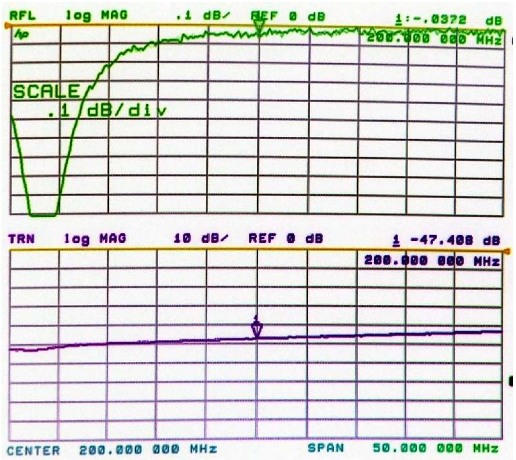

Figure 5: The switch in open state, top trace S_{11}, bottom trace S_{21}.

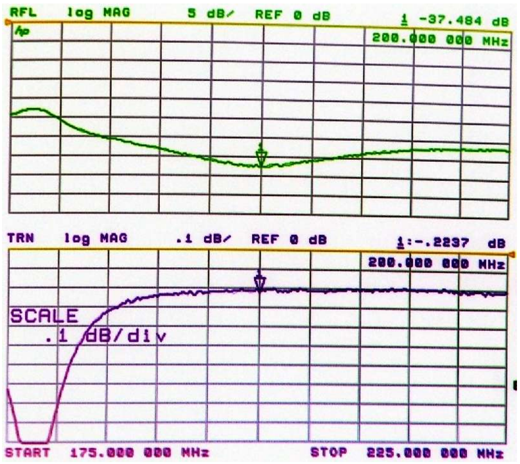

Figure 6: The switch in closed state, top trace S_{11}, bottom trace S_{21}.

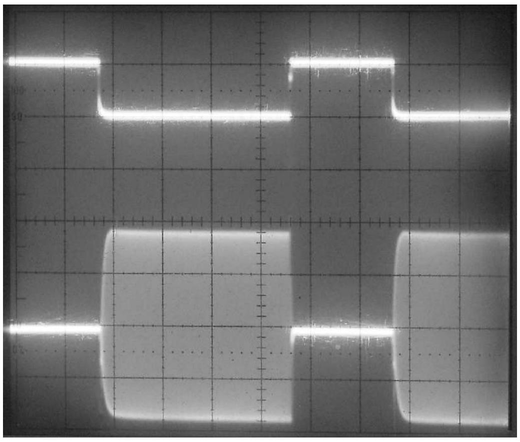

Figure 7: Switched signal. (Top trace scale corresponds to 50V/div, bottom trace corresponds to +17dBm RF signal. Time scale: 100us/div)

5. CONCLUSION

The high power switching unit for the MRI RF system is discussed. Preliminary tests at 200W power level were performed. The sufficient isolation between the RX and TX ports was found and a very low return loss was measured. Acceptable heat dissipation at high power was observed. After successful testing, the final rigid RF housing will be produced.

6. REFERENCES

[1]Bělohrad D., Húsek V., Kasal M., "RF Power Switch for MRI", In Conference Proceedings of 10th International Conference Radioelektronika 2000, Bratislava, Slovak Republic

[2]MiniCircuits, High Isolation GaAs coaxial switch datasheets, www.minicircuits.com

[3]Microsemi, HUM2010 PIN diode datasheet, www.microsemi.com