2010 Symposium on Security Detection and Information Processing

A High Isolation Switching Unit for MRI System

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Abstract

The magnetic resonance imaging (MRI) system mainly consists of a large powerful magnet, a high power frequency tunable RF source, several receivers, L-C parallel resonance circuits, timing control unit, signal processing unit and a T/R switching unit. In order to protect the receivers from overload, and to obtain clear images the switching unit should meet the several requirements: low insertion, high isolation and fast switching speed.

Such a switching unit with 1.5 Kilowatts handling capability is presented employing PIN diodes as key elements. This paper consists of four parts. 1) how to specify a PIN diode; 2) how to drive a PIN diode, and then presents a new method to drive PIN diode. It is no need to utilize neither optocoupler nor isolated power; 3) how to design a switch employing PIN diodes. 4) A simulation for the switch was performed to analyze its approximately specifications in advance and some measured results of the actual switch are shown.

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Keywords: PIN diode; T/R switch; MRI; Low insertion; Driver

1. Introduction

The basic magnetic resonance imaging (MRI) system used for medical diagnosis consists of a very large, powerful magnet to surround a chamber that is large enough for a patient to lie down inside it.

It also uses a high power, frequency tunable RF source that can be rapidly switched on and off. This produces a large RF field perpendicular to the magnetic field. This RF field is focused by the body coil. The RF source and both coils must be tunable in both frequency and impedance to “match” the impedance “of the patient’s body” [1].

In the MRI system the signal is usually processed by two separate paths. In order to obtain the magnetic resonance signal from the sample (biological tissue), it is excited by an RF signal of defined properties first. After switching off the excitation, the sample response (associated electric magnetic signal) is detected. Due to Rx and Tx sharing the same coil, the correct signal path must be switched by a 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 (+61.8 dBm) and the receiver (-50 dBm).

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doi:10.1016/j.proeng.2010.11.042
In this paper a switching unit for MRI system was designed. Due to a very long recovery time of the preamplifier after input overload, the crosstalk between the transmitter and the receiver is the critical parameter. The preamplifier’s input power must be kept within its linear operating region. For our particular case, the power level of -50 dBm is tolerated.

2. Switch design

2.1. Selection of PIN Diode

Selection of PIN diode is dependent on many conditions, which consist of working frequency range, bandwidth requirement, RF power characteristics (peak power, peak power, pulse duration and duty cycle), switching time requirement, bias conditions (forward bias, reverse bias), circuit impedance, shunt or series assembly, maximum acceptable insertion loss, minimum isolation needed, VSWR and distortion requirement, static characteristics (applicable break down voltage, forward series resistance, carrier lifetime, thermal resistance), mechanical and packaging constraints [2].

The switching speed in any application depends on the driver circuit, as well as the PIN diode. The primary PIN properties that influence switching speed may be explained as follows: A PIN diode has switching speed from forward bias to reverse bias, \( T_{FR} \). The diode characteristic that affects \( T_{FR} \) is \( \tau \), carrier lifetime. The value of \( T_{FR} \) may be computed from the equation:

\[
T_{FR} = \tau \ln(1+I_F/I_R) \quad (sec.)
\]

Where: \( \tau \) is carrier lifetime, \( I_F \) is forward bias current, \( I_R \) is initial reverse current.

And \( T_{RF} \) depends primarily on I region width \( W \).

When the PIN diode is forward biased, the stored charge, \( Q_s \), must be much greater than the incremental stored charge added or removed by the RF current, \( I_{RF} \). To insure this, the following inequality must hold:

\[
Q_s = \tau \times I_F >> I_{RF} / (2\pi f) \quad (2)
\]

If working frequency is at 64 MHz, \( f = 64MHz \), \( I_F = 0.2A \), \( I_{RF} = 2A \), that is \( 0.2 \times \tau >> 2/(2\pi \times 6.4 \times 10^7) \), \( \tau >> 0.25 \mu s \). so the carrier time should larger than 2.5 \( \mu s \). There are several chips according with this requirement, such as hum2010, um4010, produced by Micro-semi Inc., and MA4PK2001 produced by M/A-COM Inc.

2.2. Topology of switch

The switch configuration, is shown Fig.1. Transmit-path consists of single series PIN diode. Receive-path consists of two series-connected PIN diodes, two shunt-connected PIN diodes and limiters.

![Figure 1. Switch configuration with series-shunt connections](image)

2.3. Driver design

The switching speed of a PIN control device is dependent upon both the driver and the PIN to be switched. Driver switching can be enhanced through the use of speed-up capacitors and coils [3], as shown in Figure 2 (C1,
L3), a classic driver. The driver shown in Fig. 2 may be used for moderate speed application, not suitable for fast speed and high voltage purpose. The reason is that high voltage NPN or PNP transistor usually has longer time characteristic. Even utilizing speed-up capacitors and coils, it is difficult to obtain a switching time faster than 2 microseconds. Hence, in high-speed and high-voltage driver, MOSFET has the inherent benefit. The rise time and fall time of MOSFET may up to tens of nanoseconds, even faster. A high voltage driver circuit utilizing MOSFET (Vishay, IRFR310) is shown in Figure 3. Two opto-couplers are utilized to drive MOSFETs; Two isolated-powers is utilized to isolate low voltage and high voltage.

3. Simulations

The characteristics of the switch unit were simulated by ADS software 2006A of Agilent. The principal simulation results are shown in Figure 4, 5, 6, 7.
4. Measurements

The performance of switch prototype was measured in lab using E5071C network analyzer, Agilent corp. they were measured from 300 kHz to 200 MHz, at 5 kHz step. The poorest isolation of Rx path is -62 dB, shown in Fig. 8. Insertion loss of Rx path is smaller than -0.4 dB at working frequency range, and that is a rather better result, shown in Fig. 9. But there were three parallel resonances (Rx path) and two parallel resonances (Tx path) falling within the desired pass-band. These resonances show up as distinct attenuation notches at frequencies of occurrence. I am trying to solve it. The switching characteristic is rather better, faster than 1 microsecond, shown in Figure 12, 13, 14.
5. Conclusion

A high power switching unit for the MRI RF system is discussed. The sufficient isolation between the Rx and Tx ports was found and a very low insertion was acquired. The power dissipation of switching driver is acceptable. The switching speed faster than 2 microsecond was observed.

Reference

[1] Microsemi Corp., The PIN Diode Circuit Designers’ Handbook, Microsemi Corp., Chapter 8, 1998.
[2] Product brochure, Chelton Telecom & Microwave: Diodes, Ferrite devices, Filters, France, p4
[3] Joseph F. White, Microwave Semiconductor Engineering, chapter 2, US, 1982, pp.119-134.