CHAPTER - 8

PIN DIODE CONTROL CIRCUITS FOR MAGNETIC RESONANCE IMAGING SYSTEMS

NOTES

MAGNETIC RESONANCE IMAGING SYSTEMS

INTRODUCTION

Magnetic Resonance Imaging (MRI) Systems manufacturers use a substantial number of very sophisticated Microwave Components in the RF and Signal Processing parts of their systems.

The basic MRI system used for medical diagnosis consists of a very large, powerful magnet to (0.1 to10 Telsa) surrounding 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.

HIGH - FIELD MRI RF RECEIVER COILS [1]

Special-purpose coils are designed to optimize the signal-to noise-ratio (SNR) from a given region of the body. State-of-the-art coil systems include the use of four or more coils with four separate receivers. This method is often referred to as a phased array system although the signals are not added such that the signal phase information is included [1].

Normally, the RF signal is in the range of 10 to 100 MHz. During a typical set of clinical image measurements, the entire frequency spectrum of interest is of the order 10 KHz, which is an extremely narrow band, considering that the center frequency is about 100 MHz. This allows the use of single-frequency matching techniques for coils because their inherent bandwidth always exceeds the image bandwidth. This is an extremely important consideration when specifying PIN diodes for coil switching elements.

The quality of the MR images depends on the Signal-to-Noise Ratio (SNR) of the acquired signal from the patient. SNR is of the utmost importance in obtaining clear images of the interior of the human body.

MRI RF - COIL DESIGN PRINCIPLES RELATED TO PIN SWITCHING DIODES

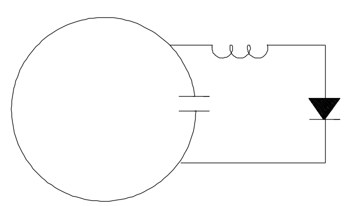

Figure 8.1 Simple Circular Loop With One Switched Gap

Figure 8.1 is a simple model of a circular loop with a single Capacitive gap. The gap is shunted by a series combination of an RF coil (L_S) and a PIN diode. The individual reactances of L_S and C_G are about 50 Ohms at the operating frequency. For simplicity, the bias circuitry and the 50 Ohm RF output line across the PIN diode are not shown. The value of Ls is chosen such that the Inductive Reactance of the coil (L_S) and the Capacitive Reactance of the gap are in parallel (phase) resonance when the PIN diode is forward biased. This parallel resonance causes a large impedance (or zero Conductance) to appear across the gap, causing the RF loop current to decrease to zero (open circuit or OFF state). Multiple PIN Diode Switch Configurations are also used in MRI System designs [1].

A practical MRI coil would have two or more gaps [1]. A second gap is needed to apply an RF synchronization pulse of frequency distribution {[sin x] / x} to time the initial test pulse and the image response pulse. The Capacitive gaps permit the flow of RF current through the MRI Loop. The PIN diode bias network inhibits the flow of RF current through the PIN diode, although the diode must withstand the RF line voltage when it is back biased.

KEY CHARACTERISTICS OF MRI RF - COIL PIN SWITCHING DIODES

Exclusion Of Magnetic Materials

PIN diode must not contain any magnetic materials, either associated with the die, die attach metalization system, or the RF package assembly. The existence of magnetic materials in the PIN diode structure distorts the static magnetic fields associated with the various coils and will interfere with system calibration and accuracy of clinical measurements.

Maximize Signal To Noise Ratio

When the MRI coil switches are OFF (i.e., reverse biased), the receivers are listening to the image return pulse. The receivers' SNR is degraded by the OFF impedance of the RF switch. This effect is specified by the Reverse Bias Leakage Current (I_R) at the PIN diode's Reverse Bias Breakdown Voltage (VBR). I_R @ VBR is alternatively specified by the equivalent parallel resistance (R_P) of the reverse biased PIN diode [Chapter One].

The gradual increase of SNR due to the increase of reverse bias leakage current is the result of poor passivation of the PIN diode's I-region. Microsemi PIN diodes are passivated with a unique proprietary glass passivation process to avoid this problem.

Impedance Matching Of The MRI Coils To The Patient's Body Impedance.

The most usual RF frequencies used for commercial MRI System design are 21 MHz and 64 MHz. The Image search and tune bandwidths are 4 KHz, 8 KHz, and 16 KHz. The absolute values of PIN diode parasitic impedances is less important than their potential variation from lot to lot. For such narrow band applications, these parasitic impedances can be compensated in the initial design of the switch.

PIN DIODE BIAS CONDITIONS FOR MRI COIL SWITCH APPLICATIONS

Since MRI Systems are designed to operate in the HF and VHF Bands, the bias conditions described in Chapter Two for HF Band High Power Switches apply, with the proviso that the PIN diodes are embedded in parallel resonant circuit across a loop gap.

FORWARD BIAS CONDITION

Since the forward bias resistance (R_S) of the PIN diode decreases as the bias current increases (Figure 3.4), Microsemi recommends the maximum bias current level compatible with the bias circuitry available, with 50 mA as a minimum value. The R_S of the forward biased PIN diode in Figure 8.1 adds to the loss of the switch circuit when in parallel resonance, which decreases the open circuit impedance across the gap.

REVERSE BIAS CONDITION

A conservative design would require that the VBR of the PIN diode chosen for a MRI switch design should be at least equal to the peal-to-peak RF Line Voltage and that the reverse bias applied to the PIN diode in the OFF state is at least equal to the peak value of the RF Line Voltage.

RF SWITCH DRIVER CONSIDERATIONS

During the High Power Reverse Bias condition, the RF Voltage should not exceed the PIN diode's VBR. If the RF Voltage swing exceeds the VBR, the driver must have sufficient reverse bias current capability to achieve the desired Switching Speed (Ts), but it must also provide the excess reverse current required during the high power RF pulses. Under this reverse biased leakage condition, the PIN diode may heat appreciably, causing an increase in the leakage current. If the leakage current is large enough, thermal runaway will cause the PIN diode to be destroyed.

RF POWER HANDLING

In a practical SPDT switch for an MRI body coil it would be required to handle 10 KW of RF power.

Power Handling capability is specified by the device manufacturer and depends on:

Maximum Power That Can Be Dissipated By The PIN Diode (P_d Max)

Thermal Impedance From The PIN Die To Thermal Ground (Φ_{JC})

Temperature At Which The Thermal Ground Is Maintained (T_A)

Current MRI designs use PIN diodes mounted on threaded stud packages, either directly on the electrical ground (C-style) or insulated from the thermal ground (D-style).

MICROSEMI PIN DIODES SOLD TO U.S. MRI EQUIPMENT MANUFACTURERS

P / N	VBR
UM 4006	600 V
UM 4010	1000 V
UM 4306	600 V
UM 4010	1000 V
UM 4006	600 V
UM 4010	1000 V
UM 9415	50 V
UM 2106	600 V
UM 2110	1000 V
HUM2010	1000 V
HUM2015	1500 V
HUM2020	2000 V

These devices are available in the glass leaded package (Style B), the 4 - 40 NC Stud package (Style C) and the insulated Stud package (Style D). The UM 2100 series is available in the SMT MELF package. The HUM2020 series is available as an axial leaded or studed versions. The stud thread size is 4-40 NC or 6-32 for the isolated stud version.