MicroNotes

MicroNote #711A

ANALYSIS OF NMR / MRI COILS USING PIN DIODE SWITCHES

by:

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Micronote # 711A gives an overview of various classes of MRI RF coils and discusses the PIN diode characteristics necessary for fabricating these MRI coil switches.

Radio-frequency (RF) coils, known also as RF resonators and RF probes, are essential components in a MRI system. They are sometimes referred to as resonant antennas, but that can be confusing. An Electromagnetic field propagates from an Antenna whereas the "near field" associated with the resonator is of interest to the MRI coil designer.

RF coils are used to transmit and receive the RF signals. The first function is to generate the Larmor frequency to excite the nuclei to be imaged. The second function is to pick up signals emitted by the nuclei at the "same" frequency. These are transmit and receive coils, respectively.

The magnetic field generated by the transmit coil is referred to as the B1 field. The B1 field vector is orthogonal to that of the Bo field vector, which is provided by the MRI machine's permanent magnet.

To obtain high quality MRI images, RF coils must satisfy two basic requirements:

One: The RF transmit coil must be able to produce a homogeneous B1 field in the volume of interest (within the machine's bore) at the Larmor frequency so that the nuclei can be excited uniformly.
Two: The RF receive coil must have a high SNR and be able to capture signals with the same gain at any point in the volume of interest.

RF coils, used for transmit and receive, must have good B1 homogeneity and high SNR.
Because the direction of B1 is orthogonal to that of Bo, the design of RF coils is fundamentally different from the design of the magnet, shim, and gradient coils.
The shim and gradient coils are associated with the Bo, B1 fields and are used to improve
the uniformity of the magnetic field in the bore of the MRI machine.

In recent years, many types of RF coils have been developed and they can be categorized according to their shapes:

The first group is classified as volume coils, which include Helmholtz coils, saddle coils, and bird cage coils [1]. Birdcage coils may be high pass or low pass structures. Volume coils are often used for both transmit and receive functions.

The second group is classified as surface coils, which include single loop and multiple loop coils of various shapes [2]. These coils are usually much smaller than the volume coils. Surface coils have higher SNR because they receive background noise only from nearby regions. They have poor B1 field homogeneity and hencem are used mainly as receive coils.

IMPORTANT PIN DIODE CHARACTERISTICS FOR MRI COIL SWITCHES

PIN diodes are used as the switching element in MRI coil switches because they contribute:

Low Insertion Loss in the forward bias state - this is a major issue in coil design because many diodes are used per array and the overall loss must be low.

High Isolation in the reverse bias state is important to achieve the required transmitter / receiver isolation for receiver protection - are important issues

Microsemi PIN diodes also contribute low leakage current in the reverse bias state, insuring that the attendant noise contribution does not degrade the Signal to Noise ratio.

Minority Carrier Lifetime
Long minority carrier lifetime (t) [3] is needed for High Power Switching in HF-band. Lifetime is a property of the PIN diode I-region. Under forward bias conditions, free carriers do not immediately recombine, but do so after a finite time period (t in µs). Rectifier diodes (pn-junctions & Schottky-junctions) have values of in the picosecond range. Their injected carriers combine almost immediately upon entering the I-region.

Power Control Gain
Long lifetime PIN diodes have a property called power control gain. Effectively, 50mA of d-c bias can control 5 Amperes of RF current - this means that the diode will not rectify with large values of RF current present.

Non-magnetic PIN Diodes
Non-magnetic Packaging of PIN diodes is essential if the diodes are to be located in regions of high magnetic field strength.

RF - DC current independence - the PIN diode is a 2 lead device. Both RF and DC currents flow through the diode junction. If the embedding network is properly designed, the RF and DC circuits function independently.

Reference [3] contains detailed discussions of the PIN diode characteristics mentioned Above and References:

[1] Jianming Jin, "Electromagnetic Analysis and Design in Magnetic Resonance Imaging", CRC Press, 1999

[2] Zhi-Pei Liang & Paul C Lauterbur, "Principles of Magnetic Resonance Imaging",
John Wiley, 2000

[3] PIN Diode Circuit Designer's Handbook - Chapter 2 - PIN diode switches & Chapter 8 - "PIN Diode Control Circuits for MRI Systems