Technical Article

Create a Power Supply for an MRI Application

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Magnetic resonance imaging (MRI) uses a large magnet and radio waves to look at organs and structures inside your body. There are a number of challenging design requirements when designing a power supply for MRI applications. Because of the sensitivity of the measurements made by an MRI machine, the oscillator frequency of the power supplies needs to be precisely placed at a frequency that will not corrupt the MRI image.

The switching frequency of the power supply must be synchronized to a 2.488MHz clock because as the MRI is scanning, it radiates a high magnetic field, typically in the range of 1-3 Tesla. Because traditional magnetic-core materials used in power supplies would saturate under such levels, air-core inductors replace the magnetic cores. However, for an inductor having no ferromagnetic core material, the air-core approach provides very low inductance values.

One solution to the MRI power supply is the LM5140-Q1, an automotive-qualified dual-channel synchronous buck controller. One of the features of the LM5140-Q1 that make it desirable for a MRI application is its ability to be synchronized to an external clock up to 2.6MHz.

The LM5140-Q1 works in many nonautomotive applications because it solves certain specific design challenges. For example, since the device operates at 2.488MHz, you can use it in an MRI power supply.

MRI Inductor Design Steps

The inductance required for an MRI power supply is proportional to the switching frequency, as shown in Equation 1:

$$L = \frac{V_{OUT}}{\Delta I \times F_{SW}} \times D \qquad (1)$$

where L is inductance in microhenries, V_{OUT} is the output voltage, ΔI is the inductor ripple current, F_{SW} is the switching frequency and D is the duty cycle.

Once you have calculated the required inductance, you can use Equation 2 to determine the air-core inductor size:

$$L = \frac{(d^2 \times n^2)}{(18d + 40l)} \qquad (2)$$

where L is inductance in microhenries, d is the coil diameter in inches, l is the coil length in inches and n is the number of turns.

Looking at Equations 1 and 2, you can see that a higher switching frequency will result in a lower inductor value. A lower inductance value yields a smaller air-core inductor.

An alternative to the LM5140-Q1 is the LM5141 controller. The LM5141 is the commercial single-channel equivalent of the LM5140-Q1, and has the same features as the LM5140-Q1.

Table 1 lists the typical power-supply requirements for MRI equipment. The highest power rail is 12V at 20.5A, from a 48V (nominal) input. The combination of metal-oxide semiconductor field-effect transistors (MOSFETs) $R_{DS(ON)}$ and switching losses (which dominate MOSFET losses when operating at 2.488MHz) make thermal management extremely challenging.

The solution is to replace the MOSFETs with gallium nitride (GaN) FETs. GaN FETs provide significant efficiency improvements over MOSFETs because they have nearly zero reverse recovery, lower $R_{DS(ON)}$ and a lower gate charge (Q_G), reducing the losses to a more manageable level. GaN FETs have critical gate-drive requirements, so the LM5113 GaN FET driver is also necessary.

Table 1. MRI Power Rails

V_{IN} (V)	F_{SW} (MHz)	V_{OUT} (V)	I_{OUT} (A)
46-50	2.488	3.3	7.2
46-50	2.488	5	0.6
46-50	2.488	8	20.5
46-50	2.488	12	20.5
46-50	2.488	15	2.4
46-50	2.488	-8	15.84
46-50	2.488	-15	15.84

One of the more challenging design requirements for MRI applications is the need for a negative output voltage at high output currents. This presents another challenge to overcome. In Table 1 are the power requirements for an MRI inverting buck-boost power supply, 48V to -15V (and 48V to -8V), at 15.84A. The inverting buck-boost topology transfer function (Equation 3) requires the LM5140-Q1 to be able to withstand V_{IN} + V_{OUT}, $50V_{MAX}$ + 15V = 65V.

$$V_{OUT} = -V_{IN} \times \frac{D}{1-D} \qquad (3)$$

The LM5140-Q1 is able to operate with an input voltage of 65V (70V absolute maximum), overcoming the danger of overvoltage stresses.

Summary

The most valuable capability of the LM5140-Q1 controller in the context of MRI applications is its ability to be synchronized at 2.488MHz, reducing the size of the air-core inductors and keeps the switch-mode power supply switching frequency outside the sensitive ranges of MRI equipment. This allows for accurate processing of the measured signals in MRI equipment, which is the key to obtaining high quality images. TI offers a wide variety of products for MRI systems and equipment manufacturers, including op amps, DSPs, multi-channel high- and low-speed data converters, clocking distribution, interface, and power management.