

Effective RF shielding with carbon fiber composites for simultaneous PET/MRI

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Abstract: Radio frequency (RF) interference and gradient induced eddy currents have been a major challenge in building a simultaneous PET/MRI system, a new carbon fiber composite material is found to be a good RF shield while introducing negligible gradient eddy currents. It also provides excellent structural support for the PET detector components. This material is therefore promising for the design of PET/MRI systems.

Introduction: A prototype PET insert system has been built to be used simultaneously with a 7T (300 MHz) Bruker Biospec MR system [1]. In order to eliminate RF interference at 300 MHz, metal enclosures were used as shielding while placing these enclosures at a sufficient distance away from the MRI's isocenter to minimize gradient-induced eddy current on these metal enclosures. Though the PET insert has shown promising results, its physical design limits potential further improvements, e.g. adding more detector rings to increase PET sensitivity and axial field of view. Eliminating the fiber optical bundle, which connects the scintillator to the photodetectors, and moving the photodetectors and their associated preamplifiers closer to the MRI isocenter while adding more detector rings, becomes the preferred approach. However, concerns regarding RF interference and gradient-induced eddy currents are the major hurdles to overcome. In order to minimize RF interference while minimizing gradient-induced eddy currents, a careful study of RF shielding design is essential. Carbon fiber (CF) materials have been studied as an effective RF shielding material [2]. In this abstract, preliminary data have shown that CF composite material is a promising RF shielding material for a simultaneous PET/MRI system.

Materials and Methods: A 7T (300 MHz) Bruker Biospec MR system is used for this work. MRI gradient electronics are turned off. A single PET detector module is built consisting of an array of lutetium oxyorthosilicate (LSO) scintillator elements read out by a position sensitive avalanche photodiode (PSAPD). The PSAPD is then AC coupled to preamplifiers. The PET module was placed at the center of the RF coil. A Tektronix DsPO7254 oscilloscope (OS) is used to acquire data. Four data channels are recorded. Channel (Ch) 1 records raw PET data which is the readout of the preamplifier through a capacitor of 1 nF. Ch2 records one of the energy signals which is the output of the spectroscopy shaping amplifier. Ch3 records the timing signal of the PET detector which is the output of a constant-fraction discriminator (CFD). Ch4 is connected to a blanking pulse that is generated by the MRI RF amplifier electronics. It is used as a trigger to locate the 300 MHz RF signal. A single RF pulse at 300 MHz with duration of 20 μ s, and 500ms repetition time is generated. For experiment #1, its transmission power is set at 13dB down from full power. All PET electronics are turned off. 300 MHz interference is observed by the OS. Seven sets of data are recorded with different shielding materials: 1) no shielding; 2) 0.001" thick copper (Cu) shielding, axial length 151mm, inner diameter (ID) 63 mm; 3) 0.002" thick Cu, with same dimensions; 4) 0.003" thick Cu with same dimensions; 5) carbon fiber (CF) shielding (purchased from CST Composites, Caringbah, NSW, Australia), axial length of 151mm, ID of 60mm and OD of 63mm; 6) The same CF shield with 0.003" Cu added; 7) a longer CF shield that has an axial length of 596mm with the same ID and OD. In experiment #2, the RF coil is shielded by the longer CF tube (shielding situation #7) and data is recorded while changing RF transmission power attenuation from 13dB to 1dB. Experiment #3 is a repeat of #1, except that the preamplifier power to the PET detector is now switched on. Three sets of data are studied under 3 different shielding conditions. 1) without shielding; 2) 0.003" thick Cu with axial length of 151mm; 3) 151mm long CF tube.

Results and Discussion: The results of experiment #1 are shown in Table 1. Without RF shielding, an interference of 164.2 mV is generated by RF coil at 13dB. With better shielding, the interference is significantly reduced. Different thicknesses of Cu offer similar shielding effectiveness, but CF provides slightly better shielding. Adding additional Cu around the CF tube doesn't improve shielding in this case. Remaining cross talk between the MRI's RF and the PET detector module is due to radiation from the coaxial cable feeding the MRI RF coil. This is demonstrated via the improved shielding measured with the longer CF. Results of experiment #2 are shown in Fig.1. As transmitted RF power increases, RF interference increases as well. Nevertheless, even with high RF power, the CF provides effective shielding. For experiment #3, a sample of the observed RF interference is shown in Fig. 2 when no RF shield is used. Obviously strong RF interference is observed in the raw PET data (yellow, Ch1), two incidences of interference occur in the energy spectrum (blue, Ch2), and two unwanted pulses are found in timing signal (pink, Ch3) at the beginning and ending of the RF pulse. Note that green pulse is the blanking RF pulse used for triggering. Table 2 shows the RMS voltage of RF interference under the three different shielding conditions for experiment #3. When either 0.003" Cu or CF is used as shielding, interference in the energy spectrum and the timing spectrum cannot be observed on the OS even though very low (2.503 mV RMS) 300 MHz RF interference shows up in the raw PET spectra. In general, under an ideal PET operating environment, (e.g. 300 MHz is not present), a noise of 0.64mV RMS is observed on Ch1 of the OS when the preamp is turned off and 1.14mV RMS is observed when the preamp is powered on in the lab. When CF tube is used as shielding, RF interference is successfully reduced almost to noise levels. With better shielding on the RF cables, the CF tube shielded PET insert is capable of further reducing RF interference at 300 MHz to within the noise level of the PET detector preamplifier.

References: [1] C. Catana, et al, "Simultaneous in vivo positron emission tomography and magnetic resonance imaging," PNAS; 2008; 105(10), 3705-3710. [2] J. Keith, et al, "Shielding effectiveness density theory for carbon fiber/nylon 6,6 composites," Polym. Compos.; 2005; 26:671-678

Table 1. Results of experiment #1. RMS Voltage of the observed RF interference.

Setup No.	1 st (no shield)	2 nd (0.001" Cu)	3 rd (0.002" Cu)	4 th (0.003" Cu)	5 th (CF, 151mm)	6 th (0.003" Cu & CF, 151mm)	7 th (CF, 596mm)
V _{rms} (mv)	164.2	2.333	2.206	2.249	1.739	1.824	1.400

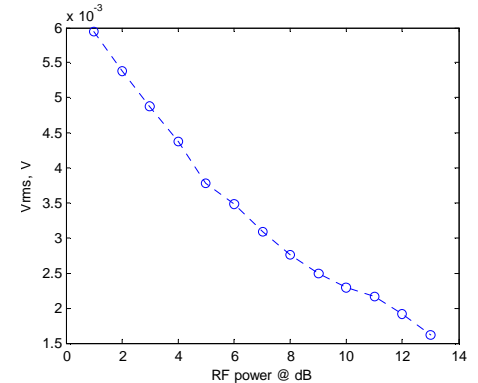


Fig. 1 Exp. #2, Vrms of RF interference vs. attenuated RF power.

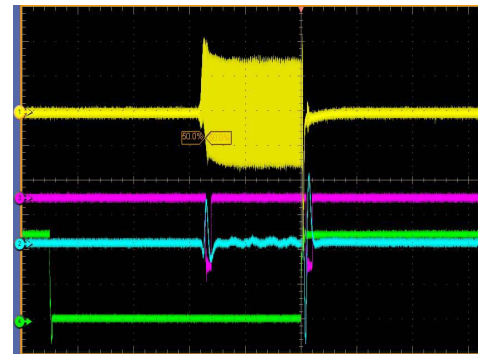


Fig. 2 Exp.#3 OS snapshot when no shielding is presented.

Table 2. Results of experiment #3. RMS Voltage of the observed RF interference

Setup No.	1 st (no shield)	2 nd (0.003" Cu)	3 rd (CF, 151mm)
V _{rms} (mv)	137.2	3.521	2.503