Compensation for thermally-induced loads on PET detectors from MR stimulus in simultaneous PET/MR imaging

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Target Audience: Anyone interested in the technical details of simultaneous PET/MR imaging.

Purpose: A high performance Time-of-Flight, MR-compatible PET system was developed and integrated with a 3T MR scanner for simultaneous PET/MR imaging. The PET detector ring was mounted between the RF shield and the MR gradient coil. Eddy currents induced in the RF shield by the changing gradient field lead to increased temperature around the PET detectors. This temperature change compromises the performance of the PET detector. In this study we evaluated the impact of the thermal loads caused from high intensity gradient pulses on the PET ring. To mitigate the issue, a temperature compensation algorithm was developed to maintain PET performance. We will discuss details of the mechanism of heating and challenges in implementing a temperature compensation algorithm.

Methods: The entire PET detector (scintillator array, silicon photomultiplier (SiPM) array, electronics, cold plate, shielding) were assembled and placed on the outer surface of the novel RF body coil and the MR RF shield, and inside the gradient coil of the standard MR750w 3T scanner (Figure 1). Table I below shows the system parameters. There are 28 compact detector modules in the PET ring, each of which comprises 5 detector units (figure 2). Each unit has two thermistors that measure temperature within the unit (10 thermistors in each module). Liquid cooling was employed to regulate the temperature within the PET detector modules. To perform thermal load tests, PET data was acquired with high intensity EPI X- and Y-gradient echo (GRE) protocols, which give rise to significant eddy current heating in the RF shield next to the PET detector cover shielding. The EPI sequences were run for two hours and PET data collection continued post EPI sequences until the detector temperature reached steady state. Thermally-induced SiPM gain drifts due to variation in temperature with gradient pulsing were captured. Creating a model of temperature variation at the pixel level was proposed, and gain compensation was implemented by adjusting the bias of each SiPM diode independently. A thermal regulation algorithm was developed and applied real-time to correct the 511 keV PET energy peak drift. As a measure of efficacy of this thermal drift compensation strategy, normalized PET coincidence rate was measured both with and without MR stimulus.

Results: The EPI GRE sequences in X- and Y-directions had noticeable impact on the temperature of the detectors – with different patterns for X and Y gradients (figure 3). Figure 4 shows the temperature variation around the ring, with larger temperature gradient on the top and bottom regions of the ring (due to applied gradients in Y-direction). The plot shows the percent peak shifts at different locations around the ring. After implementing the gain compensation, the shift in the energy peaks was significantly reduced as shown in figure 4. With gain compensation for temperature, the ratio of normalized PET coincidence rate with and without gradient pulsing indicated negligible loss in count rate, when compared to data without compensation.

Conclusions: Gradient-induced eddy currents have caused sufficient heating in SiPM based PET detectors to affect their performance. Measuring the temperature shift at many points, and correcting gain shifts on a per-pixel level, allows recovery of the performance. Our goal is to acquire uncompromised simultaneous PET/MR patient data of clinical significance.

PET/MR System

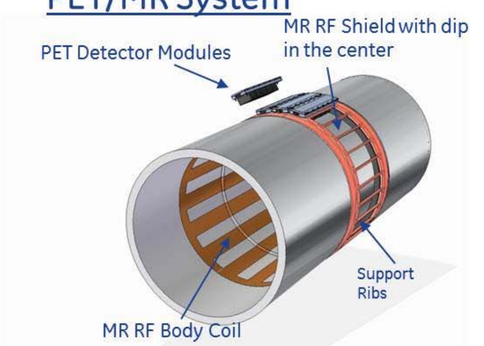

Fig.1. Schematic of the prototype PET/MR system

PET detector assembly for PET/MR

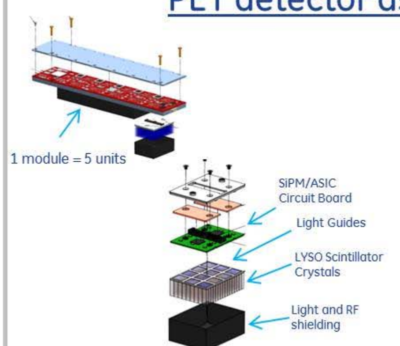

Fig.2. PET detector module and unit

Table I. PET/MR System Parameters

Scintillation Material	Lutetium based scintillators
Crystal dimensions	3.95 x 5.3 x 25 mm³
Photodetector	SiPMs
Total number of detector blocks/ crystals	5 rings of 112/ 20160
PET Patient FOV (Transaxial/Axial)	60 cm/25 cm
MRI magnet	3 T MRI GEHC MR750w

Gain Compensation for Temperature

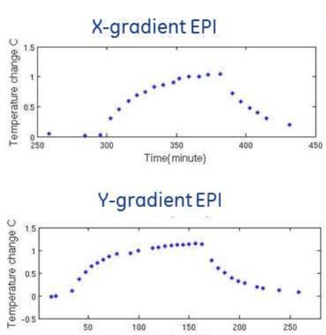

Fig.3. Temperature change on PET detectors recorded during X-(top) and Y-(bottom) EPI pulsing.

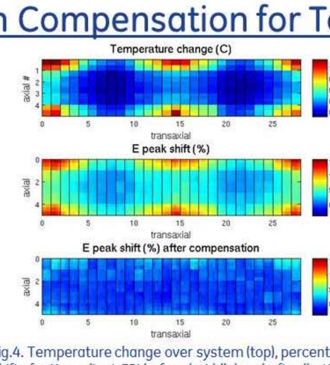

Fig.4. Temperature change over system (top), percent PET energy peak shifts for X-gradient EPI before (middle) and after (bottom) applying compensation for temperature.

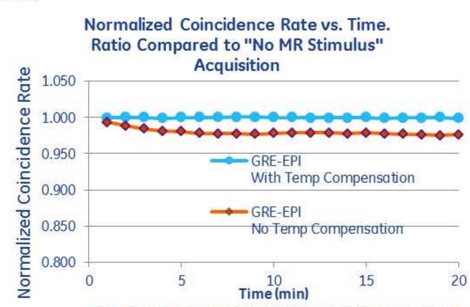

Fig.5. Plot showing ratio of MR Off Vs. MR stimulus with and without gain compensation for temperature.