Evaluation of mesh photomultiplier tube operation for dual modality PET/MRI systems

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Introduction: Beside the benefits achieved in through the combination of PET/CT (positron emission tomography (PET) and x-ray CT), several additional advantages can be achieved in PET/MRI. These include improved spatial and temporal correlation, flexible imaging region location, and dynamic studies with fMRI [1-2]. Field cycled MRI (FCMRI) is an alternative concept for performing an MRI experiment that uses two resistive magnets in place of the single superconducting magnet [3]. Two major characteristics of this system: feasibility for an open bore configuration (*Fig.1.a*), and relatively low fringe field distribution (*Fig.1.b*), facilitate the design of a PET/FCMRI system and reduce the magnetic field immunity requirement of the PET detectors.

Avalanche photodiode (APD) PET detectors show good performance in high magnetic fields; however, APDs place relatively stringent requirements on the scintillator, and the signal acquisition technology is still under development. Mesh photomultiplier tubes (PMT) are expected to be more immune to the magnetic field than conventional PMTs and can potentially be used to improve the PET system resolution by operating in a position sensitive mode [4]. The feasibility of implementing simultaneous PET/FCMRI using mesh PMTs was studied and the results are presented below. The benefits include the inheritance of mature PMT technology in PET detection, better temporal and spatial correlation (*Fig.1.c*) than interleaved or sequential solution [1-2], as well as the reduction of total imaging time and radiation dose.

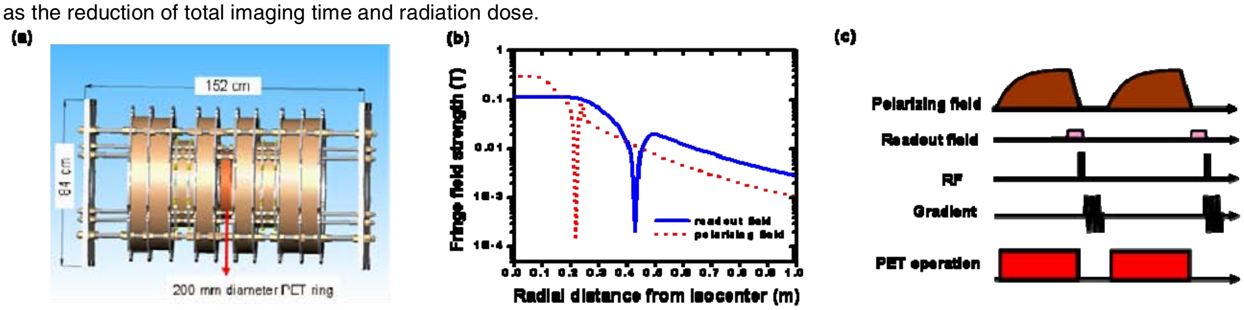

Fig.1. (a) Diagram of open field cycled MRI and PET system. (b) The fringe field strength along PET detector's direction in the prototype design. (c) Simultaneous PET/FC-MRI operation sequence

Methods: The performance of a fine mesh PMT (Hamamatsu H6153-70) in both static and dynamic magnetic fields was tested. A transverse magnetic field was produced by a pair of Helmholtz coils which had an efficiency of 0.8 mT/A and provided up to a maximum of 30 mT. The field inhomogeneity over the extent of the PMT was determined to be less than 2%. A parallel IGBT circuit was used to generate dynamic magnetic fields with three different dB/dt values (8 T/s, 12 T/s and 16 T/s) in order to simulate FC-MRI system operation. A NaI(Tl) scintillator and a ^{22}Na source of activity 0.02 uCi were used. The relative detector gain, energy resolution, time resolution, and efficiency, were measured as a function of the position of the PMT within the magnetic field. In the dynamic magnetic field, the detector behavior during magnetic field transients (before, during, and after removal of the magnetic field) and long term performance stability were measured (*Fig.2*).

Results: Relative gain was found to increase slightly to 1.05 for fields up to 10 mT and then decrease to 0.08 as the field was increased up to 25 mT. This is attributed to the mesh dynode design and the transparency factor correction [5]. The energy resolution at zero field as 6.4% and this remained stable for field values below 10 mT. Energy resolution worsened to 12.4% for field values up to 25 mT. Time resolution worsened to 19.1 ns (from 11.8 ns without field) when the field reached 25 mT. The efficiency and position sensitivity were unaffected by static fields up to 25 mT. For the dynamic field exposure, both the gain and energy resolution recovered completely ~2-3 ms after the end of the field pulse and then remained stable (*Fig.2*) for all three dB/dt values applied. The F-test was applied to compare system stability with and without the magnetic field. The calculated value of the F statistics was 0.911 for the relative gain and 1.15 for the energy resolution, and they are both significantly smaller than critical F value: 3.52 (degree of freedom: 19). This indicates that the system stability was not significantly degraded due to the application of the magnetic field sequence.

Discussion: These results show that the mesh PMT maintains good performance for exposure to transverse magnetic fields up to 25 mT. This represents a significant improvement over conventional PMTs, which have been shown to be adversely affected for fields of 5 mT [1]. In the dynamic magnetic field, rapid recovery of normal operation within 2-3 ms, with good stability have been observed. Referring to *Fig 1.b*, the 25 mT field exposure limit means that the mesh PMTs must be positioned at a radius of 40cm or larger within our proposed FCMRI system for small animal imaging, with optical coupling to a scintillator located at 0.1 m. Alternatively, the polarizing magnet design could be altered in order to expand the size of the inherent field null around a radius of 20 cm. Both of these options are currently under consideration for our system design.

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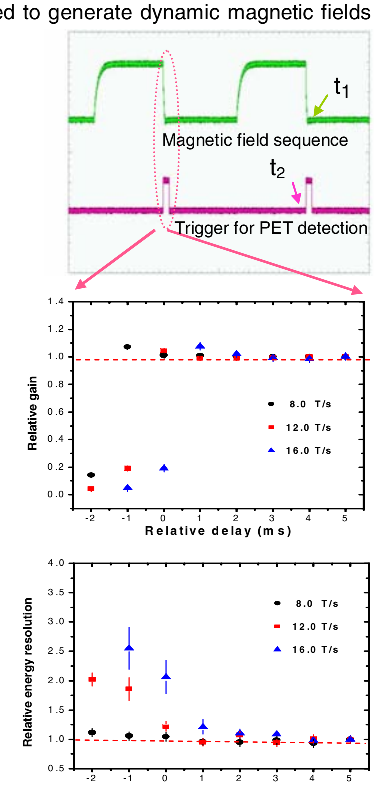

Fig.2 Top: Data acquisition sequence for FC-MRI and PET system. Center: relative gain recovery process. Bottom: relative energy resolution recovery process. (Relative time represents t_2-t_1.)