Hybrid TOF-PET/MRI local transceiver coil

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Introduction

In order to enhance diagnostic capabilities PET and MRI devices were combined into a single device providing an access to both metabolic and morphological information during a single examination. The commercial solutions consider two concepts of the both device integration, as shown on Fig.1. The first option allows to avoid a several important technical constraints, as listed in the table, met for the hybrid devices design [1].

Influence of MRI on PET	Influence of PET on MRI
Strong static magnetic field	Introducing magnetic field inhomogeneities
Rapidly switched gradient fields	
Radiofrequency pulse waves	Radiofrequency noise from detectors electronics
Scattering of gamma quanta on MRI setup elements	

Some of the constraints has been already overcome or suppressed to the limits allowing for both PET and MR images registration, i.e. by replacing the standard photomulitpliers with the silicon photodiodes, introducing RF shielding material arround the PET detector electronics, placing PET detectors outside the volume enclosed by MRI radiofrequency coils (as on Fig. 1 (right)).

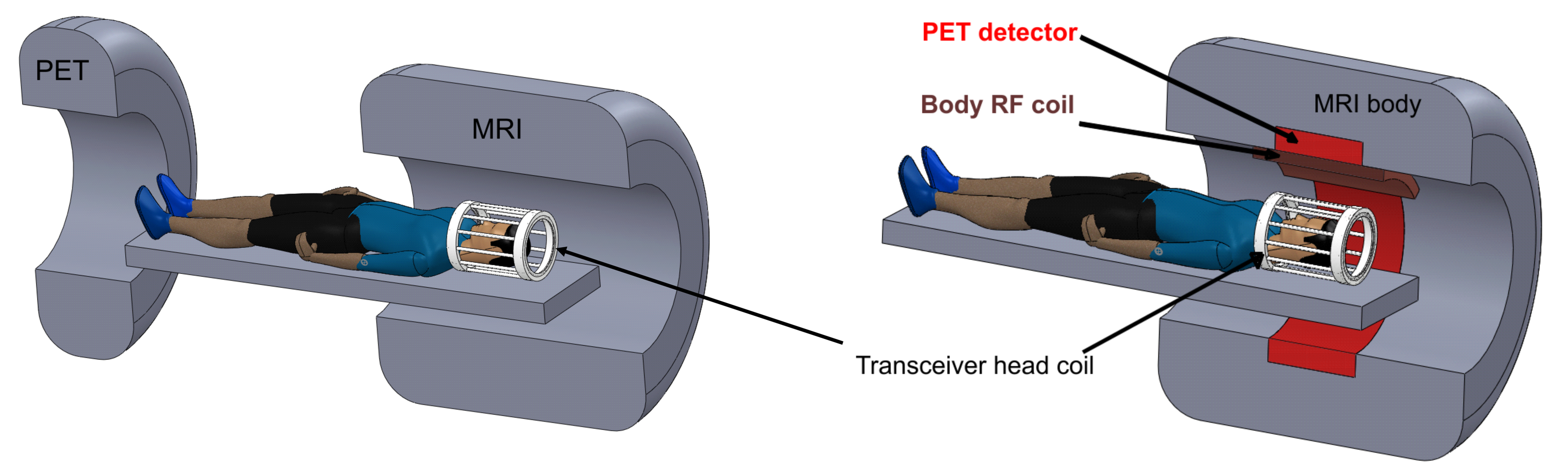


Fig. 1 Two approaches for combined PET/MRI device design [1]: (left) separate scanners with the common patient bed to be sequentially moved between scanners; (right) hybrid PET/MRI device with the PET detectors built-in the construction of the MRI scanner body. The local transceiver head coil has been visualized to facilitate further considerations.

Difficulties with the MRI local coils use

In spite of a possibility of the whole body and simultaneous PET and MR imaging the problem of use of the local MRI transmit-receiver (transceiver) coils still remains (Fig. 2). Such coils are designed to be close to the imaged object (head for example – Fig. 2 (left)), thus enhancing the MR image quality in comparison to the whole body coil use that is built in the MRI scanner body (see Fig. 1 right).

Coils are made of plastic and metal conductors which are on the way of propagating annihilation gamma quanta, thus they can be scattered accidentally. Scattering effects (Fig. 2 (right)) may cause the worsening of a spatial resolution of the PET diagnostic images.

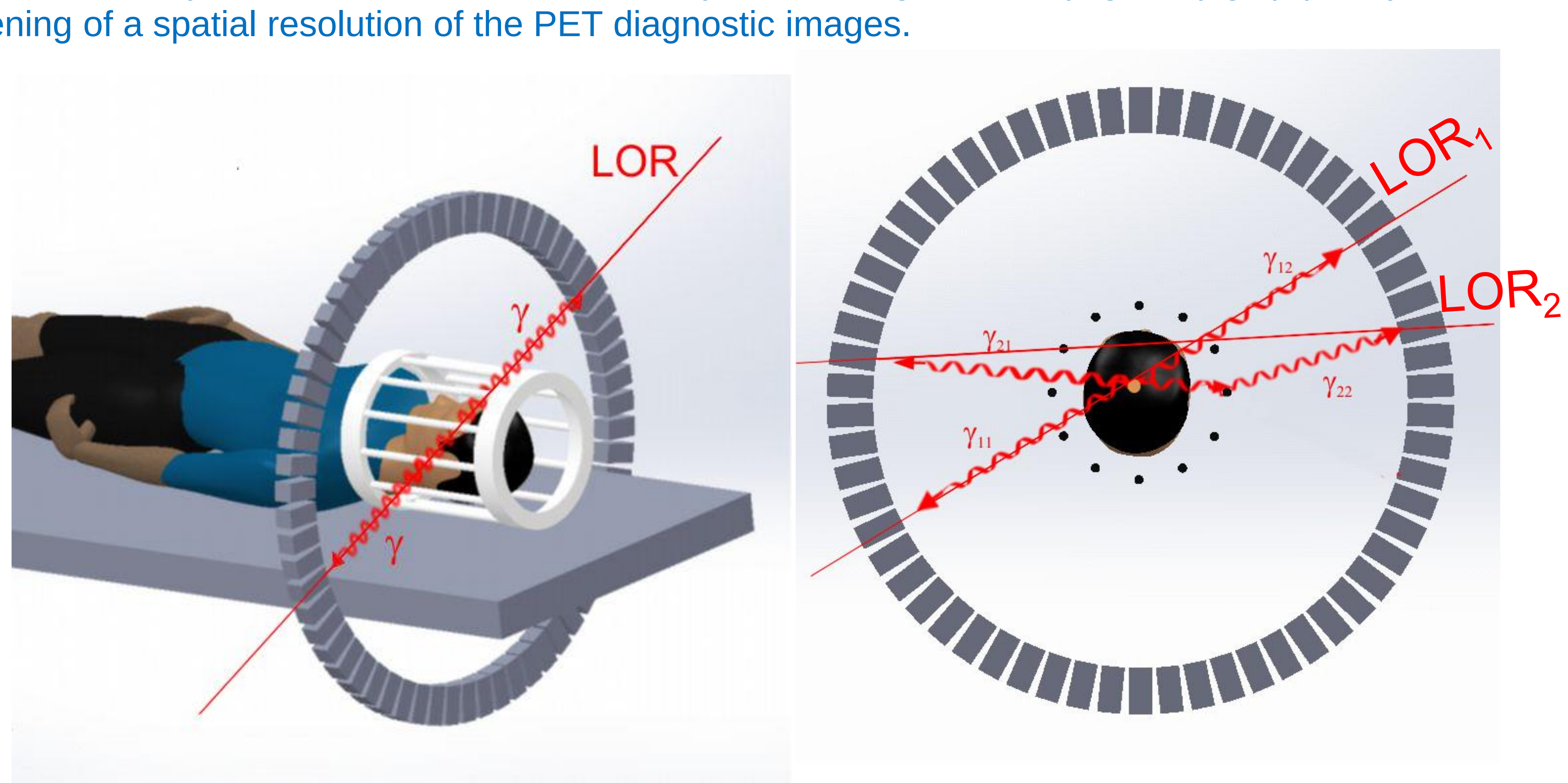


Fig. 2 (left) Schematic view of the local transceiver head coil placed inside the PET detectors ring as commonly used in commercial systems. Two gamma quanta from a single annihilation propagate colinerly through the coil open spaces - marked with red wavy arrows. The red straight line - direction of propagation that connects the two oposite PET detectors which detected the qamma quanta is called Line-of-Response (LOR);
(right) Example of scattering effects of gamma quanta in the coil construction that may affect the reconstructed diagnostic image. The orange point represents the true gamma quanta volume source whereas the one reconstructed by the intersection of two LORs (LOR$_1$ and LOR$_2$ between the detectors reached by γ_{21} and scattered γ_{22} gamma quanta) is beyond the patient.

Limitation of recent technology

The only way to avoid the effects of gamma quanta scattering on the MRI hardware is to place the PET detectors inside the MRI transceive coil. This was not fully successful so far, due to constraints from the geometry of PET detectors based on inorganic crystals as LSO, LBS etc. (Fig. 3). Present solutions requires a large modification in existing coils optimised design lowering the MR signals detection performance and increasing the costs.

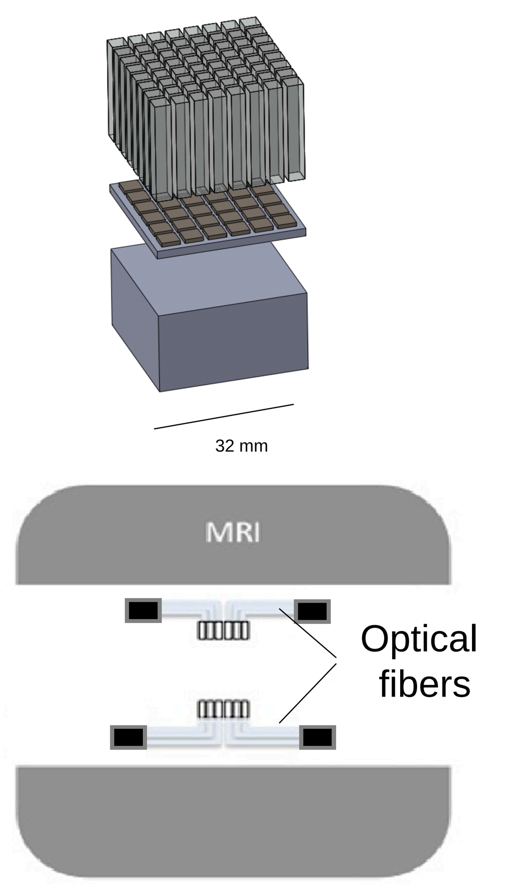


Fig. 3 (top) Visualisation of popular PET detector based on inorganic crystals array and silicon photomultipliers (Si-PM) read-out from the bottom. The trivial size constraints from the PET detection ring dimensions not suitable to fit in the most of local transceiver coils. The electronics (grey box) would have to stay in the volume of strong RF signals inside the coil or (bottom) the crystals would have to be connected with the optical fibers to guide the scintillation light to the detection electronics outside the problematic volume of strong MRI influence. Main constraint of the solution is the space limitation in the local coil.

Application of novel PET detectors

Novel approach to the gamma quanta detection has been proposed by the J-PET collaboration [2-5].

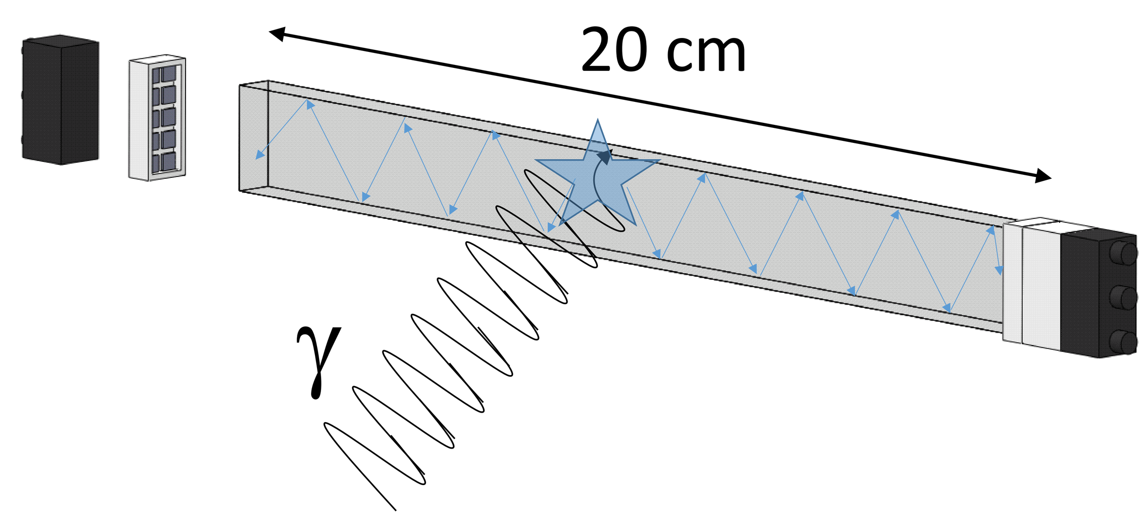


Fig. 4 PET detector developed by the J-PET collaboration based on organic plastic scintillator in form of a rectangular stripe. Both ends of the stripe are monitored by arrays of Si-PM sensitive to the scintillation photons (blue arrows) propagating along the stripe, as in a waveguide, after emission due to Compton scattering of the annihilation gamma quanta. Signals time differences between both ends of the stripe is used for determination of gamma quanta scattering position along the strip.

Main advantages of the J-PET detectors in terms of hybrid coils design
Non-magnetic scintillating material flexible in terms of shape and size to be adapted to existing well designed coils (costs, performance).
Stripe geometry allowing for sensitive electronics location outside the coil volume.
Full coverage of the coil volume with the scintillating material.
Scintillator strip acts as a waveguide – losses on scintillator-waveguide surface avoided in comparison to the commercial solutions.

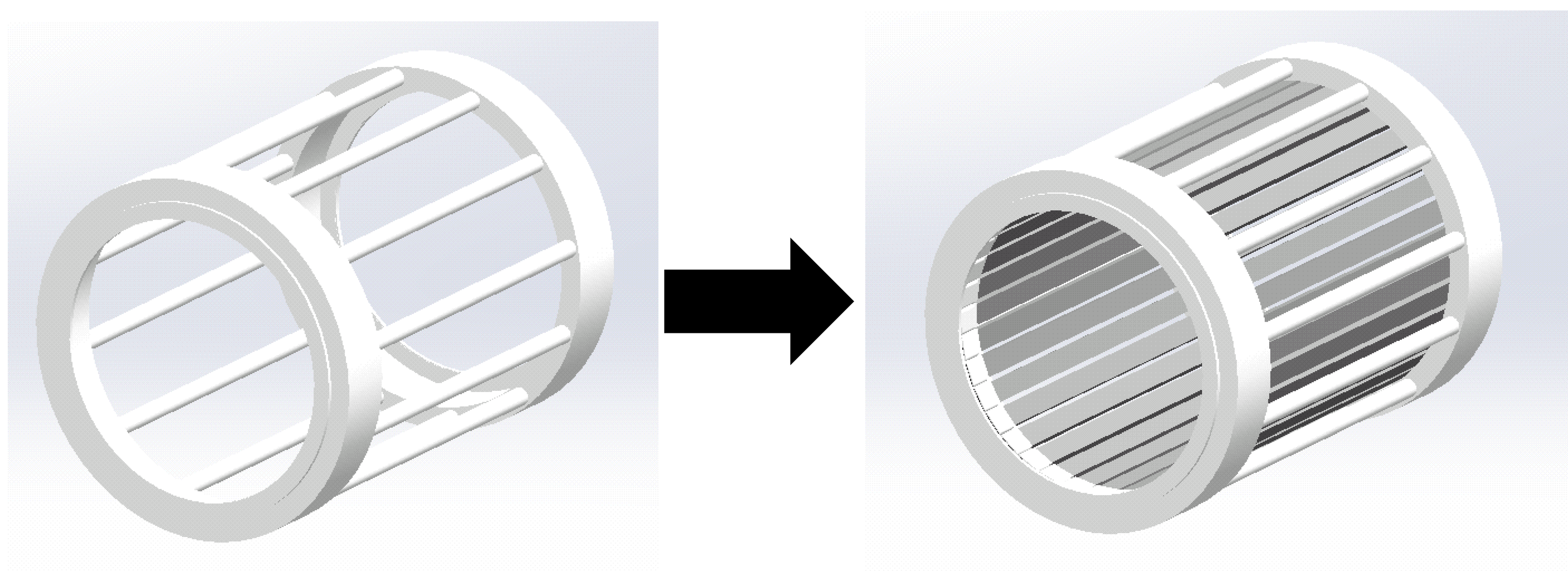


Fig. 5 Visualisation of an idea of standard head bird-cage coil (left) extension by novel PET detection modules arranged circumferentially inside the coil volume to form a PET/MRI hybrid coil (right). Peripherial position of the electronics favours a significant reduction of the RF waves influence.

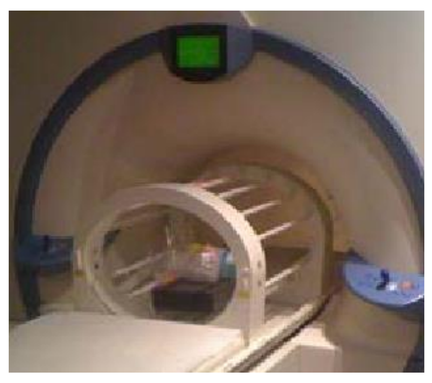
Fig. 6 Custom arrangement of the PET detecion modules may be adapted to various MRI coils geometries (surface coils, saddle coils) providing full and uniform coverage of investigated volume.

Plans and perspectives

The J-PET detector module equipped with the Si-PM matrices and digital front-end electronics are being now tested and developed in the J-PET collaboration as shown below.

Fig. 7 (left) Photos of the prototype of novel J-PET detection module; scintillating stripe is wrapped in the black lightproof foil;
(right) 2 x 5 Si-PM array with front-end boards attached from behind (green boards on left photo).

Tests of modules detection performance in an MRI scanner are to be soon carried out also with the use of local chest bird-cage coil used for human lung imaging [6].



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