Jornadas LIP 2012

PET/MRI with ClearPEM Technology

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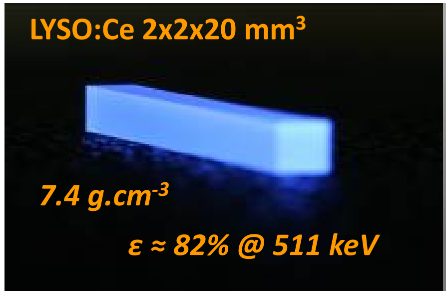
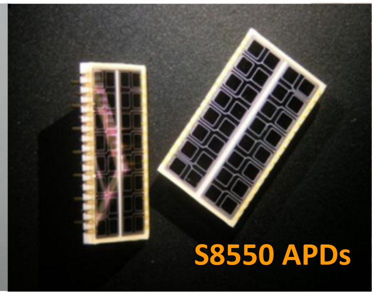
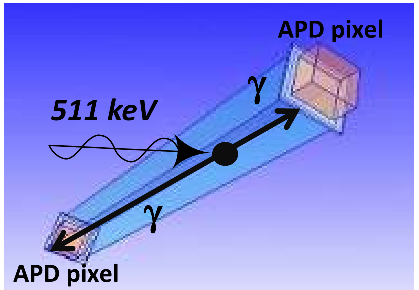
Outline

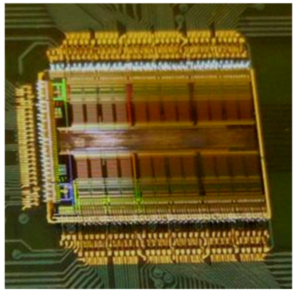
1. A Short Review on the ClearPEM Front-end Electronics
2. PET-MR Electromagnetic Compatibility Issues
3. 7T Magnet Facility
4. Mutual Electromagnetic Interference Tests and Analysis
   - 4.1. RF Interference from MR RF Coils
   - 4.2. RF Interference from PET Front-End Electronics
   - 4.3. Gradients Effects on PET Front-End Electronics
   - 4.4. MRI Susceptibility Artefacts caused by PET materials
5. Summary & Conclusions







Light sharing readout scheme



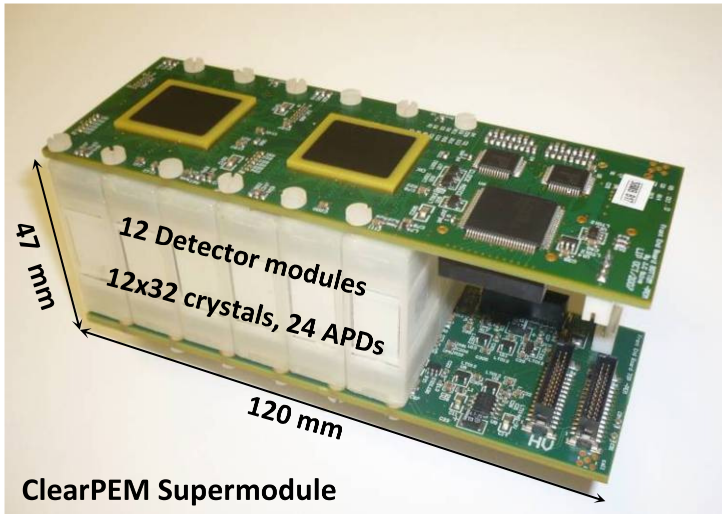
AMS 0.35 μm CMOS, 70 mm2

Front-End Electronic Boards (FEBs)

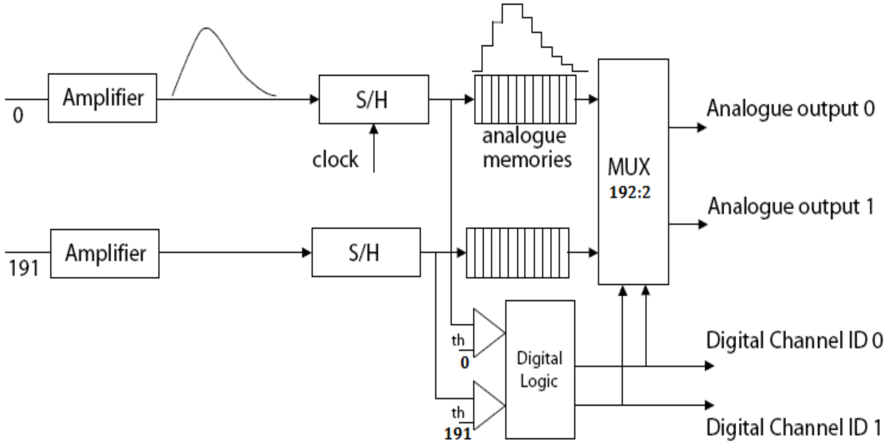
2 ASICs - 2x192 channels (50 MHz)

2 high-speed dual ADC (10bits, 50 MHz)

1 LVDS ChannelLink Serializer (2.4 Gbps)



Application-Specific Integrated Circuit (ASIC) for APD readout



Mutual Electromagnetic Interference (EMI)

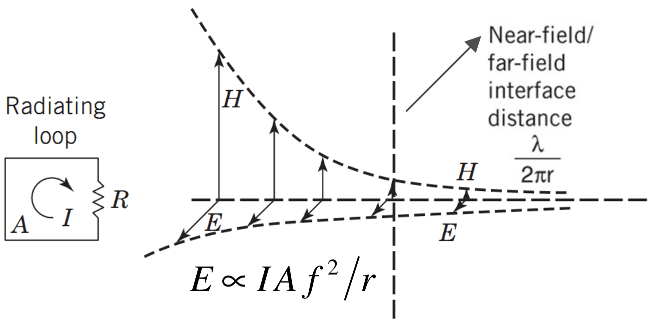
PET: strong magnetic fields (7T) :: pulsed RF :: switched gradient fields

- Avalanche Photodiodes (APDs) are insensitive to **B0**
- Front-end Electronics: EMI with pulsed RF power†
- Time-varying magnetic fields will induce electromotive forces (ε^{ind}) in closed circuits††
- Lorentz forces on power conductors parallel to **B0** field lines $\vec{F} = I\int d\vec{\ell}\times\vec{B}$

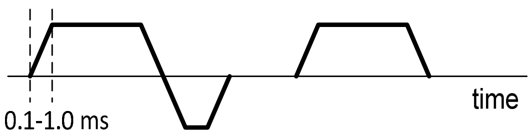
MRI: magnetic susceptibility of PET materials :: RF interference :: loss of SNR

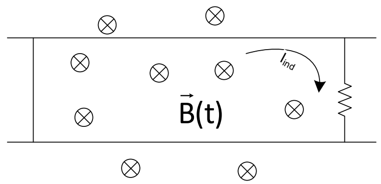
- Required highly homogeneous Bo (< 1 PPM) to avoid image susceptibility artifacts
- MRI signal is very low: susceptible to be contaminated by high-frequency fields radiated by digital electronics
- EMI should be minimized -> loss of SNR -> loss of MRI sensitivity

† Radiated fields from current loops



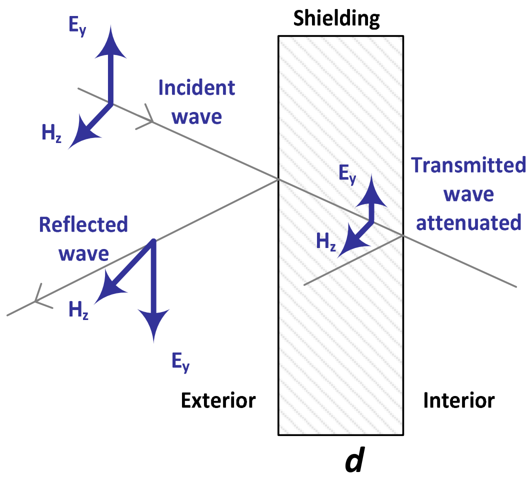
††switched gradient fields **B**(**r**,t)





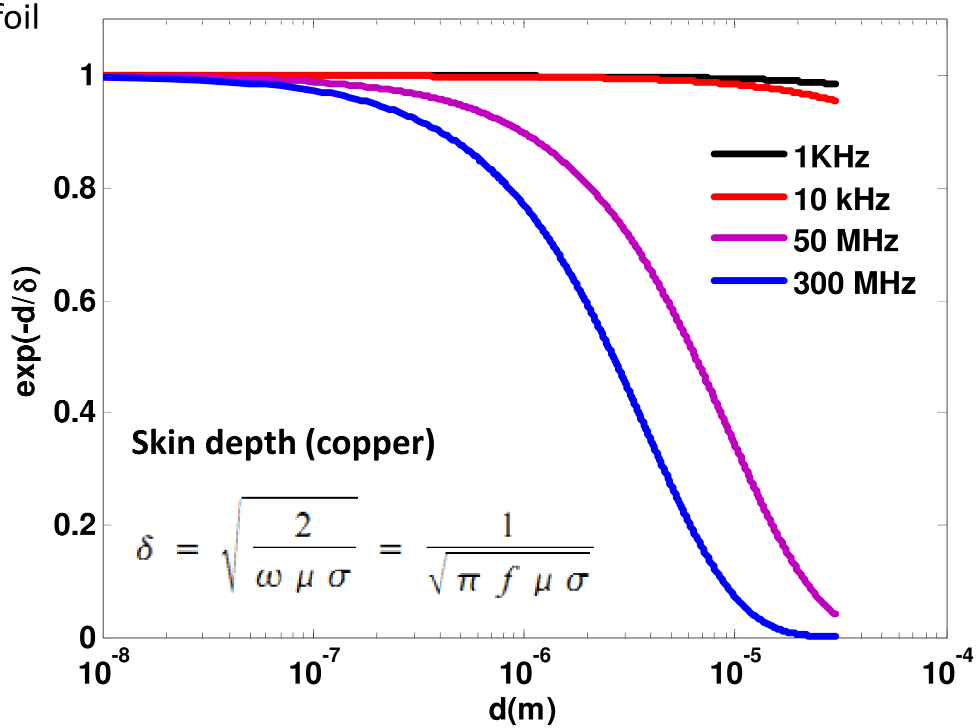
Faraday´s law: $\varepsilon^{\text{ind}} = -\dfrac{\partial \Phi}{\partial t} = -\dfrac{\partial}{\partial t}\int \vec{B}(t).d\vec{S}$

Electromagnetic Shielding to avoid mutual EMI



- EM Shielding behave like an antenna avoiding EMI between PET front-end electronics and RF coils
- BUT it will also absolve RF power from RF coils (lowering SNR)
- and leading to B1 inhomogeneities inside RF coil FOV

- surface Eddy Currents are induced by switched gradient fields
- minimize eddy currents by fragmentation of shielding foil

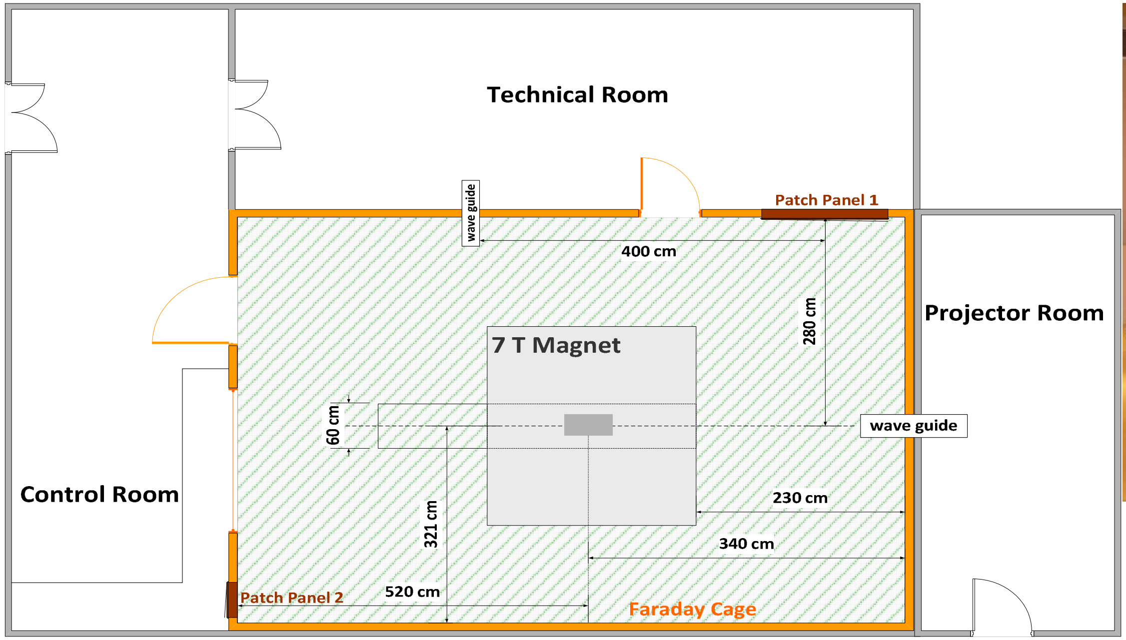


Other PET-MR system integration problems

- Digital data transmission
- Cabling and power consumption
- Cooling system
- Mechanical structure
- Space constrains

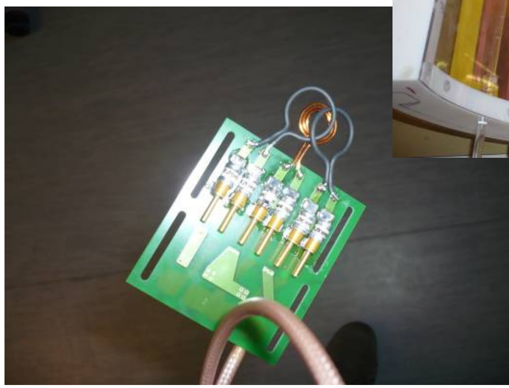
3. 7T Magnet Facility

Center for Biomedical Imaging
Lausanne, Switzerland



- the 1st ultra-high field 7T for brain imaging installed in Europe in 2008
- inner diameter of ~30 cm
- dedicated Lab for the research and development on RF Coils

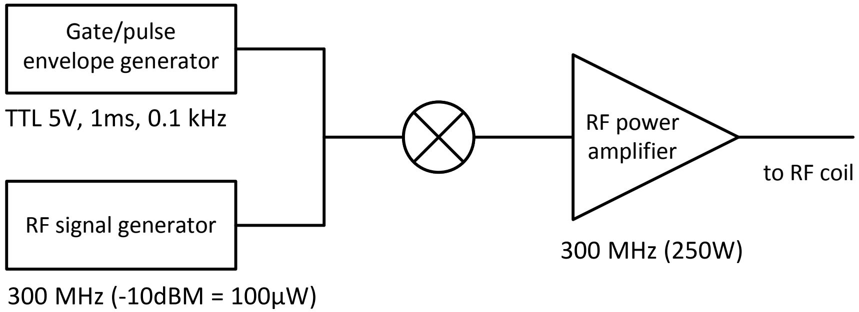
7T human brain RF surface coil

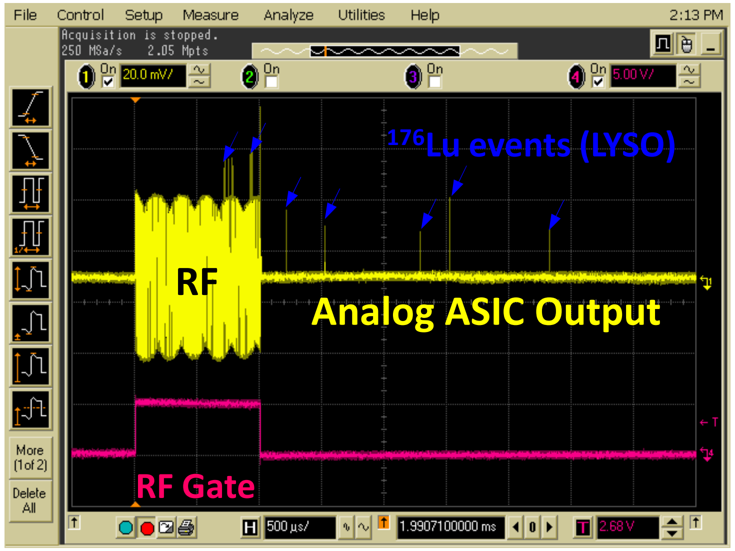


14.1T small-animal RF coil

4.1. RF Interference from MR RF Coils

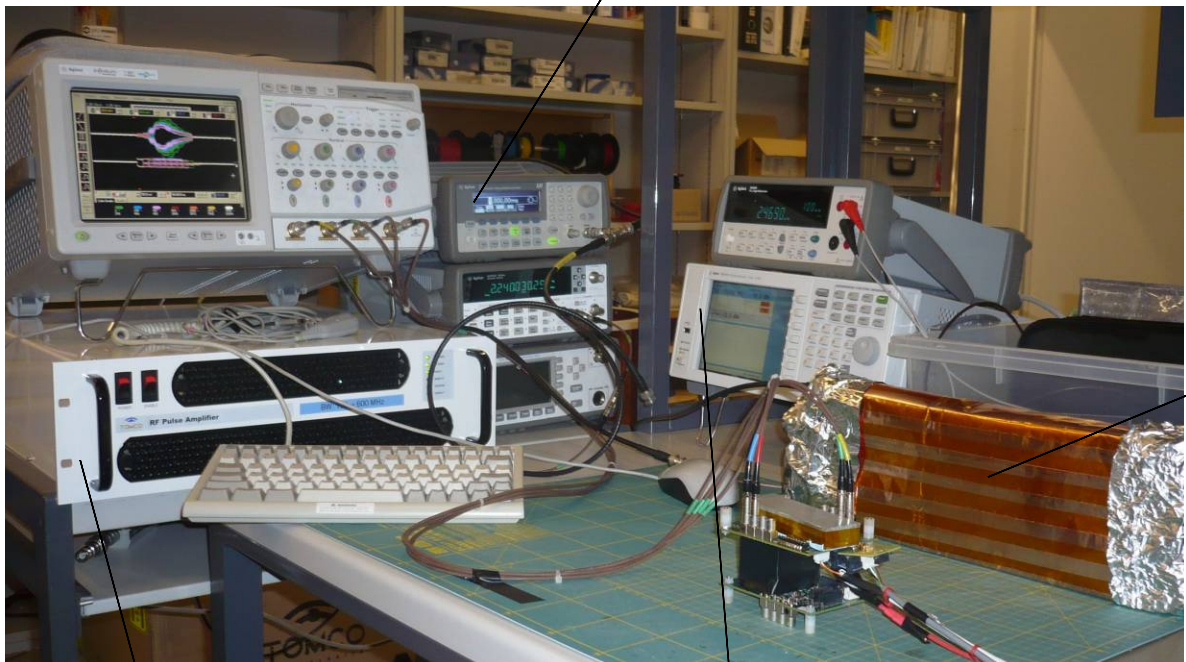
An Introduction ….

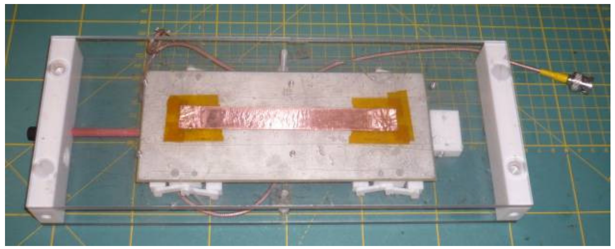


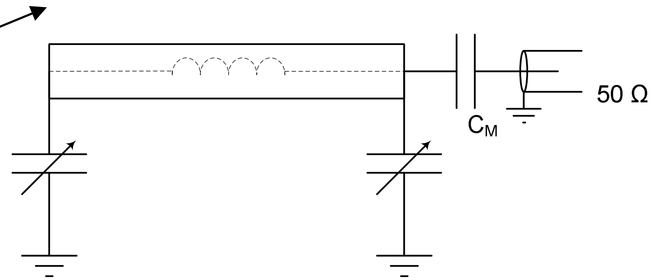


Agilent Infinium 1GHz 4GSa/s

20 MHs Waveform Generator
Agilent 33220A





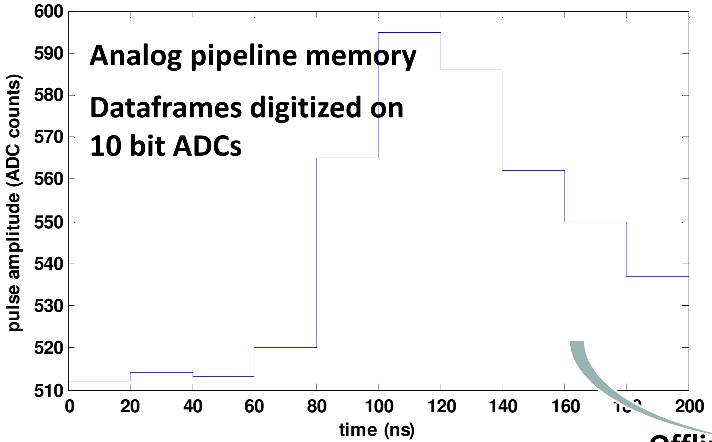


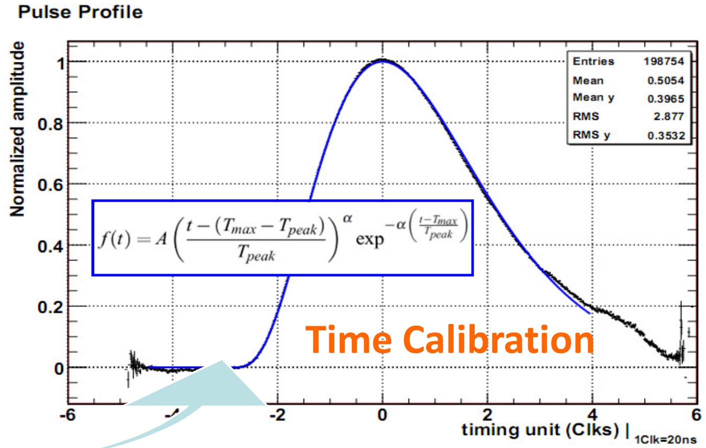
RF Pulse Amplifier (100-600 MHz BW)
TOMCO Technologies BT00100-Delta, 100W

RF Signal Generator (9 kHz-3 GHz)
Agilent N9310A

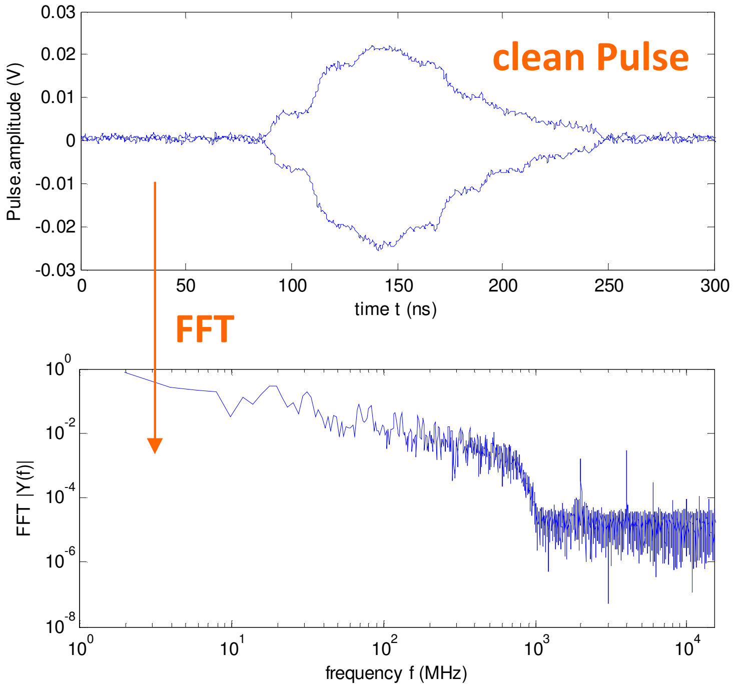
4.1. RF Interference from MR RF Coils

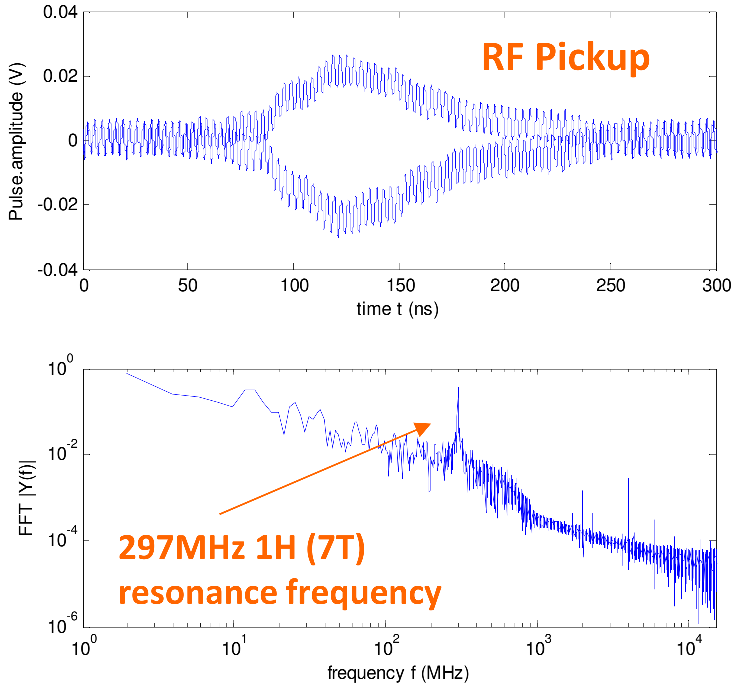
Review on ASIC data readout



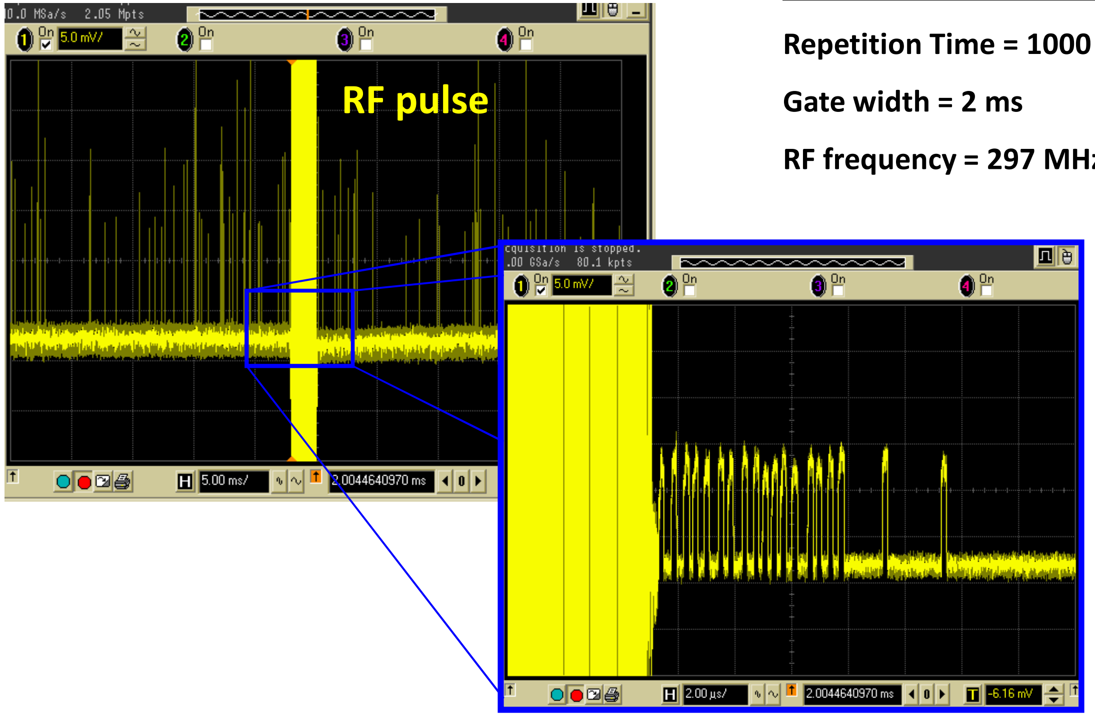


Offline waveform recovery





4.1. RF Interference from MR RF Coils

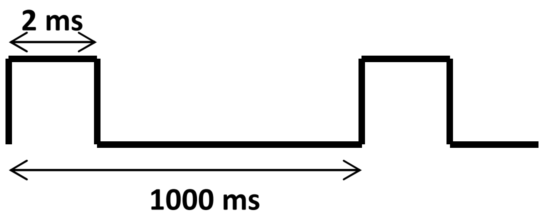


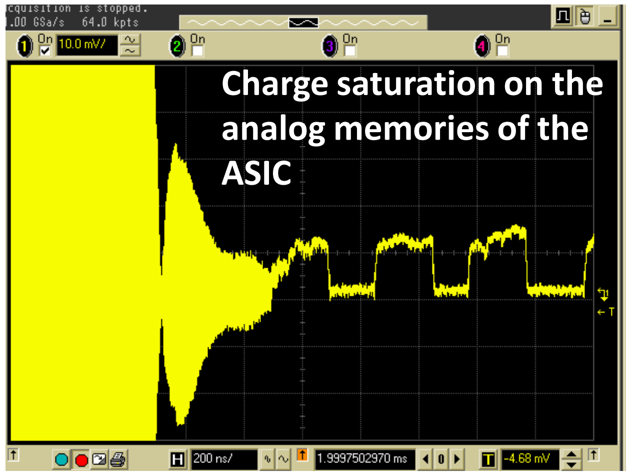
RF pulse sequence

Repetition Time = 1000 ms

Gate width = 2 ms

RF frequency = 297 MHz

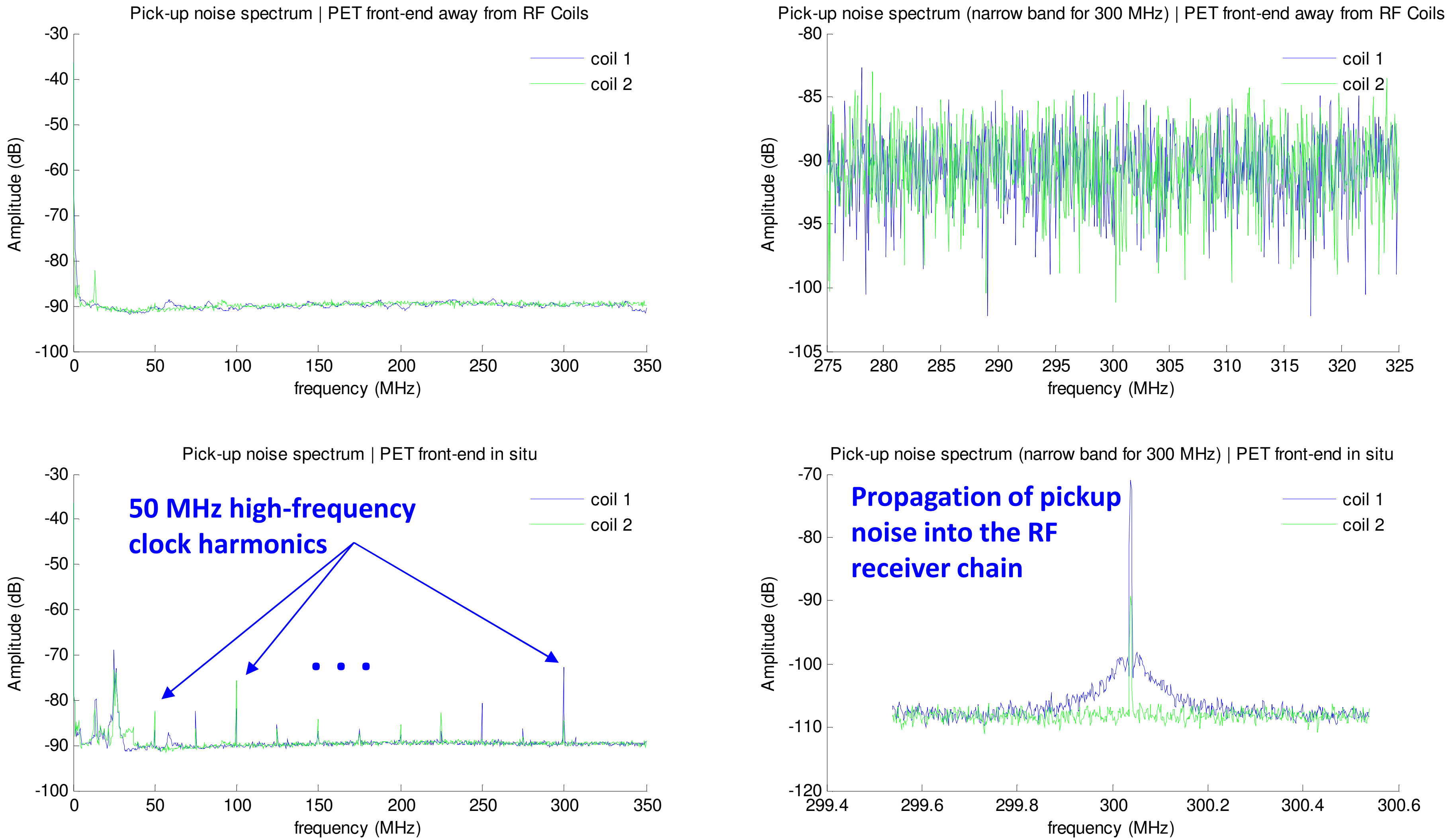




- Pulsed RF tolerance of the front-end electronic boards was assessed as function of the RF Power
- At P<50W, the LVDS analog output of the ASIC rejects common-mode RF noise pickup
- At a maximum P=2.8kW, we have observed a saturation of the front-end ADCs dynamic range during the RF pulse, and a self-triggering state induced by RF eddy currents that create a burst of events remaining over 1.2 ms after the RF pulse
- EMI shielding have shown to be very efficient if well designed

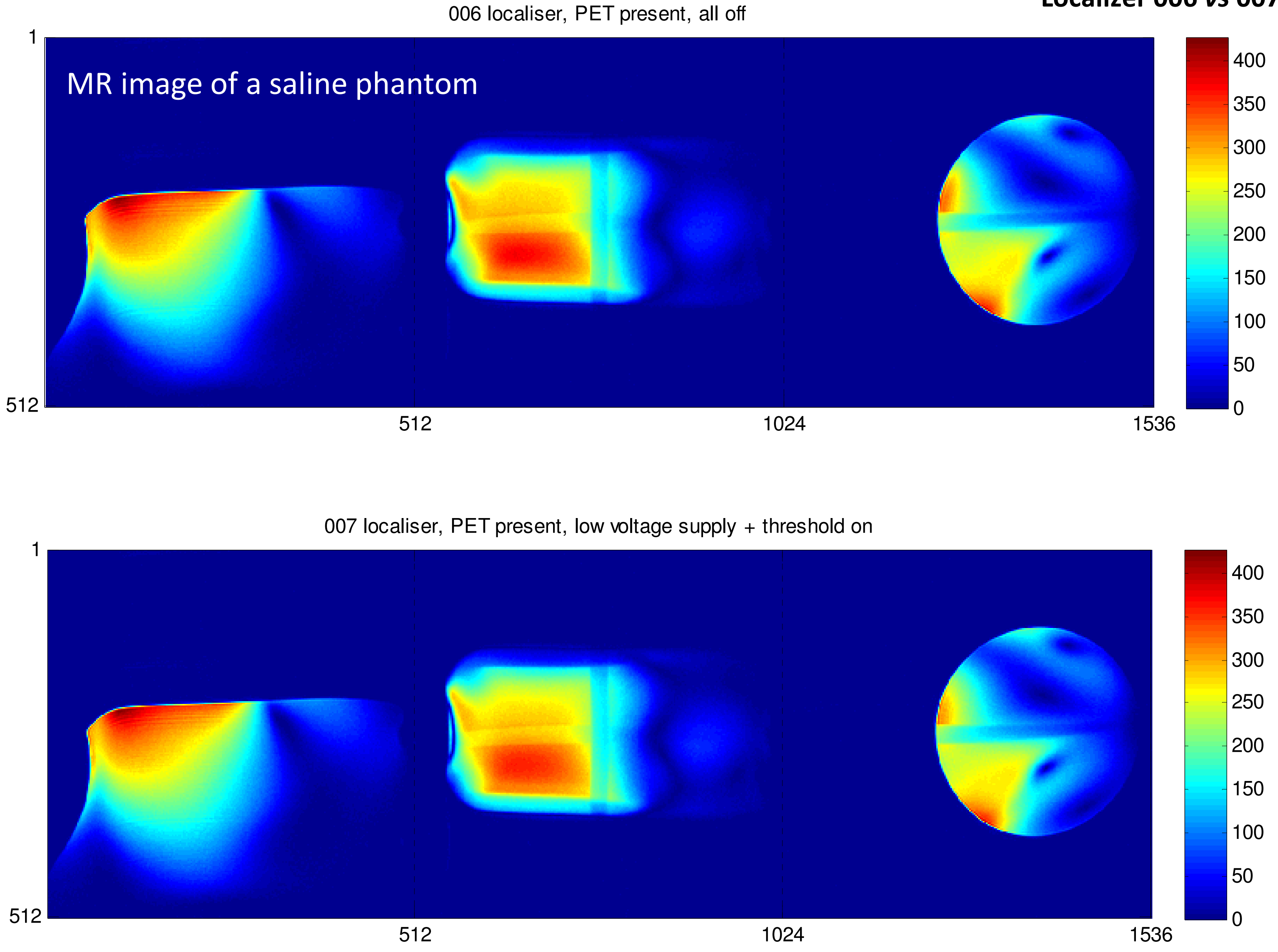
4.2. RF Interference from PET Front-End Electronics

Agilent 4396B Spectrum Analyzer



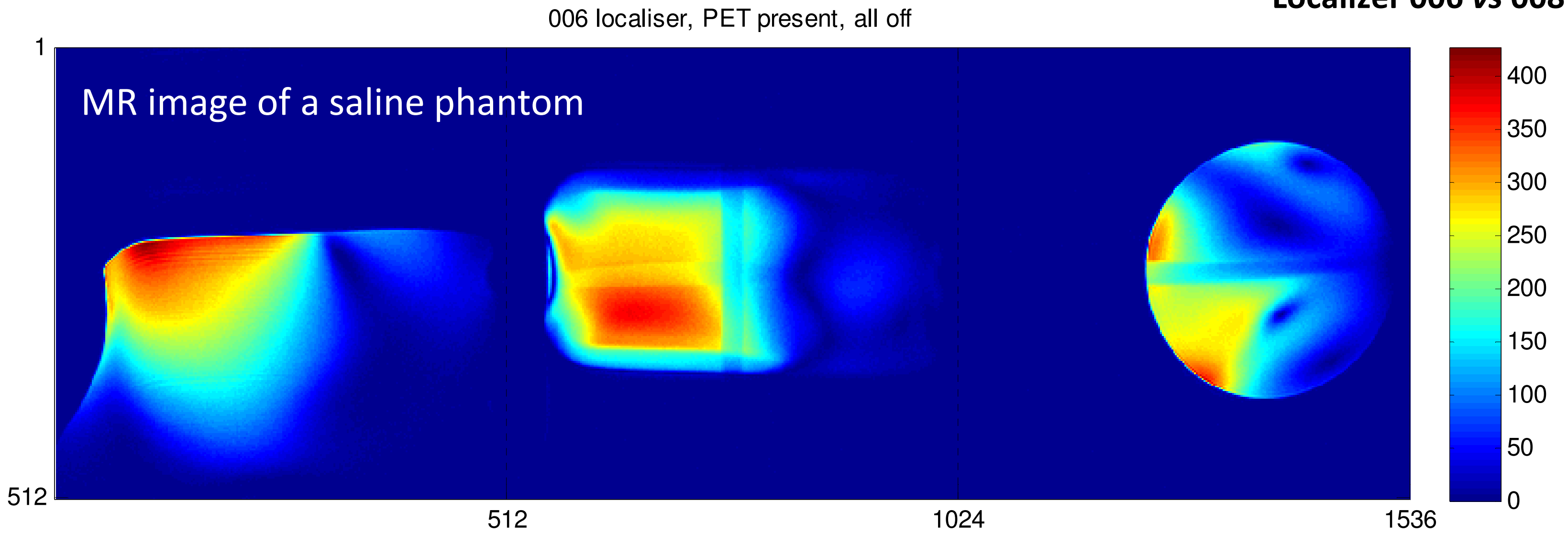
4.2. RF Interference from PET Front-End Electronics

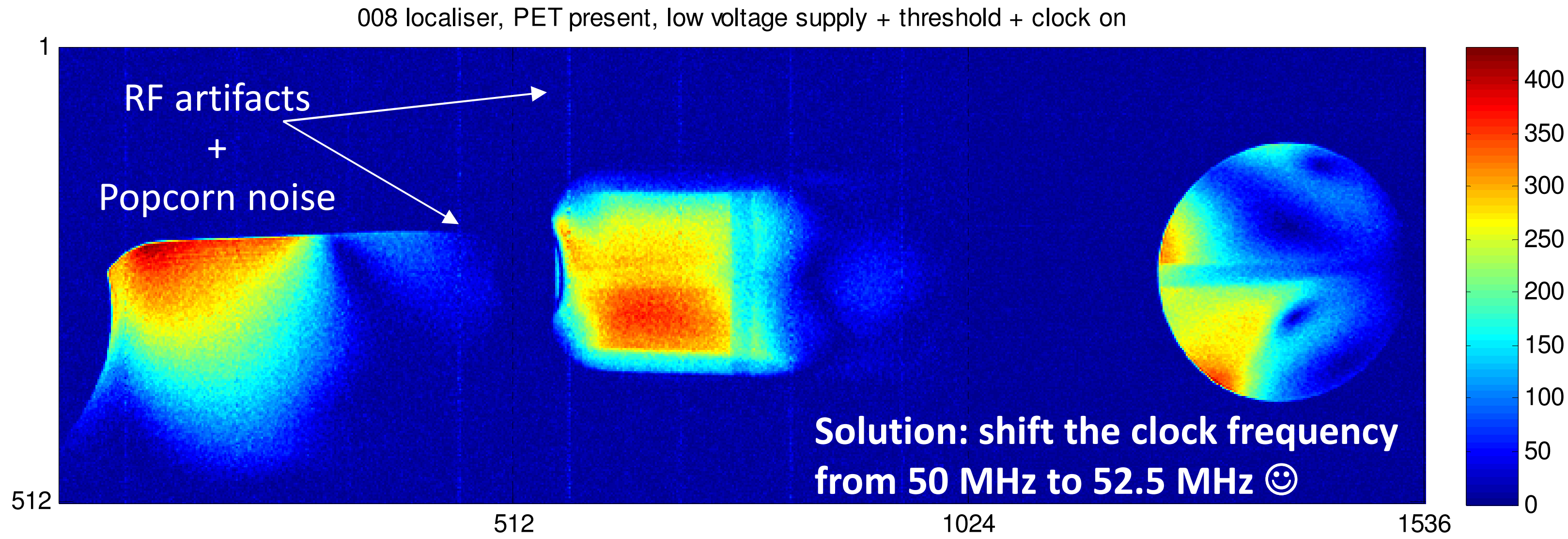
Localizer 006 *vs* 007



4.2. RF Interference from PET Front-End Electronics

Localizer 006 *vs* 008



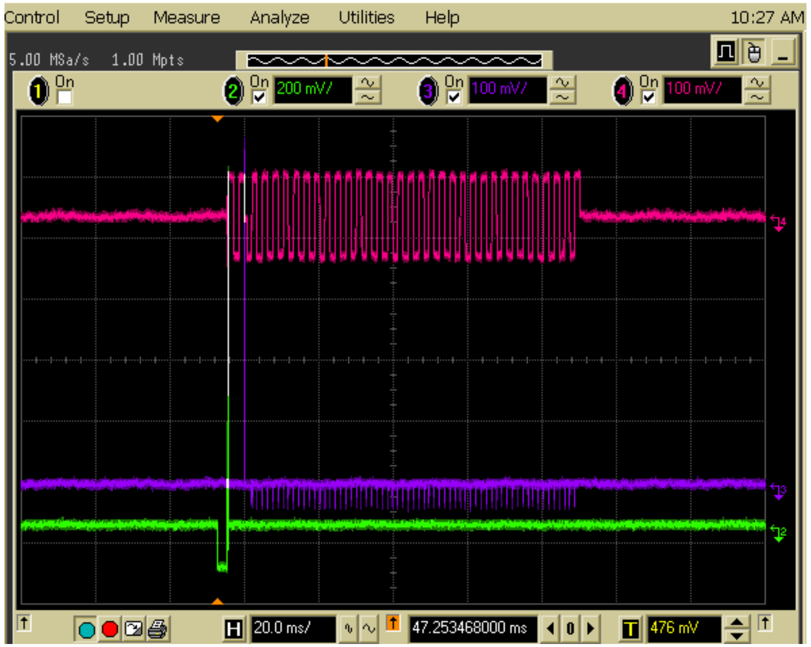


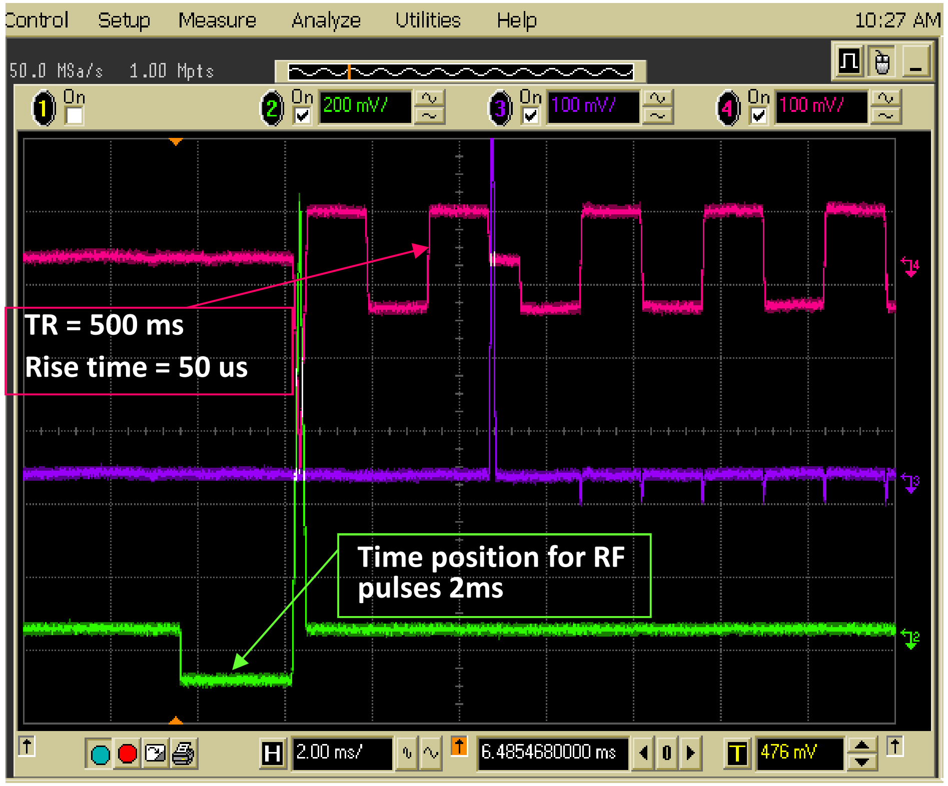
4.3. Gradients Effects on PET Front-End Electronics

An Introduction ….

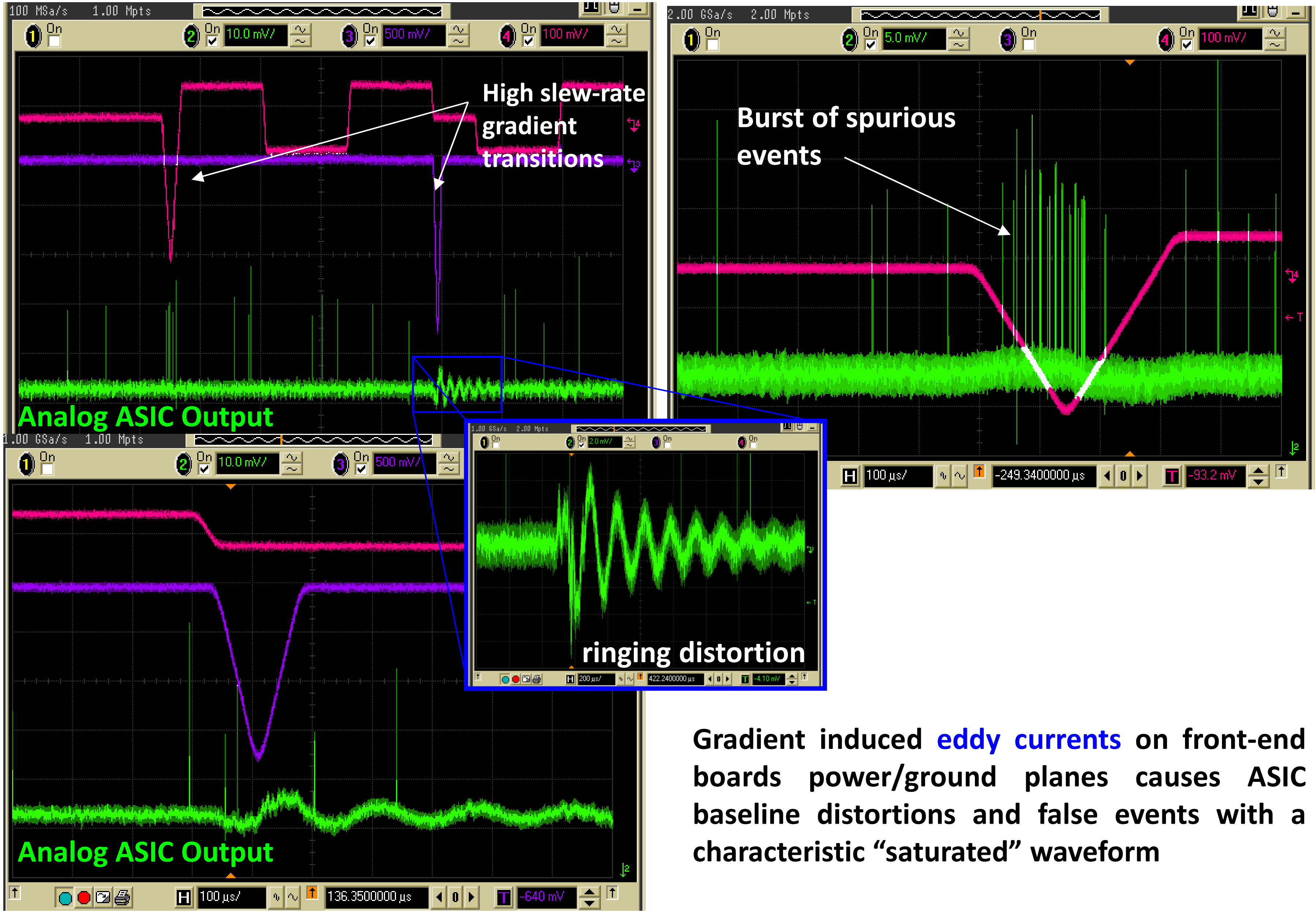
Magnetic Field Gradients: **linearly varying magnetic fields applied in addition to the main magnetic field B0 to achieve spatial encoding (just as a single voxel localization)**

Echo-Planar Imaging (EPI) Readout Sequence
CH2 - Slice Selection
CH3 - phase encoding
CH4 - frequency encoding





4.3. Gradients Effects on PET Front-End Electronics



Gradient induced eddy currents on front-end boards power/ground planes causes ASIC baseline distortions and false events with a characteristic "saturated" waveform

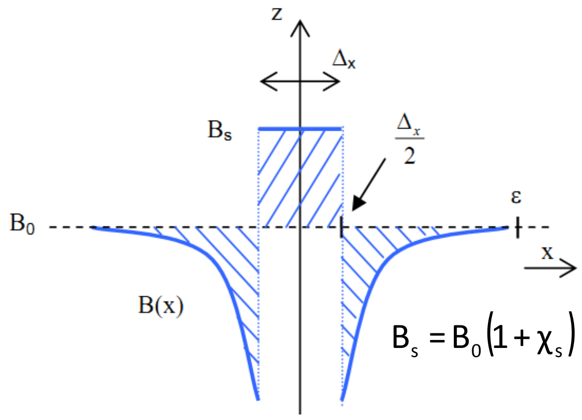
4.4. MRI Susceptibility Artifacts caused by PET materials

An Introduction ….

- B0 required to be strong but highly homogeneous < 10^{-6} (1 PPM)
- weakly magnetic materials (low χ_v) causes local magnetic field distortions
- object shape, orientation and vol. susceptibility χ_v determine spatial field distortions
- B0 field distortions -> susceptibility image artefacts
- PET materials should be magnetic compatible

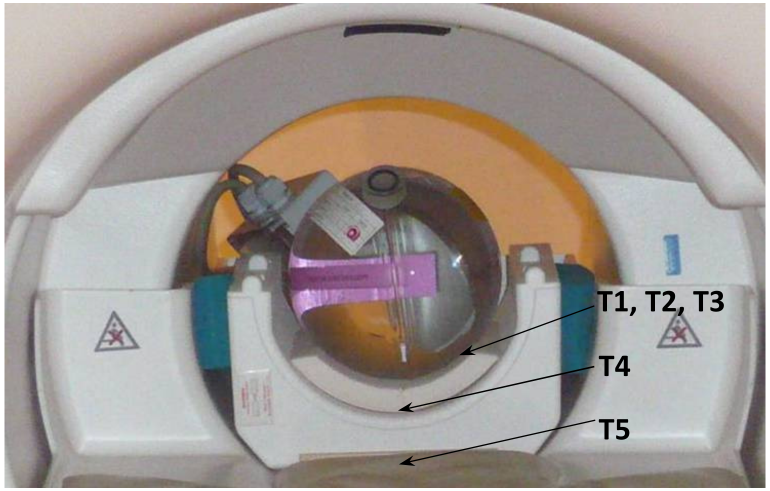
Detector Modules
Front-End Electronics Boards
Cables and Connectors
Cooling Plates
Mechanical Structure
Shielding Foils

Material	Volume magnetic susceptibility, χ_v (SI)
gold	-34×10^{-6}
copper	-9.63×10^{-6}
water (37ºC)	-9.05×10^{-6}
human tissues	-11.0 to -7.0×10^{-6}
graphite*	-8.5×10^{-6}
silicon	-4.2×10^{-6}
aluminium	20.7×10^{-6}

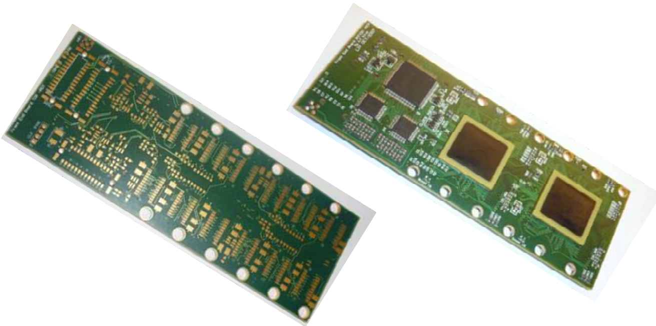


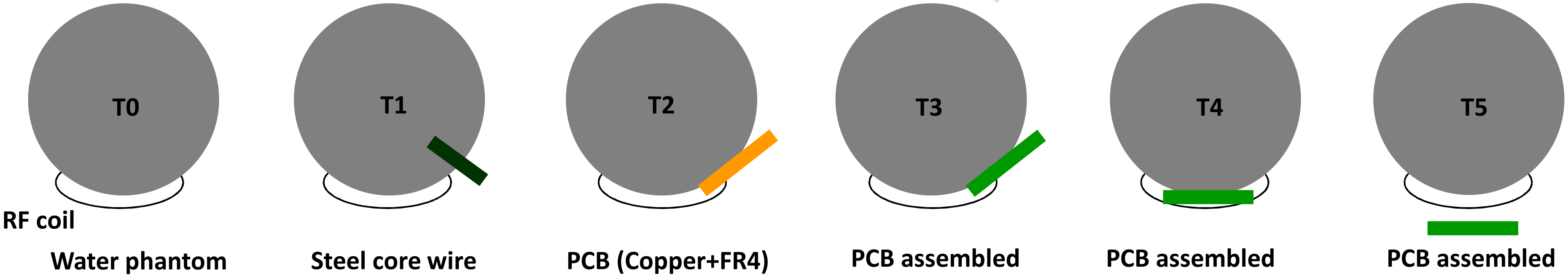
- Susceptibility artifacts must be evaluated
- Known non-uniformity B0 maps -> possible corrections by shim coils

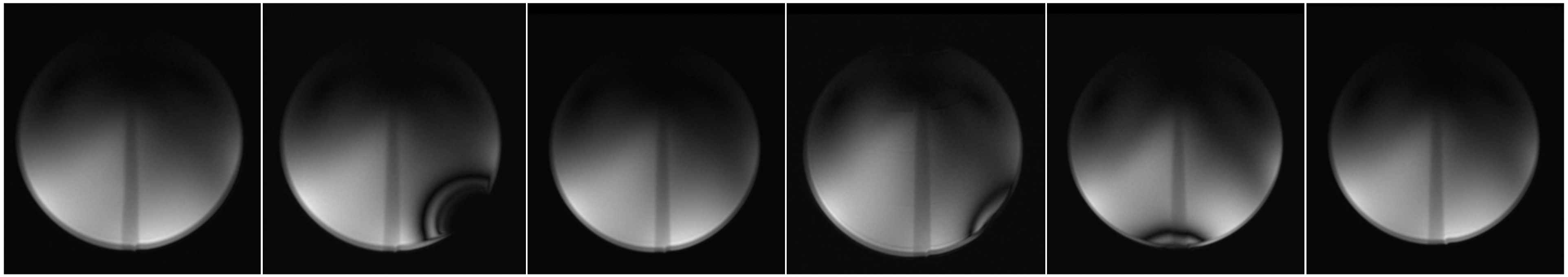
4.4. MRI Susceptibility Artifacts caused by PET materials



Preliminary evaluation of magnetic susceptibility image artefacts caused by PET front-end materials

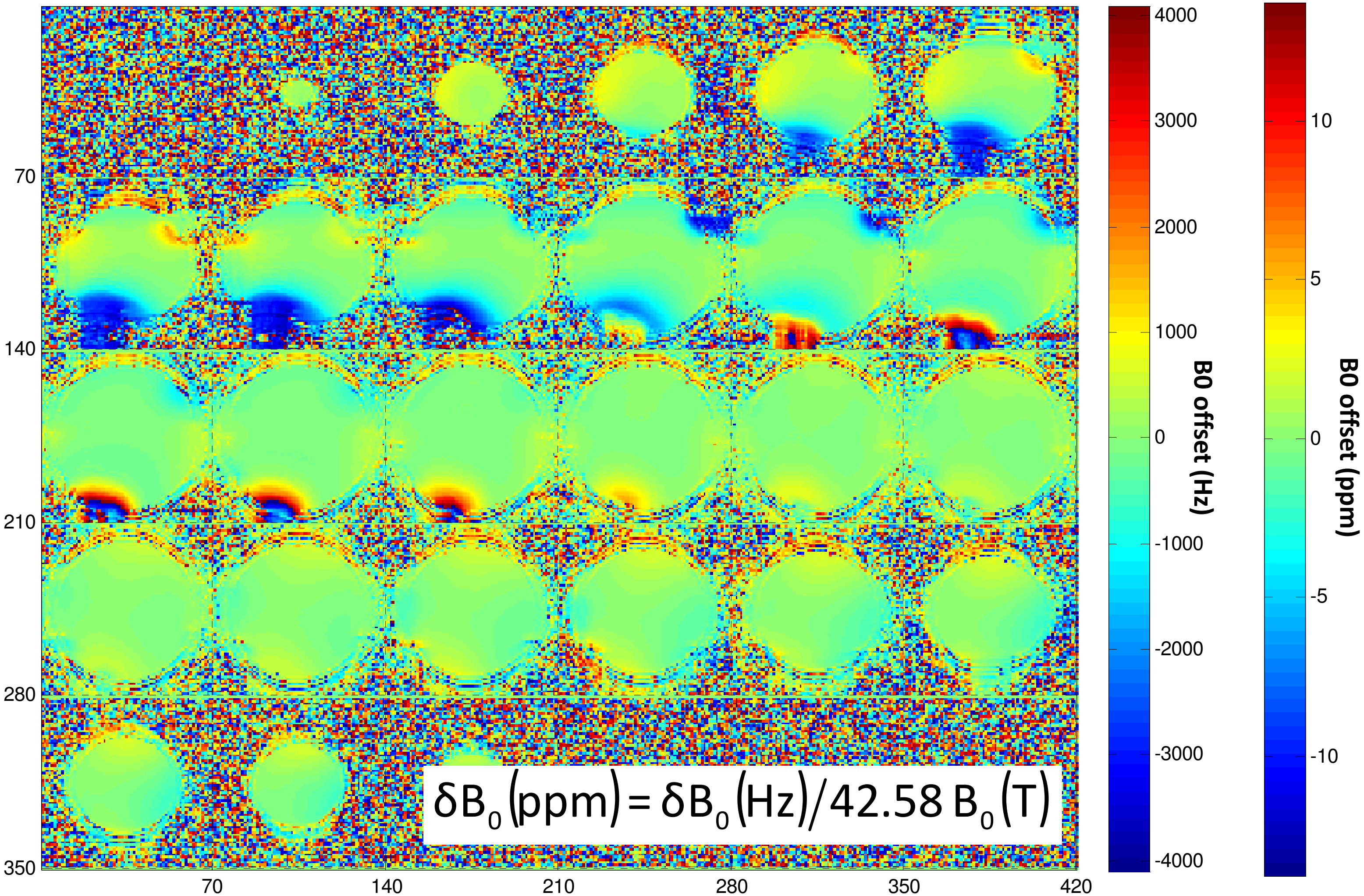






4.4. MRI Susceptibility Artifacts caused by PET materials

036p B0 map, PET head stage + cables present, located at top left of phantom



- Experimental tests have been carried out in a 7T magnet to study the mutual EMI mechanisms and the feasibility of integration of the ClearPEM front-end electronics on a combined PET-MR system;
- The tolerance of the PET front-end electronics to pulsed RF power was assessed, and the high-frequency noise pickup on MR acquired images was found to be due to radiative fields from digital electronics on PET front-end;.
- EMI shielding have proved to be efficient. However, the current state of development resides on the Grounding and EMI Shielding optimization to block conducting and radiative paths suitable for RF pickup and propagation;
- High slew-rate Gradient transitions have shown inducing eddy-currents on the front-end electronics and are the cause of the observed ASIC baseline distortions and bursts of spurious events;
- B0 field distortions up to 10 ppm were observed caused by PET front-end boards materials (APD connectors contains a nickel plating);
- 7T B0 field have shown no degradation on the detector performance (still continuing with 13.2 % fwhm energy resolution @511 keV and 4.47 ns fwhm time resolution);

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