Noise Susceptibility Measurement of Front-End Electronics Systems

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Outline

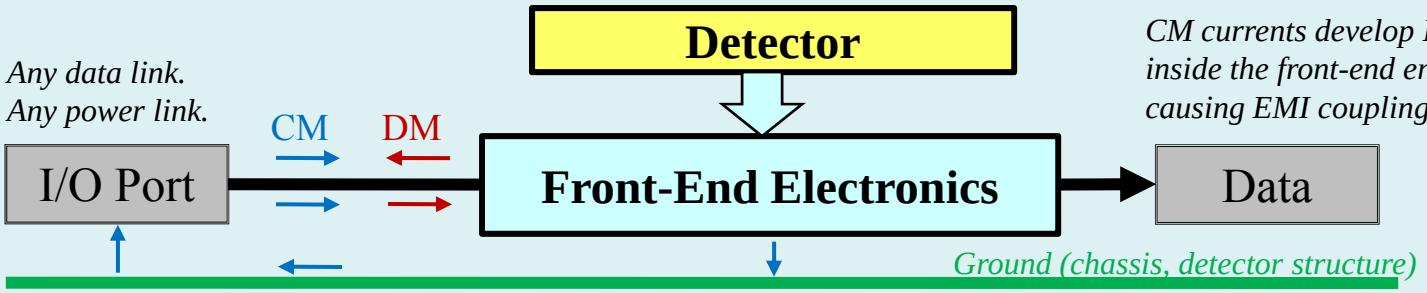
Exposing systems to controlled EMI sources to evaluate their impact on the output data in a quantifiable manner.

- **Noise coupling into front-end systems.**
  - Conducted noise.
  - Radiated noise.
- **Susceptibility to conducted noise.**
  - Measurement method.
  - Susceptibility of the ATLAS Roman Pots prototype.
  - System tests with DC/DC converters on TOTEM.
- **Susceptibility to electric fields.**
  - Evaluation method.
  - Susceptibility of the TOTEM front-end against electric field.
- **Susceptibility to magnetic couplings**.
  - Evaluation method.
  - Susceptibility of the TOTEM front-end against inductor field.

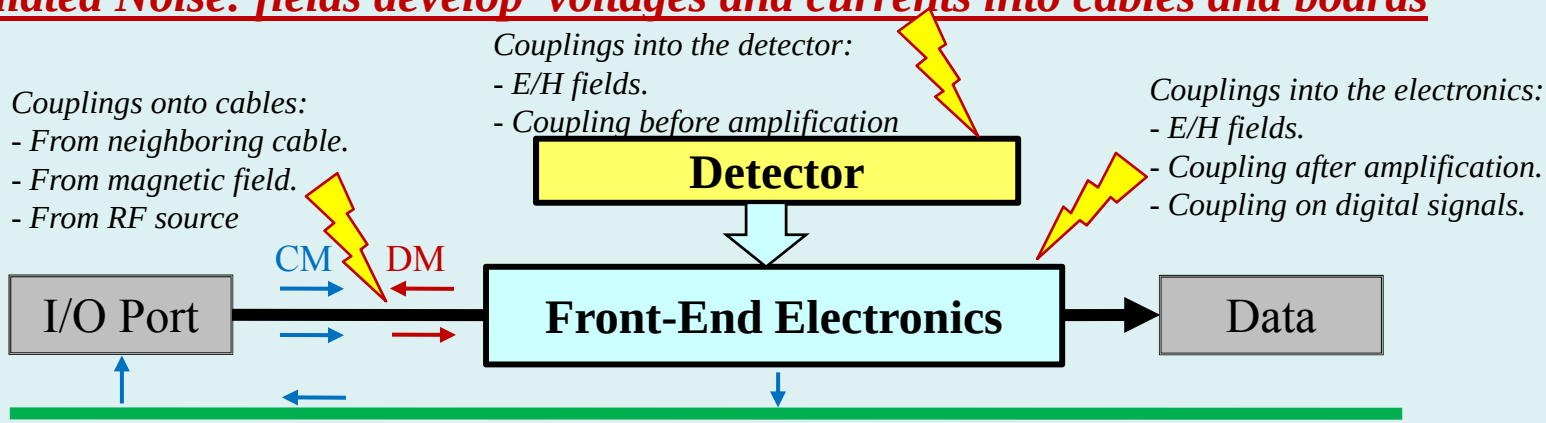
Noise Coupling into Front-End Systems

Summary of Disturbances

Conducted Noise: propagates along the cables

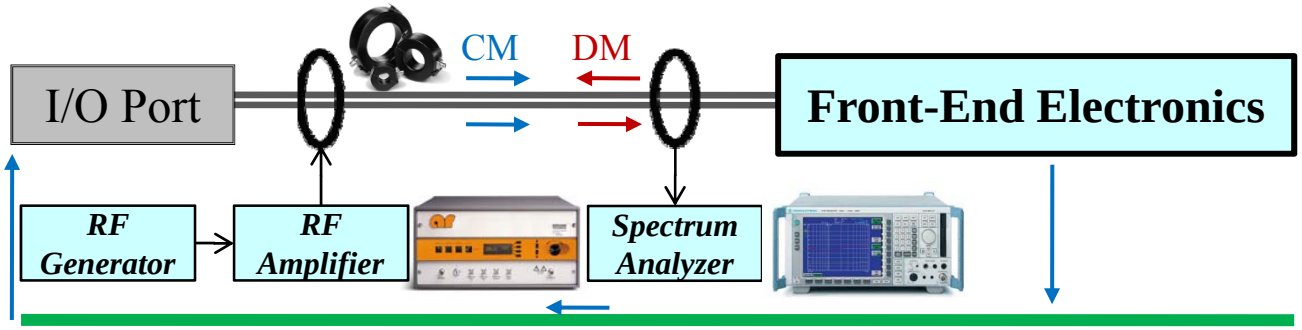


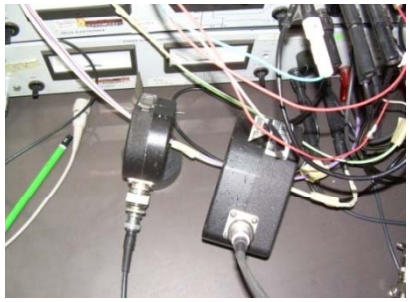
➢ ***Radiated Noise: fields develop voltages and currents into cables and boards***



Susceptibility to Conducted Noise

Measurement Method

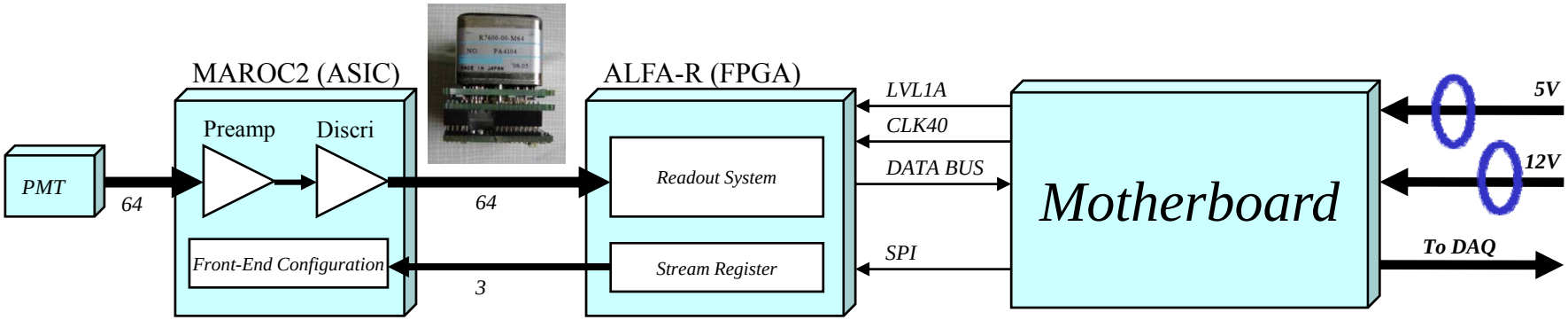


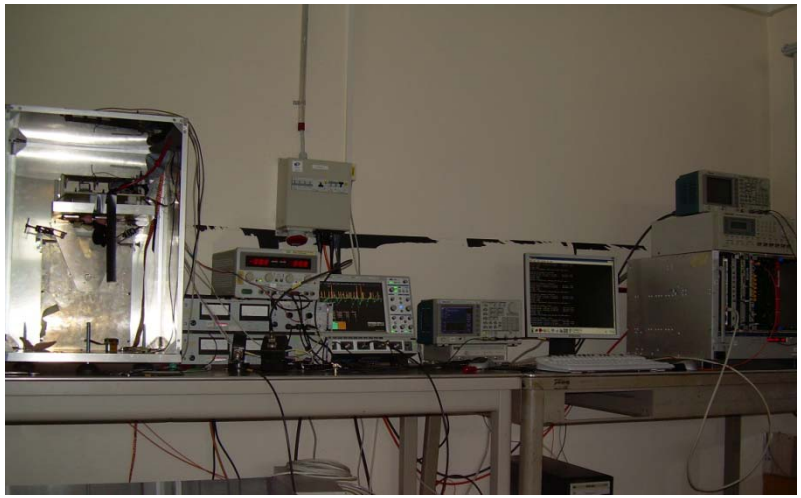


- A test signal is provided by a RF generator, followed by a power amplifier.
- A current injection probe couples inductively the test signal into the cable.
- A second current probe is used to monitor the test current with a spectrum analyzer.
- The test frequency is swept, typically between 100 kHz and 30 MHz, keeping the current amplitude constant, ranging typically from few µA to few mA.

Susceptibility to Conducted Noise

The ATLAS Roman Pots Front-End

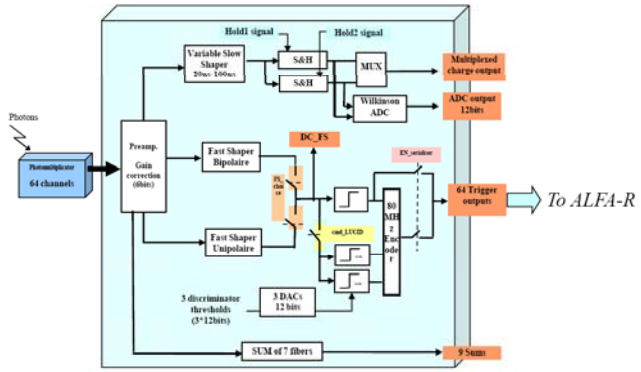




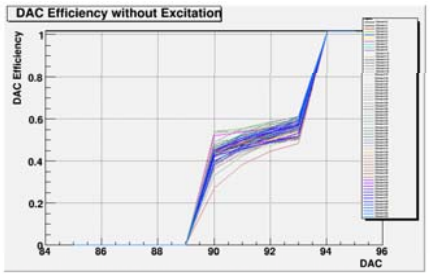
- Common mode currents are injected in the 12V input port first, after in the 5V port, with magnitudes up to 10 mA in the ferquency range between 150 kHz and 30 MHz.
- The 12V powers exclusively the motherboard, which is fully digital. It was found to be insensitive to the injected current.
- The 5V powers the front-end chips (MAROC, FPGA), with analog circuitry. It was found to be sensitive to the injected current.

Susceptibility to Conducted Noise

Susceptibility Figures



Refer to: "MAROC: Multi Anode Readout Chip", S. Blin, TWEPP 2007.

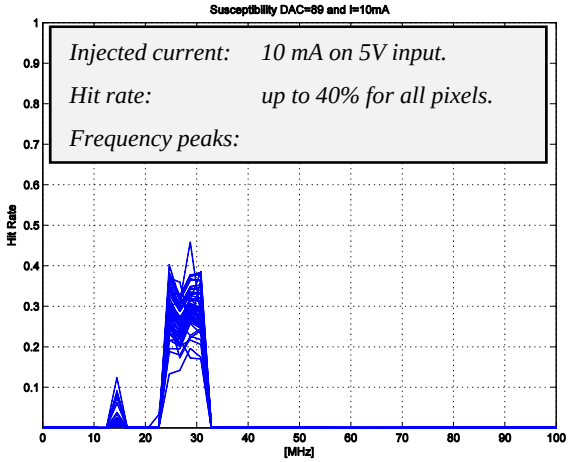


At nominal gain, three parameters are swept:

- Test frequency (1 MHz – 100 MHz)
- Current amplitude (1 mA – 10 mA).
- Threshold DAC (88 to 94)

The noise hit rate is a function of current, frequency and DAC

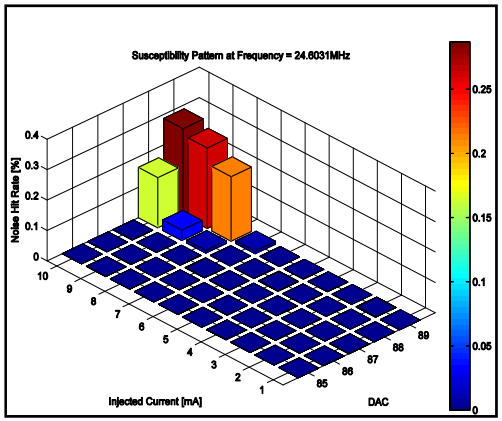
At a given threshold, the maximum noise current permitted is established for every critical frequency

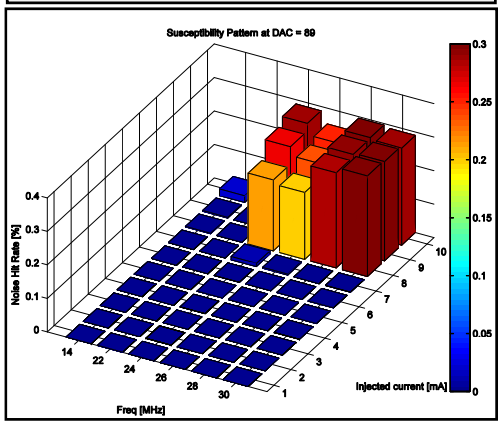


Injected current: *10 mA on 5V input.*

Hit rate: *up to 40% for all pixels.*

Frequency peaks:

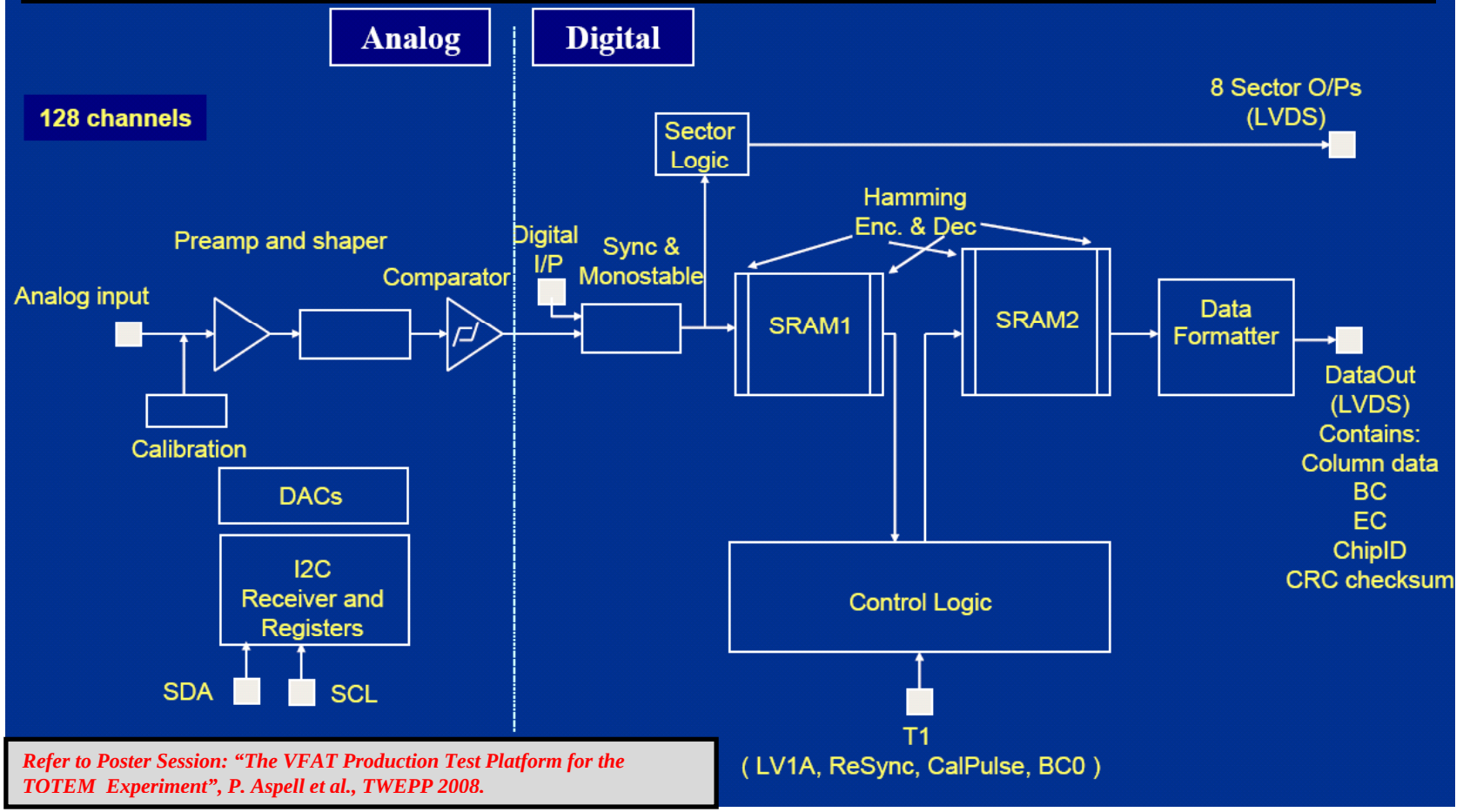




Example of measured boundary: ICM < 7 mA, between 20 and 35 MHz, for DAC=89

The TOTEM Front-End

"VFAT2 : A front-end system on chip providing fast trigger information, digitized data storage and formatting for the charge sensitive readout of multi-channel silicon and gas particle detectors.", **P. Aspell** *et al. , TWEPP 2007.*

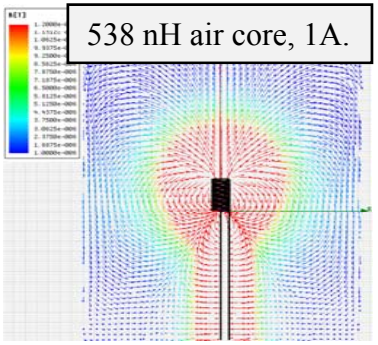


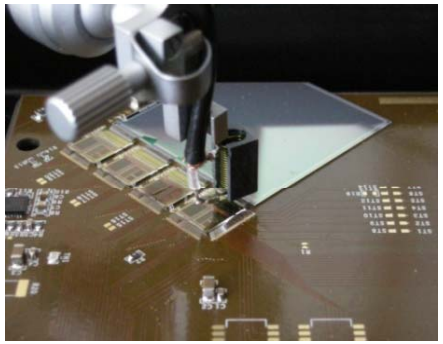
Refer to Poster Session: "The VFAT Production Test Platform for the TOTEM Experiment", P. Aspell et al., TWEPP 2008.

Susceptibility to Magnetic Field

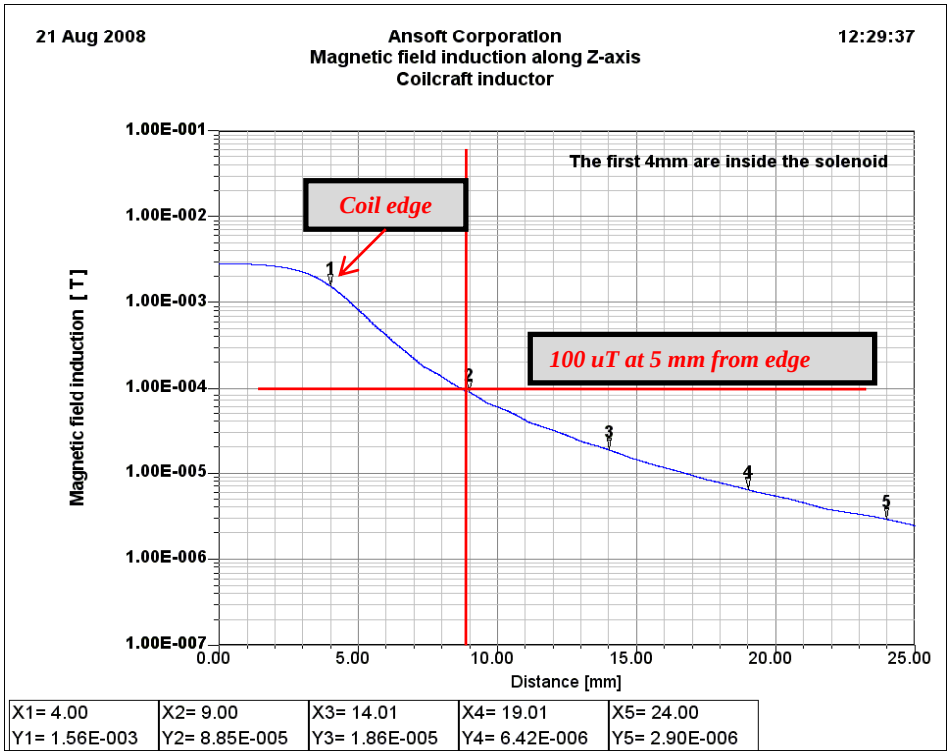
Evaluation with air core inductors on TOTEM

The susceptibility of systems to the magnetic field emitted by inductors of power converters is a major concern. System tests were carried out on TOTEM, with a coil driven by an amplified RF source. The coil is accurately positioned above the detector, the bondings and the ASICs and the induced noise is analyzed from the test DAQ.



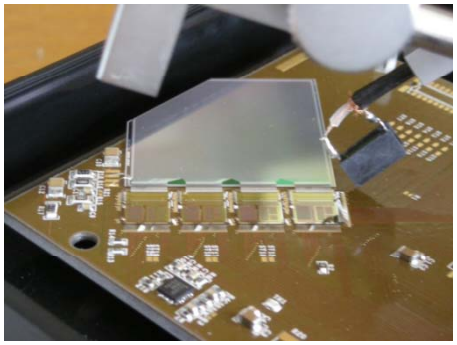


Distance to center (mm)	Field (uT)
4	1560
9	88
14	19
19	6.4
24	2.9

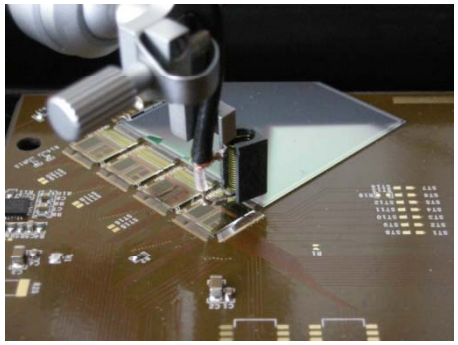


Susceptibility to Magnetic Field

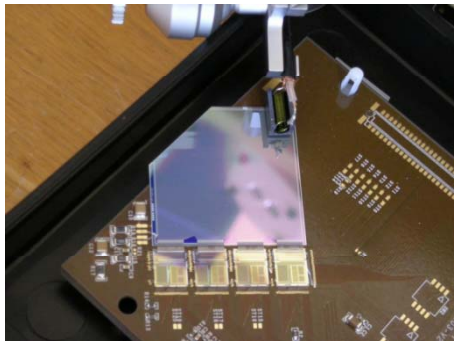
Sensitivity to location and incident angles



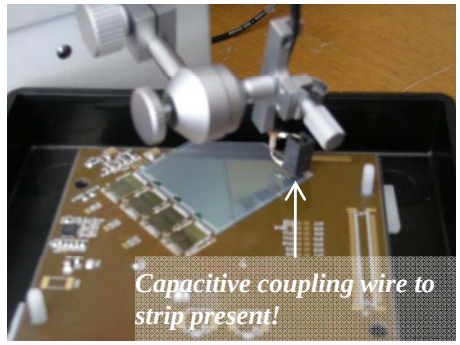
$1A_{pk}$, 1MHz
Inductor focused obliquely on the bonding



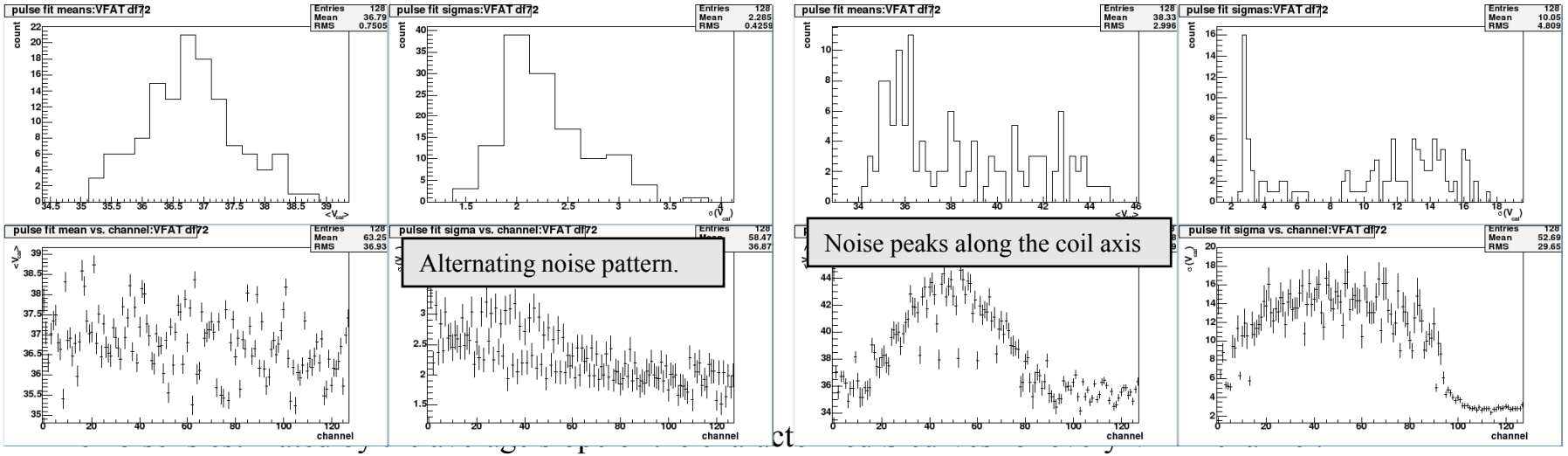
$1A_{pk}$, 1MHz
Inductor focused straight on the bonding



$1A_{pk}$, 1MHz
Inductor focused in parallel to the sensor (along VFAT 1)



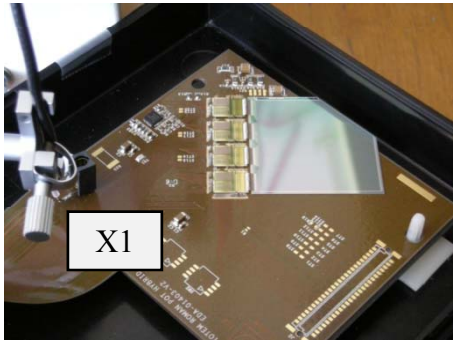
$1A_{pk}$, 1MHz
Inductor focused straight on the sensor (along VFAT 1)

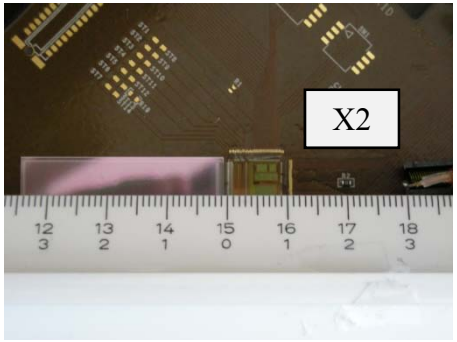


Susceptibility to Magnetic Field

Sensitivity to location and incident angles

Far distance susceptibility.





$1A_{pk}$, *1MHz*

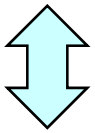
Inductor far from the bonding with different orientations

Noise estimated at 1MHz, 1A peak, exposing VFAT1 channels.

VFAT#	Nominal Noise	Bondings		Sensor		Far distance	
		Oblique	Straight	Parallel	Straight	X1	X2
1	1.76	2.3	12.87*	10.05*	4.14	1.78	1.79
2	1.81	2.14	3.96	3.97	2.35	1.78	1.80
3	1.68	1.88	2.20	2.94	1.84	1.59	1.72
4	1.56	1.70	1.87	2.18	1.65	1.63	1.67

* Distorted S curves.

- The bondings and the sensor area are similarly sensitive.
- The noise peaks at VFAT#1, that corresponds to the exposed region.
- VFAT#1 is insensitive to the coil 30 mm away of the bondings, as it can be predicted by the simulation (< 2.9 uT at 19mm).



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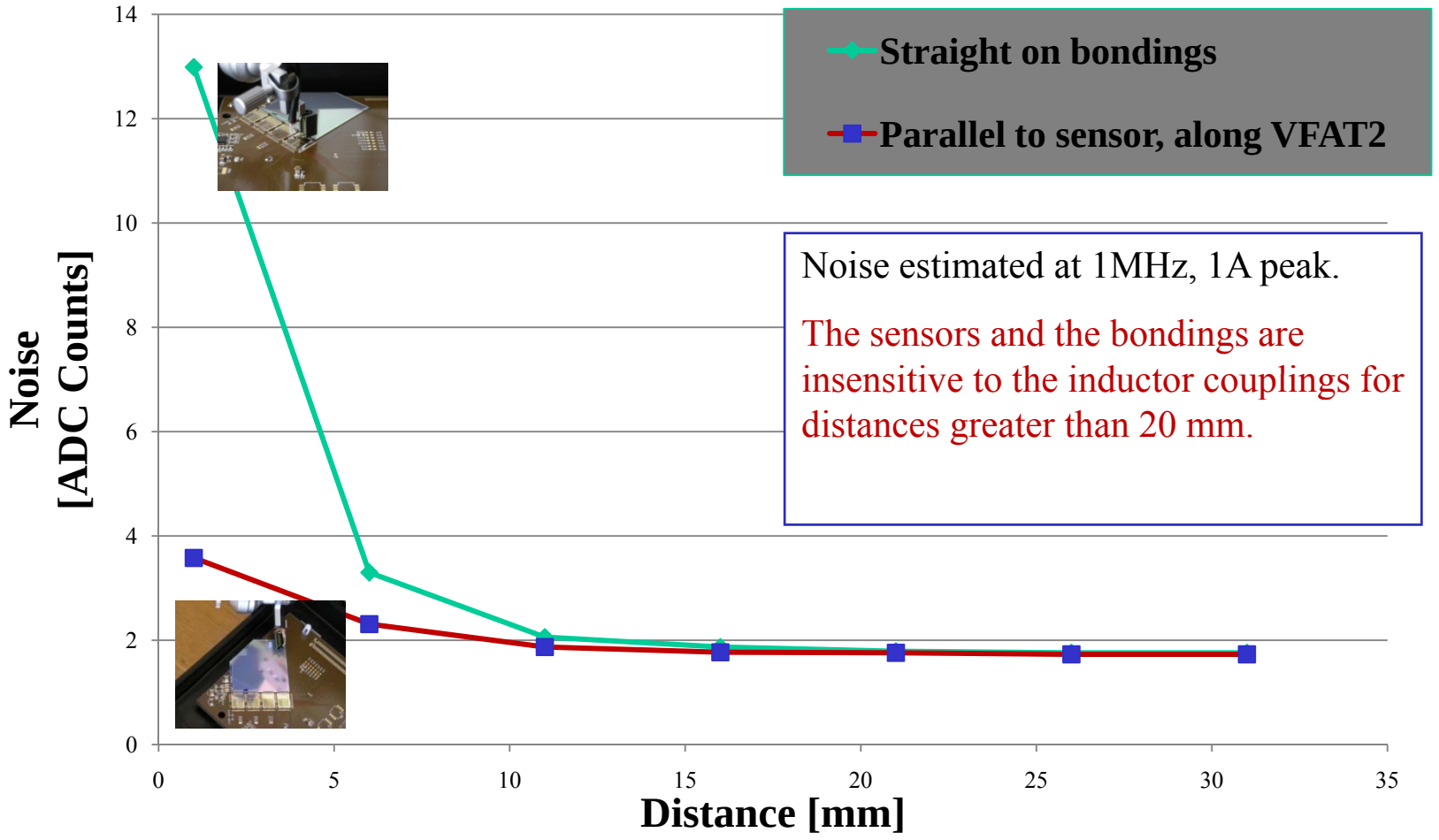
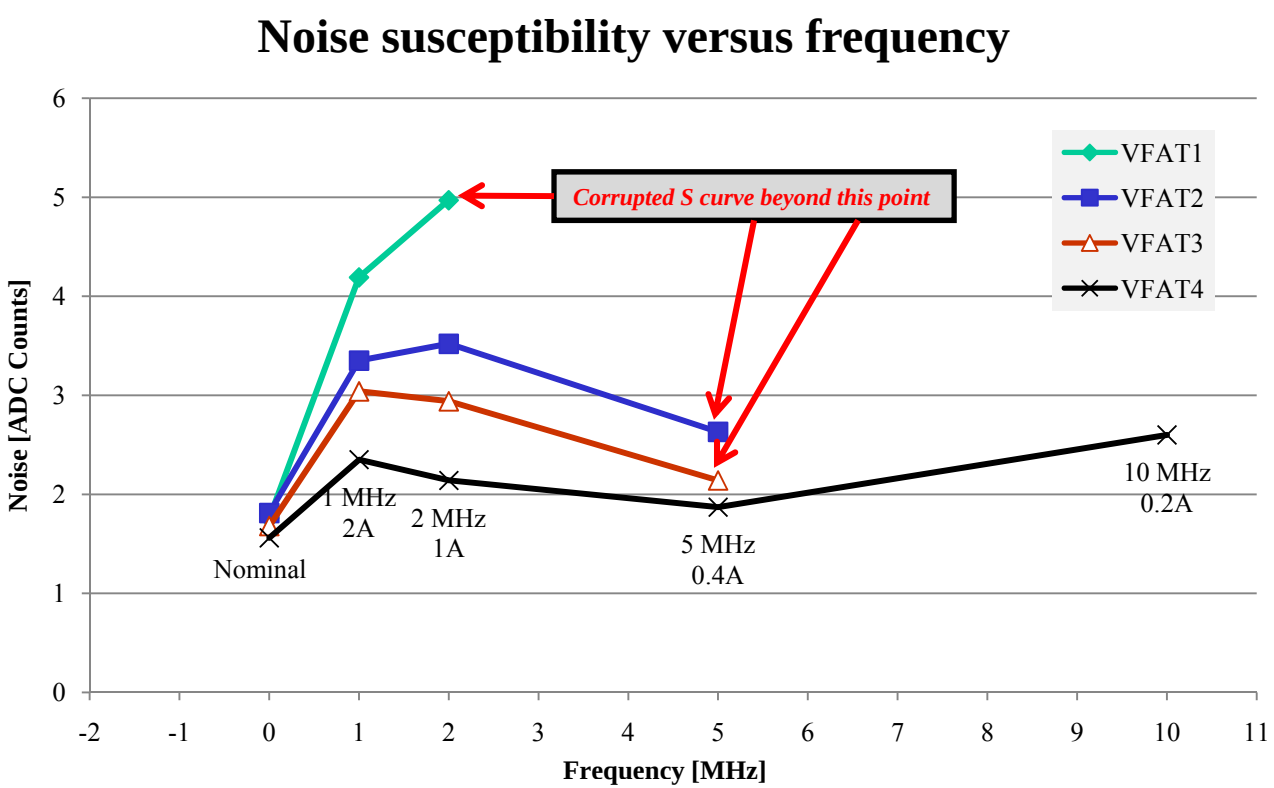
Susceptibility to Magnetic Field

Sensitivity as function of distance

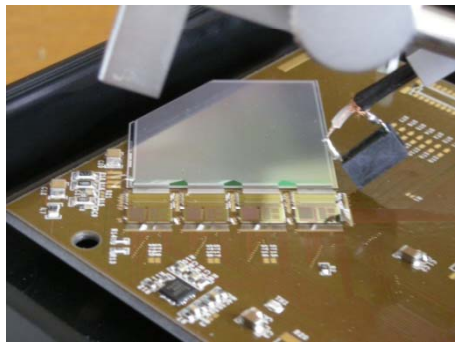


Susceptibility to Magnetic Field

Sensitivity to frequency



Inductor focused obliquely on the bonding

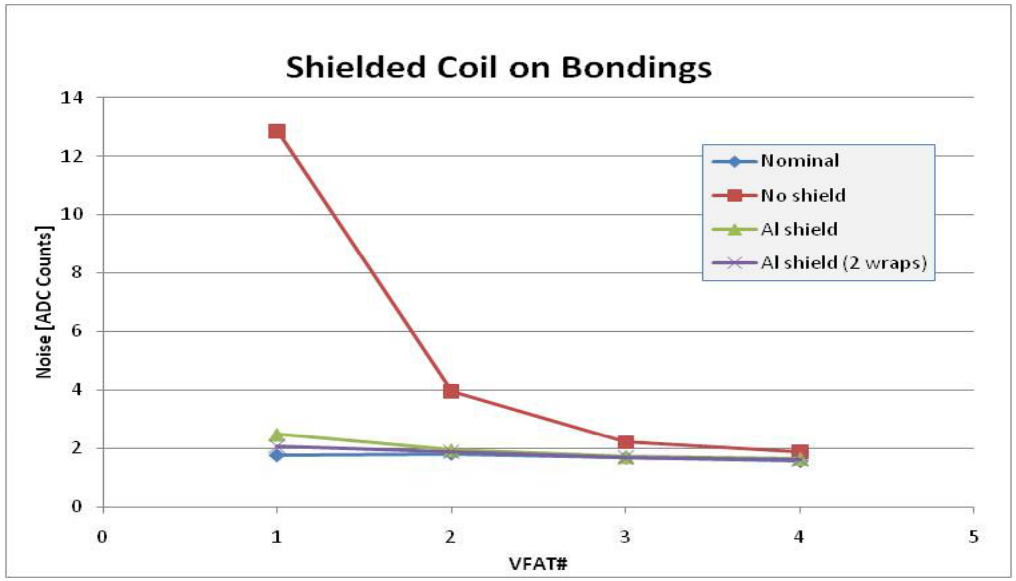


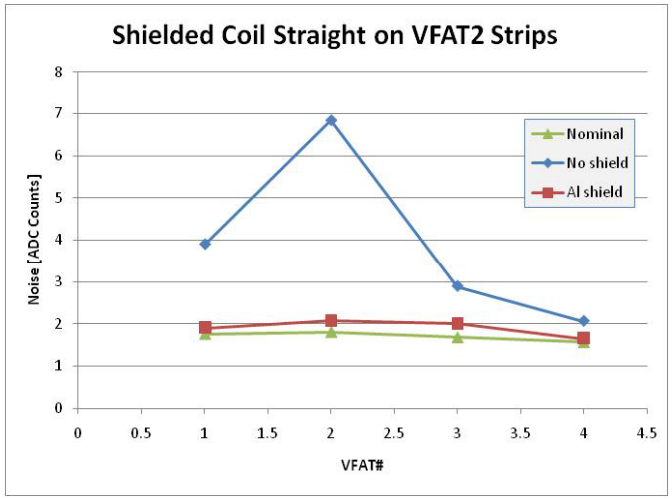
The TOTEM system showed noise sensitivity increasing with the frequency:

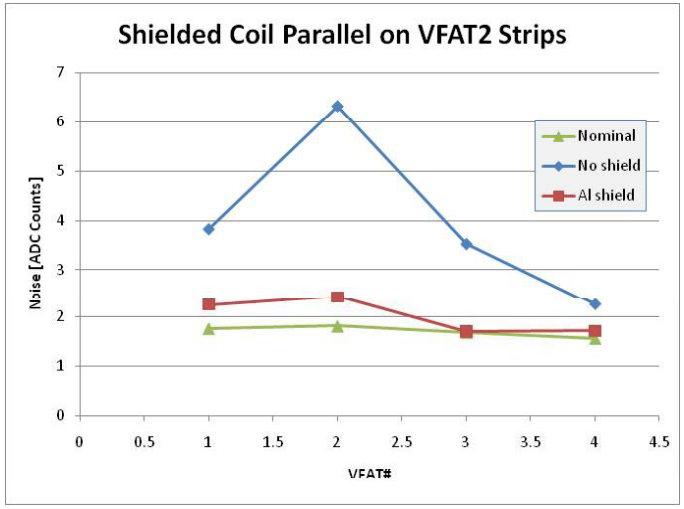
- System not able anymore to extract correct S curves parameters.
- The test was made at constant dB/dt: (I*f = constant).

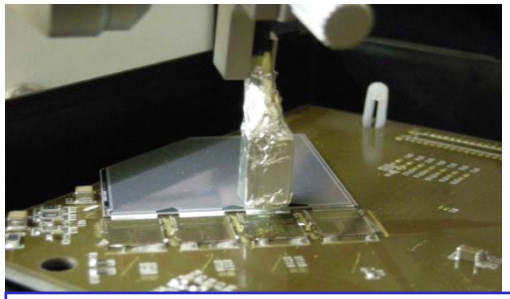
Susceptibility to Magnetic Field

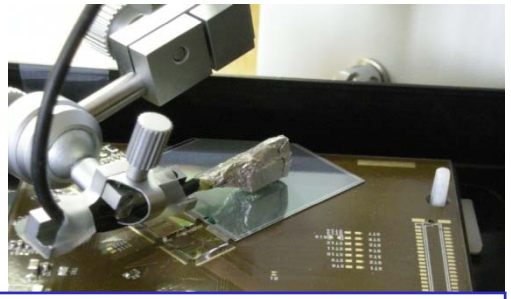
Shielding of inductor (Al wrap)









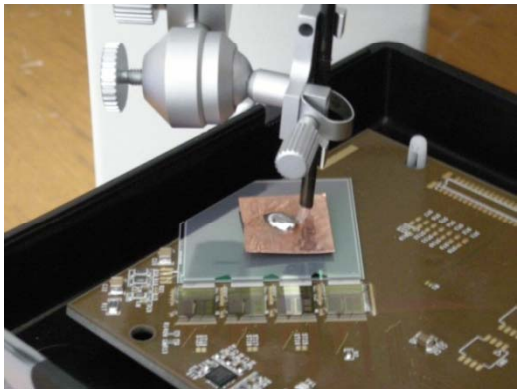


The shielding of the coil with Al foil allows protecting the front-end against radiated couplings.

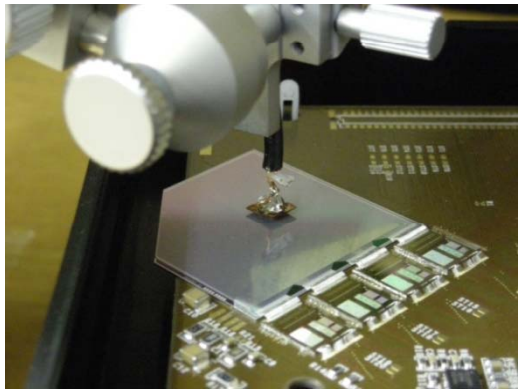
Susceptibility to Electric Field

Evaluation on TOTEM front-end

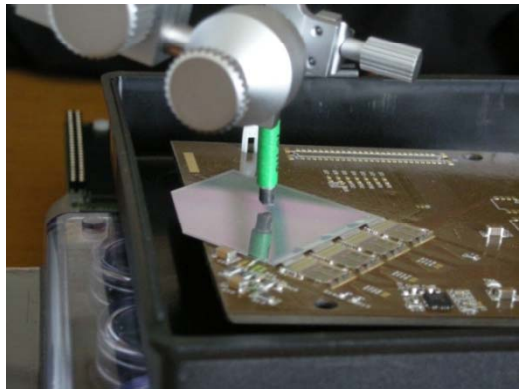
Large plate cap. coupling



Small plate cap. coupling.

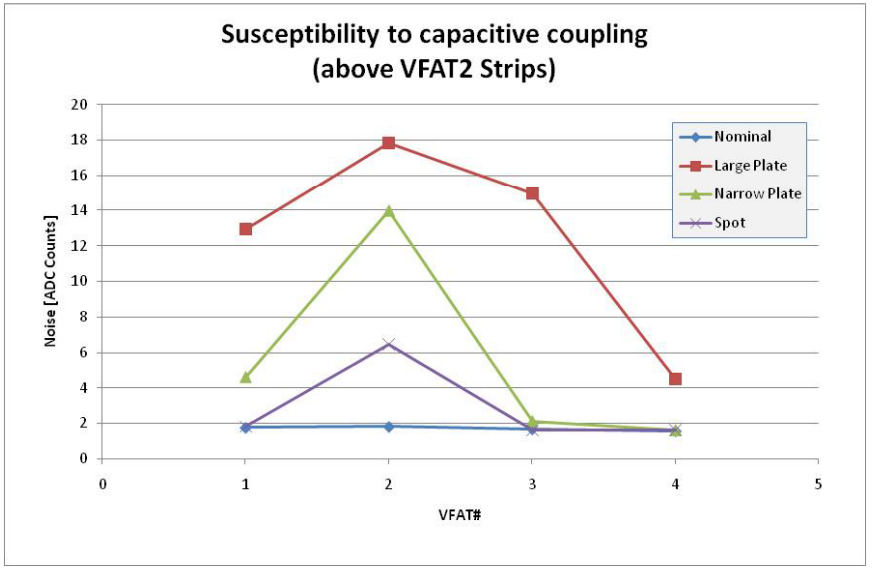


Spot cap. Coupling (wire end).



The system showed also sensitivity to capacitive coupling (electric field):

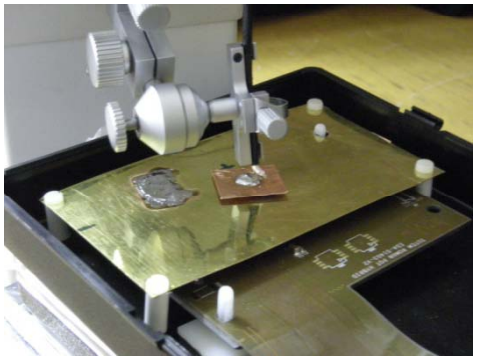
- 3.4V/1MHz: signal equivalent to the one present on the inductor wires.
- Exposed areas develop large noise.



Susceptibility to Electric Field

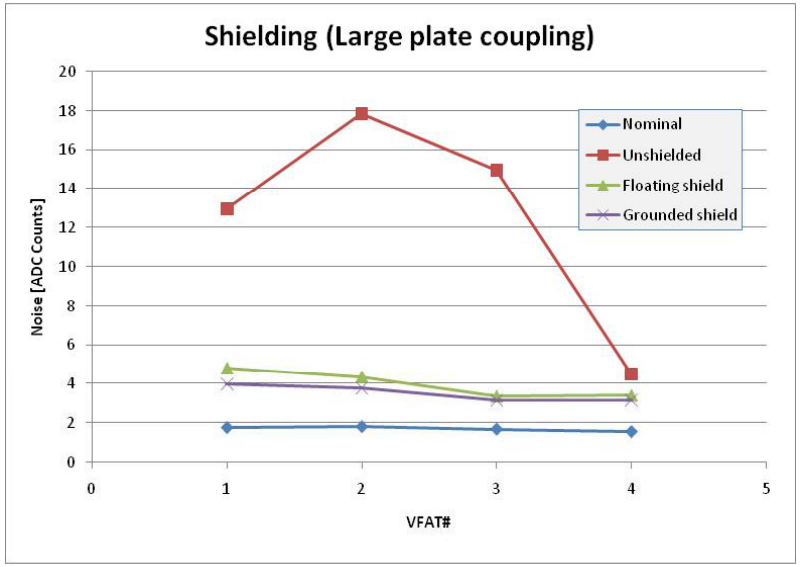
Electrostatic shielding

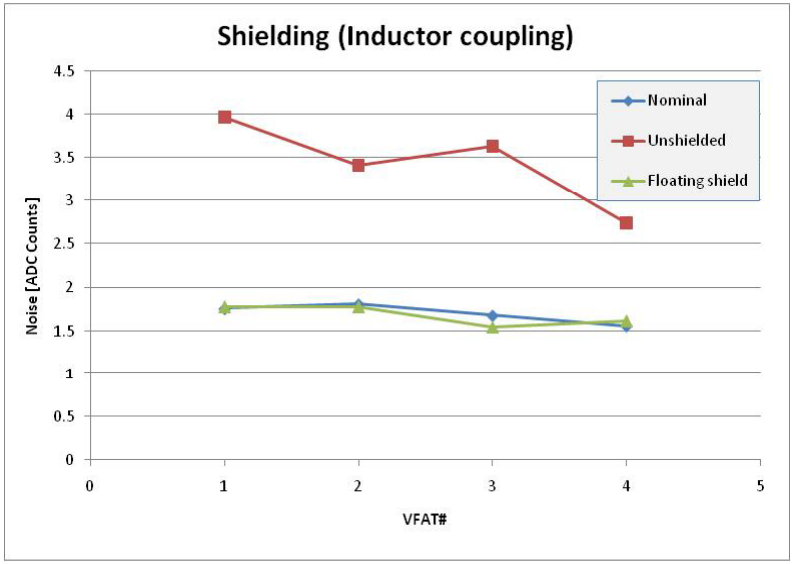
Large plate cap. Coupling along VFAT#1.



A copper plate allows reducing the coupled noise significantly

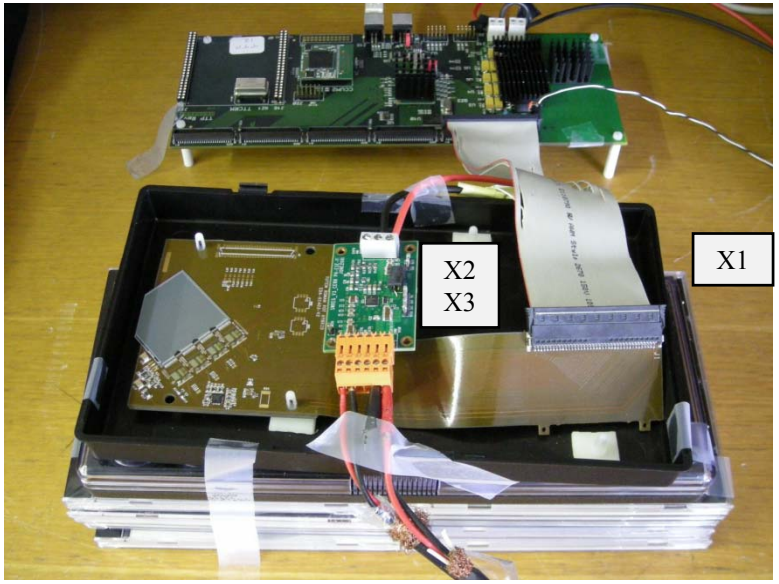
- E field noise gets spread on all VFATs.
- The best performance is achieved with a grounded plate (as expected).
- The plate shields also the emissions from the coil.

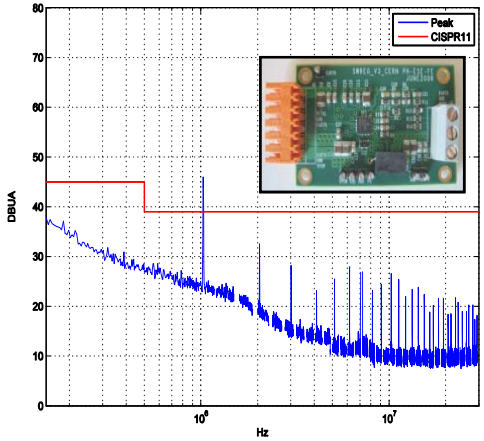




Susceptibility to Conducted Noise

System tests with DC/DC Converters on TOTEM





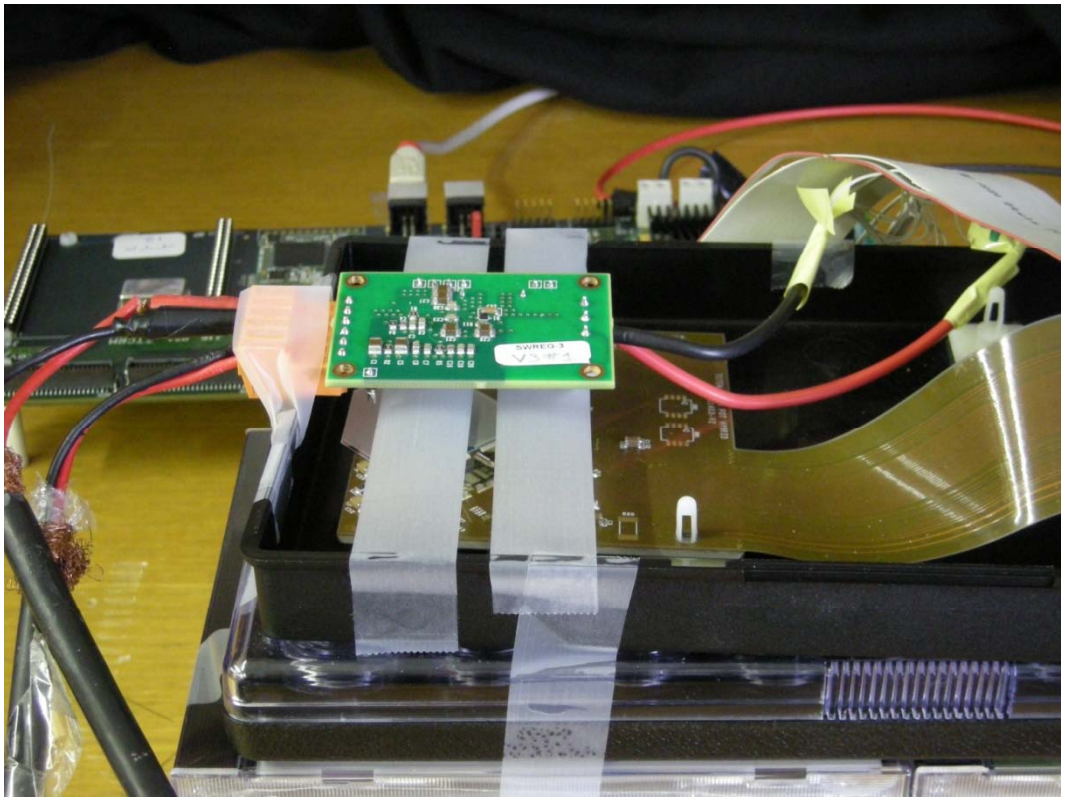
The front-end TTP was powered by a DC/DC converter prototype (PH-ESE) with low output noise characteristic.

- *The TOTEM system was found to be sensitive to electric and magnetic couplings on its inputs (sensors, bondings, preamps) for distances < 30 mm.*
- *If powered with a DC/DC converter, it is exposed to conducted noise (CM currents).*
- *3 locations were exercised, with no impact on the noise performance of the system.*

VFAT #	Nominal Noise	X1 (far, long cable)	X2 (close, long cable)	X3 (close, short cable)
1	1.76	1.70	1.73	1.76
2	1.81	1.72	1.70	1.73
3	1.68	1.55	1.62	1.62
4	1.56	1.59	1.59	1.59

Susceptibility to Conducted Noise

System tests with DC/DC Converters on TOTEM



• *DCDC mounted on top of the detector without shield, d < 15 mm to be able to see some coupling effect.*

VFAT #	Nominal Noise	X4 (top of strips)
1	1.76	2.79
2	1.81	2.32
3	1.68	1.85
4	1.56	1.76

Conclusions

- Systems are exposed to conducted noise, electric fields and magnetic fields. Simple test methods to evaluate their susceptibility were proposed, but it remains difficult to disentangle the radiated components.
- The characterization of the conducted noise susceptibility can be carried out accurately, allowing to set precise requirements for the power supplies.
- The susceptibility to radiated fields can be easily evaluated:
  - It is possible to discriminate between electric and magnetic couplings.
  - Geometrical bondaries can be defined.
  - Shielding methods can be evaluated.
- The evaluation on the TOTEM front-end predicted susceptibility to both electric and magnetic couplings that are typically found in power converters, for distances of less than 20 mm. The susceptibility could be strongly reduced using shields.
- The TOTEM front-end was successfully operated, powering it with a low noise DC to DC converter, without increasing the system noise, without the addition of any shield, down to distances of 15 mm of the most critical location (bonding and strips).