EMSA 2010

# A Very Low 1/f Noise ASIC Preamplifier for High Sensitivity Search-Coil Magnetometers

LPP* / L2E+

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# General Introduction

- Objectives: To go one step further in the electronics development and integration of the LPP space instruments (Magnetometers & Particles detectors).

  ⟹ Reduce considerably the **mass**, the **overall dimensions** and the **power consumption** of the electronics.

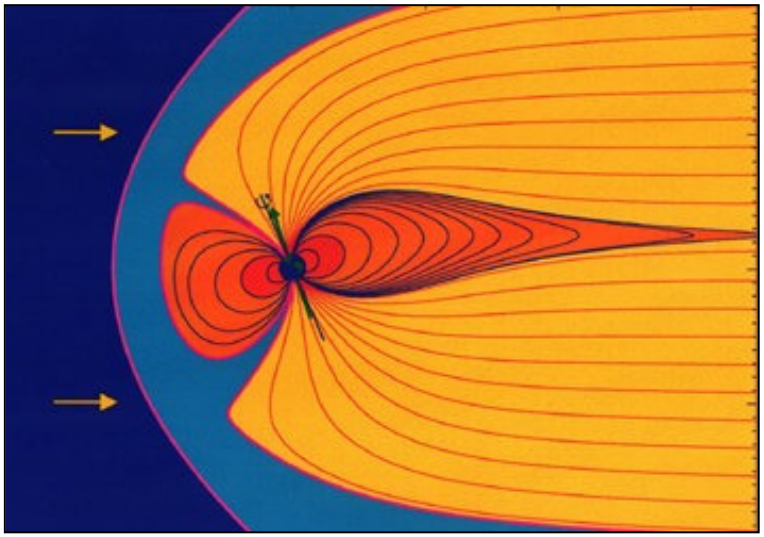
  ⟹ Improve the **radiation hardness of the design** and take it **into account at the start** of the design.

- Tools: CMOS 0.35um technology has been used to design and develop an ASIC (Application Specific Integrated Circuit) preamplifier for the search-coil.

- LPP competences for Instrumental contribution in the project
- L2E competences for Microelectronic contribution in the project

# Space Plasma Investigations

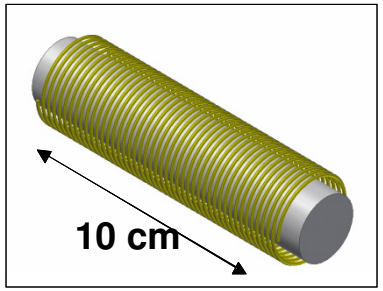
- The **magnetic field of the earth is « disrupted» because of solar activity** (CLUSTER mission, 2000, four satellites flying on tetrahedral cluster)



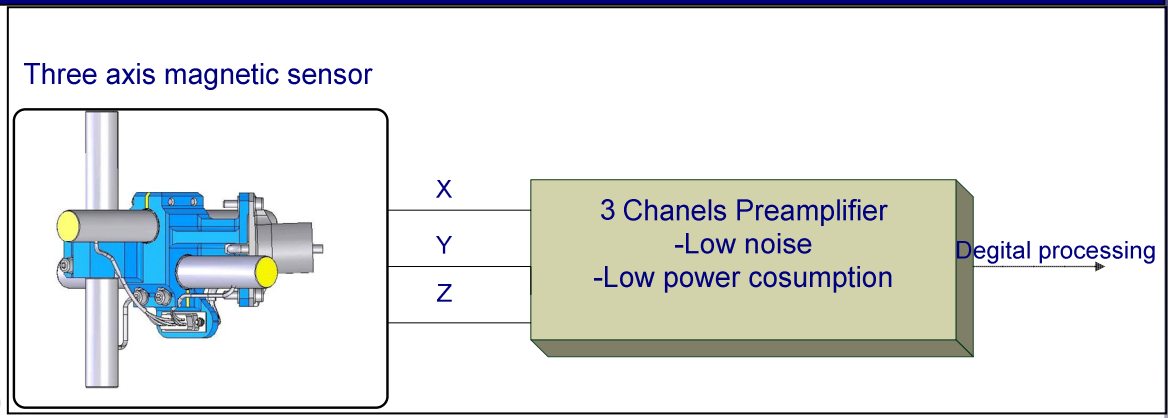
**Magnétosphère terrestre**

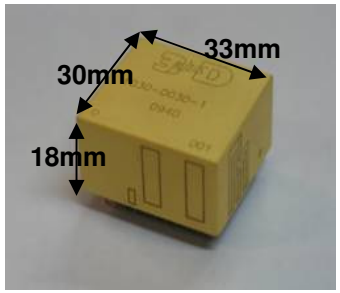
- The measurement of magnetic field allow us to:
  - Understand the earth magnetosphere dynamic
  - Prevent for example the events that are accompanied by disruption of telecommunications signals on land and in space.

# The Principle of Search Coil Magnetometer

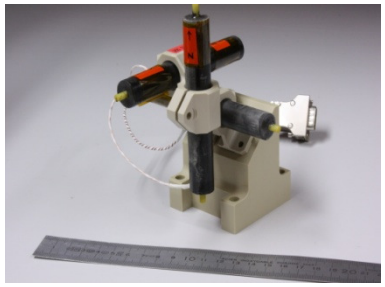



A 10cm length, 12mm diameter
and 15000 turns search-coil sensor (one axis)

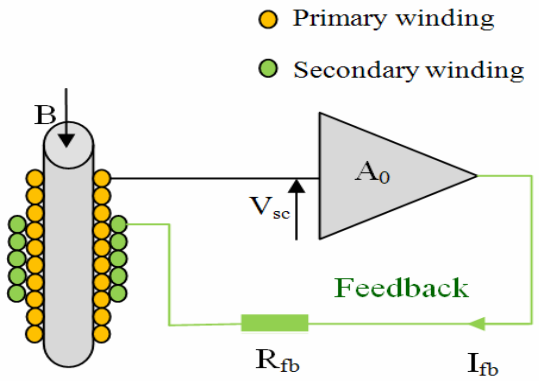



3D+ Technology



MMS Search-coil




Search coil & Preamplifier principle

| ***Freq*** | 10 Hz | 100 Hz | 1 kHz |
|---|---|---|---|
| ***NEMI*** | 2 pT/√Hz | 0.3pT/√H | 50 fT/√Hz |

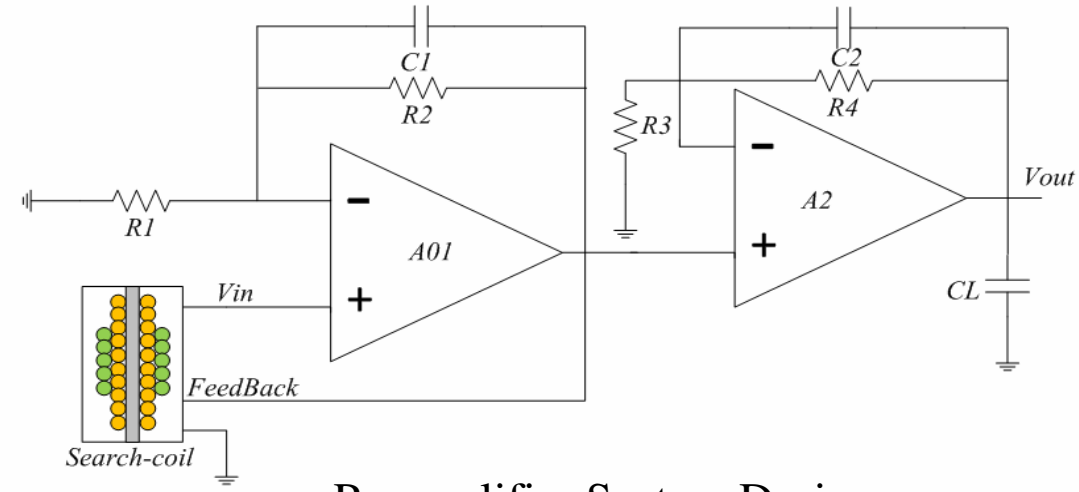
z

Sensitivity of MMS Search coil vs Frequency

| ***mass*** | ***Power*** | ***Input Noise*** |
|---|---|---|
| 210 g | 166 mW | 4 nV/√Hz |

Characteristics of MMS Preamplifier

# System Design




Preamplifier System Design

The current feedback of the search coil is sent by the first block of the amplification

The ASIC preamplifier is modelled by two blocs of amplification:

- The midgain $A_{01}$ of the first amplifier is set by 1 + R2/R1
- The midgain $A_2$ of the second amplifier is set by 1 + R4/R3

Total gain of the ASIC preamplifier is A01+ A2

**ASIC Preamplifier specifications**:

- Input noise: 4 nV/√Hz @ 10 Hz
- Gain: 80 dB
- Power consumption: < MMS one
- (ASIC + Search-coil) NEMI: 2 pT/√Hz @10 Hz

# Design Approach and Noise Considerations

To conserve the sensitivity ($2\,pT/\sqrt{Hz}$ @ $10Hz$) of the search-coil, the input noise of the preamplifier has to be less or equal to $4nV/\sqrt{Hz}$ at 10 $Hz$.

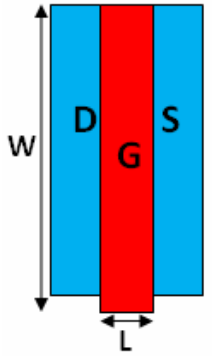
Sources of noise in the ASIC preamplifier design:

**Resistor noise:** $\overline{V_n^2}(f) = 4kTR$ $[V^2/Hz]$

If the R value increases => noise increases

**Transistor noise:**

- *Thermal noise* $S_i = \frac{8kT}{3} \times \frac{1}{g_m}$ *where* $g_m = \sqrt{2 I_d k \frac{W_{eff}}{L_{eff}}}$ $[V^2/Hz]$




- *Flicker noise*:

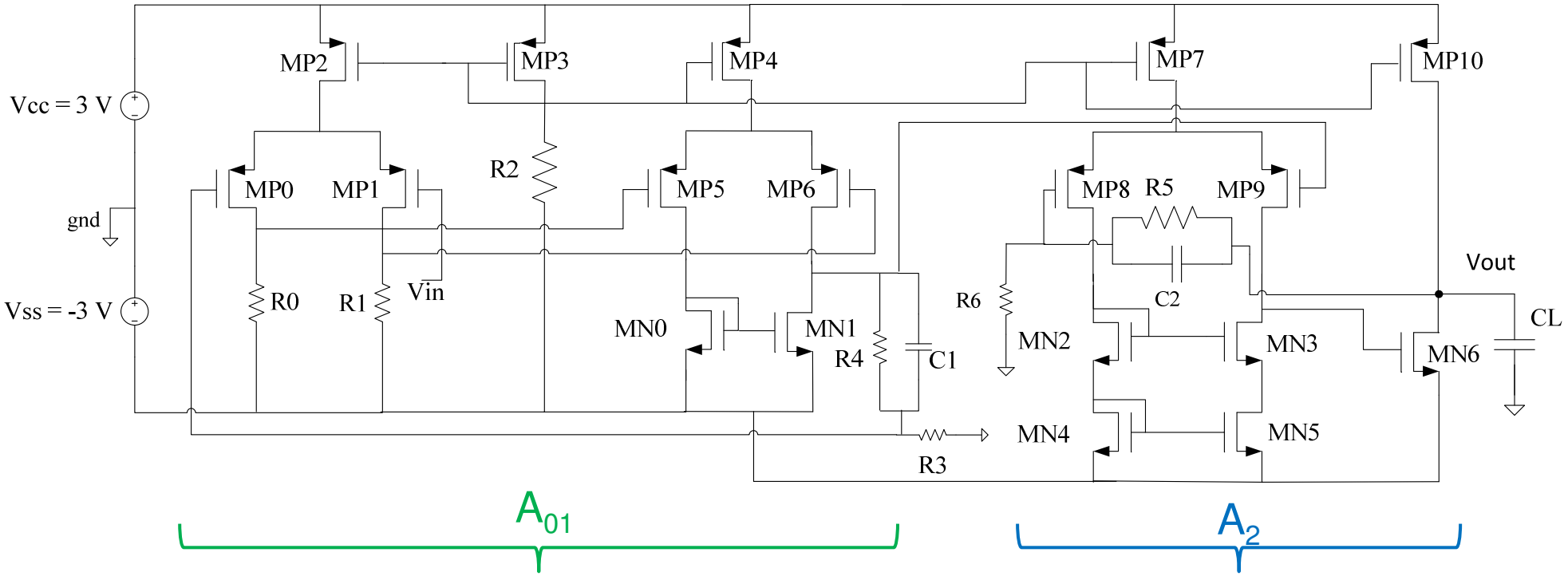
NMOS Transistor: $S_v = \frac{1}{C_{ox} L_{eff}^2} \times \frac{KF.I_d^{AF}}{f} \times \frac{1}{g_m^2}$ $[V^2/Hz]$

PMOS Transistor: $S_v = \frac{1}{C_{ox} L_{eff} W_{eff}} \times \frac{KF.I_d^{AF}}{f} \times \frac{1}{g_m^2}$ $[V^2/Hz]$

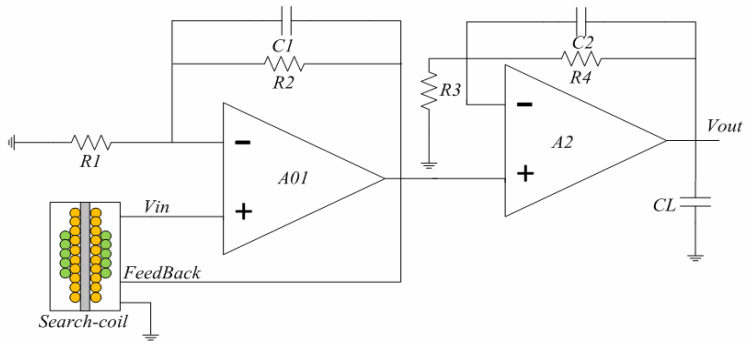
| | NMOS | | PMOS | |
|---|---|---|---|---|
| | Thermal | 1/f | Thermal | 1/f |
| $W_{eff}$ ↗ | ↘ | ↘ | ↘ | ↓ |
| $L_{eff}$ ↗ | ↗ | ↘ | ↗ | --- |

1/f noise is lower for PMOS transistor if we use a large $W \times L$

# ASIC Preamplifier Schematic

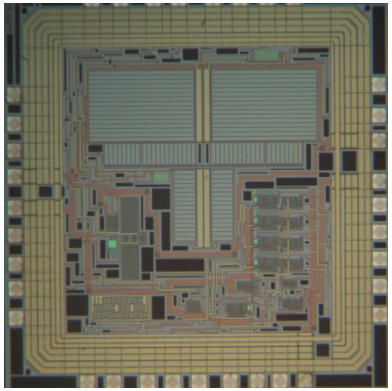



- Supply voltage: +/- 3 V
- Input referred noise: 4 nV/√Hz
- Gain: 83 dB (> 10000)
- Power consumption: 12 mW

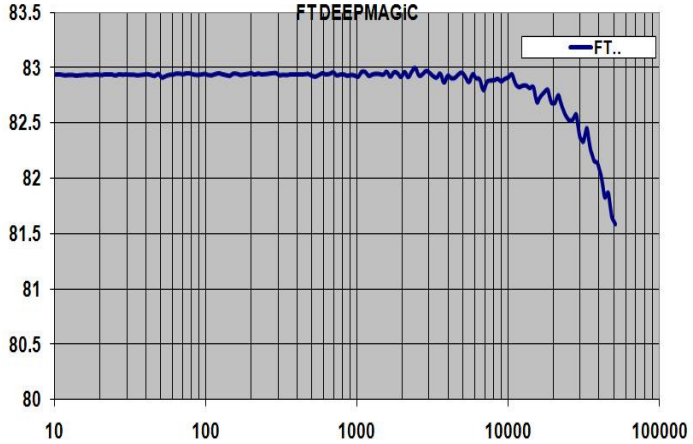


# Experimental Results

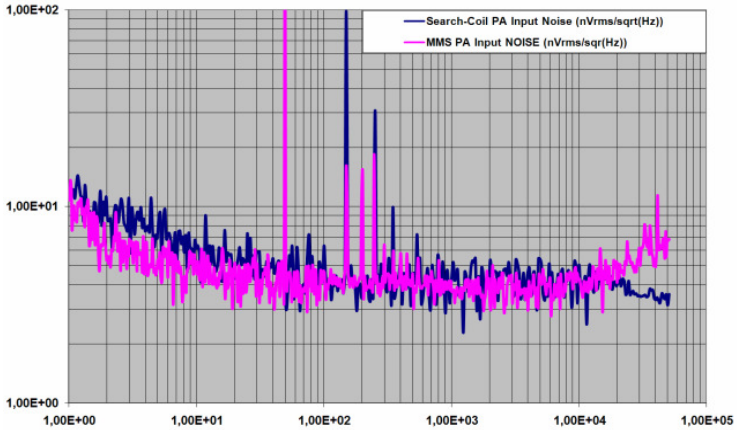
The preamplifier has been fabricated in CMOS 0.35 µm four metal technology



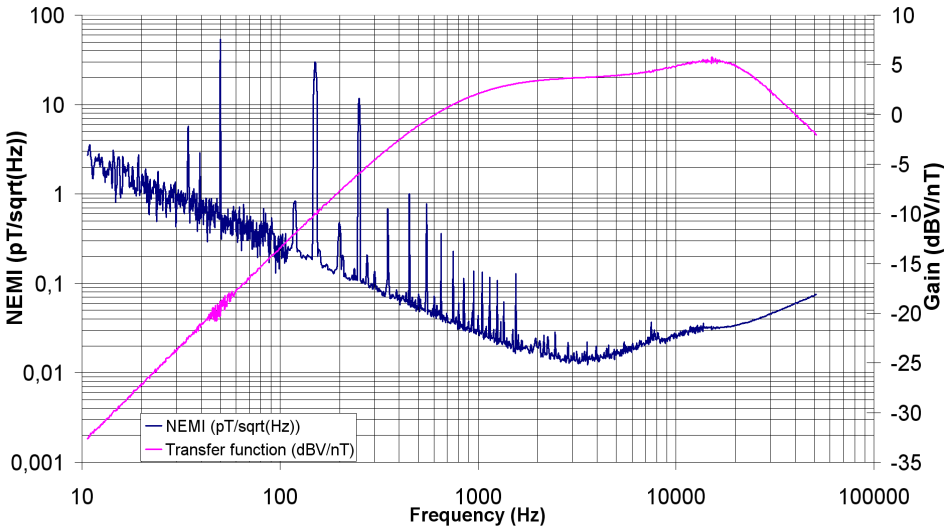
*Microphtograph of 2.2 x 2.3 mm chip containing one amplifier*




*Measured transfer function of the ASIC amplifier*




*Measured amplifier input-referred voltage noise spectrum for the Search coil and MMS PA*




Noise Equivalent Magnetic Induction of low noise ASIC combined to a 10 cm search coil designed for MMS spacecraft

# Conclusion

. A $4nV/\sqrt{Hz}$ @ 10 Hz ASIC preamplifier for a search coil magnetometer has been designed and fabricated.

. The NEMI of the search coil combined with the preamplifier is $2pT/\sqrt{Hz}$ @ 10 Hz and $14fT/\sqrt{Hz}$ @ 4 kHz ( the same performance than MMS)

. The power consumption of the preamplifier is about *12 mW ( 166 mW for the 3D+ amplifier)*

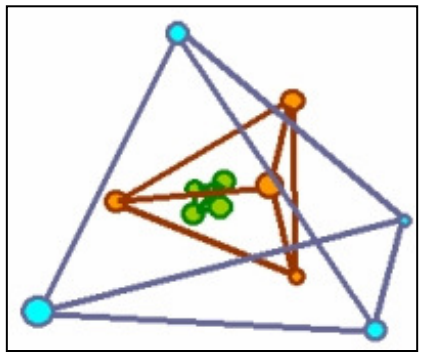
. The area silicon chip of the preamplifier : *5.40mm$^2$ (2.27 x 2.38) very low than MMS preamplifier surface (4 cm$^2$)*

. The bulk of the ASIC preamplifier is negligible than MMS one

# Perspectives

- **Integration of the power supply regulation on the same chip of the preamplifier**
- **Our first ASIC PA will be flown onboard a Norwegian rocket in 2011**
- **The chip is under radiation testing at the moment**
- **Prospective spatiale européenne 2015-2025**

  - **Cross-Scale :** multiscale analysis of space plasma (turbulence, shock, acceleration ,...). R&T needed: light Wight and miniaturized instrumentation



**(ESA Doc.)**

  – **Generally:** Increase chances of selection on study missions of space plasmas.