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NFC dosimeter tag for radiotherapy treatments based on commercial MOSFETs

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3rd ELICSIR Training School

Introduction

Why NFC tags with sensing capabilities?

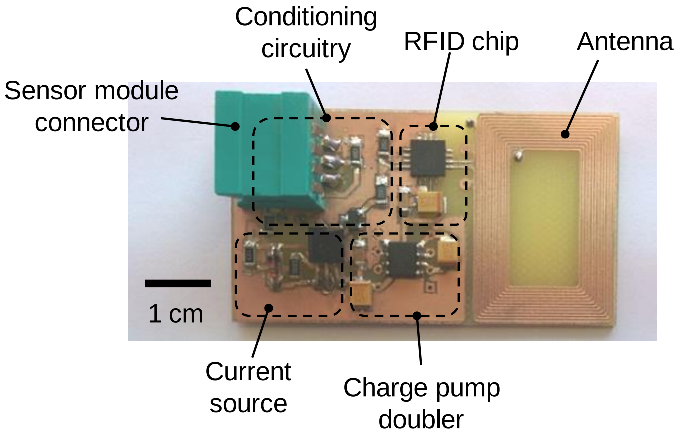
- Energy Harvesting => No batteries required
- NFC is very popular on Android devices
- Cost saving
- Possibility to laminate and sterilize the device
- Construction in flexible substrates
- Only a smartphone and the tag is required
- Easy to use

Introduction

Related NFC radiation dosimeters

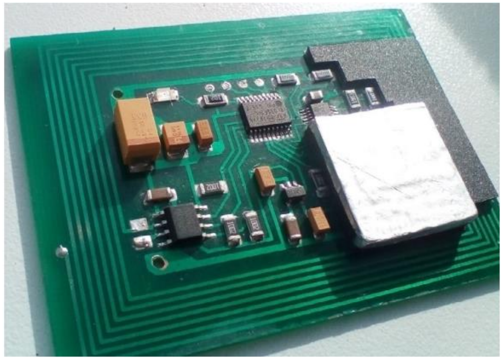
Our previous work

- Interchangeable MOSFET sensor module based on ZVP3306
- Small size
- NFC band: 13.56 MHz
- NFC chip as controller



Other examples

- ID-card-size dosimeter for continuous personnel monitoring (range of cGy)
- Based on phototransistors and film badges
- NFC band: 13.56 MHz
- NFC chip + microcontroller

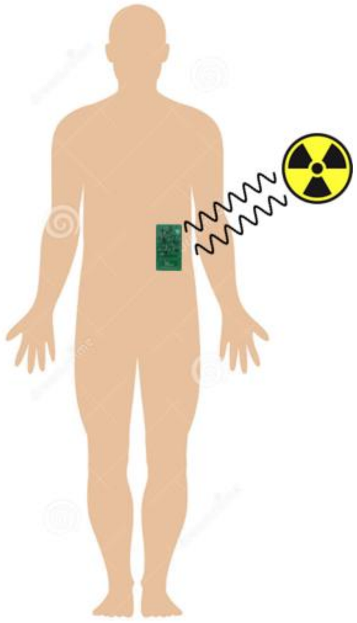


Motivation:

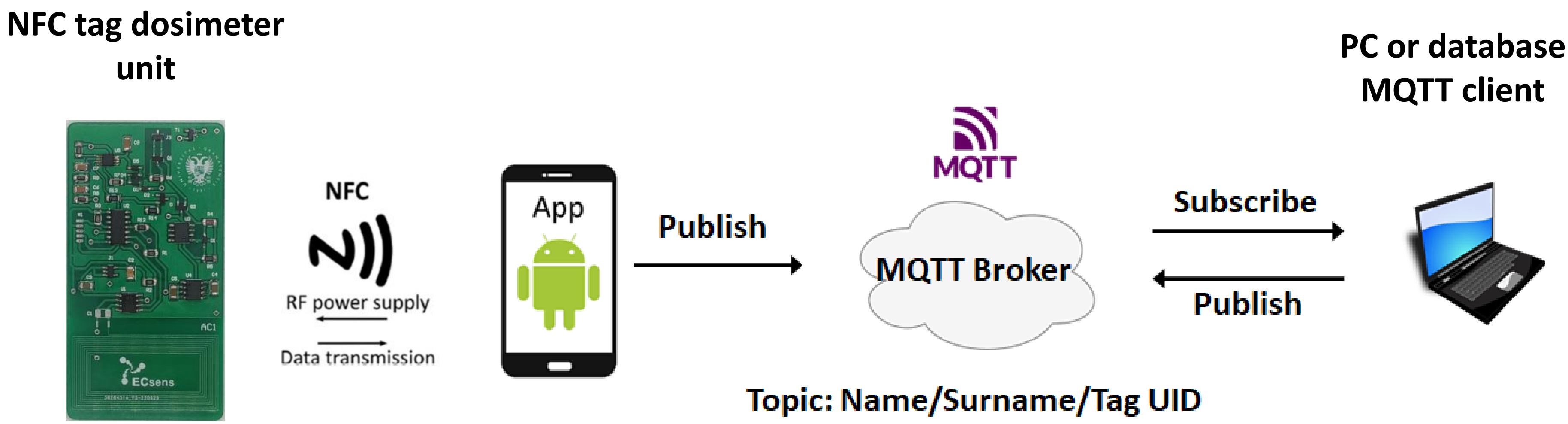
Our Goal

- To develop a battery-less NFC tag reader for MOSFET dosimeters. Improve and upgrade the previous system.

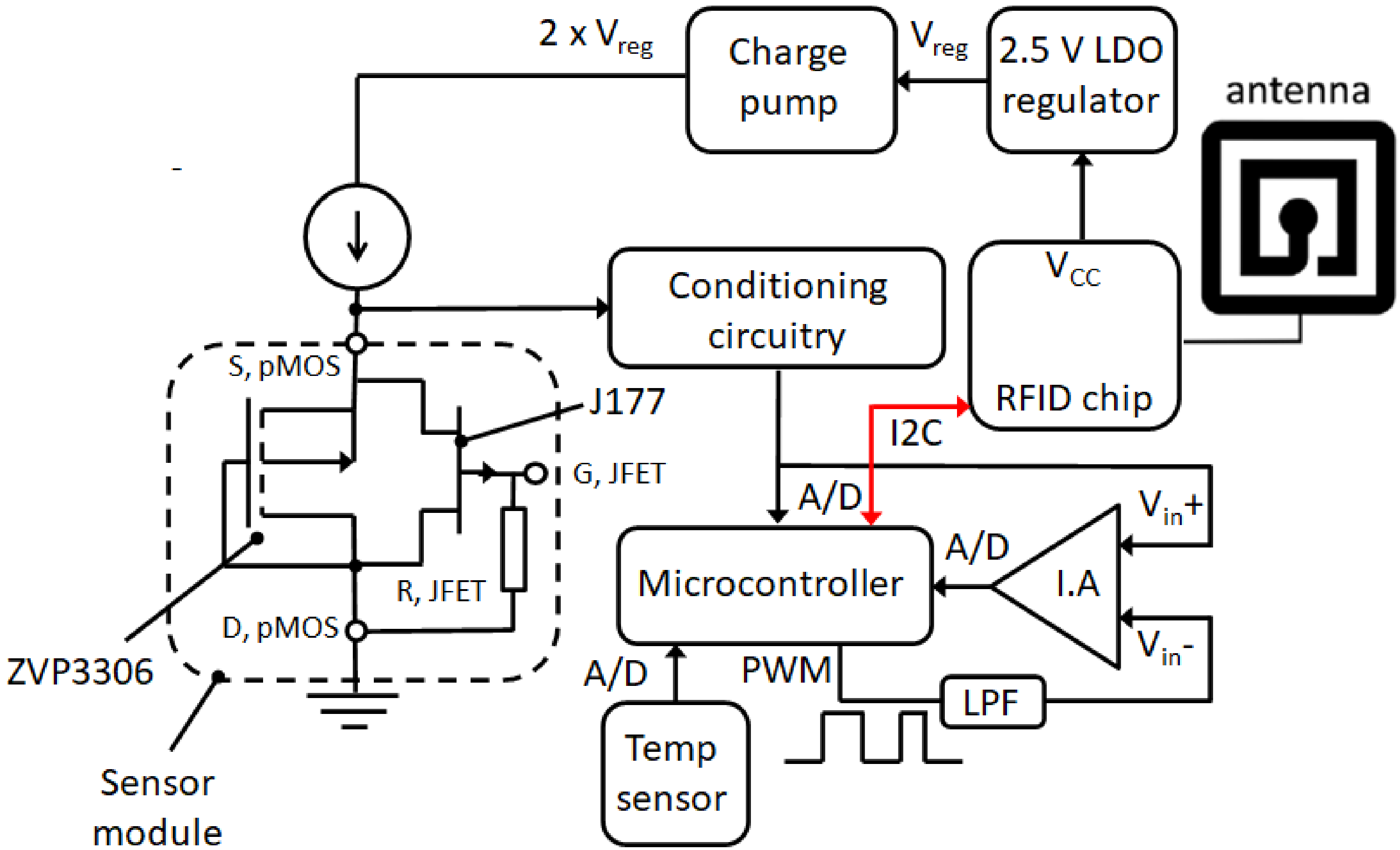
- Cost saving
- MOSFETs have a good linear response to radiation
- MOSFETs low current consumption
- No batteries or wires are required
- Potential application in radiotherapy treatments
- Small size
- User-friendly interface. Easy to use



Our system:


NFC tag dosimeter unit
NFC
RF power supply
Data transmission
App
Publish
MQTT
MQTT Broker
Topic: Name/Surname/Tag UID
PC or database MQTT client
Subscribe
Publish

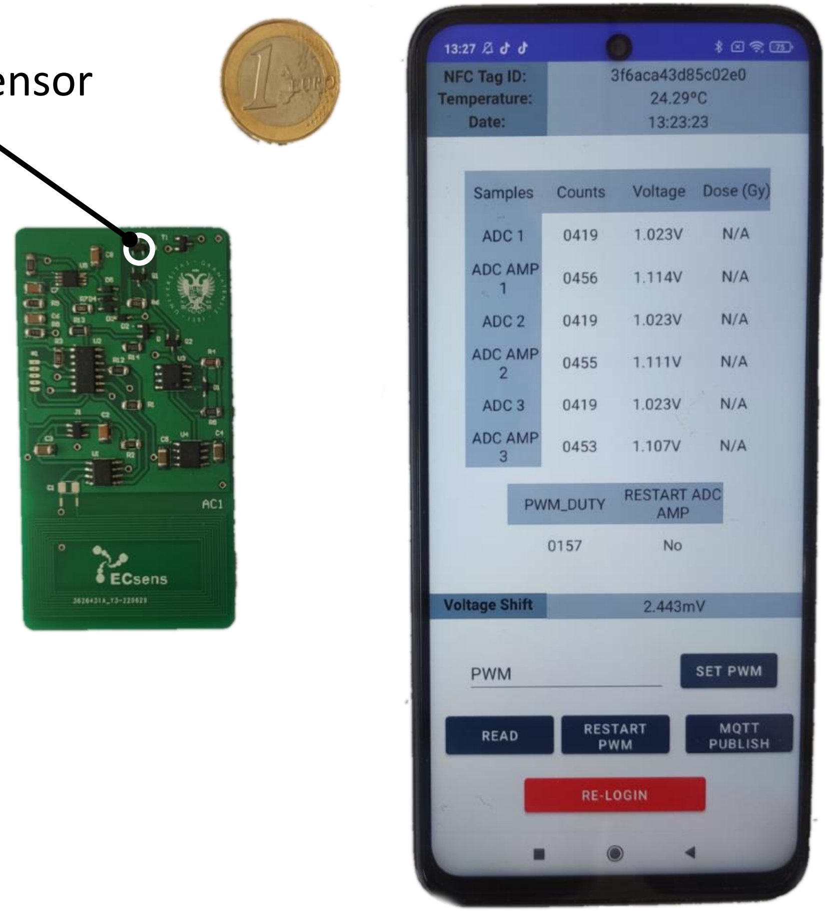
NFC tag: block diagram



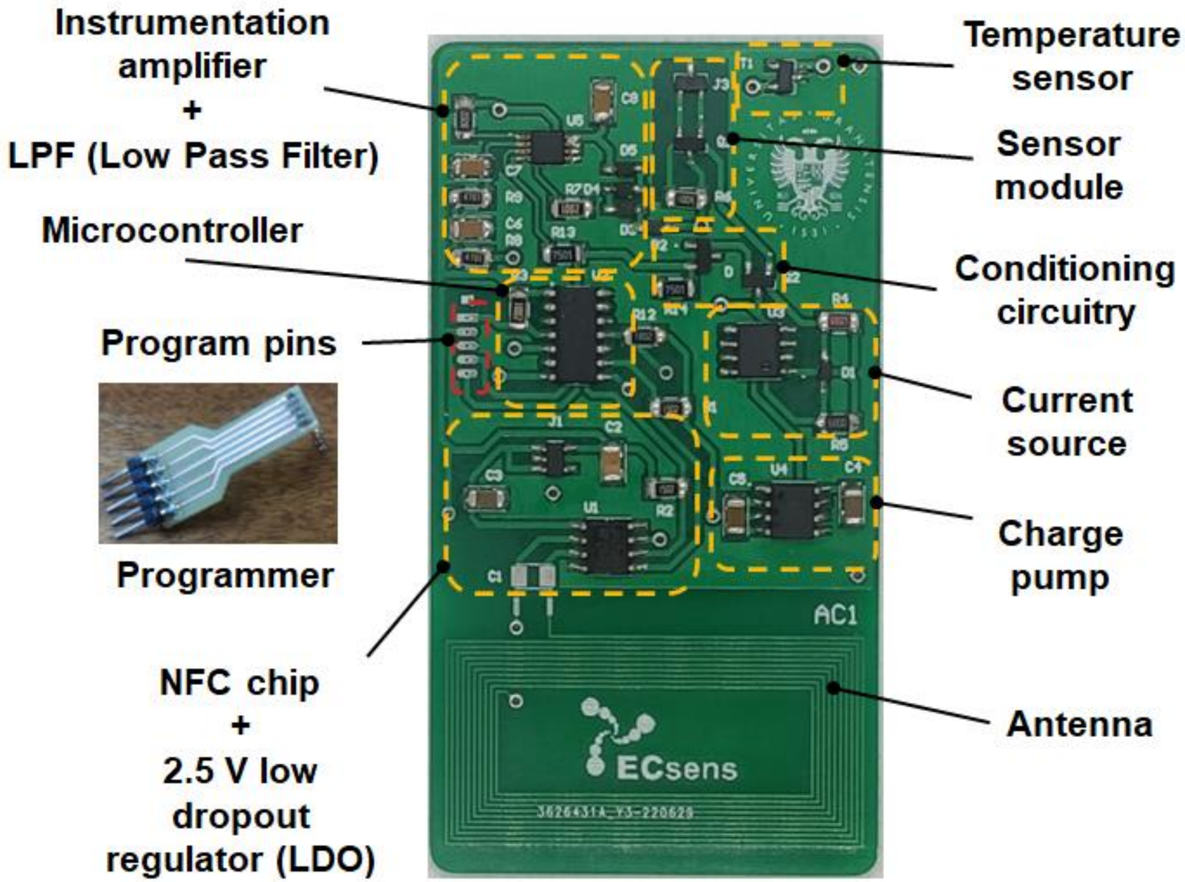
ECsens Electronic and Chemical sensing solutions

NFC tag: Size comparison

pMOS sensor



NFC tag: functional blocks

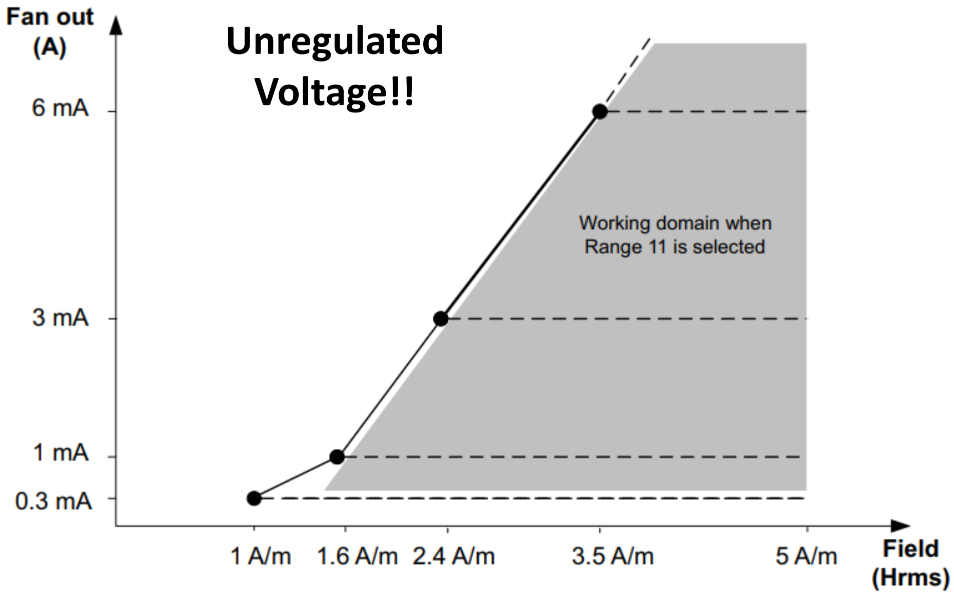


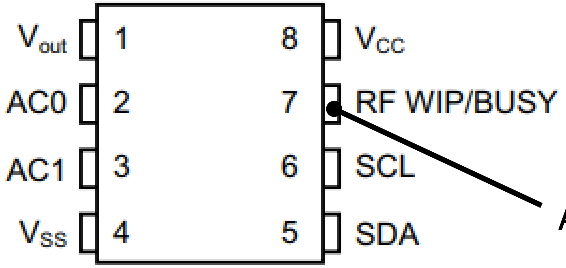
- Ultra-low consume (3.3 mW)

NFC tag: RFID chip

M24LR64E

- Manufacturer: STMicroelectronics
- Energy Harvesting
- 64 kB EEPROM memory, that can be written and read via NFC or I2C
- ISO 15693 and ISO 18000-3



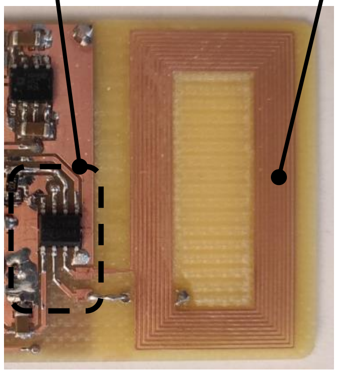


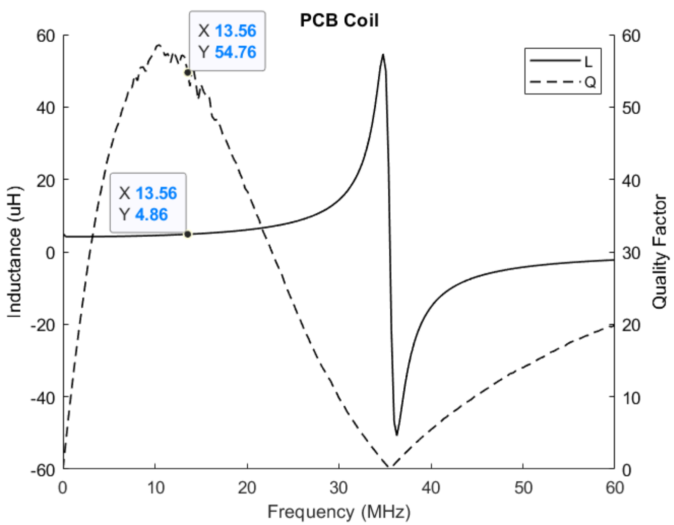
An interrupt can be generated to the microcontroller

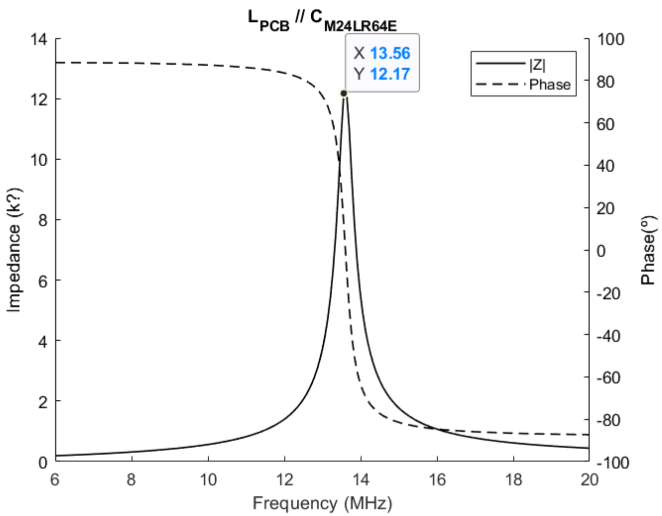
NFC tag: Antenna

- Antenna: L_{PCB} // $C_{M24LR64E}$
  - $C_{M24LR64E}$ =27.5 pF (theoretical), for resonance at 13.56 MHz → L = 5.01µH
  - L_{PCB}, 10 turns → 4.86 µH → resonance at 13.62 MHz
  - Can be corrected with a parallel capacitor
  - Rs → 2.45 Ω

NFC chip Antenna



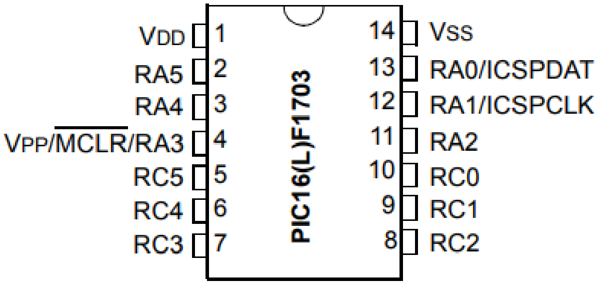


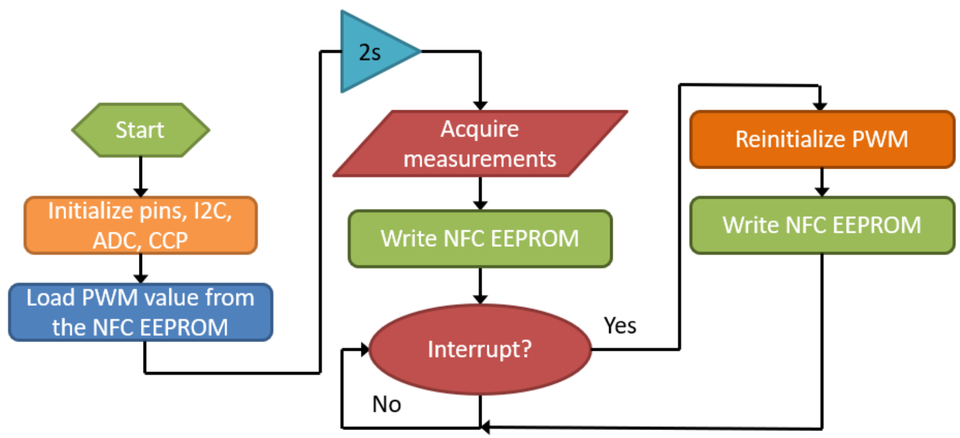


NFC tag: Microcontroller

PIC16LF1703 eXtreme Low-Power series (XLP)

- Manufacturer: Microchip
- Operating current: 32uA/ MHz @ 1.8 V typical
- Operating voltage range: 1.8V to 3.6V
- Serial communications: SPI, I2C
- 10-Bit Analog-to-Digital Converter (ADC)
- Compare/Capture/PWM module (CCP)

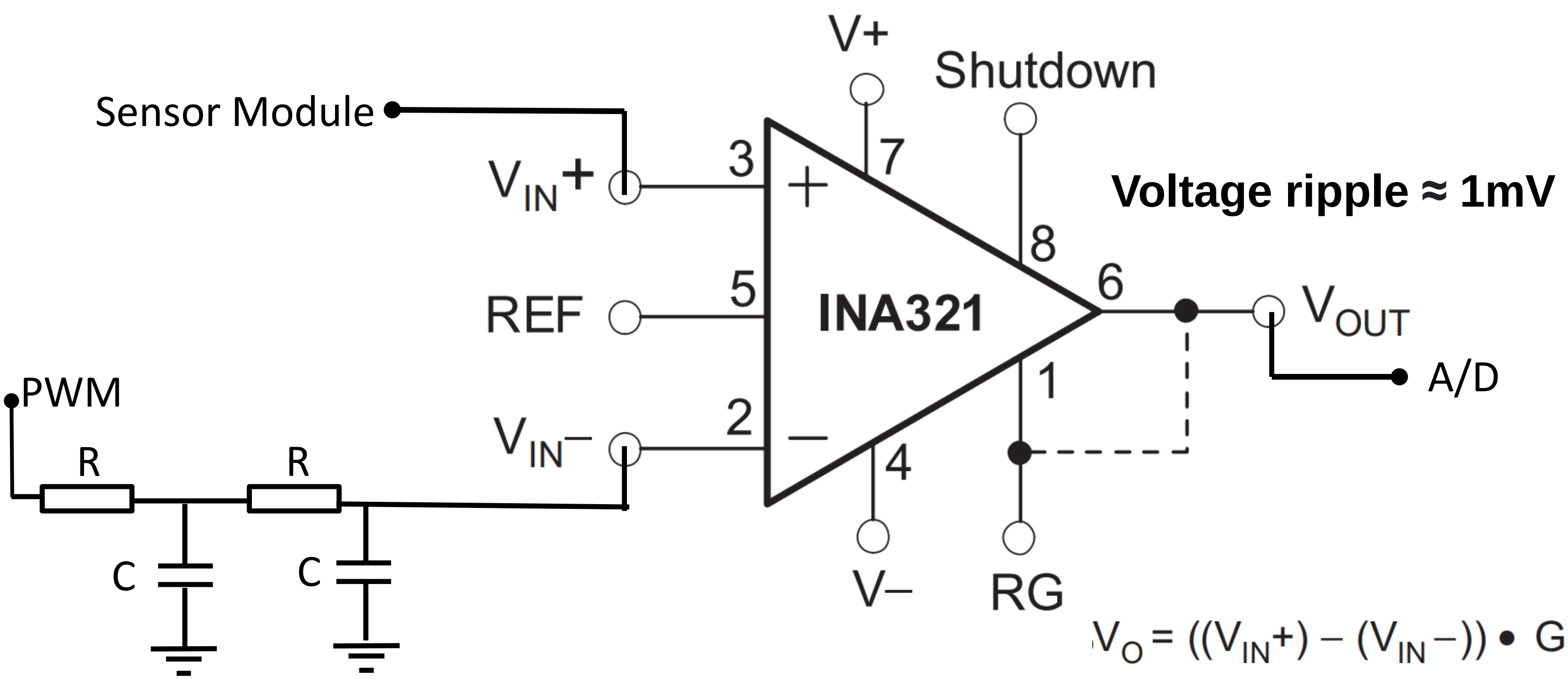




NFC tag: Tag IA

INA321

- Manufacturer: Texas Instruments
- Low quiescent current: 40 μA per channel.
- RAIL-TO-RAIL
- Low offset voltage: 200 μV
- High CMRR: 94 dB
- Supply voltage: 2.7 to 5.5 V



$$V_O = ((V_{IN}+) - (V_{IN}-)) \bullet G$$

NFC tag: Analog circuitry

Buffer and signal conditioning:

- Avoid the source current subtraction
- Thermal compensation
- To reduce the emitter voltage

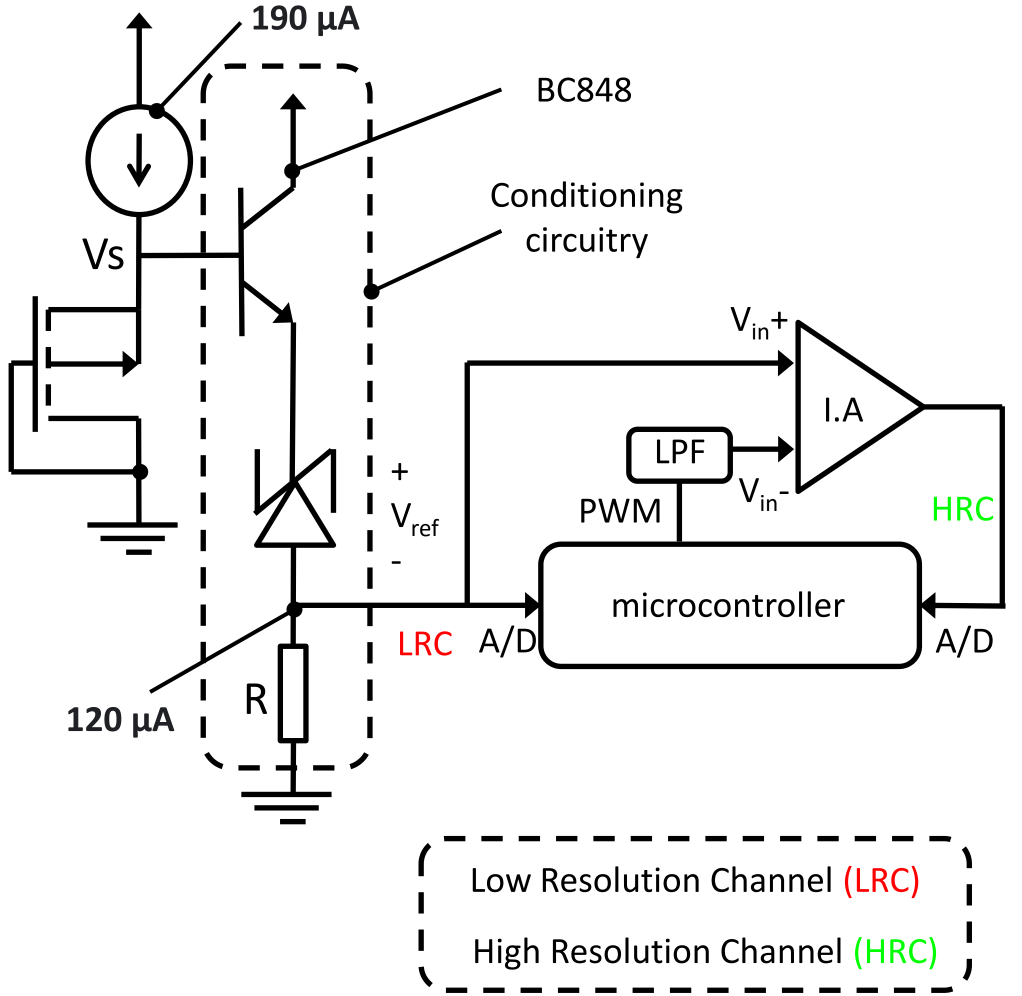
down to the 0.9-1.5 V range.

$$V_{in}^{ADC} = (V_S - V_{BE} - V_{ref})$$

$$\left.\begin{aligned} \Delta V_{in}^{ADC} &= \alpha \Delta T \\ \Delta V_S &= \alpha_S \Delta T \\ \Delta V_{BE} &= \alpha_{BE} \Delta T \end{aligned}\right\}$$

$$\alpha_{LRC} = (\alpha_S - \alpha_{BE})$$

$$\alpha_{HRC} = (\alpha_S - \alpha_{BE}) + \alpha_{IA}/G$$



NFC tag: Analog circuitry

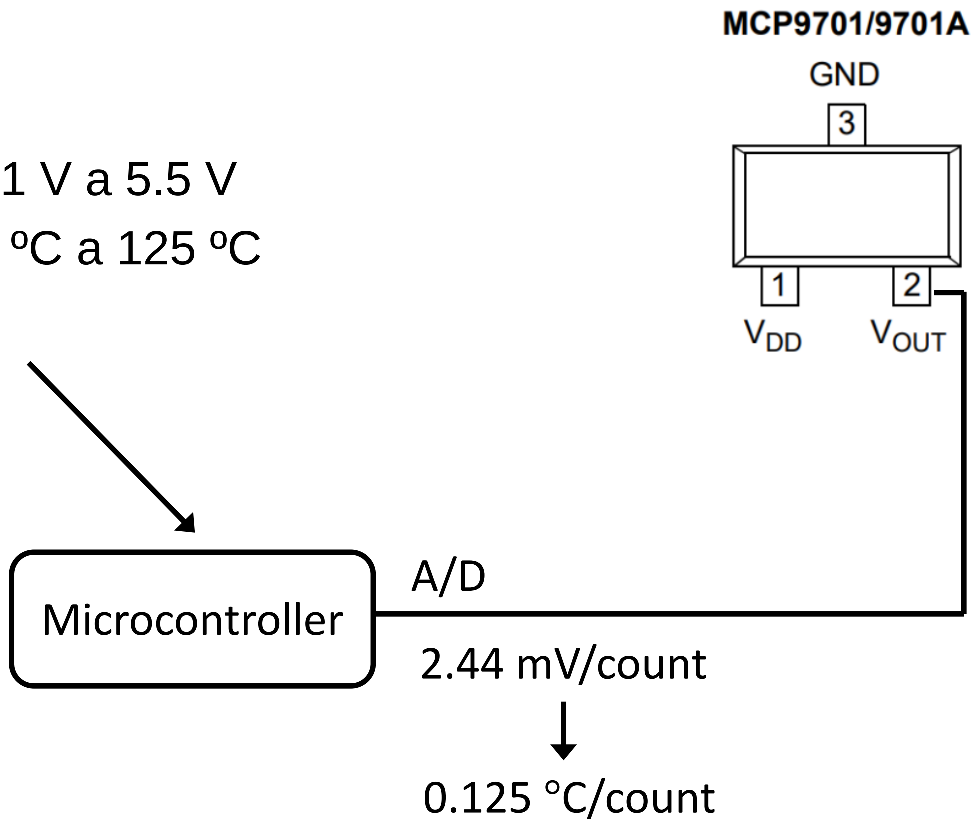
Reduction of thermal drift

	$\alpha_S\ (mV/°C)$	$\alpha\ (mV/°C)$	Reduction (%)
V_S (LRC)	-1.76 ± 0.33	-0.45 ± 0.08	75 %
Amplificated V_S (HRC)	-1.76 ± 0.33	-0.32 ± 0.05	82 %

NFC tag: Temperature sensor

MCP9701A

- Manufacturer: Microchip
- Quiescent current: 6 µA
- Supply voltage range: 3.1 V a 5.5 V
- Temperature range: - 40 ºC a 125 ºC
- Sensitivity: 19.5 mV/ºC



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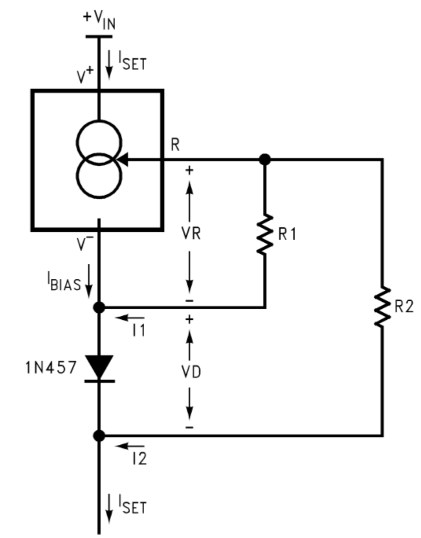
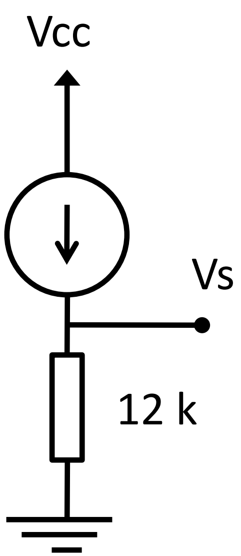
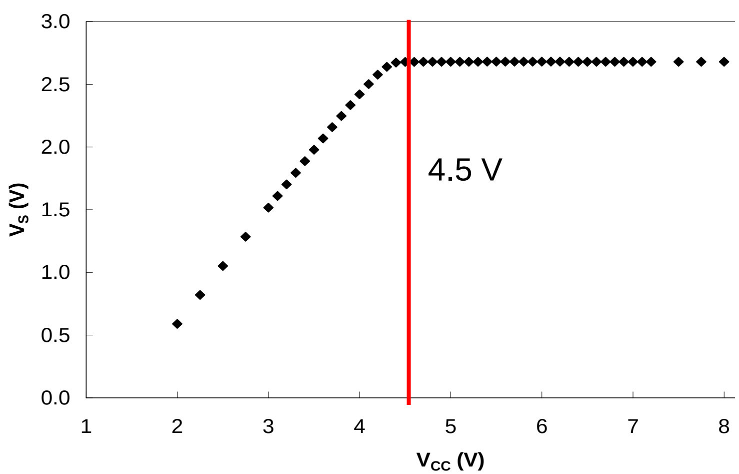
NFC tag: Power management

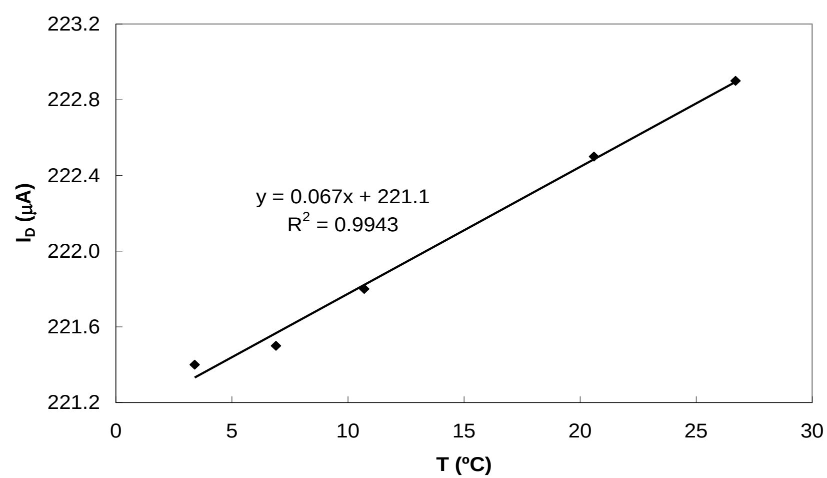
Current source and supply:

- Based on LM334 (Texas Instruments, USA)
- Circuit for thermal compensation suggested by the manufacturer
- Load: Resistor of 12 kΩ, DC source from 2 to 8 V
- Minimum voltage: 4.5 V.
- The voltage regulator does not provide enough voltage
- Use of a DC/DC up converter









NFC tag: Power management

Voltage regulator MCP1824-2502

- Low quiescent current: 120 µA
- Input Operating Voltage Range: 2.1V to 6.0V
- Typical Output Voltage Tolerance: 0.4%

	SOT-23	
Pin	Fixed	Adjustable
1	V_{IN}	V_{IN}
2	GND (TAB)	GND (TAB)
3	$\overline{SHDN}$	$\overline{SHDN}$
4	PWRGD	ADJ
5	V_{OUT}	V_{OUT}
6	—	—

Voltage doubler

- Charge-pump DCDC converter: low quiescent current (600 µA)
- ADM660: Voltage doubler, from 2.5 to 5.0 V

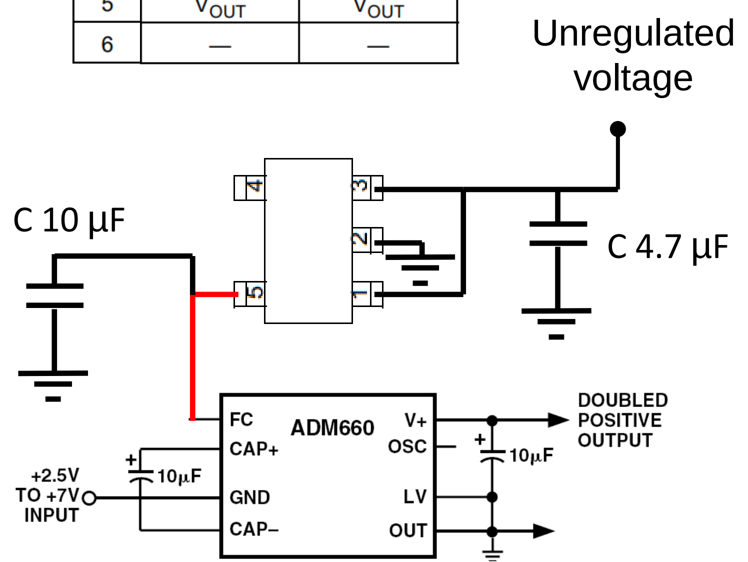
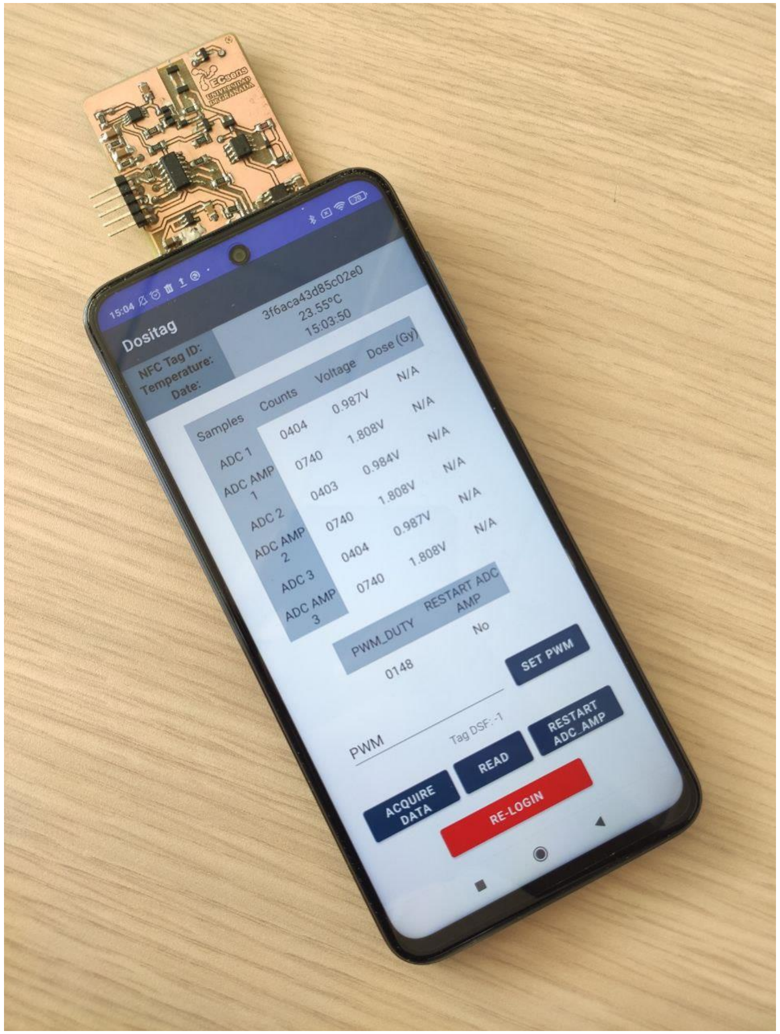


Figure 8. Voltage Doubler Configuration

Android App: Measurement protocol

1. The smartphone is placed on top of the tag

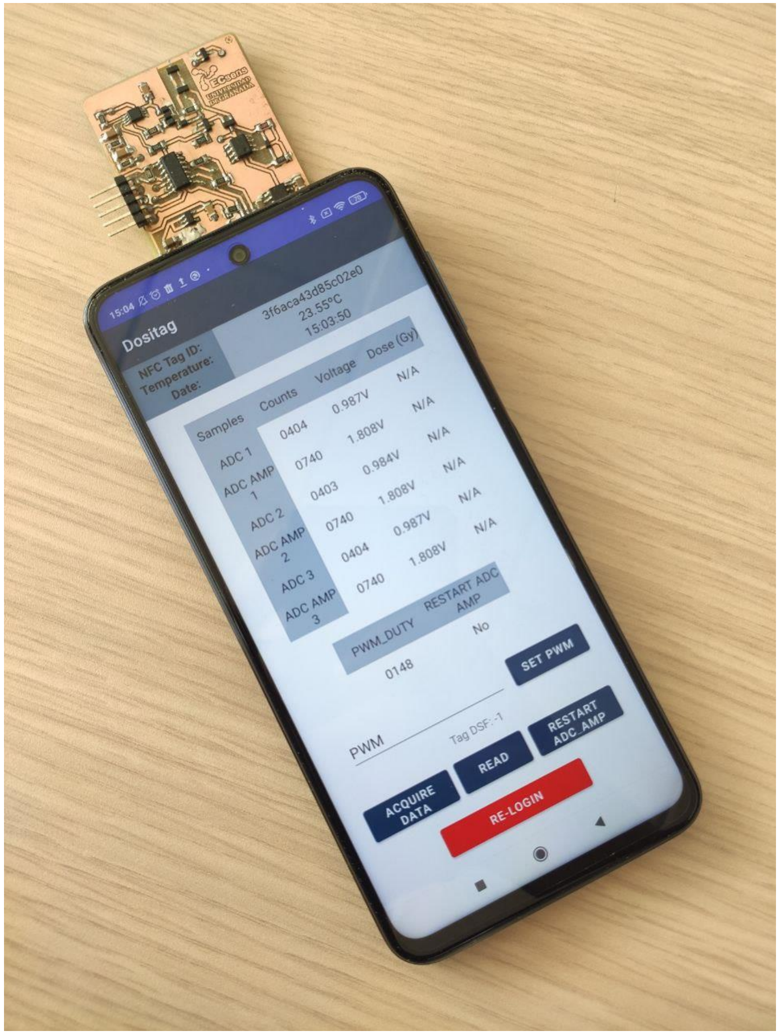


Android App: Measurement protocol

1. The smartphone is placed on top of the tag

↓

2. The system makes the zero. The smartphone is removed



Android App: Measurement protocol

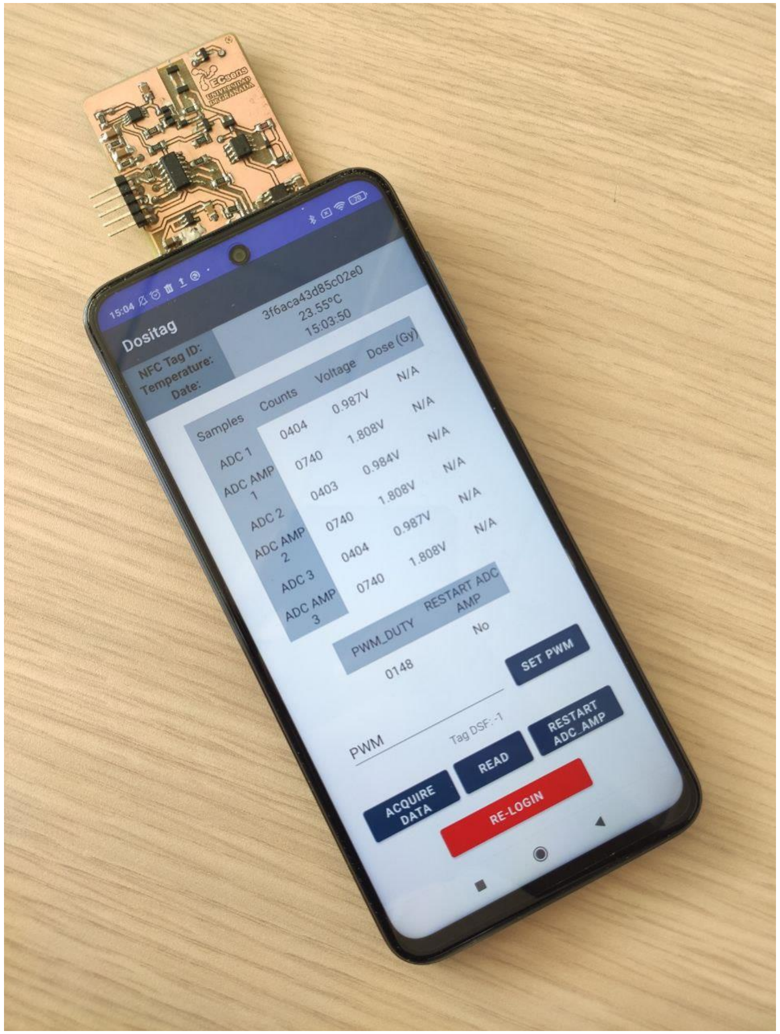
1. The smartphone is placed on top of the tag

↓

2. The system makes the zero. The smartphone is removed

↓

3. The Smartphone is placed again. The system acquires the measurements.



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Android App: Measurement protocol

1. The smartphone is placed on top of the tag

↓

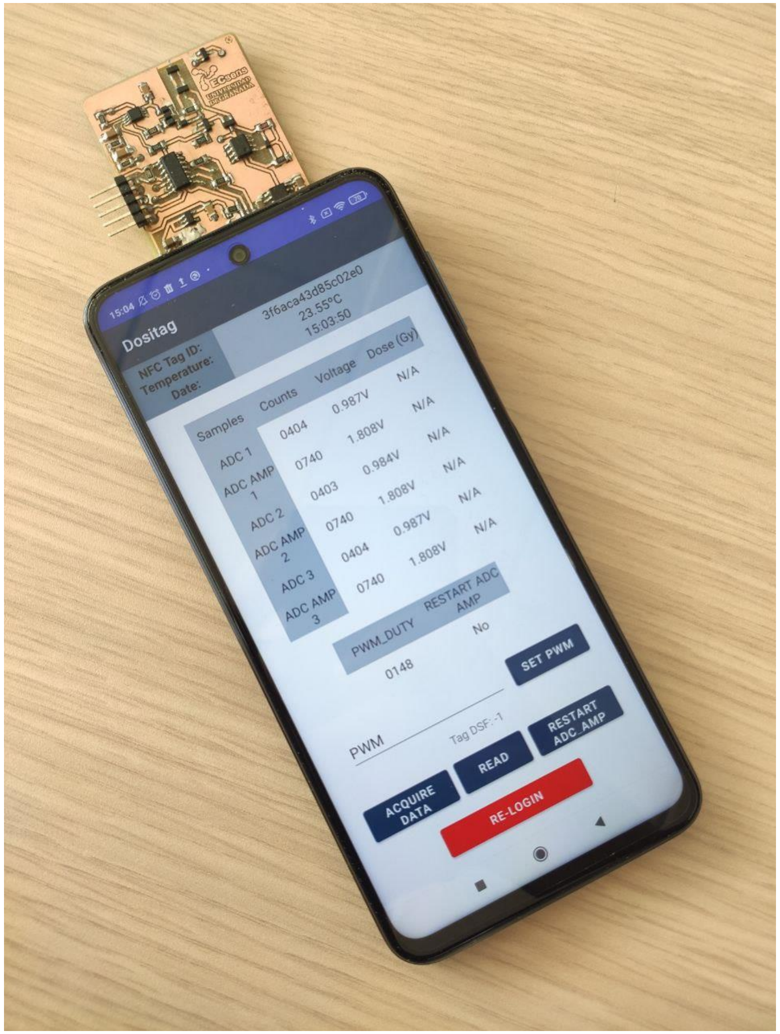
2. The system makes the zero. The smartphone is removed

↓

3. The Smartphone is placed again. The system acquires the measurements

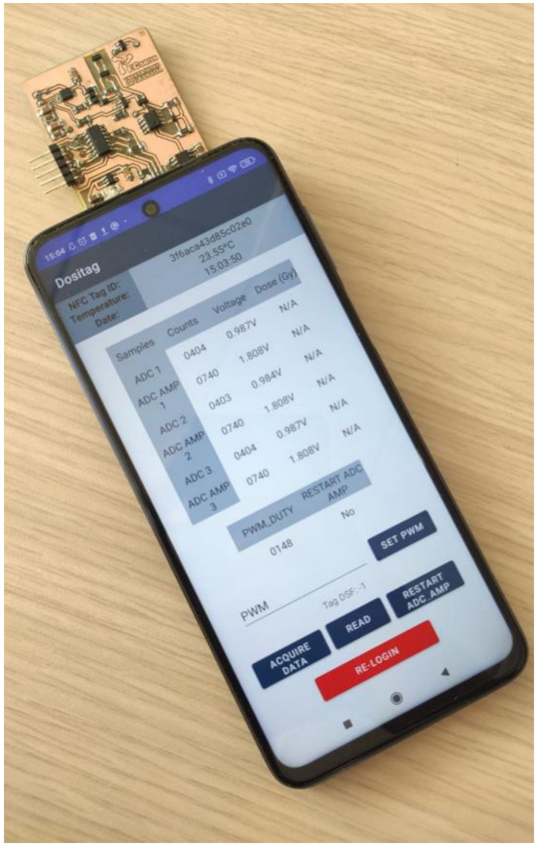
↓

4. Finally, the amplificated and direct voltage shift is presented in the Smartphone



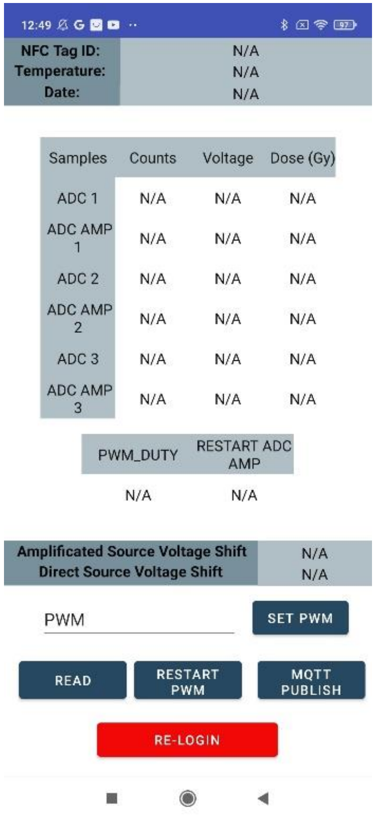
Android App: Measurement protocol

1. The smartphone supplied the tag when it is placed on top of it and the coils are overlapped
2. Zeroing: The tag waits one second for the system to stabilize, and then:
    1. The PWM value is loaded from the EEPROM and set
    2. Direct and amplified Vs voltage are measured
    3. Direct and amplified Vs values are stored in the EEPROM of the NFC chip
    4. The values are read by the Smartphone when the user presses the “READ” button



Android App: Measurement protocol

3. **Dose measurements:** The smartphone is placed over the tag again. The measurement has been started when the tag waits one second
    1. The PWM value is loaded from the EEPROM and set.
    2. The direct and amplified source voltage are measured and stored in the EEPROM of the NFC chip.
    3. The data are read by the smartphone from the NFC chip when the user press “READ” button
    4. The user presses the “RESTART_ADC_AMP” button to reset the PWM to make the zero in the next measure



4. **Data presentation:** The Smartphone presents the current direct and amplified source voltage shift

$$V_{shift} = Vs_{current} - Vs_{zeroing}$$

Dose measurements: Experimental method

Experimental setup:

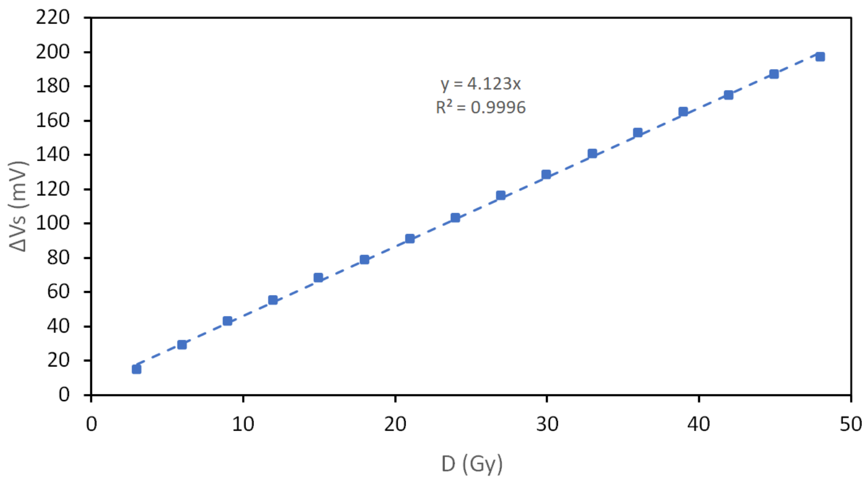
- Two NFC readers are irradiated using a LINAC Siemens Artiste
- Photon beans of 6 MV irradiation field of 20x20 cm^2.
- 1.5 cm of solid water as a buildup layer.
- Sessions of 3 Gy.

Measurement protocol:

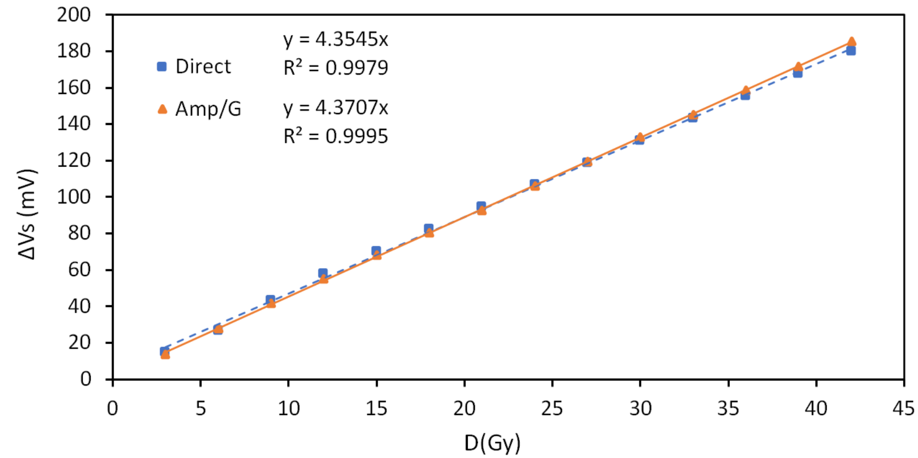
1. The zero was made with NFC reader by resetting the PWM and measure the direct and amplified source voltage
2. The total area of the tag were irradiated (Siemens Artiste)
3. After 3 minutes the source voltage was measured again
4. The voltage shift was calculated
5. Finally, the PWM is restarted and repeat the process every 15 minutes

Results

DosiTag 1



DosiTag 2



	Sensitivity (mV/Gy)		Total dose (Gy)	Resolution (cGy)
	LRC	HRC		
DosiTag 1	4.12 ± 0.02	-	57	79
DosiTag 2	4.35 ± 0.17	4.37 ± 0.04	42	2

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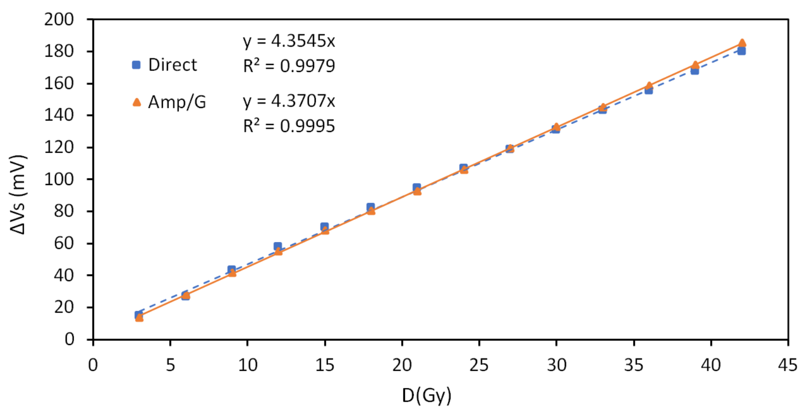
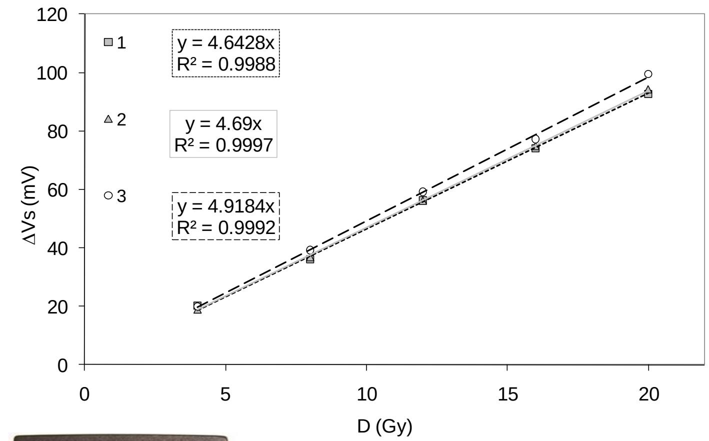
Electronic and Chemical sensing solutions

Previous work

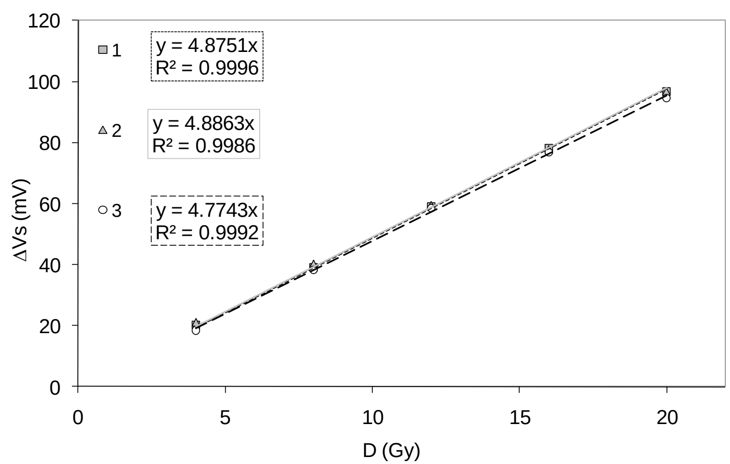
NFC Tag



Previous NFC Tag

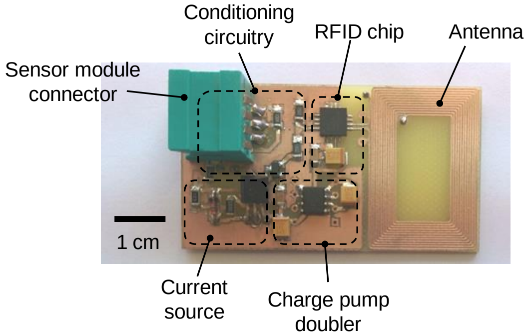


Desk reader



	Sensitivity (mV/Gy)
NFC Tag	4.37 ± 0.04
Previous NFC Tag	4.64 ± 0.15
Desk reader	4.85 ± 0.07

Improvements over the previous work



Feature	Previous NFC dosimeter	DosiTag	Improvement/novelty
Circuit architecture	Only NFC chip	MCU + NFC chip	Inclusion of MCU allows the full control of the measurement variables (time, start/end, etc.)
NFC chip model	SL13A (AMS)	M24LR64E (STMicroelectronics)	The SL13A chip is a discontinued device
Sensitivity	(4.75 ± 0.15) mV/Gy	(4.37 ± 0.04) mV/Gy	Although average sensitivity has slightly been reduced, its associated uncertainty has been significantly reduced
Resolution	17 cGy	2 cGy	Resolution has improved by a factor of 8
Total dose	20 Gy	42 Gy	Total irradiation dose has been increased
Smartphone	Rooting required	No need to root	No root access is needed in the smartphone
Smartphone app	Designed for Android 5.1	Designed for Android 10	Smartphone app has been redesigned and improved. Higher Android versions are supported
IoT capabilities	No IoT implemented	Cloud service (based on MQTT protocol)	Integration with IoT allows classification, distribution and storage of patient's data
Irradiation area	Only sensor module	Whole tag	New version allows the irradiation of the complete dosimeter tag, not only the sensor module
Tag encapsulation	Not possible	Possible	Previous sensor connector made tag encapsulation impossible to be sterilized or submerged in liquids
Holder structure	Ad-hoc wood structure	No structure/holder is required	Previous version required a holder structure to ensure adequate and repeatable energy harvesting

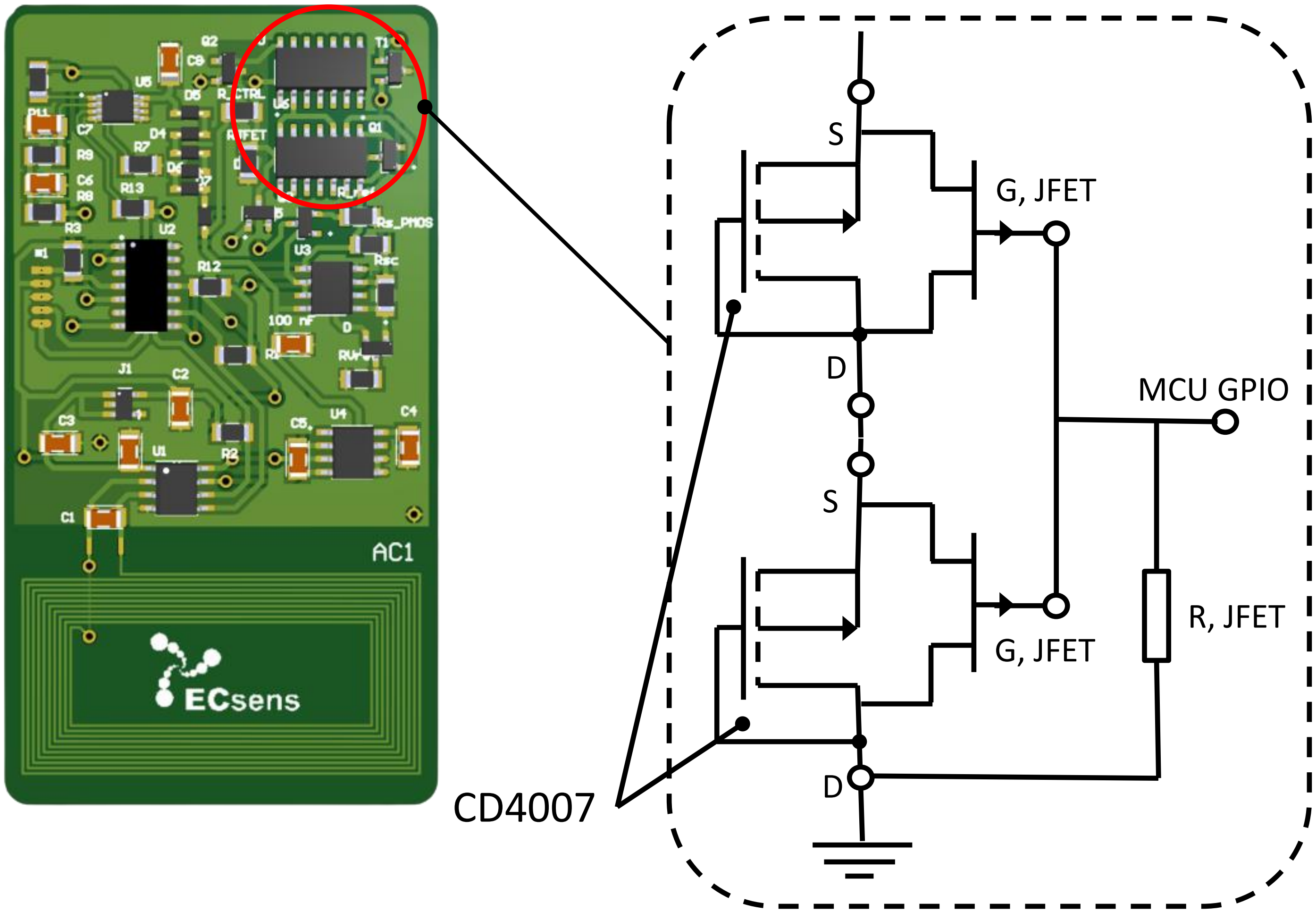
Costs

Component	Encapsulation	Manufacturer	Distributor	Ud	Price
PIC16LF1703	SOIC-14	Microchip	RS Components	1	1.521 €
M24LR64E	SOIC-8	ST Microelectronics	RS Components	1	0.929 €
ADM660	SOIC-8	Analog Devices	RS Components	1	6.35 €
LM334M	SOIC-8	Texas Instruments	RS Components	1	1.467 €
1N4148	SOD-123	Vishay	RS Components	5	0.13 €
BC848C	SOT-23	Diodes Zetex	RS Components	1	0.125 €
LM385	SOT-23	Texas Instruments	RS Components	1	1.604 €
ZVP3306FTA	SOT-23	Diodes Incorporated	Mouser	1	0.73 €
J177	SOT-23	Onsemi	Mouser	1	0.43 €
MCP1824T-2.5 V	SOT23	Microchip	RS Components	1	0.536 €
Condensadores	SMD(1,10uF)	KEMET, Samsung	RS Components	4, 2	0.953, 0.582 €
Resistencias	SMD 1206	-	RS Components	13	0.15 €
INA321	VSSOP-8	Texas Instruments	Mouser	1	2.93 €
Condensadores	SMD (3 pF, 100nF)	KYOCERA, KEMET	RS Components	1, 1	0.128, 0.176 €
MCP9700	SOT-23	Microchip	Mouser	1	0.371 €
TOTAL	-	-	-		**24.87 €**

ECsens Electronic and Chemical sensing solutions

In development

Sensor module

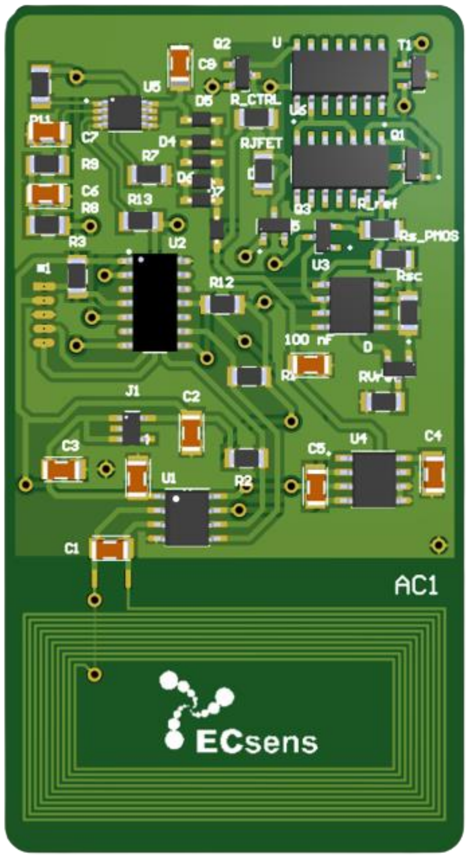


Sensitivity of each pMOS:
(5.27 ± 0.07) mV/Gy

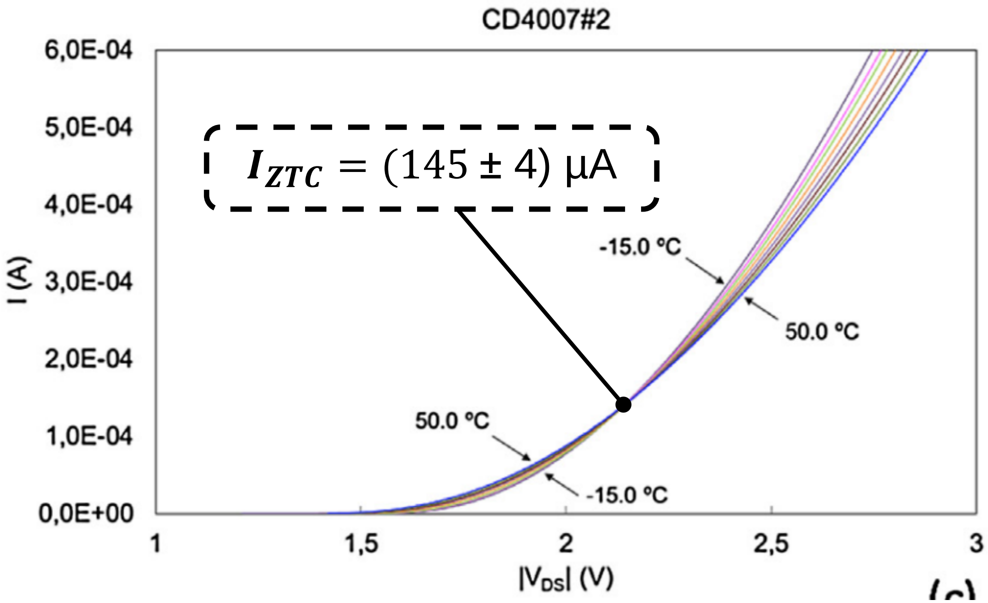
Different chips:
Avoid the body effect

ECsens
Electronic and Chemical sensing solutions

In development

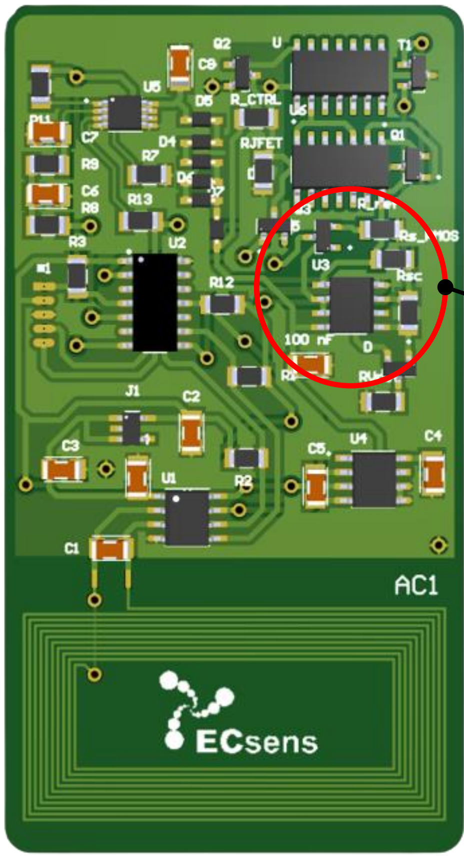


Thermal compensation CD4007

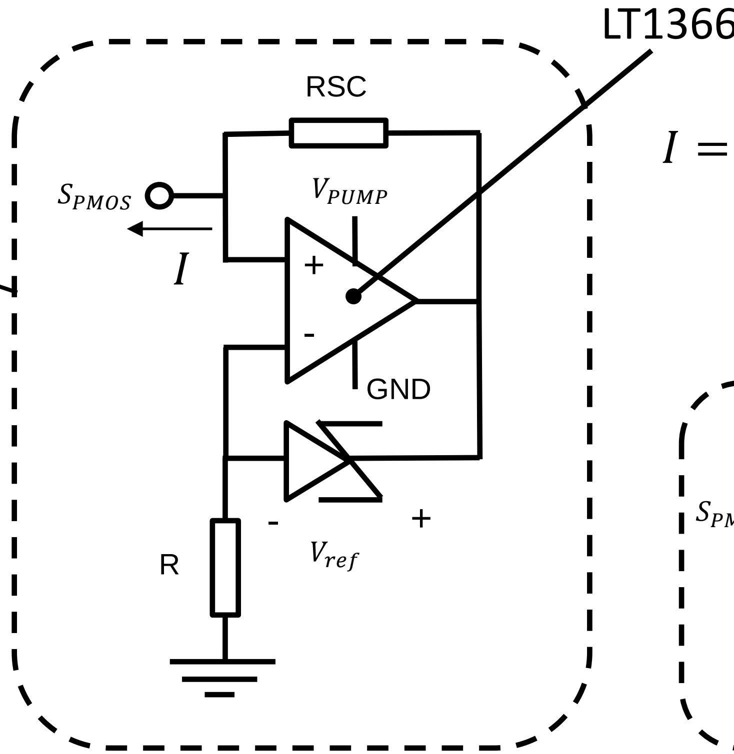


- Easier thermal compensation
- No additional devices are required

In development

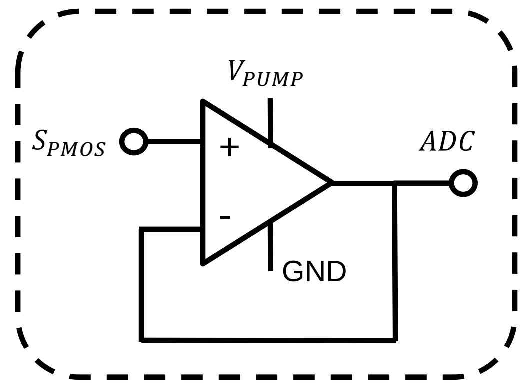


Current source



$$I = \frac{V_{ref}}{RSC}$$

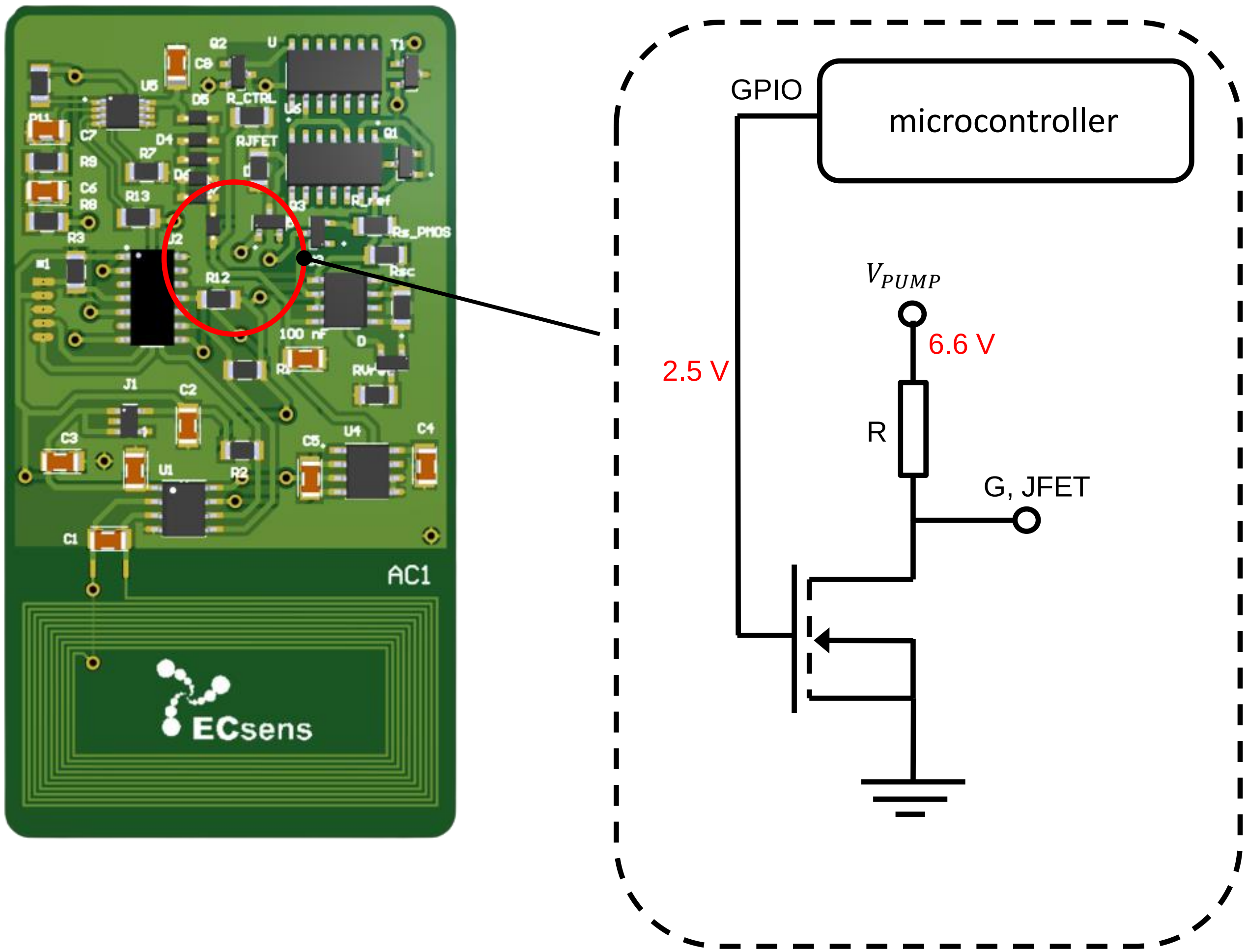
Voltage follower



- Avoid the current subtraction of the PMOS source

In development

JFET gate control



- The microcontroller performs multiple measurements
- No smartphone root is required

Conclusions

- The NFC reader topology is suitable for dose measurements
- The inclusion of the Internet of Things (IoT) facilitates the classification and storage of the data
- A very good inductive coupling is necessary to harvest enough energy
- Higher resolution than the previous NFC reader is achieved (17 cGy vs. 2 cGy).
- The whole tag was irradiated
- The system is still accurate after high doses of radiation, so it can have several uses
- Very good linearity is shown.
- A good sensitivity of (4.37 ± 0.04) mV/Gy is shown

Current and future tasks

- Test and validate the new design with the CD4007 pMOS transistor
- Laminate the card
- System construction in a flexible substrate
- Improve the database for storing the measurements

References

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Thank for your attention!!