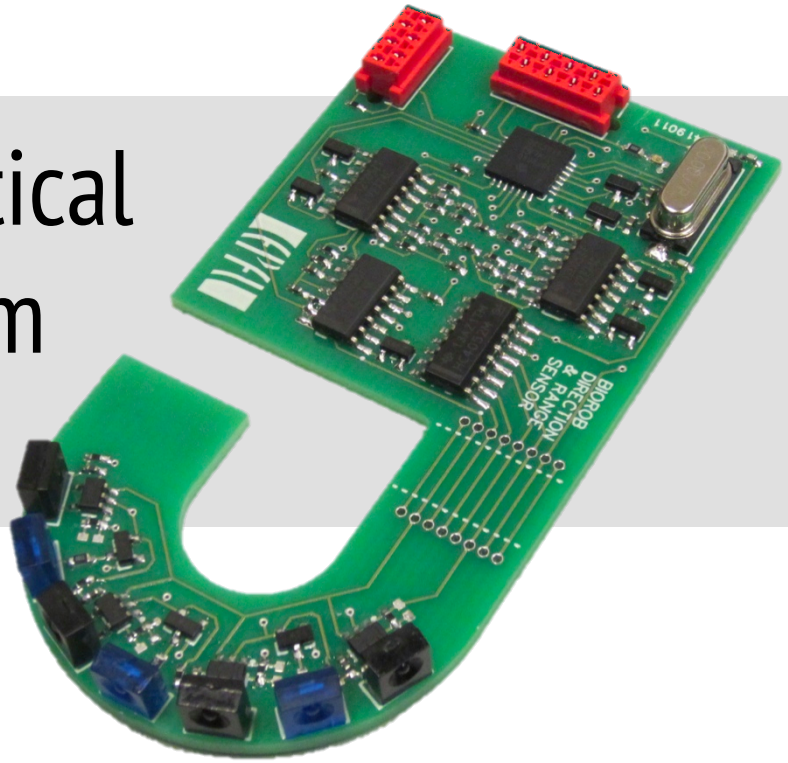
BIOROB
EPFL Biorobotics Laboratory

Design of an Infrared / Optical Relative Positioning System for Mobile Robots



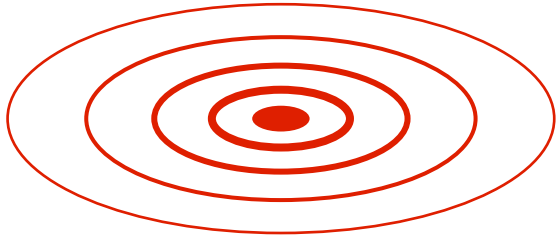
Semester Project

Raphael Cherney

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

GOALS

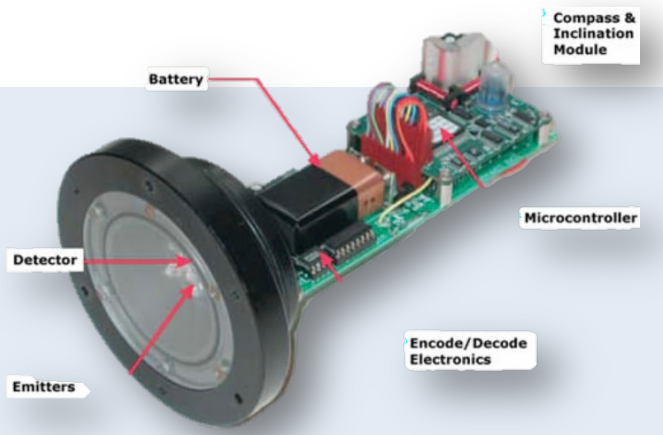
- Design a system that uses modulated IR or optical signals to determine the distance and direction to a modulated transmitter
  - Works in different lighting conditions
  - Visible light could provide better performance in water
- Decode low bandwidth data sent over the optical channel (e.g. 8 bit ID)
- Study the possibility of using the same sensor for obstacle sensing (by adding some transmitter at its side)



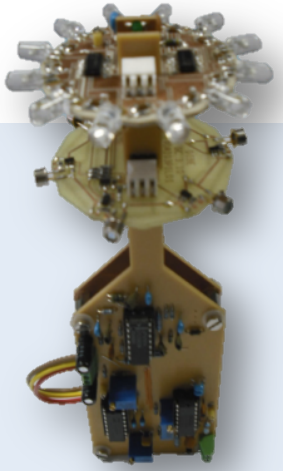
Photograph by A. Crespi

STATE OF THE ART

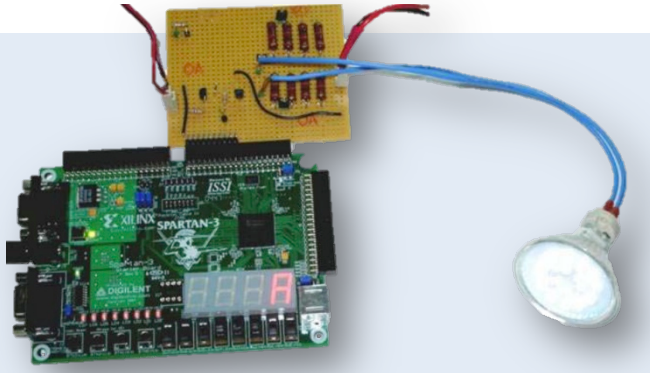
UNDERWATER



Tivey, 2004; WHOI

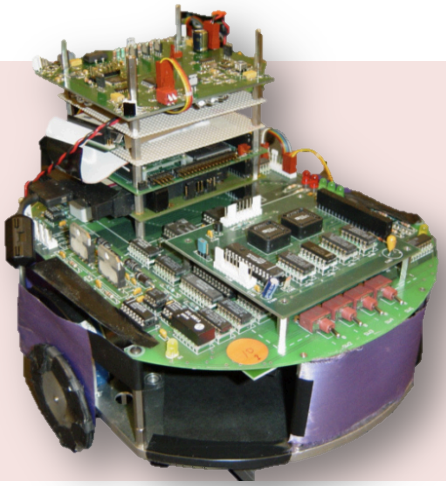


Anguita, 2010; Genova

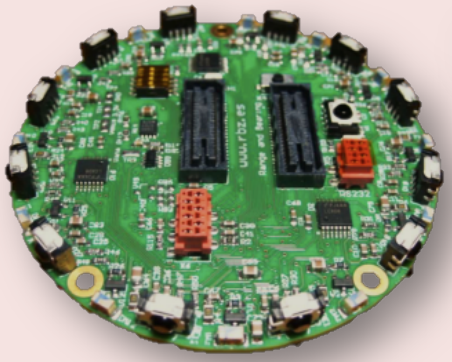


Hernandez, 2006; CEDINT

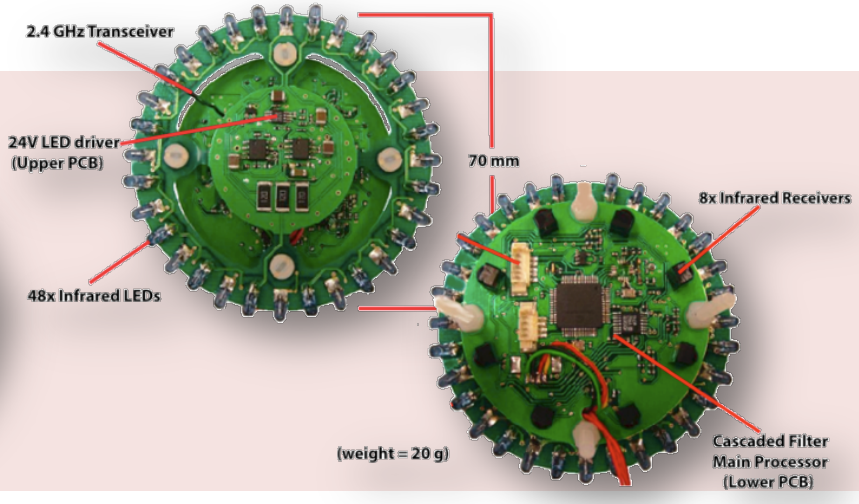
MOBILE ROBOTS



Kelly, 2004; USC



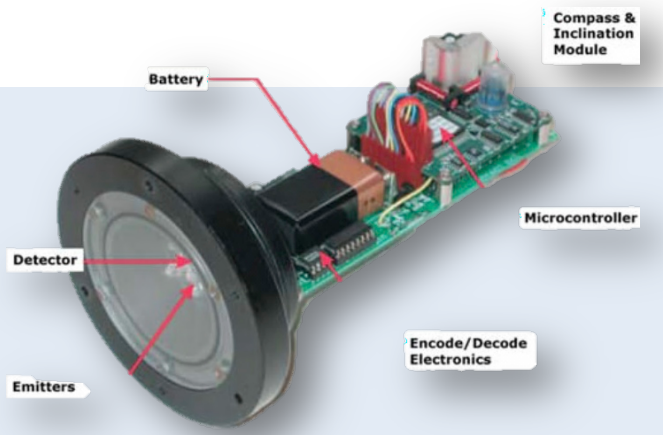
Gutiérrez, 2008; ETSI



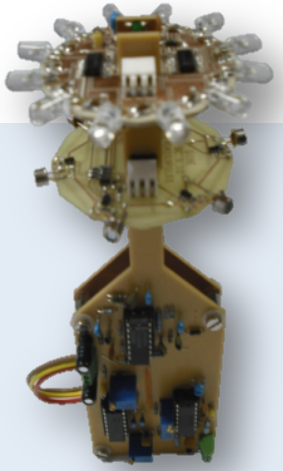
Roberts, 2009; EPFL

STATE OF THE ART

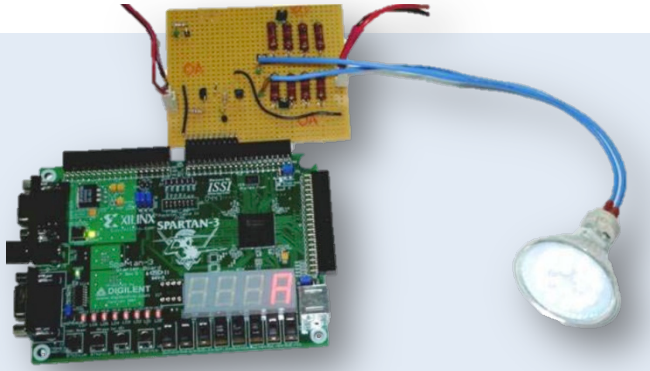
UNDERWATER



Tivey, 2004; WHOI

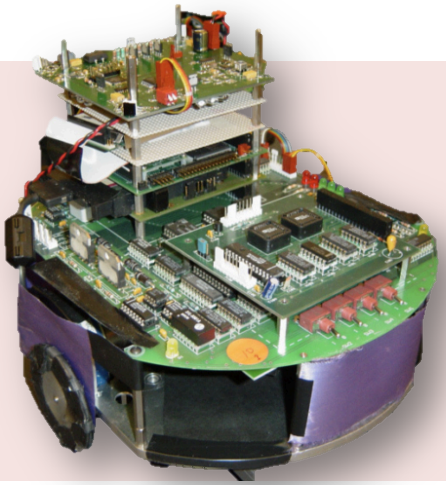


Anguita, 2010; Genova

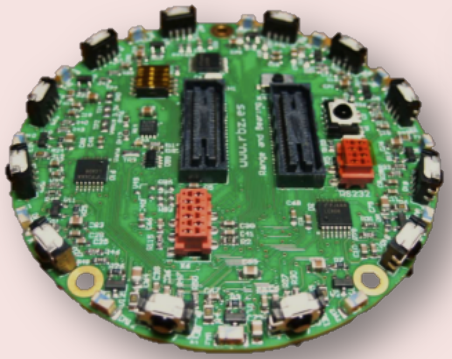


Hernandez, 2006; CEDINT

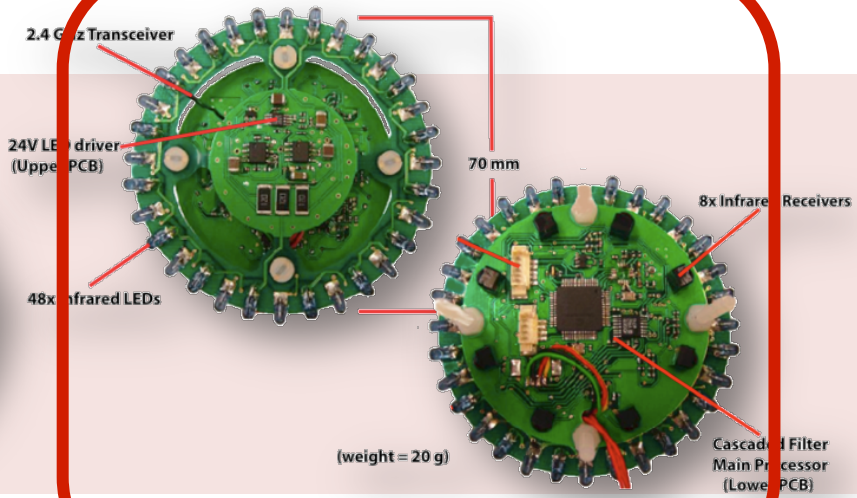
MOBILE ROBOTS



Kelly, 2004; USC



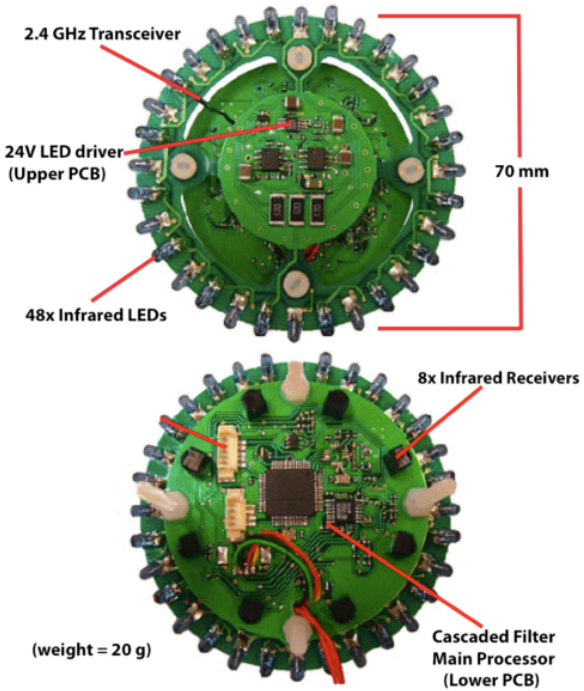
Gutiérrez, 2008; ETSI



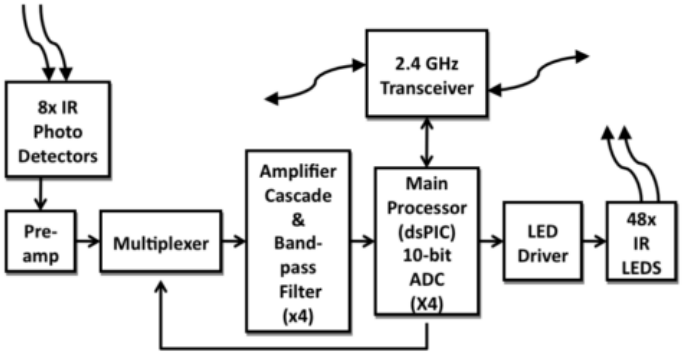
Roberts, 2009; EPFL

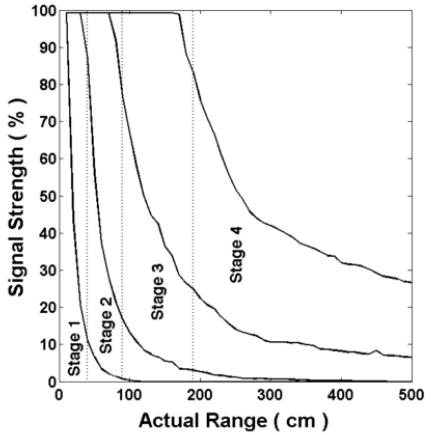
STATE OF THE ART

Range and Bearing Infrared Transceiver (RABIT)



- Good range (similar constraints)
- Novel cascaded filter/amplifier chain



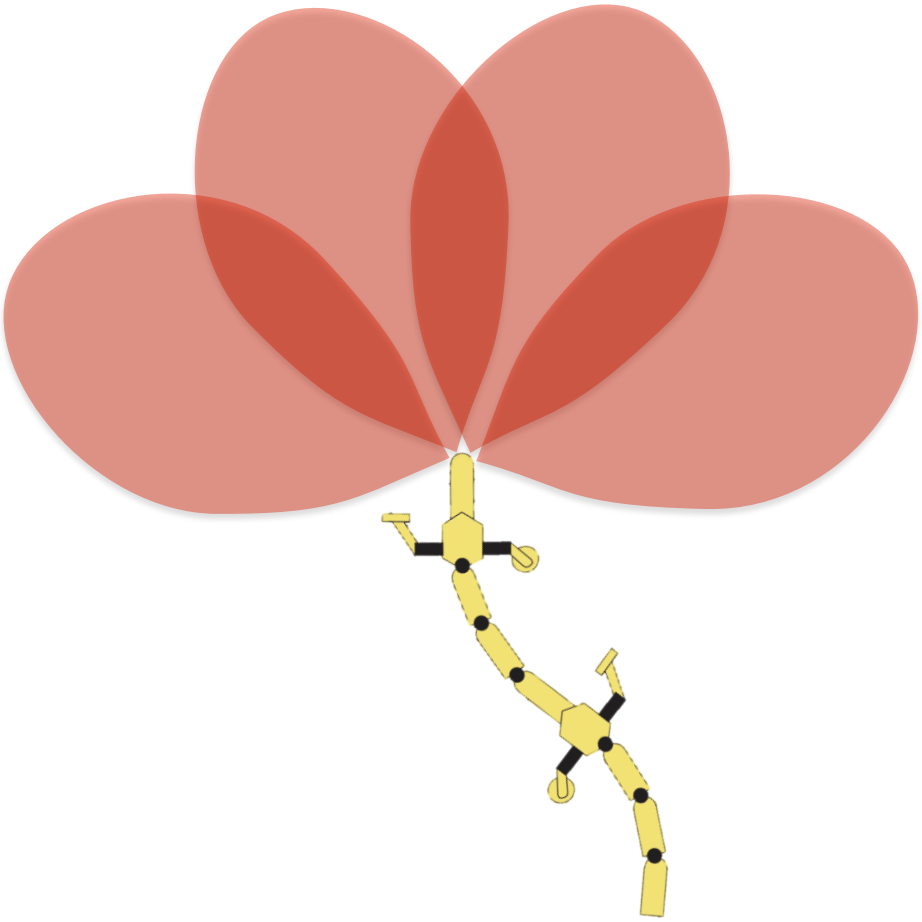


- Too large
- Communication done through radio

Roberts, James et. al. *2.5D Infrared Range and Bearing System for Collective Robotics*. 2009.

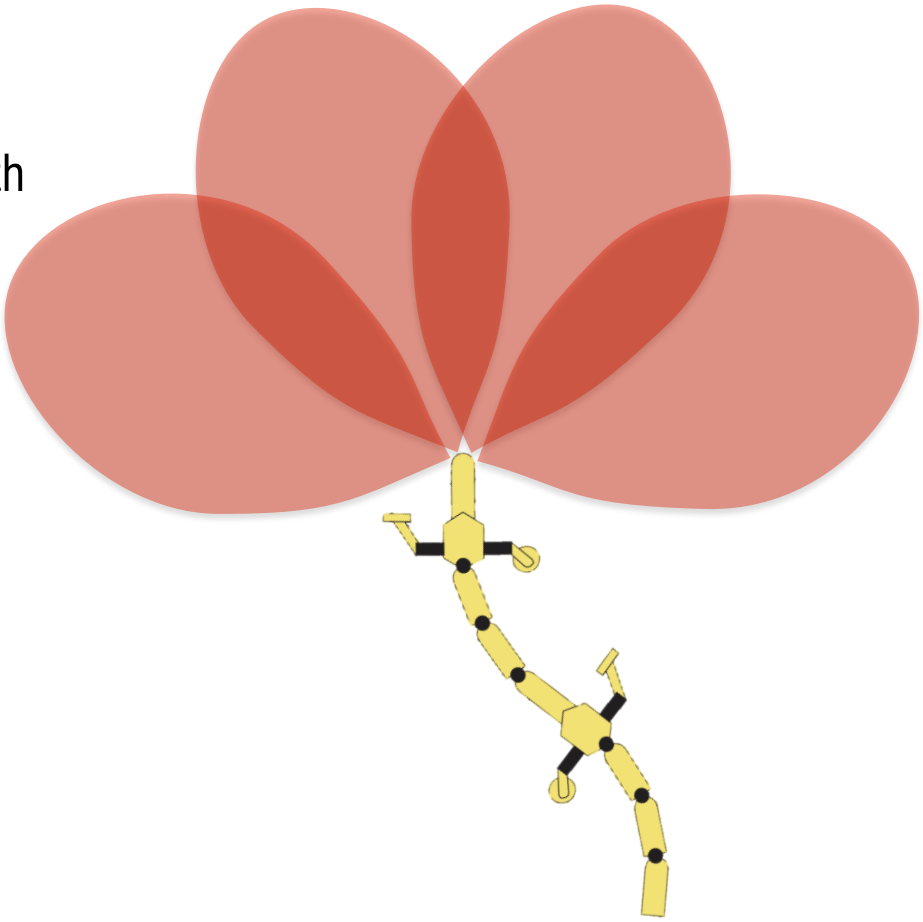
DESIGN

- Detector array



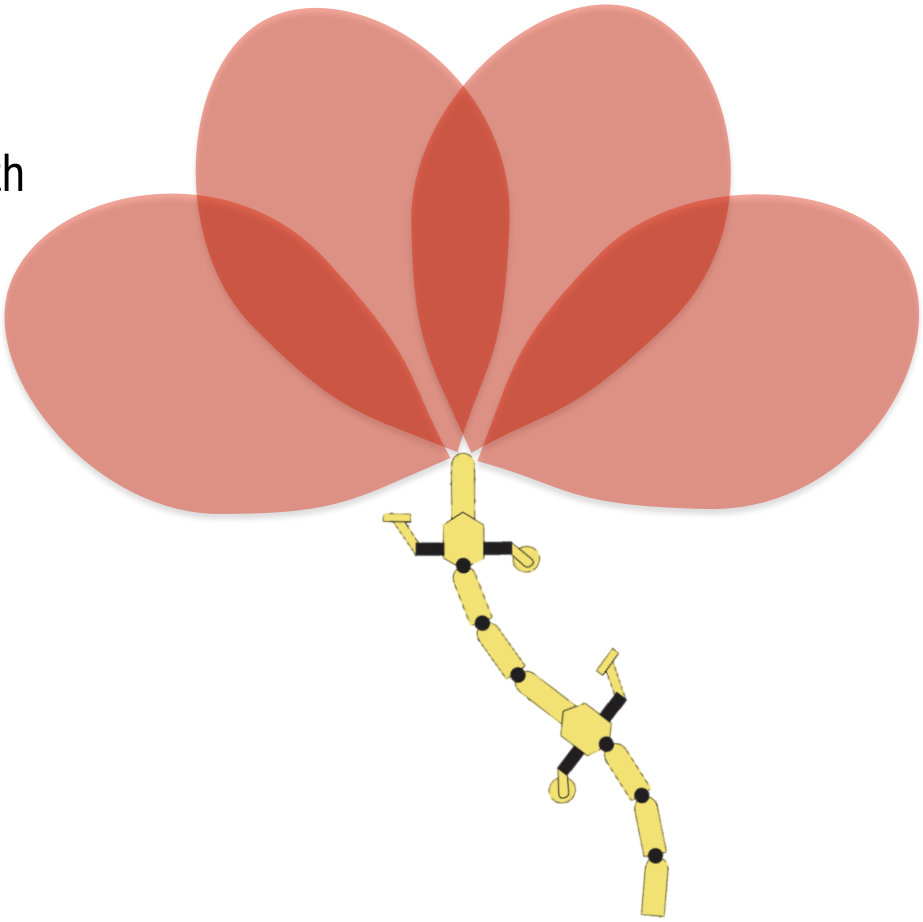
DESIGN

- Detector array
  - Direction determined based on sensor positions with strong signals
  - Distance estimated from signal strength



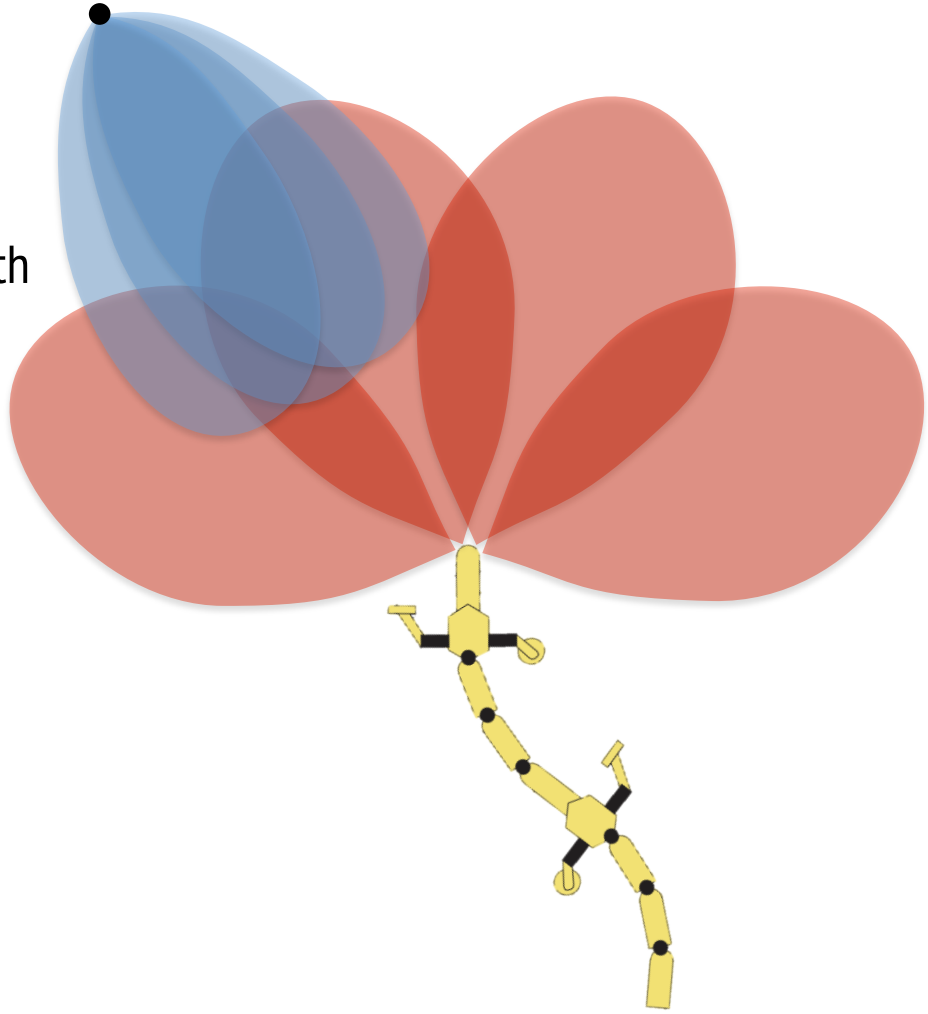
DESIGN

- Detector array
  - Direction determined based on sensor positions with strong signals
  - Distance estimated from signal strength
- Modulated signals (10 kHz carrier)



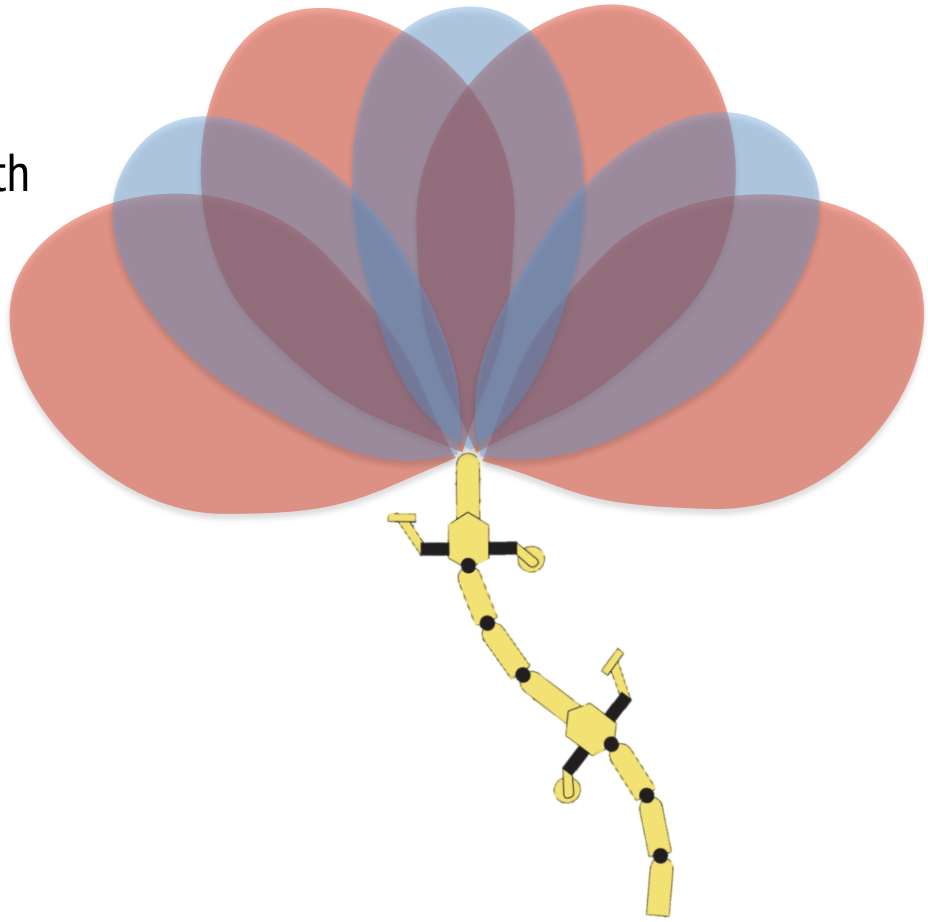
DESIGN

- Detector array
  - Direction determined based on sensor positions with strong signals
  - Distance estimated from signal strength
- Modulated signals (10 kHz carrier)
  - Active beacon



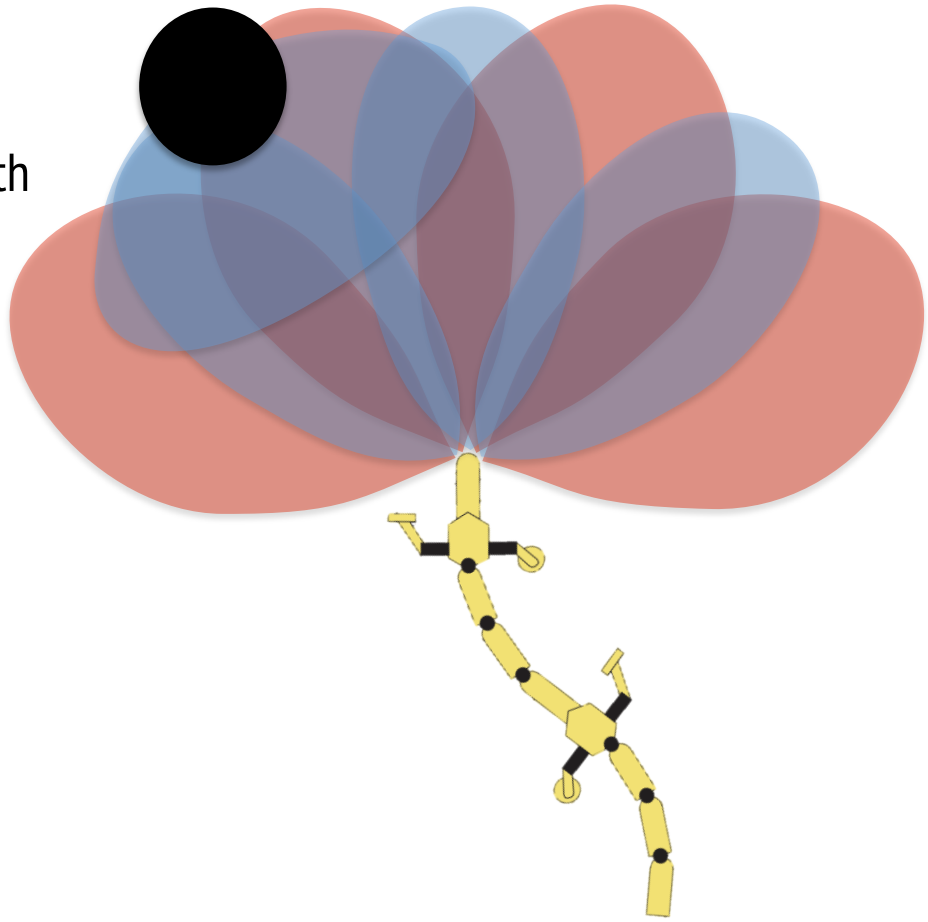
DESIGN

- Detector array
  - Direction determined based on sensor positions with strong signals
  - Distance estimated from signal strength
- Modulated signals (10 kHz carrier)
  - Active beacon
  - Onboard transmitter



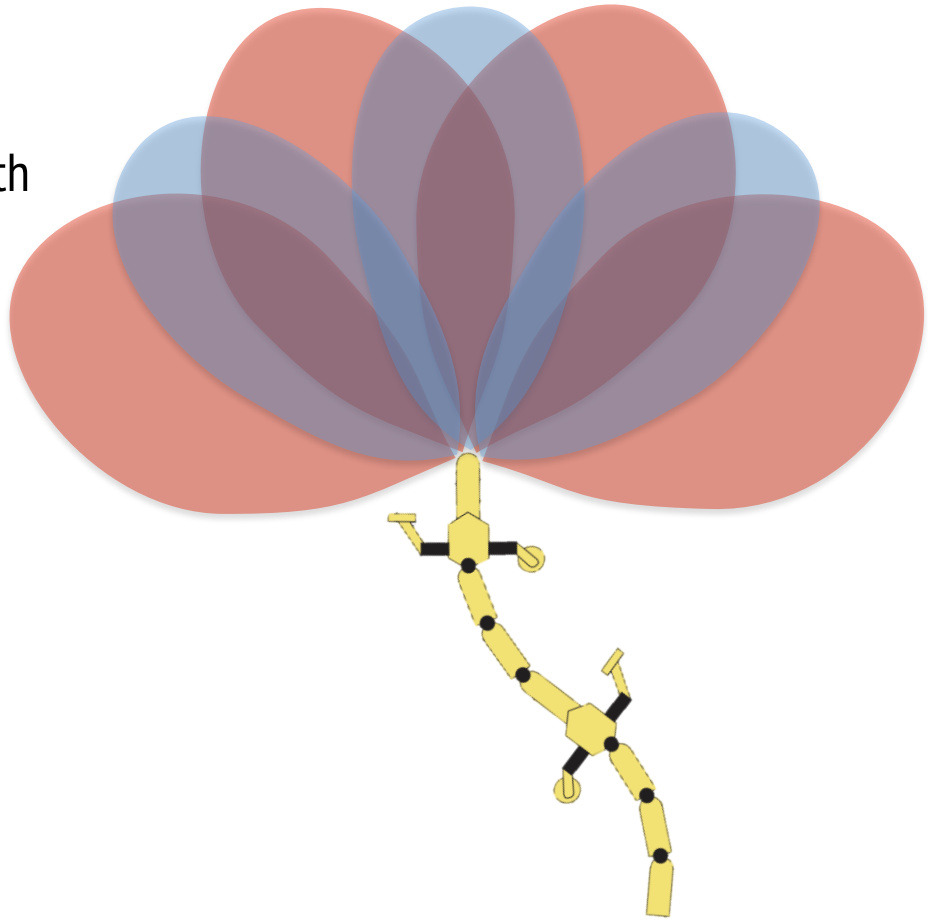
DESIGN

- Detector array
  - Direction determined based on sensor positions with strong signals
  - Distance estimated from signal strength
- Modulated signals (10 kHz carrier)
  - Active beacon
  - Onboard transmitter



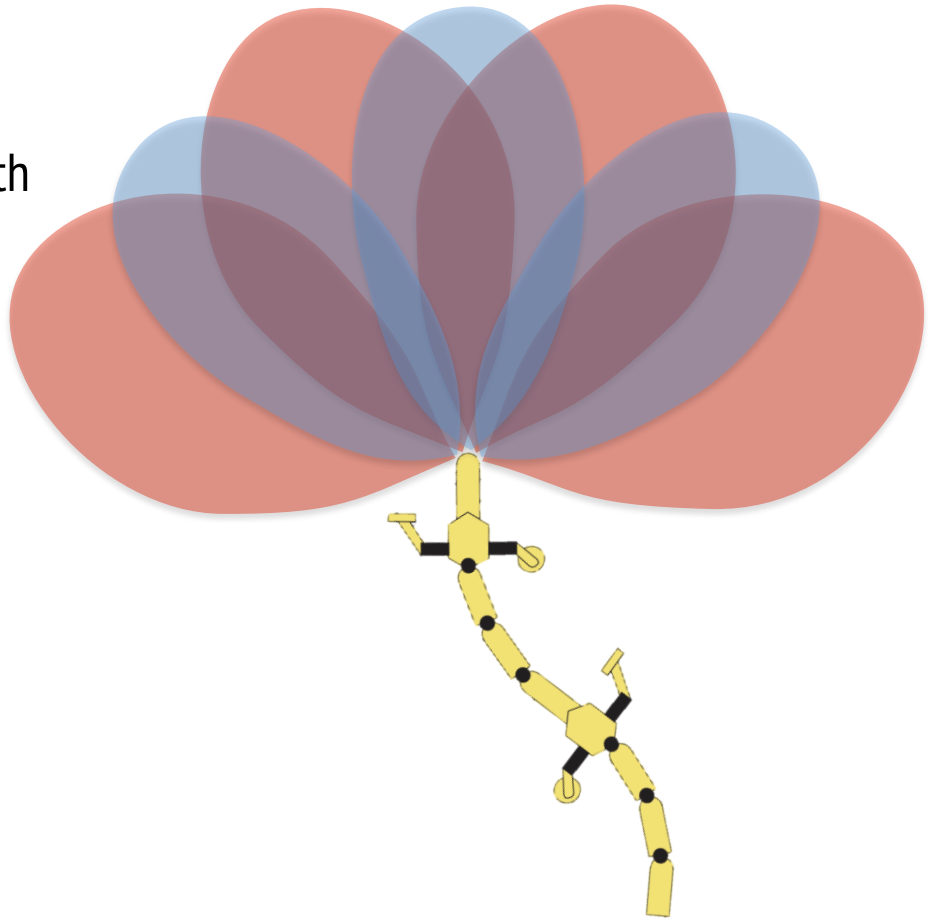
DESIGN

- Detector array
  - Direction determined based on sensor positions with strong signals
  - Distance estimated from signal strength
- Modulated signals (10 kHz carrier)
  - Active beacon
  - Onboard transmitter
- Transmit data over optical channel (PWM, PPM, OOK)



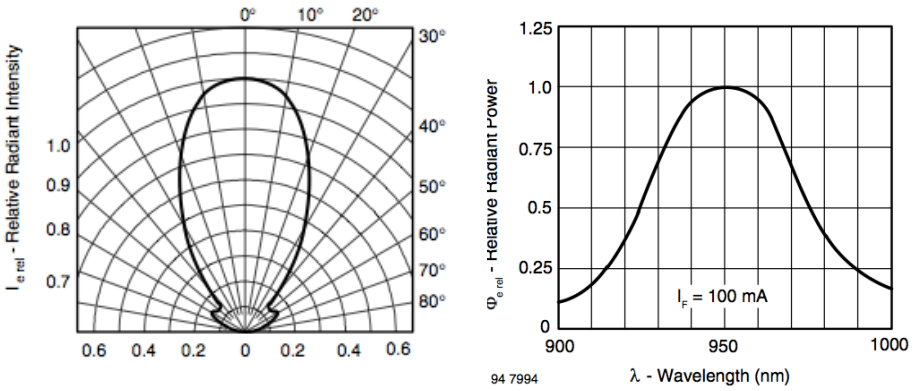
DESIGN

- Detector array
  - Direction determined based on sensor positions with strong signals
  - Distance estimated from signal strength
- Modulated signals (10 kHz carrier)
  - Active beacon
  - Onboard transmitter
- Transmit data over optical channel (PWM, PPM, OOK)
- Works with visible or infrared light (depending on transmitter and detector choice)



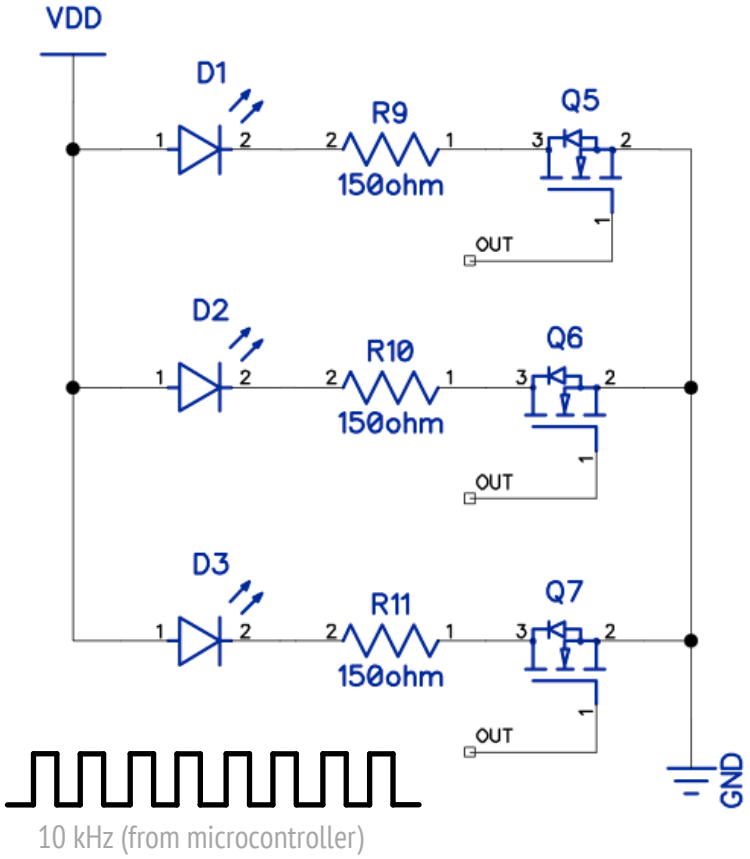
TRANSMITTER (onboard)

- Modulated 10 kHz carrier
- Uses TSKS5400 infrared emitting diode:



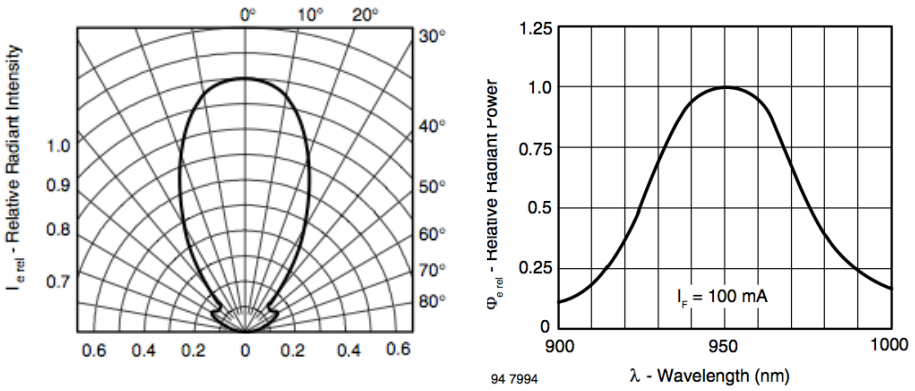
- Can be easily modified to allow for other transmitters (including visible LEDs)

Transmitter Array



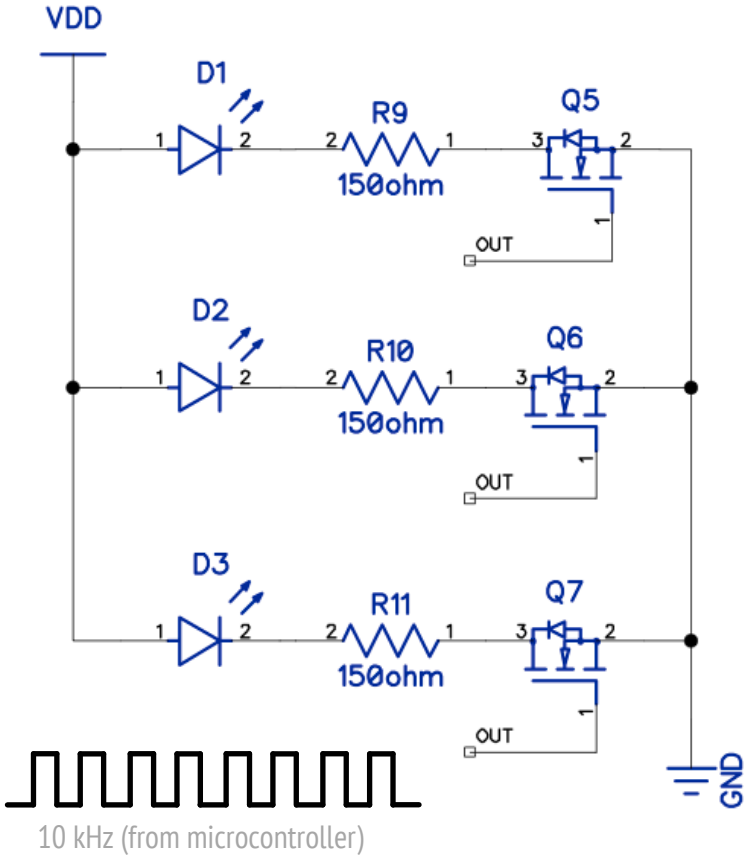
TRANSMITTER (onboard)

- Modulated 10 kHz carrier
- Uses TSKS5400 infrared emitting diode:



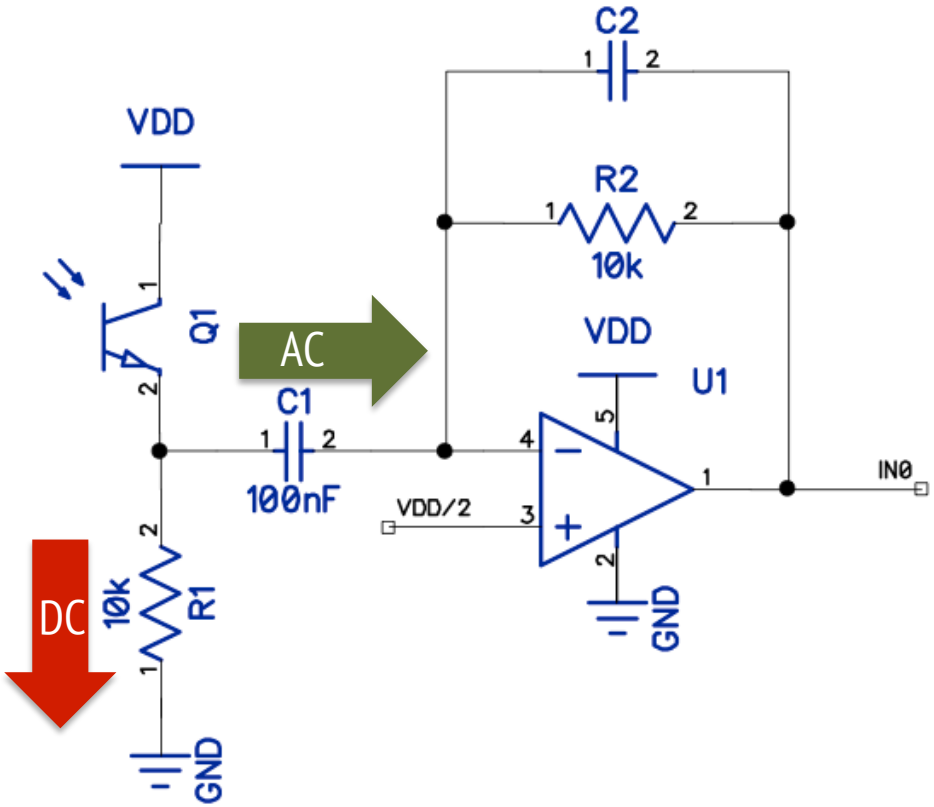
- Can be easily modified to allow for other transmitters (including visible LEDs)

Transmitter Array

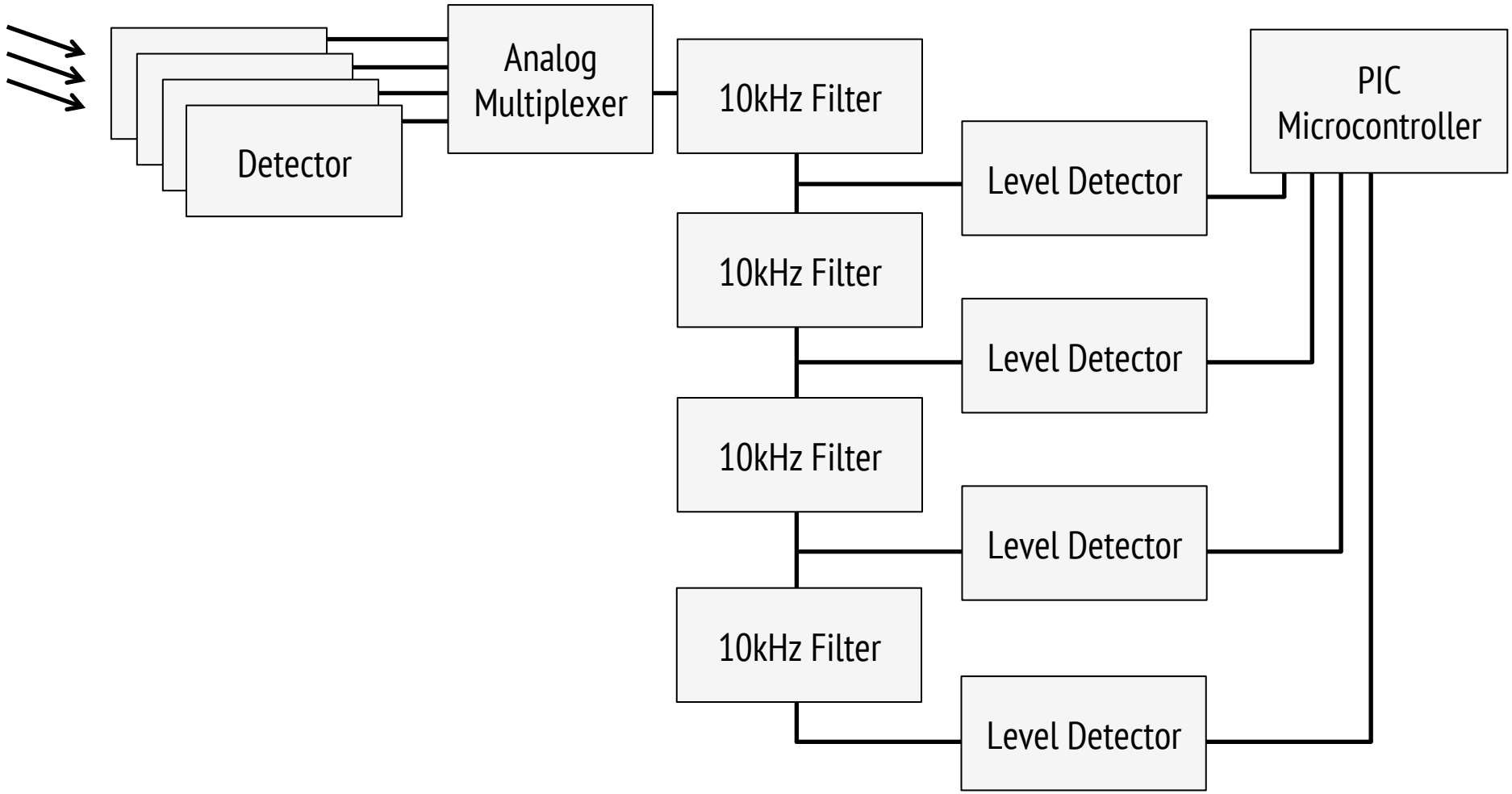


DETECTOR

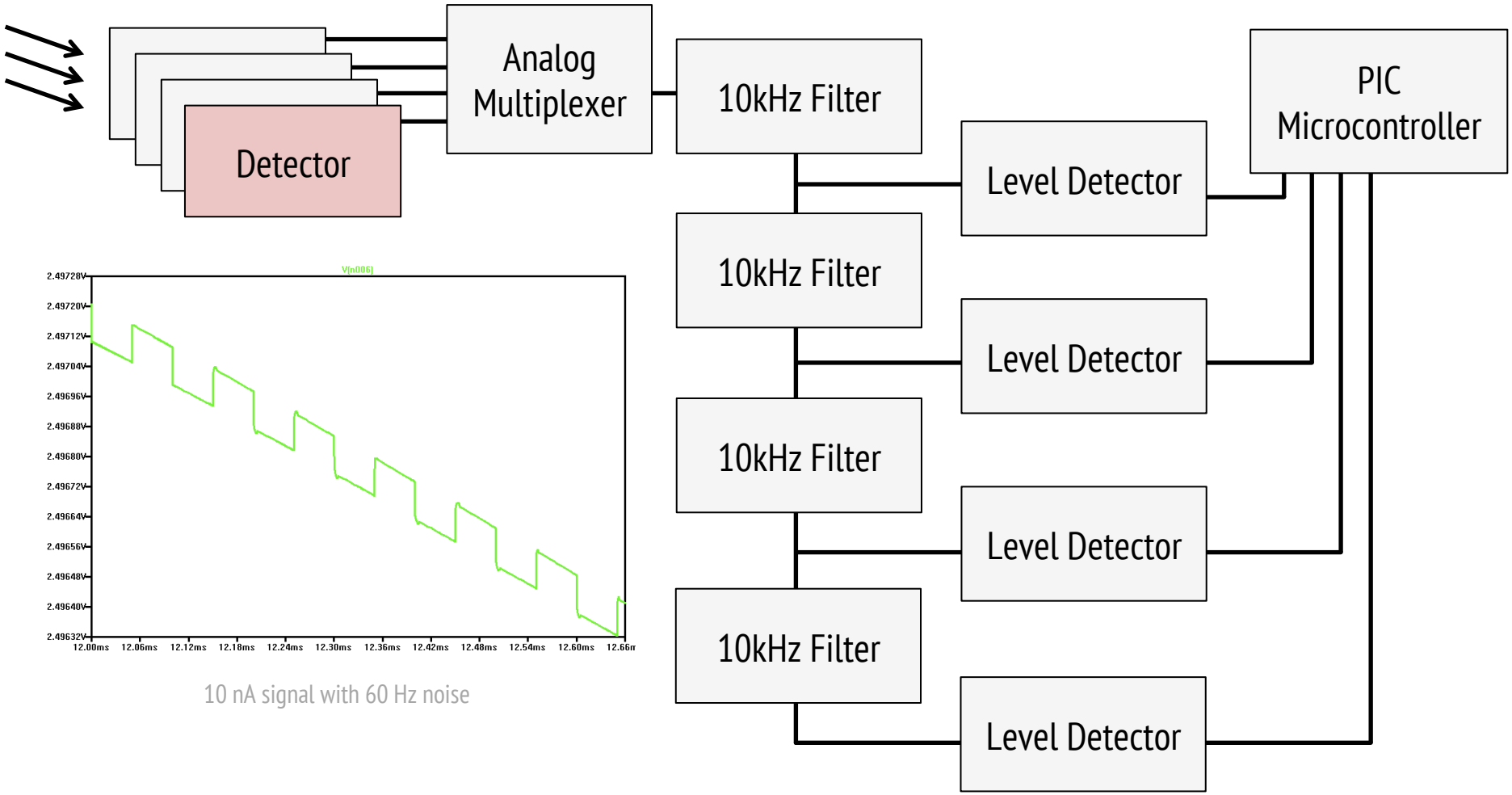
- AC-coupled transimpedance amplifier
- DC current (ambient light signal) passes through the resistor while the AC signal is passed to the amplifier



RECEIVER

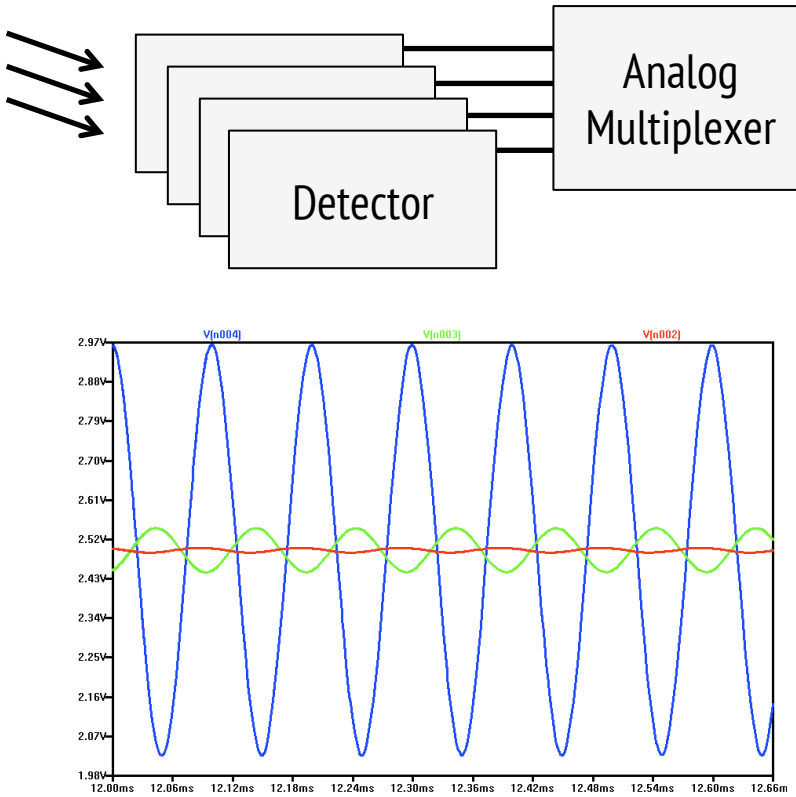

Detector
Analog Multiplexer
10kHz Filter
10kHz Filter
10kHz Filter
10kHz Filter
Level Detector
Level Detector
Level Detector
Level Detector
PIC Microcontroller

RECEIVER

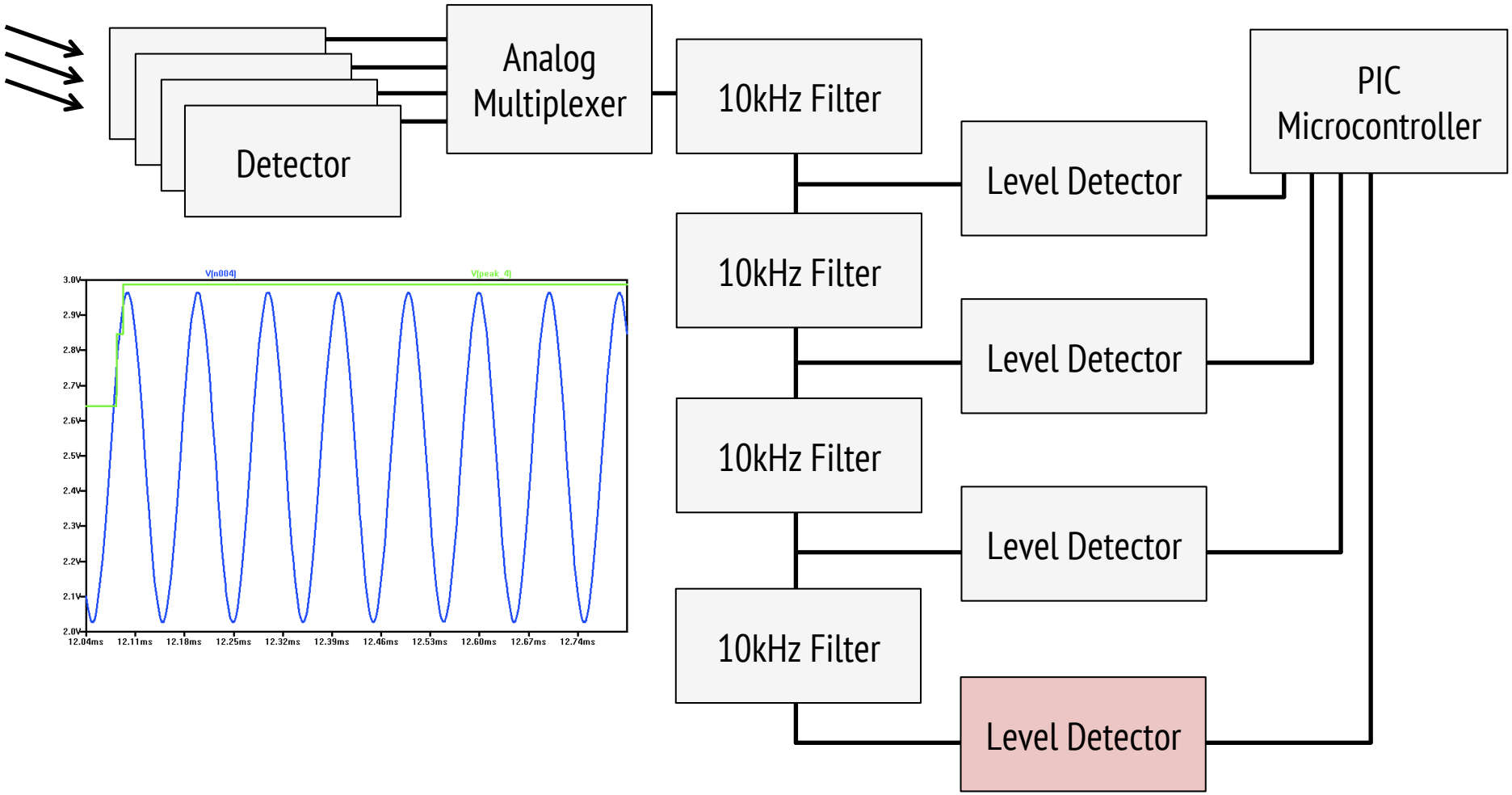


10 nA signal with 60 Hz noise

RECEIVER

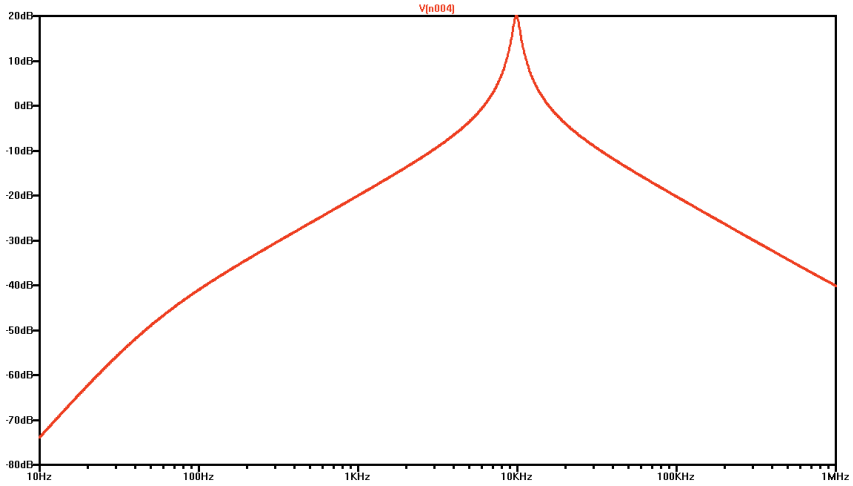

Detector
Analog Multiplexer
10kHz Filter
10kHz Filter
10kHz Filter
10kHz Filter
Level Detector
Level Detector
Level Detector
Level Detector
PIC Microcontroller
V(n004)
V(n003)
V(n002)
2.97V
2.88V
2.79V
2.70V
2.61V
2.52V
2.43V
2.34V
2.25V
2.16V
2.07V
1.98V
12.00ms
12.06ms
12.12ms
12.18ms
12.24ms
12.30ms
12.36ms
12.42ms
12.48ms
12.54ms
12.60ms
12.66m

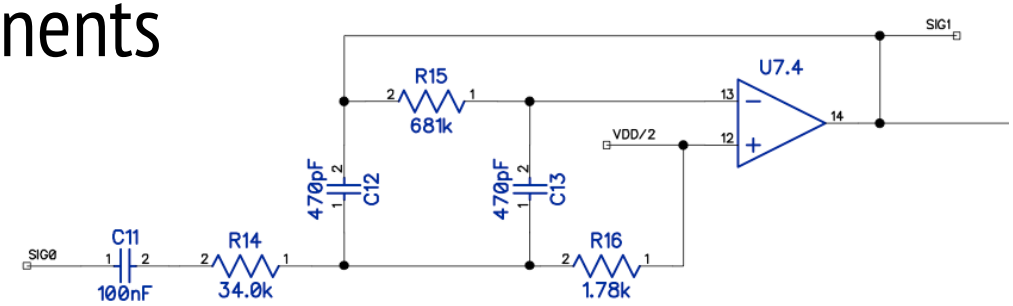
RECEIVER


Detector
Analog Multiplexer
10kHz Filter
10kHz Filter
10kHz Filter
10kHz Filter
Level Detector
Level Detector
Level Detector
Level Detector
PIC Microcontroller
V(n004)
V(peak_4)
3.0V
2.9V
2.8V
2.7V
2.6V
2.5V
2.4V
2.3V
2.2V
2.1V
2.0V
12.04ms
12.11ms
12.18ms
12.25ms
12.32ms
12.39ms
12.46ms
12.53ms
12.60ms
12.67ms
12.74ms

AMPLIFYING FILTERS

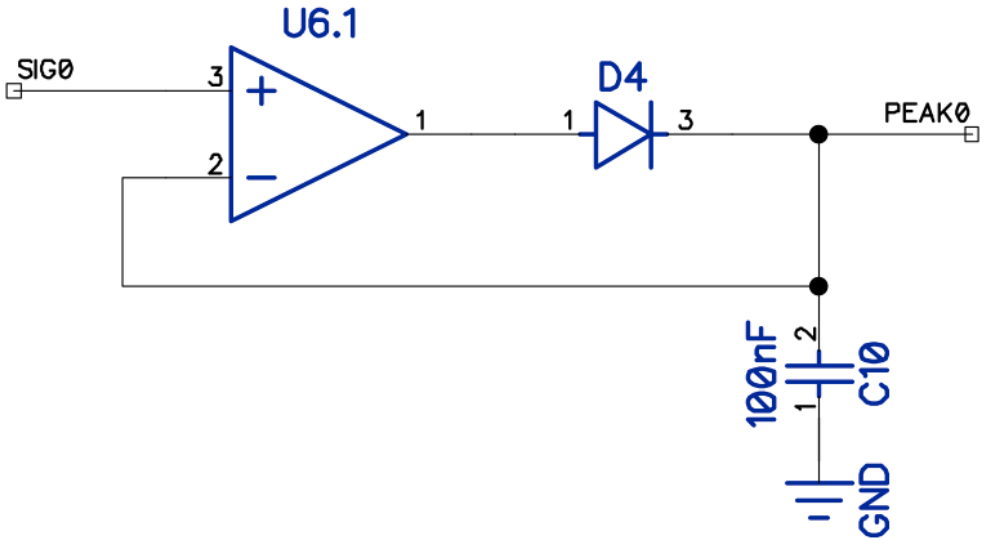
- Active, narrow band pass filters
  - modified Deliyannis filter
- Gain of 10 for selected frequency
- Relatively few components
- 4 cascaded stages
  - danger of ringing

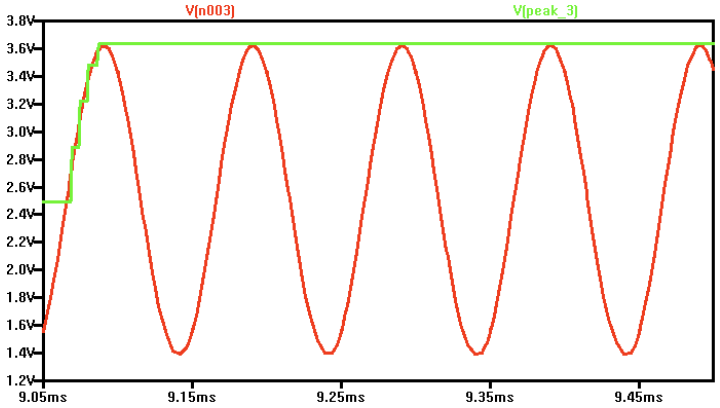




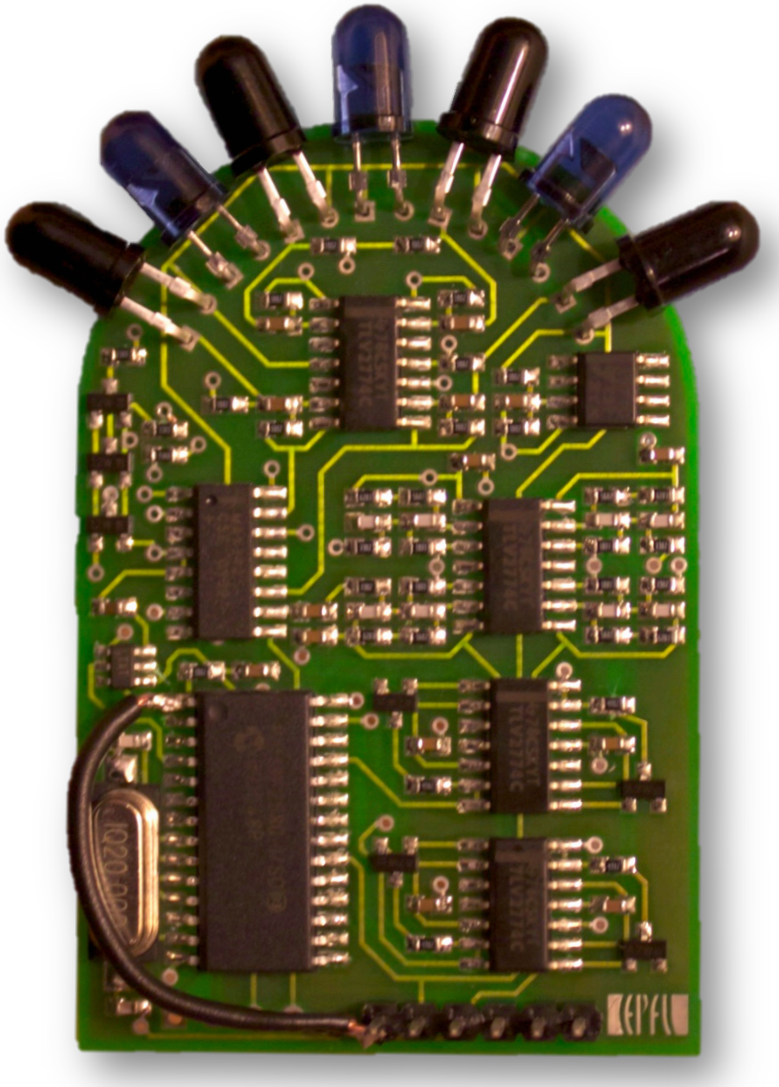
LEVEL DETECTOR

- Simple, few components
- Can be reset by microcontroller (switch pin to output)
- Maximum level is one diode drop below VDD



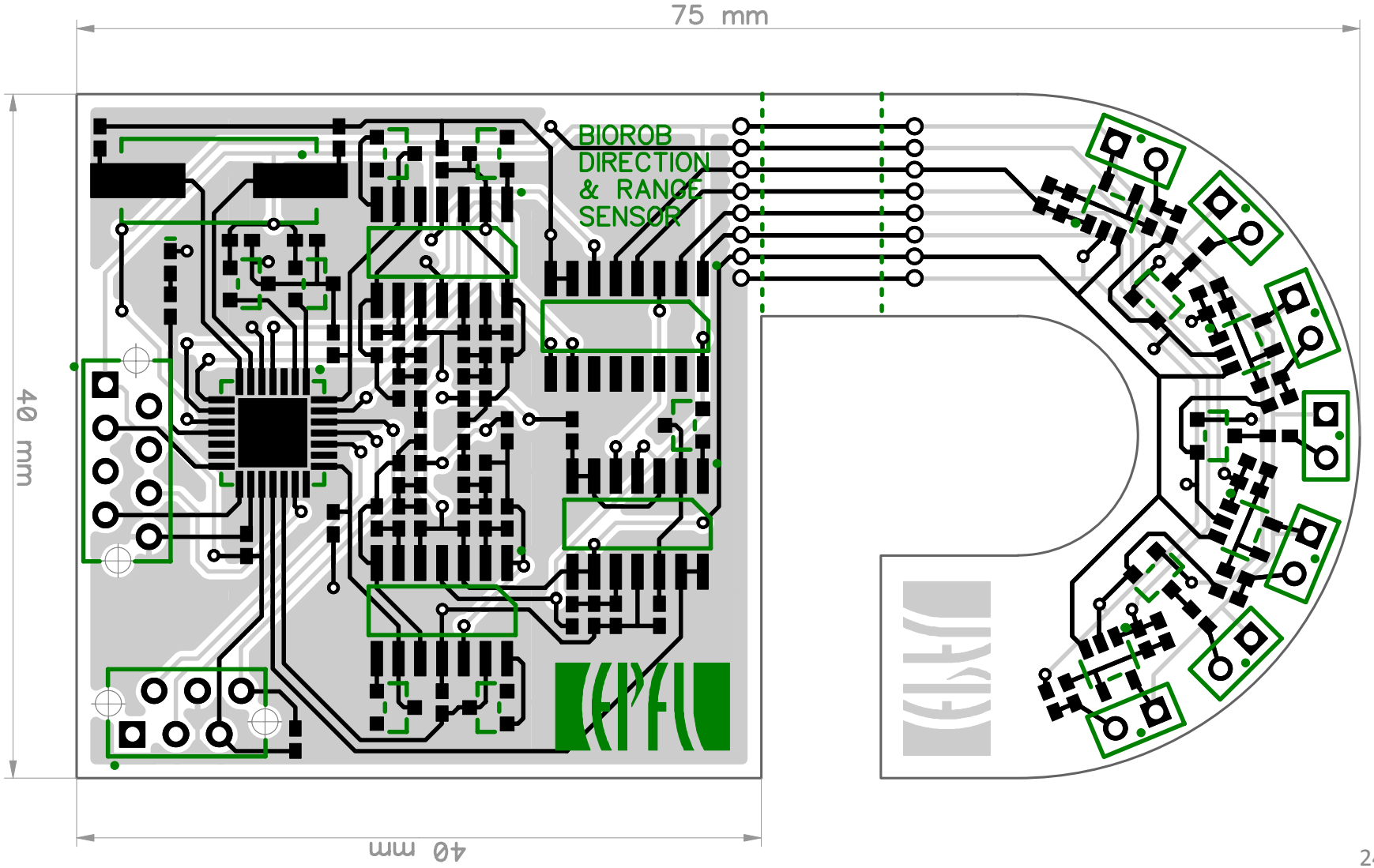


FIRST PROTOTYPE

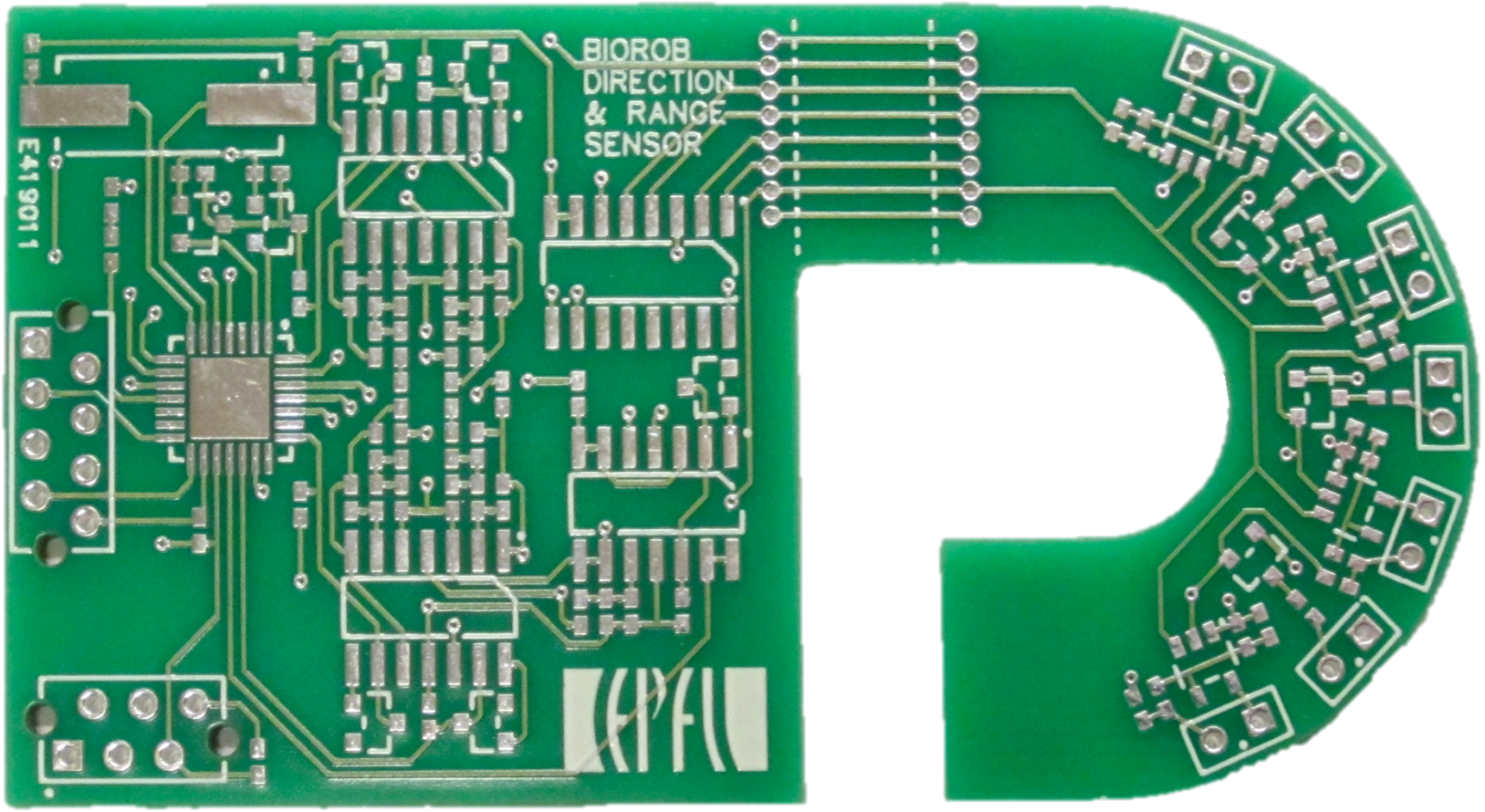


- Test analog circuit
- Prototype firmware
- Catch design errors

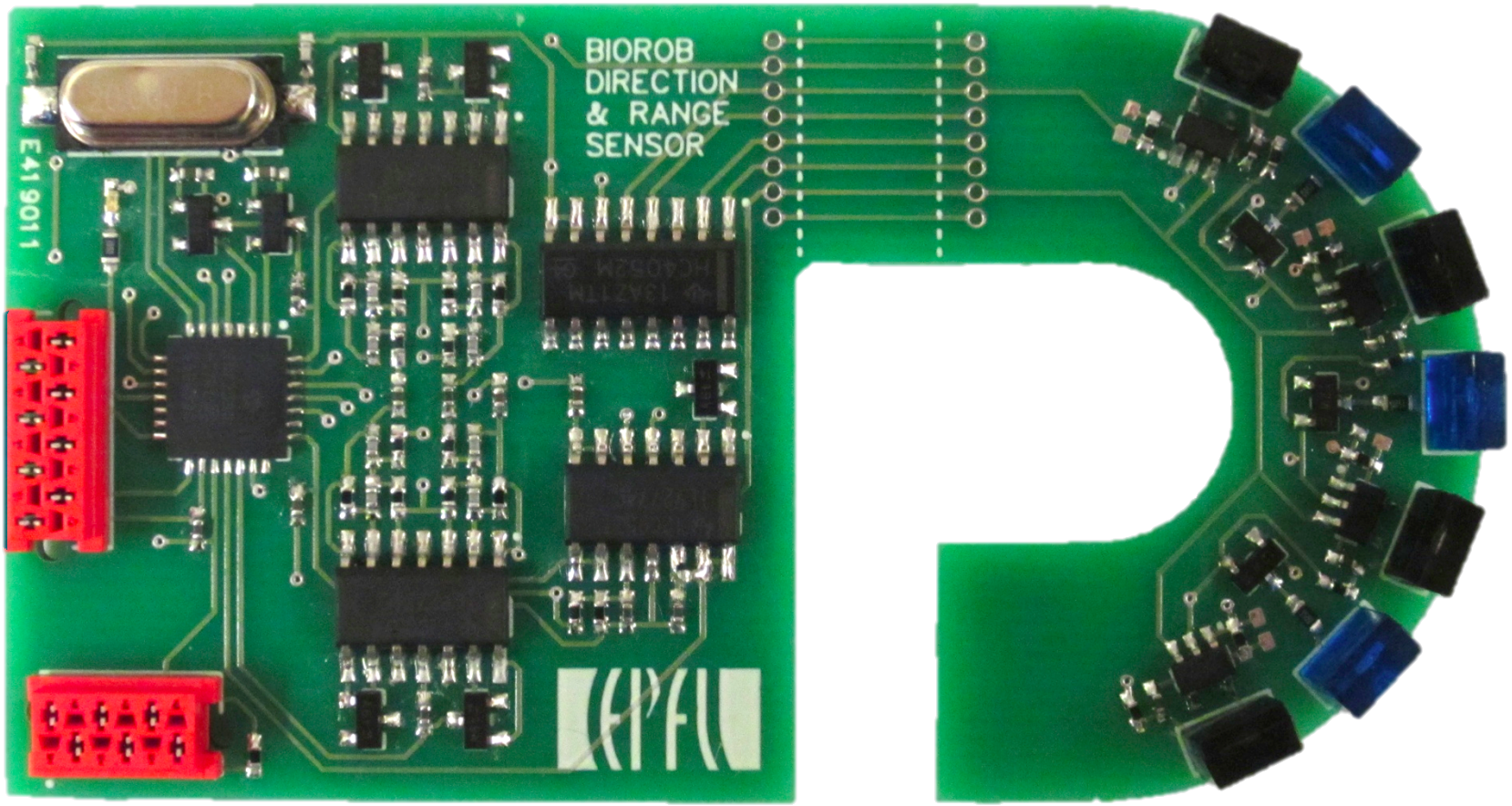
SECOND PROTOTYPE



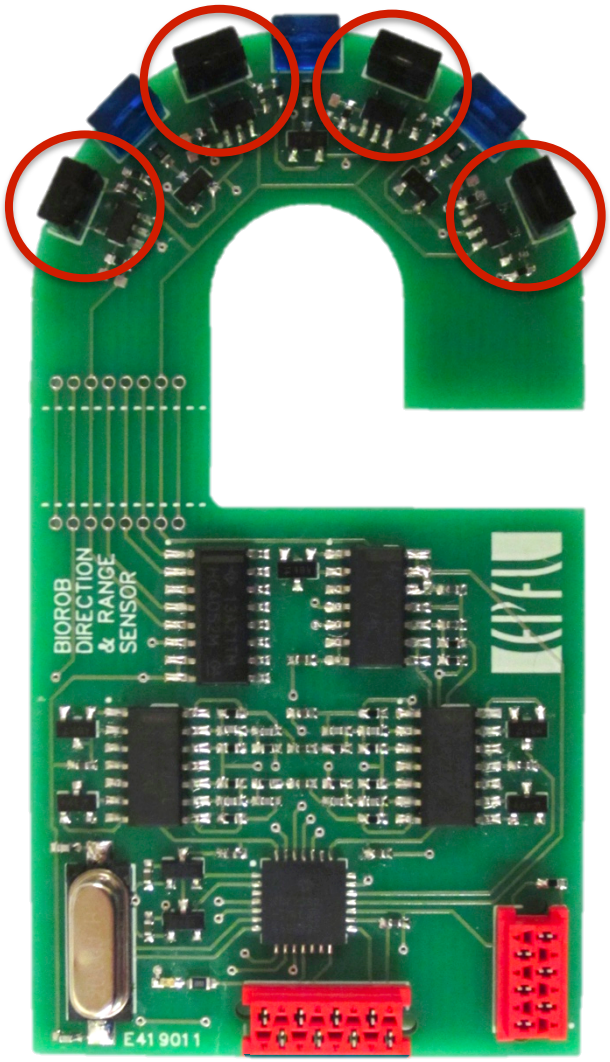
SECOND PROTOTYPE



SECOND PROTOTYPE

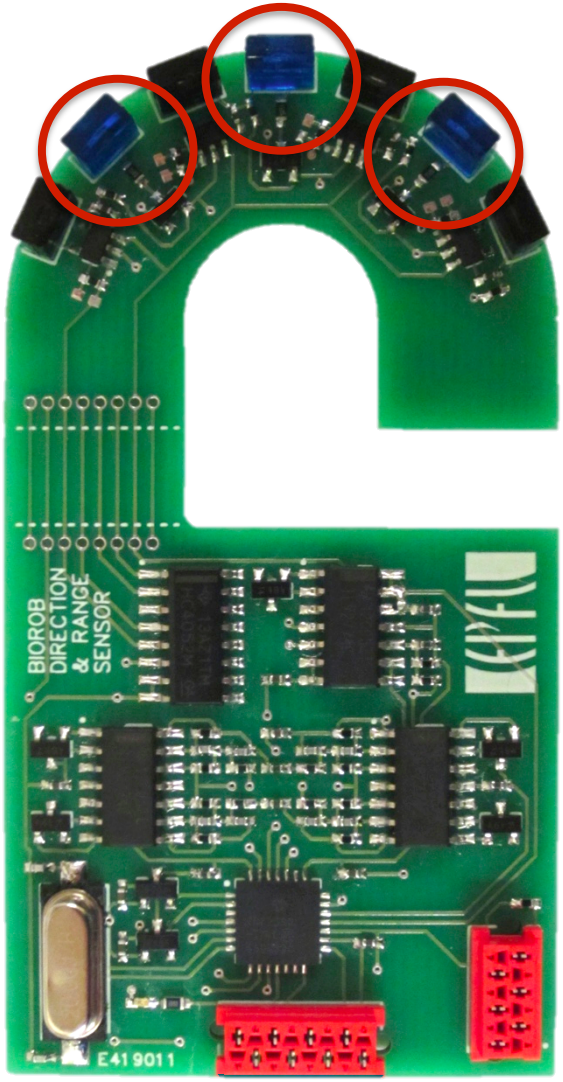


SECOND PROTOTYPE



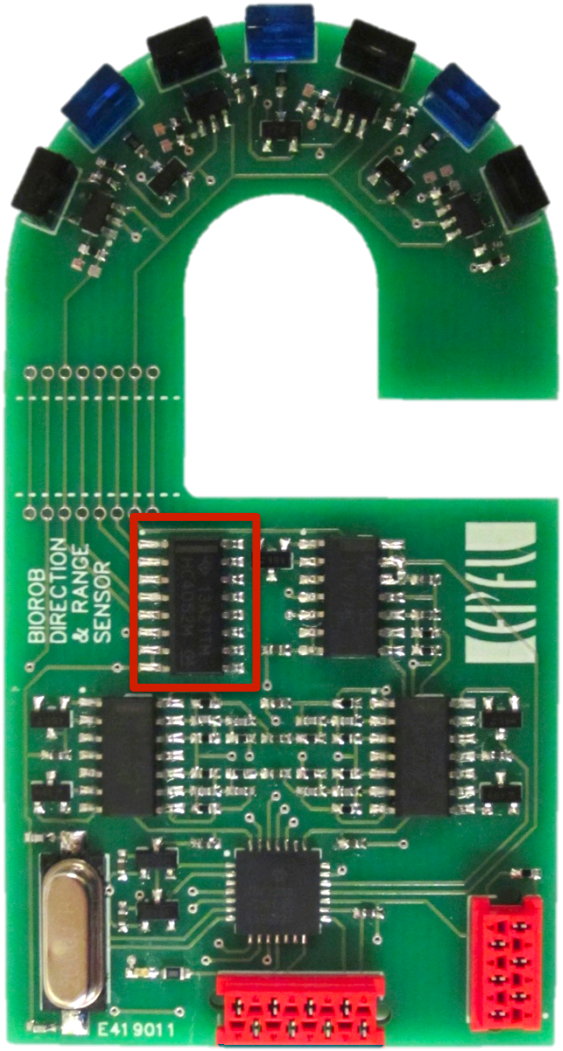
- Detector array

SECOND PROTOTYPE



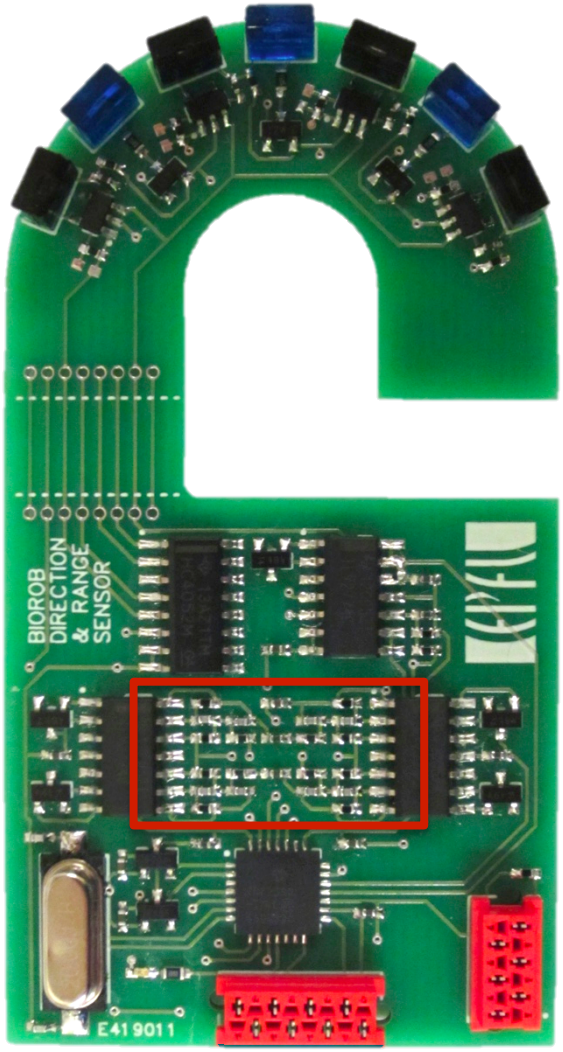
- Detector array
- Transmitter array

SECOND PROTOTYPE



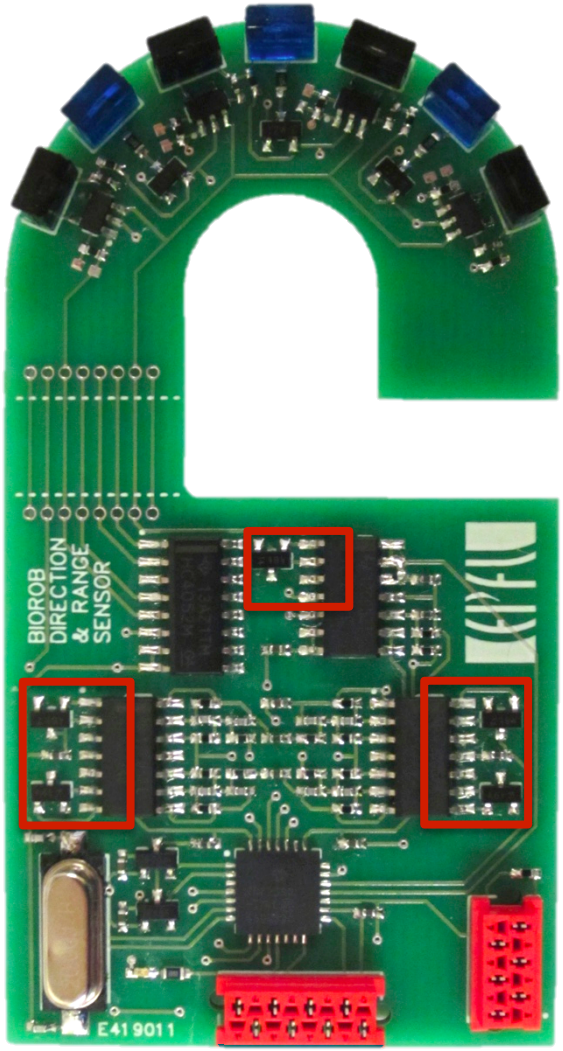
- Detector array
- Transmitter array
- Analog multiplexer

SECOND PROTOTYPE



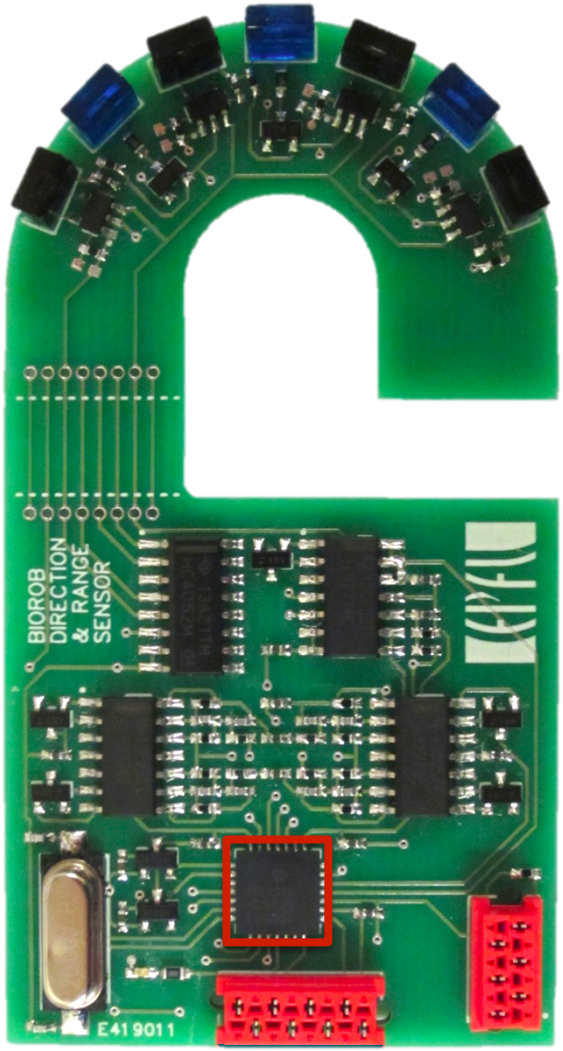
- Detector array
- Transmitter array
- Analog multiplexer
- Cascaded 10 kHz filters

SECOND PROTOTYPE



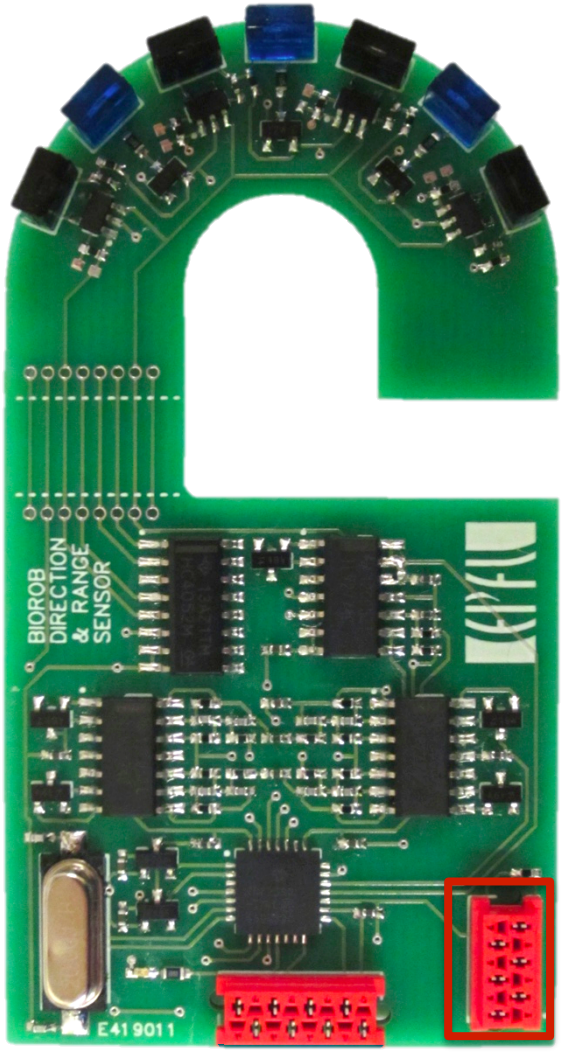
- Detector array
- Transmitter array
- Analog multiplexer
- Cascaded 10 kHz filters
- Peak detectors

SECOND PROTOTYPE



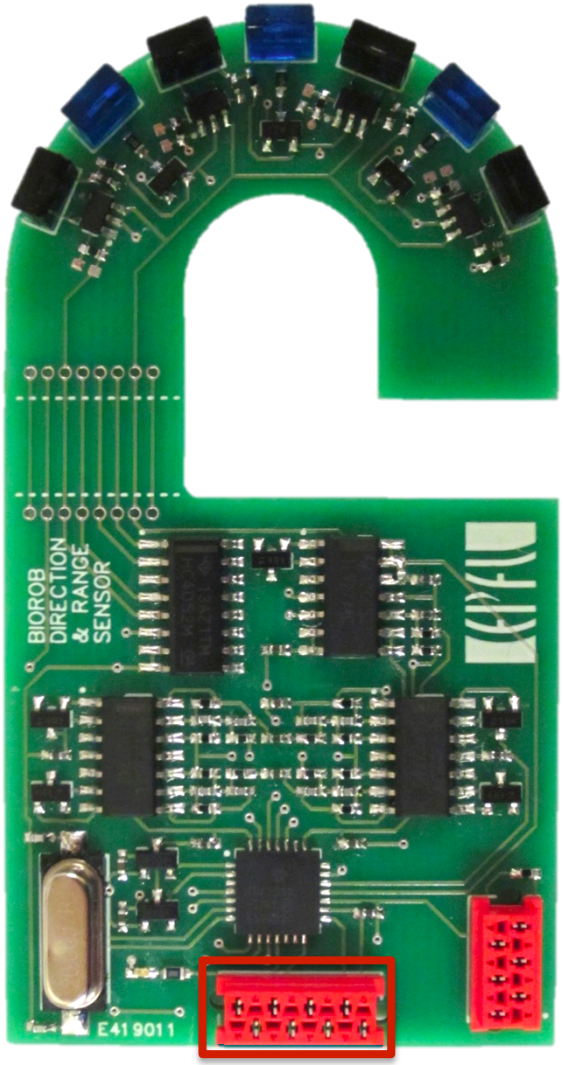
- Detector array
- Transmitter array
- Analog multiplexer
- Cascaded 10 kHz filters
- Peak detectors
- Microcontroller

SECOND PROTOTYPE



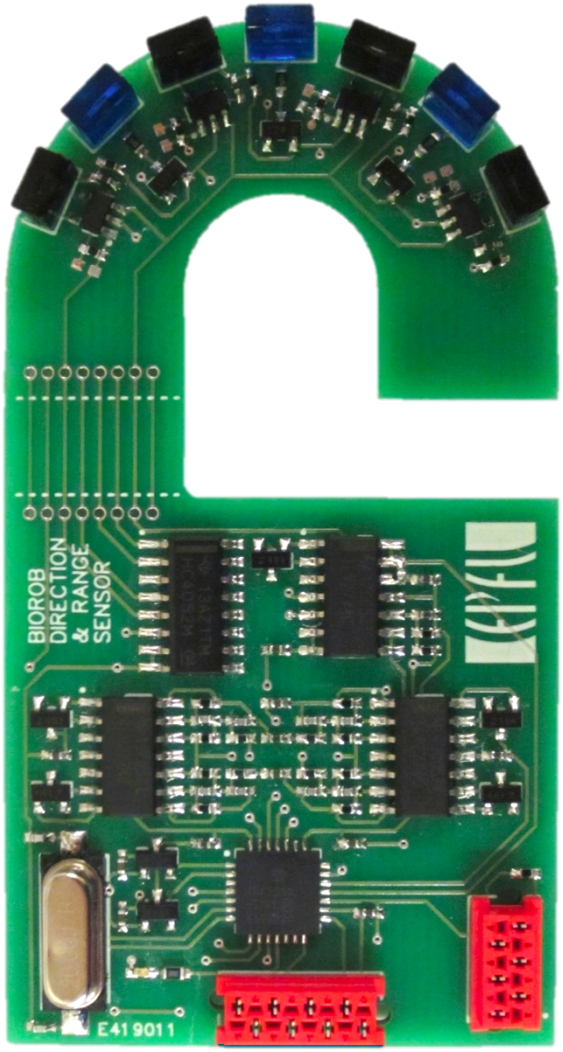
- Detector array
- Transmitter array
- Analog multiplexer
- Cascaded 10 kHz filters
- Peak detectors
- Microcontroller
- Programming port

SECOND PROTOTYPE



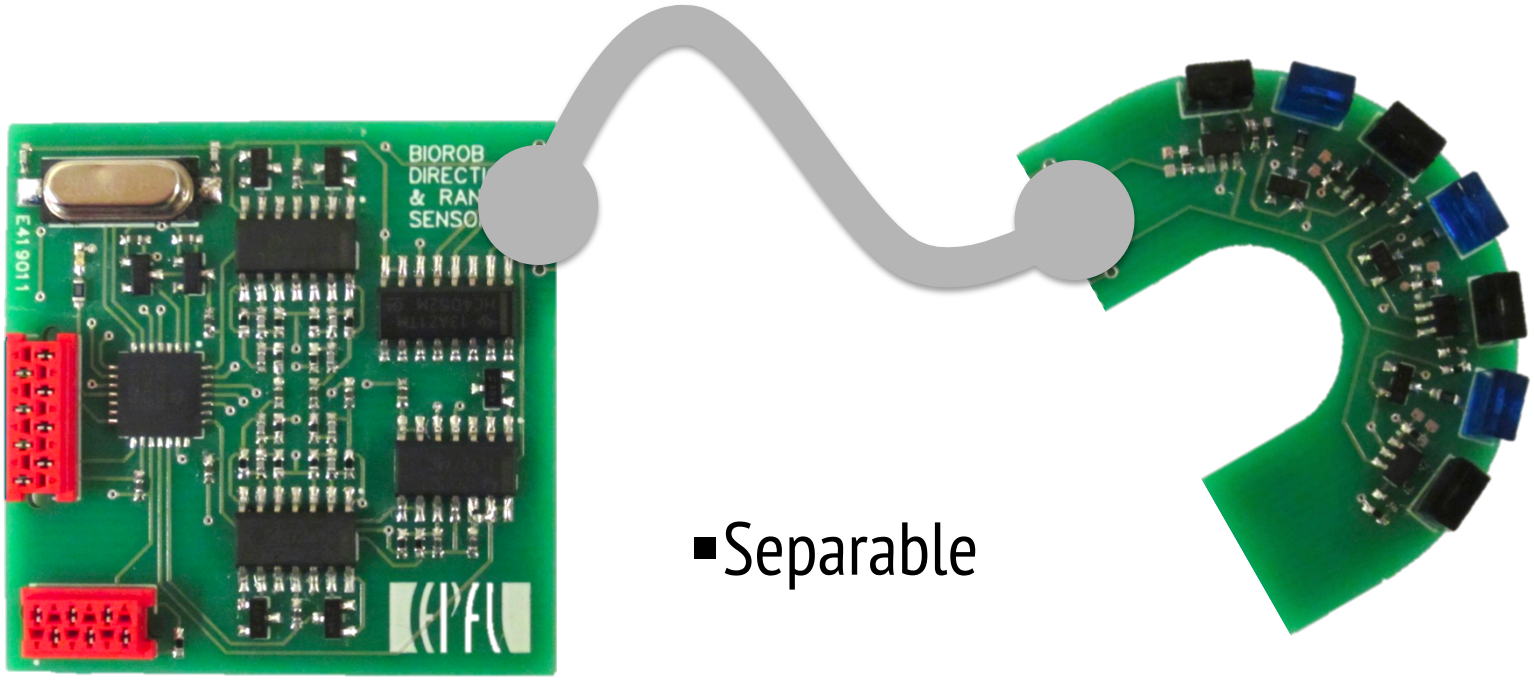
- Detector array
- Transmitter array
- Analog multiplexer
- Cascaded 10 kHz filters
- Peak detectors
- Microcontroller
- Programming port
- Interface port

SECOND PROTOTYPE



- Detector array
- Transmitter array
- Analog multiplexer
- Cascaded 10 kHz filters
- Peak detectors
- Microcontroller
- Programming port
- Interface port
- And…

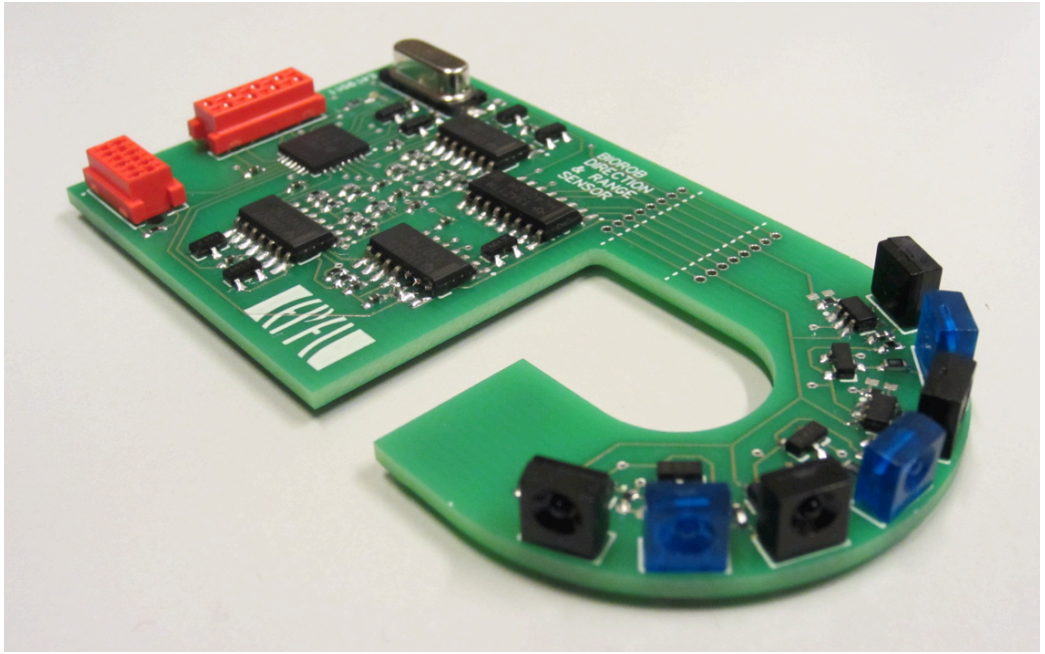
SECOND PROTOTYPE

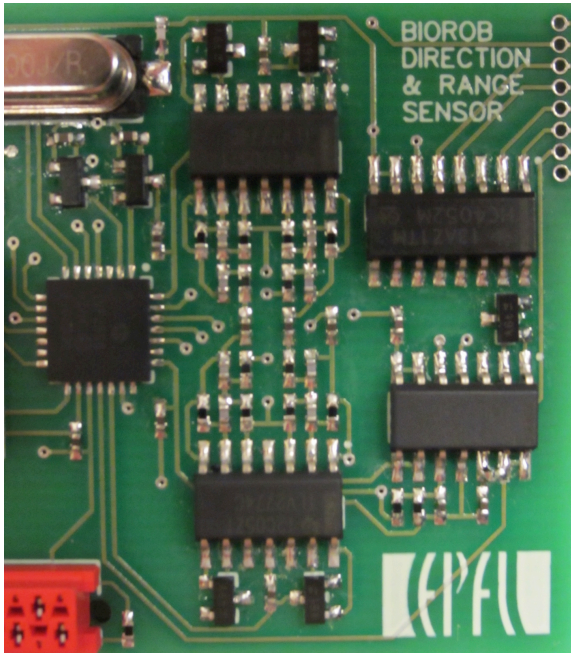


- Separable

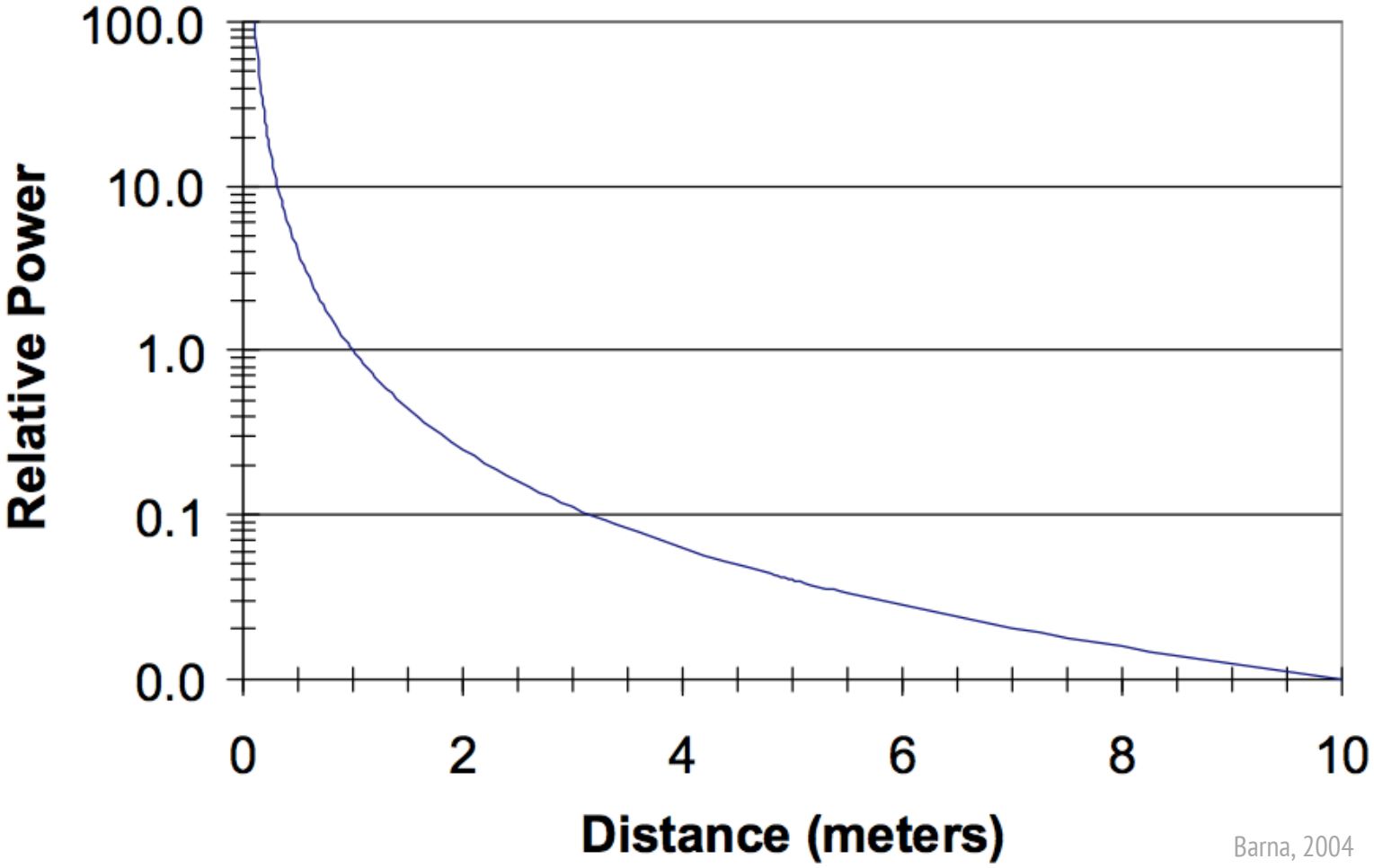
SECOND PROTOTYPE

- Small size (4 cm x 4 cm + detector)
- Few components
- Single 5V supply



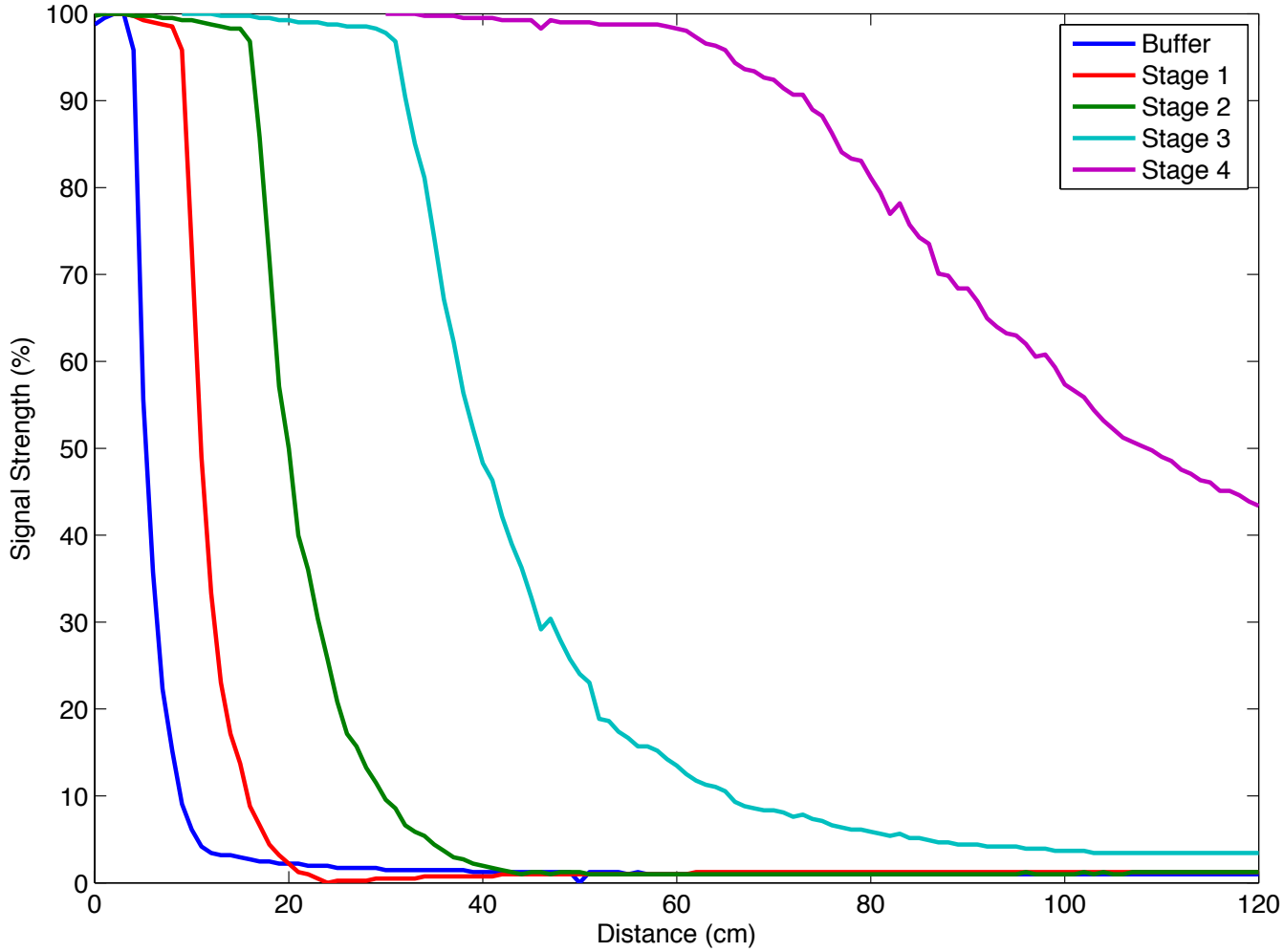


DISTANCE

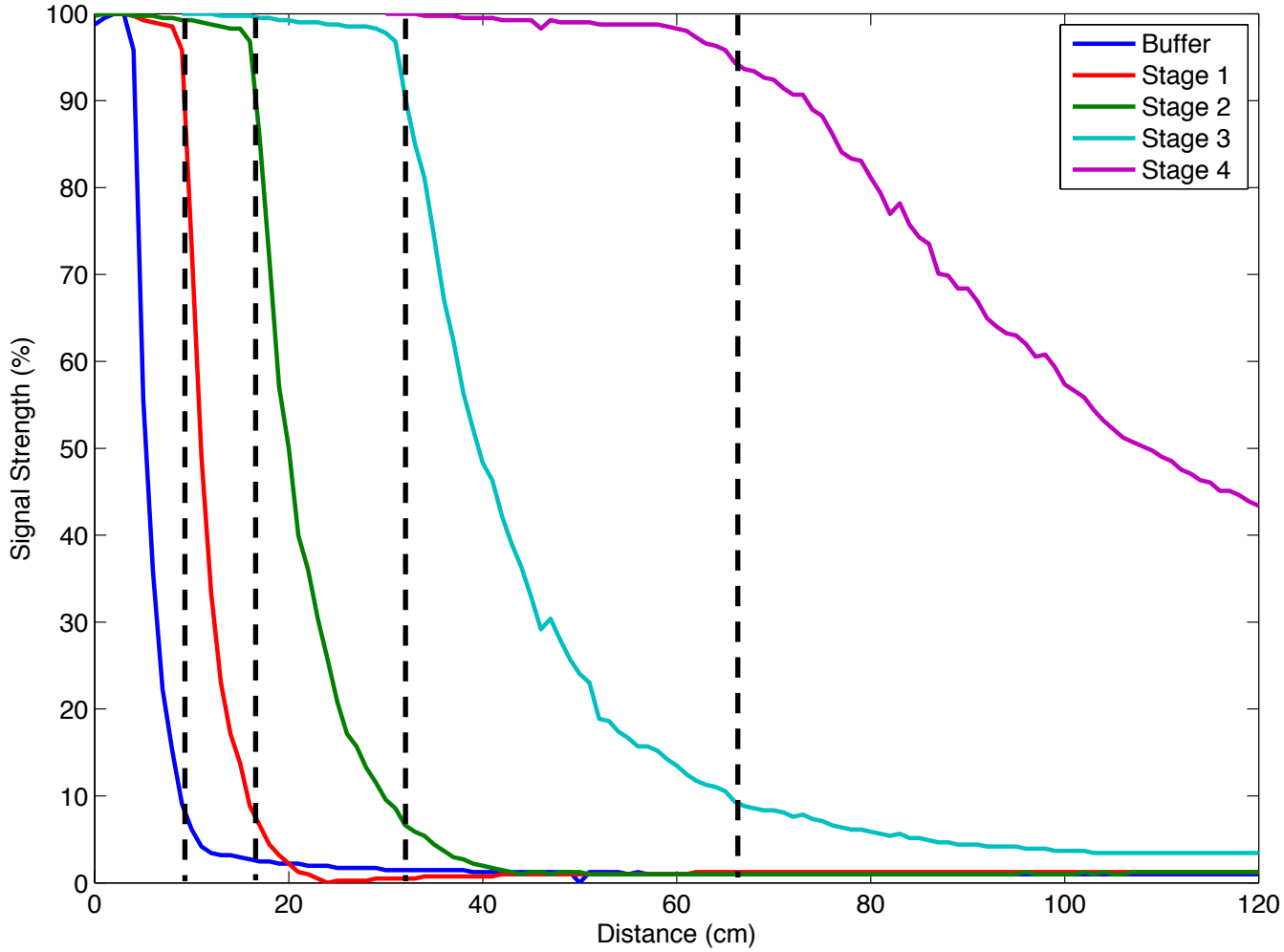


Barna, 2004

DISTANCE using low power transmitter



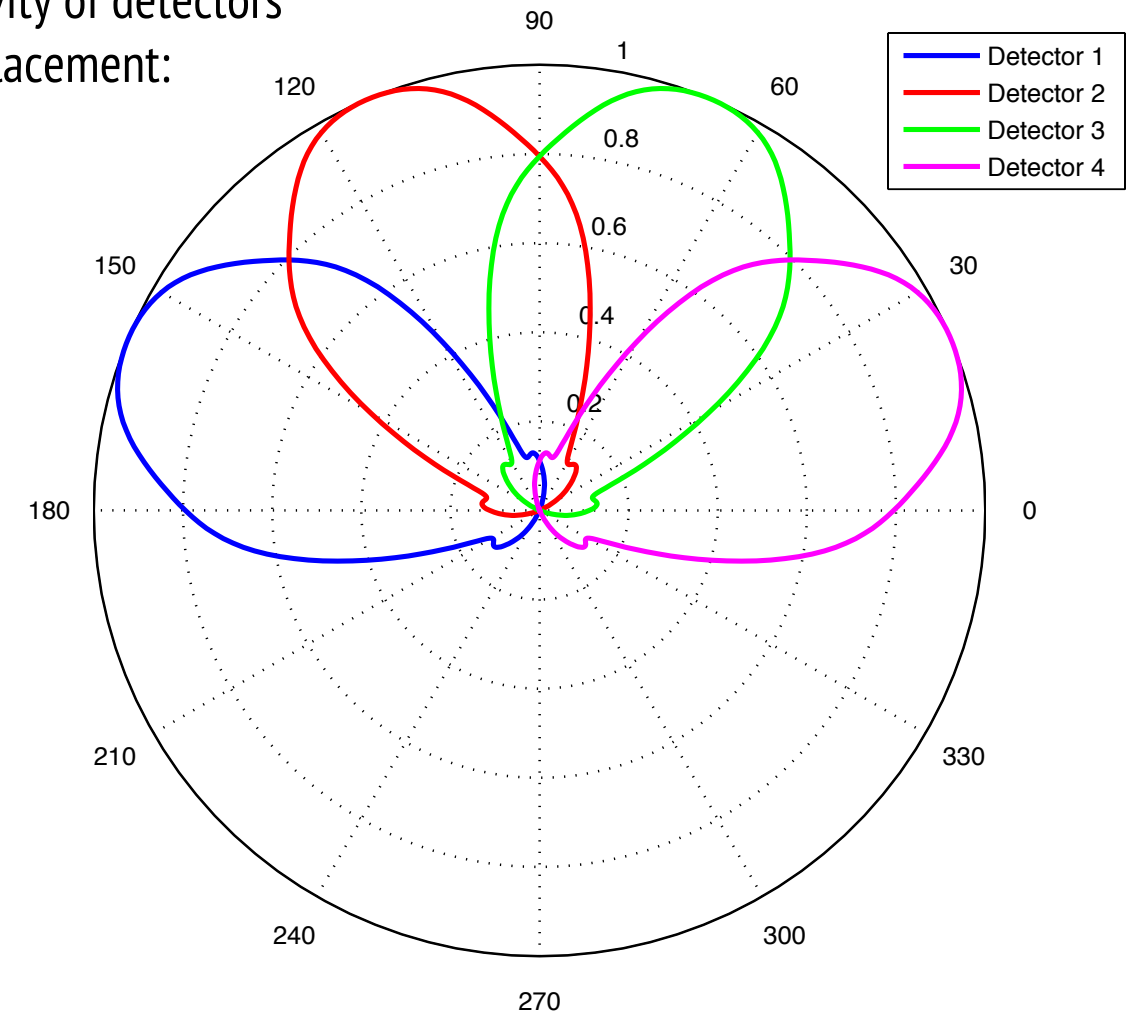
DISTANCE using low power transmitter



Note that the Buffer signal is noisier

ANGLE DETERMINATION

Relative sensitivity of detectors vs. angular displacement:



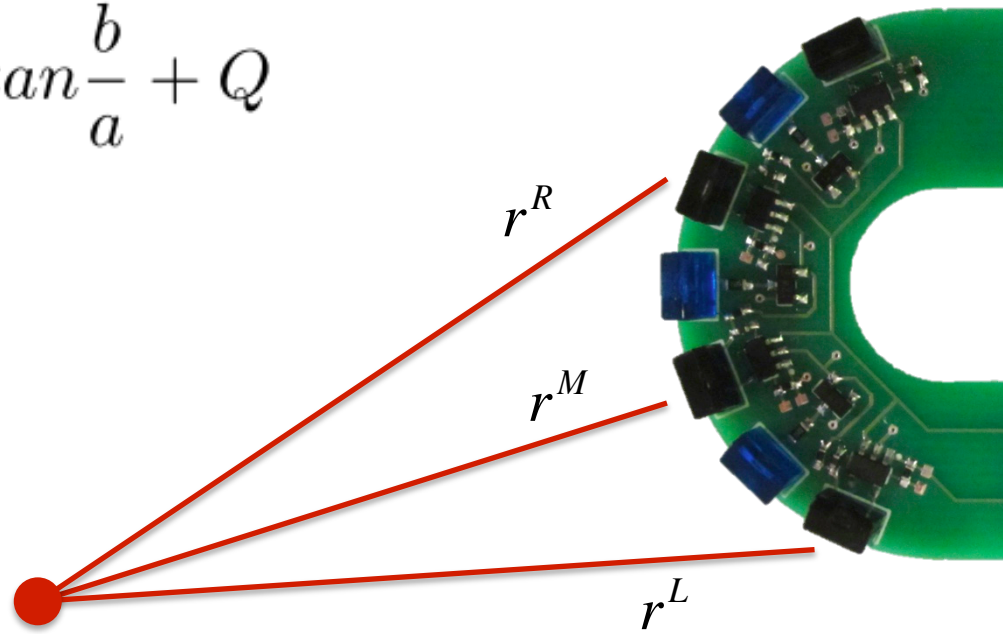
ANGLE DETERMINATION

- If we assume that the angular sensitivity profile is given by $r' = r \cdot \cos(\theta)$, we can compute the following solution:

$$r = \frac{1}{\sqrt{a^2 + b^2}} \qquad \theta = arctan\frac{b}{a} + Q$$

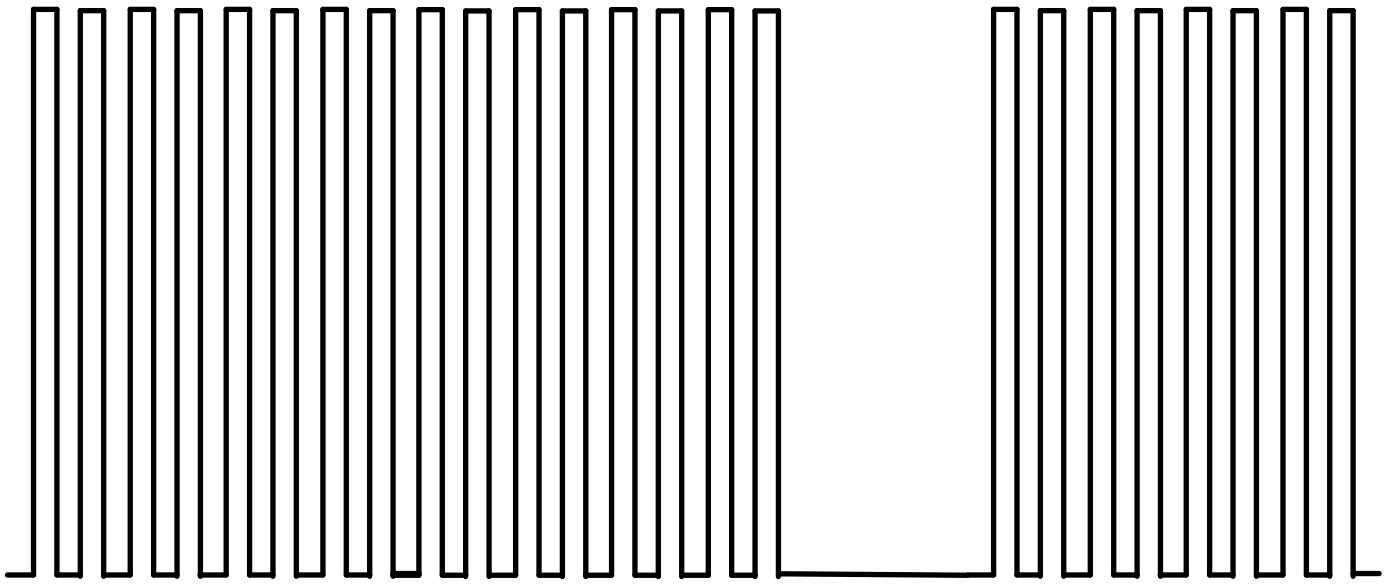
$$a = \frac{r^L + r^R + 2.r^M}{2.cos(\frac{\pi}{4}) + 2}$$

$$b = \frac{r^L - r^R}{2.sin(\frac{\pi}{4})}$$



DATA TRANSMISSION

- Pulse width modulation
  - very low data rate



FUTURE WORK

- Integrate into salamander
- High power transmitter
- Efficient firmware

Photograph by A. Herzog

THANK YOU

- Auke Jan Ijspeert
- Alessandro Crespi

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FÉDÉRALE DE LAUSANNE

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EPFL Biorobotics Laboratory

QUESTIONS