IC1301 -WiPE

Wireless and Batteryless Temperature Measuring Circuit Using a Single Light Emitting Diode

03.05.2016

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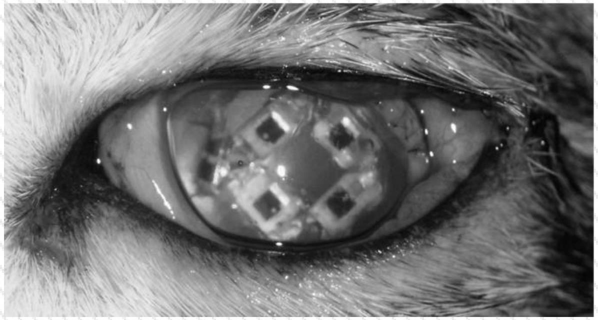
Main Objective

- Solve the low photodiode voltage and conversion efficiency problems associated with optically powered smart microsystems
- To demonstrate a compact energy management framework for harvesting optical energy from a LED as well as transmitting data using the same LED.

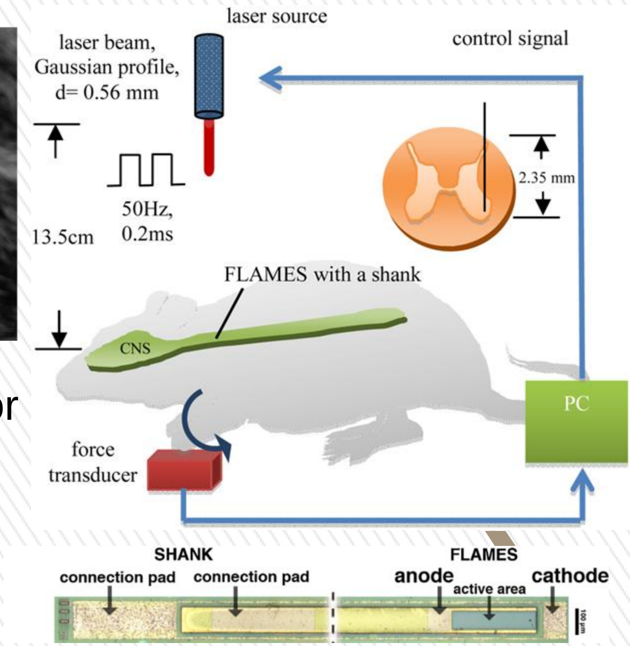
Optical energy harvesting microsystems

- » Optical (photovoltaic) energy harvesting delivers greatest power in smallest volume
- » Favorable for wireless, batteryless smart microsystems that are required to be very small (~1 mm^3)

Commercialized IC for specimen tagging purposes [1]



Epi-retinal electrical stimulator powered by an array of PIN diodes [2]



Individually adressable microstimulators [3]

…but there is a catch

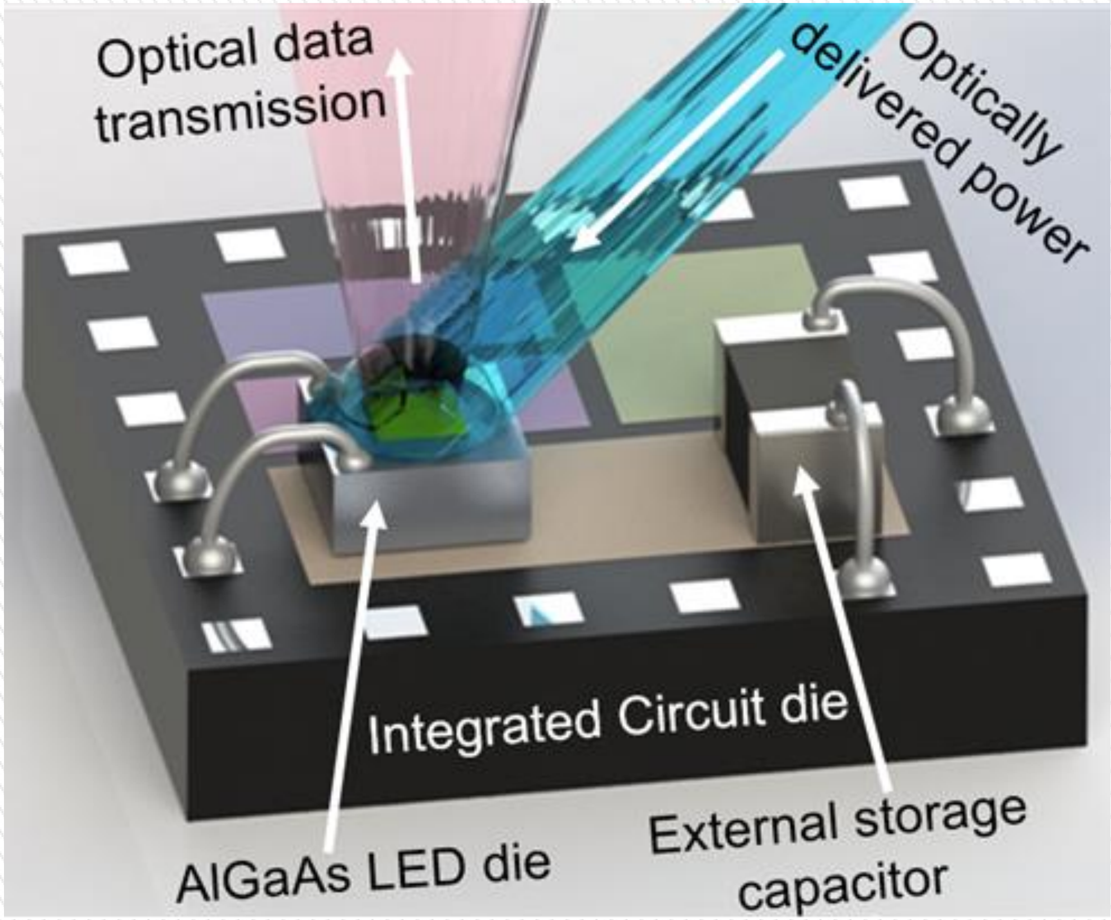
- A silicon photodiode can only supply around 0.6V under illumination. Very problematic if sensors and analog electronics are to be integrated into the design
- Connecting on-chip CMOS photodiodes in series is problematic and inefficient [4]. SOI photodiodes can be connected in series without efficiency loss [5]. However, SOI wafers are *VERY expensive*.
- A charge pump can be used to elevate 0.6V to around 1.2V at greatly reduced efficiency [6].
- On-chip photodiodes take up *expensive* silicon real estate. The additional charge pump must be large as well, to support large current loads. This leaves very small area functional blocks such as sensors, processor units, memory, etc.

Transmission of data

- A smart microsystem is expected to communicate with its user, transmitting sensor readings, device ID, etc.
- Standard silicon photodiodes have NO ability to emit photons. For optical transmission, a LED or laser diode must be used.
- Additional antenna for RF transmission increase the overall size.

Typical current microsystem solutions:
Optical power transfer, RF data transmission

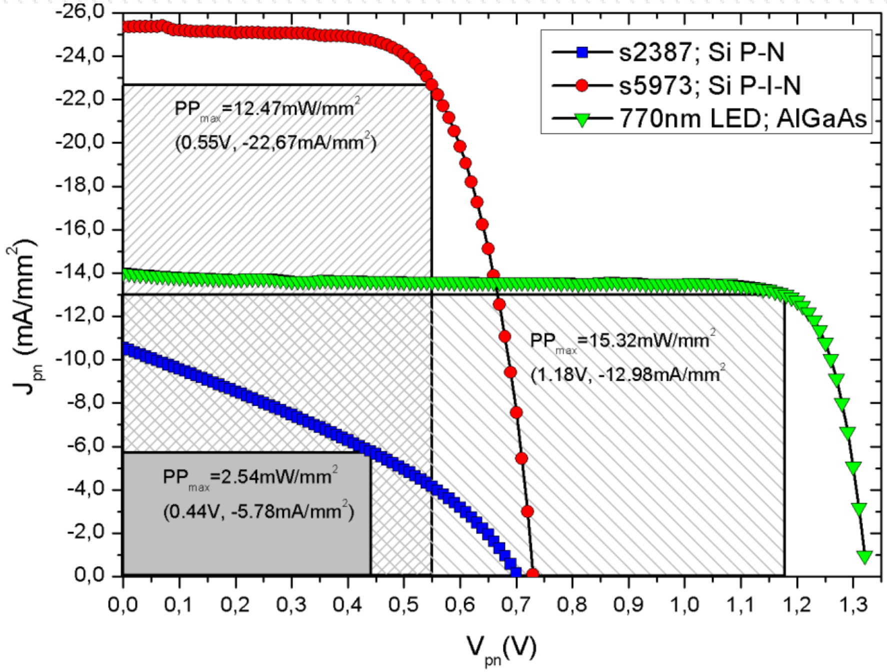
Our solution to the problem

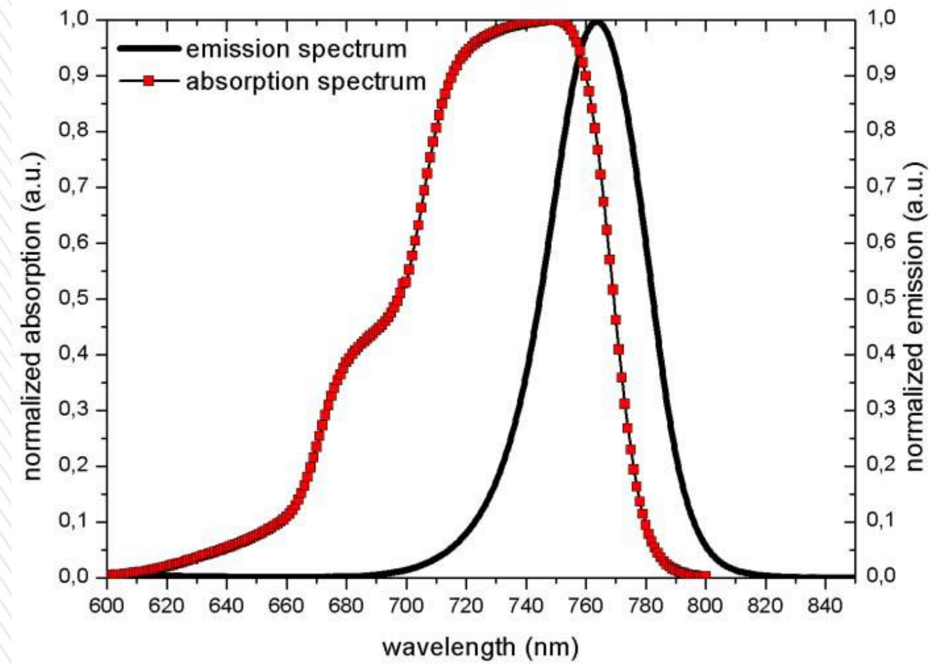


» **Use a single LED to harvest energy and transmit data**

- **Maximizes the utility of the unavoidable external component**
- **Greater power conversion efficiency**
- **Usable open circuit voltage without need for elevation.**
- **Saves on-chip area**

LED as a photovoltaic cell

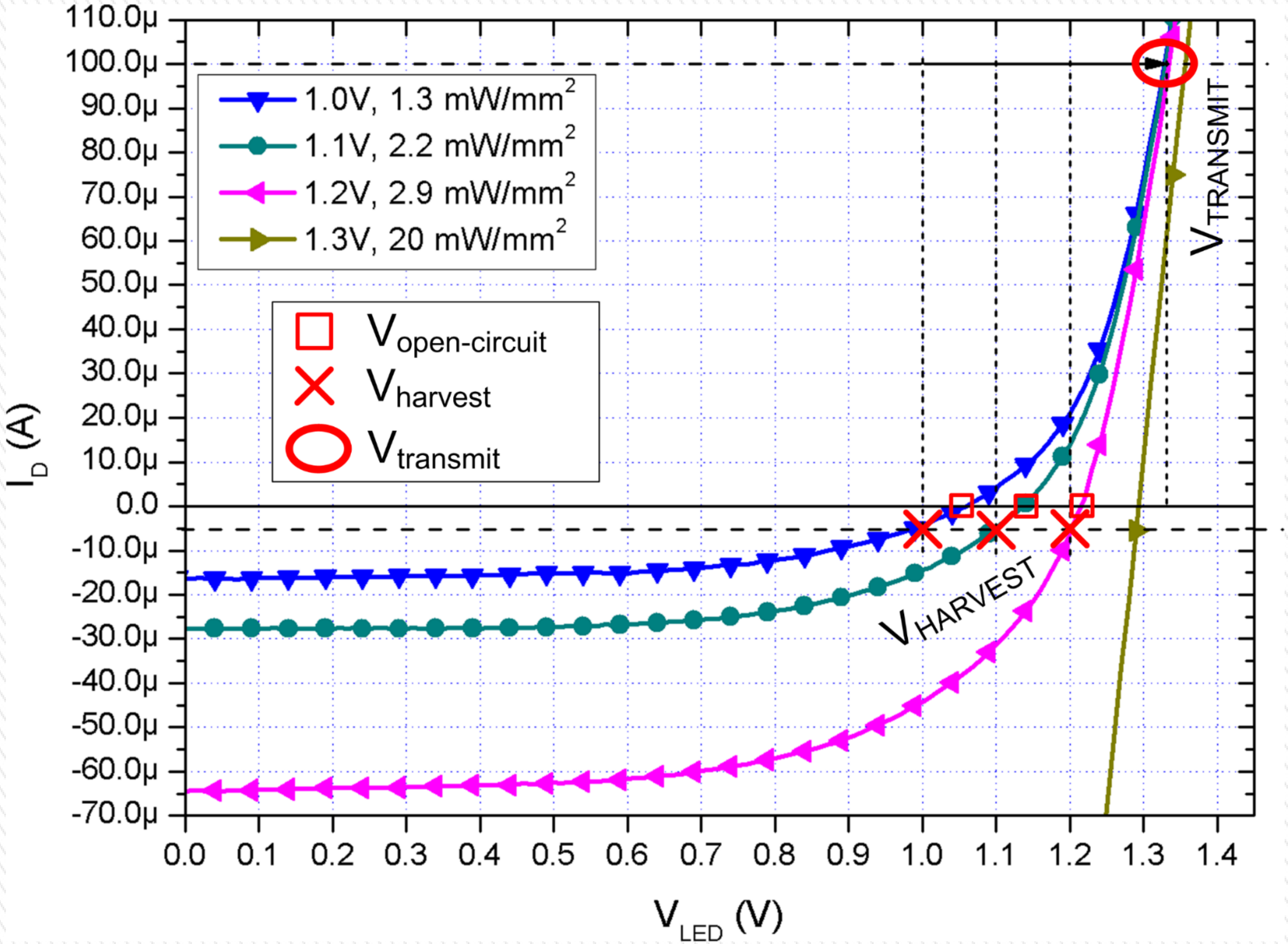




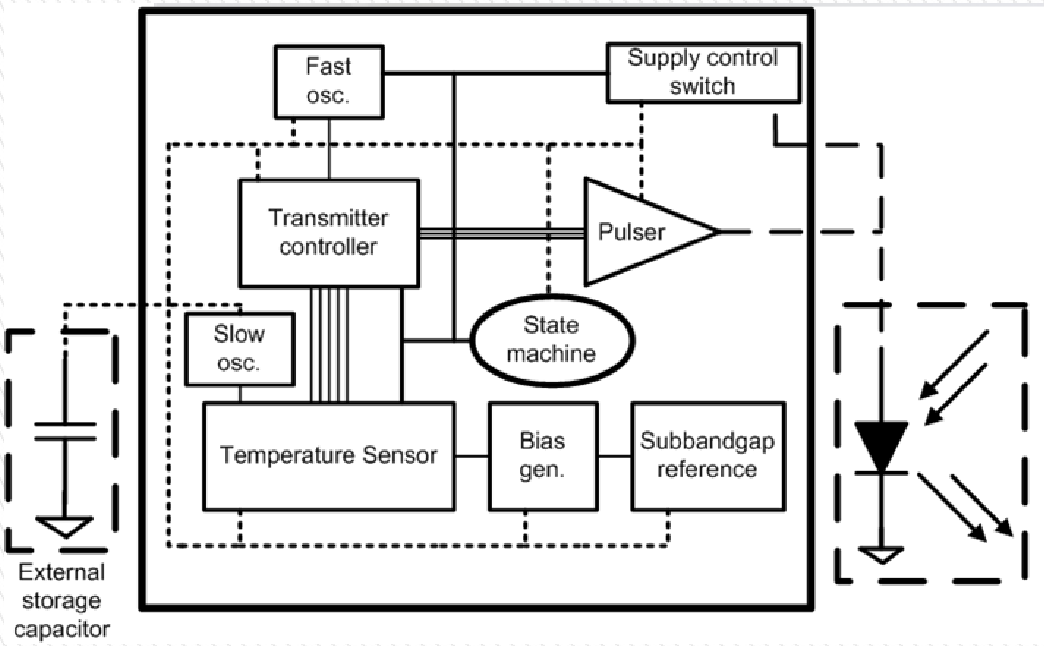
- A 770nm LED is used to collect energy from 680nm laser beam delivering **1.2 V** and >1mA. Silicon PIN photodiode can deliver **0.6 V**.
- **LED has 22% optical to electrical energy conversion efficency for this wavelength.**

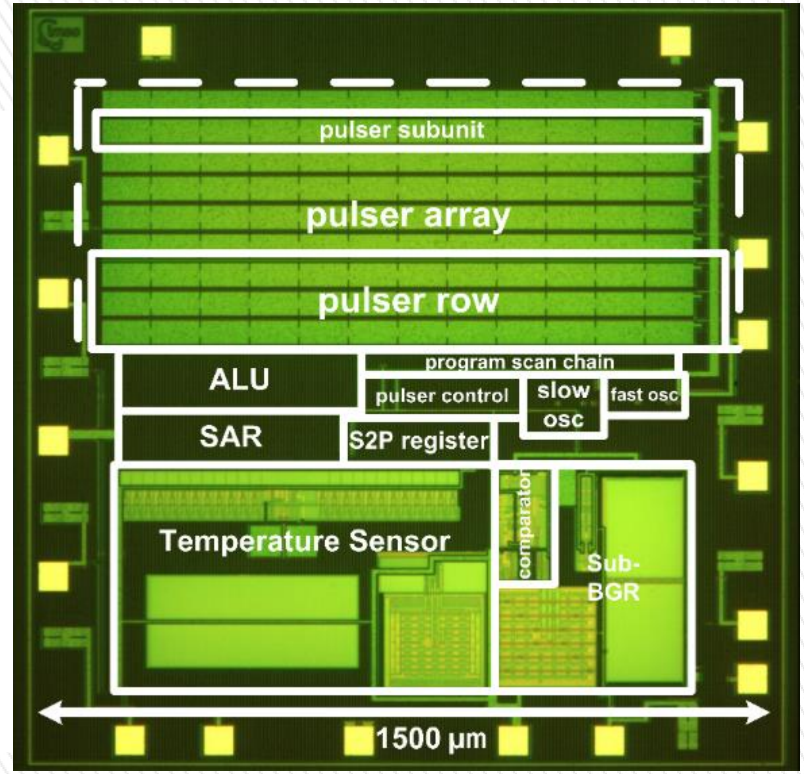
“A great solar cell has to be a great LED.”
Eli Yablonovitch, “Solar Cell Breaks Efficiency Record”, *IEEE Spectrum*, 2011.

I-V of LED under illumination



Wireless & Batteryless Temperature Sensor



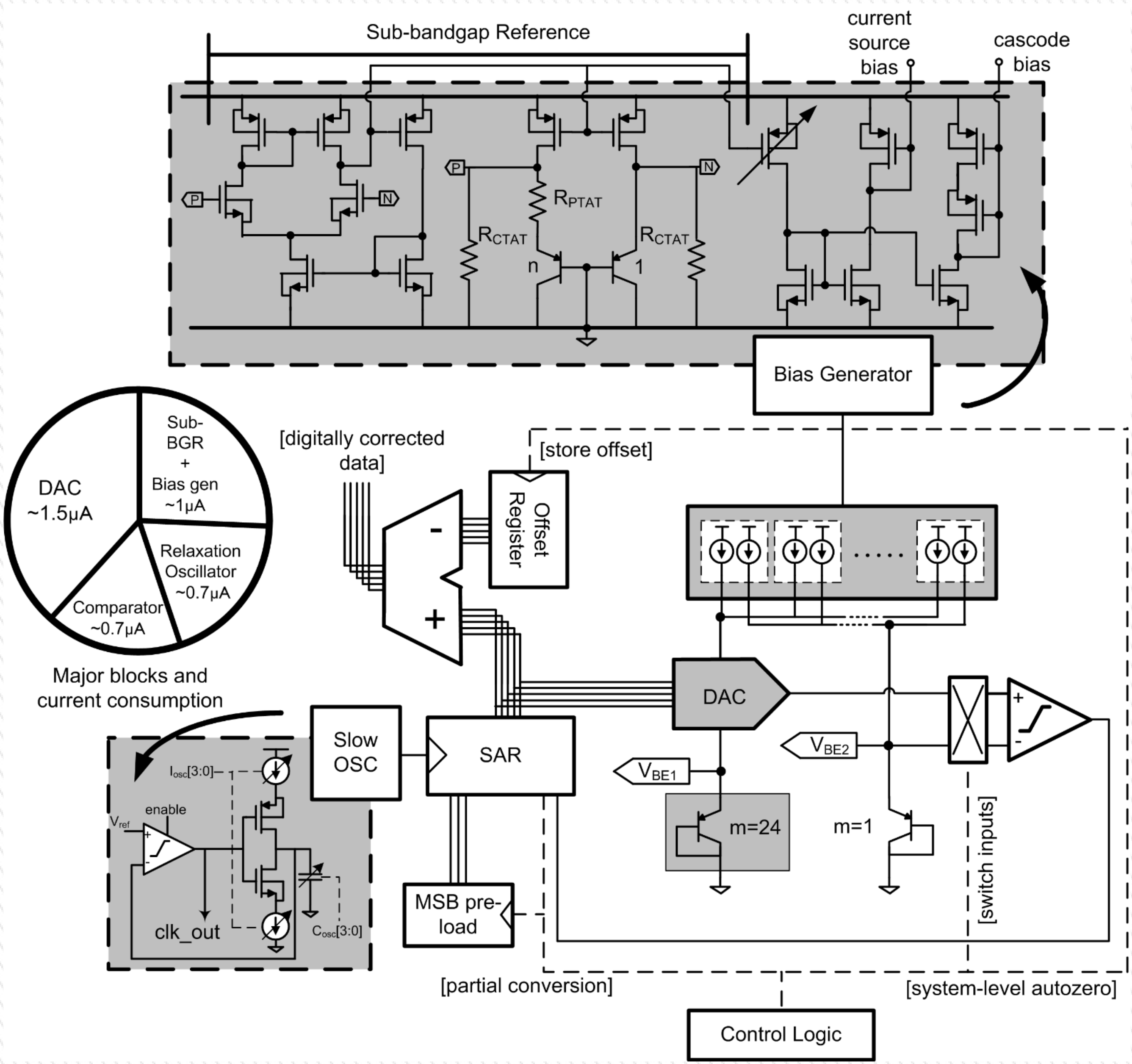


Layout of IC fabricated using UMC 0.18um process

The microsystem is designed to operate at a nominal voltage of 1.2 V, dissipating 5.5 µW.

Work in collaboration with Asst. Prof. Tamer Ozgun

System Details

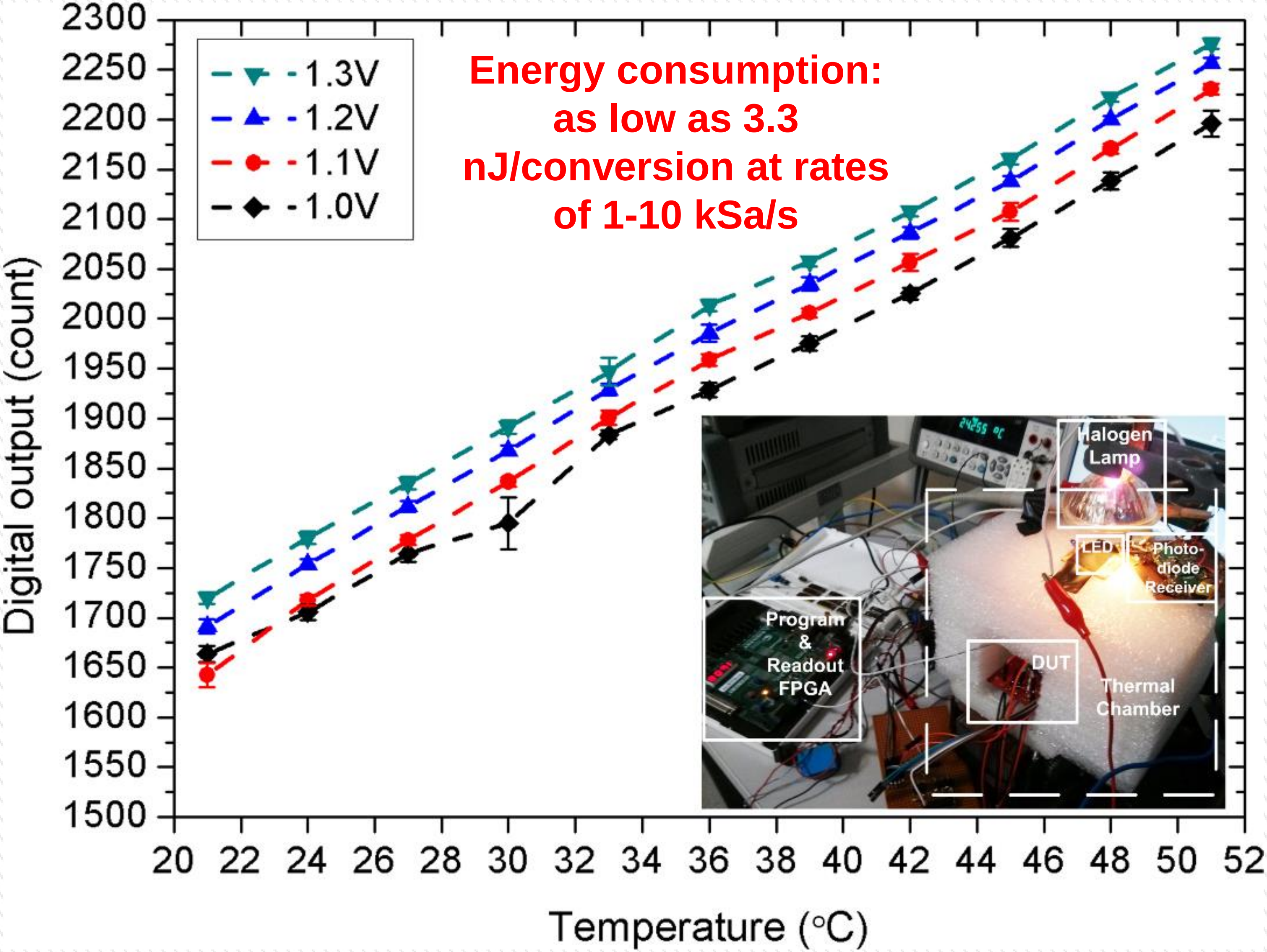


Temperature Sensor Block

- Sub-bandgap reference generator
- Digitally programmable oscillator
- Bias generator,
- Auxiliary circuits: measures BJT junction temperature based on ΔV_{BE} technique (comparator and switches)
- SAR ADC
- 12 bit DAC (8 bit R-2R and 4 bit thermometer coded current steering)

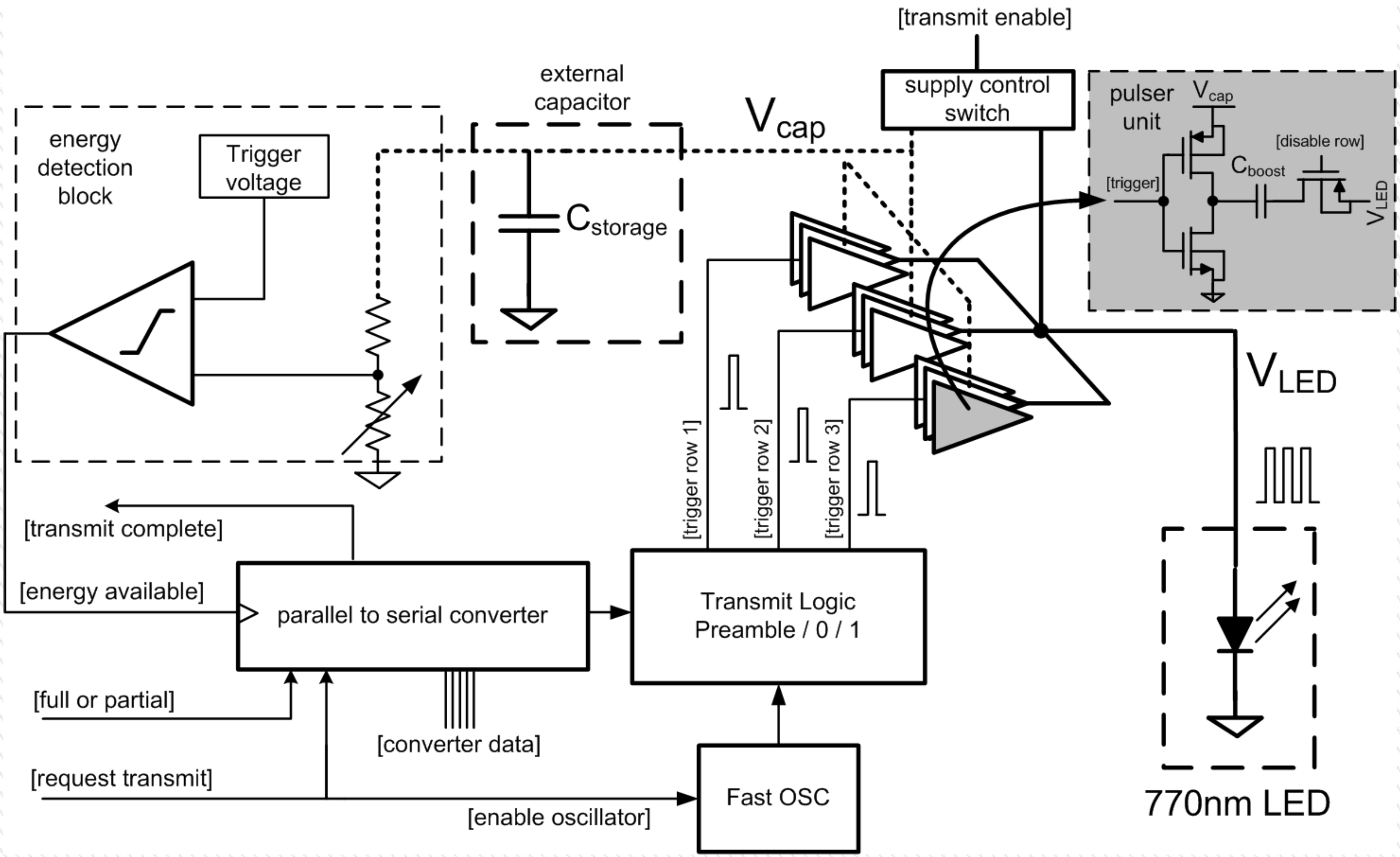
Outputs the digital temperature data after some correction processes.

Temperature Sensor Results



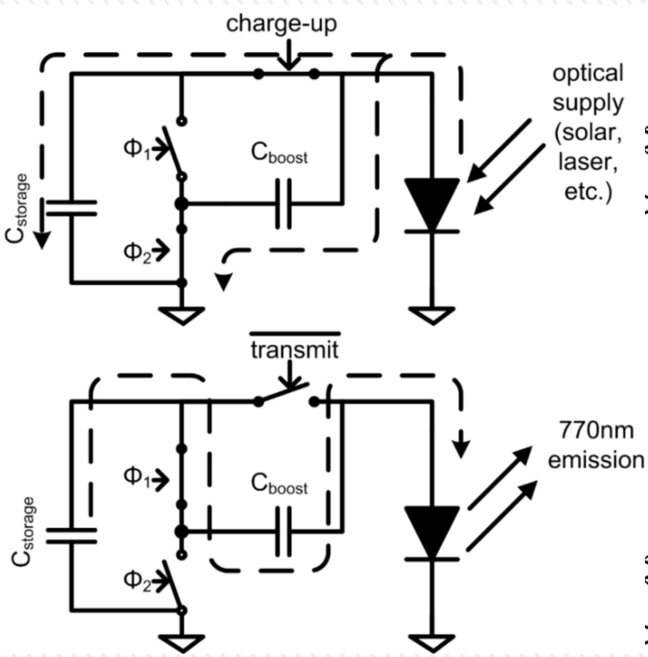
Energy consumption: as low as 3.3 nJ/conversion at rates of 1-10 kSa/s

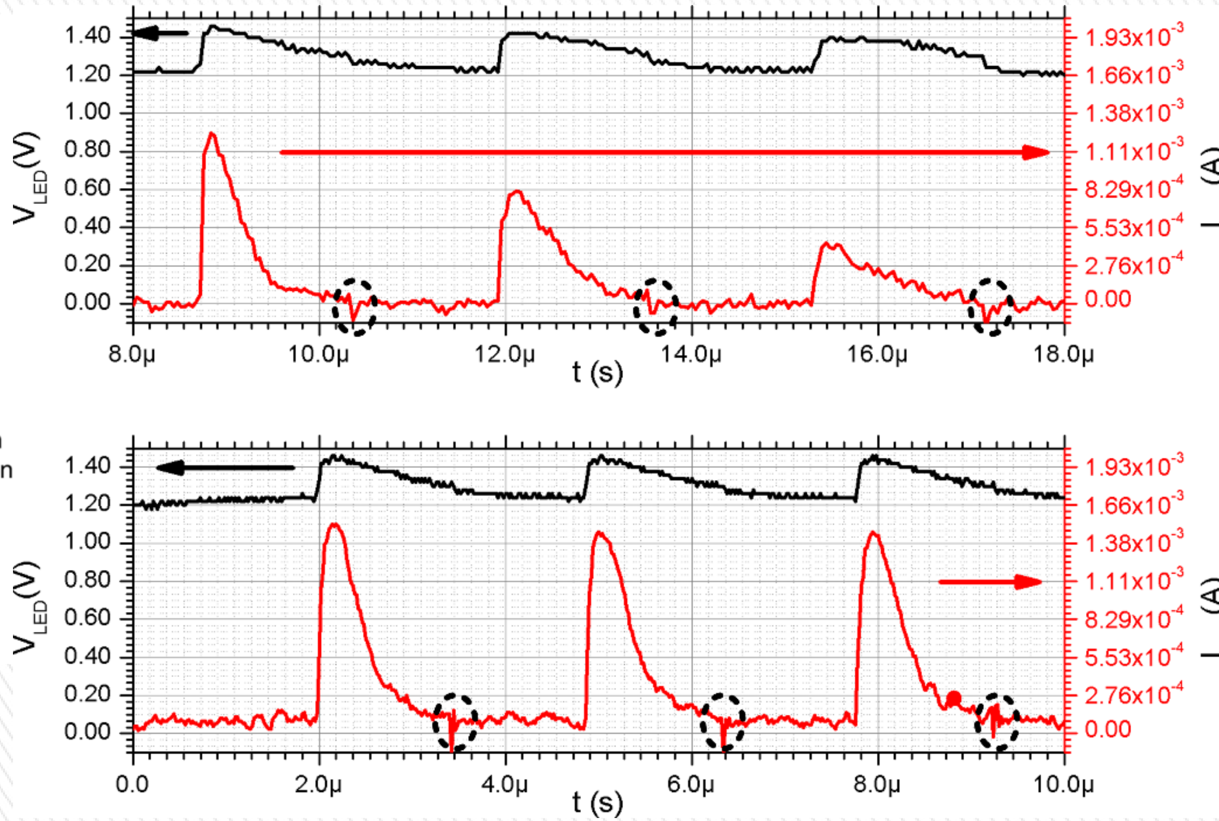
Optical Transmitter



» Pulser units are designed to be modular. They are connected in parallel to send consecutive pulses. Only one external capacitor is necessary; each row has its own dedicated internal capacitor

Voltage Boosting for LED



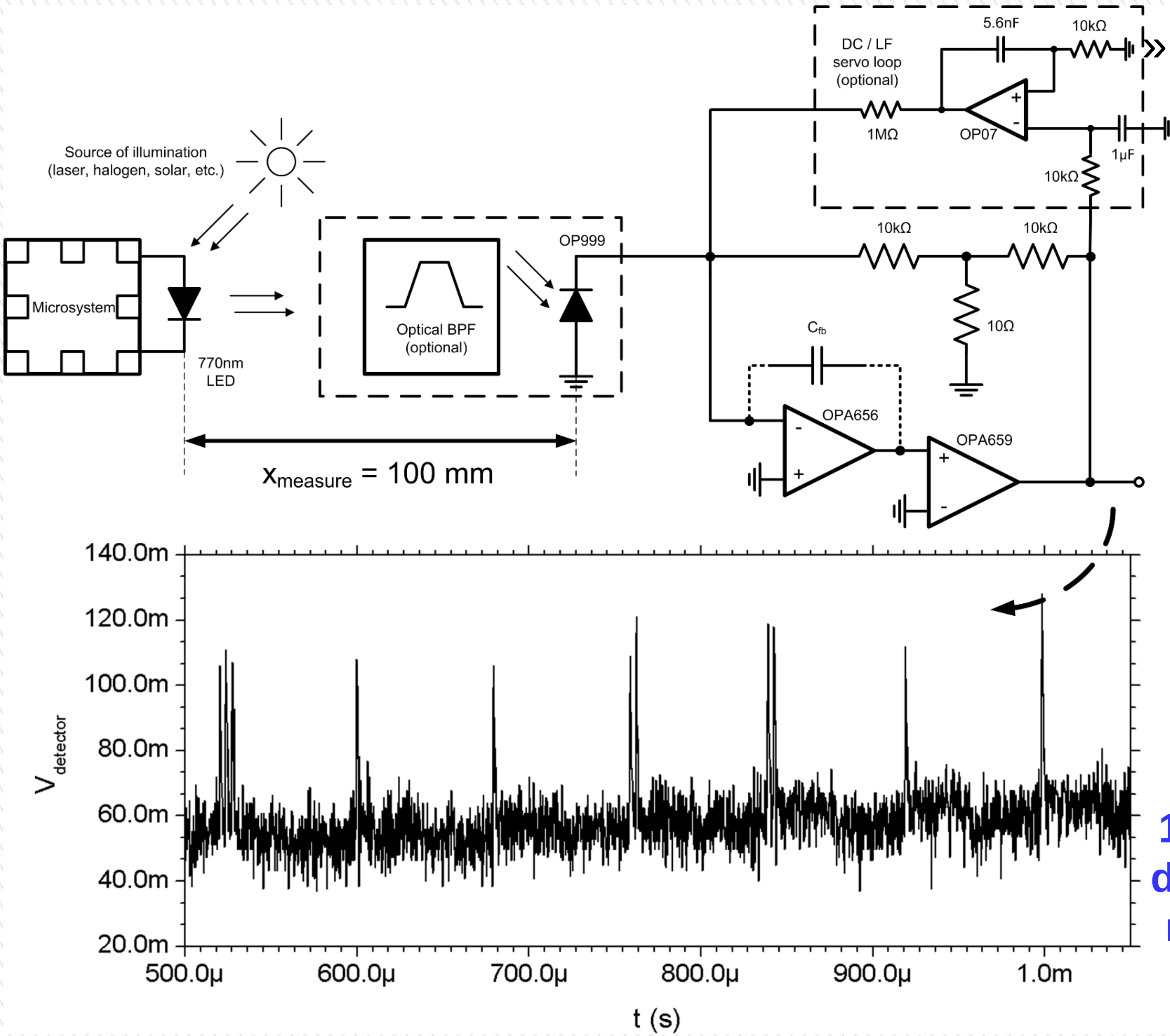


A new approach

» Let the LED current charge the capacitors by itself, then connect two capacitors in parallel.

» This boosts the total voltage instantaneously, overcoming the energy barrier for photon emission. Requires NO additional power consumption.

Optical Data Received from 10 cm



Multiple pulsers are triggered to send a stream of pulses.

Single pulse: Logic 1

Double pulses: Logic 0

Triple pulses: The preamble symbol

After all pulses are sent, capacitors are charged up again.

Energy Consumption: 1 nJ/bit

10 cm distance detection with 6 mW/mm2 light intensity.

Conclusion

» Wireless and batteryless 12 bit temperature sensing system is realized in UMC 0.18 um technology.

» System needs 5.5 µW at 1.2 V.

» 5-10µW @1.2 V is available from the LED in direct sunlight (with 325x325 µm2 area).

» A new voltage booster-transmitter circuit is realized for LED.

» LED consumes 1 nJ/bit during transmission.

» Detection from 10 cm distance is achieved using 6 mW/mm2 laser light power intensity.

Acknowledgements

Bogazici University Research Fund BAP 6037, 6520 and 7640 and State Planning Organization TAM Project (2007K120610)

References

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» [8] E. Yablonovitch *et.al.*, *IEEE J. Photovolt.*, vol. 2, no. 3, pp. 303–311, Jul. 2012.