

Redes de sensores inalámbricos (RSI)

Plataformas de hardware

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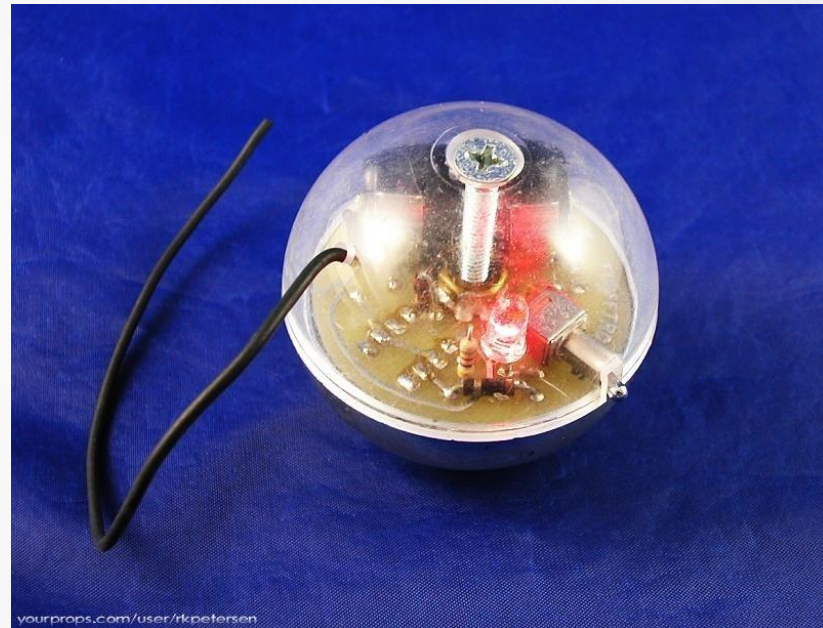
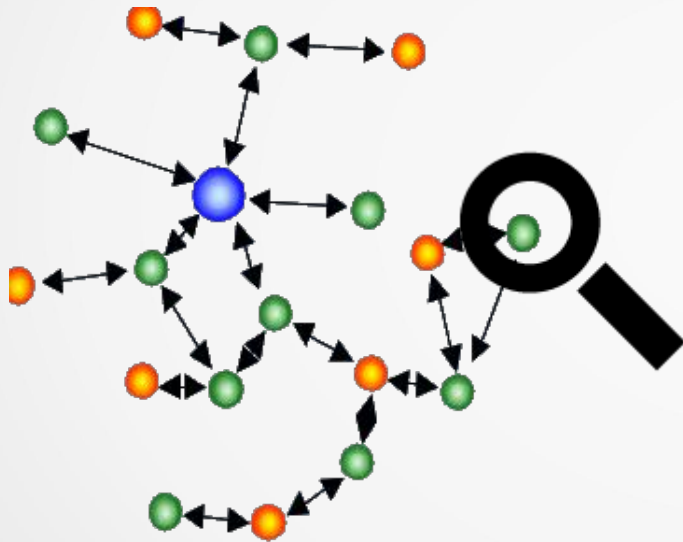
Objetivos

- Introducir la arquitectura de hardware de un nodo.
- Describir las funciones de cada subsistema.
- Dar ejemplos de implementación de cada uno.
- Describir soluciones concretas de nodo, especialmente las utilizadas en el curso.

Agenda

- Introducción: nodo
- Subsistemas o bloques constitutivos del nodo
 - Radio
 - Sensores
 - Alimentación
 - Microcontrolador
- Plataformas de hardware
 - utilizadas en el curso (kits)
 - otras (proyectos y productos)

Introducción



Nodos: requerimientos

- Características
 - bajo *todo*



costo

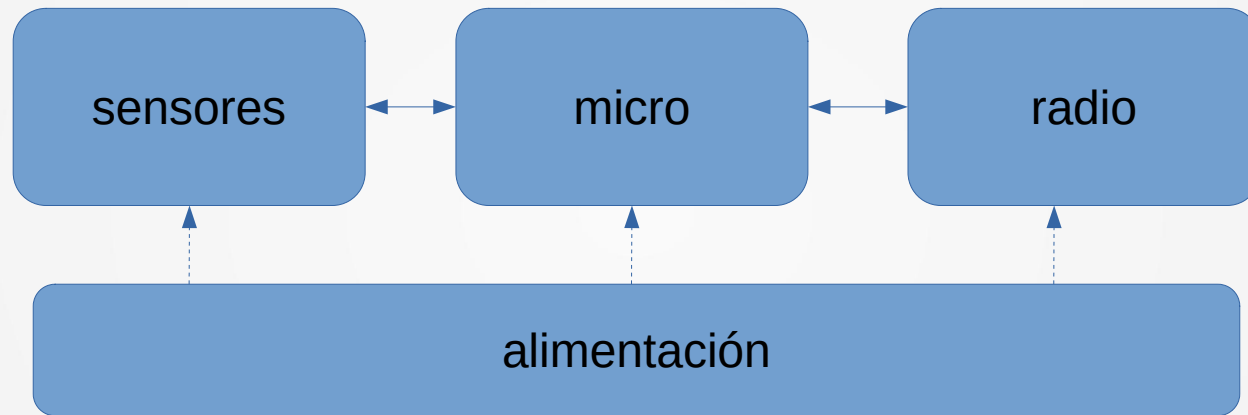


tamaño

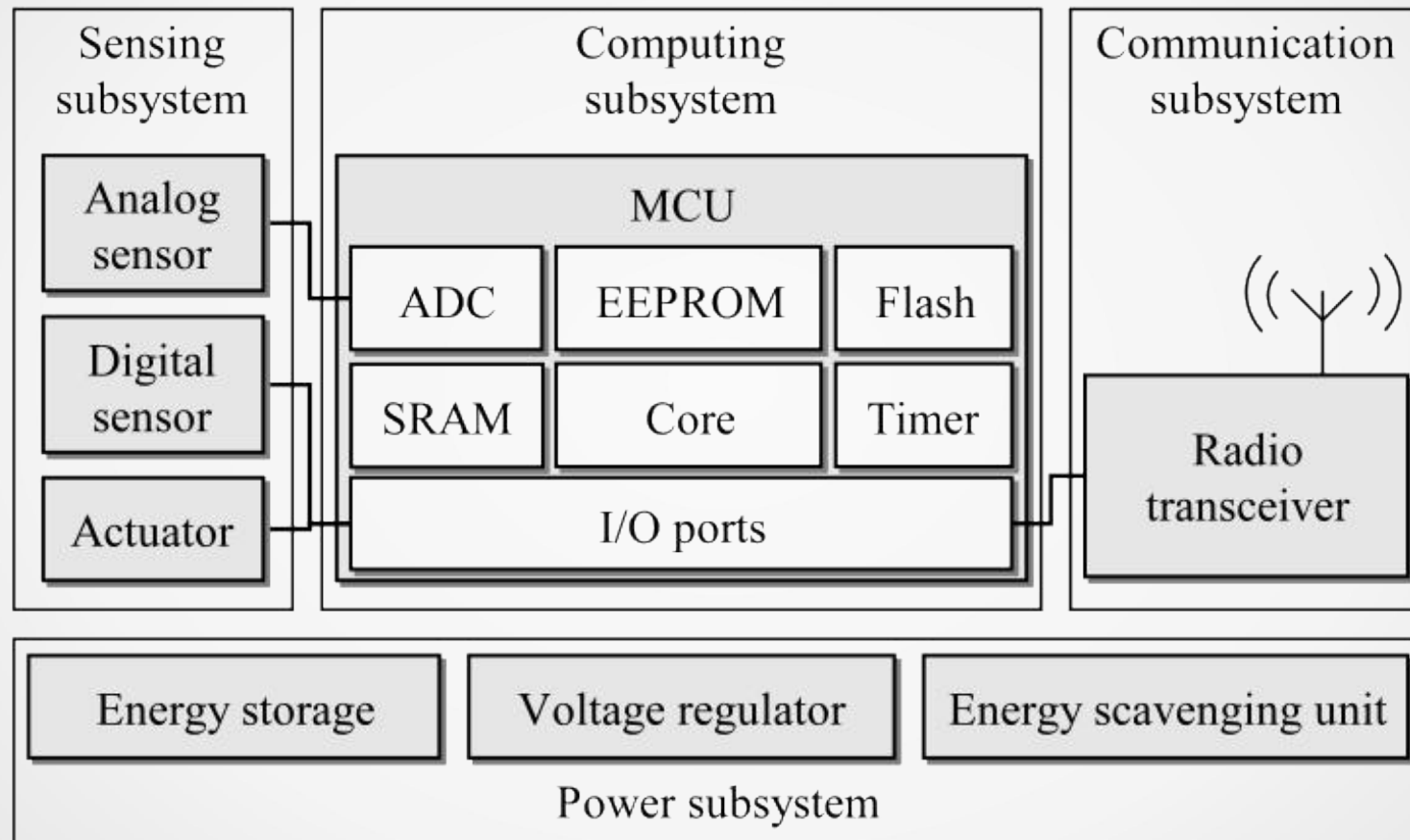


consumo

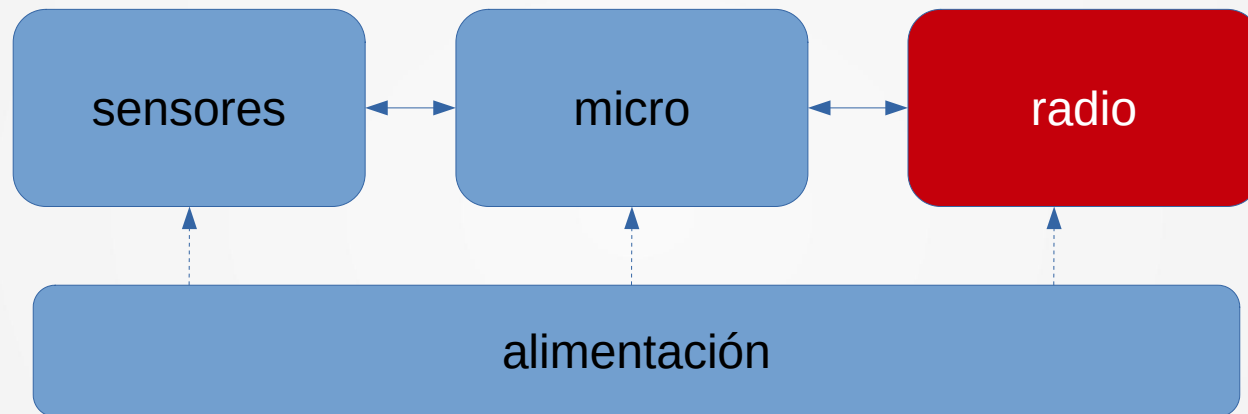
Nodo: diagrama de bloques



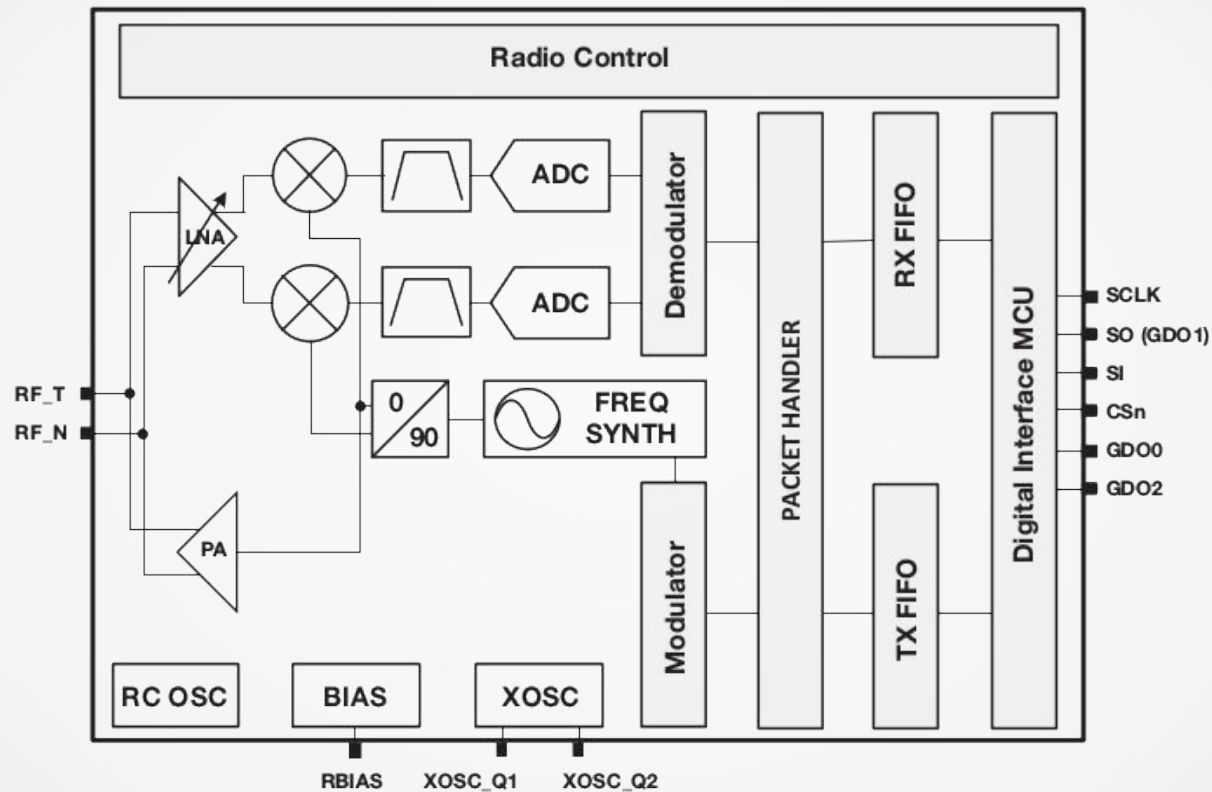
Nodo: diagrama de bloques detallado



Nodo: radio

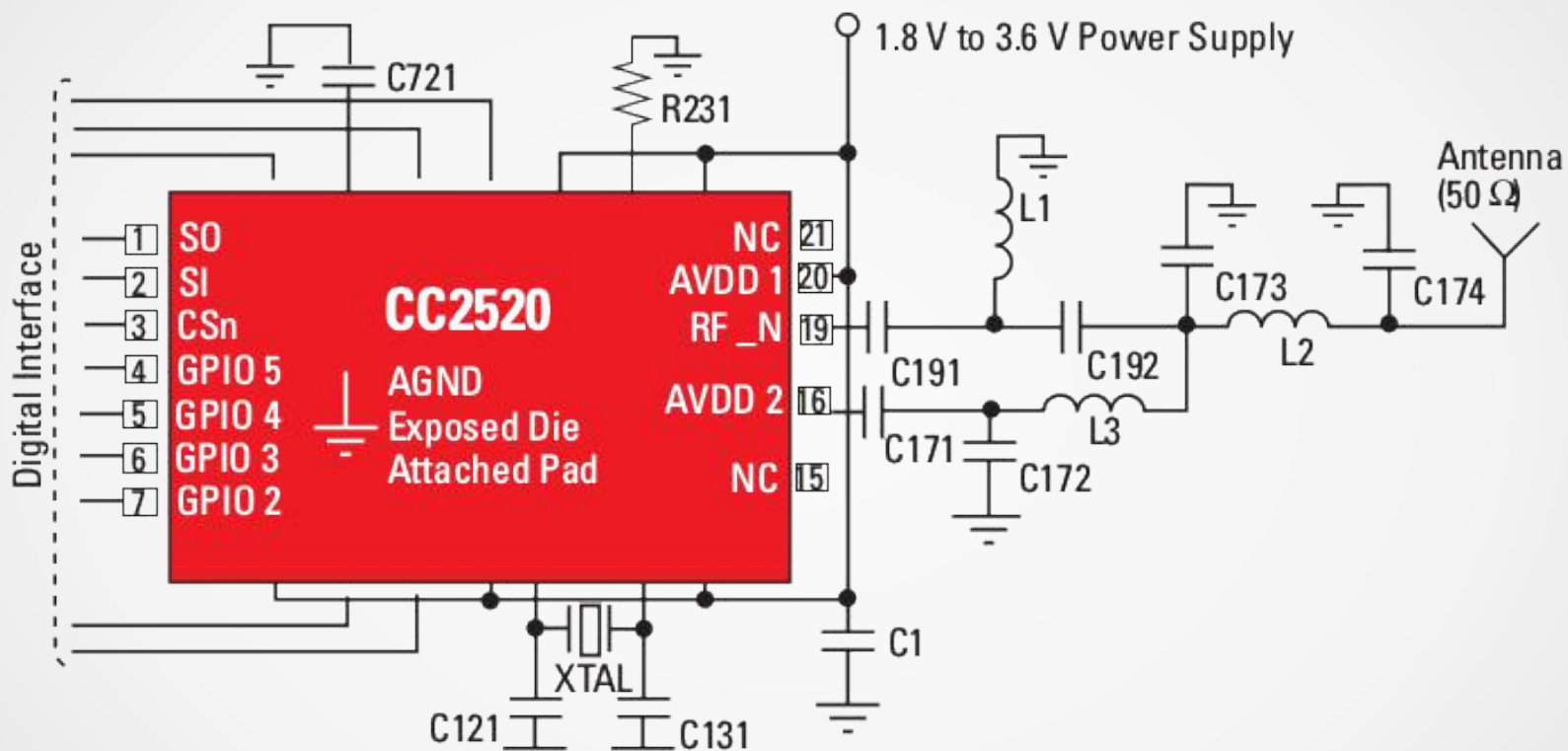


Radio: diagrama de bloques



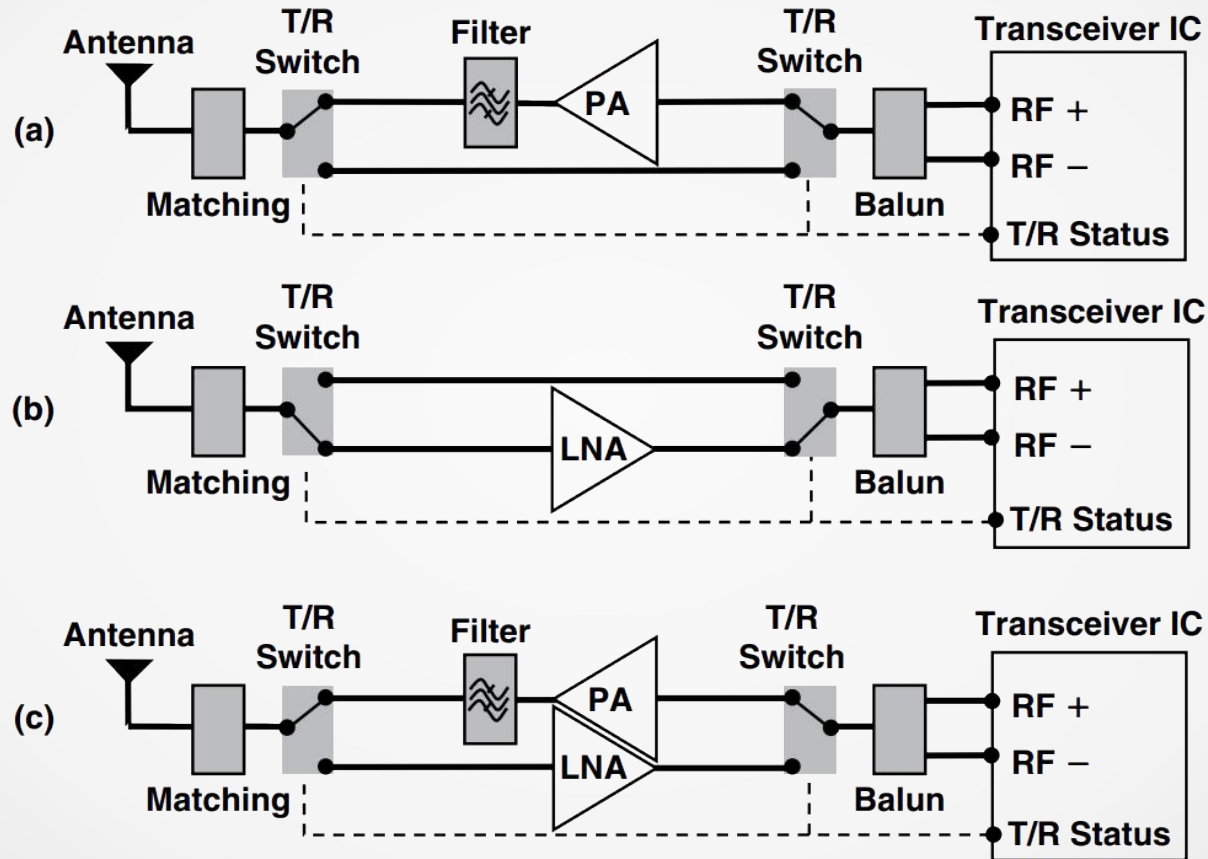
CC110L block diagram.

Radio: circuito de aplicación (CC2520)

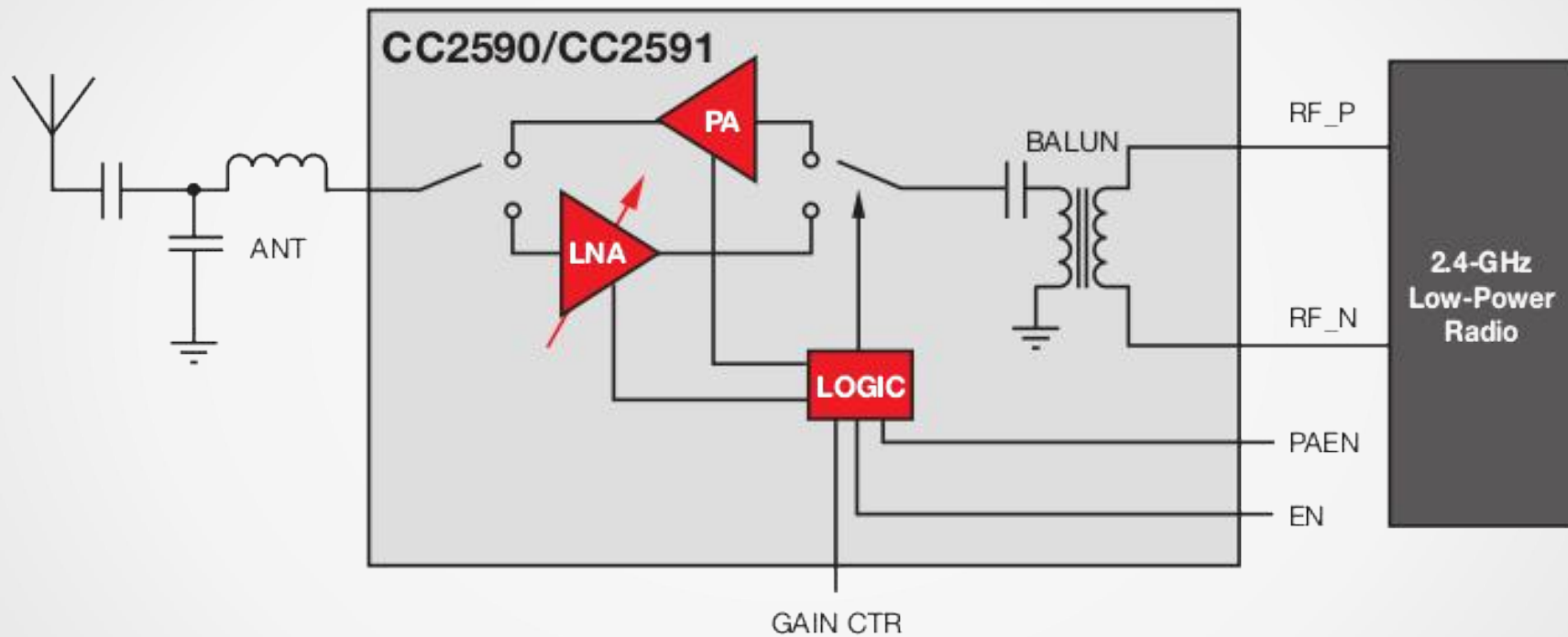


CC2520 application circuit.

Radio: PA/LNA (power & low noise amp.)

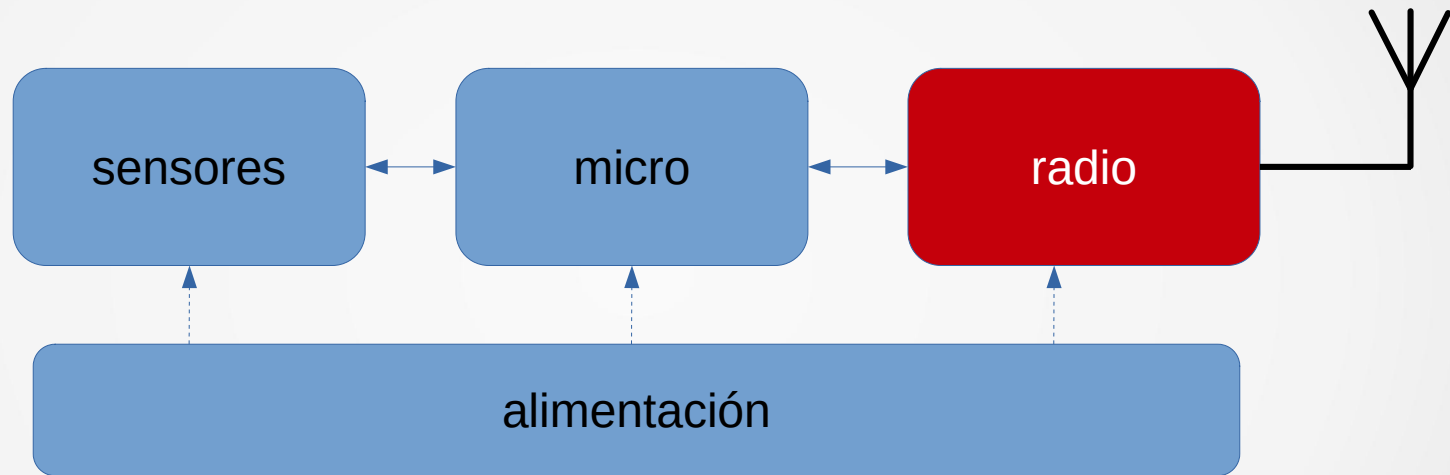


Radio: PA/LNA ejemplo



CC2590/CC2591 block diagram.

Nodo: antena






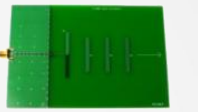



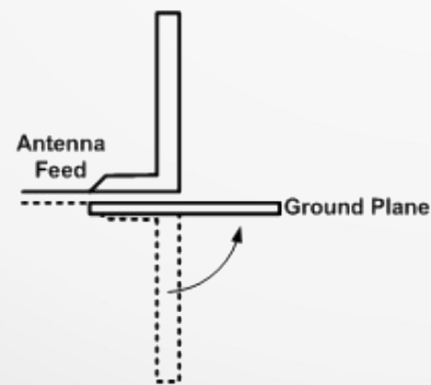
Antenas



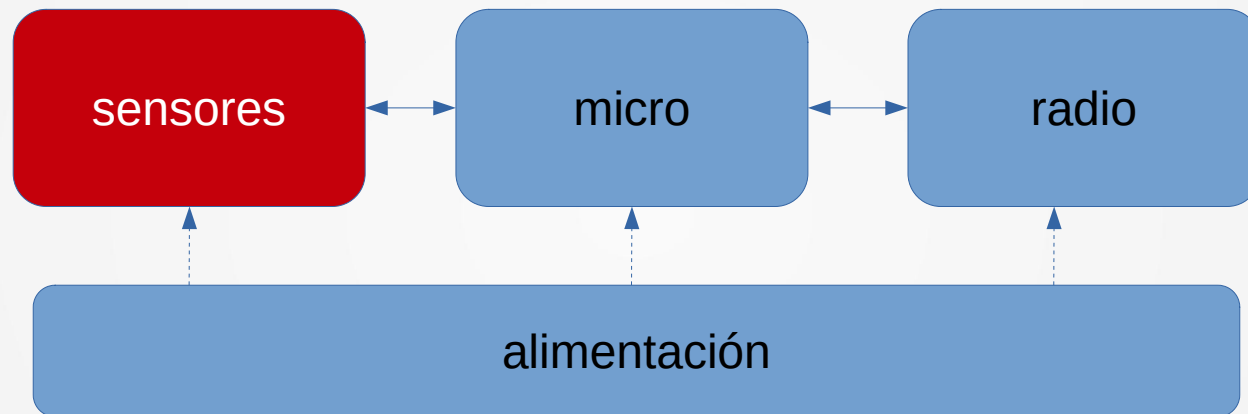
Antenna Selection Quick Guide

DN035

							
Design / Application Note	DN007 *1	AN043 *2	DN004	DN041	DN024	DN034	AN048
Frequency	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz
Typical Efficiency	80%(EB) 94%(SA)	68%(EB)	80%(EB)	65%(Zlight2)	76%(EB) 94%(SA)	72%(SA)	55%(USB)
Bandwidth@ VSWR 2:0	280 MHz	101 MHz	100 MHz	150 MHz	354 MHz (SA)	497 MHz	150 MHz
Dimensions (mm)	26 x 8	15 x 6	46 x 9	45 x 2.5	38 x 25	150 x 100	7 x 3



Nodo: sensores



Sensores: clasificación

- transductor: magnitud física
 - Temperatura y humedad del aire
 - Luz
 - etc.
- interfaz eléctrica
 - analógica: 0-Vcc, 4-20mA, etc.
 - digital: SPI, I2C, etc.
- diferentes “gama”
 - aficionado (hobbyist)
 - industrial

Sensores: temp. & humedad (SH11)

- Temperature & Humidity: Sensirion® SHT11
 - Temperature
 - Range: -40 ~ 123.8 °C
 - Resolution: : ± 0.01 (typical)
 - Accuracy: ± 0.4 °C (typical)
 - Humidity
 - Range: 0 ~ 100% RH
 - Resolution: 0.05 (typical)
 - Accuracy: ± 3 %RH (typical)



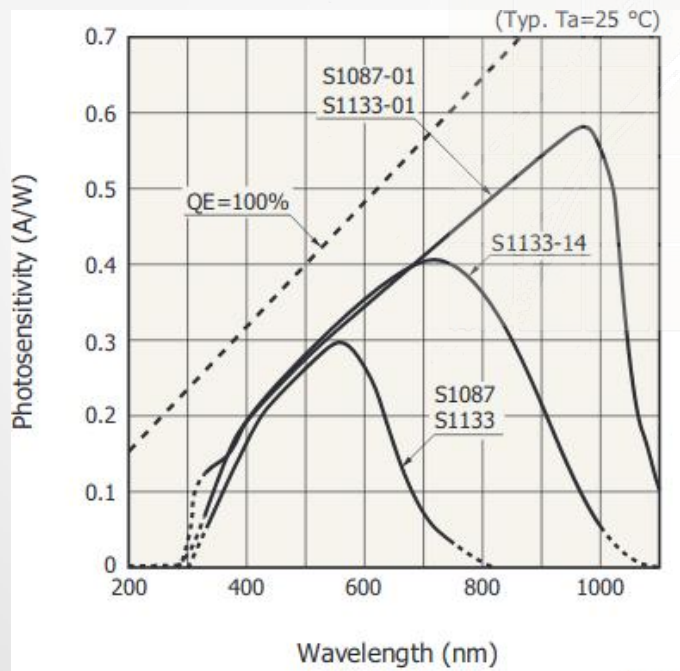
SHT11
Sensirion



TMP75C
Texas Instruments

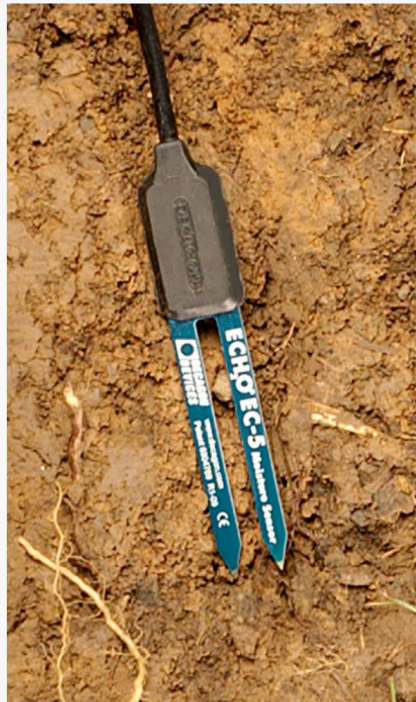
Sensores: luz (S1087)

- Light: Hamamatsu® S1087 Series
 - Visible & Infrared Range
 - 560 nm & 960 nm peak sensitivity wavelength



Sensores: humedad de suelo (decagon)

- Decagon
 - EC-05
 - 10-HS



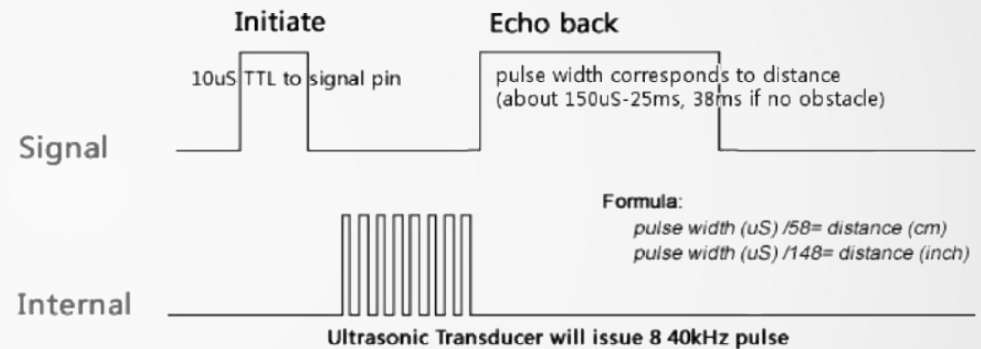
EC-05 (Decagon)



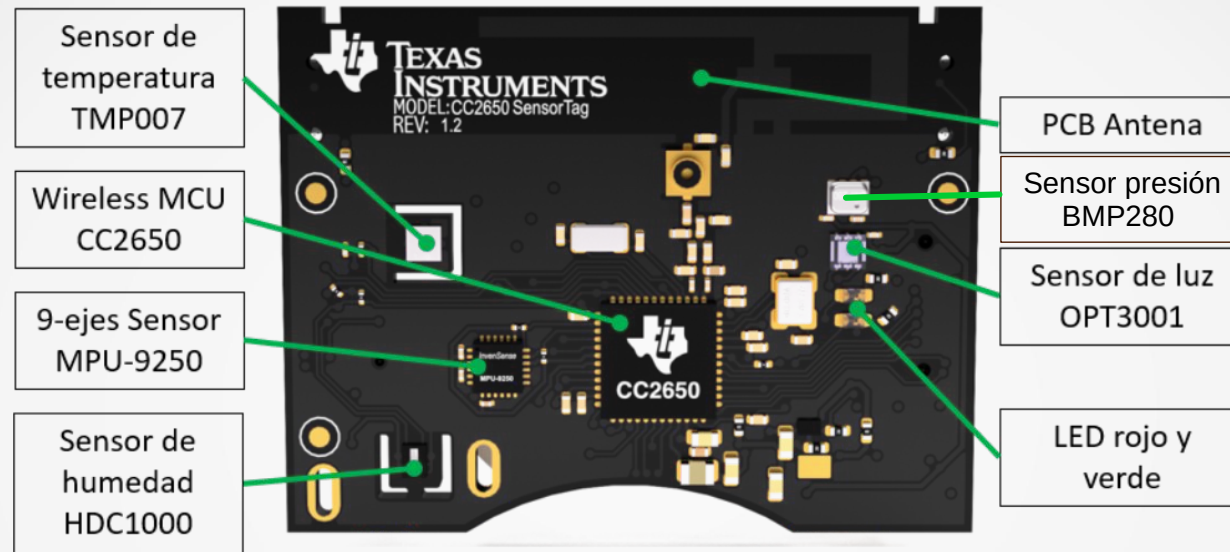
10-HS (Decagon)

Sensores: distancia (ultrasonido)

- HC-SR04
 - Power Supply :+5V DC
 - Current:
 - Quiescent <2mA;
 - Working: 15mA
 - Effectual Angle: <15°
 - Ranging Distance : 2cm – 400 cm
 - Resolution : 0.3 cm
 - Trigger Input Pulse width: 10uS



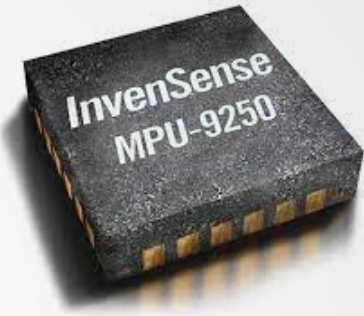
Sensores: kit Sensortag (TI)



- **TMP007** (TMP007)
- **MPU-9250** (TDK Invens.)
- **HDC1000** (Texas Inst.)
- **BMP280** (Bosh)
- **OPT3001** (Texas Inst.)

Sensor: MPU-9250

- System in Package (SiP con dos chips)
 - MPU-6500
 - 3-axis gyroscope
 - 3-axis accelerometer
 - onboard Digital Motion Processor™ (DMP™)
 - MotionFusion algorithms
 - AK8963
 - 3-axis digital compass.



Sensor: barométrico (presión)

- BMP280 (Bosh)



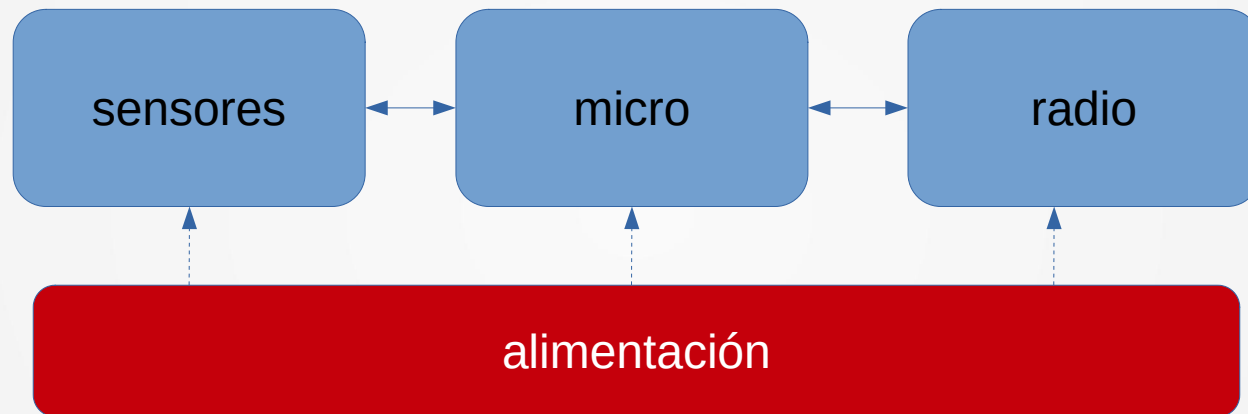
BMP280 TARGET APPLICATIONS

- ▶ Enhancement of GPS navigation (e.g. time-to-first-fix improvement, dead-reckoning, slope detection)
- ▶ Indoor navigation (floor detection, elevator detection)
- ▶ Outdoor navigation, leisure and sports applications
- ▶ Weather forecast
- ▶ Vertical velocity indication (e.g. rise/sink speed)

BMP280 (preliminary) Technical data

Package dimensions	8-pin LGA with metal 2.0 x 2.5 x 0.95 mm ³
Operation range (full accuracy)	Pressure: 300 ... 1100 hPa Temperature: 0 ... +65 °C
Supply voltage V _{DDIO}	1.2 ... 3.6 V
Supply voltage V _{DD}	1.71 ... 3.6 V
Interface	PC and SPI
Average current consumption (typ.) (1 Hz data refresh rate)	2.74 μA (ultra-low power mode)
Average current consumption in sleep mode	0.1 μA
Average measurement time	5.5 msec (ultra-low power preset)
Resolution of data	Pressure: 0.18 Pa (equiv. to <10 cm) Temperature: 0.01 K
Absolute accuracy P = 950 ... 1100 hPa (T = 0 ... +65 °C)	~ ±1 hPa
Relative accuracy pressure (typ.) p=950 ... 1050 hPa (+25 °C)	± 0.12 hPa (equiv. to ±1 m)
Temperature coefficient offset (+25° ... +40 °C @900hPa)	1.5 Pa/K (equiv. to 12.6 cm/K)

Nodo: alimentación



Alimentación: soluciones

- Pilas (baterías primarias)
 - autonomía limitada, sin embargo
 - si muy bajo consumo: pila ~ dispositivo
- Recolección + almacenamiento + conversor tensión
 - funcionamiento sin interrupciones
 - computación intermitente
- Alimentación de red eléctrica

Alimentación: pilas (battery)

PRODUCT DATASHEET

ENERGIZER E91



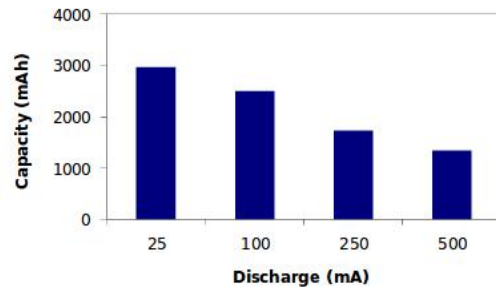
AA

Specifications

Classification:	Alkaline
Chemical System:	Zinc-Manganese Dioxide (Zn/MnO ₂) No added mercury or cadmium
Designation:	ANSI-15A, IEC-LR6
Nominal Voltage:	1.5 volts
Nominal IR:	150 to 300 milliohms (fresh)
Operating Temp:	-18°C to 55°C (0°F to 130°F)
Typical Weight:	23.0 grams (0.8 oz.)
Typical Volume:	8.1 cubic centimeters (0.5 cubic inch)
Jacket:	Plastic Label
Shelf Life:	10 years at 21°C
Terminal:	Flat Contact

Milliamp-Hours Capacity

Continuous discharge to 0.8 volts at 21°C





PRODUCT DATASHEET

ENERGIZER L91 Ultimate Lithium



AA

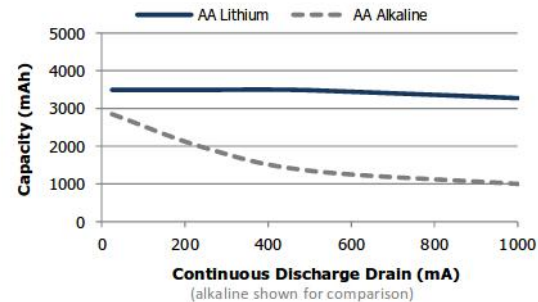
Specifications

Classification:	"Cylindrical Primary Lithium"
Chemical System:	Lithium/Iron Disulfide (Li/FeS ₂)
Designation:	ANSI 15-LF, IEC-FR14505 (FR6)
Nominal Voltage:	1.5 Volts
Sizing Compatibility:	E91 NH15 1215
Storage Temp:	-40°C to 60°C (-40°F to 140°F)
Operating Temp:	-40°C to 60°C (-40°F to 140°F)*
Typical Weight:	15 grams (0.5 oz.)
Typical Volume:	8.0 cubic centimeters (0.49 cubic inch)
Max Discharge:	2.5 amps continuous 4.0 amps pulse (2 sec on / 8 sec off)
Lithium Content:	Less than 1 gram
Typical IR:	120 to 240 milliohms (depending on method)
Shelf Life:	20 years at 21°C
More Details:	On-Line Catalog-Application Manual (Li/FeS ₂)
Shipping:	Please refer to PSDS Document
Certifications:	  This battery has Underwriters Laboratories component recognition (MH29980) II IC Ex Ia IIC Ga BaseEq 14ATEX0107U

*All data shown tested at 21°C unless otherwise stated.

Milliamp-Hours Capacity

Constant Current Discharge to 0.8 Volts

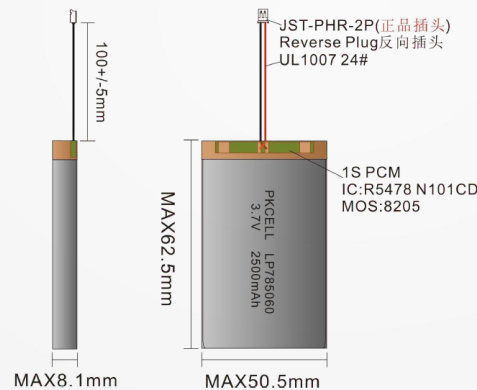
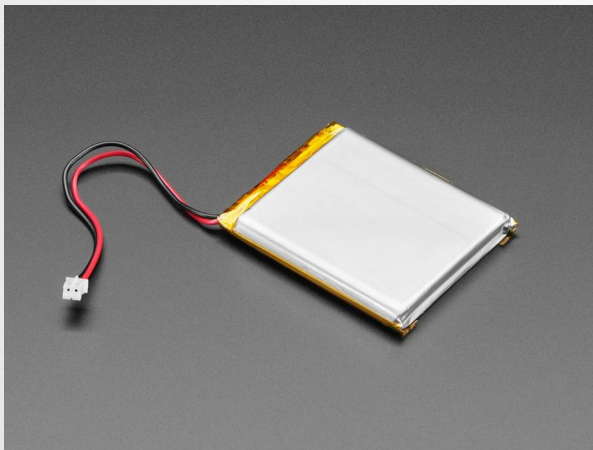


Alimentación

- Recolección de energía
 - solar
 - vibraciones
 - temperatura (diferencia)
 - eólica (micro molinos)
- Almacenamiento de energía
 - baterías recargables
 - supercondensadores
- Conversión de tensión / cargador
 - V_o (almacenamiento) \rightarrow V_{in} (dispositivo)

Alimentación: batería recargable

- Ejemplo
 - Lithium Ion Polymer Battery 3.7V 2500mAh



<https://www.adafruit.com/category/574>

Power / Lilon & LiPoly / Batteries

	Lithium Ion Battery - 3.7V 2000mAh PRODUCT ID: 2019 Lithium-ion polymer (also known as 'lipo' or 'lipoly') batteries are thin, light, and powerful. The output ranges from 4.2V when completely charged to 3.7V. This battery has a capacity of 2000mAh. If you need a larger (or smaller) battery, we have a full range of LiPoly batteries. The batteries come pre-attached with a genuine 2-pin JST-PH connector as shown and...	Notify Me \$12.50 Out of stock
	Lithium Ion Polymer Battery Ideal For Feathers - 3.7V 400mAh PRODUCT ID: 2898 Lithium-ion polymer (also known as 'lipo' or 'lipoly') batteries are thin, light, and powerful. The output ranges from 4.2V when completely charged to 3.7V. This battery has a capacity of 400mAh for a total of about 1.9 Wh. If you need a larger (or smaller) battery, we have a full range of LiPoly batteries. The batteries come pre-attached with a genuine 2-pin 25mm...	Notify Me \$6.95 Out of stock
	Lithium Ion Polymer Battery - 3.7v 1200mAh PRODUCT ID: 228 Lithium-ion polymer (also known as 'lipo' or 'lipoly') batteries are thin, light, and powerful. The output ranges from 4.2V when completely charged to 3.7V. This battery has a capacity of 1200mAh for a total of about 4.5 Wh. If you need a larger battery, we also have a 2500mAh+ model. The batteries come pre-attached with a 2-pin JST-PH connector as shown and include...	Notify Me \$9.95 Out of stock
	Lithium Ion Polymer Battery - 3.7v 500mAh PRODUCT ID: 1578 Lithium-ion polymer (also known as 'lipo' or 'lipoly') batteries are thin, light, and powerful. The output ranges from 4.2V when completely charged to 3.7V. This battery has a capacity of 500mAh for a total of about 1.9 Wh. If you need a larger (or smaller) battery, we have a full range of LiPoly batteries. The batteries come pre-attached with a 2-pin JST-PH...	Notify Me \$7.95 Out of stock
	Lithium Ion Polymer Battery - 3.7v 2500mAh PRODUCT ID: 328 Lithium-ion polymer (also known as 'lipo' or 'lipoly') batteries are thin, light, and powerful. The output ranges from 4.2V when completely charged to 3.7V. This battery has a capacity of 2500mAh for a total of about 10 Wh. If you need a smaller battery, we also have a 1200mAh model. The batteries come pre-attached with a genuine 2-pin JST-PH connector as shown and...	Notify Me \$14.95 Out of stock
	Lithium Ion Polymer Battery - 3.7v 100mAh PRODUCT ID: 1570 Lithium-ion polymer (also known as 'lipo' or 'lipoly') batteries are thin, light, and powerful. The output ranges from 4.2V when completely charged to 3.7V. This battery has a capacity of 100mAh for a total of about 0.4 Wh. If you need a larger battery, we have a full range of bigger cells. The batteries come pre-attached with a genuine 2-pin JST-PH connector as...	Notify Me \$5.95 Out of stock

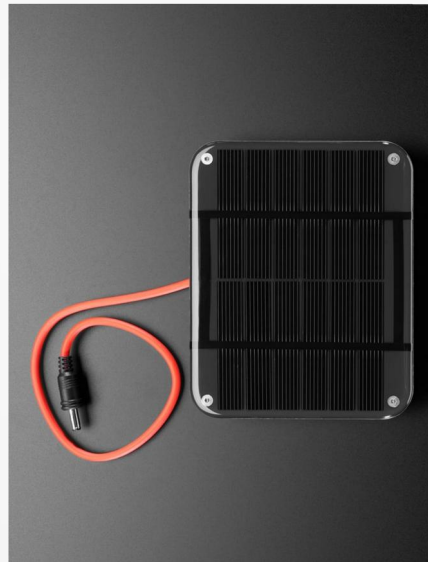
<https://www.adafruit.com/product/328>

Alimentación: panel solar

- Ejemplo:
 - Small 6V 1W Solar Panel

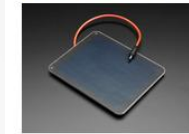
Output

- Open Circuit Voltage: 7.7V
- Peak Voltage: 6.5V
- Peak Current: 180mA
- Peak Power: 1.2W
- Power Tolerance: +/-10%



<https://www.adafruit.com/product/3809>

Power / Solar / Panels



6V 2W Solar Panel - ETFE - Voltaic P126

PRODUCT ID: 3305

These panels come to us from Voltaic Systems, makers of fine solar-powered bags and packs. These are waterproof, scratch-resistant, and UV resistant, and they use 12 high-efficiency monocrystalline SunPower cells with 22+% efficiency (praise the sun!). Each cell has a nominal voltage of 0.5V so we call this a "6V" panel! They output a nominal 6V at 330 mA peak via a...

Add to Cart

\$19.95
14 in stock



5V 10W Solar Panel - ETFE - Voltaic P110

PRODUCT ID: 3303

These panels come to us from Voltaic Systems, makers of fine solar-powered bags and packs. These are waterproof, scratch-resistant, and UV resistant, and they use 10 high-efficiency monocrystalline SunPower cells with 22+% efficiency (praise the sun!). Each cell has a nominal voltage of 0.5V so we call this a "5V" panel! They output a nominal 5V at a 1,670mA peak via...

Add to Cart

\$64.95
3 in stock



Round Solar Panel Skill Badge - 5V / 40mA

PRODUCT ID: 700

This skill badge is self-fulfilling! Normally you would get the badge after the project is done, but in this case, the badge can be part of the project! The solar panel is epoxied into a round disc 55mm diameter (about 2.2 inches), its rugged and looks cool besides. We include a sticky foam pin back you can attach to the back of the panel to mount it onto a backpack...

Add to Cart

\$2.95
11 in stock



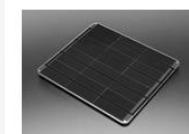
5V 1.2W Solar Panel - ETFE - Voltaic P124

PRODUCT ID: 3308

These panels come to us from Voltaic Systems, makers of fine solar-powered bags and packs. These are waterproof, scratch-resistant, and UV resistant, and they use 10 high-efficiency monocrystalline SunPower cells with 22+% efficiency (praise the sun!). Each cell has a nominal voltage of 0.5V so we call this a "5V" panel! They output a nominal 5V at 200 mA peak via a...

Add to Cart

\$14.95
33 in stock



Colossal 6V 9W Solar Panel - 9.0 Watt

PRODUCT ID: 2143

These 6 Volt, 9 Watt panels come to us from Voltaic Systems, makers of fine solar-powered bags and packs. They are waterproof, scratch resistant, and UV resistant. Using a high efficiency monocrystalline cell and outputting 6V at 1.5A via 3.5mm x 1.5mm DC jack connector, they are a nice upgrade to the 2W or 3W panels we have been carrying. The substrate is an...

Add to Cart

\$78.95
20 in stock



Solar Bug Kit 2.0 from Brown Dog Gadgets - 4 Pack

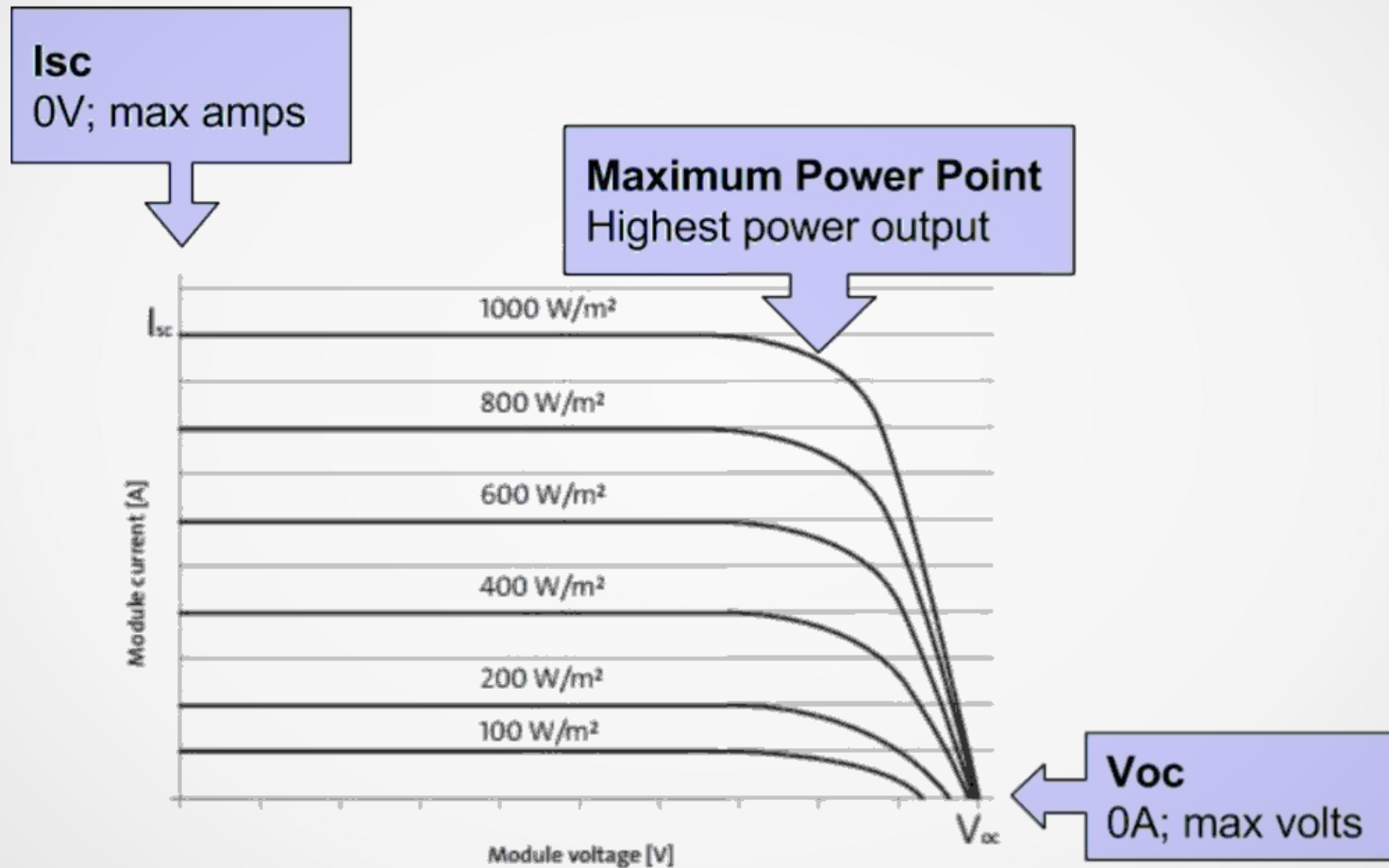
PRODUCT ID: 2415

Create multiple solar-powered insects that moves with this fun-filled STEM project from Brown Dog Gadgets! Learn about solar energy by creating a simple solar circuit in minutes using only conductive tape! Cut out your bug, decorate it, then add your solar cell and vibrating motor. All parts are connected with our special Maker Tape conductive tape, perfect for...

Add to Cart

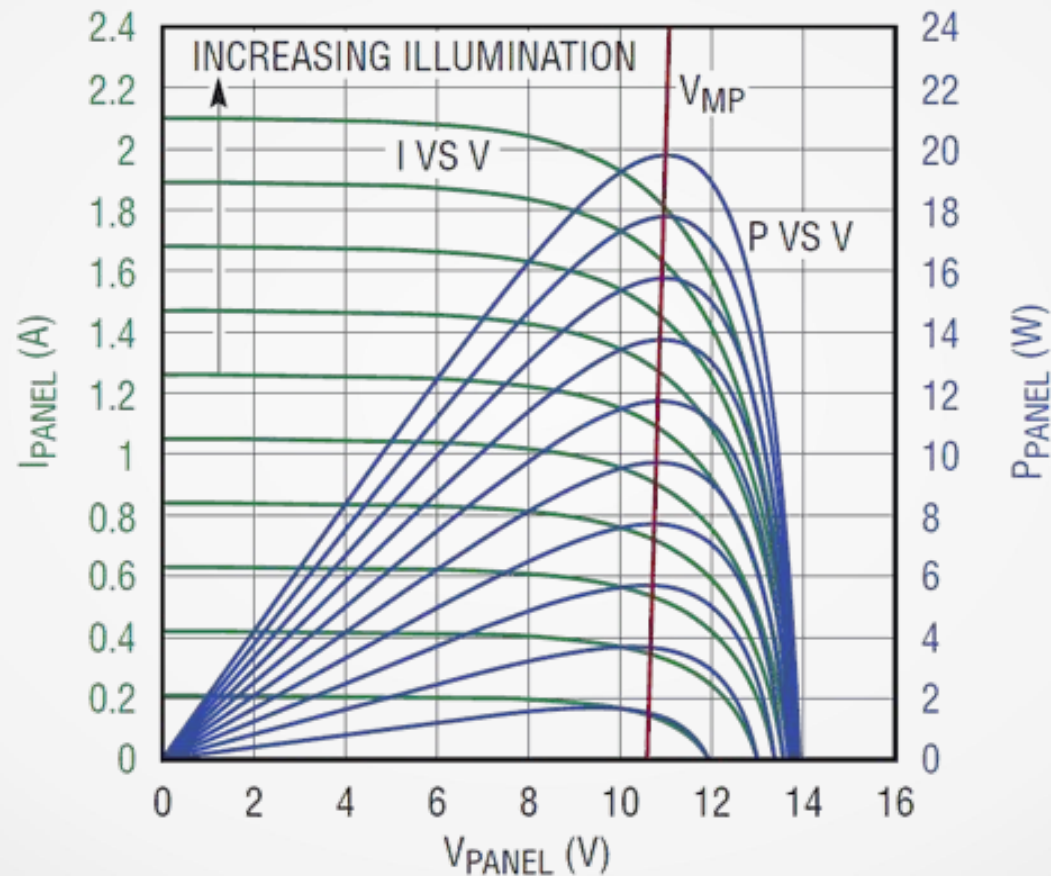
\$24.95
17 in stock

Alimentación: panel solar



<https://www.altestore.com/blog/2016/04/how-do-i-read-specifications-of-my-solar-panel/>

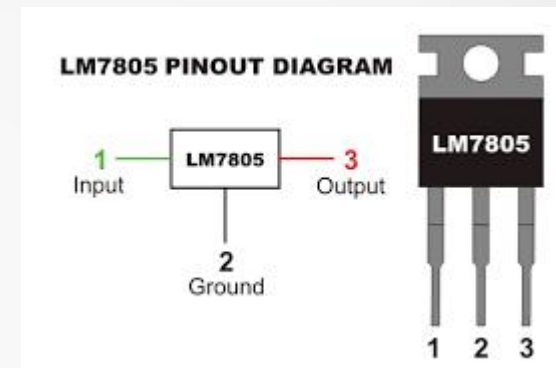
Alimentación: panel solar



<https://learn.adafruit.com/usb-dc-and-solar-lipoly-charger/design-notes>

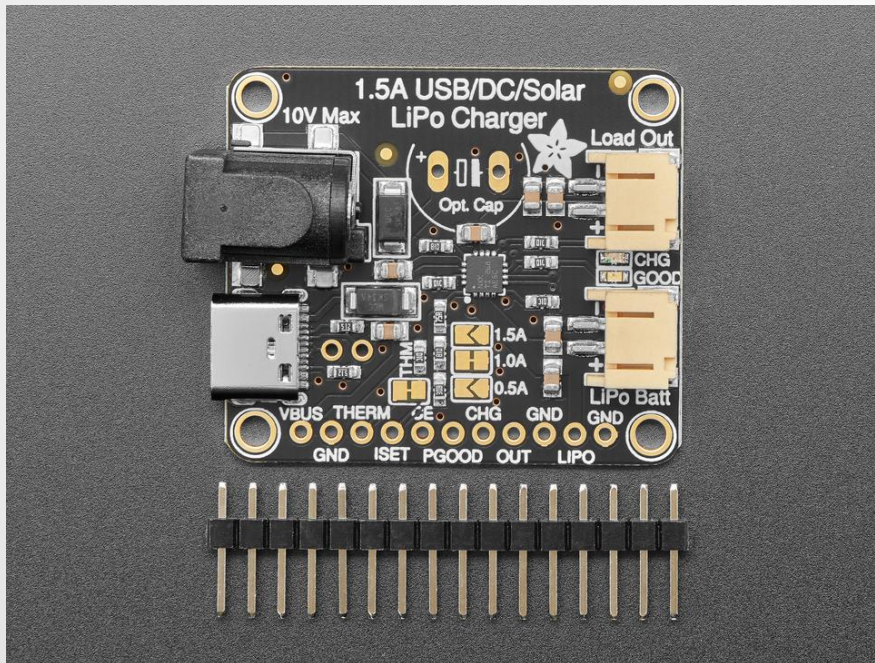
Alimentación: conversores de tensión

- Tipos
 - Reguladores lineales
 - Conmutados (DC-DC)
 - up, down, up-down
 - Cargadores (funcional. MPTT)
- Consideraciones
 - límites de tensiones
 - salida/s: fija, programables
 - eficiencia



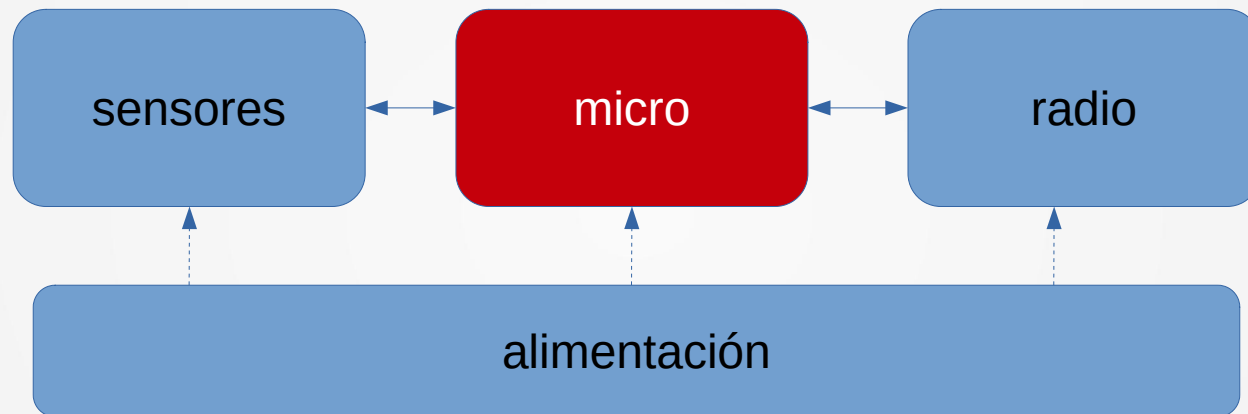
Alimentación: solución

- Ejemplo: bq24074
 - Universal USB / DC / Solar Lithium Ion/Polymer charger



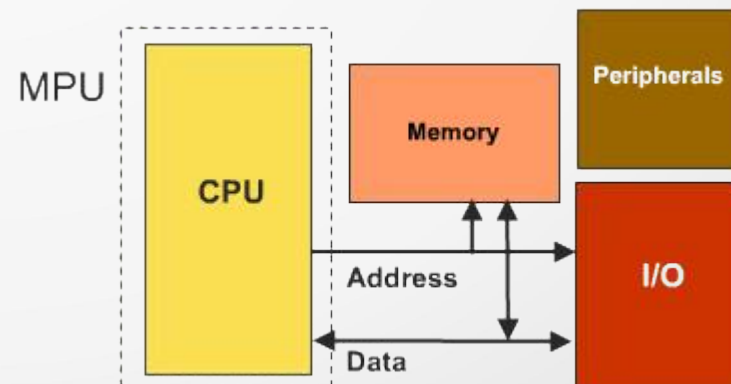
<https://www.adafruit.com/product/4755>

Nodo: microcontrolador



Microcontrolador: requerimientos

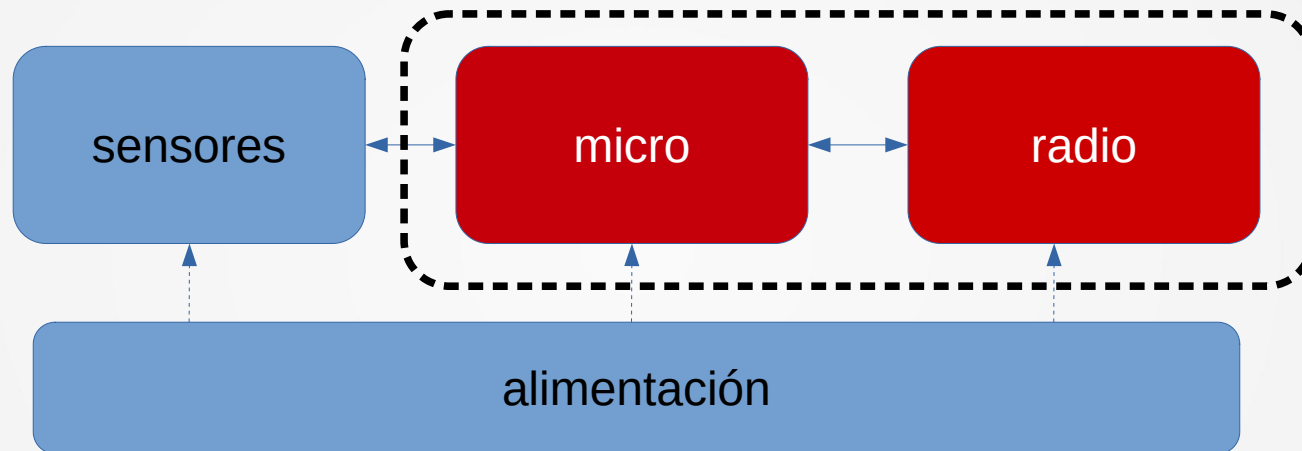
- Memoria de código: Flash, FRAM
- Memoria de datos: RAM (FRAM+cache)
- Memoria datos bulk: logs, datos, file system
- Potencia de procesamiento:
 - velocidad de reloj, arquitectura N-bits, FPU (necesario?)
- Consumo
 - modos de operación



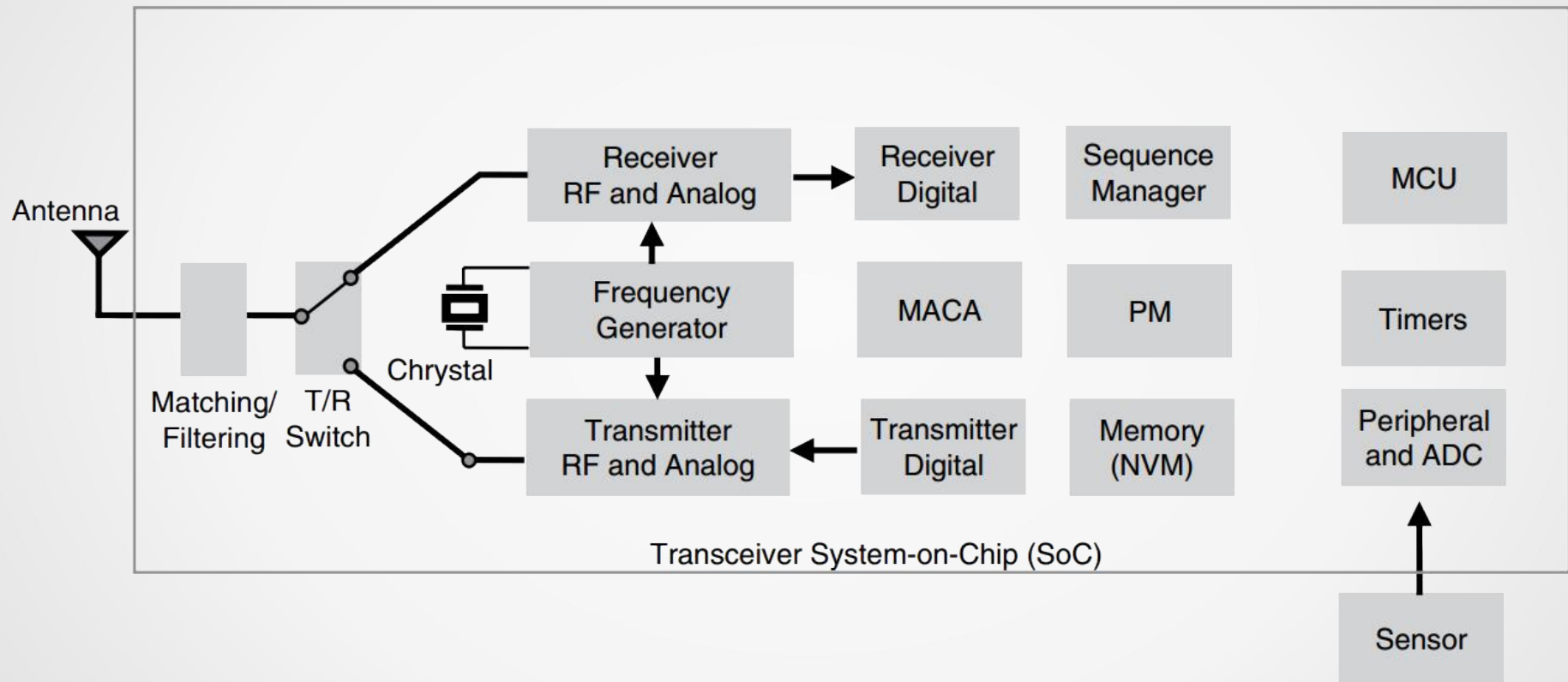
Microcontrolador

- Funciones
 - Ejecutar aplicación de usuario
 - Sistema operativo
 - Pila de comunicaciones
- Periféricos básicos y comunes
 - SPI, I2C, UART, ADC, DAC (PWM), I/O digitales
 - Otros:
 - DMA, Security Engine, MPU...

Nodo: system-on-chip (SoC)



Radio: diagrama de bloques (SoC)



Hardware: opciones “core”

- chips
 - MCU + radio
 - SoC (system-on-chip)
 - SiP (system-in-package)
- módulo
- board / kit
 - evaluation
 - developing
 - prototyping

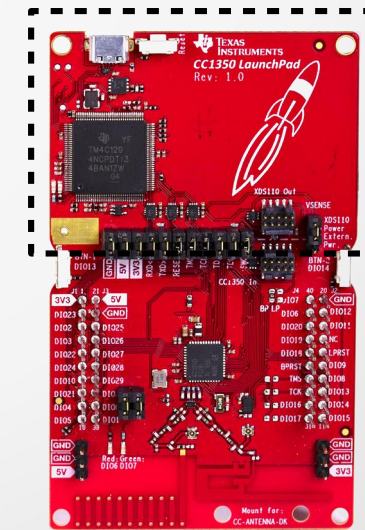
chips



módulos



boards / kits



prog.
JTAG

Recomendaciones

- Características
 - Generales
 - tensión de alimentación
 - corriente / potencia de consumo (modos)
 - duty cycle (tiempo “on” / “período”)
 - RF
 - link budget: PTx (dB), Sensibilidad
 - microcontroladores
 - memoria SRAM / Flash
 - periféricos

Nodos: ejemplos

- Plataformas de hardware: nodos/kits
 - sky (2011-2022?)
 - remote-b (2017-2022?)
 - launchpad sensortag (2023-...)
- Proyectos
 - Proyecto INIA-FPTA
 - Monitoreo microclimático
 - Proyecto fin de carrera:
 - Sistema de Monitoreo y Control de Cultivo Indoor de Cannabis

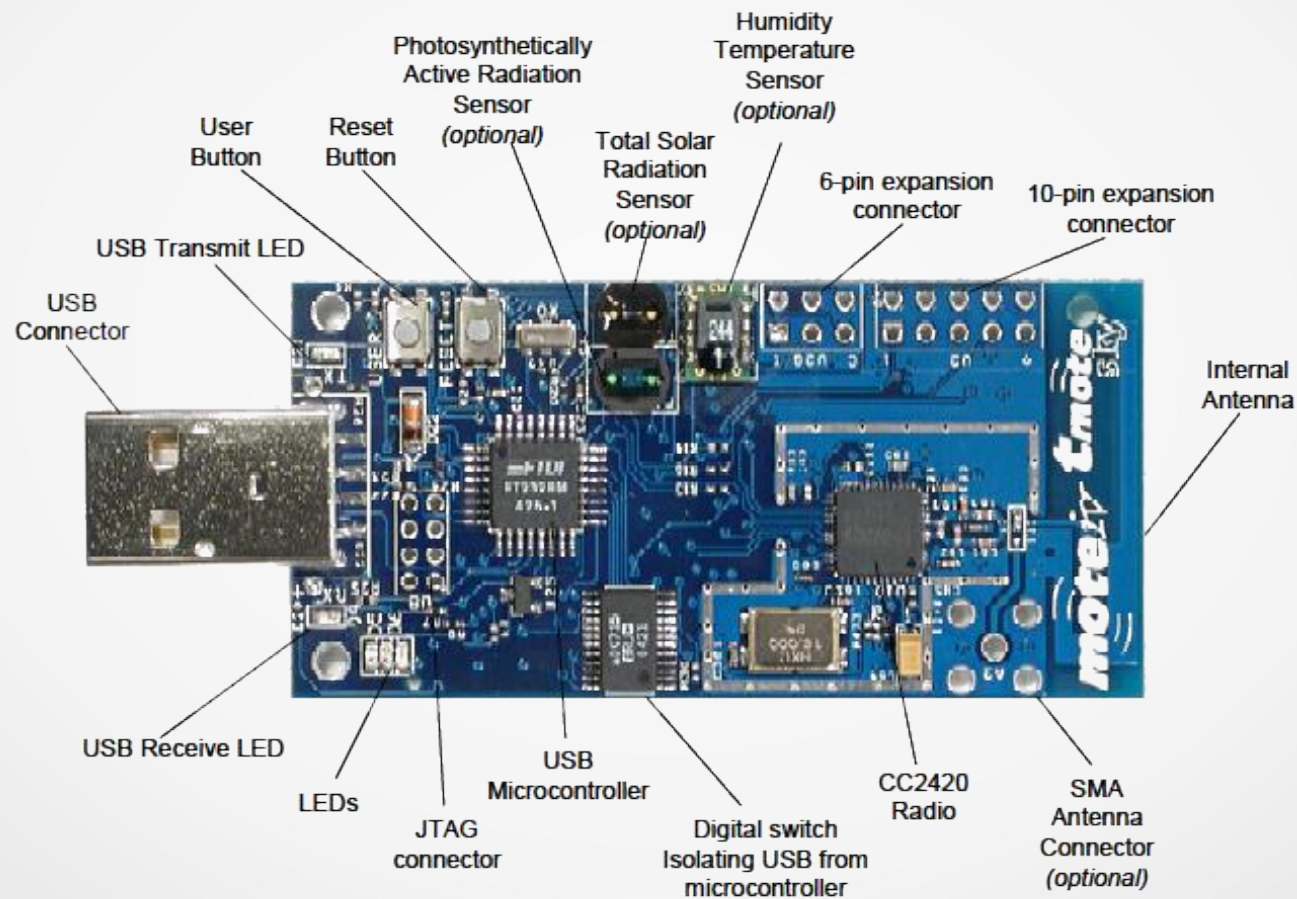
Nodo: sky

- **sky / telosB compatible: tmotesky, CM5000**
 - Micro: MSP430F1611
 - Radio: CC2420
 - Sensores:
 - Light 1: Visible Range
 - Light 2: Visible & Infrared Range
 - Temperature & Humidity Sensirion® SHT11



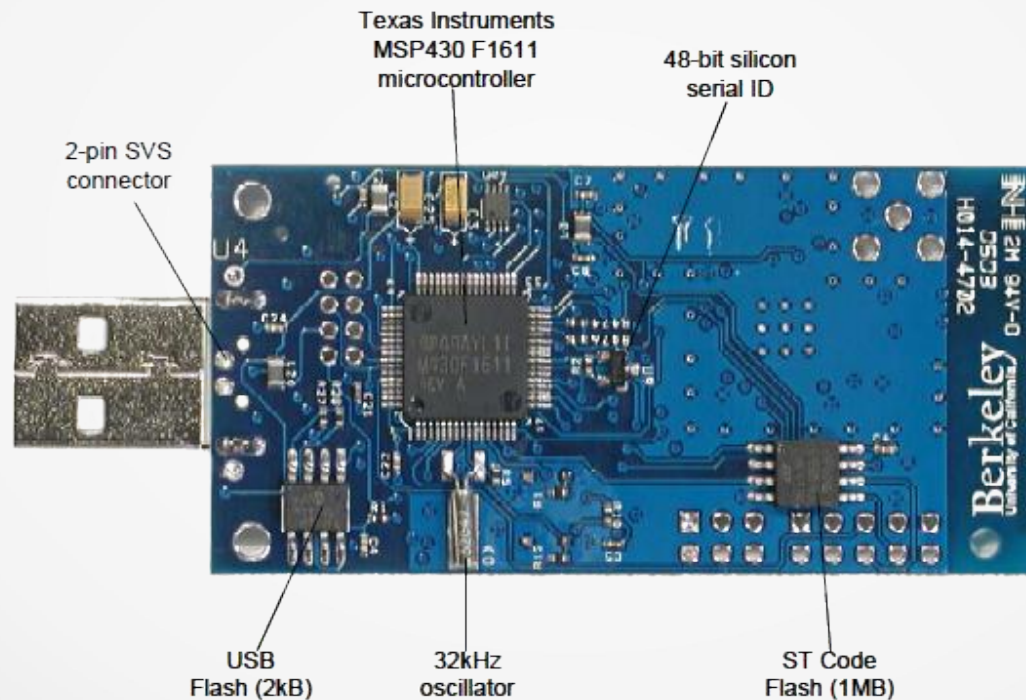
Nodo: sky

- sky / telosB compatible (tmotesky, CM5000)



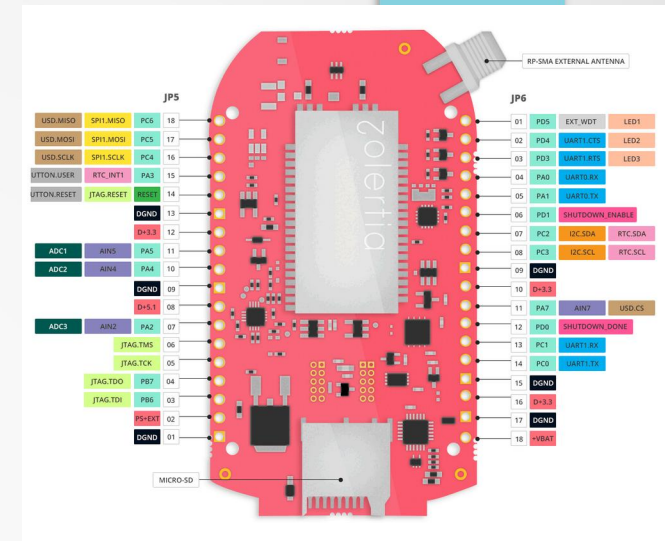
Nodos: ejemplos

- sky / telosB compatible (tmotesky, CM5000)



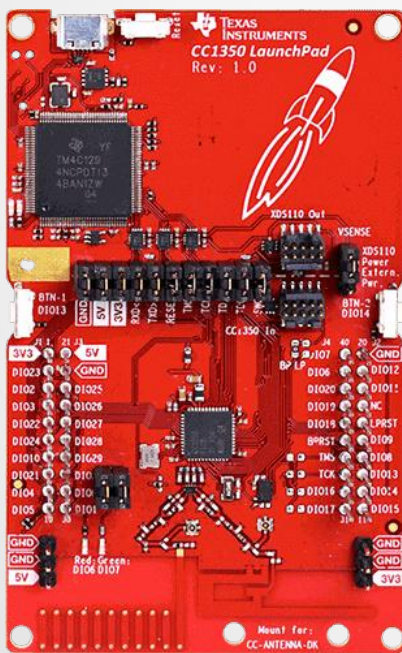
Nodo: remote-b

- CC2538 system on chip (SoC)
 - ARM Cortex-M3
 - up to 32 MHz
 - FLASH: 512 kB
 - RAM: 32 kB
 - 2.4 GHz IEEE 802.15.4 RF interface,
- CC1200 868/915 MHz RF transceiver
- LEDs
- Botones

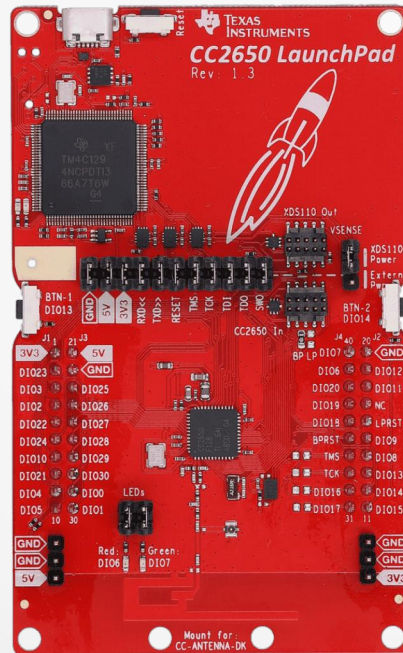


Nodos: LaunchPad & Sensortags

	CC1350	CC2650
LaunchPad	CC1350 LaunchPad	CC2650 LaunchPad
sensortag	CC1350 Sensortag	CC2650 Sensortag



Launchpad



Sensortag



CC1350 vs. CC2650: similitudes

- **Microcontroller**

- Powerful ARM® Cortex®-M3
- Up to 48-MHz Clock Speed
- 128KB of In-System Programmable Flash
- 8KB of SRAM for Cache
- 20KB of Ultralow-Leakage SRAM
- 2-Pin cJTAG and JTAG Debugging
- Supports Over-The-Air Upgrade (OTA)

- **Ultralow-Power Sensor Controller**

- Can Run Autonomous from the rest
- 16-Bit Architecture
- 2KB of Ultralow-Leakage SRAM for Code and Data

- **Low Power**

- Normal Operation: 1.8 to 3.8 V

- **Peripherals**

- All digital pins can be routed to any GPIO
- Four General-Purpose Timer Modules
- 12-Bit ADC, 200-ksamples/s, 8-Channel Analog MUX Continuous Time Comparator
- Ultralow-Power Analog Comparator
- Programmable Current Source
- UART / I2C / I2S
- 2× SSI (SPI, MICROWIRE, TI)
- Real-Time Clock (RTC)
- AES-128 Security Module
- True Random Number Generator (TRNG)
- Integrated Temperature Sensor
- etc.

CC1350 vs. CC2650: diferencias

- **CC1350** dual-band wireless MCU
 - Bluetooth Low Energy (BLE) 4.2 Specification (2.4GHz)
 - Sub-1 GHz Long Range
 - Wireless M-Bus (EN 13757-4) and IEEE® 802.15.4g
 - versiones: CC1350US 915 MHz, CC1350EU 868 MHz
- **CC2650** multiprotocol 2.4 GHz wireless MCU
 - Bluetooth Low Energy (BLE) 4.2 Specification (2.4GHz)
 - IEEE 802.15.4 PHY and MAC (2.4-GHz)
 - ZigBee® and 6LoWPAN, and ZigBee RF4CE remote.

Launchpad vs. sensortag

- Launchpad
 - Wireless MCU (CCxxxx)
 - LEDs / BTN
 - Program. / debug (incluido en placa)
- Sensortag
 - sensores :)

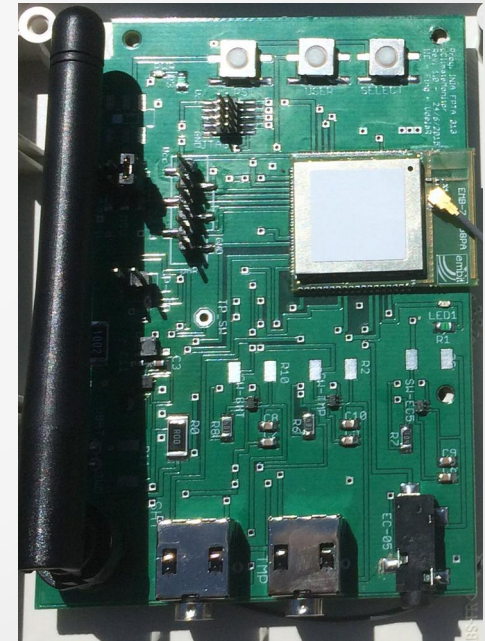
	Sensortag	BoosterPack
Humidity	HDC1000 (TI)	BME280
Temperature	BMP280 (Bosh)	BMP280
Pressure	BMP280	BMP280
Light	OPT3001 (TI)	OPT3001
Internal	TMP007 (TI)	TMP007
External	TMP007	TMP007
Accelerometer	MPU-9250 (TDK)	BMI160
Gyroscope	MPU-9250	BMI160
Magnetometer	MPU-9250	BMM150

Nodo: ejemplos

- **uclim – IIE (Proyecto INIA-FPTA)**
 - CCC2538 (Cortex M + tranceiver) + CC2592 (PA/LNA)
 - 32 KB RAM
 - 256 KB Flash
 - ~10 mA active / ~1uA sleep
 - DC/DC Switching reg. (2.1 & 2.5 VDC)



EMB-Z2538PA

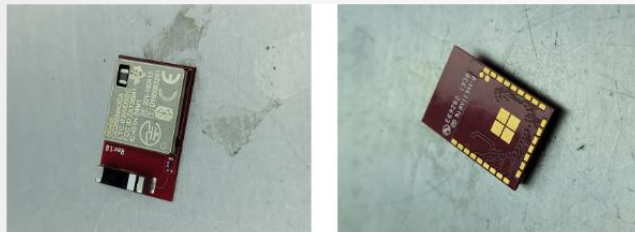


Ejemplos: SMC

- **Sistema de Monitoreo y Control de Cultivo Indoor de Cannabis**
 - Nodos:
 - control distribuido
 - sensor (“maceta”)

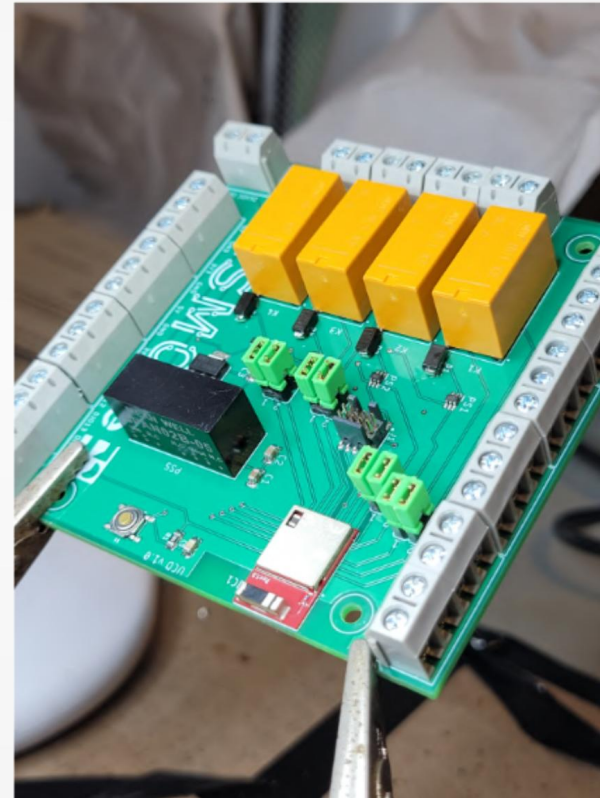
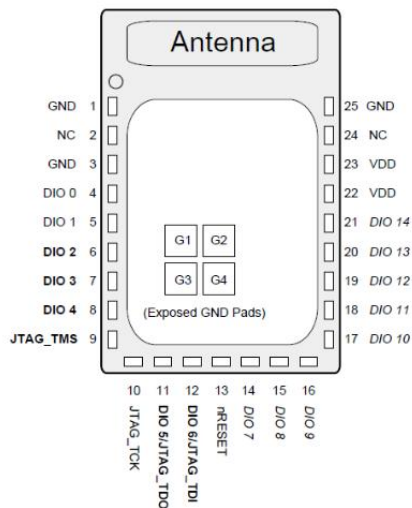
Ejemplos: SMC

- Control distribuido



(a)

(b)



módulo CC2650MODA (Texas Inst.)

Ejemplos: SMC

- **Nodo sensor (maceta)**



Planificación clases

- 1) Introducción RSI
- 2) Plataformas de hardware**
- 3) Arquitectura 6LoWPAN (IPv6)
- 4) Plataforma de software: Contiki-NG (parte 1)
- 5) Plataforma de software: Contiki-NG (parte 2)
- 6) Capa de aplicación: CoAP / MQTT
- 7) Capa de red: RPL
- 8) MAC
- 9) IEEE 802.15.4 / 6lowpan
- 10) Capa Física & antenas
- 11) IoT y las RSI



gracias... ¿más preguntas?