Embedded System 1

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POLITECNICO DI MILANO

How to provide power to embedded systems

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Power source

- Rechargable batteries

Typical Power Management

- Main functions and architeture
- Portable power systems

Wireless charging

- Architecture
- Standards
- Example of designs

References

Battery-powered Embedded Systems

- Batteries can be used to make objects portable

- This can be done if the energy requirements of the object are compatible with the size of the battery

- Power management assumes a key role in device power consumption, minimizing energy wasting

- **Reliability**
- **Capacity (Ah)**
- **Peak current**
- **Temperature range**
- **Efficiency**
- **Charging time**
- **Deterioration**
- **Size**
- **Different form factors**
- **Discharge current (long term)**
- **….COST…**
- **…and COST!!!!**

Rechargeable batteries

Most commonly used batteries

Nichel-Cd (1946)

Li-Ion (1991)

Li-Po (1996)

Nichel - Cadmio

Main features

Tech Specs

- Energy/volume 50-150 Wh/L
- Energy/weight 40-60 Wh/kg
- Lifetime 2000 rechange cycles

Pro

- Hard to damage
- High duration (charge/discharge cycles rate)
- Low series resistance (can supply high currents)
- Low degradation when not used

Cons

- Difficult production process
- Reduced capacity
- Memory effect reduces capacity

Tech Specs

- Energy/volume 250-620 Wh/L
- Energy/weight 100-265 Wh/kg
- Lifetime 400-1200 cycles

- **Pro**
  - Can have different form factors
  - No deterioration due to charge/discharge cycles
  - No memory effect (complete discharge not required)
- **Cons**
  - Ageing from the fabrication time
  - High deterioration due to heat
  - May explode if over-charged or heated (built-in protection circuit)
  - Complete discharges can damage the battery

LI-Po

Main features

Tech Specs

- Energy/volume 250-730 Wh/L
- Energy/weight 100-265 Wh/kg
- Lifetime 400-100 cycles

- **Pro**
  - Higher energy capacity
  - No memory effect
  - Less degradation compared to Li-Ion batteries
  - Highly shapeable
  - Reduced charge times
- **Cons**
  - Highly flammable when perforated
  - May explode if over-charged or heated (built-in protection circuit)
  - Highly sensitive to charge/discharge cycles

Protection circuit

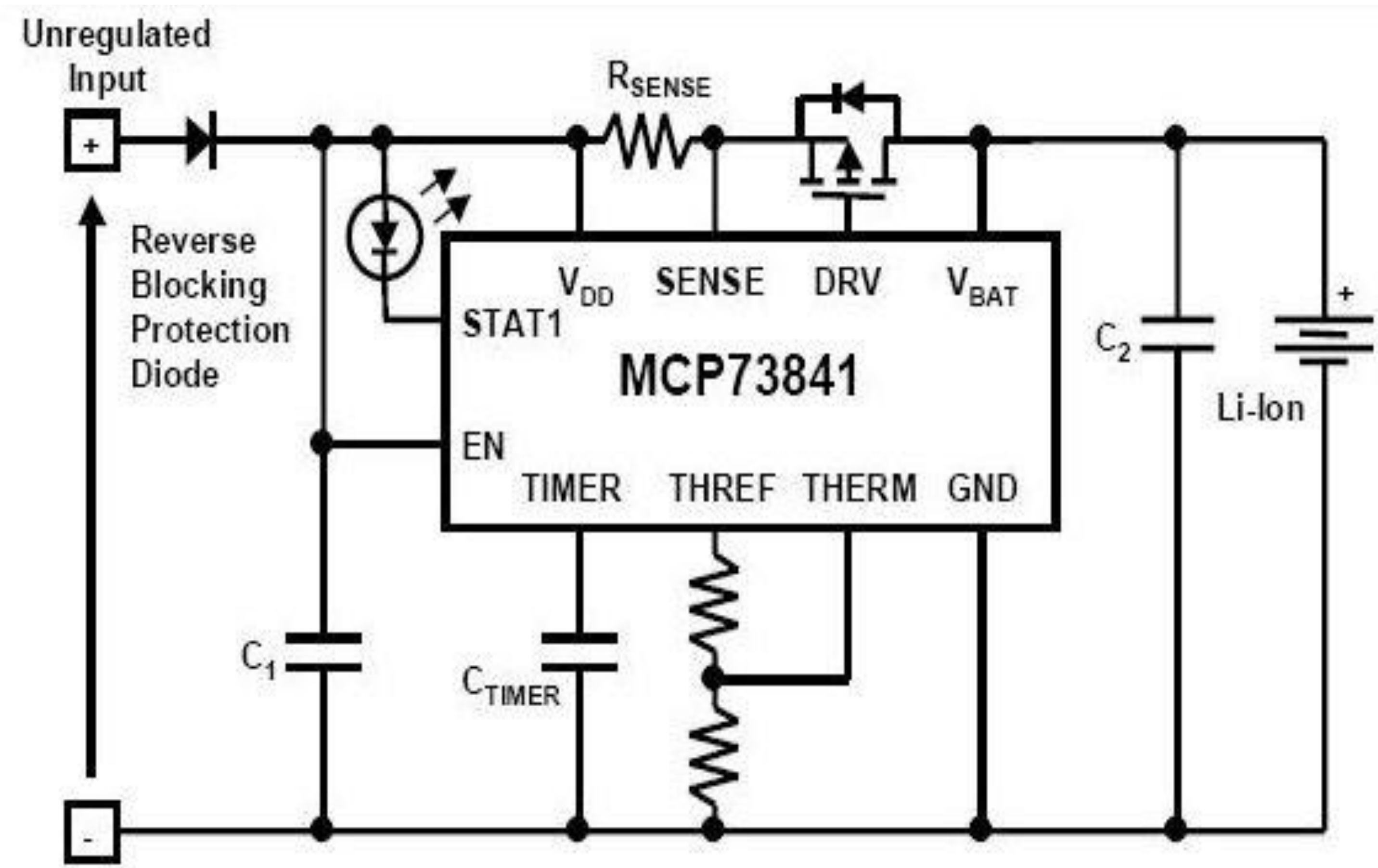
Protects the battery in case of

- Short-circuit on power supply
- Complete discharge
- High voltage during charge phase
- High temperature

Like every circuit it occupies space and drains energy

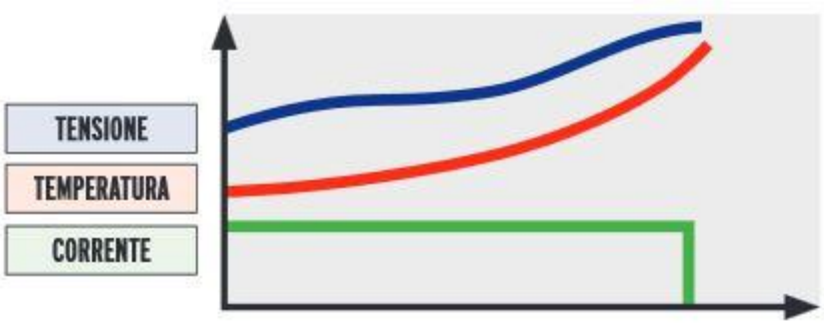
Protection circuit

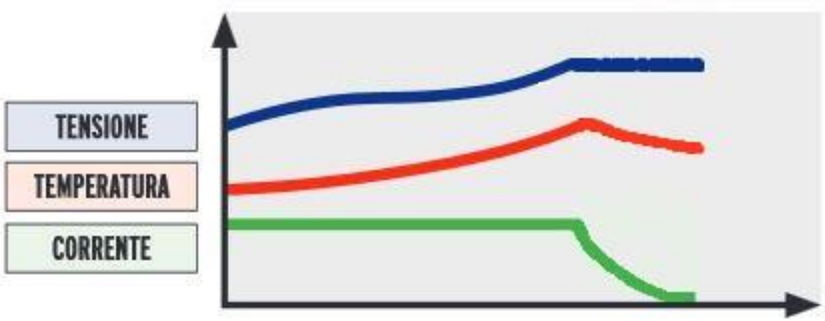
Example

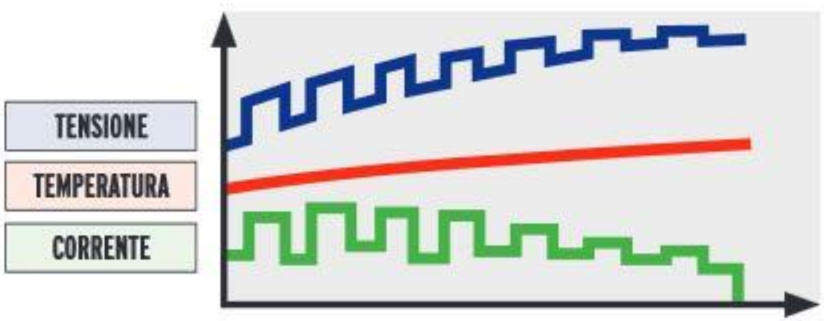


Protection circuit

Determines the charge rate to reduce battery wear







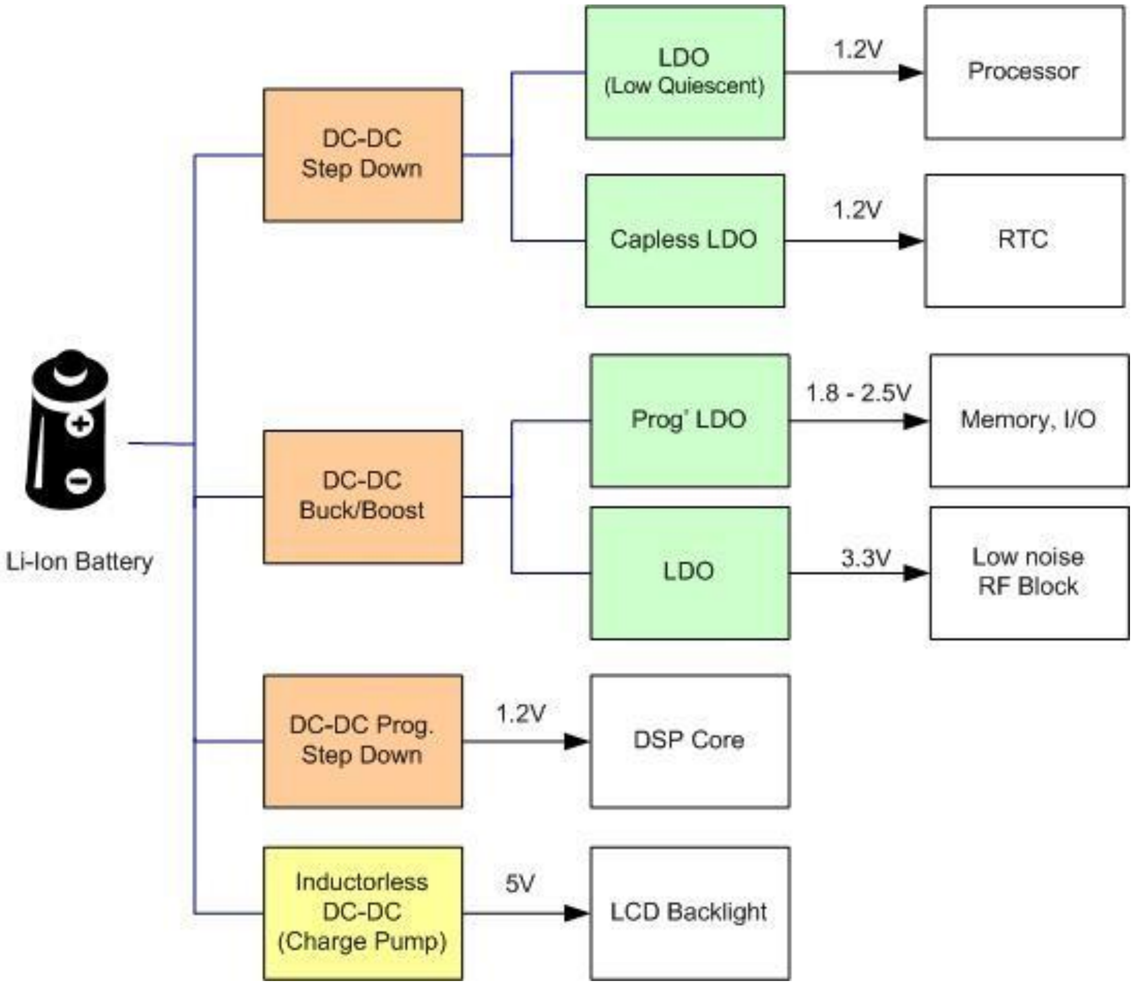
Power Management

- **Mixed circuits (analog and digitals) needs different PDN (Power Distribution Network)**
  - Different power supplies

- **A single system may need different voltage to power each of its blocks**

- **The ability to modulate the power supply voltage allows power-saving techniques**
  - Dynamic power can be reduced in digital circuits by lowering voltage when the system is idle, or there is no need of computing power

Typical Portable System Power Management



DC-DC Converters

- **Linear LDO**
  - Output voltage is regulated with an internal loop

- **Switching (buck-boost, boost, buck)**
  - The conversion is done with an inductor which stores magnetic energy for a given time, the energy is then transferred to the load as a controlled voltage

LDO

(Vout<Vin)

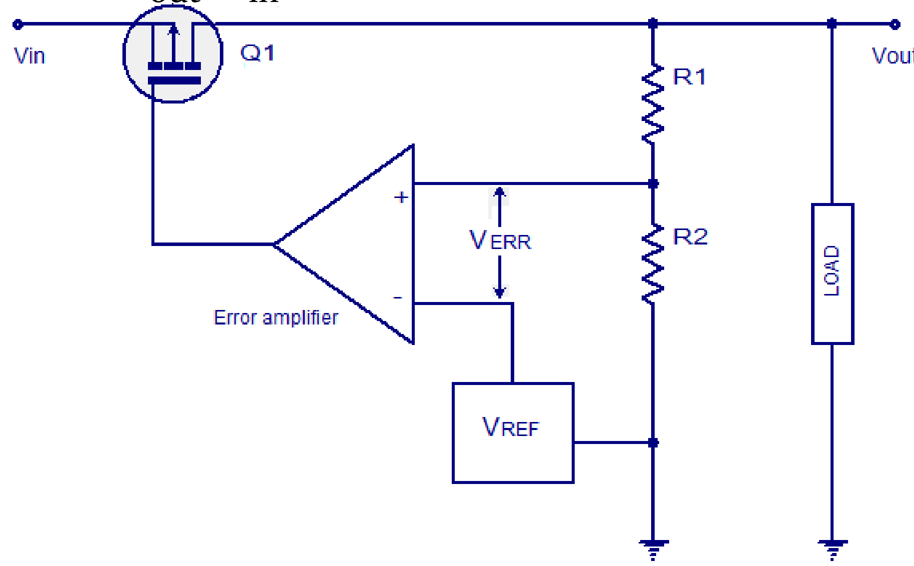
- **Low Drop-Out regulator**
- **Optimal if Vout is a bit lower then Vin**
- **Used for medium/low power applications**
- **Clean Vout**
- **Vout can be changed by varying Vref**
- **Low sensibility on the output currents for frequencies where opamp gain is high (dozens of kHz)**

$$V_{OUT}\frac{R_2}{R_1+R_2}=V_{REF}\rightarrow V_{OUT}=V_{REF}\frac{R_1+R_2}{R_2}$$

$$\eta=P_{out}\,/P_{in}$$

$$\Rightarrow \quad \eta\approx V_{out}/V_{in}$$

$$I_{out}\approx I_{in}$$



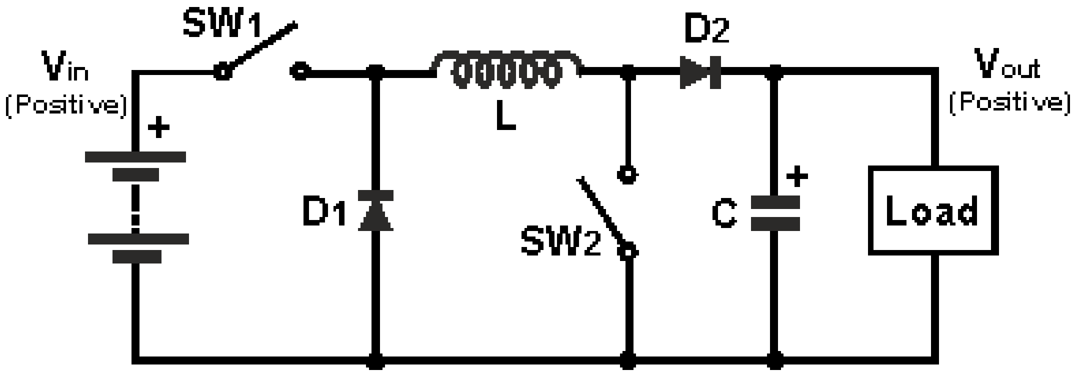
LDO voltage regulator schematic

www.circuitstoday.com

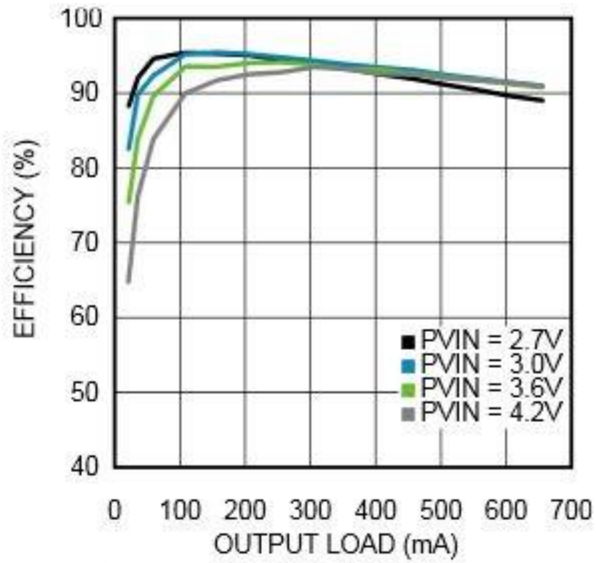
DC/DC buck-boost

Vout>Vin; Vout<Vin

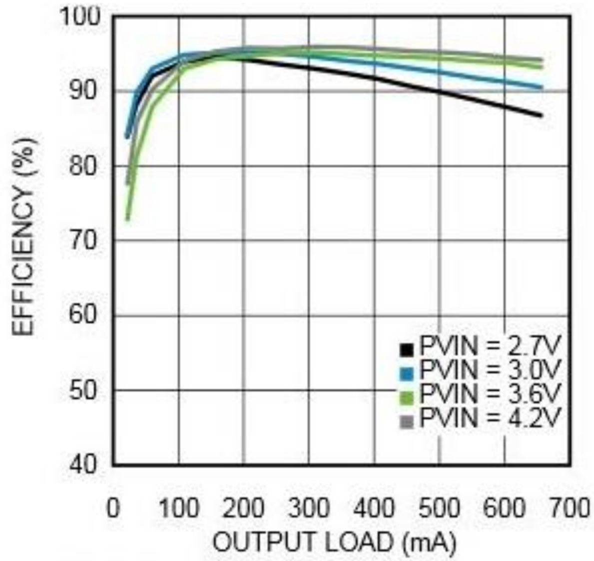
- **Output can be higher or lower then input depending on the application**



- **Efficiency is almost constant and depends on the difference between input and output (90%-95%)**

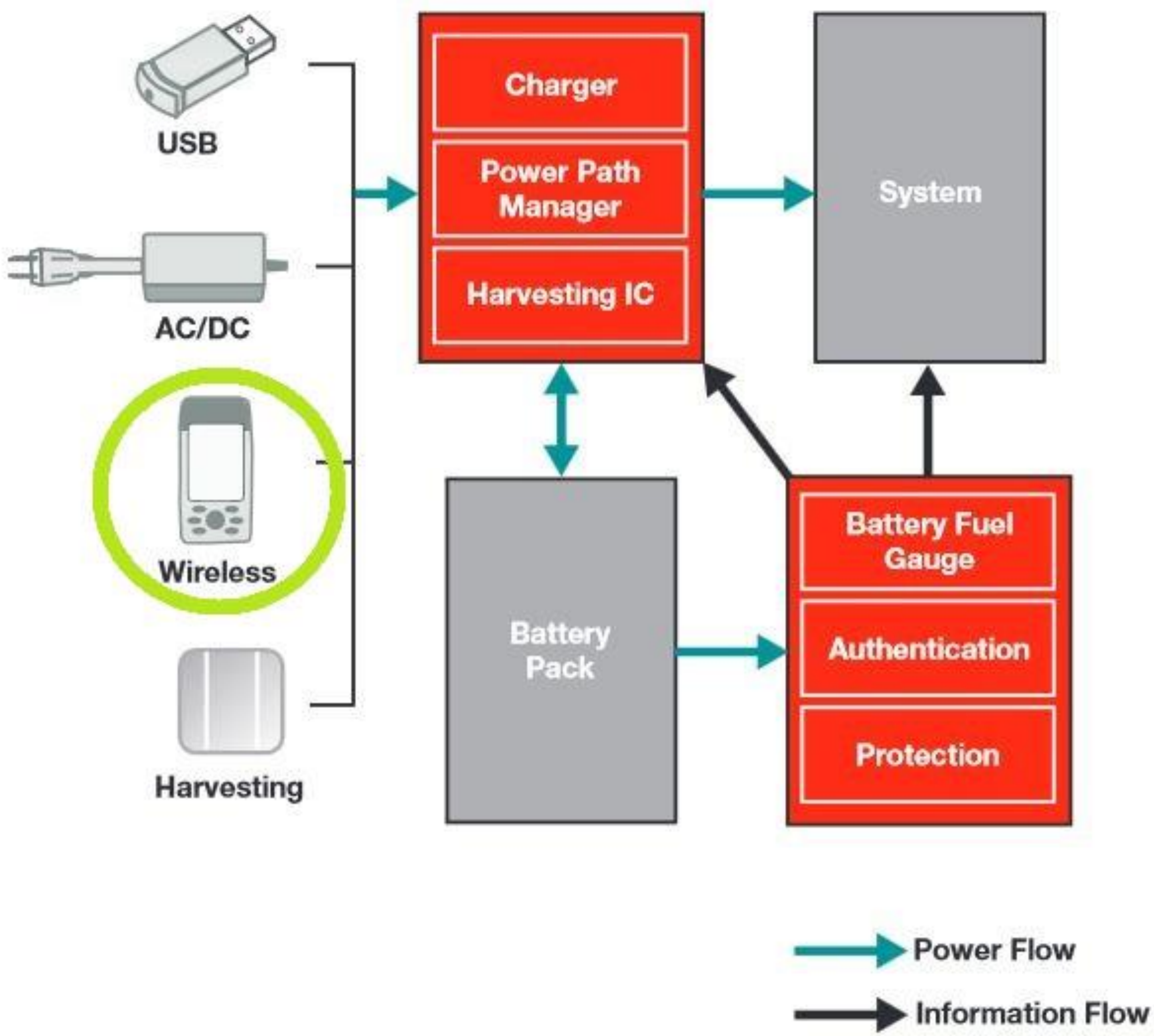


V_{OUT} = 2.4 V



V_{OUT} = 3.6 V

Portable Power System Diagram



Wireless Charging

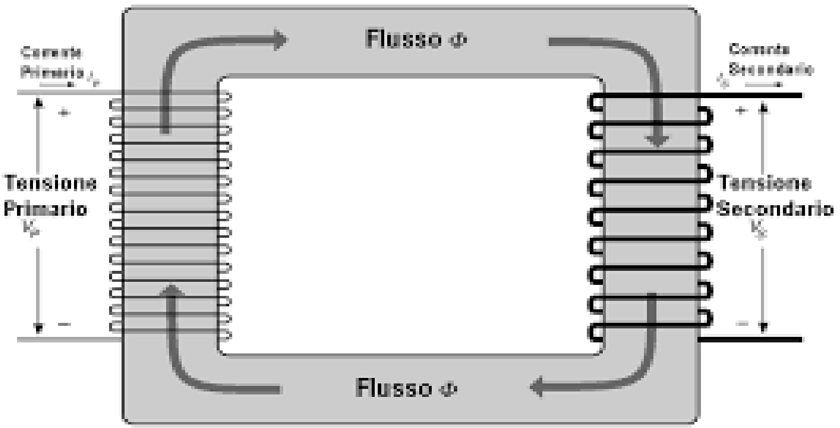
- **Magnetic induction is the most common wireless energy transfer method**

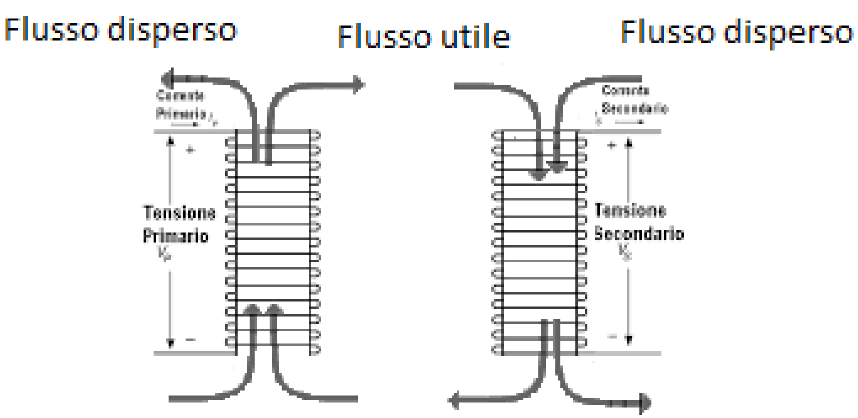
- **An alternative to this method is the use of electromagnetic radiations (microwaves) which can guarantee higher distances between charger and devices**

Magnetic Induction Method

- Growing number of wireless charge enabled devices
- Wireless transmitter can be integrated into commonly used objects

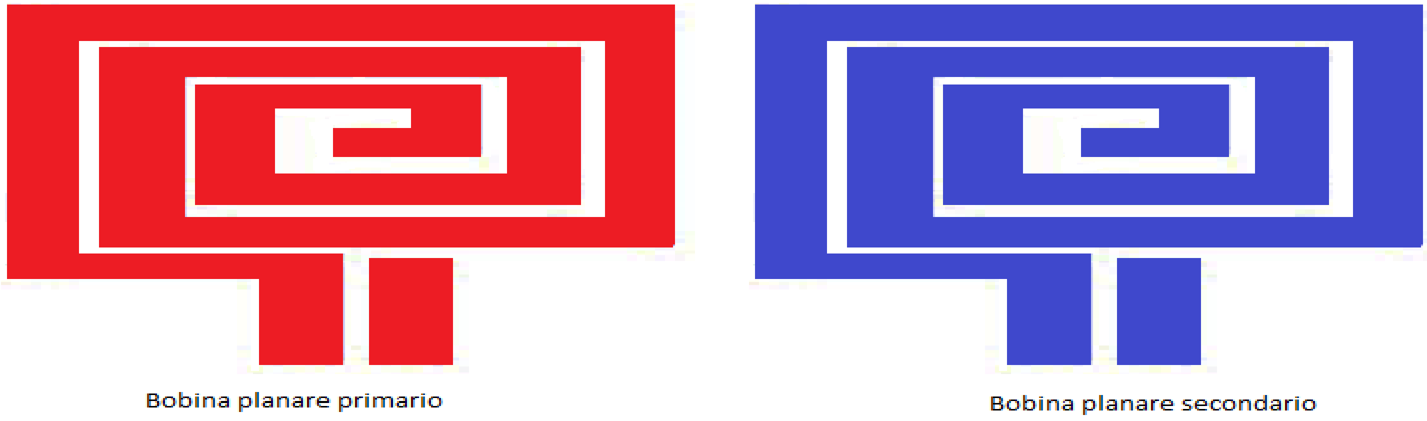
Magnetic Induction Method

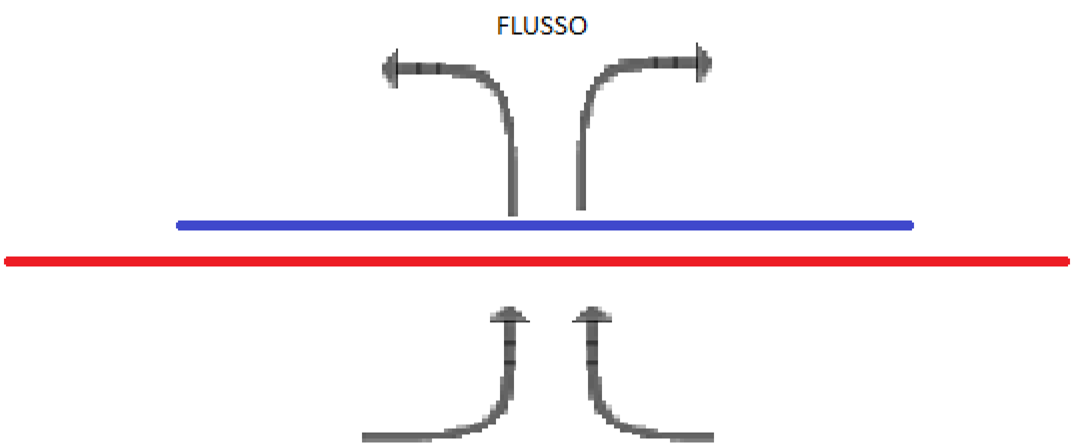




- **Absence of ferromagnetic core causes non-optimal coupling between the two circuits due to dispersed flow**

Magnetic Induction Method





Planar coils are easy to embed into compact devices

Magnetic Induction Method

- **Inductor merit factor** $Q = \frac{\omega L}{R} = 2\pi \times \frac{\text{Energia immagazzinata}}{\text{Energia dissipata per ciclo}}$

$\omega \uparrow \rightarrow Q \uparrow$

- **Efficiency lowers when**
  - with distance (z/D > 1)
  - coils diameters are too different (D2 / D <0.3)
- **Good efficiency (> 90%) when**
  - low distance (z / D <0.1)
  - coils have similar dimensions (D2 / D = 0.5..1)

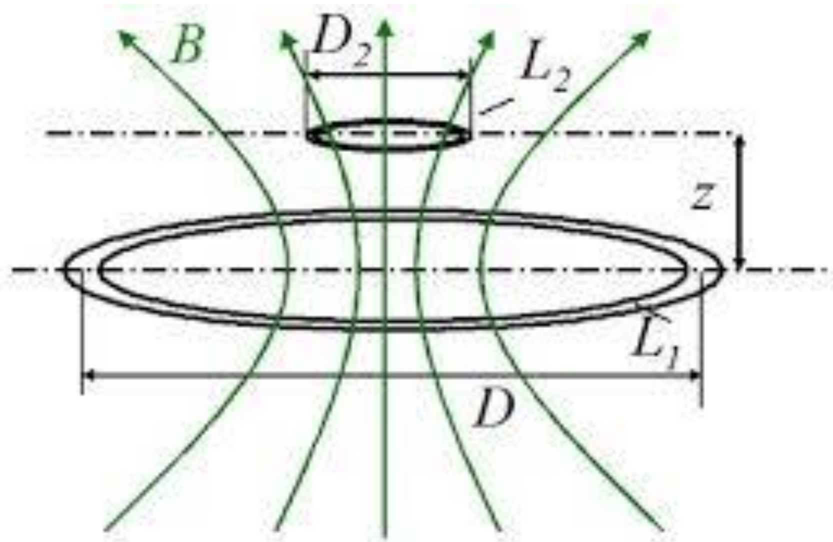
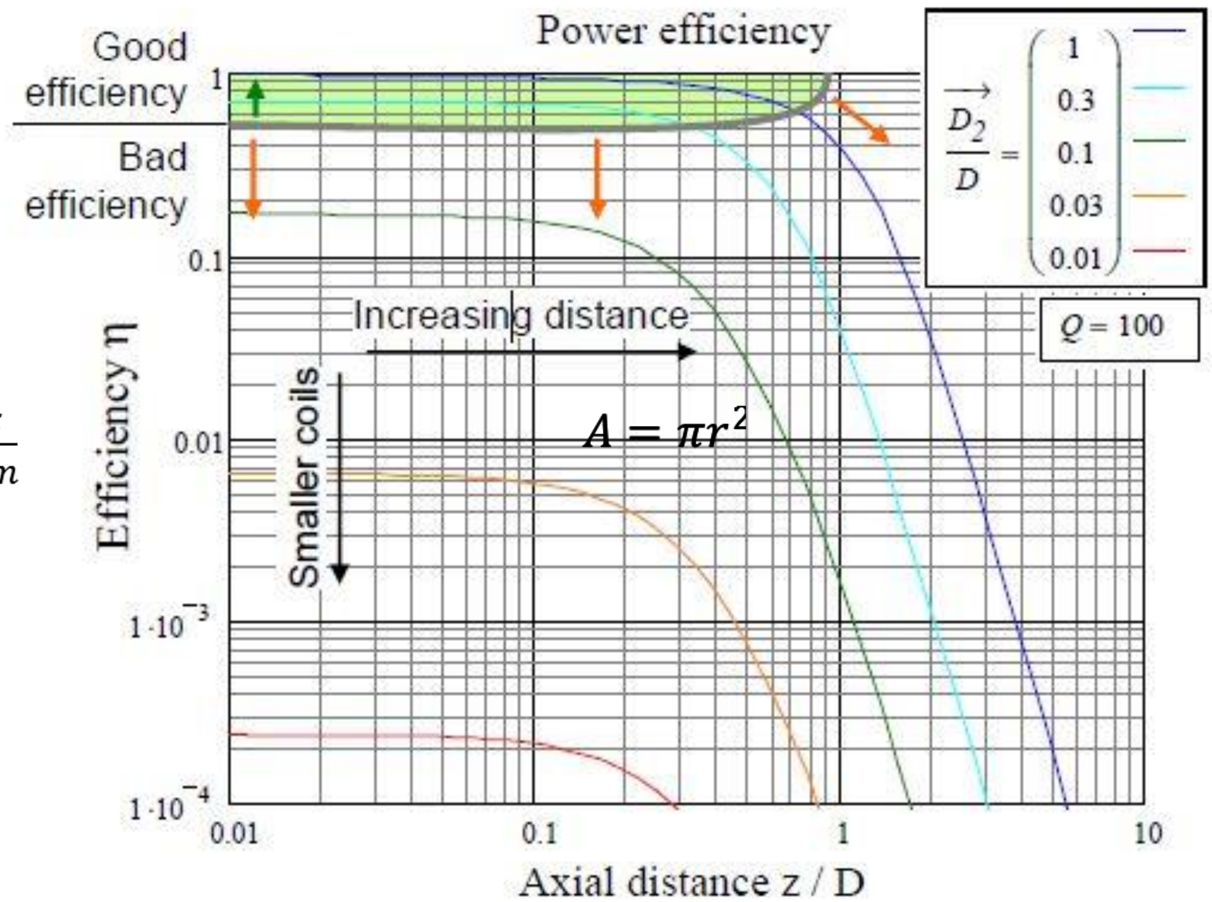


Figure 1 Typical arrangement of an inductively coupled power transfer system

Power efficiency

- **Functions relatives to coils with merit factor of Q = 100**

$$\eta = \frac{Pout\_sec}{Pout\_prim}$$



Qi Standard for wireless charging

- **Interface standard for inductive electrical power transfer, developed by Wireless Power consortium in 2008**

- **WPC encompasses more than 140 members around the world**

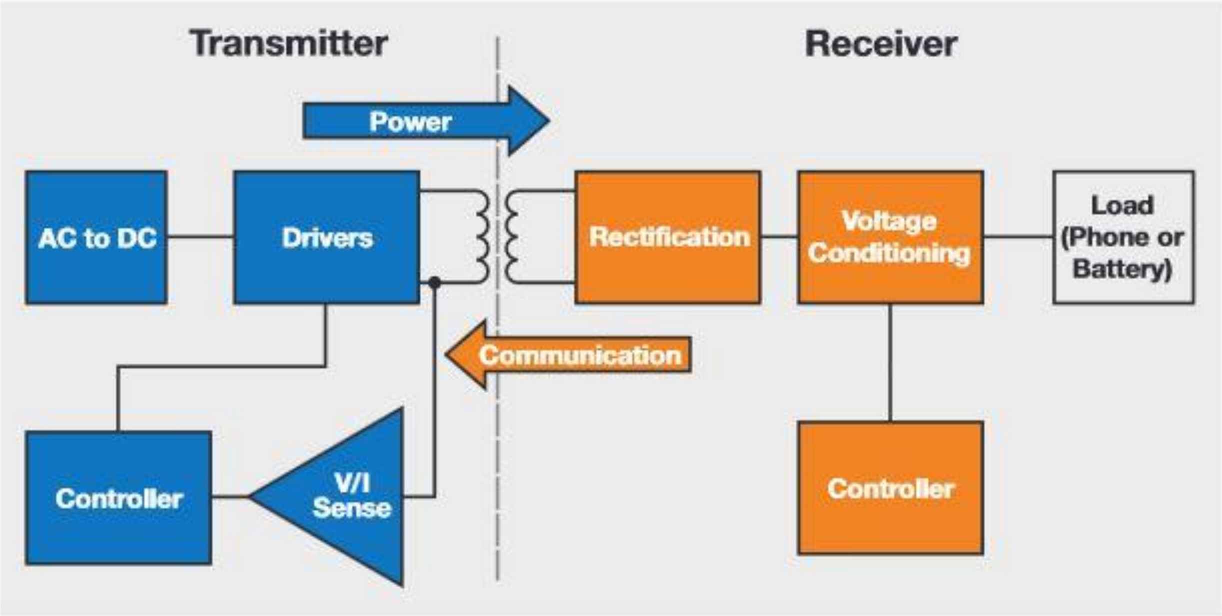
Qi Standard for wireless charging

- **Maximum distance between the charging base and the device is 4 cm (usually 0.5 cm)**
- **Inductive energy transfer between two coils**
- **Up to 5W can be transferred**

Certified "Qi"
standard for wireless charge

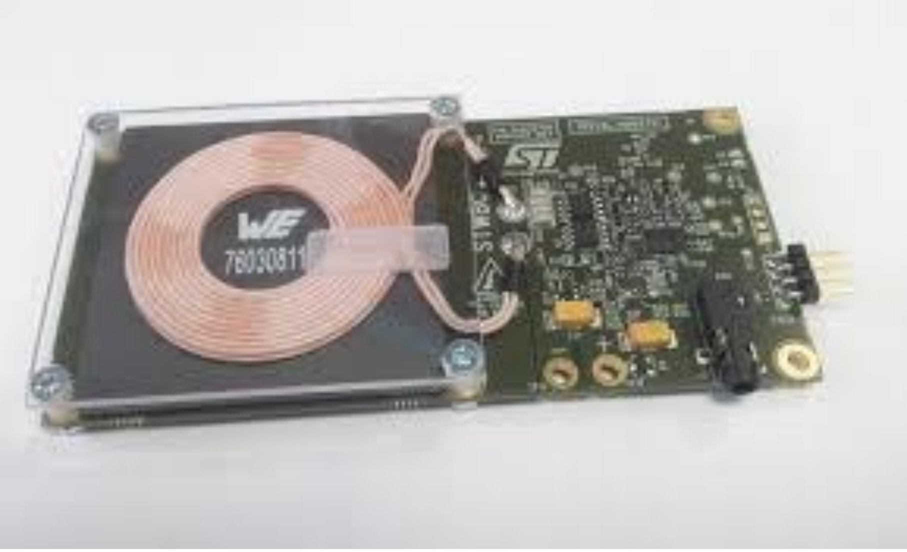
Qi Standard for wireless charging

- **Qi standard defines 3 key areas of the system**
  - **Transmitter**: element which provides inductive power;
  - **Receiver**: element which uses the energy;
  - **Communication**: uni-directional from receiver to transmitter



Qi - Transmitter

- **The transmitter is composed of:**
  - Coil used for energy transfer;
  - Coil driver, necessary for the communication;
  - Demodulation circuit for primary voltage or current
  - (see communication)

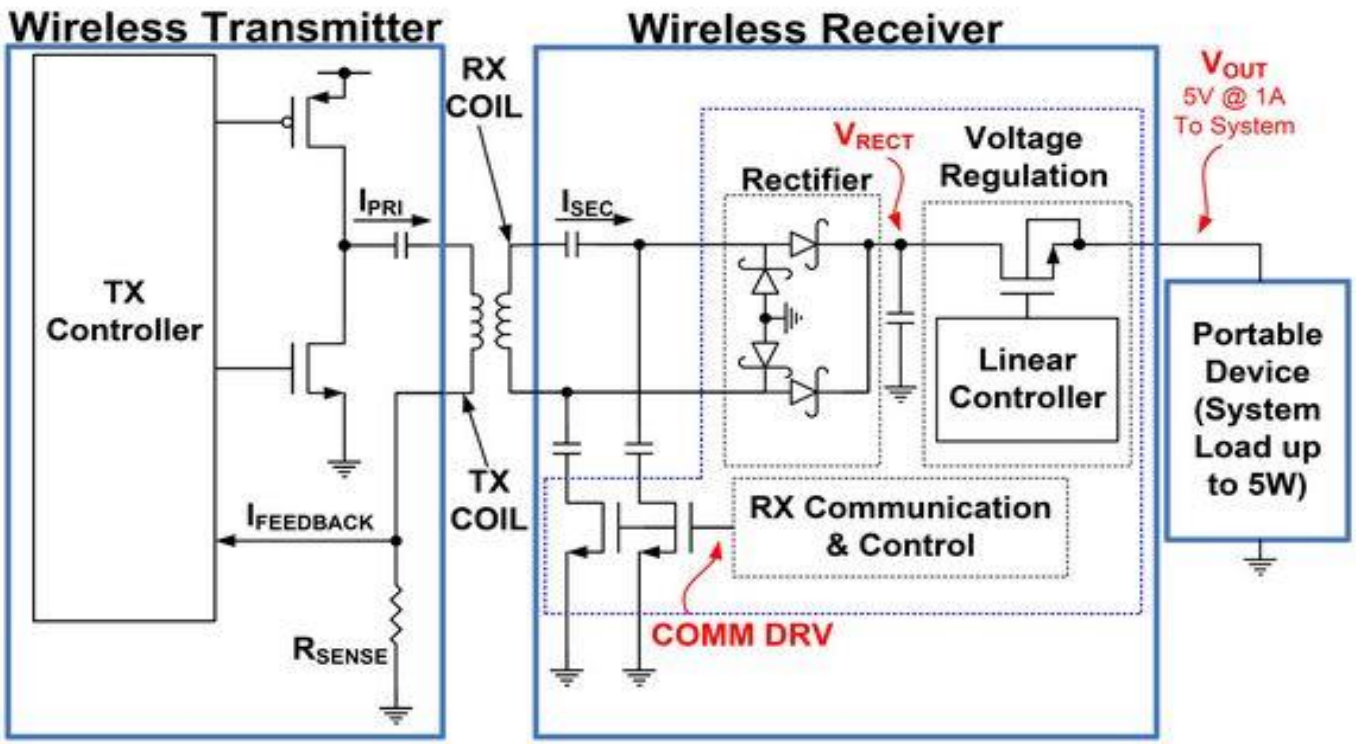


Qi – Receiver, main components

- **Coil magnetic coupled with transmitter coil**
- **AC/DC converter**
- **Controller which manages the communication**

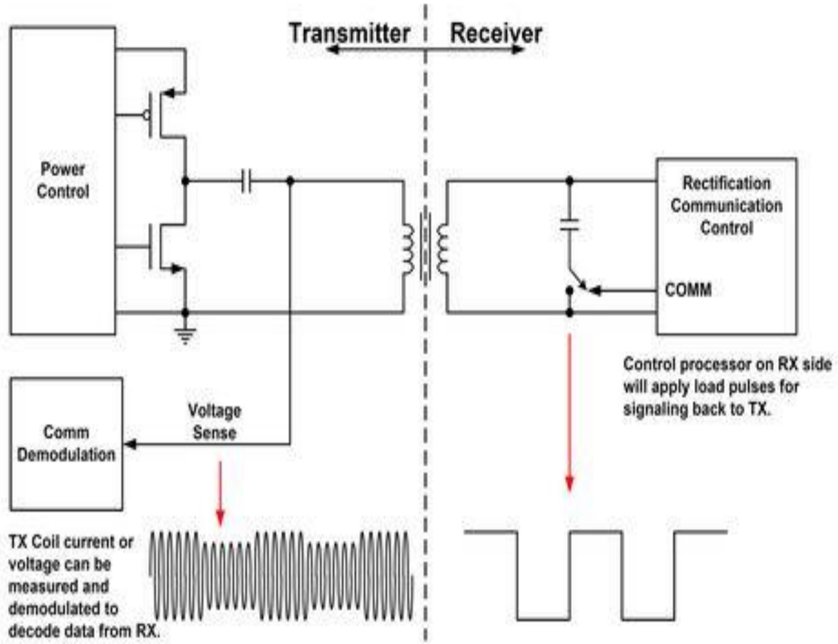
Qi – example of implementation

- **Transmitter: resonant circuit which generates a sinusoidal signal on the coil**
  - Signal freq. is in the rage of 100-200 kHz
- **This signal induces a e.m.f. on the receiver coil used by a rectifier-regulator circuit to power the system**



Qi – Communication

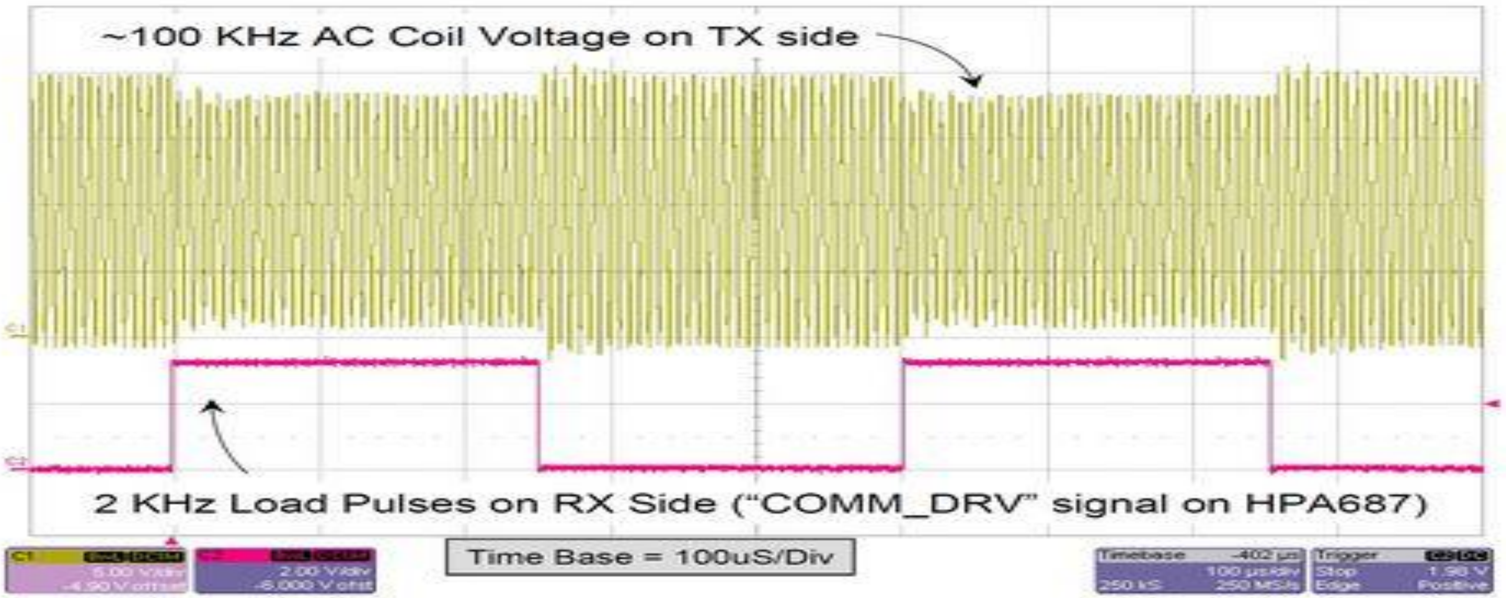
- **Communication between transmitter and receiver is done using load modulation**
  - Impedance variations of the receiver coil causes variations in the output voltage and current at transmitter; the information is associated to those variations
  - Transmission is done without energy dissipation from receiver
  - Switching frequency is in the order of kHz



Qi – Communication: ASK modulation

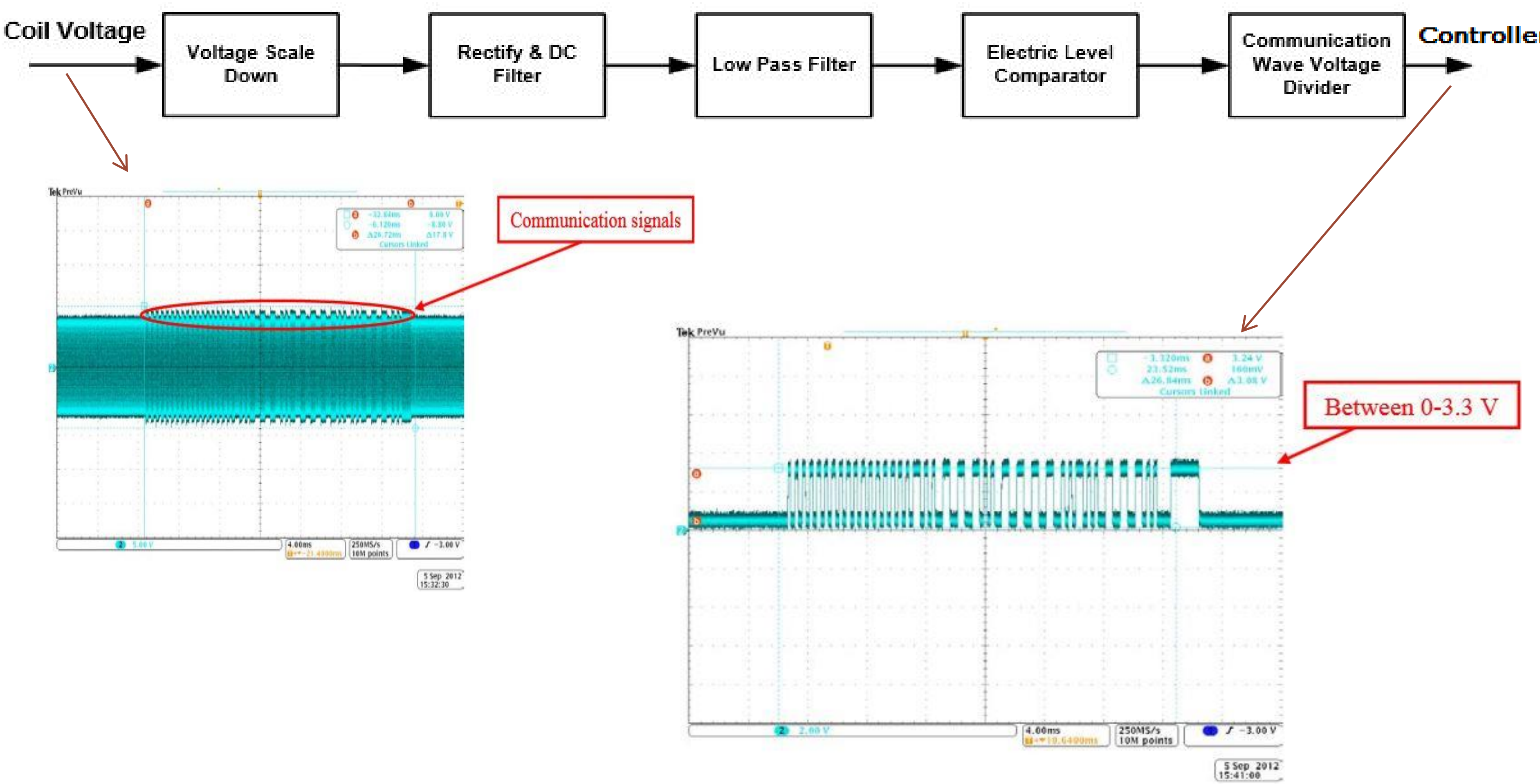
- **Amplitude Shift Keying (ASK) is a relatively simple modulation scheme**
    - ASK is equivalent to the amplitude modulation of the analog signal, and the carrier frequency signal is multiplied by a binary digital.
- **Frequency and phase are kept constant, and the amplitude is variable according the symbol to be transmitted**
- **Information bits are passed through the carrier's amplitude**
- **Called binary amplitude shift keying (2ASK) because signals can take only two binary levels, 0 or 1**

- **Modulation results**



- **Merit factor and transmission efficiency can be increased with higher carrier frequencies**

Qi – Communication



Qi – Protocol

- **Communication phases as described by Qi standard**
  - **Analog ping**
    - transmitter detects the presence of an object
  - **Digital ping**
    - a longer version of the analog ping, gives receiver the time to reply. If the packet is valid transmitter continues to power the coil
  - **Identification and configuration phase**
    - receiver sends necessary information to be identified and to configure the power transmission

Qi – Protocol

- **Power-transfer phase**
  - receiver sends packets to transmitter at regular time intervals (250ms) to increase or decrease power supply;
- **End power transfer**
  - to end power transfer, the receiver sends an “End power” message or sends no communication for 1.25 seconds. The transmitter enters then a low-power state

Qi – Protocol

- **Signal strength**
  - used to align RX unit on the charging pad
- **Control error packet**
  - returns a signed integer value (-128 to +127) that indicates the degree of error between the value of the input voltage seen by the RX and its desired input voltage
- **End power transfer packet;**
- **Rectified power packet**
  - this is an unsigned integer value that communicates the amount of power the RX sees at the output of the rectifier circuit
  - The TX uses this information to determine the overall coupling efficiency as well as to determine when the RX is at its maximum power limit

ST - WBC

- **as WPC, Power Matters Alliance (PMA) is a global industry organization whose mission is to advance a suite of standards and protocols for wireless power transfer**

The STWBC is the digital controller for wireless battery charger (WBC) transmitters (TX) from STMicroelectronics, offering the most flexible and efficient solution for controlling power transfer to a receiver (RX) in WBC-enabled applications such as phones, wearables, and other battery powered devices that use electromagnetic induction for recharging.

As a member of the Qi Wireless Power Consortium and the PMA (Power Matters Alliance), ST ensures full compatibility with these leading wireless charging protocols and holds certification for the Qi 1.1.2 A11 standard.

The STWBC performs all the functions for transmitter control: thanks to the internal 96 MHz clock and supporting both half-bridge and full bridge topologies, it is able to precisely control the amount of transmitted power to match the requirements of the receiving unit in terms of maximizing the efficiency of the power transfer.

ST - WBC

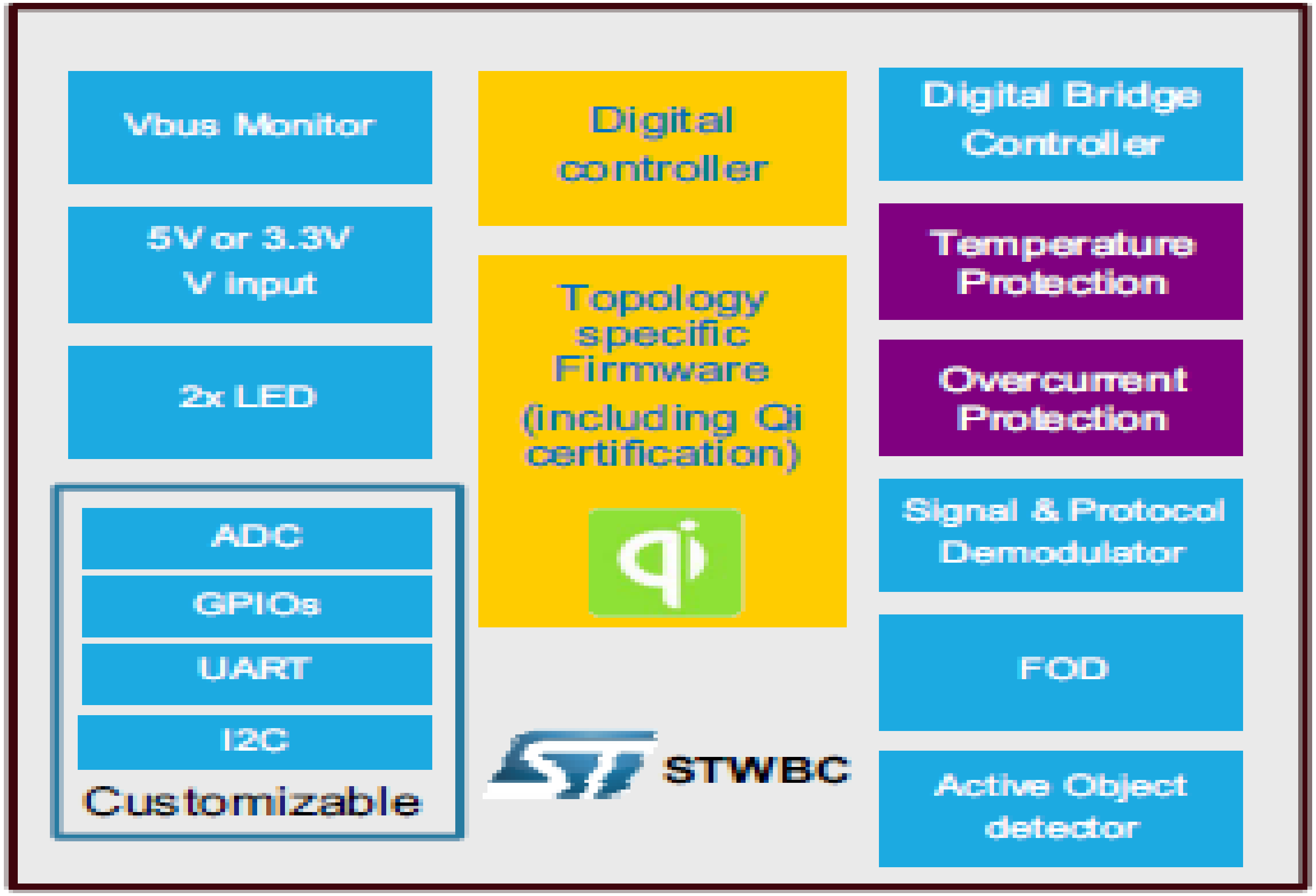
Applications

- Certified Qi A11
  - Evaluation board: STEVAL-ISB027V1
  - Power rate: 5W
  - Input: 5V
- Qi A13[a]
  - Power rate: 5 W
  - Input: 5 - 16 V, 12 V
- Wearable[a]
  - Power rate: 2 W
  - Input: 5 V
- PMA[a]
  - power rate: 5 W
  - input: 5 V

Features

- Digital controller for wireless battery charger transmitter
- Multiple Qi certified and PMA standard compatible
- Support for up to 5 W applications
  - Mobile
  - Wearable, sports gear, medical
  - Remote controllers
- Native support to half-bridge and full bridge topologies
- 5 V supply voltage
- 2 firmware options
  - Turnkey solution for quick design
  - APIs available for application customization[a]
- Peripherals available via APIs[a]
  - ADC with 10 bit precision and 1 MΩ input impedance
  - UART
  - I^2C master fast/slow speed rate
  - GPIOs

ST – WBC, Device architecture



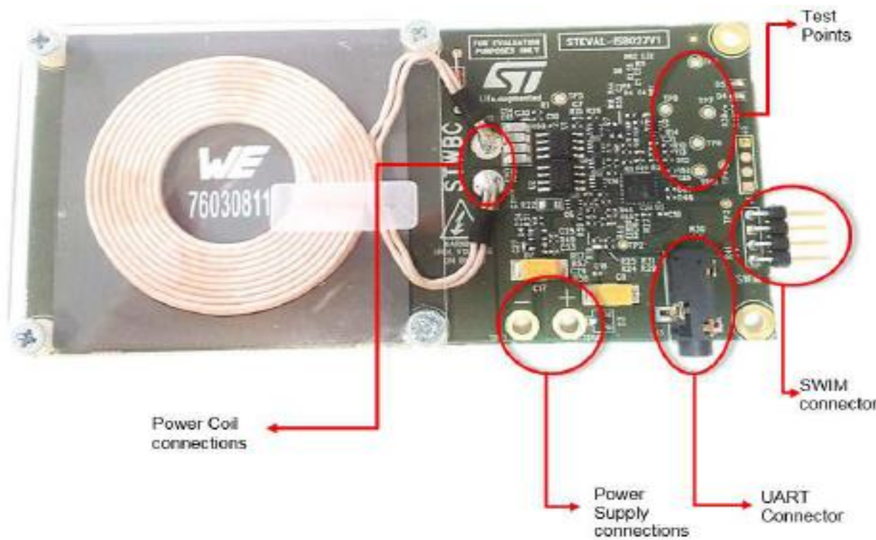
STEVAL-ISB027V1

Description

The STEVAL-ISB027V1 is a Qi 5 Watt wireless battery charger transmitter evaluation board based on the STWBC digital controller for wireless battery charger transmitters. The solution is certified in accordance with the Qi standard, A11 topology. The STEVAL-ISB027V1 provides a complete kit which includes the STWBC IC, firmware, layout and tools. The layout is based on a cost-effective 2-layer PCB.

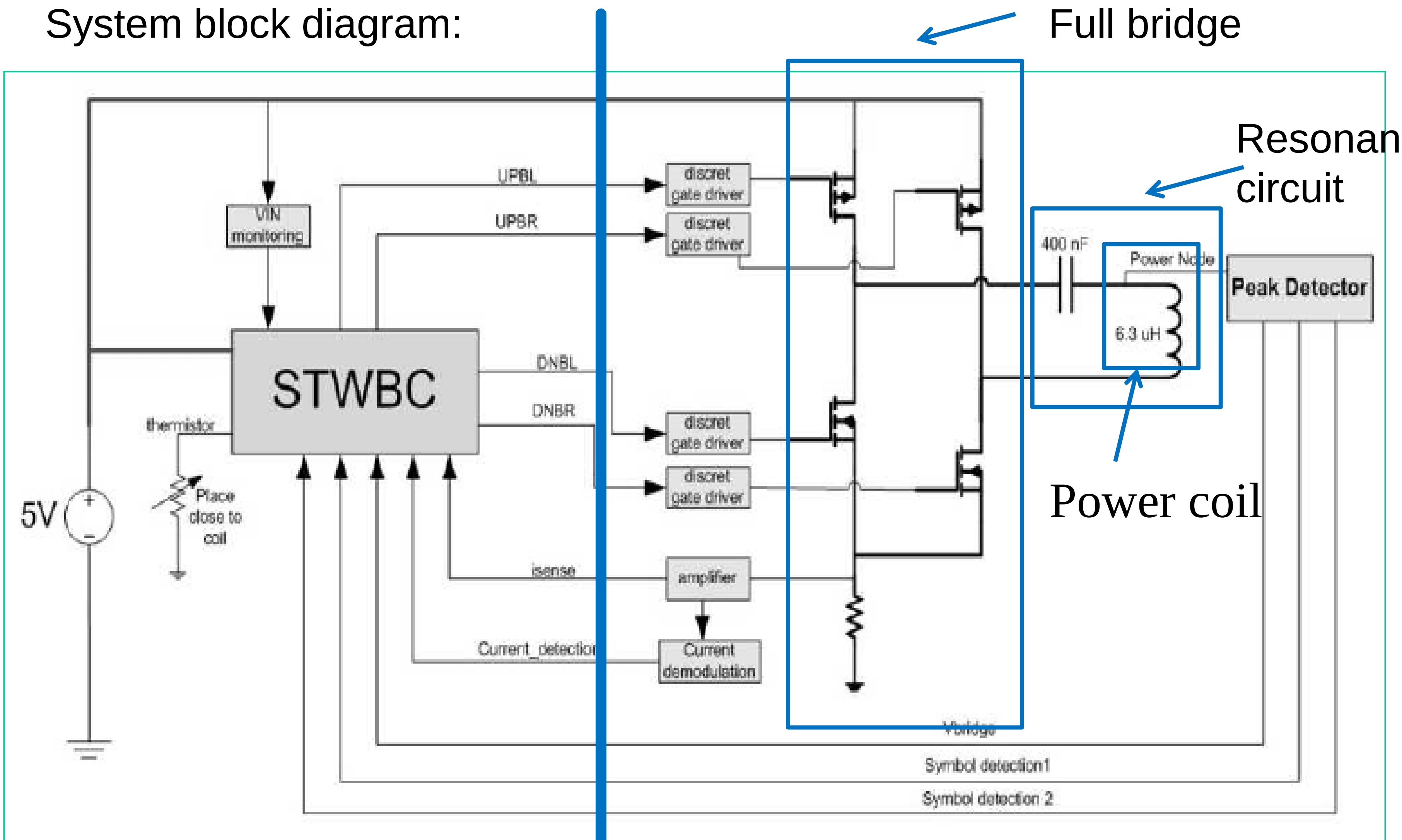
The STEVAL-ISB027V1 board has the following features:

- WPC Qi 1.1.2 certified
- Standard Qi A11-type transmitter and coil
- Resistive and capacitive modulation
- Foreign object detection (FOD)
- LEDs for charge status indication
- UART connection for user interface
- SWIM connection for firmware download
- 5 V power supply



STEVAL-ISB027V1

System block diagram:



CONTROLLER POWER

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- https://en.wikipedia.org/wiki/Lithium_polymer_battery
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Power management:

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- http://corsiadistanza.polito.it/on-line/Elettronica_di_Potenza_v2/lezionee3/lezione.pdf
- http://www.ti.com/lit/ds/snvs793d/snvs793d.pdf
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Wireless charging / Qi standard:

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