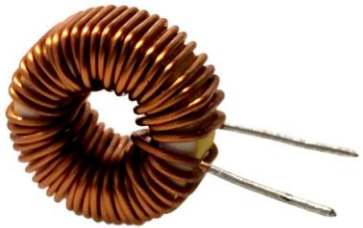
Power Management

Energy Source

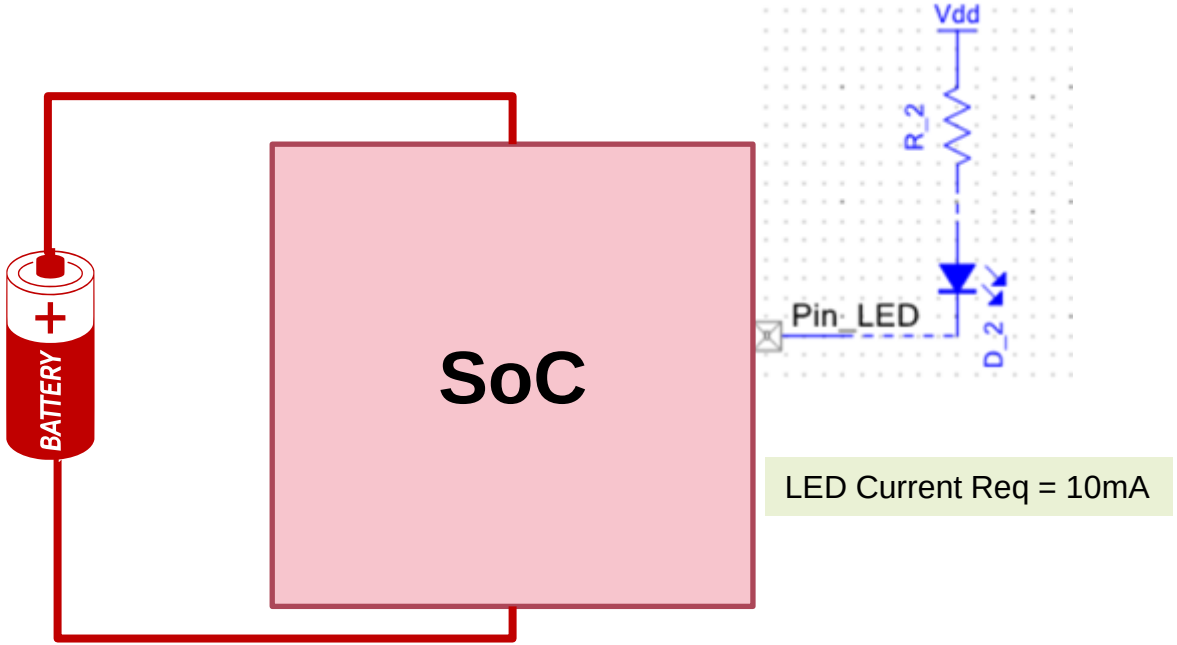
- **Battery vs. Capacitors – The differences**
- **Specifications ?** **(mAh, max-voltage, min-voltage, peak-current, impedances, thermal rating, leakage current, etc.,)**

Why not inductors ?



Battery Design

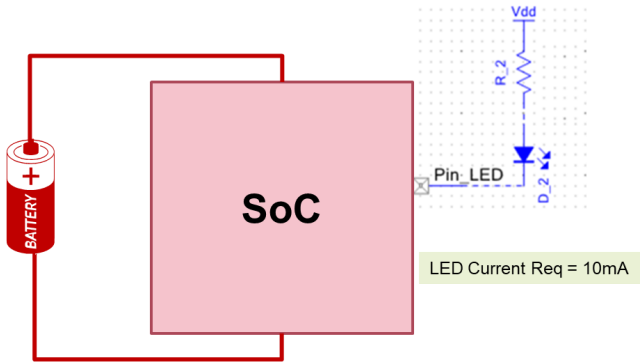
Application – Turn LED ON for 1 second for every 100 seconds



LED Current Req = 10mA

Design Steps

- **Step-1:** Identify the required operating voltage $\mathbf{V_{DD}}$
- **Step-2:** Identify the **average** current requirement of the application (I_{Avg})
- **Step-3**: Estimate the required lifespan of the system (T_{Life})



Application – Turn LED ON 1 second for every 100 seconds

SoC Requirement

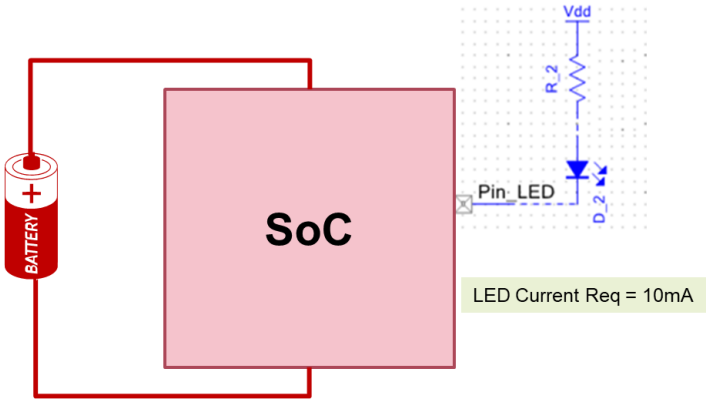
$\mathbf{V_{DD}}$ = 1.8V to 5V
Current Requirement (LED-ON) = 10mA + PSoC Current (~2mA)
Current Requirement (LED-OFF) = PSoC Current (~2mA)
I_{Avg} = (12mA*1s + 2mA*99) /100 = 2.12mA
T_{Life} = 1 Year = 365*24 hours

Battery Specification

Voltage = ?
Capacity (mAh) = ?

Question ?

- What if the battery available are either 1V or 12V, but the SoC requires a supply between 1.8V to 5V to operate ?

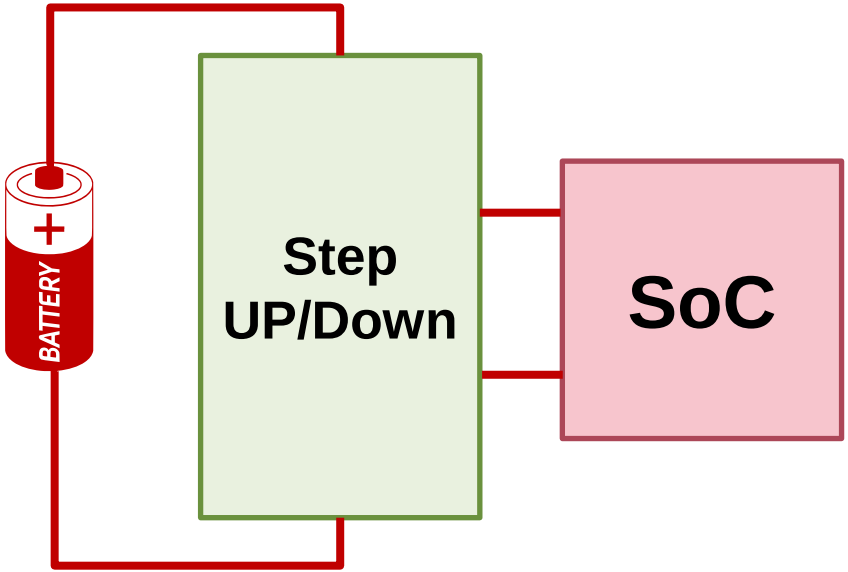


Application – Turn LED ON 1 second for every 100 seconds

SoC Requirement

V_{DD} = 1.8V to 5V
Current Requirement (LED-ON) = 10mA + PSoC Current (~2mA)
Current Requirement (LED-OFF) = PSoC Current (~2mA)
I_{Avg} = (12mA*1s + 2mA*99) /100 = 2.12mA
T_{Life} = 1 Year = 365*24 hours

Step-Up/Down



Application – Turn LED ON 1 second for every 100 seconds

SoC Requirement

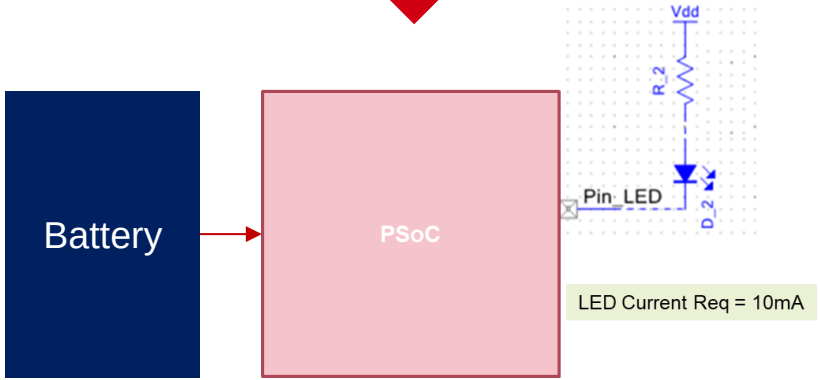
V_{DD} = 1.8V to 5V
Current Requirement (LED-ON) = 10mA + PSoC Current (~2mA)
Current Requirement (LED-OFF) = PSoC Current (~2mA)
I_{Avg} = (12mA*1s + 2mA*99) /100 = 2.12mA
T_{Life} = 1 Year = 365*24 hours
Required Capacity = 2.12mA*365*24 hours = 18571mAh
Energy Required ~ 3V * 18571mAh

Battery Specification
Voltage = X (in volts)
Required Capacity = 3V * 18571mAh / X

Generic Battery Design

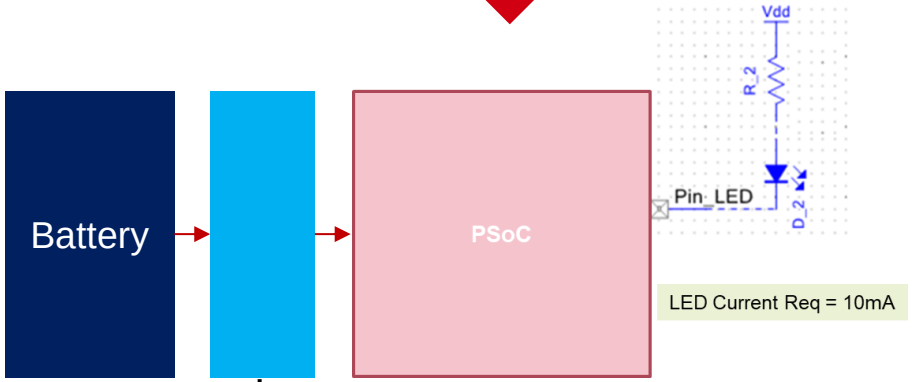
Battery-voltage is (1) within the (min, max) voltage requirement of the embedded system (2) Else

Yes



Application – Toggle LED ON 1 second for every 100 seconds

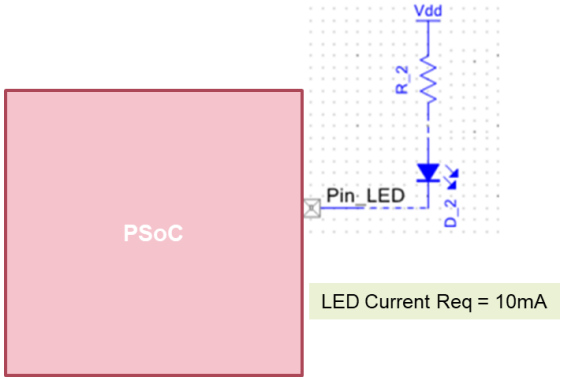
No



Power Mgmt. Step-Up or Step-Down Converters, Storage Elements and Allied Ckt Etc.,

Power Optimization

Place the SoC in low-power mode as and when required



Application – Toggle LED ON 1 second for every 100 seconds

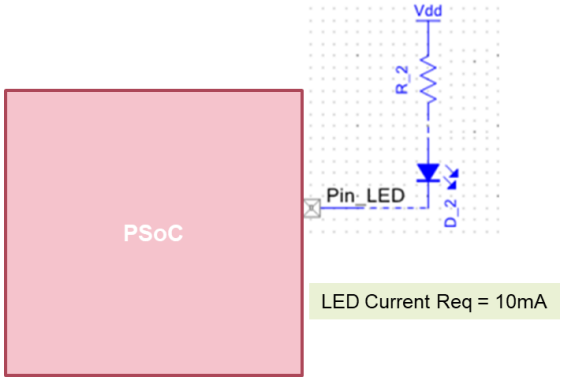
Method-1: SoC is active only when LED is ON

Method-2: SoC is active only to toggle LED states

Battery Requirement ?

Method #1

Place the SoC in low-power mode as and when required



Application – Toggle LED ON 1 second for every 100 seconds

Method-1: SoC is active only when LED is ON

Example Calculation

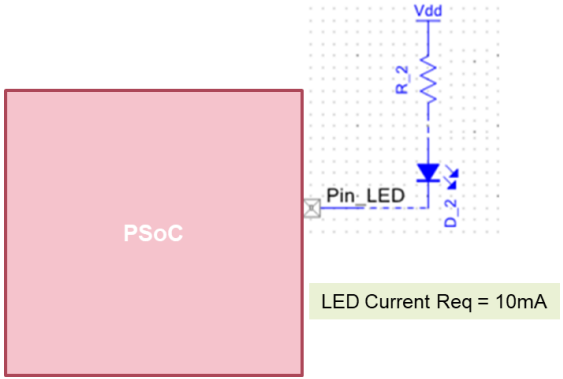
V_{DD} = 1.8V to 5V
Current Requirement (LED-ON) = 10mA + PSoC Current (~2mA)
Current Requirement (LED-OFF) = PSoC Current (~0mA)
I_{Avg} = (12mA*1s + 0mA*99s) / 100 = 0.12mA
T_{Life} = 1 Year = 365*24 hours

Battery Specification

Voltage = 3.7V (Li-Ion Battery)
Capacity (mAh) = 0.12mA * 365 * 24 = **1051 mAh**

Method #2

Place the SoC in low-power mode as and when required



Application – Toggle LED ON 1 second for every 100 seconds

Method-2: SoC is active only to toggle LED states

Example Calculation

V_{DD} = 1.8V to 5V
Current Requirement (LED-ON) ~ 2mA*100us + 10mA*1 + 2mA*100us
Current Requirement (LED-OFF) = PSoC Current (~0mA)
I_{Avg} = 0.1mA
T_{Life} = 1 Year = 365*24 hours

Battery Specification

Voltage = 3.7V (Li-Ion Battery)
Capacity (mAh) = 0.1mA * 365 * 24 = **876 mAh**

Power Modes

Table 1 Power mode specs

Power mode	Current range (typical) (VDD = 3.3 V to 5.0 V)	PSoC™ 4000/ 4000S/ 4100S/ 4100S plus/ 4100S plus 256k/ 4100S max	PSoC™ 4100 BLE	PSoC™ 4200 BLE	PSoC™ 4200DS	PSoC™ 4500S	PSoC™ 4700S	PSoC™ analog coprocessor	PSoC™ 4100PS	PSoC™ 4100/ 4200	PSoC™ 4100M/ 4200M	PSoC™ 4200L
Active	1.3 mA to 14 mA	–	–	–	–	–	–	–	–	–	–	–
Sleep	1.0 mA to 3 mA	0	0	0	0	0	0	0	0	0	0	0
Deep sleep	1.3 µA to 15 µA	35 µs	25 µs	25 µs	35 µs	35 µs	35 µs	35 µs	35 µs	25 µs	25 µs	25 µs
Hibernate	150 nA to 1 µA	Not applicable	2 ms	0.7 ms	Not applicable					2 ms	0.7 ms	0.7 ms
Stop	20 nA to 80 nA	Not applicable	2 ms	2.2 ms						2 ms	2 ms	1.9 ms

Reference: PSoC™ 4 MCU low-power modes and power reduction techniques

Power Modes

Table 2 PSoC™ 4 MCU power modes and resources availability

Subsystem	Active	Sleep	Deep sleep	Hibernate	Stop
CPU	ON	Retention[1]	Retention	OFF	OFF
SRAM	ON	ON	Retention	Retention	OFF
High-speed peripherals (SPI, UART, etc.)	ON	ON	Retention	OFF	OFF
Universal digital blocks (UDBs)	ON	ON	Retention[2]	OFF[3]	OFF
VDAC	ON	ON	Retention[2]	OFF	OFF
SPI slave and I²C slave (SCB-based)	ON	ON	ON	OFF	OFF
High-speed clock (IMO, ECO, and PLLs)	ON	ON	OFF	OFF	OFF
Low-speed clock (32 kHz) (ILO and WCO)	ON	ON	ON	OFF	OFF
Brown-out detection	ON	ON	ON	ON	OFF
Continuous time block (CTB) (opamp and comparators)	ON	ON	ON	OFF	OFF
Continuous time block mini (CTBm) (opamp and comparators)					
ADC	ON	ON	OFF	OFF	OFF
Low-power comparators	ON	ON	ON	ON	OFF
GPIO (output state)	ON	ON	ON	ON	Frozen[4]

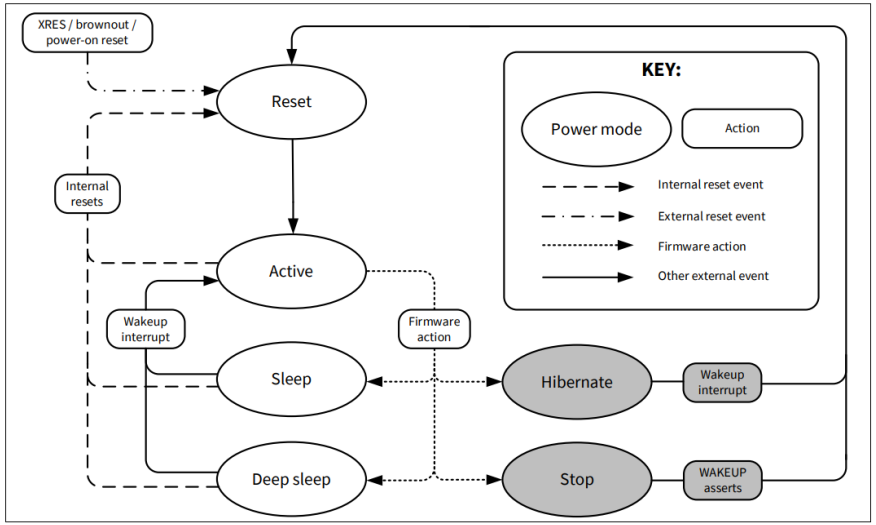


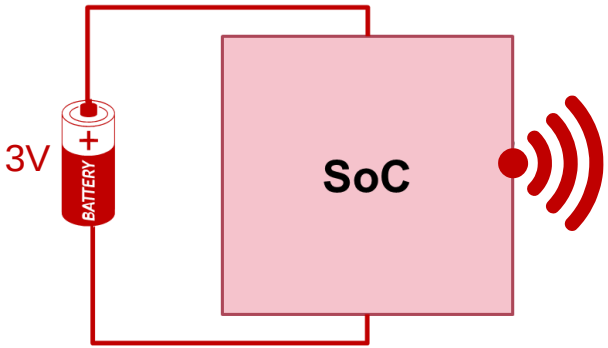
Figure 1 PSoC™ power mode transitions diagram

Wakeup Source = GPIO or Counter Interrupt or …

Reference: PSoC™ 4 MCU low-power modes and power reduction techniques

Exercise

Question: Turn SOC ON and send a BLE beacon for 1 second, every 24 hours over a period of 1 year. Estimate the battery capacity required.



Assumptions

Power Supply = 3V
Current Requirement (SoC ON + BLE Beacon Transmit) = 10mA
Current Requirement (SoC and BLE in Power Saving Mode) = 1uA

Calculations

Average Current ~ (10mA*1s + 1uA*24hours)/ 24hours = 1.1uA

Average Power = Average Current x Power Supply = 3.3uW

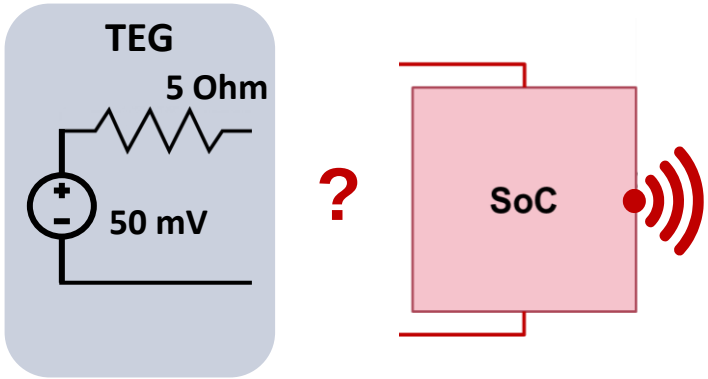
Operational Life = 1 Year

Energy Required Over a Period of 1 Year = 3.3uW x 1 Year = 28.9mWh

Required capacity of the battery, C = 29mWh / 3V = 9.6mAh

Powering from TEG

TEG: Thermoelectric Generator



Turn SOC ON and send a BLE beacon for 1 second, every 24 hours over a period of 1 year.

Assumptions

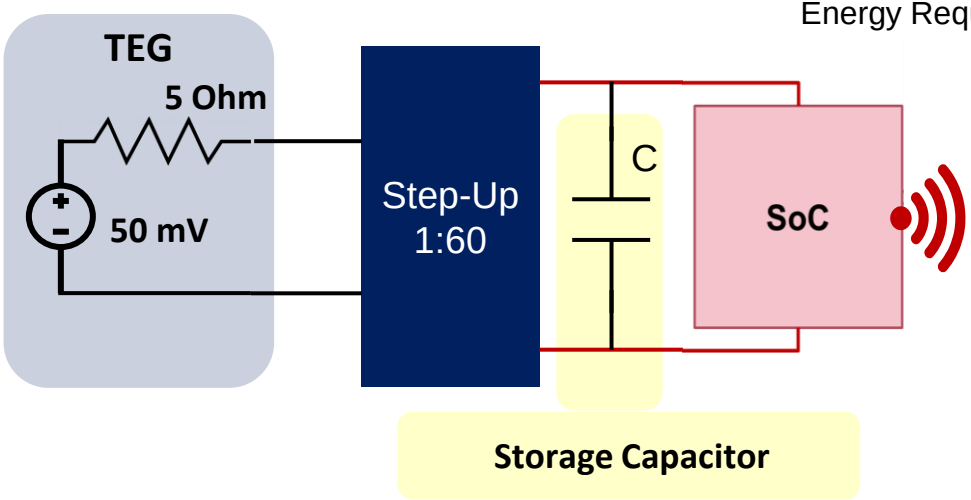
Power Supply = 3V
Current Requirement (SoC ON + BLE Beacon Transmit) = 10mA
Current Requirement (SoC and BLE in Power Saving Mode) = 1uA

Calculations

Average Current ~ (10mA*1s + 1uA*24hours)/ 24hours = 1.1uA
Average Power = Average Current x Power Supply = 3.3uW
Operational Life = 1 Year
Energy Required Over a Period of 1 Year = 3.3uW x 1 Year = 28.9mWh

Powering from TEG

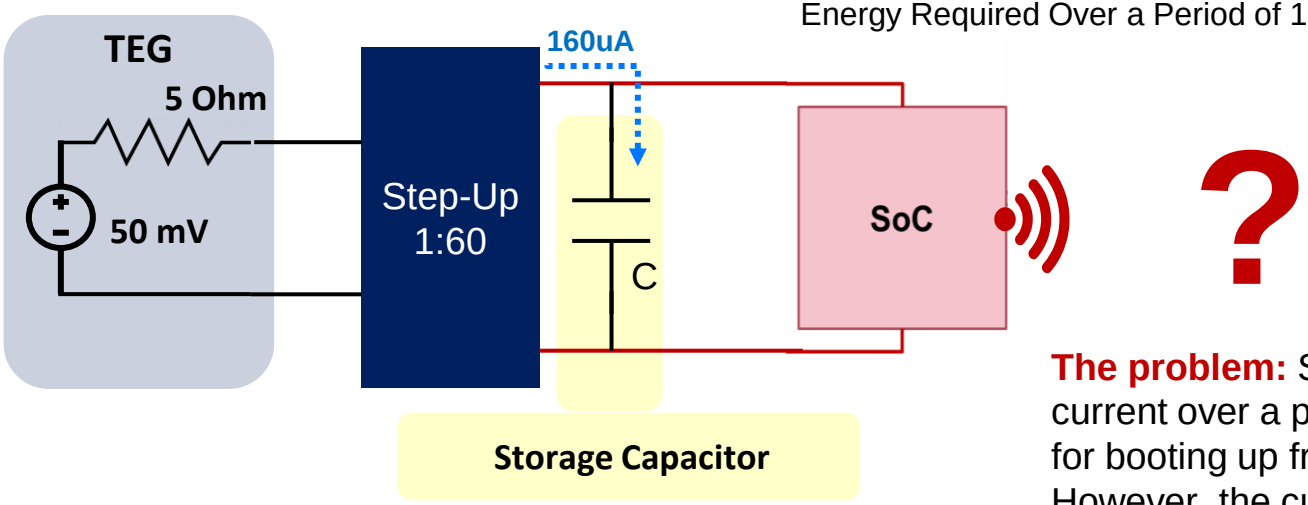
Application Requirements
SoC Voltage = 3V
Average Current ~ (10mA*1s + 1uA*24hours)/ 24hours = 1.1uA
Average Power = Average Current x Power Supply = 3.3uW
Operational Life = 1 Year
Energy Required Over a Period of 1 Year = 3.3uW x 1 Year = 28.9mWh



?

The Problem

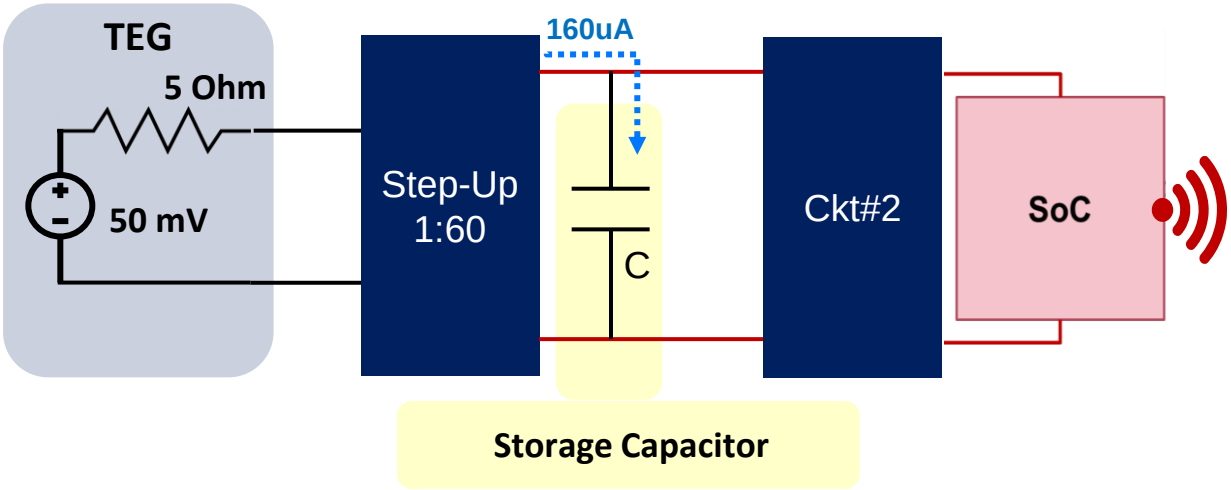
Application Requirements
SoC Voltage = 3V
Average Current ~ (10mA*1s + 1uA*24hours)/ 24hours = 1.1uA
Average Power = Average Current x Power Supply = 3.3uW
Operational Life = 1 Year
Energy Required Over a Period of 1 Year = 3.3uW x 1 Year = 28.9mWh



Cold Start – Turning ON SoC from powered down state.

The problem: SoC consumes mA of current over a period of tens of milliseconds for booting up from powered-off state. However, the current sourced by the step-up converter is only 160uA.

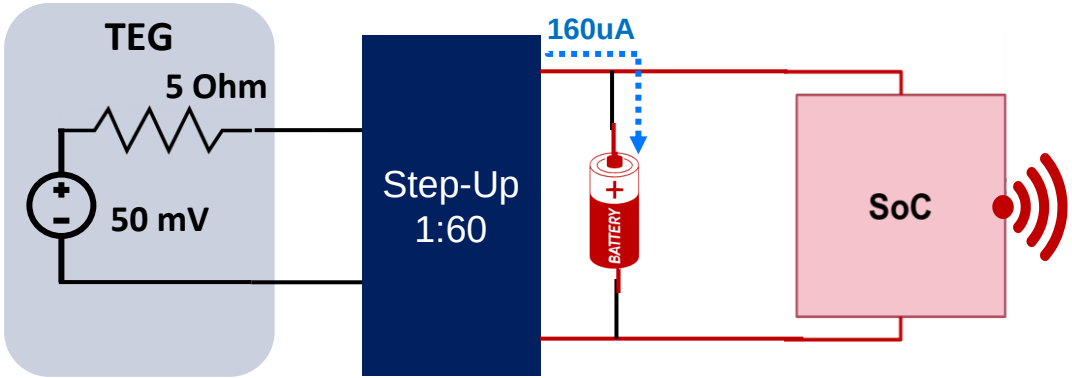
Solution#1



Ckt#2:

- Purpose: Connects/Disconnects the storage capacitor with SoC
- Connect the SoC with the storage capacitor when the voltage/charge across the capacitor is sufficient to cold start the SoC. When and how to disconnect the storage capacitor from SoC ?
- How to design the storage capacitor ?

Solution#2



- Replace the storage capacitor with a low mAh battery. Helps cold boot the SoC.
- The battery will be replenished by the TEG during normal operation of the SoC → Perpetual Operation