IoT system for remote sensing
SLG51003

This white paper presents the development of an IoT device for remote sensing, detailing the implemented system logic, the integration of power management ICs (PMICs), and the results obtained from a typical IoT deployment.

Contents

Terms and Definitions

IC	Integrated circuit
IR	Infrared
LED	Light-emitting diode

1. References

For related documents and software, please visit: Power GreenPAK | Renesas

[1] Go Configure Software Hub, Software Download and User Guide, Renesas
[2] GreenPAK Development Tools, Power GreenPAK Development Tools, Renesas
[3] GreenPAK Application Notes, GreenPAK Application Notes Webpage, Renesas
[4] SLG51003, Datasheet, Renesas

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2. Introduction

The Internet of Things (IoT) technology is designed to build a big network of interconnected devices that collect and share information and take actions based on the obtained data. IoT smart devices are revolutionizing various industries and aspects of daily life by combining connectivity, automation, and data processing.

These devices are usually equipped with communication modules like Wi-Fi, Bluetooth, Zigbee, or cellular networks. These enable seamless data exchange with other devices and central systems for different purposes such as smart thermostats adjusting temperature settings based on user preferences and environmental data or humidity and temperature sensors in farms with automatic irrigation systems.

IoT devices are designed to collect data from their surroundings through sensors and sometimes process it locally or send it to cloud systems for analysis. The ability to interact with other IoT devices or platforms is key, allowing a cohesive smart ecosystem.

Particularly, most IoT devices are optimized for low power consumption to extend battery life and reduce energy costs.

All previous characteristics allow IoT technology to be used in different applications:

- **Smart Homes:** Devices like smart speakers, lights, doorbells, and thermostats enhance comfort and security while optimizing energy usage.
- **Healthcare:** Wearable health monitors track vital signs, providing real-time feedback to patients and healthcare providers.
- **Industrial IoT (IIoT):** IoT sensors monitor machinery and production lines, enabling predictive maintenance and reducing downtime.
- **Transportation:** Connected vehicles use IoT for navigation, traffic management, and vehicle diagnostics.
- **Agriculture:** Smart irrigation systems use environmental data to optimize water usage, improving crop yields.
- **Retail:** IoT enables inventory tracking and personalized shopping experiences through connected sensors and devices.
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As can be concluded from the mentioned applications, sensors are the backbone of IoT devices, capturing data from the physical environment. Some commonly used IoT sensors include:

- **Temperature Sensors:** Monitor environmental or device-specific temperatures, crucial in HVAC systems and industrial machinery.
- **Proximity Sensors:** Detect the presence of objects or people, used in smart lighting and security systems.
- **Motion Sensors:** Identify movement, commonly found in alarms and automated lighting systems.
- **Environmental Sensors:** Measure humidity, air quality, or barometric pressure, aiding in weather predictions and air quality management.
- **GPS Sensors:** Provide location data, essential for navigation and asset tracking.
- **Biometric Sensors:** Track health metrics like heart rate, blood pressure, or oxygen levels, widely used in wearable health devices.
- **Battery Consumption and Power Management in IoT Devices**

One of the critical challenges for IoT devices is managing battery consumption effectively. Many IoT devices operate on small batteries, making energy efficiency a top priority.

Strategies to optimize power usage include:

- **Low-Power Communication Protocols:** Technologies like Bluetooth Low Energy (BLE) and Zigbee are designed to reduce the energy required for data transmission.
- **Sleep Modes:** Devices can enter low-power states when not actively collecting or transmitting data.
- **Energy Harvesting:** Some devices leverage solar panels to supplement their power needs.

- **Optimized Hardware Design:** energy-efficient sensors help minimize power consumption.

By combining innovative sensor technologies, intelligent software, and optimized power management, IoT smart devices are becoming indispensable tools for improving quality of life and operational efficiency across multiple domains. As technology advances, the capabilities and applications of IoT devices will continue to grow, shaping a more connected and automated future.

3. Static and dynamic characteristics of SLG5100X LDOs

The SLG5100X series features high-performance Low Dropout (LDO) regulators. These LDOs are known for their low noise and high Power Supply Rejection Ratio (PSRR), making them ideal for sensitive devices, such as sensor and communications modules.

The LDOs have specific characteristics that make them useful for remote applications, where current consumption and power control are key factors:

- **Power Sequencer**: The SLG5100X series includes a flexible power sequencer that controls the enabling and disabling of LDOs, with up to six resource enable steps. This enables the design to manage efficiently the power sequence, reducing unnecessary power consumption.
- **Current Limiting**: Each LDOs in the SLG5100X series has a programmable current limit in both LDO modes. That is, LDO and bypass modes. With this capability, the current consumption can be managed effectively, not only to reduce consumption but also to prevent overcurrent situations that may damage the device.
- **Protection Features**: The SLG5100X devices come with various protection features such as under-voltage lockout (UVLO), thermal shutdown, and configurable temperature alerts. These features help in maintaining the stability of the power supply and protecting the device from potential damage. More info about these features can be found on AN-CM-377

On each SLG5100X, different types of LDOs are available, each one with different characteristics and applications.

- **High-Performance LDOs (HP LDOs)**: They are designed to minimize internal noise, which is crucial for applications requiring clean power. They typically have low output noise and high Power Supply Rejection Ratio (PSRR). This makes them useful for meeting stringent power performance requirements, turning them an excellent choice for advanced camera modules and other small multi-rail applications
- **High-Voltage LDOs (HV LDOs)**: HV LDOs are designed to handle higher input voltages and provide stable output voltages for various applications. They offer efficient power management to meet the demands of applications requiring higher input voltages and stable output voltages, making them ideal for a wide range of industrial and consumer electronics applications.
- **Low-Voltage LDOs (LV LDOs)**: These devices are designed to provide stable power at lower input voltages, offering efficient power management for applications operating at lower voltages, ensuring reliable performance and minimal power consumption.

A summary of input and output voltages, current consumption in different operating modes and dynamic performance is shown in the next table:

Table 1: LDOs power characteristics of SLG51003

LDO Type	Input Voltage Range	Output Voltage Range	Output Current	Quiescent Current	Shutdown Current	Line Transient Response	Load Transient Response
HP LDO	2.8V to 5.0V	2.4V to 3.3V	Up to 475 mA	170 µA	240 nA	0.3 mV	30 mV
HV LDO	1.7V to 5.0V	1.2V to 3.75V	Up to 500 mA	13 µA	240 nA	2 mV	28 mV
LV LDO	0.8V to 1.5V	0.5V to 1.4V	Up to 800 mA	8 µA	240 nA	2 mV	21 mV
Load Switch	0.5V to 1.4V	-	Up to 800 mA	2 µA	240 nA	-	-

Quiescent Current presented under I_{OUT} = 0 mA for LDOs and for LV LDO in Load Switch mode Quiescent Current in OFF Mode.

Line transient response refers to the SLG51003 LDOs output response to sudden voltage changes at the input. It is analyzed how they handle a voltage drop at the input that is 100 mV below its typical operating level. Line voltage is changed as a high-speed transient event, changing in 1 us and with current output kept constant at high current levels (the value depends on the LDO type).

Load transient response refers to the SLG51003 LDOs capability to maintain a stable output voltage when the load current changes rapidly. In this case, it is evaluated the output voltage change load current (IOUT) increases from 1 mA to high level currents (depending on the LDO type) within 1 µs.

4. Analysis of power consumption in typical IoT sensors and communication modules

As mentioned in previous sections, power consumption is a critical factor in the design and operation of electronic devices, particularly those that rely on battery power as is the case with IoT Devices. Understanding the power requirements of different components helps in optimizing the overall energy efficiency and to analyze the advantages of integrated LDOs in SLG5100X series.

Sensors

Sensors are essential components in a wide range of applications, including environmental monitoring, health tracking, and industrial automation. The power consumption of sensors varies significantly based on their type and operating mode (fully operational mode also called active mode and low-power operational mode or sleep mode).

In the next items, a general analysis of several types of sensors are studied. Consequently, the common characteristics for each type of sensor (obtained from the research on different sensor models specifications) are presented

- **Temperature Sensors**: there are both analog and digital output sensors, designed for a large applications portfolio where it can be found industrial applications, general purposes and clinical-grade applications. Generalizing can be unfair, but there are some common characteristics that can be considered to ensure a reliable operation in most sensors.
    - **Supply Voltage Range:** Temperature sensors typically operate within a supply voltage range of 2.7V to 5.5V, with some low-power models designed to function at voltages as low as 1.8V.
    - **Active Mode Consumption**: In active mode, temperature sensors continuously monitor and report temperature readings. The power consumption in this mode typically ranges in hundreds of µA.

  - **Sleep Mode Consumption**: When not actively measuring, temperature sensors enter a low-power sleep mode, with power consumption dropping to around 10µA.
- **Pressure Sensors**: this type of sensor has several formats and measurement methods depending on the application and technology. They are usually less sensitive than temperature sensors, and their shape and technology vary with the application type. There are board mount sensors designed for air pressure measurement, sensors for industrial applications including liquids and gases pressure measurement or, also, series for medical applications.
  - **Supply Voltage Range**: Pressure sensors usually operate between 3.0V and 5.5V, although some low-power designs can function at voltages as low as 1.8V.
  - **Active Mode Consumption**: Pressure sensors consume more power in active mode, with values ranging typically in hundreds of µA. This mode is used when continuous pressure monitoring is required.
  - **Sleep Mode Consumption**: In sleep mode, power consumption is reduced to tens of µA, conserving energy when the sensor is not in use.
- **Humidity Sensors**: the variety on technologies and formats of these sensors define different characteristics and requirements. However, general specifications can be obtained by generalizing the requirements of different sensor IC's.
  - **Supply Voltage Range**: Most humidity sensors operate within a range of 2.0V to 5.5V, with some ultra-low-power variants designed for operation as low as 1.8V.
  - **Active Mode Consumption**: Humidity sensors typically consume less than 100µA in active mode, where they continuously measure and report humidity levels.
  - **Sleep Mode Consumption**: When inactive, these sensors consume lower 10th of µA in sleep mode.
- **Accelerometers**: these sensors have less variety in terms of power requirements, due to common technologies. They are usually MEMS sensors, with different designs depending on the application they are intended to be used for.
  - **Supply Voltage Range**: Most accelerometers operate within a range of 2.0V to 3.6V, with some low-power variants supporting operation down to 1.8V
  - **Active Mode Consumption**: Accelerometers, which measure acceleration and movement, consume current in mA range while in active mode.
  - **Sleep Mode Consumption**: In sleep mode, power consumption is significantly reduced down to tens of µA.
- **Proximity Sensors**: in this case, the measurement method is the key factor for sensor type classifying. The common methods are inductive, capacitive and optical measurement, the last one being the lower power consumption variant.
  - **Supply Voltage Range**: Proximity sensors typically operate within a range of 2.5V to 5.5V, with some models optimized for low-power operation at voltages as low as 1.8V.
  - **Active Mode Consumption**: Proximity sensors, which detect the presence of nearby objects, have a consume power in hundreds of µA range while in active mode.
  - **Sleep Mode Consumption**: In sleep mode, the power consumption typically lays bellow 100µA.

Table 2 shows the parameters described previously, to summarize and verify SLG5100X compliance with the analyzed sensors. The parameters mentioned for the SLG5100X correspond to the performance that can be obtained from the LDOs integrated in the PMIC series, while the ones mentioned for the sensors correspond to the worst case scenario.

Table 2: Power requirements of sensors

	SLG51003	Temperature Sensors	Pressure Sensors	Humidity Sensors	Accelerometers	Proximity Sensors
Supply Voltage	HP: 2.4 - 3.3 V HV: 1.2 - 3.75 V LV: 0.5 - 1.4 V	2.7 to 5.5 V	3.0 to 5.0 V	2.0 to 5.5 V	2.0 to 3.6 V	2.5 to 5.5 V
Typical current consumption	HP: 475 mA HV: 500 mA LV: 800 mA	up to 1 mA	up to 1 mA	100 µA	up to 10 mA	100 µA
Current consumption in sleep mode		up to 100 µA	up to 100 µA	up to 10 µA	up to 100 µA	up to 100 µA

As can be seen from the table, SLG5100X integrated LDO's are compatible with power requirements for different sensors used in common IoT applications.

In the case of communication modules, the rapidly evolving paradigm of the Internet of Things (IoT) makes the selection of the right communication module a crucial key for ensuring efficient and reliable connectivity. Among the most popular communication technologies are Bluetooth, WiFi, LoRa, and Zigbee. Each of these technologies has unique characteristics that make them suitable for different applications.

There are some criteria that are widely used to choose the communication technology first, and then the specific module:

- **Range**: Determine the required communication range. LoRa is suitable for long-range applications, while Bluetooth and Zigbee are better for short-range communication.
- **Data Rate**: Assess the data rate needs of your application. WiFi offers high data rates, making it ideal for data-intensive applications.
- **Power Consumption**: Consider the power requirements. Bluetooth and Zigbee are known for their low power consumption, making them suitable for battery-operated devices.
- **Network Topology**: Evaluate the network structure. Zigbee's mesh networking is beneficial for applications needing robust and scalable networks.
- **Cost**: Factor in the cost of modules and their integration into your devices.

In all cases, the industry of IoT is working on new standards or communication methods based on some key trends that is ends shaping its future:

- **Security and Privacy**: ensuring data security and privacy is paramount. In this context, new implementations are looking for robust encryption and secure communication protocols to protect sensitive data.
- **AI Integration:** Combining IoT with artificial intelligence (AI) is becoming increasingly common. AI can enhance data analysis and decision-making processes, making IoT systems more intelligent and responsive.
- **Edge Computing**: Measurement systems or remote industrial working requires processing data closer to the source (at the edge) to reduce latency and bandwidth usage. This is the main reason why this trend is now particularly important for new devices, especially in WiFi modules due to its high data rate.
- **Sustainability**: There is a growing emphasis on developing energy-efficient IoT solutions to minimize environmental impact. Low-power communication technologies like LoRa and Zigbee are gaining traction in this context.

WiFi Communication Modules

WiFi communication modules are widely used in devices that require wireless connectivity. The power consumption of these modules varies based on their operational mode.

- **Supply Voltage Range**: WiFi modules typically operate at power supply voltages of 3.3V or 5V. Some modules may support a wider range, such as 2.7V to 3.6V.
- **Active Mode Consumption**:
  - In active mode, WiFi modules consume the most power, typically ranging from 100mA to 300mA. This mode is used during data transmission and reception.
- **Idle Mode Consumption**:
  - When the module is not actively transmitting or receiving data but is ready to wake up, the power consumption is lower, ranging from 10mA to 50mA.
- **Sleep Mode Consumption**:
  - In sleep mode, the WiFi module enters a low-power state, with power consumption significantly reduced to between 1mA and 5mA. This mode is used to conserve energy when the module is not needed.

Bluetooth Communication Modules

Bluetooth communication modules are known for their energy efficiency, especially in low-power applications. Their power consumption also varies based on the operational mode.

- **Supply Voltage Range**: These modules operate with power supply voltage of 3.3V or 5V.
- **Active Mode Consumption**:
  - In active mode, where the module is actively transmitting and receiving data, the power consumption ranges from 30mA to 100mA.
- **Idle Mode Consumption**:
  - In idle mode, the module is not actively communicating but is ready to connect. Power consumption in this mode ranges from 1mA to 10mA.
- **Sleep Mode Consumption**:
  - Bluetooth modules consume very little power in sleep mode, with values typically between 0.1µA and 1µA. This mode is used to maximize battery life when the module is not in use.

Lora Modules

LoRa (Long Range) modules are widely used in IoT applications due to their ability to provide long-range communication with low power consumption.

- **Supply Voltage Range**: These modules typically operate within a voltage range of 2.1V to 3.6V, with 3.3V being the most common operating voltage, ideal for battery-powered applications
- **Active Mode Consumption**:
  - In this case, corresponding to the situation of active data transmission and reception, the power consumption is typically around 40mA.
- **Sleep Mode Consumption**:
  - LoRa modules usually include a sleep mode which helps to reduce power consumption in several orders for battery-powered devices. Current consumption in this case varies typically between 1µA and 5µA.

ZigBee Modules

ZigBee is a popular wireless communication protocol in IoT applications due to its low power consumption and mesh networking capabilities.

- **Supply Voltage Range**: These modules are typically designed to operate within a voltage range of 2.1V to 3.6V.
- **Active Mode Consumption**:
  - For active data transmission and reception, the power consumption is typically around 45mA.
- **Idle Mode Consumption**:
  - In idle mode, the module ready to establish communication when needed but not actively transmitting. Power consumption in this state typically ranges from 1 mA to 10 mA.
- **Sleep Mode Consumption**:
  - As in previous modules, ZigBee modules also include a sleep mode for low power consumption. Current consumption in this case varies typically between 2μA and 10μA.

Table 3 shows the parameters described previously, to summarize and verify SLG5100X compliance with the analyzed communication modules. The parameters mentioned for the SLG5100X correspond to the performance that can be obtained from the LDOs integrated in the PMIC series, while the ones mentioned for the modules correspond to the worst case scenario.

Table 3: Power requirements of communication modules

	SLG51003	WiFi	Bluetooth	LoRa	ZigBee
Supply Voltage	HP: 2.4 - 3.3 V HV: 1.2 - 3.75 V LV: 0.5 - 1.4 V	3.3 to 5 V	3.3 to 5 V	2.1 to 3.6 V	2.1 to 3.6 V
Current consumption in active mode	HP: 475 mA HV: 500 mA LV: 800 mA	100-300 mA	30-100 mA	40 mA	45 mA
Current consumption in idle mode		10-50 mA	1-10 mA	1-10 mA	1-10 mA
Current consumption in sleep mode		up to 5 mA	up to 1 μA	up to 10 μA	up to 100 μA

As it can be seen from the table, SLG5100X integrated LDO's are compatible with power requirements for different communication modules used for IoT applications. Also, it can be easily concluded that power consumption of sensors and communication modules is a crucial consideration for designing energy-efficient systems. Sensors typically have lower power consumption, especially in sleep mode, while communication modules consume more power.

5. Implementation and Configuration of an IoT power control system

Different application notes are available analyzing capabilities of SLG5100X PMICs. It is recommended to analyze the AN-CM-356 SLG51000, SLG51001 and SLG51002 Power Sequencer and AN-CM-357 Power Profile for Advanced Sensor Applications.

As a summary, a typical IoT system is based on a communications module (as WiFi, Bluetooth, LoRa or Zigbee), a central control unit (a microcontroller) and peripherals to implement the user desired actions.

As mentioned before, in many cases these systems are battery powered, so power consumption control is a key factor that must be considered in the implementation.

In Figure 1, a generalized block diagram of IoT applications is shown.

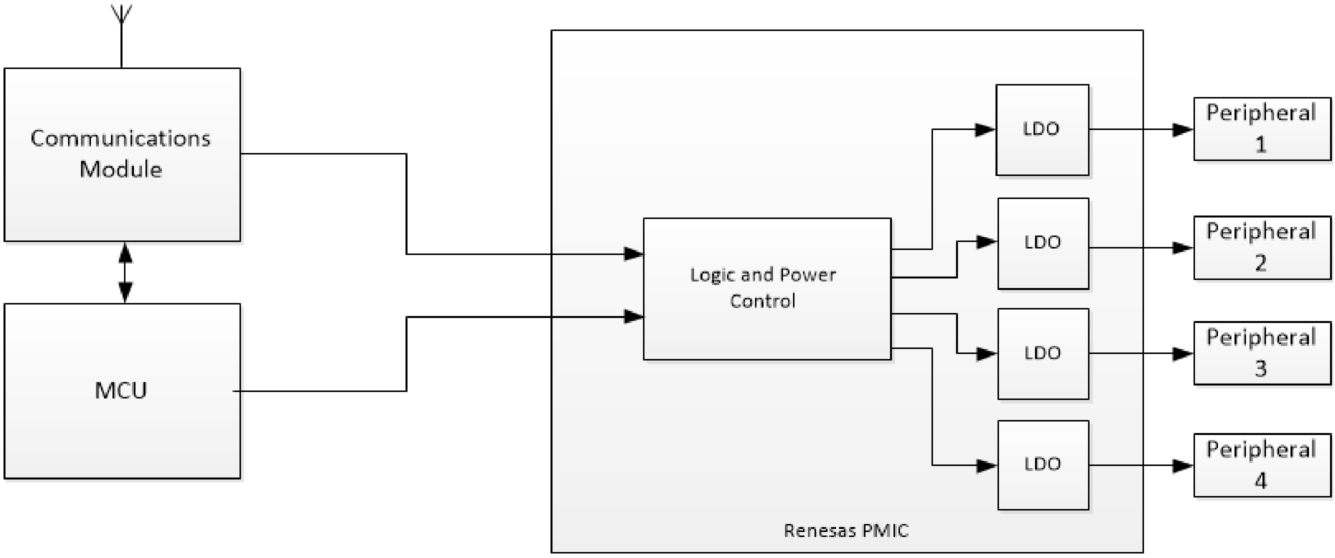

Figure 1. Conceptual diagram of IoT system powered by SLG5100X

Communications modules and peripherals vary depending on the application, as is expected. Table 4 shows the representative components for most common IoT applications that may used as building blocks in Figure 1.

	Smart Home	Healthcare	Industrial	Transportation	Agriculture	Retail
Communications Module	Wifi/Zigbee	Bluetooth	Wifi/LoRa	LoRa	LoRa	Wifi/LoRa
Sensors	Temperature Humidity Proximity	Temperature Pressure Accelerometer	Temperature Pressure Humidity	Accelerometer	Temperature Humidity	Temperature Proximity
Low Power	No	Yes	No	Yes	Yes	No

6. Conclusion

In this white paper, a complete analysis of IoT system power requirements is made. It includes not only the typical sensors of such type of applications, but also the communications module that are common for these systems.

Those requirements are compared with the power characteristics of the LDOs embedded on the SLG5100X ICs, demonstrating the compatibility and applicability of those integrated circuits in this system type. This analysis included basic parameters, such as operating voltage levels and current consumption.

The comparisons made in this white paper show how the power features of Renesas PMICs can be applied, being useful not only in terms of power supply, consumption and control but also in terms of the size of the entire control system, which is smaller than many other implementations and outlines where Renesas PMICs are not used.

Revision History

Revision	Date	Description
1.00	July 16, 2025	Initial release.