Ultra-Low Power Short Range Radio Transceivers

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Overview

Recent years witnessed tremendous growth in the wireless sensor networks (WSN) market and for ultra-low power (ULP) radios. The applications for such radios expanded from heavily duty-cycled spot measurement transmissions to more data intense continuous links, while being powered from smaller batteries and alternate sources of power such as energy harvesting (EH) devices. WSN applications include short-range machine-to-machine (M2M), medical sensors around the body and a multitude of other applications for emerging markets in sensing and automation.

Wireless sensors around the body are broadly classified into two categories of networks: wireless personal area network (WPAN) and wireless body area network (WBAN). WPAN is the network space around an individual that covers the living or working space nearby, typically up to ten meters. This includes protocols such as Bluetooth® and ZigBee®. WBAN is a smaller wireless space around a person, usually up to one meter and is used for communicating between sensors associated with the human body. Although both WPAN and WBAN are distinct network spaces, many applications overlap the two spaces. Advances in radio technology and low power sensors led to opening up of new arenas for WSN. Another important component for ultra-low power WSN is efficient energy storage and management. Micro-power batteries, such as thin-film batteries, have greatly advanced in technology in recent years along with micro-power management solutions. Advances in ULP technology have replaced the need for AA or AAA batteries to much lower battery capacities and sizes. Hence small, flexible and smart wireless sensors with long battery life are a reality.

A new class of wireless sensors powered by harvested energy, so they do not need battery replacement, is the latest in WSN technology for sensing and monitoring hard-to-reach environments and applications where energy can be harvested. Wireless sensors working on harvested energy have a set of needs that are more stringent than regular wireless sensors: low peak-power, ultra-low standby current and other needs, apart from general low power consumption. This is a relatively new field within WSN and has wide-spread applications including medical, M2M, military and other research areas.

The technology and design considerations on the short range radio transceiver play a key role in efficiency of such low power wireless sensors. The requirements for the transceiver to fit applications mentioned above can be categorized as shown in Figure 1.

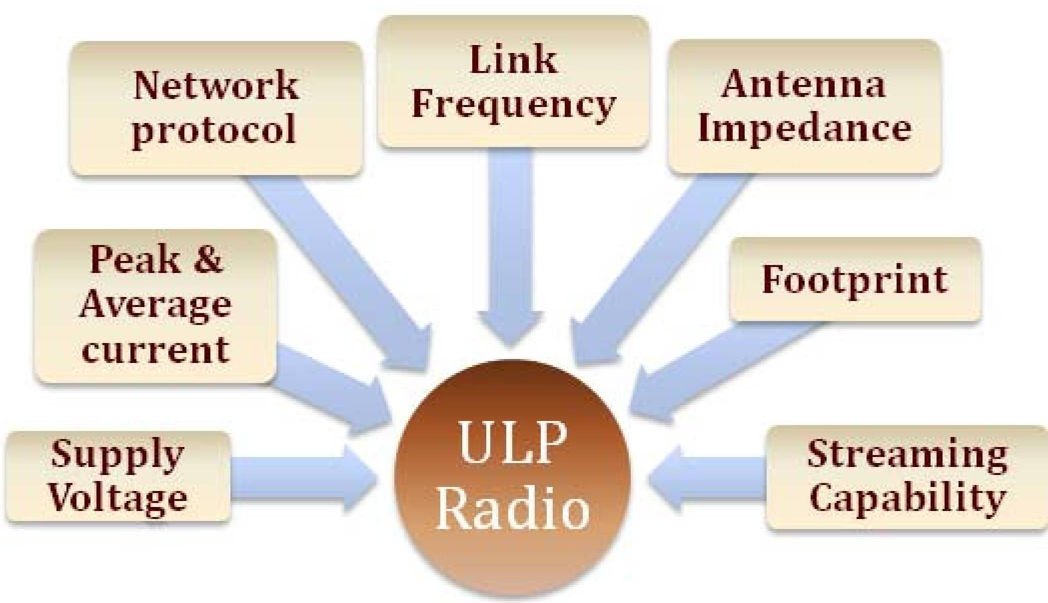

Figure 1: **Requirements for an Ultra-Low Power Radio Transceiver**

Key Factors

The power supply requirement of the transceiver is a key factor in the wireless sensor design and application. Since most ULP sensors run from tiny batteries and energy harvesting sources, sub 2V supply voltages are highly desired. Most sensors run out of a single cell, depending on battery chemistry. Radio transceivers that work down to 1.1V give additional flexibility to sensor design and reduce power management constraints. The supply voltage, power amplifier (PA) energy consumption (at comparable range) and link data rate are often ignored when comparing different solutions. However, all three have a substantial impact. A radio operating at 2.5V consumes twice as much power as a radio with the same current consumption but operating at 1.25V. Operating at higher voltage is only required when output power in excess of 5dBm is needed. This is not the case for short-range applications, as output power is rarely over 0dBm. Low supply voltage is an easy way to reduce power consumption at the system level, but it requires a radio frequency (RF) integrated circuit (IC) designed for low voltage operation.

Peak current is another key parameter for transceivers. Almost all wireless based sensor networks rely on duty-cycling to save power and restrict the usage of radio space. This generates peaks in the current consumption profile of the sensor. Radios that have high peak currents impose constraints on the power management and makes meeting power supply rejection more difficult.

This constraint is even more important for wireless sensors that run from harvested energy sources. Often energy harvester transducers have higher output impedance than batteries. The micro-power management layer between the transducer and the sensor converts the supply characteristics, including source impedance. Therefore, the low peak current consumption in the radio transceiver reduces constraints on the power supply of the wireless sensor.

For a radio transmitter, the power consumption of the PA can be very large. Many 802.15.4 or Bluetooth radios consume 25-40mW for a 25-meter free-space range, wasting over 95 percent of it. Figure 2 shows energy per bit versus peak power of some available solutions for 25m free-space range. For battery or energy harvesting powered systems, the optimum combination would ideally be close to the lower left corner.

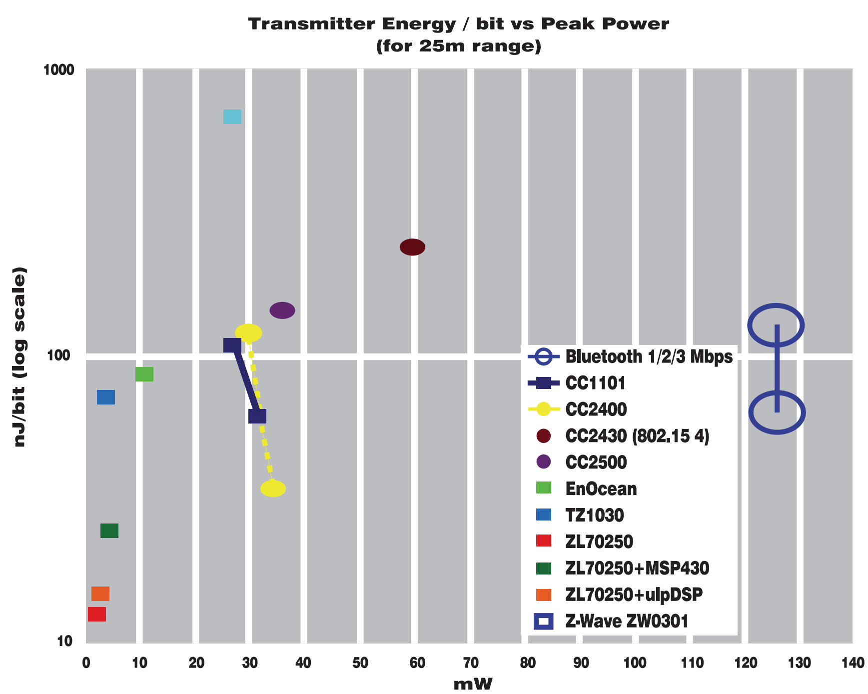

Figure 2: **Energy per Bit Versus Peak Power**

The principal parameter from a transmitter PA point-of-view comes from the receiver. Its sensitivity defines, for a given range, how much power must be radiated. Most radios fall into the –85dBm to –95dBm sensitivity range, resulting in a factor of 10 in PA power consumption. The three main factors impacting power consumption are receiver sensitivity, carrier frequency and output impedance. They are additive, and together can represent over two orders of magnitude in PA power consumption variation for an identical range.

Figure 3 compares voltage supply, transmit and receive power consumption of popular radio transceivers.

Other IC level specifications, like leakage current and wake-up time, also affect the power consumption. However, while they are critical for very low payload data rates, their importance diminishes past 10bit/s.

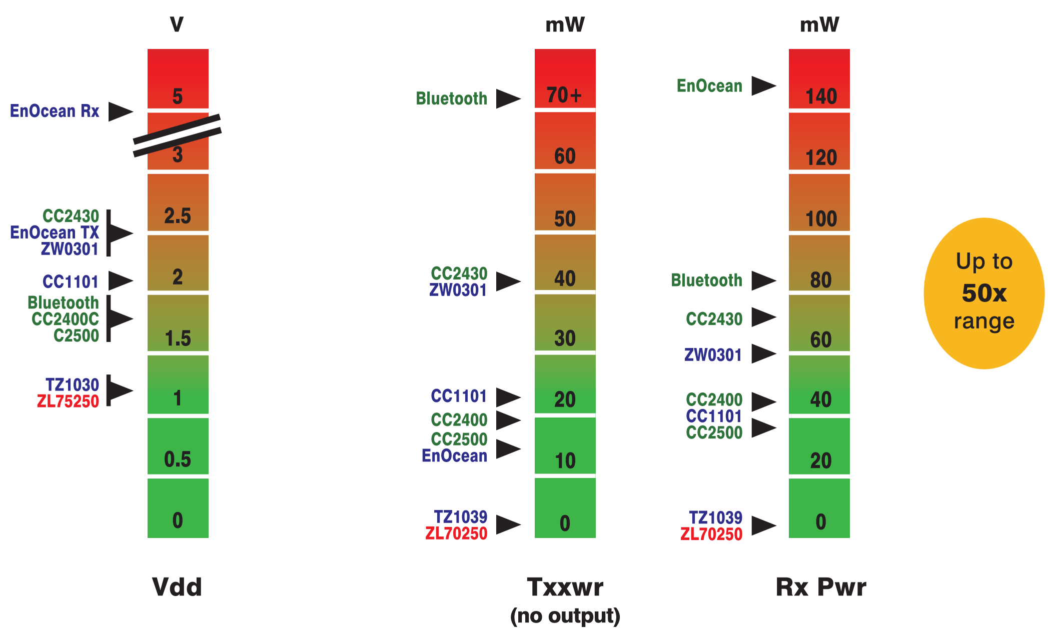

Figure 3: **Operating Voltage, TX and RX Power of Some Available Radio Transceiver Solutions**

Another important parameter that affects PA power consumption is output impedance. Most radios have output impedance below 100Ω. Low impedance is only required for high output power (long range), but it results in up to five times higher current consumption than higher output impedance options, which are more suited for short reach wireless interconnect applications. Overall, assuming a similar receiver sensitivity and PA efficiency, a high impedance 900MHz radio would use only 1mW in its PA to achieve the same range as a 50Ω 2.4GHz radio using 25mW to 40mW.

The choice of carrier frequency is an important parameter for the transceiver. The two available options within industrial, scientific and medical (ISM) radio bands are 2.4GHz or sub-GHz frequencies. Some of the factors to consider with this choice are:

- Range
- Power consumption
- Data rates
- Antenna size
- Interoperability (standards)
- Worldwide deployment

Wi-Fi®, Bluetooth and ZigBee technologies are heavily marketed 2.4GHz protocols used extensively in today's markets. However, for low power and lower data rate applications, such as wireless sensors, wireless medical monitoring, home security/automation and smart metering, sub-GHz wireless systems offer several advantages, including longer range for given power, reduced power consumption and lower deployment and operating costs. Sub-GHz carrier frequencies have certain advantages over 2.4GHz:

- Range and signal quality. As radio waves pass through walls and other obstacles, the signal weakens. Attenuation rates increase at higher frequencies, therefore the 2.4GHz signal weakens faster than a sub-GHz signal. 2.4GHz radio waves also fade more quickly than sub-GHz waves as they reflect off dense surfaces. In highly congested environments, the 2.4GHz transmission can weaken rapidly, which adversely affects signal quality.
- Biological tissues absorb RF energy as a function of frequency. Lower frequencies can penetrate the body easily without being absorbed, meaning better RF link or less power consumed for a sub-GHz link compared to 2.4GHz.
- Even though radio waves travel in a straight line, they do bend when they hit a solid edge (such as the corner of a building). As frequencies decrease, the angle of diffraction increases, allowing sub-GHz signals to bend farther around an obstacle, reducing the blocking effect.

The Friis equation demonstrates the superior propagation characteristics of a sub-GHz radio, showing that path loss at 2.4GHz is 8.5dB higher than at 900MHz. This translates into 2.67 time longer range for a 900MHz radio, since range approximately doubles with every 6dB increase in power. To match the range of a 900MHz radio, a 2.4GHz solution would need greater than 8.5dB additional power.

Besides the need for higher power for the same link budget, the 2.4GHz band has higher chances of interference. The airways are crowded with colliding 2.4GHz signals from various sources, such as home and office Wi-Fi hubs, Bluetooth-enabled computer and cell phone peripherals and microwave ovens. This traffic jam of 2.4GHz signals creates a lot of interference. Sub-GHz ISM bands are mostly used for proprietary low-duty-cycle links and are not as likely to interfere with each other. The quieter spectrum means easier transmissions and fewer retries, which is more efficient and saves battery power.

Both power efficiency and system range are functions of the receiver sensitivity plus the transmission frequency. The sensitivity is inversely proportional to channel bandwidth, so a narrower bandwidth creates higher receiver sensitivity and allows efficient operation at lower transmission rates.

For example, at 300MHz, if the transmitter and receiver crystal errors (XTAL inaccuracies) are both 10 ppm (parts per million), the error is 3kHz for each. For the application to efficiently transmit and receive, the minimum channel bandwidth is two times the error rate, or 6kHz, which is ideal for narrowband applications. The same scenario at 2.4GHz requires a minimum channel bandwidth of 48kHz, which wastes bandwidth for narrowband applications and requires substantially more operating power.

In general, all radio circuits running at higher frequencies, including low-noise amplifier, power amplifier, mixer and synthesizer, need more current to achieve the same performance as lower frequencies.

Range, low interference and low power consumption are basic advantages of sub-GHz applications over 2.4GHz applications. One of the disadvantages often cited is that the antennas are larger than those used in 2.4GHz networks. The optimal antenna size for 433MHz applications, for instance, can be up to seven inches. However, antenna size and frequency are inversely proportional. If node size is an important design consideration, developers can raise the frequency (up to 950MHz) in order to employ a smaller antenna.

Overall power consumption of a wireless sensor is not only a function of physical layer items such as radio architecture, carrier frequency, and antenna choice, but is also a function of the amount of time the radio needs to run in order to transport the payload data over air. This is dependent on the data rate requirement and the protocol overhead to establish and maintain the communication link.

The data rate is one of the most important factors defining the power consumption in duty-cycled wireless links. The average power is almost inversely proportional to the link data rate. A 100kbps radio will consume almost half the power of a 50kbps radio for the same payload. For a given payload, a higher data rate can be seen as a way to improve the energy efficiency. When comparing RF transceivers, energy per bit is a better indicator than current consumption. But high data rate radios are often those with the higher peak currents. These are highly undesirable for most small batteries or energy harvesters because they result in large, leaky, storage capacitors, generally a few hundreds of µF.

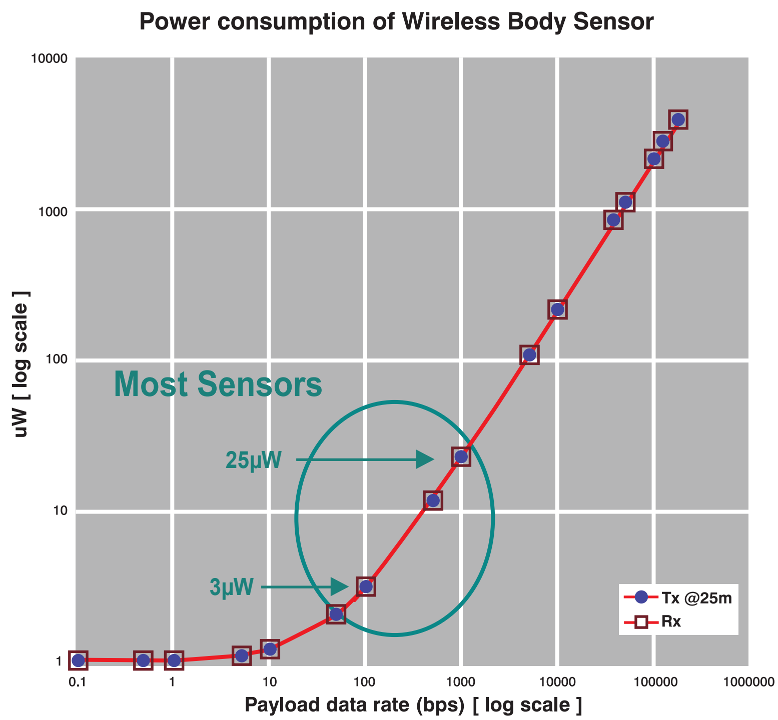

Figure 4: **Average Power Versus Payload Data Rate of a Wireless Sensor Using the ZL70250 Transceiver**

At the network level, the protocol has a major impact on the average power budget. Today's standards, such as 802.15.4 (ZigBee) or Bluetooth, offer highly sophisticated link and network layers. But these stacks amount to 50-75 percent of the radio power consumption and larger overheads. For ultra low-power systems, the "one size fits all" standardized option is rarely the optimum solution. Instead, ultra low-power applications should consider using a protocol optimized to their need.

The latency requirement of the network has a significant impact as well. The amount of time nodes spend listening, or sniffing, is a function of latency. Low latency means continuous or frequent sniffing. In highly duty-cycled systems the receiver power due to sniffing is the largest portion of the power budget. For example, in 802.15.4 mesh networks about 9 percent of the system power is used for receive. In higher payload systems, sniffing may not be as dominant but receive power will still be over 50 percent of the RF budget. The lowest possible receiver power consumption is often essential to achieving ultra low-power RF telemetry.

Microsemi's Low Power Radio Technology

Microsemi is a leader in a wide range of solutions, including ULP radios and power management. ZL70250 is a fully integrated ultra-low power sub-GHz ISM band transceiver from Microsemi, meant for applications where power is critical. Despite its very low power, the ZL70250 still has enough data rate to also support voice or sound communications. With over 186 kbps, it has enough bandwidth to carry a continuous bio-signal such as ECG, telephone quality voice link or higher quality sound with some ULP signal processing. With an overall power consumption of about 4–5mW, a headset small enough to fit in the ear could operate for over 10 hours and a wireless stethoscope patch using a thin-film battery could continuously monitor chronic respiratory diseases or support the study of sleep apnea.

Ultra-low power RF technology is critical in applications where power is at a premium and payload is greater than 10 bits/sec. Where previous body-worn wireless sensors could only be used for slowly varying parameters, new RF technologies can help observe faster changing physiological parameters, such as heart and brain electrical activity or blood oxygenation, which require on the order of 0.5 to 5 kbps to extract meaningful waveforms. A wireless body sensor based on the ZL70250 would consume, on average, less than 100µA, making thin-film batteries or even thermo-electric energy harvesters viable power options.

ZL70250 comes as a CSP package (approximately 2mm x 3mm), ideal for easy assembly while keeping form factor of the device to a minimum. ZL70250 has a standard 2-wire and SPI interface for control and data transfer by any standard microcontroller. This gives the customer the option to choose the microcontroller that fits the specific application.

The typical use of ZL70250 as a sensor is shown in Figure 5.

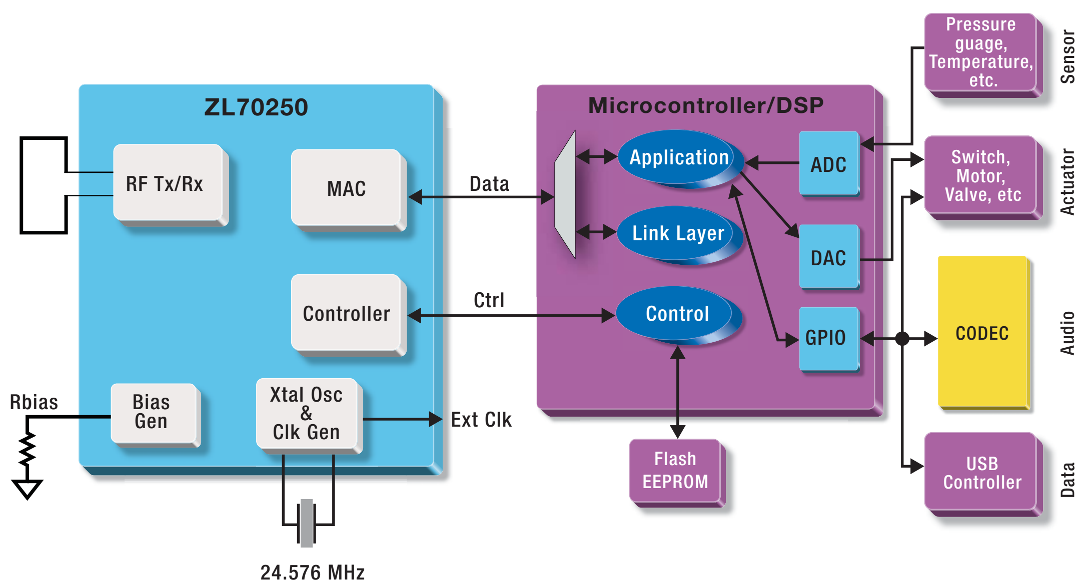

Figure 5: **Block Diagram of a Typical Wireless Sensor Based on ZL70250**

A microcontroller typically interfaces with the ZL70250 and application-specific sensor or output device. For example, in the case of a Lead-1 ECG, a ULP analog front-end, with the output connected to the ADC of the microcontroller that runs the application and communication protocol, results in a wireless ECG solution with extremely low power so that it can run from a CR series coin cell for about a week continuously. Some other similar ultra low-power reference design successes include a 3-axis accelerometer and a pulse-oximeter.

ZL70250 has one of the lowest peak currents in the industry, making it ideal for energy harvested applications. A prototype of a wireless body-worn sensor to measure body temperature was successfully developed using a thermo-electric generator (TEG). Figure 6 shows the structure of such a sensor that does not ever need battery replacement.

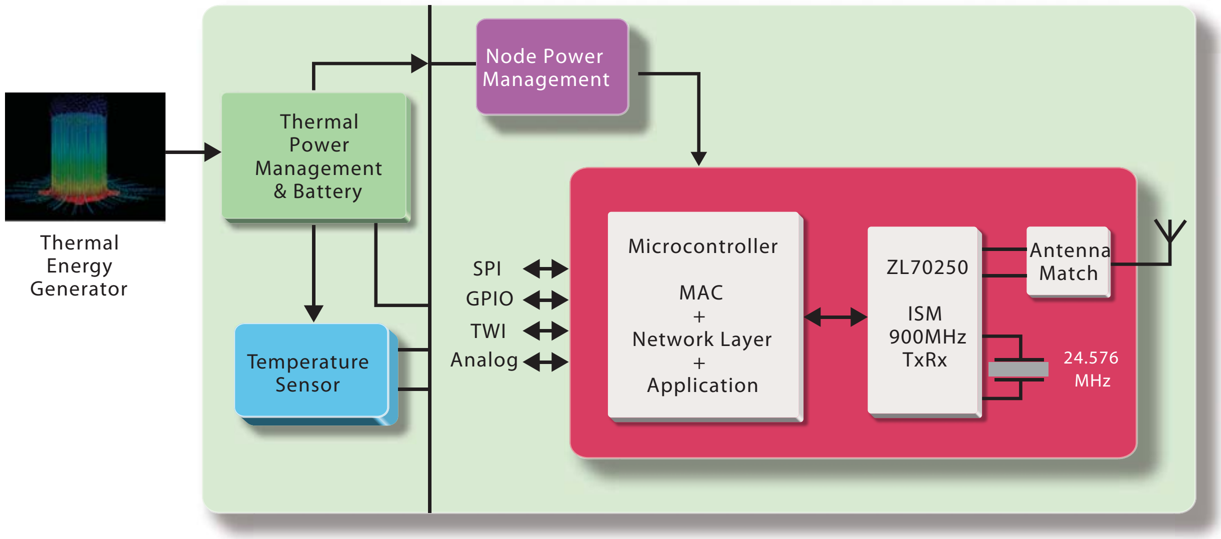

Figure 6: **Block Diagram of Wireless Sensor Powered by Energy Harvester**

Conclusion

Sub-GHz ISM band ultra-low power band transceivers, such as ZL70250, target a position in the market space to address the stringent needs required for applications such as wireless sensors powered by energy harvesters, continuous monitoring of bio-signals for wearable wireless medical devices, and sensing applications in short-range machine-to-machine applications that encompass both WPAN and WBAN network areas using cutting edge ultra-low power technologies.

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