Using Ultra Low Power Equipment in Hazardous Areas

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Intrinsic Safety is achieved by limiting the power and energy in hazardous areas to levels below those that cause a spark or ignition. Over the past decade, power requirements of electronic equipment have reduced significantly. Plant interfaces and sensors can be connected together and to control systems using low power wireless communication networks. This equipment can provide a complete measurement solution for use in hazardous locations, eliminating the need for wiring, intrinsic safety barriers and explosion proof conduits and housings. This paper will examine the safe application of low power instrumentation and wireless technologies and discuss the design, selection and implementation of ultra low power systems in hazardous areas.

Introduction

Electrical equipment installed in hazardous areas is of concern because the potential energy stored and consumed by these devices is often great enough to ignite flammable mixtures. Traditionally, protection from explosion in hazardous environments has been accomplished by either using explosion proof apparatus which can contain an explosion inside an enclosure, or pressurization or purging which isolates the explosive gas from the electrical equipment. Intrinsically safe equipment on the other hand is defined as “equipment and wiring which is incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific hazardous atmospheric mixture in its most easily ignited concentration” [1]. This is achieved by limiting the amount of power available to the electrical equipment in the hazardous area, to a level below that which will ignite the gases. In order to have a fire or explosion, three elements have to be present. These are fuel, oxygen and a source of ignition. An intrinsically safe system assumes the fuel and oxygen is present in the atmosphere, but the system is designed so the electrical energy or thermal energy of a particular instrument loop can never be great enough to cause ignition. Intrinsically safe apparatus cannot replace these methods in all applications, but where possible can provide significant cost savings in installation and maintenance of the equipment in a hazardous area. The basic design of an intrinsic safety barrier uses zener diodes to limit voltage, resistors to limit current and a fuse. Hazardous areas may contain flammable gasses or vapors, combustible dusts, or ignitable fibers or flyings. There are different systems used internationally classify the type of hazard. In most cases the equipment is designed for the worst case, which would be to assume the explosive atmosphere is always present and the electrical or thermal energy is the lowest required to cause a fire or explosion.

Intrinsic Safety Limits & Classifications

The energy required to ignite various gas groups have been proven by experimentation. Graphs of this data have been produced, and can be used to indicate safe levels of energy. A very small amount of energy is required to cause an ignition, for example, a mixture of Hydrogen in air requires only 2OµJ of energy [2]. In electrical circuits the mechanism for the release of this ignition energy is one or more of the following:

- Open circuit or short circuit components or interconnections in a resistive circuit
- Short circuit of components or interconnections in a capacitive circuit
- Open circuit components or interconnections in an inductive circuit
- Ignition by hot surfaces.

Intrinsically Safe Equipment

Intrinsically safe equipment used in hazardous areas must be designed and approved for the environments in which they operate. Sensors designated intrinsically safe (IS) must have insufficient energy to cause ignition of the rated hazard. Compliance testing ensures that an IS-rated device has been tested and a determination made of how much energy would cause a reaction.

Certain devices, such as switches and terminal boxes and similar items of simple construction, do not contribute to the energy available for sparking or heating as they are essentially inert and their parameters can easily be defined because of their simplicity. These are called simple apparatus and the definition is that such apparatus will be a component or assembly of components of simple construction having well-defined electrical parameters. The original definition of simple apparatus in BS 5501 Part 1 (1977) [16] was 'devices in which, according to the manufacturers specifications, none of the values of 1.2volts, 0.1 amps 20µJ or 25mW were exceeded'.

In most installations the equipment in the hazardous area will be connected to other equipment in a non-hazardous area. The equipment mounted in the hazardous area must first be approved for use in an intrinsically safe system. Equipment outside the hazardous area can only be connected to IS devices through an "external apparatus" called a safety barrier designed to limit the amount of current, and hence energy, that can pass in the circuit under any fault condition. This passive barrier establishes a protection mechanism, which prevents overvoltage and limit current. Should a short circuit occur on a signal or power line, the barrier prevents ignition. Every intrinsically safe device must be powered off a barrier. The barrier must be matched to the entity parameters of the IS device to make sure it is protected. The barrier is mounted in the non-hazardous area. The connection is illustrated below.

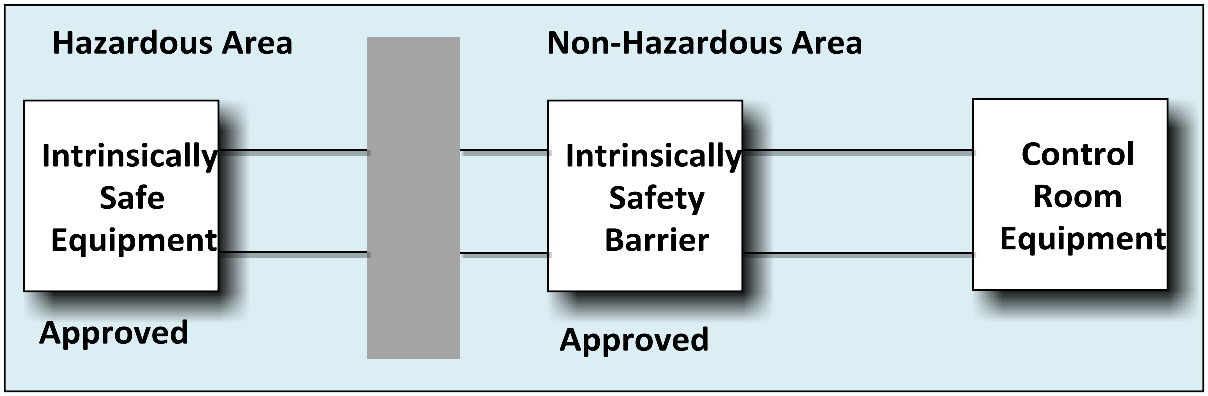

Figure 1. **Wired Intrinsically Safe Equipment**

Devices such as transmitters, power supplies, batteries, capacitors, and inductors can create or store energy that is greater than the allowable intrinsic safety limits set forth by the governing body. The danger is generally not in their energy storage capacity, but in the intentional or accidental release of the stored energy due to short circuits or open circuits. These electrical shorts and opens can be during normal circuit operation and faulted circuit conditions. To use these energy storage devices in a hazardous location the voltage, current, and device temperature must be limited to values that have been proven safe by controlled experimentation.

Of particular concern is the energy discharge capability of a power supply or battery. Both of these devices intentionally provide voltage and current, the sum of which can easily cause an ignition spark due to a short or open. These devices must be current limited and voltage limited to prevent spark energy discharge due to a shorted or open device in the circuit With all of the circuit protection and energy limiting devices installed in the circuit, it is also important to be sure that the circuit will still operate as intended under normal operating conditions.

Wireless IS Devices

Clearly a self contained wireless sensor would present a significant advantage over the above by potentially eliminating the wiring and barriers between the hazardous and non-hazardous areas. A wireless IS device can provide significant advantages in the ease of deployment, faultfinding and upgradability.

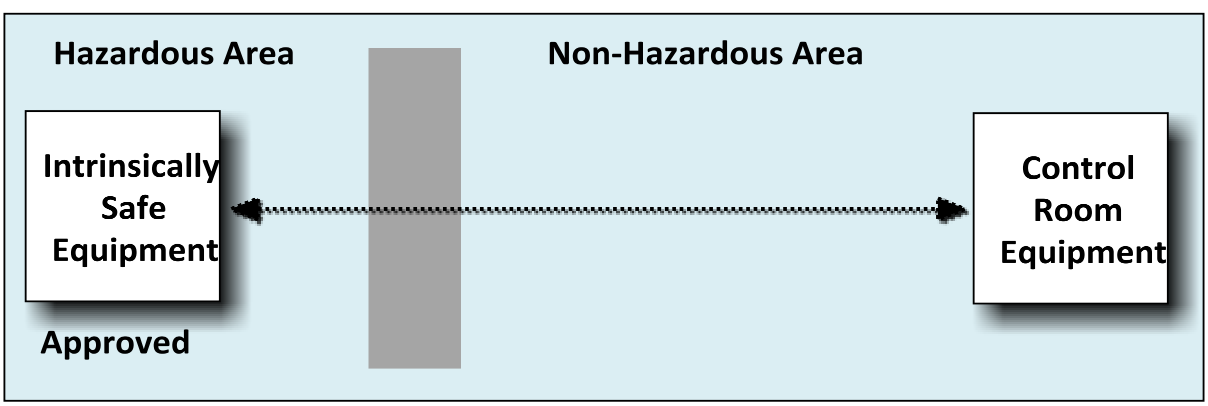

Figure 2. Wireless Intrinsically Safe Equipment

While wired IS devices are still dominant in terms of market demand, there is a significant growth in demand for wireless IS devices. According to a 2006 survey by Venture Development Corporation the highest shipment growth rates are expected for both of the monitoring and control component categories, with shipments of wireless transmitters forecast at a 35% compound annual growth rate, and networking products at 26.1%. The slowest shipment growth rates are forecast for intrinsically safe phones (2.8%) followed by radios & pagers (4.4%).The survey results show the relative demand for wireless vs. wired IS products

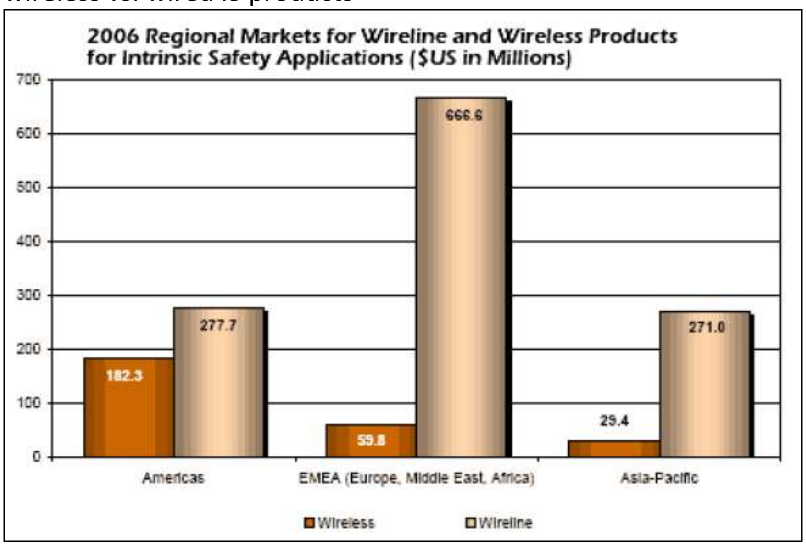

Figure 3. Market for Intrinsic Safety Products (2006)

Electronic Equipment Power Consumption

The ENIAC (1944) is generally considered to be the first electronic computer [8]. It required 18,000 vacuum tubes and weighed 20 tons, and it was more of a huge calculator than a computer. The power consumption was 150 kW. The Whirlwind, designed by IBM in 1952 (75,000 tubes, 275 tons), consumed 750 kW. The introduction of transistors in the design of computers achieved a significant decrease in power consumption. A transistor consumes roughly 1000 times less than a vacuum tube. For example the TX0 designed in 1957, was an 18-bit machine containing 3500 transistors and consuming 1 kW. Despite this improvement in technology, huge mainframe computers continued to consume large amounts of power. The IBM 360 Model 91, announced in 1964, consumed a significant fraction of 1 MW.

During the 1960's and 1970's, the integrated circuit and the microprocessor were developed. It was observed that the number of transistors on an integrated circuit doubled every 2 years. This led to the well known Moore's Law. This is illustrated in the following graph [9].

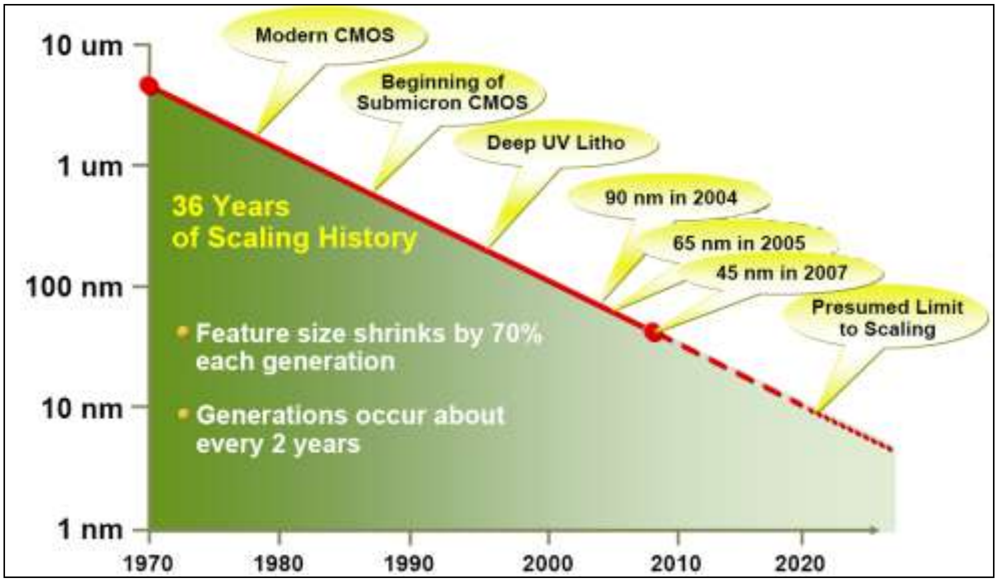

Figure 4. **Integrated Circuit Process Size Reduction**

A less well known corollary to Moore's Law relates to power consumption. As the number of transistors increases and the process size decreases, so does the power consumption of the circuit. Named after Texas Instruments engineering guru Gene Frantz, Gene's Law holds that "power consumption of integrated circuits decreases exponentially" over time and because of that the whole system built around chips will get smaller, and batteries will last longer [10]. Since the introduction of Gene's Law in 1994, there has been a ten-fold reduction every two years in the power required by integrated circuits. This is illustrated in the two graphs below [9].

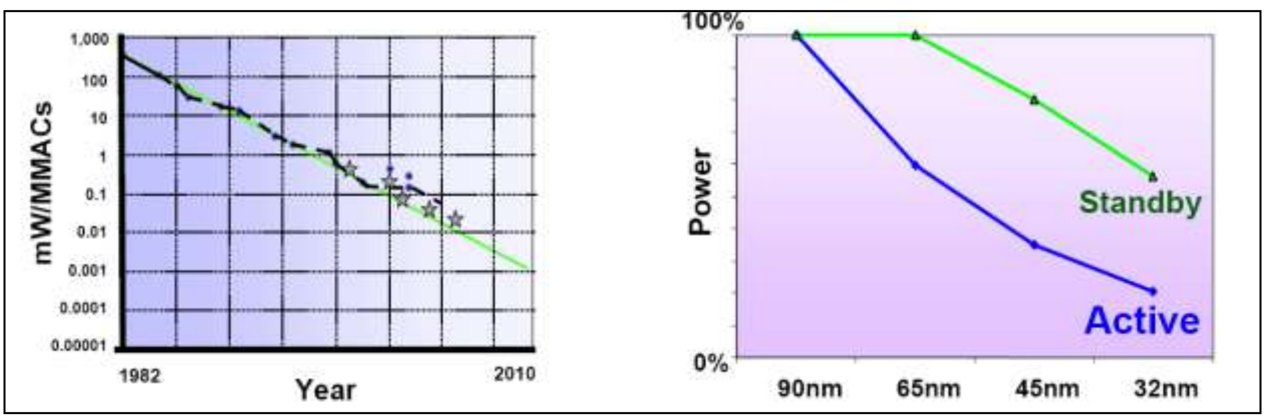

Figure 5. **Integrated Circuit Power Consumption Reduction**

This power reduction has largely been driven by the introduction of sophisticated, battery-powered, portable devices, such as cellular phones, music players and PDA's.

Intelligent Sensor Networks

Historically plant devices have been connected together using wires. These are typically from a plant controller like a PLC, to variety of digital and analog inputs and outputs as shown below.

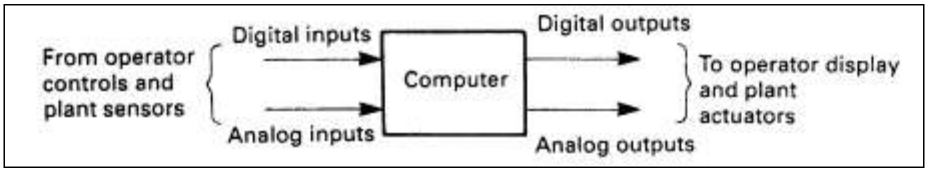

Figure 6. **Discrete Sensor Connections to Plant Controller**

A plant may contain numerous PLC's which must be wired to a control room or master controller. This is usually accomplished with some type of communications network or fieldbus [11]. These provide

- Reduced wiring due to the multi-drop capability
- Flexibility of supplier choices due to interoperability
- Reduced control room equipment due to distribution of control functions to the device level
- Increased data integrity and reliability due to the application of digital communications

This is shown below:

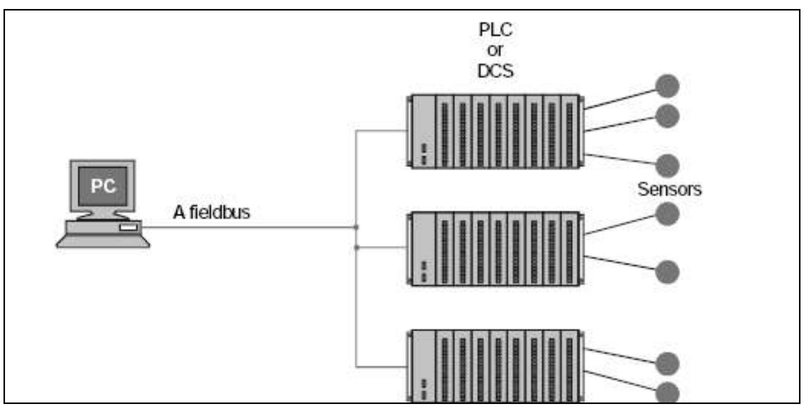

Figure 7. **Sensor Connections to Plant Controller Using a Fieldbus**

Further evolution of the system can be made by replacing the wire connections with wireless data connections. This can be used as a primary system or as a backup to cable or fiber-optic.

Ultra Low Power Sensor Networks

Micro-power wireless sensor systems have gained increasing importance for a variety of civil and military applications. The advances in micro-electromechanical systems (MEMS) technology, interfaces, signal processing, and RF circuitry has enabled the development of wireless sensor nodes [12]. The focus has shifted from communicating between plant devices and a base station, to creating wireless networks of communicating micro-sensors, as illustrated below.

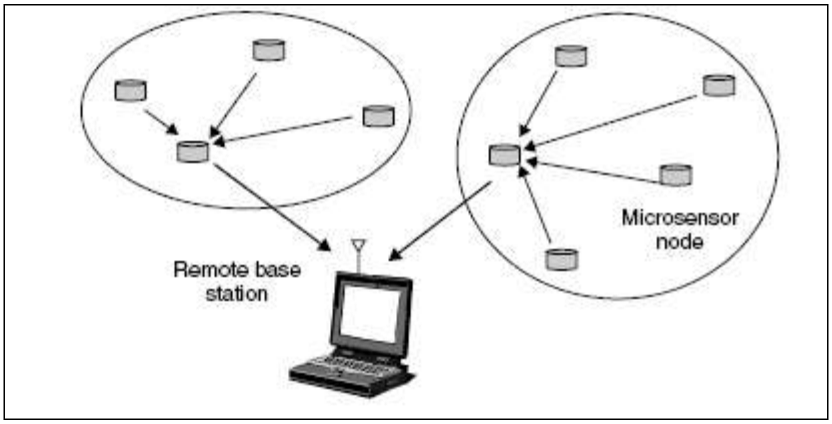

Figure 8. Ad-hoc Wireless Sensor Connections to Plant Controller

These sensor networks aggregate complex data to provide comprehensive information from their environment. Individual micro-sensor nodes are typically not as accurate as their more expensive macro-sensor counterparts but their size and cost enables the networking of hundreds or thousands of nodes in order to achieve high quality, easily deployed, fault-tolerant sensing networks. A key challenge in the design of a micro-sensor node is low energy dissipation. A power-aware system design employs a system whose energy consumption adapts to constraints and variations in the environment, onboard resources, or user requests. This has led to power-aware design methodologies which offer scalable energy savings that are suited to the application. These methodologies could be used for the deployment of wireless sensors in a hazardous area.

The wireless personal area networks (WPAN) used in ultra low power sensor networks ,are lower in power, cost and performance when compared with technologies such as IEEE 802.11 (WiFi). This is illustrated below:

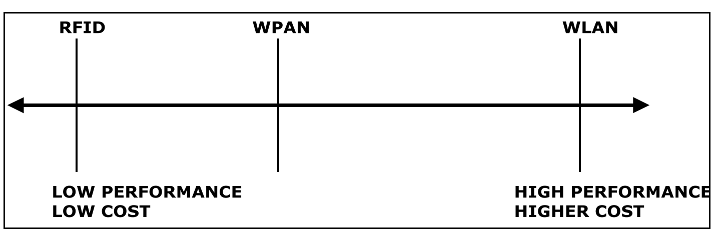

Figure 9. Wireless Technology Continuum

The table below compares the features of the common wireless networks IEEE 802.11 (Wi-Fi), IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4 (Zigbee) [13]

ZigBee (WPAN)	Bluetooth (WLAN/WPAN)	Wi-Fi (WLAN)
802.15.4 standard	802.15.1 standard	802.11 standard
250 kbps	1 Mbps	Up to 54 Mbps
TX: 35 mA	TX: 40 mA	TX: 400+ mA
Standby: 3 uA	Standby: 200 uA	Standby: 20 mA
32-60 KB memory	100+ KB memory	100+KB memory
Lighting, sensors, RC peripherals	Telecom audio, cable replacement	Enterprise, home access points
Mesh networking	Point to multi-point	Point to multi-point

Table 1: Comparison Between Wireless Networks

The power consumption between Bluetooth and Zigbee networks diverges dramatically when the data transmission interval is low as is shown in the following comparison.

Example 1 **High-Duty Cycle**
- 5 Byte Data Transmission in intervals of 1.28 seconds
- assuming 200 mAh available battery capacity
- Battery lifetime based on **Bluetooth*:* 15 days**
- Battery lifetime based on **Freescale ZigBee**: **33 days**

Example 2 **Event Driven Applications (security system scenario)**
- Network coordinator is on all the time (not battery powered)
- Sensor transmitting every 60 seconds + 10 events per days
- Based on 2 AA batteries
- Battery lifetime based on **Bluetooth*:* 100 days**
- Battery lifetime based on **Freescale ZigBee**: **3559 days or 9.8 years**

Future Trends

With the performance of equipment ever increasing while power consumption is decreasing, the following question could be asked. Could ultra low power intelligent sensors become inherently intrinsically safe similar to simple apparatus? Would it be possible to have a hazardous area which is populated with these intelligent sensors that wirelessly transmits data from the hazardous area back to a safe area with minimal certification? The following table indicates the ignition energies for various gas mixtures [3].

Sub Group	Hydrogen	Oxygen	Air	Calibration	
	% VV	% VV	% VV	Current mA	Energy µJ
IIA	48 ± 2	None	52 ± 2	67	211
	85 ± 2	15 ± 2	None	67	211
IIB	38 ± 2	None	62 ± 2	43	89
	75 ± 2	25 ± 2	None	43	89
IIC	30 ± 2	17 ± 2	53 ± 2	20	19
	60± 2	None	40 ± 2	20	19

Table 2: Current and Energy for Various Gas Mixtures

The safe current and energy values can be contrasted with the power consumption of various wireless systems in the table below [15].

Standard	Frequency Band	Modulation Type	Data Rate Mbps	Receive Power mW	Transmit Power mW	Link Margin dB
WLAN 802.11G	2.4GHz	64-QAM (OFDM)	54	1320	2145	95
	2.4GHz	BPSK (ODFM)	6	1320	2145	115
802.15.4	2.4GHz	O-QPSK	0.25	26.5	28.3	105
	2.4GHz	O-QPSK	0.25	30.1	27.8	95
Bluetooth 802.15.1	2.4GHz	2-GFSK	1	70	49	85.5
N/A	2.4GHz	2FSK	0.3	0.33	1	92
	1.9GHz	OOK	0.005	0.4	1.2	96.3

Table 3: Power Consumption of Wireless Network Equipment

While the existing wireless technologies do not appear to meet the IS requirements for simple apparatus (1.2 volts, 0.1 amps 20 µJ or 25 mW simultaneously), the following design example illustrates that this is feasible [15]. The transceiver block diagram is shown below:

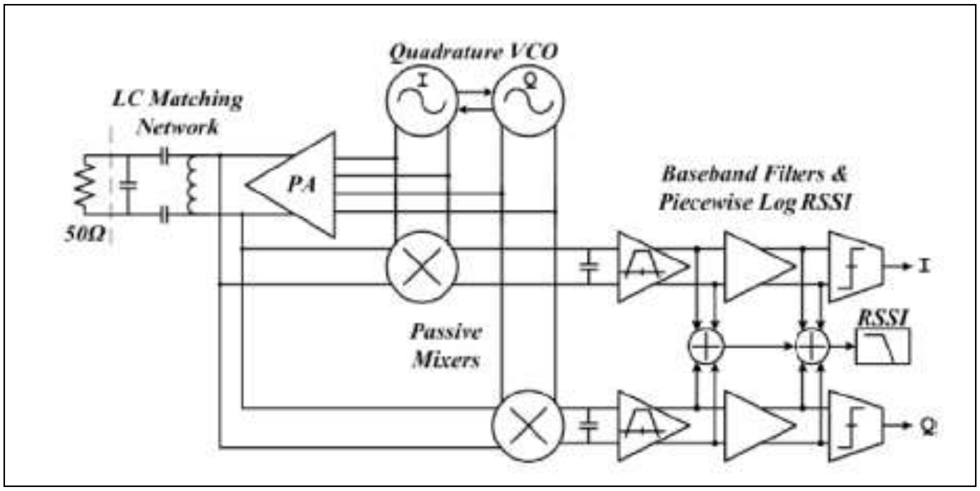

Figure 10. Ultra Low Power Transceiver Block Diagram

The 2.4GHz transceiver is implemented in a 0.13µm RF CMOS process and achieves 1nJ per received bit and 3nJ per transmitted bit with 300µm transmit power and 7dB receiver noise figure and 92dB link margin. A 400mV supply was chosen for this system to accommodate a single solar cell as the power source. In sunlight the entire transceiver could operate continuously from a 2.6mm x2.6mm silicon solar cell. The power amplifier efficiency is 44% and the power overhead is estimated as 400µW for transmission 170µW for reception. The measured transceiver performance data is shown below.

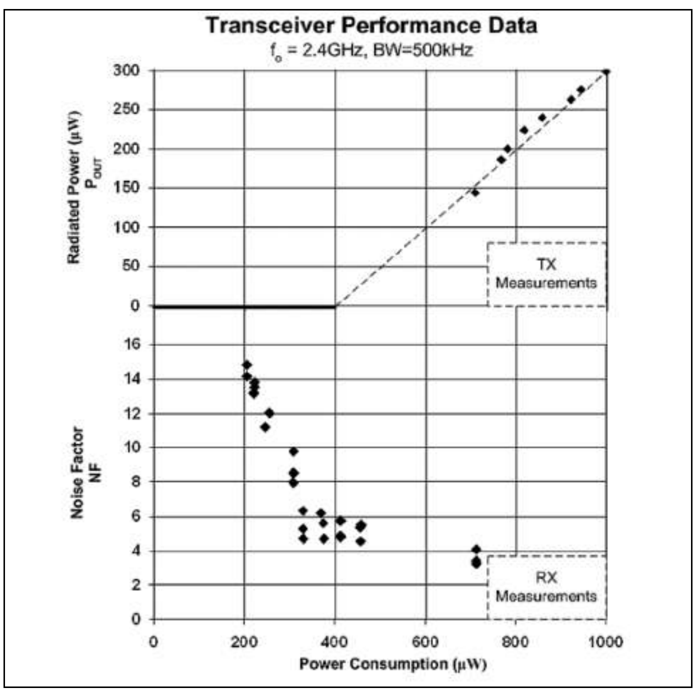

Figure 11. Ultra Low Power Transceiver Performance

Energy Scavenging

Supplying power to a network of sensor-transmitters has traditionally required expensive wiring installation or routine battery changes. Gathering data using wired sensors from difficult or certain hazardous locations may be impossible, or compromise the safety of personnel installing wiring or replacing batteries. The vast reductions in the size and power consumption of electronic circuitry have led to focused research efforts on the development of small and efficient power sources. Known as energy harvesting or energy scavenging, the current emphasis has been on developing on-site generators that transform an available environmental energy (light, kinetic, and thermal gradient) into electrical energy.

Energy scavenging is still in its infancy and there are significant technical challenges that need to be addressed to make it a mainstream replacement for batteries and AC power. One of these is the electronic circuitry needed to capture, accumulate and store energy. The device must then switch the power from its energy store to the application. Devices that generate power from ambient sources present problems in generating a predictable flow of electricity for the operation of electronic circuits. These can range from zero power and trace amounts of power that are unusable, to where the power generated is so great that it could burn out the circuitry. The development challenge is to make these devices a reliable and predictable power supply for the operation of wireless sensor networks and other applications.

Ideally each sensor node should be self-sufficient from an energy perspective. As the installed life may span 10 years or more, the energy storage capability of a node is limited by the storage medium (battery or capacitor) and the size constraints. While a single-time charge could work for applications with life cycles below one year, replenishment of the energy supply using energy scavenging is desirable. The table below illustrates the finite power density of state-of-the-art energy sources [15].

Power Source	**Power Density** $\frac{\mu W}{cm^3}$	**Lifetime**
Lithium Battery	100	1 year
Micro Fuel Cell	110	1 year
Solar Cell	10 to 15000	∞
Vibrational Converter	375	∞
Air Flow	380	∞
Temperature Gradients	50	∞

Table 4: Power Source Comparison

Unfortunately the energy storage requirement is in direct conflict with the IS power limitations. By increasing the volume for energy storage, we can achieve a self sufficiency for a wireless sensor node from an energy utilization perspective. The energy stored may then be well in excess of that allowed for IS equipment in the hazardous area.

A combination of energy scavenging, energy storage and ultra low power equipment will be required to meet these requirements. AdaptivEnergy has recently announced an energy scavenging device called Joule-Thief. A kit is available using Joule-Thief technology that demonstrates the advantages of energy harvesting and radio frequency (RF) technology for wireless sensing, monitoring or ambient intelligence. The Joule-Thief energy harvesting device is based on ruggedized laminated piezo (RLP) technology, which enables compact energy harvesting modules to power applications such as wireless sensors. These wireless sensors could be used to gather ambient intelligence to detect and report critical conditions in factories, automobiles, office buildings, homes and other environments—all without wiring or batteries. These devices could also find their way into hazardous areas in the future.

Conclusion

Approved intrinsically safe equipment installed in hazardous areas does not have sufficient energy to ignite any hazardous gasses. The connection of any intrinsically safe equipment from the hazardous area to the non-hazardous area is made using a safety barrier which is matched to the intrinsically safe equipment. The use of wires and safety barriers can be eliminated by using battery powered wireless sensor equipment.

The current consumption of electronic equipment has been reducing 10 fold every two years since the development of the integrated circuit. This has facilitated the development of ultra low power wireless sensor networks. Some of these networks are intelligent and are able to connect and transmit data in an ad-hoc manner. As the power consumption reduces further, it may be possible for intelligent wireless sensor devices to be theoretically achieve the status of simple apparatus. The provision of continuous, safe power by energy scavenging devices could further enhance the deployment of this equipment.

References

1. ANSI/ISA RP12.06.01-2003 Recommended Practice for Wiring Methods for Hazardous (Classified) Locations Instrumentation Part 1: Intrinsic Safety
2. Sean Clarke IEng MSc, Basic Techniques of Intrinsically Safe Circuit Assessment
3. Alan McMillan C Eng FlEE FlnstMC, Electrical Installations in Hazardous Areas
4. Extech Safety Systems, Design of intrinsically safe systems, - Vector, August 2008
5. Ronan, The Art of IS
6. Jeanine Katzel , Eye on Hazardous Area Sensors, Control Engineering , January 2007
7. Paul S. Babiarz, Intrinsic Safety Circuit Design
8. Low-Power Electronics Design, CRC Press LLC, 2005
9. ? Bill Krenik P.E., Ph.D, Next Generation Wireless – what's just around the corner, Wireless Business Unit, Texas Instruments June 27, 2008
10. Michael Lisse, John Sviokla and David Choi, Batteries Included, Context Magazine, October-November 2001
11. Srinivas Medida , IDC Pocket Guide on Industrial Automation For Engineers and Technicians Rev 1.04
12. Klewer , Ultra Low-Power Electronics And Design
13. Zigbee Overview, Freescale Semiconductor
14. Intrinsically Safe Devices: Global Market Assessment, 2nd Edition, Venture Development Corporation (VDC)

15. Brian Otis and Jan Rabaey, Ultra-Low Power Wireless Technologies for Sensor Networks
16. Information from AdaptivEnergy - http://www.adaptivenergy.com/
17. Steve Mackay, Myths and Actual Practice with Industrial Data Communications and Hazardous Areas, IDC Technologies
18. Anna Ha´c , Wireless Sensor Network Designs, University of Hawaii at Manoa, Honolulu, USA