Wireless

Introducing wireless proximity switches

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Sensors and actuators are found in large numbers on every production line in every industry. And each and every one of them requires data and power cabling. Not only are these cables costly to install, they are also a frequent source of failure.

Help is now on the way! ABB is introducing a novel wireless proximity switch that incorporates a communication module for the power supply, signal transmission and man-machine communication, and so has no need for cables.

Fueled by fast-paced technological development, wireless devices are now gradually being introduced in industrial environments. Their use, however, has tended to be limited. Today, you may be able to use a wireless link to configure a field device or check a motor's condition, but no-one so far has been able to solve the complex task of closed-loop control with wireless and battery-free sensors. That is, until now.

Why wireless in industry?

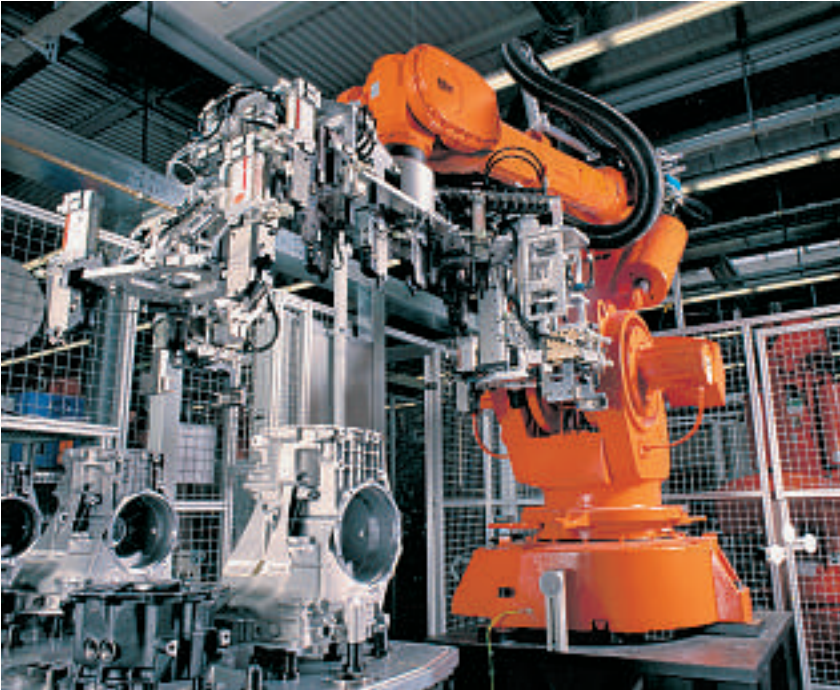The last few years have seen a revolution in wireless communication. High-volume production in the consumer and office automation market have made advanced communication solutions available at an astonishingly low cost. The telecommunication industry has facilitated matters by creating *worldwide* standards for wireless links, like 802.11, Bluetooth, GSM, Zigbee, etc, thus removing the need for region-specific solutions.

Recognizing that modern industrial IT solutions require advanced wired and wireless communications as important enabling technologies, ABB has been closely monitoring the ideas, technologies and companies emerging from the office automation and telecom businesses. The promise of this sector is endorsed by the ARC business analysis

"Wireless technology is expected to have a major impact on the manufacturing industries in the next five years."

ARC, May 2001

1 Gear assembly – one of many industrial applications in which large numbers of proximity switches are used

company, which stated in May 2001, "wireless technology is expected to have a major impact on the manufacturing industries in the next five years."

But what is the special attraction of wireless technology for industrial applications, and what does industry expect to achieve by utilizing the technology?

Put simply, wireless technology has three main advantages: it reduces cost thanks to its easy installation, simpler engineering and the reduction in materials needed; it increases productivity by introducing mobility, flexibility and fast network access; and it allows new value-adding applications and services like portable clients and operator terminals, faceplates, remote diagnostics, etc.

These inherent advantages of wireless communication are fully exploited in the new ABB wireless proximity switch.
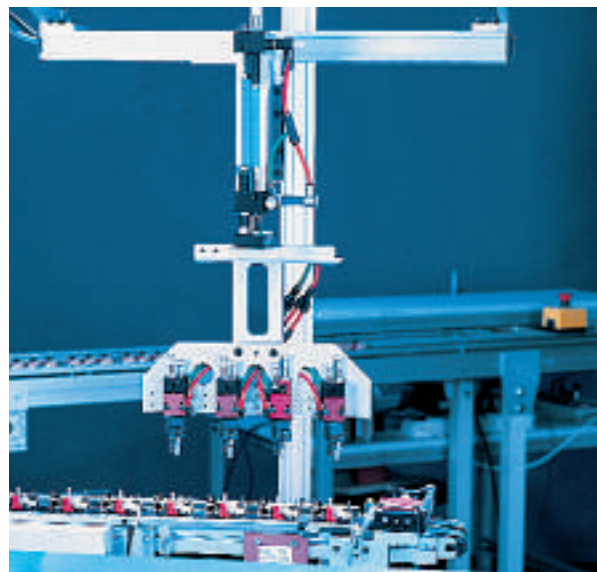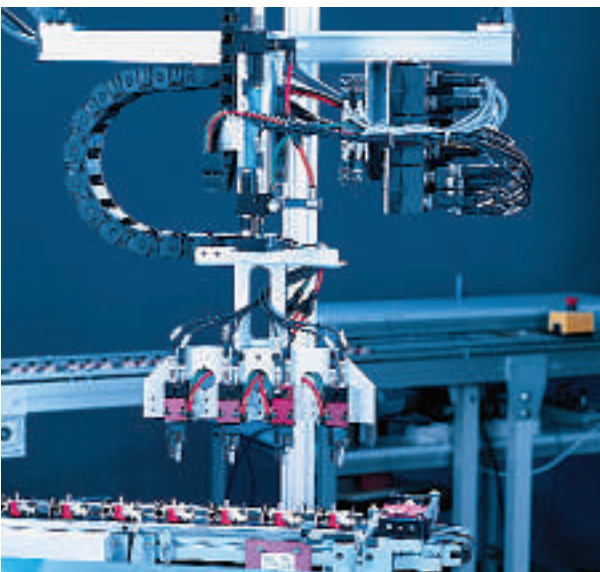
Wireless proximity switches

Inductive proximity switches are the most widely used position sensors in machine control 1 . With high reliability and without actual physical contact, they inform the controller about the progress of a machine's movement. Since inductive proximity switches are designed to

2 With and without sensor cables. Special mechanical constructions are necessary for the cabling.

3 Typical cell on an engine assembly line with wireless proximity switches (A) clustered at the robot gripper, primary loops (E), two power supplies (D), two antennas (B) and one input module (C).

detect metal targets, they are generally insensitive to dirt.

However, there is a problem – the connections between the sensors and the control system. These are fixed multicore cables, fitted with either a plug or with terminals. Although integrating inductive proximity switches in the machine design has become relatively simple, cable engineering and installation is still relatively laborious, especially when cables move with each machine movement **2**.
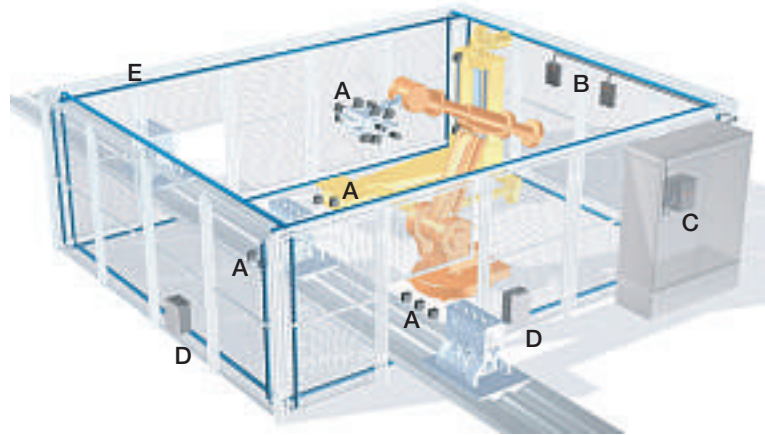
Today, the machine designer has various technical solutions at hand for increasing the reliability of electrical connections between moving machine components, but most of these, like slip-ring transmitters, are only suitable for special applications. Using flexible cable ducts and highly flexible cables is a more standard way to increase the reliability of such connections.

Nevertheless, cables remain the main source of sensor faults and machine downtime. Getting rid of the cables, then, represents a major step forward [1]. This is exactly what ABB's new wireless proximity switches were designed to do.

Easy to define, difficult to solve

The problem presented to a group of ABB researchers in 1998 was as simple to define as it was difficult to solve: Provide a direct replacement for traditional proximity sensors, completely without wires or batteries. A tough challenge, to be sure. Yet, what four years ago seemed to warrant the label 'mission impossible' has now become reality.

The researchers, based in Norway, Germany and Switzerland, divided the problem into three areas: the wireless communication system, the wireless power supply, and the low-power sensor.

The first of these, the wireless communication system, has to be just as reliable as wired sensors. As these sensors are part of closed-loop control systems, strict timing constraints also apply. The technology should be cheap and also have a low power budget. To add to the difficulty, the sensors should be able to co-exist with interfering systems, such as Bluetooth and Wireless Local Area Networks (WLANs), as well as with any self-interference arising from up to a few thousand wireless sensors on the factory floor. Clearly, no existing radio standard comes even close to fulfilling these requirements.

The wireless power supply posed a similar, if more fundamental challenge. Whereas battery technology may have improved over the last decade, no battery could provide the minimum of ten years maintenance-free operation

required by the system. A number of technologies were investigated, including thermocouples, photovoltaic cells, fuel cells, etc. The only solution that proved viable was inductive coupling, whereby a small magnetic field set up throughout the volume of a machine is converted into usable electrical power by the sensor units.

The third task was to develop the basic sensing technology, at power levels two orders of magnitude below traditional technology.

Central to the solutions for all of these problem areas is the overall system architecture, and this will be looked at first.

System architecture

The system **3** has four primary loops (E) installed around the manufacturing cell. These are fed by two power supplies (D) that set up an alternating current in the loops, producing a magnetic field throughout the cell. Wireless proximity switches (A) within the cell have small coils that pick up the energy from the magnetic field and convert it to elec-

tric power. The sensors also have small radio transceivers and low-power electronics that handle the wireless communication link. The sensors communicate with an input module (C) via antennas (B) mounted in the cell. This module behaves rather like a traditional, wired input module. It can handle up to 60 wireless proximity switches simultaneously and is connected to the control system via an ABB FieldBusPlug [2]. Five input modules can co-exist within the same area, allowing up to 300 sensors in one manufacturing cell to be served.

Throughout the development of the system, user-friendliness has been the watchword. Therefore, simple installation guidelines and configuration procedures have been developed. The user can install the system without having expertise in wireless power or communication technologies. The sensors are easily configured using the display (LCD) and foil switches on the input module. While meeting all the requirements of a traditional, wired system, the wireless alternative offers additional advantages such as diagnostics and self-monitoring; troubleshooting and sensor replacement are much easier than with current technology.

Wireless power supply

Although considered acceptable in the consumer world, regular battery charging or replacement is not a practical option in an industrial application. This is all the more so if there are hundreds of sensors, which may be mounted in inaccessible

locations or in machines running day and night. What is needed is an energy autonomous device [3] or wireless power supply, and ultra-low-power electronics.

Generally speaking, the auxiliary energy can be either:

■ Included in the system: eg, batteries, fuel cell, etc.
■ Taken from the system's environment: light, heat, vibration, user activation, etc.
■ Transmitted to the system: optical, radio frequencies, acoustic, etc.

The definition of the problem makes the first one of these a non-starter, while the second is too unreliable and uncontrollable for the strict reliability requirements of industry. After a thorough evaluation of the various options offered by the third approach it was concluded that the

only viable solution is one based on magnetic coupling.

The 'magnetic supply'

The basic principle of a magnetic field induced power supply can be described by the well-known transformer model with parasitic elements **4**. In our case, the primary winding (B) is a large coil around the cell (called the *volume*), the secondary side a nearly unlimited number of small receiver coils (C), each with a ferrite core to increase the flux collected by the coil.

The parasitic elements, therefore, dominate and the main coupling factor is the magnetic field strength at the secondary position. If the primary coils are set up in a Helmholtz-like arrangement, this parameter is fairly constant over a
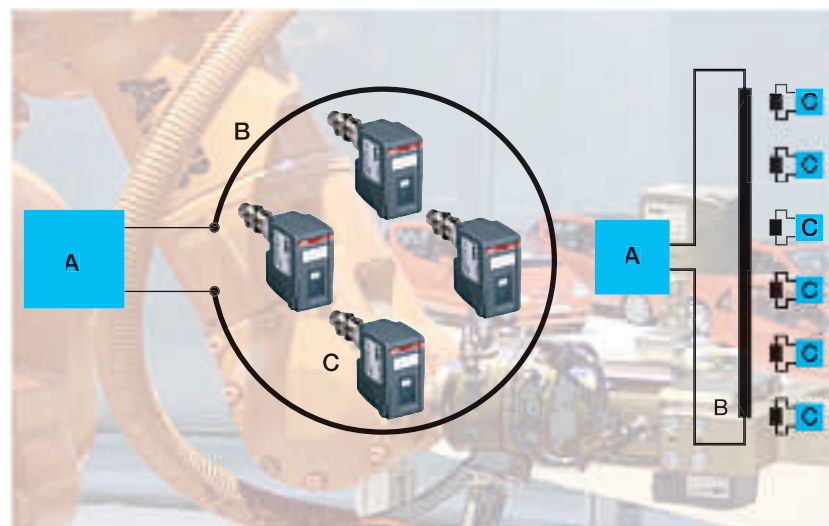
4   Wireless power supply

A power supply (A) feeds primary loop (B) with a current at 120 kHz. Sensors (C) within the primary loop are equipped with secondary coils. The right-hand schematic shows the equivalent circuit diagram with loose coupling.

large volume. Although people will not be working continuously in the cell, the field strength lies within all international occupational regulations and recommendations [4].

The losses are surprisingly small, being mainly determined by the coil conduction losses due to skin and eddy-current effects.

Resonant medium frequency power supply

Such a 'transformer' is best operated in a resonant mode, in which the large (leakage) inductance is compensated. Operation with low voltage or current is then possible. Such a power supply should also be able to cope with:

■ Changes in the environment, eg caused by large, mobile metallic obstacles, like robots.

■ Large 'load' variations, like differently sized primary coils (ie, inductance values), and variable losses, eg eddy currents in adjacent metallic objects.

The primary supply, therefore, needs an automatic, fast and highly accurate controller to rigidly maintain the fixed 120-kHz resonant frequency regime.

Omni-directional receiver structure

To achieve significant power on the receiver side, the coils there also have to be operated in a resonant mode. Further, to achieve constant power output regardless of orientation in relation to the primary field vector, an orthogonal set-up of three coils has been chosen. Being

easily tuned, this arrangement is well suited for mass production.

Rotating field

As a unidirectional field could be unintentionally shielded by the intrusion of metal objects, a rotating field is used instead.

Assuming a worst-case shielded, minimum field strength, the achievable secondary-coil power levels depend mainly on the coil size and the core size and shape used. A typical specific worst-case value achieved in the first prototypes is 1 mW/cm^2 at 6 A/m. Significantly higher power levels can be provided if required, eg for industrial actuators (valves, small drives).

The power supply system should be

able to serve typical manufacturing cells up to $6 \times 3 \times 3 \text{ m}^2$ in size. Being modular, it can be expanded to serve several such cells.

Wireless communications

The wireless communication subsystem transmits the sensor signals to the input module, which can be compared to a base station in a cellular system. It must satisfy the rigorous demands of an industrial environment, ie have very fast response times (generally much less than 10–15 ms), serve a large number of sensors located in a cell of several meters radius, and guarantee high data transmission integrity, even where radio propagation may be affected by obstacles and interference **5**.
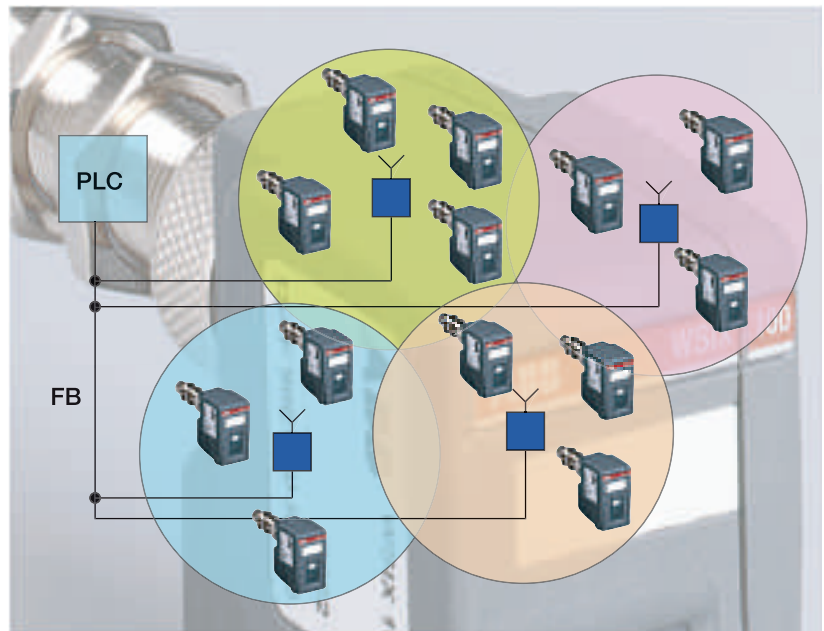
5 Wireless communication

Each input module collects data from the sensors in 'its' area and transfers it via a fieldbus (FB) to the machine controller (PLC).

6 Communication module electronics
Omni-directional receiver coil for the power supply and an integrated antenna (foreground) for the radio communication

None of the existing systems evaluated in an extensive study satisfied all these requirements. For example, passive electronic tagging systems, as used in department stores, do not have sufficient range and flexibility and WLANs or short-range wireless links such as Bluetooth [5] do not support large numbers of sensors.

It was therefore decided to design a new system tailored to the needs of the wireless sensor, while re-using as many of the available standard low-cost components as possible.

The new system operates in the 2.4-GHz radio band allocated to ISM (Industrial, Scientific and Medical) users. A sophisticated input module designed by ABB ensures that the complexity resides in the input module rather than in the sensor. One such module wirelessly can handle up to 60 sensors. Although similar to a WLAN base station in many respects, the ABB design has several features that clearly set it apart:

■ Simultaneous transmission and reception of radio signals; full-duplex operation is not possible with Bluetooth and WLANs.

■ Simultaneous reception of the strongest and weakest signals. The difference in power between a strong signal and a weak one may be as much as a million to one!

■ Interference suppression. Reception of a very weak sensor message or signal is possible even though a large interfering signal may exist at some adjacent frequency.
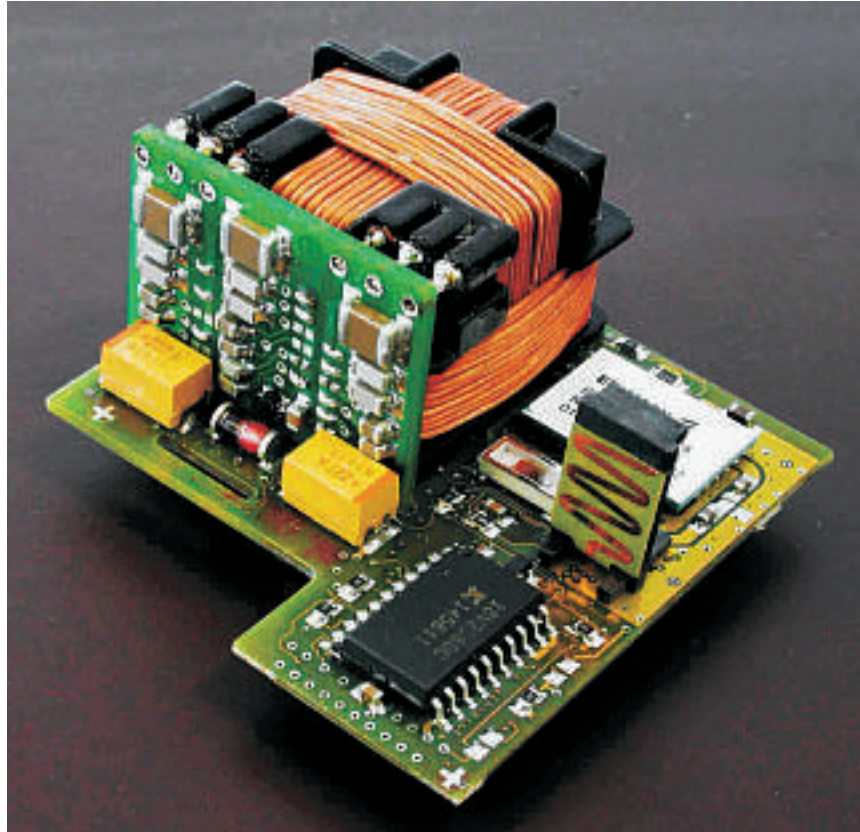
■ Transmit and receive antennas at the input modules may be periodically switched to provide a diversity of radio propagation paths as a protection against fading and shadowing effects.

The sensor communication hardware is based on a standard Bluetooth transceiver (radio) in order to benefit from economies of scale, component integration (small size) and low power consumption. In particular, the communication antenna **6** on the sensor transceiver module must be carefully chosen. Its radiation characteristics should be omni-directional in order to achieve uniform transmission performance irrespective of the sensor's orientation with respect to the input module antennas.

An optimized input module and sensor hardware, however, are not enough when other requirements (eg, high reliability, short message delays and provision for large numbers of sensors) have to be met. A tailor-made communication protocol solves this problem. It provides sensors with collision-free air access by allocating each sensor a specific time/frequency slot for its messages. The parameters of this time division multiple access and frequency duplex multiplexing scheme (TDMA/FDM) are chosen to meet the requirements of large numbers of sensors, ensure a short response time

Wireless proximity switches on a robot gripper. Demonstration at Hanover Fair 2002

and make full use of the available radio band. A novel frequency hopping scheme, combined with error detection and automatic message retransmission in case of failure, ensures that the messages from the sensors are reliably delivered, even in the presence of interfering systems such as Bluetooth, WLANs, microwave ovens and electronic tagging systems.

To ensure that power consumption is kept as low as possible, the sensor communication module hibernates until a change in the sensor state occurs. When an event takes place at the sensor, the sensor quickly establishes the radio link by means of a pilot signal from the input module, before transmitting the message. Typically this takes 2 ms, with worst-case scenarios of 10–15 ms if the message

must be re-transmitted several times. For system diagnostic purposes, the sensors also transmit an 'I'm alive' message twice per second.

Low-power sensing

Proximity sensors are one of the basic and most ubiquitous sensors in manufacturing machines and robots. Their operation is based on a tuned low-frequency oscillator circuit which emits a sensing field from the sensor head. When the sensor approaches a metallic object the oscillator experiences some de-tuning. The resulting change in the oscillating waveform is detected and an appropriate sensor signal is produced.

The wireless sensor power consumption must be kept as low as possible.

This can be achieved by ultra-low-power electronics or by reducing the duty cycle of the sensing – instead of continuously measuring, the sensor is turned on, a measurement is taken, and the sensor is then switched off for a 'long' time. After investigating these two possible solutions, it was decided to use a commercially available sensor head with low-power electronics and adapt it accordingly.

Going to market

At the Hanover Fair 2002 in Germany, ABB gave a live demonstration of the first pre-production wireless proximity switches 7 . They attracted great interest, machine builders and end-users alike being able to see for themselves the advantages of using them in assembly

8 The wireless proximity switch has two parts: the communication module (gray) with foil switch and LEDs, and the cylindrical sensor head (silver).

Unbound future

With the introduction of wireless proximity switches, ABB has taken wireless automation a significant step forward. The fundamental challenges of power distribution and the reliability and delay of communication have been successfully resolved.

While the system described here is intended for wireless proximity switches, the technology could easily be extended to other sensors and actuators. The generic power supply and communication technology could find their way into new ABB applications as yet unthought of.

machines, on production lines and in robot applications.

The second quarter of 2003 will see the start of sales. The initial assortment consists of wireless proximity switches, one type of power supply, primary loop cable, one radio antenna and an input module, which communicates via an ABB FieldBusPlug with the machine controller.

The wireless proximity switches have two main parts **8**: the communication module and a sensor head. Power supply, signal transmission and the man-machine-communication are provided by one single type of communication module. To cover switching distances from 1.5 mm up to 15 mm there are sensor heads with sizes M8×1, M12×1, M18×1 and M30×1.5, in flush and non-flush design.

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