Kulite Wireless Sensors

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ABSTRACT

Wireless technology and the sensor industry are advancing in terms of capability, performance, size, and standardization. A number of potential new applications for transducers can be considered when coupled with wireless capability. Previous wireless sensor designs have used narrowband radios and proprietary communications protocols. Using more than one of these can be a problem, however, since these devices can interfere with each other and disrupt the flow of data. A wireless sensor architecture is proposed that provides enough flexibility to use in many applications. Multiple sensors can be used and work together in an integrated network. An example of a sensor using this design is provided.

1) Comparing Wired vs. Wireless installations

A typical transducer installation can be described as follows:
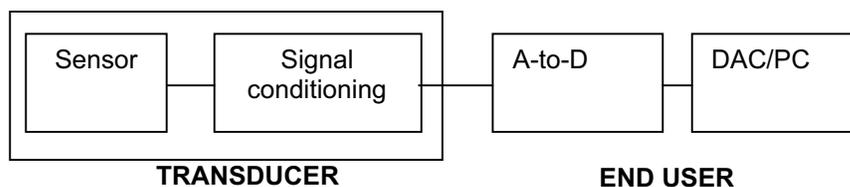
Figure 1   Typical Wired Sensor Installation

A typical Kulite transducer consists of a silicon sensor mated to circuitry that can compensate, filter, amplify, and/or linearize the analog output in an appropriate way for the end user's application. Typically, the end user converts the analog signal into digital data for processing by a data acquisition computer.

A wireless sensor adds functionality by including an analog-to-digital converter and data processing to deliver data directly in a format for computer. A typical installation would look like this:
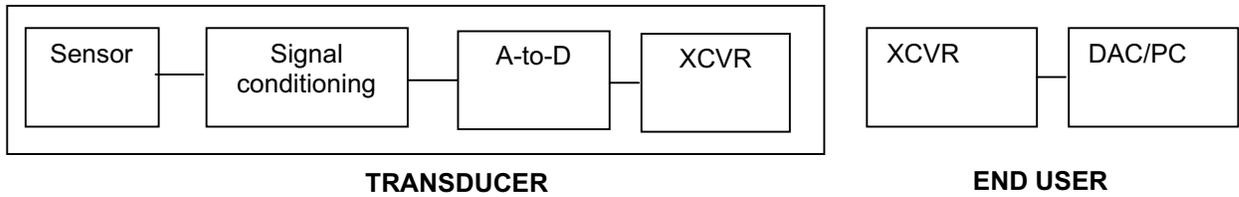
Figure 2 Wireless Sensor Installation

In the case of multiple sensors, the reduced installation effort is even more apparent. Multiplexing and switching can be replaced with wireless networking:
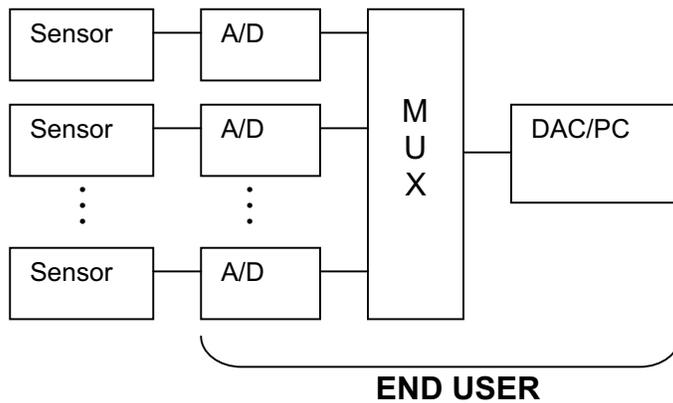
Figure 3   Multiple Sensors in a Wired Installation
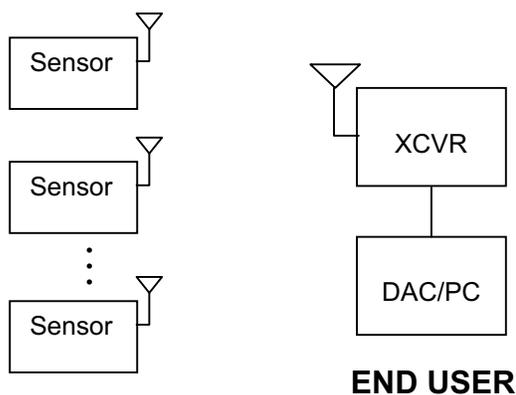
Figure 4   Multiple Transducers with Wireless Networking

2) Design Goals

The Kulite wireless transducer is designed to provide many benefits:
- May be built with any of Kulite's wide range of high-accuracy silicon sensors.
- Maintain accuracy over a wide temperature range using advanced compensation techniques.
- Networking capability
- Operate in noisy environments with other RF interference
- Provide security of data transmission.
- Maximize transmission range
- Reduced total installed cost

In addition, the design needed to be based on a flexible platform, to allow rapid customization for unique customer applications.

3) System Design

A Block diagram of the Wireless Transducer follows:
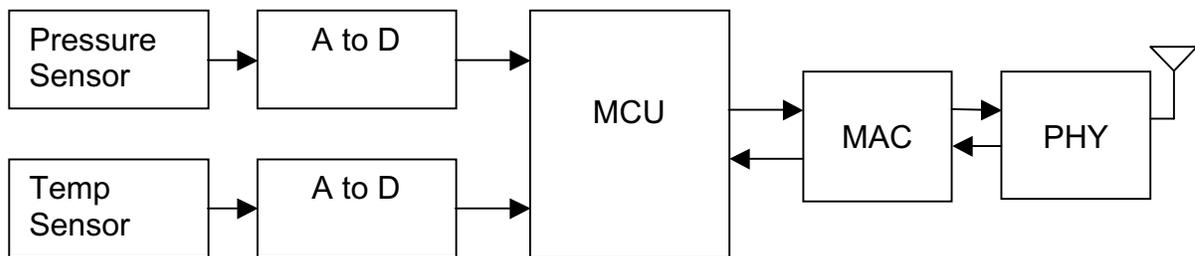
Figure 5   Wireless Transducer Block Diagram

Pressure Sensor: Kulite manufactures piezoresistive bridges to meet many applications. For each bridge, some small compensation circuitry is used to bring the sensor output into a range suitable for processing. The components for this circuit are unique for each sensor, but the rest of the transducer design is independent of the sensor used. Thus, the wireless transducer can be made for virtually any pressure range.

Temperature Sensor: A temperature sensor is used for compensating the output of the pressure sensor, since silicon resistors change with temperature. As an added feature, the temperature sensor output is also available from the wireless transducer.

16-bit A-to-D: This converts the analog voltage to a digital number. 16-bit A-to-D's are used for maximum accuracy: $2^{16} = 65536$, which corresponds to 0.02% resolution.

MCU processor: The MCU serves as the brains of the sensor. The processor serves several functions:

1. Obtain digitally converted data from the sensors
2. Compensate the pressure sensor output for temperature. The algorithm uses polynomial curve fitting to deliver extremely accurate results.
3. Convert the sensor output into a data stream for the end user.
4. Process requests from the end user
5. Communicate with the Media Access Controller (MAC)
6. Store calibration data, serial number, address, and other data in memory.

A set of programming commands is available to the user:

Command	Description	Values
$00Bb	Set baud Rate to b (5,6,7or8)	(b: 5:9600, 6:19200, 7:38400, 8:115000)
$00Laa	Set device address	(aa: 00 to FF address in Hex)
$00Ccc	Set Config. Register(cc)	
$00C?	Read Config. Register	
$nnWaabb	Write to EEPROM	(aa: addr. in Hex; bb: one byte Hex)
$nnVv	Set Average mode	(v: 0 – 7: 0 = No Avg. 7=High Avg.)

The following command set is used to communicate with the transducers (nn is the device address)

Command	Description	Response
$nnP	Request Pressure	*#####.## (0 to 10000.00)
$nnT	Request Temperature	*-/+###.# (-100.0 to 999.9)
$nnU	Request Units Code	*pt (p: Press. units, t: Temp. units)
$nnA	Request X-ducer type	*AA…AAA(10 char. String)
$nnS	Request Serial No.	*#########
$nnD	Request Last Cal Date	*wwyyyy (week, year)
$nnM	Request Mfr. Date	*wwyyyy
$nnB	Request Baud Rate Code	*# (5, 6, 7, 8)
$nnE	Request EEPROM Dump	*eeee…eee (512 bytes)
$nnF	Request Full Scale Press	*##### (0 to 10000)

Media Access Control (MAC): This is the processor associated with the communications standard, such as IEEE 802.11b. It performs many functions, including:

1. Encrypting data
2. Establishing and maintaining network connections
3. Power management
4. Executes the communication standard's protocol

Physical Layer (PHY): This circuit transmits and receives RF as defined by the communications standard. It includes the baseband subsystem, which processes the DSSS algorithm for interference reduction. It also includes the radio subsystem, and connects to the antenna.

4) Preferred Embodiment

A wireless sensor suitable for permanent installation in an industrial or transportation application shall be discussed. The unit will be powered with local power so that it will always be available. A voltage regulator inside the transducer will convert the power voltage to a stable reference for the sensor and Vcc for the electronics. The diagram of Figure 5 is used, with the MAC and PHY designed for use with IEEE 802.11b. The pressure range is determined by the sensor selection.

Communication Frequency – 2.4GHz:
The 2.4 GHz band is the only frequency band that can be used globally. Standards bodies and government regulators have agreed to keep the band free for use by anyone. Transducers that operate in this band can be bought and used worldwide.

Communications Standard – IEEE 802.11b
Because of its global acceptance, the 2.4GHz band is the focus for emerging communications standards. Of these, the IEEE 802.11b ("WiFi") standard was selected as the most useful standard for these applications. The 802.11b protocol offers:
1. High data rates – up to 11Mbps
2. Networks can be built up to 128 nodes
3. Easy integration into existing Ethernet networks.
4. Emerging as the dominant standard for wireless PC communication
5. Data security via WEP and WPA

Networking Capability
Using the 802.11b standard allows a network of up to 128 nodes, or 127 transducers and a test computer, as in this example
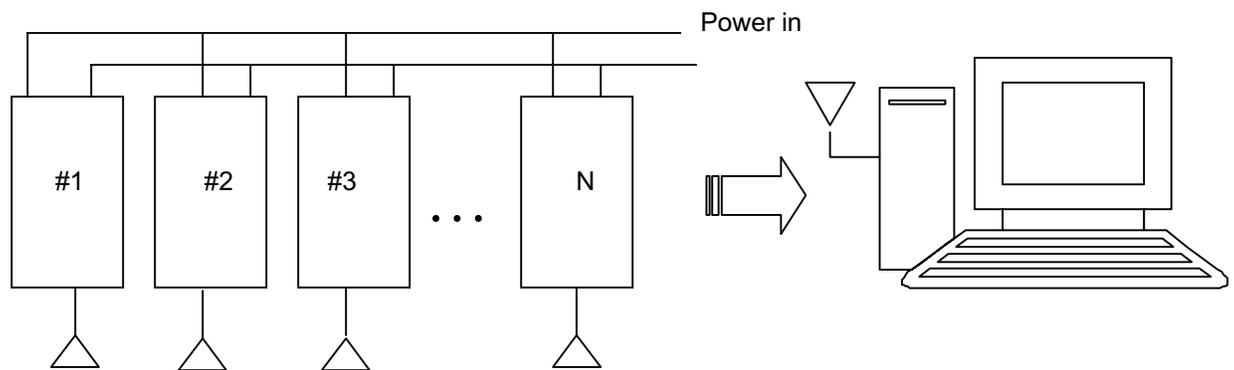
Figure 6 A Network of up to 127 Transducers can be controlled by 1 test computer

Since 802.11b is an extension of the Ethernet standard, this wireless network of sensors can be integrated into an existing local area network (LAN), and data can be monitored remotely from anywhere on the network.

Avoiding Interference with DSSS
The wireless transducers will likely be installed near other equipment transmitting RF signals. In order to reduce susceptibility to this interference, a technique called Direct Sequence Spread Spectrum (DSSS) is used. DSSS combines a data signal at the sending station with a higher data rate bit sequence, called a *chipping code* (also known as *spreading code*). Essentially, this sends a specific string of bits for each data bit sent. The receiver uses the same code and is able to reconstruct the data stream, even if it has been corrupted by noise. The longer the spreading code, the better the resistance to interference.

For example, using a spreading code of 10110111000:

- A transmitted "1" becomes 10110111000
- A transmitted "0" becomes 01001000111
- Even with several corrupted bits, the receiver can still tell the difference between a transmitted "1" and "0".

As a result of the modulation, the information energy gets distributed into the side lobes:
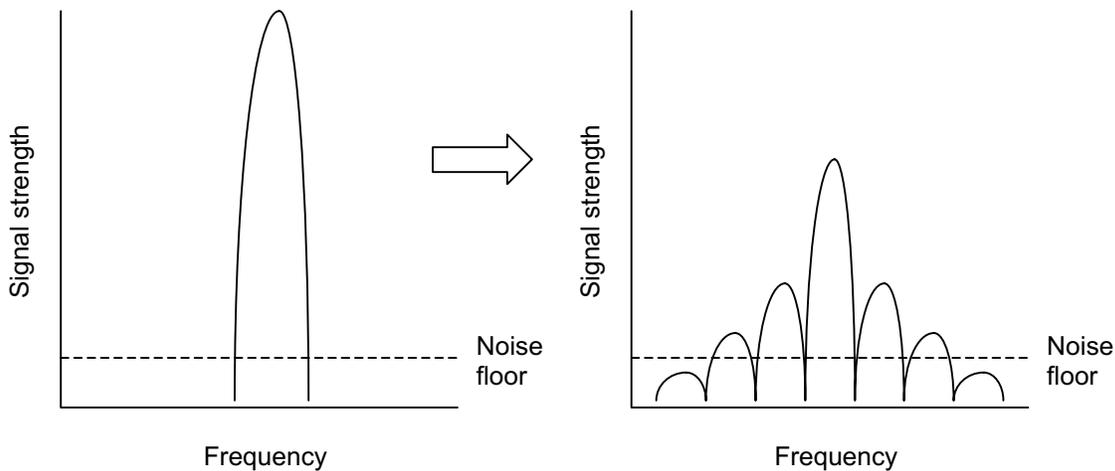
Figure 7   Spectrum Analyzer view of a Narrowband Signal vs. DSSS Signal

DSSS is very effective in environments with wideband noise. Successful transmission and reception can occur, even if the DSSS signal is below the noise floor.

Data Integrity and Security
Data from the pressure may need to be secure, or the integrity needs to be verified. With 802.11b, Wired Equivalent Privacy (WEP) is the standard protocol for encryption and authentication. A 64-bit key is used to encrypt the data, and a CRC-32 check is used to verify data integrity.

Transmission Range
FCC requirements limit the output of the radio to 1W. This has a reach of 100m in open space. However, in an office or laboratory environment, the range is reduced to 50m or less. Fortunately, the flexibility of the 802.11b networking structure allows for sub-networks to be built and interconnected so that a wireless network can be extended beyond this limitation. A set of sub-networks could each monitor a group of wireless transducers in a limited physical area and then send that data over the network (wireless or wired) to a central node or test computer for processing. A variety of hardware solutions to create these networks are readily available and affordable.

Integrating Wireless Transducers
Adding Kulite wireless transducers to an existing test system is usually straightforward. The 802.11b compatibility makes it easy to integrate into any PC-based test system. By setting up the link as a serial port, it is simple to write communication routines in test software to communicate with the transducers. Kulite has written examples of source code in Visual Basic and can provide them upon request.

5) Expanding on a Flexible Platform
The flexible architecture allows for multiple design options. Two such options will be discussed: Using Bluetooth instead of 802.11b, and using batteries.

Bluetooth and other Protocols
The MAC and PHY blocks in Figure 5 can be replaced with Bluetooth compatible circuits. Bluetooth is limited in network capability, data rates, and security. But it is lower power and is easy to set up. It is useful to think of Bluetooth as a cable replacement technology, rather than a networking technology.

	Bluetooth	WiFi
Application	Cable Replacement	Large data applications
Main Advantage	Easy to set up	Large sensor networks
Main Disadvantage	Small sensor networks	Uses lots of power
Security	Good	Better
Data	< 2 Mbps	Up to 11 Mbps
Network size	8 nodes	128 nodes
Resists interference caused by	Single-frequency sources	Wideband noise

Batteries:
New applications for pressure transducers can be considered because wireless sensors can be made in a battery-powered, completely wireless solution. For example: mobile, portable devices can be made for diagnostics and testing.

The battery powered units offer a totally wireless solution, but consideration has to be given to battery life:

- Batteries have a limited life, and transmitting uses a lot of power. Batteries are expected to provide only a few hours of transmission time before they need replacing or recharging.
- Batteries are temperature sensitive. The available power drops off dramatically with temperature. At –20'C, expect minutes of life, not hours.
- An on/off means is needed, such as a switch

The circuitry used in Kulite wireless transducers is low-power, except for the MAC and PHY subsystems used in 802.11b. Bluetooth uses somewhat less power and can be a useful alternative.

6) Conclusion

A wireless transducer has been designed that expands the applications for pressure transducers. The transducer is IEEE 802.11b compatible, and is thus easily integrated into existing test systems and data networks. The use of DSSS allows the transducer to communicate even in very noisy environments. Data security and integrity can be enhanced with the WEP protocol. The flexible design allows for expanded products, including battery powered units and Bluetooth compatible units.

References

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