Designing wireless interfaces for patient monitoring equipment

Recent advances in wireless technologies now make it possible to free patients from their equipment, allowing greater freedom and even making possible monitoring by their health provider while the patient is on the go.

By Noel Baisa

Today's patients face a depressing situation: confined to a fixed area tethered to their monitoring equipment. However, recent advances in wireless technologies now make it possible to free patients from their equipment, allowing greater freedom and even making possible monitoring by their health provider while the patient is on the go. In this article we examine the technology, typical medical monitoring applications and some of the design issues related to employing short-range wireless technology to improve the patient experience.

Note that the medical monitoring systems described in this article are not intended to diagnose or treat any health problem or disease. Nor should these devices be used in place of a call or visit to a health or medical professional. This article is presented with the understanding that the author is not engaged in administering any medical or health professional services.

Technology	Pros	Cons
900 MHz	Unlicensed band Long range	Unnecessary range increases security concern Different frequencies for U.S. (915 MHz) and EU (868 MHz)
WiFi	Large installed base of equipment Programmable for worldwide band usage	Long-packets are less robust High current draw
Zigbee	Low-power for intermittent data Short packets are more robust	Protocol stack required on host Network coordinator required
Bluetooth	Large installed base of equipment Optimized for ad-hoc networking	Seven device limit per piconet Instantaneous power similar to Zigbee

Table 1. wireless technology camparison for medical cable replacement.

Current	Normal	Single-Fault
Ground leakage	5 mA	10 mA
Touch/chassis leakage	100 μA	500 μA
Patient leakage	100 μA	500 μA
Patient auxillary leakage	100 μA	500 μA

Table 2. Leakage current limits according to IEC 60601-1.

Pulling the plugs

To remove or minimize cables requires a robust wireless link with low-power capabilities. Although many wireless standards can be used, there are important considerations such as range, throughput, security, ease of implementation and cost. An overview of popular wireless technologies for cable replacement is summarized in Table 1. Of these standards, Bluetooth is quickly becoming the preferred technology for wireless patient monitoring. It has sufficient range— too much range can cause security and power concerns—balanced throughput for stationary and battery-operated devices, encryption capabilities, reasonable cost due to installed base and ease of use—as will be seen later in this article.

A major motivation for reducing the number, or for doing away with the cables completely, is to eliminate the potentially harmful currents to the patient. Established limits, as shown in Table 2, indicate that even minute leakage currents from medical equipment can be harmful.

Going wireless has additional benefits, enabling new features:

Cable replacement. Improves patient freedom. A wireless connection improves a patient's quality of life by allowing him or her to be untethered from equipment. Patients can resume more normal activity within the 10-meter range provided by most Bluetooth solutions.

Provides galvanic isolation. The cables used for sensing and transmission of data must also isolate the patient from harmful currents, while a wireless solution already provides this isolation. The typical cited threshold for inducing ventricular fibrillation in an average adult male is 100 mA.

Reduces cabling cost. High-quality cables are a must in medical applications, where flex, breakaway, and wear characteristics are as important as conductor type, insulation and shielding. Wireless minimizes or eliminates completely cable wear and special connectors, initial investment cost and replacement costs.

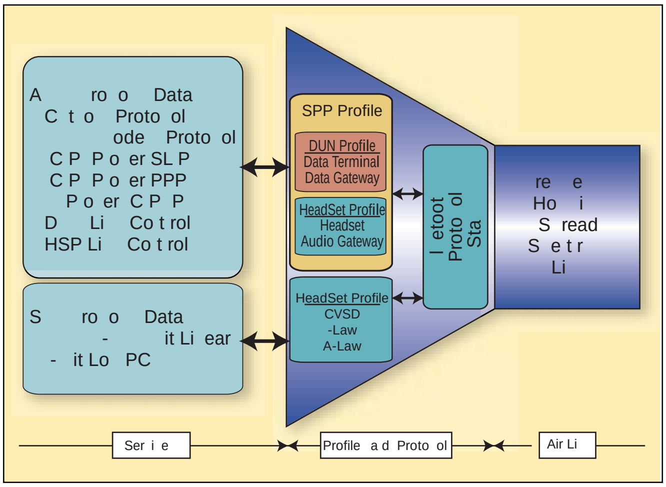

Figure 1. The virtual cable—transport/profile view.

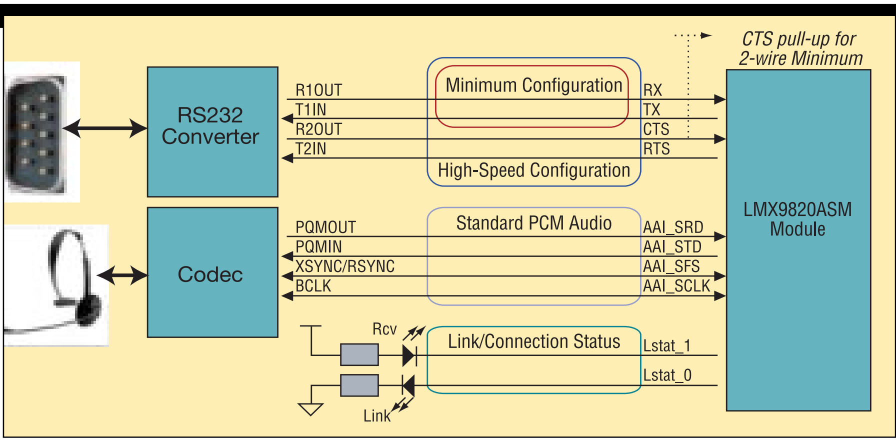

Figure 2. Various Bluetooth interface options.

Remote server access. Allows data upload for professional analysis. The dial-up networking (DUN) profile enables devices to use cell phones to connect to a remote server virtually anywhere there is cellular coverage. Once connected, it is possible to run serial link Internet protocol (SLIP) or point-to-point protocol (PPP) over the standard serial port profile (SPP) provided by Bluetooth.

Provides universal connection to Bluetooth-enabled phones. With many GSM phones, and an increasing number of CDMA phones integrating Bluetooth capabilities, it becomes possible to use these phones as modems to a remote server. The standard means of connectivity eliminates the problem of special phone connectors and the likelihood of galvanic problems.

Reduces post-operative home visits. Due to the rising costs of health care, most patients are sent home shortly after surgery, leaving follow-up to visiting nursing professionals. By using a Bluetooth phone's DUN capabilities, patients can self-administer most tests, making it possible to provide more frequent readings and thereby a higher level of care, wherein a healthcare professional can track results from a central location.

Audio gateway. Enables new wireless audio functions. Any standard Bluetooth headset can be used with existing medical equipment to allow a doctor or nurse to listen to measurement status. Equipment powered by more powerful processors can even implement voice-recognition functions over a Bluetooth link to minimize touching of equipment, thereby reducing the transmission of germs.

Bluetooth incorporates a number of built-in features such as frequency-hopping spread spectrum (FHSS), forward error correction (FEC), and optimally sized packets to make the link robust.

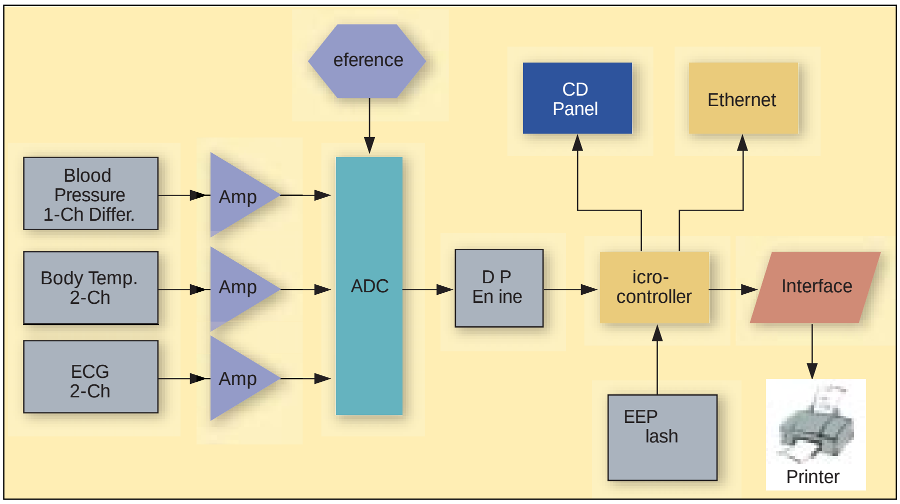

Figure 3. A patient monitoring platform—Bluetooth connects to the interface.

Bluetooth cuts the cables

Bluetooth technology has been around for sometime, which means that there is a large installed base of devices, making for ubiquitous connection to cell phones and peripherals. A number of other technologies have emerged since the introduction of Bluetooth, but it remains the only technology to date that offers all of these features and benefits:

- large point of presence—available in many handsets and headsets, increasing availability in keyboards and mice, increasing availability in industrial and commercial devices;
- frequency-hopping spread spectrum for spatial and interference robustness;
- PIN code mechanism for enhanced connection security;
- built-in encryption capability for enhanced data security; and
- low-power, fast-connect operation for personal area networks.

Typically, solutions for Bluetooth have existed as either a powerful, generic solution on a PC/PDA or as an application-specific implementation in cell phones and headsets. Usage beyond application-specific Bluetooth solutions usually meant a significant investment and expertise in stacks, profiles and operating systems. The radio-frequency design for such systems involved tweaking of loop filters and crystals and matching of baluns, front-end filters and antennas.

Cable replacement devices are increasing in popularity as equipment manufacturers replace serial data cables with a wireless equivalent that use the serial port profile (SPP). Until recently, these cable replacement solutions, while integrated, have remained fairly large. But a new type of micro-module is emerging that allows manufacturers to embed these functions into their products. Some even allow more advanced functions beyond that provided by SPP. However, SPP is versatile in that it can be used for a number of functions beyond just serial cable replacement. With the appropriate routines, a number of more advanced functions—including support for HTTP—are possible once TCP/IP services are established. One way to visualize a cable replacement is to think of the Bluetooth link as a virtual cable while the Bluetooth stack and profiles are a virtual connector, as shown in Figure 1.

System designers are often concerned about the reliability of a wireless link, citing the ambiguity of what happens if the link is lost or becomes corrupted. Bluetooth incorporates a number of built-in features such as frequency-hopping spread spectrum

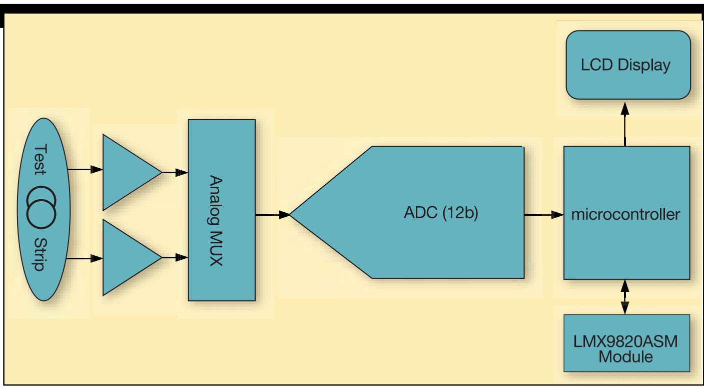

Figure 4. Glucose meter block diagram.

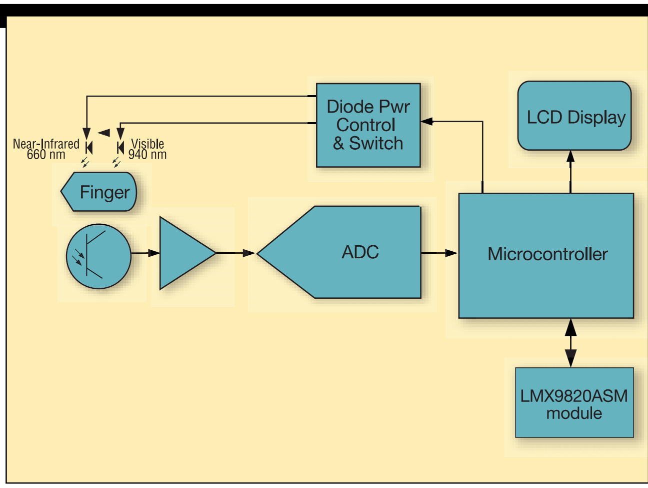

Figure 5. Pulse oximeter block diagram.

(FHSS), forward error correction (FEC), and optimally sized packets to make the link robust. Additional steps can be taken between the application layer and the transport layer to guarantee the quality of the link. Some of these techniques include the use of time-stamps with each frame of data and implementing a software watchdog function in both directions of the link once connection is established. The link watchdog function acts essentially as the equivalent of a real-time dc continuity test in a wired system.

Getting the blues

One cable replacement solution that is becoming popular in commercial, industrial and medical applications is the LMX9820ASM module from National Semiconductor. This device is often called 'Simply Blue' due to its ability to be used as a plug-and-play module for point-to-point links while also being highly customizable, for more advanced functions. Depending on the equipment design, an interface can be accomplished through either a two-wire or four-wire approach.

The dial-up networking (DUN) profile enables devices to use cell phones to connect to a remote server virtually anywhere there is cellular coverage.

Four-wire interface

A four-wire UART interface for baud rates of 115.2 kb/s up to the maximum of 921.6 kb/s is essential for pacing communications. Maximum data rates can be achieved by using the request-to-send (RTS) and clear-to-send (CTS) hardware handshaking lines. Note that many PC-type UARTs support a maximum baud rate of only 230 kb/s while older devices top out at 115.2 kb/s. A direct connection to the application processor, that bypasses the RS-232 level translation, is also usually required for these data rates.

Two-wire interface

For lower data rates, 57.6 kb/s or below, such as those found in legacy products, a two-wire interface comprising a transmit (Tx) and receive (Rx) is all that is needed. Similar to the two-wire interface, a data frame consists of eight data bits, no parity bits, and one stop bit. Even if not specifically brought out in a product, the UART port on the microcontroller is usually accessible through test pads or an internal connector since they are often used for diagnostic testing. Because some UART level converters connect to older 5 V logic, and not 3 V logic, one of the main issues to watch are the supply voltage and any voltage differences in logic levels when connecting Bluetooth modules like National Semiconductor's LMX9820ASM.

Both serial configurations, as well as audio, are shown in Figure 2. Note that the CTS line must be pulled up in two-wire implementations. A codec or DSP can be connected to the synchronous serial interface (SSI) for audio functions.

Unplugged applications

Most patient monitoring can be summarized with regard to the major functions of signal level conditioning, signal processing and data presentation. Data presentation can take the form of a wireless connection, as shown in the system diagram in Figure 3.

The following applications can benefit from short-range wireless technology by either eliminating long cables to the patient or by allowing equipment to connect to a remote network.

Blood pressure

Description. The non-invasive measurement of arterial blood pressure is performed by inflating a cuff around an arm or finger. As pressure is released, the arterial pulsation returns, with the first pressure reading known as the systolic. The pressure in the cuff continues to decrease until pulsations are no longer detected, with the last reading known as the diastolic. Typically, conversion of pulses from the physical to the electrical domain is accomplished with either a pres-

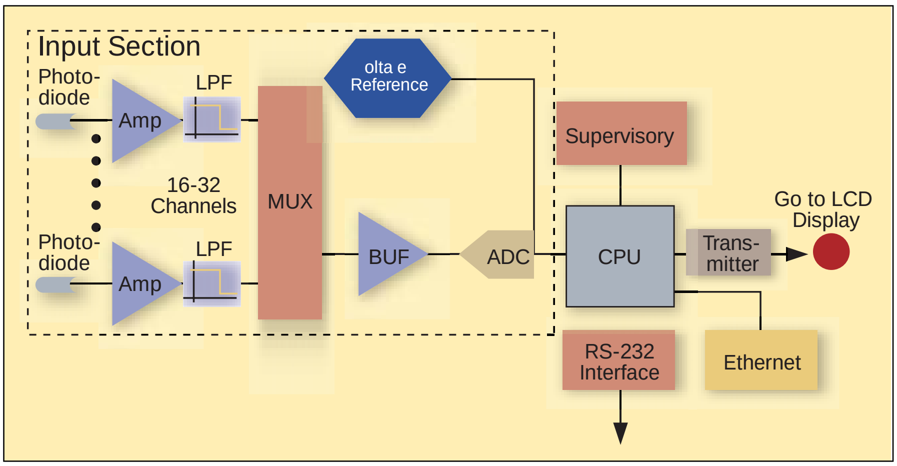

Figure 6. Blood analyzer—Bluetooth connects to RS-232 or directly to the CPU.

sure sensor or a piezoelectric strip.

Wireless improvement. Retrofitting existing equipment can be as simple as attaching a module to the RS-232 port, if it exists or by connecting a module to the UART lines of the embedded microcontroller. By slightly modifying the embedded software, it is possible to use DUN to send results to a clinic. For a continuously monitoring system, a piezoelectric sensor is required.

Glucose

Description. The density of glucose is usually measured either optically or electrically. In the case of an optical measurement, a sample is placed on a material that reacts with the glucose in the sample while an emitter and photodetector are used to measure the reflectance. For the majority of products on the market today, glucose measurement is accomplished by measuring the current that passes through the sample, which is related to the glucose content.

A test strip with the patient's blood sample is excited with a voltage source, as shown in Figure 4. The sample conducts current as a proportion of glucose. This minute current is converted and amplified by the trans-impedance converters before sampling by the analog-to-digital converter (ADC) after selection through the analog MUX. The microcontroller filters the readings and then uses a look-up table to convert the reading into standard units. The same microcontroller can be connected to a LMX9820ASM module via the UART ports to enable wireless connections.

Wireless improvement. Monitoring is an important concern to the 18 million individuals with diabetes. The majority of devices on the market today already have two-wire serial ports that can be used with PC or PDA software. Conversion to wireless can be accomplished simply by connecting a Bluetooth module to the manufacturer's nine-pin serial connector. An embedded solution is easily realized by connecting a Bluetooth module on the circuit board to the two-wire interface. There is no software impact to the glucose monitor because the PC or PDA application can access the same data through the virtual serial drivers, provided by the Bluetooth stack and profiles, as if they were connected with a serial cable.

Sleep (EEG)

Description. Monitoring brain activity requires handling signals in the range of 0.5 µV to 100 µV at frequencies that are typically less than 20 Hz. There is a challenge since it is essential to suppress the 50/60 Hz induced line noise and also to provide galvanic isolation. Wired connections are usually very long and can be restrictive when performing sleep studies.

Wireless improvement. A more convenient method to record EEG is to place the sensing and digitizing electronics into a waist-size device and equip it with a low-power, short-range wireless solution. By using a medical-grade computer or PDA, it also becomes possible to leverage existing equipment and thereby lower cost.

Arterial blood gas (SPO_2)

Description. By passing two different wavelengths of light into the human body, it is possible to measure the absorption of oxygen in the blood. ECG and pulse oximetry devices can benefit by adding a Bluetooth audio gateway, enabling the practitioner to listen to audio cues while allowing the patient to remain in a more natural, relaxed state.

The patient's pulse and oxygen saturation is computed through the absorption of visible (red) and near-infrared light. The corresponding intensity of each is measured by the phototransistor, sampled by the ADC and then filtered and finally scaled by the microcontroller, as shown in Figure 5. The microcontroller on the UART can be attached to an LMX9820ASM module to enable Bluetooth functions such as serial cable replacement or even dial-up networking.

Wireless improvement. Since pulse oximeters have now been reduced to roughly the same size as a typical finger sensor, they are already portable, making them suitable for sports and fitness monitoring. Instead of driving a display, the power budget can instead be allocated to an embedded Bluetooth module. This becomes especially compelling when considering the size, power consumption and cost of flash memory used for recording trends.

Heart rate (ECG)

Description. There are a number of locations to measure a patient's pulse that range from the chest, to the arm, wrist or even a finger. An electrocardiogram measures the electrical response of the heart allowing it to show great detail. Since signal levels are no more than 5 mV in amplitude with a 3 dB bandwidth of 0.05 Hz to 100 Hz, a gain of 46 dB to 60 dB (voltage gain: 200x to 1000x) is required, along with a common-mode rejection ratio (CMRR) greater than 60 dB to overcome interference.

Wireless improvement. The true potential for a wireless ECG is realized when the sensing and processing electronics are reduced to a portable pack, allowing cables to be significantly shorter and the patient to be ambulatory. Adding Bluetooth in this case involves connecting to the processor's UART to enable the upload of recorded data or to stream readings in real-time to a standard PDA, laptop or workstation.

Conclusion

Medical monitoring devices can be simple, like the blood analyzer in Figure 6, or complex.

However, as noted in the diagram and in the previous examples, the addition of Bluetooth to greatly enhance usability, increase electrical safety, and to provide new and more frequent means of delivering data can now be accomplished much more easily than before. Just as cell phones have freed us from the confines of a room, Bluetooth can free patients from the confines defined by a length of cable. RFD

ABOUT THE AUTHOR

Noel Baisa handles marketing for wireless technologies, including Bluetooth, cordless telephony and connectivity processors, at National Semiconductor Corporation. He has worked for National Semiconductor since 1998 and has held positions as regional and product marketing manager and as a senior applications engineer. Prior to joining National, he held various technical positions at Delphi Automotive Systems, ITT Automotive and General Motors. He earned an MSEE from The University of Michigan in Ann Arbor, MI, an MSE from Oakland University in Rochester, MI, and a BSEE from Kettering University in Flint, MI.