Keywords: spirometer, pulse oximetry, FVC, FEV1, PEF, asthma testing, emphysema testing, cystic fibrosis testing, electrical components, block diagram

TUTORIAL 4688

Introduction to Spirometers and Important Design Considerations for Selecting Electrical Components

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Abstract: This application note provides an introduction to spirometers and their basic functions. It discusses both laboratory units and portable devices for point-of-care testing, and offers guidance on selecting electrical components for each class of spirometer. Functional blocks addressed include flow sensing, signal conditioning, connectivity, power management, and display.

Overview

Spirometers measure the volume and speed of air that is inhaled and exhaled to assess lung function and to provide a first-level diagnostic test for pulmonary diseases such as asthma, emphysema, and cystic fibrosis.

There are two basic classes of spirometers: laboratory units, which are either desktop consoles or cabinet-size machines operated by trained technicians; and portable spirometers, which are either compact desktop units or handheld devices intended for general-practice and home use.

Laboratory spirometers require high performance and accuracy. Desktop units must provide precise spirometry measurements and be able to perform a range of tests, such as flow volume, tidal spirometry, and maximum voluntary ventilation.

Cabinet-size instruments like body plethysmographs are used to perform advanced pulmonary function tests, including total lung capacity, functional residual capacity, and residual volume.

Portable spirometers are gaining popularity as the point of care shifts from clinical laboratories to general-practice settings and homes. General practitioners increasingly use spirometers to establish baseline measurements for their patients and to detect potential pulmonary diseases. Low cost is important to enable spirometer deployment in these new markets. Size and power consumption are also key design considerations. These devices must operate from USB and/or battery power, include charging capabilities, and offer several connectivity options.

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Spirometry

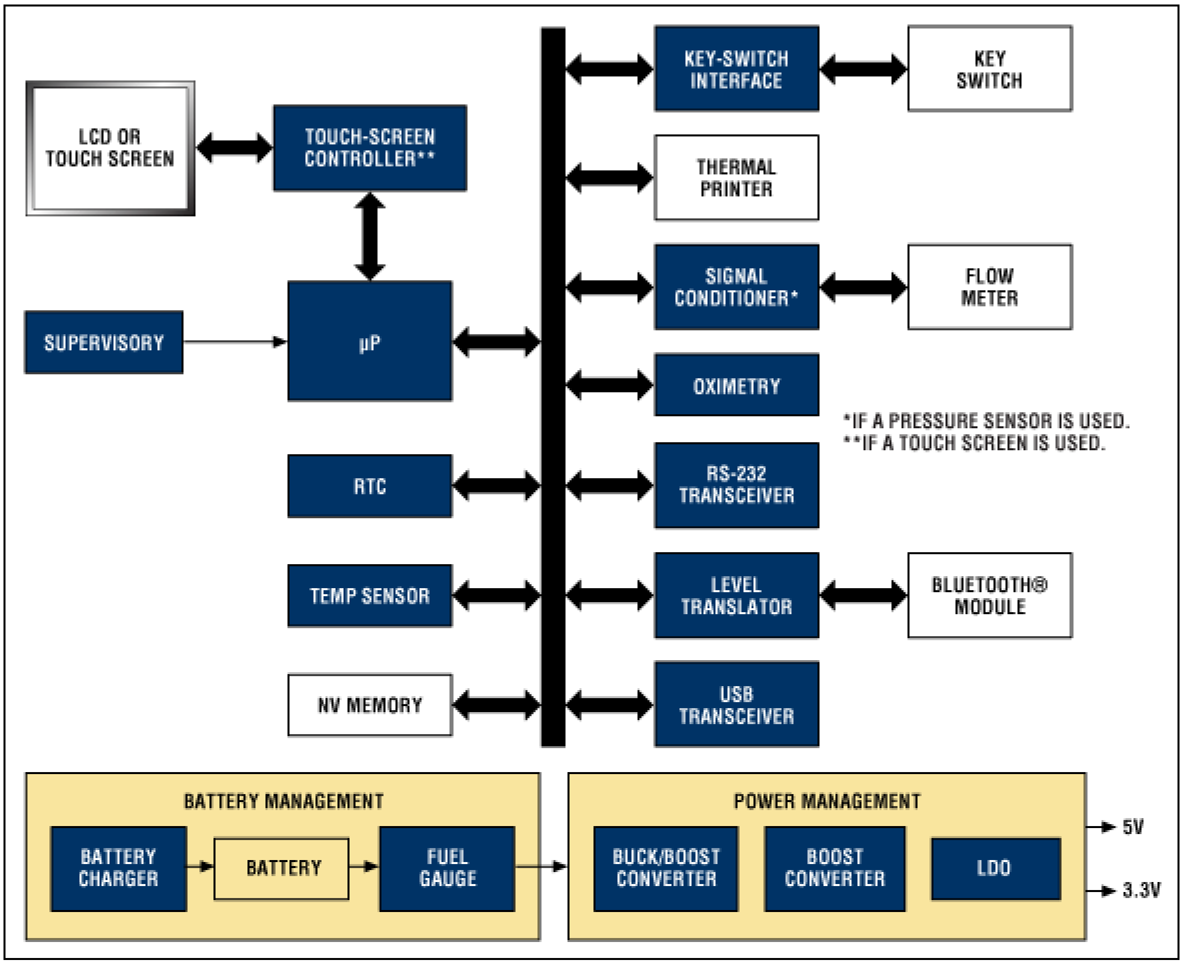
Spirometers can be used to measure several parameters:

FVC (forced vital capacity): The volume of air that can be exhaled after full inspiration.

FEV$_1$ (forced expiratory volume in 1s): The maximum volume of air that can be forcibly exhaled in the first second during an FVC maneuver.

PEF (peak expiratory flow): The maximum flow (or speed) achieved during the maximally forced expiration initiated at full inspiration.

Additional parameters such as tidal volume, maximum voluntary ventilation, flow-volume loops, and bronchial provocation can be performed, depending upon the complexity of the unit.



System block diagram of a desktop spirometer. For a list of Maxim's recommended solutions for spirometers, please visit: www.maximintegrated.com/spirometer.

Oximetry

The inclusion of pulse oximetry—which noninvasively measures oxygen saturation in arterial blood—can enable diagnostic testing for asthma. This capability can provide an all-in-one solution for walking tests; it also makes the spirometer well suited for fitness testing in sports medicine.

Spirometer Solutions

Flow-Sensing Mechanism

Spirometers frequently use turbine transducers for flow measurement. In this topology, a rotating vane spins in response to the airflow generated by the subject. The revolutions of the vane are counted as they break a light beam to determine airflow rate and volume.

Differential pressure sensors are sometimes used in place of turbine transducers. Commonly referred to as pneumotachs, these designs can measure low flow rates with high accuracy. An added advantage is cost: because they are relatively inexpensive, pressure transducers enable the implementation of disposable pneumotachs.

Front-End

For turbine-based spirometers, the front-end connecting the flow meter to the microcontroller is relatively simple, since the signal coming from the optical encoder can be easily managed by a Schmitt Trigger (**Figure 1**).

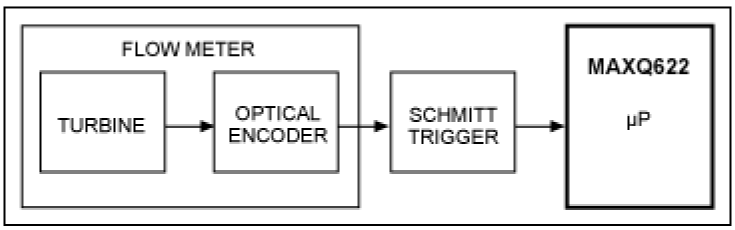


Figure 1. Typical front-end for a turbine transducer.

The front-end will be more complicated if a pressure sensor is used (**Figure 2**). In this case, a signal conditioner is needed to compensate the sensor output and remove the eventual offset. The resulting signal must then be digitized by an analog-to-digital converter (ADC), which should have a sampling rate of about 1ksps and at least 12 bits of resolution. Microcontrollers that integrate a high-performance ADC are ideal for these designs.

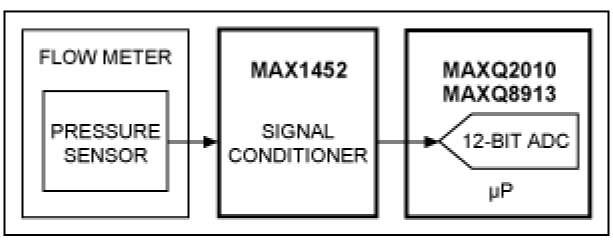


Figure 2. Typical front-end for a pressure sensor.

Connectivity

Desktop spirometers generally have a printer plus keyboard and include several communication interfaces such as RS-232, USB, and Bluetooth® for telemedicine purposes. Handheld spirometers typically use USB for data transfer and battery charging; they can also include Bluetooth capabilities.

USB and wireless connectivity options are important for managing spirometry data and monitoring patients. They allow data to be transmitted to a PC for storage, analysis, and transfer to healthcare providers, when remote monitoring is required.

Power Supplies

Desktop spirometers are frequently line powered, although they normally include lithium-ion (Li+) or nickel-metal-hydride (NiMH) rechargeable batteries as well. They generally use a 6-cell battery pack, due to the high-voltage requirements of thermal printers. Alternately, they can be powered by USB, in which case a step-up converter is used to boost the 5V to 9V. As shown in **Figure 3**, the OR-ing stage selects the source for the LDOs, which are used to generate a 3.3V rail for logic and a 5V rail for oximetry, if included.

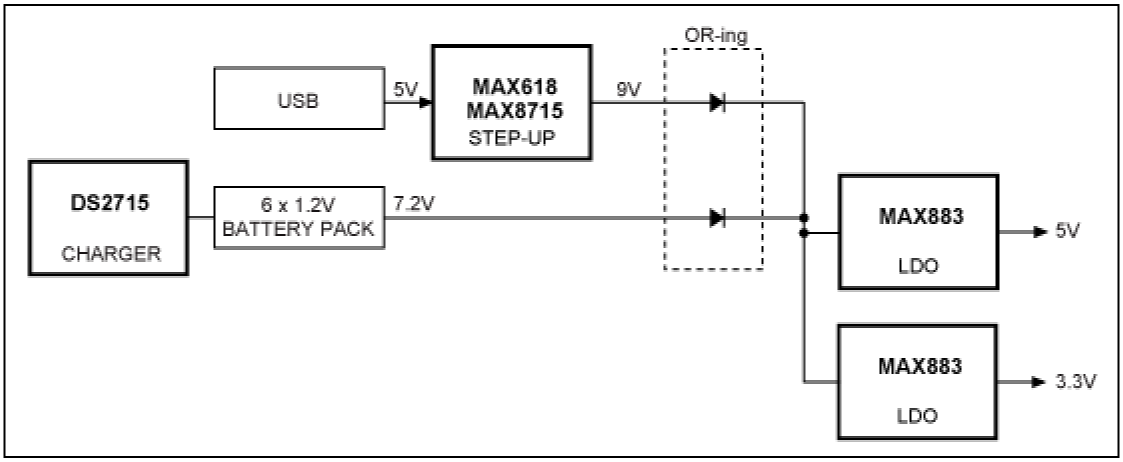


Figure 3. Power-supply example for a desktop spirometer.

Handheld spirometers can be powered by a coin-cell or single rechargeable Li+ battery. In the case of a 3V coin-cell battery, a low-power step-up converter can be used to generate the voltages required (**Figure 4**). For a rechargeable Li+ battery, a battery charger with dual inputs (USB and AC adapter) can be used to automatically select the best power source (**Figure 5**).

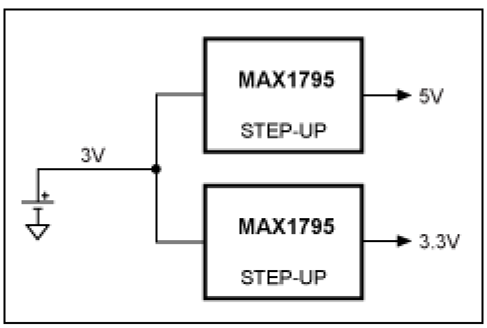


Figure 4. Power-supply example for a handheld spirometer using a coin-cell source.

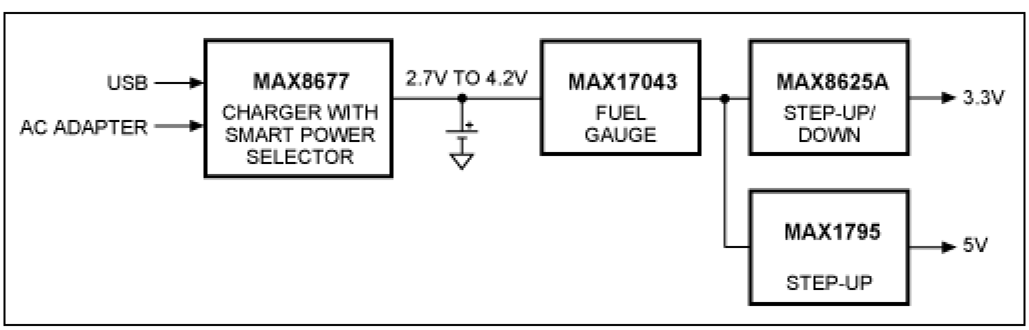


Figure 5. Power-supply example for a handheld spirometer using a single Li+ rechargeable battery.

Maxim's Smart Power Selector™ circuitry makes the best use of limited USB or adapter power by charging the battery with any input power not used by the system. This approach has the added advantage of allowing the system to operate with a deeply discharged battery or even no battery at all.

Rounding out the battery-management circuit, a fuel gauge is used to estimate the available capacity, while step-up and step-down converters provide 3.3V and 5V outputs from a 2.7V to 4.2V input supply.

Displays/Keyboards

Spirometers typically employ a full-color, backlit LCD to display patient information, spirometry parameters, spirograms, and system information, such as remaining battery life. Modern units increasingly use a touch screen in combination with a graphical user interface (GUI) to make the programming process more intuitive. Visible, audible, and haptic responses to user inputs help designers improve the user experience. Advanced touch-screen controllers from Maxim offer haptic feedback, touch processing to reduce bus traffic, and autonomous modes for precision gesture recognition.

For devices with keyboards or keypads, key switch can be managed by a debouncer that provides electrostatic discharge (ESD) protection. Integrated ESD protection can eliminate the need for discrete protection components, while facilitating compliance with IEC 61000-4-2 ESD requirements.

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Related Parts		
DS2715	NiMH Battery Pack Charge Controller	Free Samples
MAX11800	Low-Power, Ultra-Small Resistive Touch-Screen Controllers with I²C/SPI Interface	Free Samples
MAX11811	TacTouch™, Low-Power, Ultra-Small, Resistive Touch-Screen Controller with Haptic Driver	Free Samples
MAX1452	Low-Cost Precision Sensor Signal Conditioner	Free Samples
MAX17043	Compact, Low-Cost 1S/2S Fuel Gauges with Low-Battery Alert	Free Samples
MAX1795	Low-Supply Current, Step-Up DC-DC Converters with True Shutdown	Free Samples
MAX1797	Low-Supply Current, Step-Up DC-DC Converters with True Shutdown	Free Samples
MAX618	28V, PWM, Step-Up DC-DC Converter	Free Samples
MAX8625	High-Efficiency, Seamless Transition, Step-Up/Down DC-DC Converter	Free Samples
MAX8715	Low-Noise Step-Up DC-DC Converters	Free Samples
MAX883	5V/3.3V or Adjustable, Low-Dropout, Low-I_Q, 200mA Linear Regulator with Standby Mode	Free Samples
MAXQ2010	16-Bit Mixed-Signal Microcontroller with LCD Interface	Free Samples

MAXQ622	16-Bit Microcontrollers with Infrared Module and Optional USB	Free Samples
MAXQ8913	16-Bit, Mixed-Signal Microcontroller with Op Amps, ADC, and DACs for All-in-One Servo Loop Control	Free Samples

More Information
For Technical Support: http://www.maximintegrated.com/support
For Samples: http://www.maximintegrated.com/samples
Other Questions and Comments: http://www.maximintegrated.com/contact

Application Note 4688: http://www.maximintegrated.com/an4688
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