Technical Article

Designing Signal Chains for Portable Diagnostics

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There are various applications for portable diagnostic systems, including the detection of COVID-19, the flu, respiratory syncytial virus (RSV), and strep. In this article I will outline two signal chain types that are used in portable diagnostic equipment – electrochemical nucleic acid amplification (NAAT) and optical NAAT. I will also highlight Bluetooth Low Energy (BLE) devices that allow these systems to report test data wirelessly.

Electrochemical NAAT System Overview:

In order to implement electrochemical-based NAAT testers, designers need a precise analog front end to first, bias an electrochemical sensor, and then amplify the resulting signal to be sampled by a precision analog to digital converter (ADC). These low-noise and high-sensitivity signal chains enable the detection of sensor outputs with less variance, reducing sensor read times and increasing accuracy.

Both discrete and integrated signal chains can be used in this application, allowing designers to choose for high design customization or integration based on system needs. This flexibility can help mobile platform designers optimize for cost, test time, size and power consumption.

Integrated Electrochemical Signal Chain

The LMP91000 is an integrated front-end designed to reduce design time and solution size by including an integrated transimpedance amplifier [TIA], bias setting, reference, and driver op amp. This device also provides an I^2C interface that allows for custom configuration by the host MCU. The output of this device can then be sampled by an ADC. Figure 1 below shows a block diagram of the LMP91000 connected to a 3-Lead electrochemical cell.

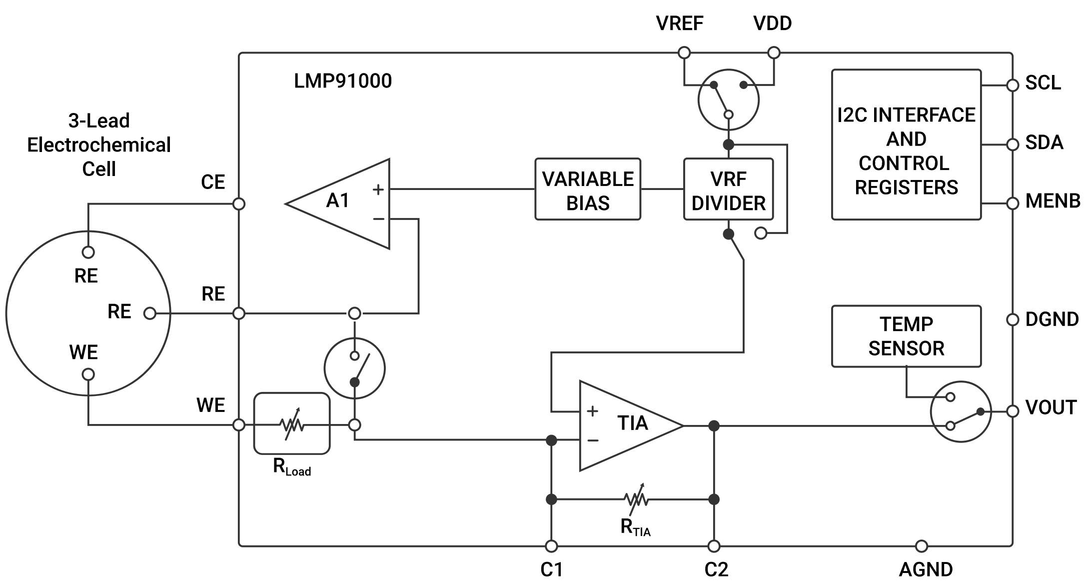

Figure 1. LMP91000 Electrochemical Cell Interface

Discrete Electrochemical Signal Chain

In discrete electrochemical signal chain implementations TI's OPA391 operational amplifier provides designers with a low noise (30 nV/√Hz), ultra-low bias current (10 fA), and low I_Q(24 µA) building block. Figure 2 shows the implementation of a discrete signal chain to interface with a 3-lead electrochemical cell using the OPA391 amplifier and the ADS1120 ADC.

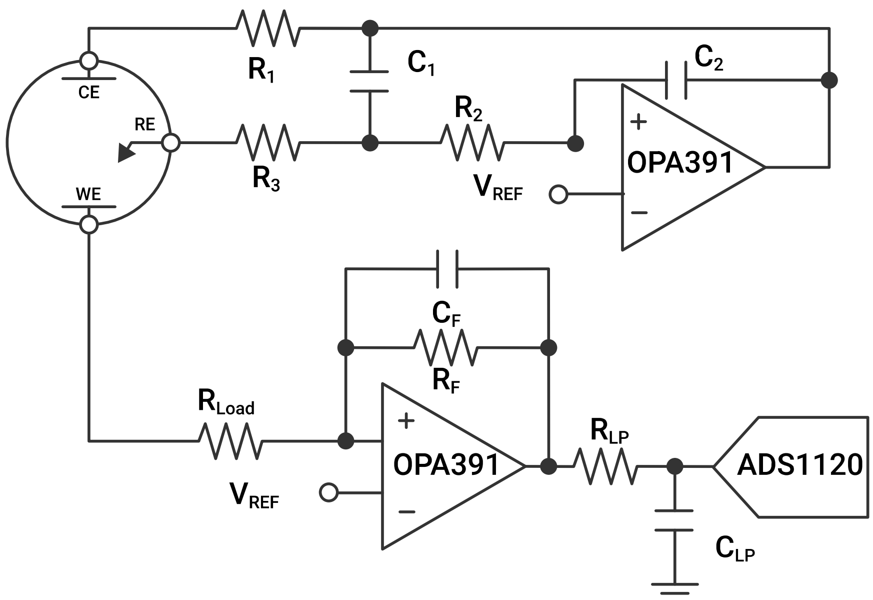

Figure 2. Discrete Electrochemical Cell Signal Chain

- TI's ADS1220/ADS1120 family of low-power 16 to 24-bit precision ADCs (with an integrated programmable gain amplifier and reference) helps to increase design flexibility and precision for both integrated and discrete signal chains

Optical NAAT System Overview:

One type of optical NAAT test used in portable diagnostic equipment is a rapid polymerase chain reaction (PCR) test. In PCR testers, the target ribonucleic acid sequence is amplified cycle by cycle; a photodetector then measures the fluorescence of the sample to quantify the viral loading in the sample. A current-input integrator or TIA converts the photocurrent to a voltage for sampling by an ADC. Some variations of PCR use thermoelectric cooling to cycle the temperature of the sample, which can lead to an increased need for devices that can provide high performance over a wide temperature range. Also, because many optical NAAT applications have low signal amplitudes, the photodetectors in these systems can have very low output currents, increasing the need for a TIA or integrator with extremely low input bias current(I_B) and low drift over temperature.

Integrated Optical Signal Chain

TI offers a large family of integrated optical signal chains; the DDC112 AFE is one such device from this family. These devices provide an integrated signal-chain for interfacing with photodetectors. For each of its two inputs, the DDC112 combines current-to voltage conversion, continuous integration, programmable full-scale range, A/D conversion, and digital filtering to achieve a precision, wide dynamic range digital result. The integration of the full signal chain (up to 256 channels) inside the devices in the DDC family saves space while enabling high throughput, reducing design complexity and minimizing time to market. Figure 3 illustrates an integrated optical signal chain using a device from the DDC112 family.

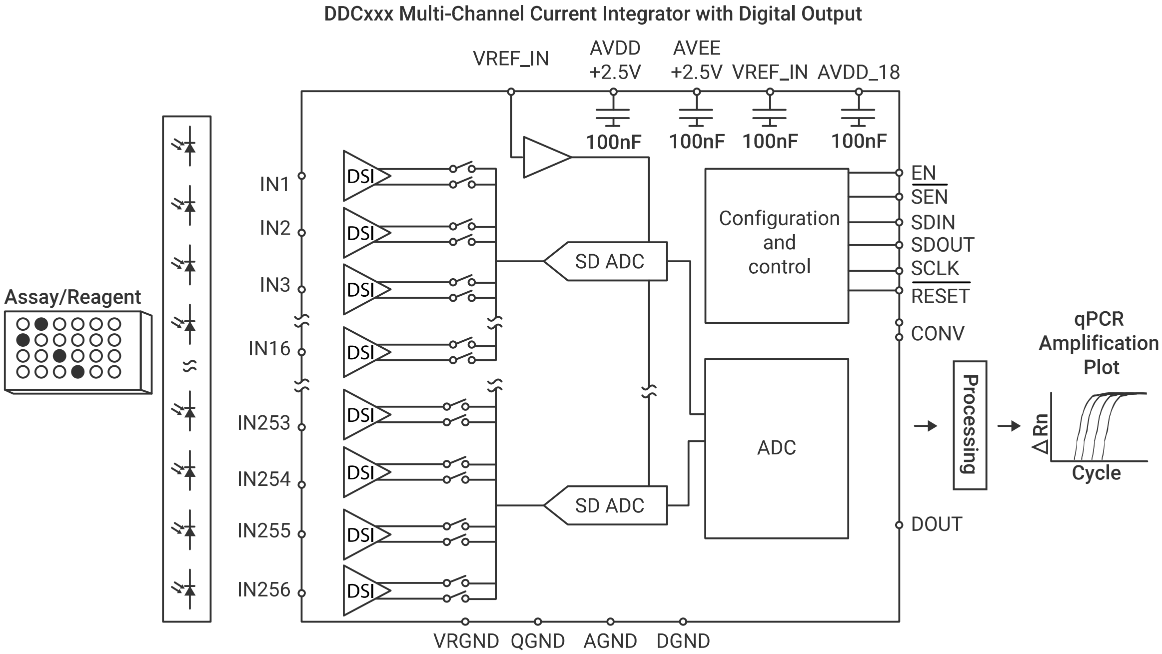

Figure 3. A DDC Integrated Optical Signal Chain for PCR

Discrete Optical Signal Chain

Discrete optical signal chains allow for system-specific customization, and excellent accuracy and sensitivity for lower channel count designs. The OPA392 amplifier features - low noise (4.4 nV/√Hz), ultra-low bias current (10 fA), and high gain bandwidth (13MHz). The ADS127L11 is a 24-bit, 400kSPS delta-sigma ADC featuring – high dynamic range (111.5dB), low THD (-120dB), and INL of 0.9 ppm of FS. These devices allow designers to implement a high-precision and customizable signal chain using discrete components. Figure 4 is an overview of a discrete optical signal chain that can be used in PCR systems.

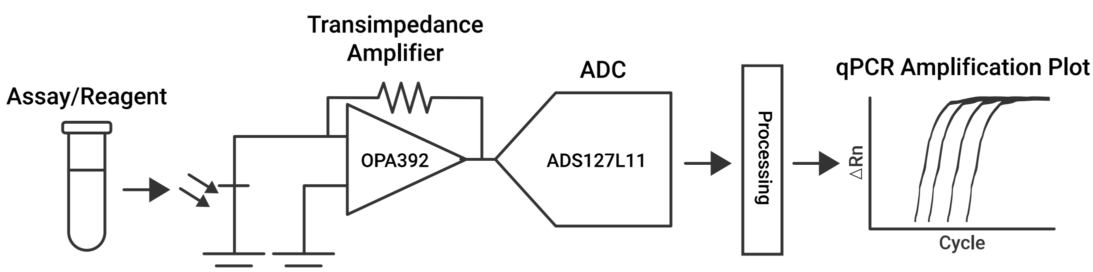

Figure 4. Discrete Optical Signal Chain for PCR

Use the TINA-TI™ system simulation to evaluate the performance of the OPA392 as a TIA, while interfacing with a photodiode. The simulation can be downloaded on the OPA392 product page under the Design Tools & Simulation tab or directly at this link.

Connectivity for Portable Diagnostics:

SimpleLink™ *Bluetooth*® devices, such as the CC2640 family of devices, can help address the design challenges of adding Bluetooth Low Energy to health diagnostic equipment.

For example:

- The small sizes (as low as 2.7 mm by 2.7 mm in the CC2640R2F wafer-chip-scale package and 7 mm by 7 mm CC2652RSIP system-in-package module with integrated passives) make it possible to design into space-constrained applications.
- The ultra-low-power devices in our SimpleLink sensor controller portfolio, with standby currents as low as 0.94 µA, help to maximize battery life.
- These devices also feature security benefits, such as secure boot, 128- and 256-bit Advanced Encryption Standard, true random number generator, and more.