

Andrew Wallace

## Designing Signal Chains for Portable Diagnostics

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<sup>2</sup>C 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.

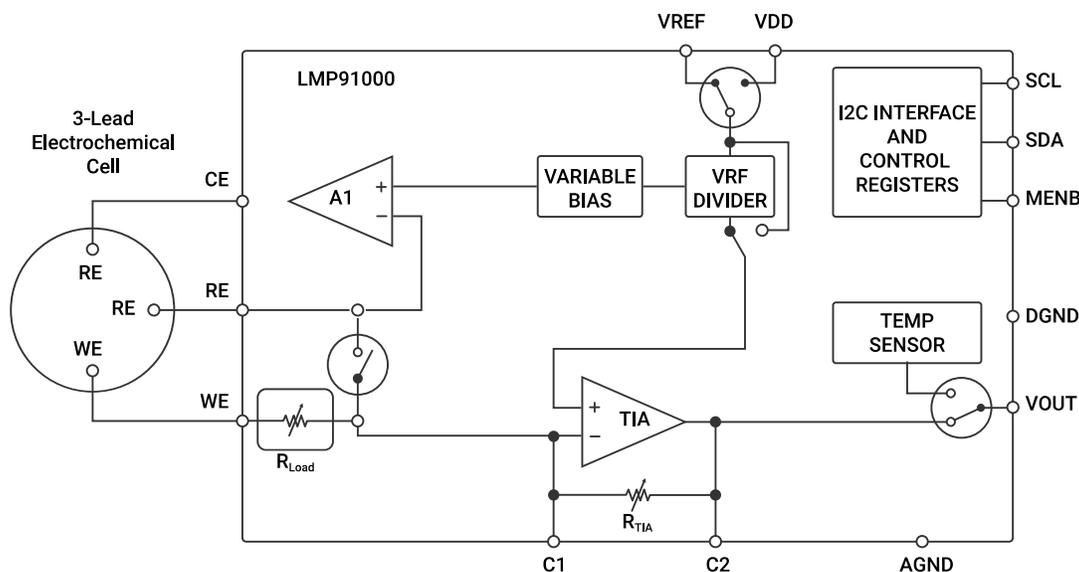
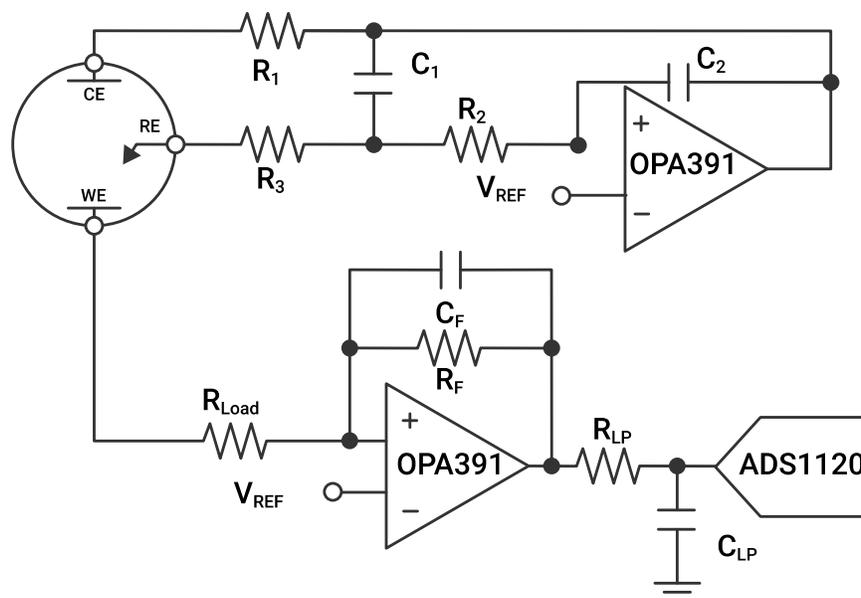


Figure 1. LMP91000 Electrochemical Cell Interface

## Discrete Electrochemical Signal Chain

In discrete electrochemical signal chain implementations TI's [OPA391](#) operational amplifier provides designers with a low noise (30 nV/ $\sqrt{\text{Hz}}$ ), ultra-low bias current (10 fA), and low  $I_Q$  (24  $\mu\text{A}$ ) 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**

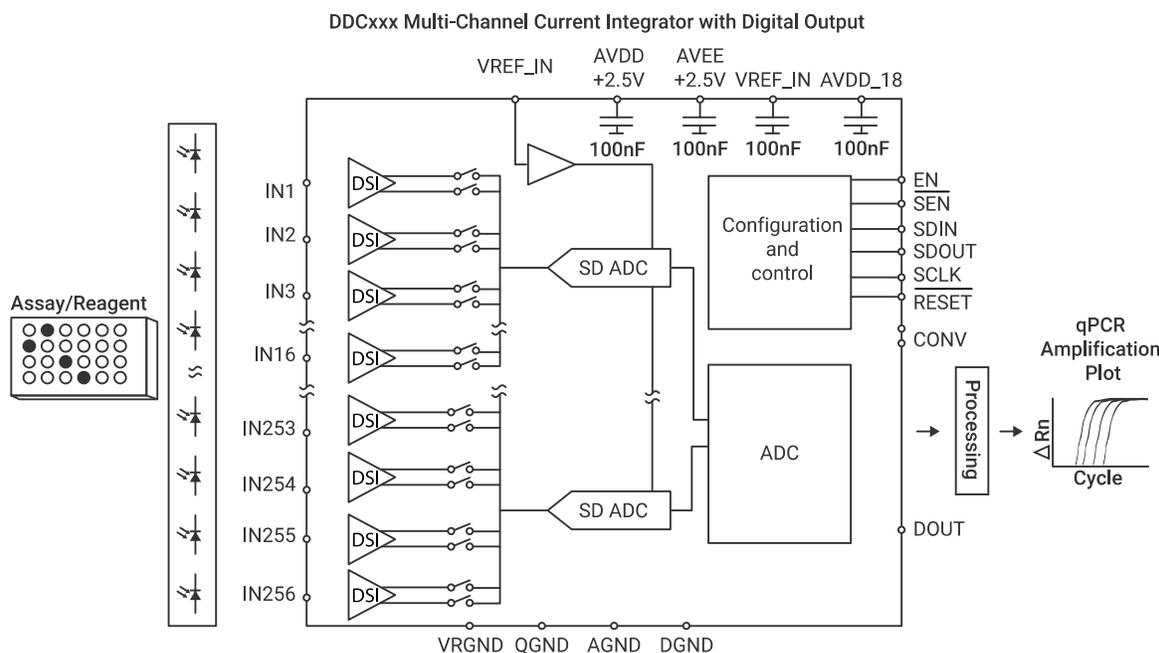
- TI's [ADS1220/ADS1120](#) family of low-power 16 to 24-bit precision ADCs (with an integrated programmable gain amplifier and reference) helps to increase design flexibility and precision for both integrated and discrete signal chains

## 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

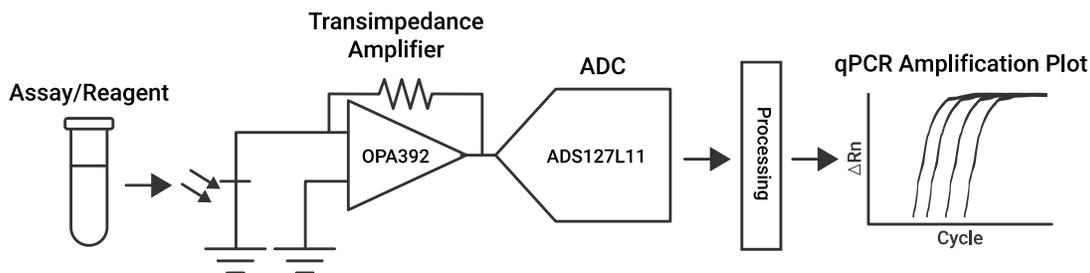
TI offers a large family of integrated optical signal chains; the [DDC112](#) AFE is one such device from this family. These devices provide an integrated signal-chain for interfacing with photodetectors. For each of its two inputs, the DDC112 combines current-to voltage conversion, continuous integration, 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  $\mu\text{A}$ , 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.

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2023, Texas Instruments Incorporated