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Introduction

The ever-growing electric vehicle (EV) market presents many opportunities to implement semiconductor technology, benefiting the vehicle's performance while assuring consumer safety. These vehicles are integrating innovative electronic solutions in the form of EV charging routines such as on-board chargers (OBC) and DC fast charging. In the realm of the analog signal chain, the performance of the vehicle's charging systems is measured through various methods, including voltage regulation, current sensing, and safety & control. Though the architecture found in these systems is comprised of more than a few components, this brief covers a particularly significant IC: the operational amplifier.

DC Fast Charging

DC fast charging represents the peak of power delivery to an electric vehicle by providing a high-voltage AC supply (up to 800V) to the vehicle's power stage which is first converted to 800VDC. This high-voltage direct current is used to charge the vehicle's batteries. A DC/DC converter is then used to lower the voltage to around 400V, bypassing the on-board charger to charge the battery of an EV.

To ensure efficiency of the system, both the input and output of the power stage is monitored. Operational amplifiers serve the role in the monitoring of the voltage/current within the AC/DC and DC/DC power stages of DC fast-charging applications to regulate the delivery of voltage to the vehicle's battery. If there is an inconsistency observed between these two voltages, the system will course correct through the power digital processing unit. There are two key methods to monitoring such a system with op amps.

A resistor voltage divider can be implemented to step down the voltage of the high-side rail. An amplifier, in this case [OPA4991-Q1](#), reads in a voltage at a suitable level relative to its input, which it can then relay to the power digital processing unit. Monitoring a voltage rail through this method is cost-effective, though this method tends to consume a higher amount of power due to the resistor divider.

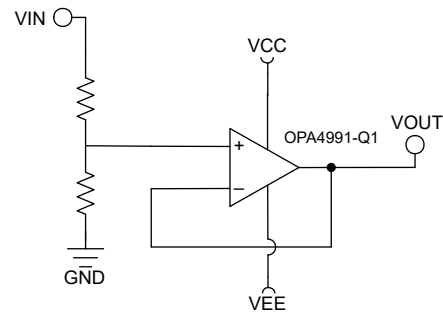


Figure 1. Voltage Division With OPA4991-Q1

On the other hand, an isolated amplifier can be used to directly monitor a high-voltage battery rail, such as TI's [AMC1301-Q1](#) precision isolated amplifier. Here, the isolated amplifier steps down the higher voltage, relative to the input, to a 3.3V differential-ended output. A low-voltage amplifier such as [TLV9001-Q1](#) takes in the differential-ended signal and produces a single-ended signal to monitor the voltage. In this case, the amplifier acts as a signal conditioner before the Analog-to-Digital Converter (ADC). [Interfacing a Differential-Output \(Isolated\) Amp to a Single-Ended Input ADC](#) provides more information on interfacing a differential-output amplifier to a single-ended input ADC.

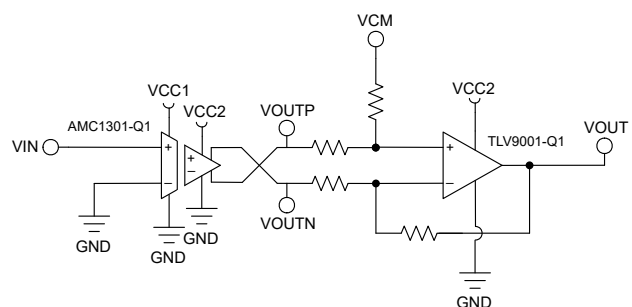


Figure 2. Differential-to-Single-Ended Conversion With AMC1301-Q1, TLV9001-Q1

On-Board Charging Systems

The On-Board Charging System (OBC) in an electric vehicle is the intermediate system between the external charging source and the battery pack located inside the vehicle which drives the powertrain.

The OBC provides many benefits including the ability to use an AC power source through an integrated converter and offers greater convenience by protecting battery life.

The OBC effectively converts the voltage and current from an AC source to DC power which charges the battery. Because the output of the AC/DC converter

in the OBC system ranges from 250 to 900 VDC, non-isolated operational amplifiers may be used to directly sense the current of the system.

There are three different methods to sense current in OBCs: in-line, inverter leg current sensing and DC-link single shunt, each with their advantages and challenges as shown in [Table 1](#).

Table 1. Current Sensing in OBC

Type of Current Sensing	Advantages	Challenges	Accuracy
In-line shunts	<ul style="list-style-type: none"> Direct and continuous phase current sensing Able to detect phase-to-phase and phase-to-GND shorts 	<ul style="list-style-type: none"> Amplifiers require high common-mode input voltage with a high common-mode rejection ratio 	High
Inverter leg current sensing	<ul style="list-style-type: none"> Lower system cost due to the usage of amplifiers with lower common-mode input voltage 	<ul style="list-style-type: none"> Unable to detect phase-to-GND shorts 	Medium
DC-BUS single shunt	<ul style="list-style-type: none"> Lower system cost as one amplifier is used to measure current Measures the power supply current 	<ul style="list-style-type: none"> Amplifiers require high bandwidth and slew rate 	Low

In-line shunt current sensing allows you to directly monitor the phase of each leg. Because the common-mode voltage is equal to that of the DC bus voltage (generally greater than 100V), an amplifier with a high common-mode input voltage range is required; therefore, an isolated amplifier is generally preferred. As mentioned in the DC fast charging application, an operational amplifier (such as [TLV9001-Q1](#)) is typically needed for differential-to-single ended conversion when interfaced with a single-ended input ADC, in order to maintain its full dynamic range & offset any introduced error.

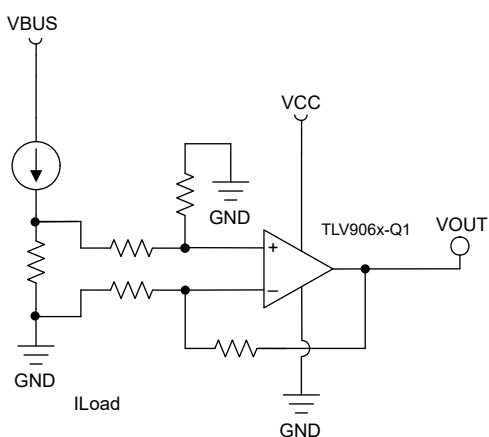


Figure 3. Low-Side Current Sensing With TLV906x-Q1

Monitoring each individual inverter leg uses a low-side current sensing topology that can be accomplished without the need of an isolated amplifier as the common-mode voltage of each leg is close to zero. There are three methods of accomplishing low-side current sensing; one-, two-, or three-shunt topologies. While single-shunt measurement techniques tend towards higher bandwidth requirements, three-shunt solutions call for lower speed, general-purpose amplifiers such as [TLV9061-Q1](#), as you are able to monitor each leg individually. An important requirement for accurate current sensing in OBC systems is ensuring the settling time is as short as possible which is why the [TLV9061-Q1](#), a 10-MHz unity gain-bandwidth amplifier (1 μ s settling time), is recommended for this application to quickly respond to changes in current.

OBCs also have the ability to operate bidirectionally, meaning power can be sent to and from the vehicle. Bidirectional charging allows the on-board charger to convert stored DC power to operable AC power to be delivered to the grid, another vehicle, or different power electronics. Moreover, single-phase chargers have a low carrying capacity (as opposed to three-phase OBCs), a specification which affects charging time. This guide on [low-side, bidirectional current sensing](#) provides a reference on how to build your circuit using a low-voltage amplifier. TI's [TLV906x-Q1](#) family of amplifiers can be implemented in two

ways for low-side bidirectional current sensing. A dual-channel, space-optimized solution can be used, with one channel for reading in voltage and the other dedicated as a reference buffer. On the other hand, two single-channel amplifiers can be used in cost-

optimized designs, where TLV9001-Q1 can be used as a reference buffer in conjunction with the faster TLV9061-Q1.

Electric Vehicle Communication Controller

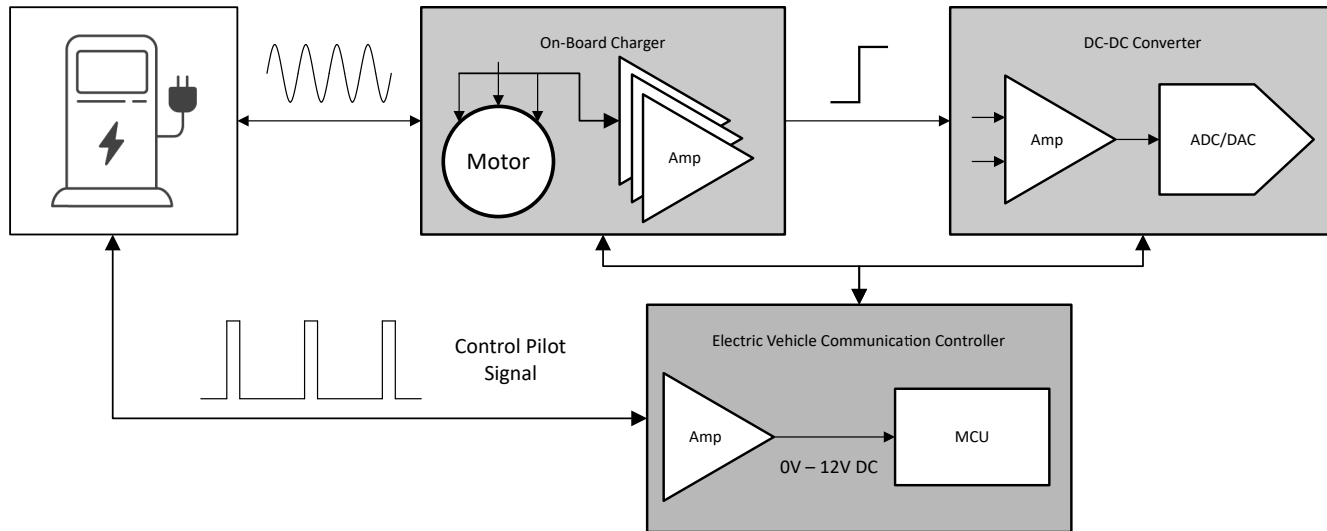


Figure 4. Amplifier Uses in Various Charging Routines

All these charging stages cannot be achieved without first ensuring the service equipment is properly connected to the vehicle. Modern day EVs make use of the Electric Vehicle Communication Controller (EVCC). The EVCC serves as a hub between external charging entities and the vehicle's internal components such as the On-Board Charger & DC/DC Converter to properly monitor their status and provide the go ahead with normal operation. EVCC provides several key functions relating to the charging state of the vehicle. For example, the controller executes the control pilot (digital communication) signal into a connection status and uses Controller Area Network (CAN), Power Line Communication (PLC) and ISO15118 (smart charging) to determine the state of the connection and operating conditions. These states include; determining if the charger is connected to the vehicle at a given time, whether charging is allowed in the current state, and the detection of errors such as short circuits. Regardless of which charging level and charging routine is active, there is constant communication to and from the EVCC.

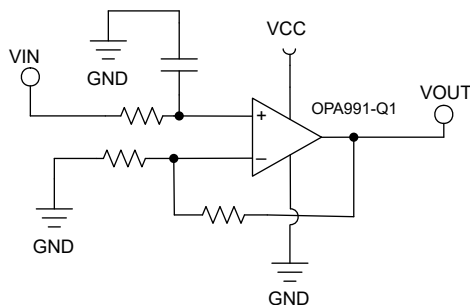


Figure 5. PWM to DC Conversion With OPA991-Q1

The 40V operational amplifier with rail-to-rail input & output architecture, [OPA991-Q1](#), can be used in the EVCC as a signal conditioner. As seen in [Figure 5](#), the op amp, generally in a non-inverting topology, is used as a low-pass filter to convert the 1kHz pulse-width modulation (PWM) signal to a DC voltage. The amplifier converts the control pilot signal from the Electric Vehicle Supply Equipment (EVSE), such as a charging station and surrounding components), and sends this information to a microcontroller unit for processing. The output voltage of the amplifier is dependent on the duty cycle of the PWM (-12V to +12V) and is fed to the MCU to denote six distinct connection stages: No connection, connected, ready for charging, connected for ventilation, short to ground, and error detection.

Conclusion

As the number of electrical components within a vehicle increase, there will be more opportunities to implement supervisory functions into automotive systems. Op amps continue to provide the sensing capability required to maintain the high voltage systems present in production EVs, as noted in applications such as DC fast charging and on-board chargers.

A growing demand for quicker charging times and greater power densities will fuel the integration of many ICs in the automotive space; operational amplifiers lend in a hand in improving the efficiency of these systems by ensuring robust performance across various key specifications for designing charging routines. As charging elements are improved upon, designers may consider TI's general-purpose solutions in future board layouts.

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