ANALOG DEVICES

Circuit Note
CN-0196

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Devices Connected/Referenced	
ADuM7234	Isolated Precision Half-Bridge 4 A Driver
ADG787	2.5 Ω CMOS Low Power Dual 2:1 Switch
ADuC7061	ARM7 Based Microcontroller with Dual 24-Bit Σ-Δ ADCs
ADuM3100	Digital Isolator
ADP1720	50 mA Linear Regulator
ADCMP350	Comparator with 0.6 V Reference

H-Bridge Driver Circuit Using Isolated Half-Bridge Drivers

EVALUATION AND DESIGN SUPPORT
Circuit Evaluation Boards
 CN-0196 Circuit Evaluation Board (EVAL-CN0196-EB1Z)
 ADuC7061 MiniKit (EVAL-ADuC7061MKZ)
Design and Integration Files
 Schematics, Layout Files, Bill of Materials

CIRCUIT FUNCTION AND BENEFITS

The circuit, shown in Figure 1, is an H-bridge composed of high power switching MOSFETs that are controlled by low voltage logic signals. The circuit provides a convenient interface between logic signals and the high power bridge. The bridge uses low cost N-channel power MOSFETs for both the high and low sides of the H-bridge. The circuit also provides galvanic isolation between the control side and power side. This circuit can be used in motor control, power conversion with embedded control interface, lighting, audio amplifiers, and uninterruptable power supplies (UPS).

Modern microprocessors and microconverters are generally low power and operate on low supply voltages. Source and sink current for 2.5 V CMOS logic outputs ranges from µA to mA . Driving an H-bridge switching 12 V with a 4 A peak current requires the use of carefully selected interface and level translation components, especially if low jitter is needed.

The ADG787 is a low voltage CMOS device that contains two independently selectable single-pole double-throw (SPDT) switches. With a 5 V dc power supply, a voltage as low as 2 V is a valid high input logic voltage. Therefore, the ADG787 provides appropriate level translation from the 2.5 V controlling signal to the 5 V logic level needed to drive the ADuM7234 half-bridge driver.

The ADuM7234 is an isolated, half-bridge gate driver that employs Analog Devices' *i*Coupler® technology to provide independent and isolated high-side and low-side outputs making it possible to use N-channel MOSFETs exclusively in the H-bridge. There are several benefits in using N-channel MOSFETs: N-channel MOSFETs typically have one third of the on resistance of P-channel MOSFETs and higher maximum current; they switch faster, thereby reducing power dissipation; and the rise time and fall time is symmetrical.

The 4 A peak drive current of the ADuM7234 ensures that the power MOSFETs can switch on and off very fast, thereby minimizing the power dissipation in the H-bridge stage. The maximum drive current of the H-bridge in this circuit can be up to 85 A, which is limited by the maximum allowable MOSFET current.

The ADuC7061 is a low power, ARM7 based precision analog microcontroller with integrated pulse width modulated (PWM) controllers that have outputs that can be configured to drive an H-bridge after suitable level translation and conditioning.

CIRCUIT DESCRIPTION
Level Translation of 2.5 V PWM Control Signal to 5 V

The EVAL-ADuC7061MKZ delivers 2.5 V logic level PWM signals, while the minimum logic high input threshold for the ADuM7234 is 3.5V with a 5 V power supply. Because of this incompatibility, the ADG787 switch is used as an intermediate level translator. The minimum input logic high control voltage to the ADG787 is 2 V, which is compatible with the 2.5 V logic from the ADuC7061. The output of the ADG787 switches between 0 V and 5 V, which is more than sufficient to drive the
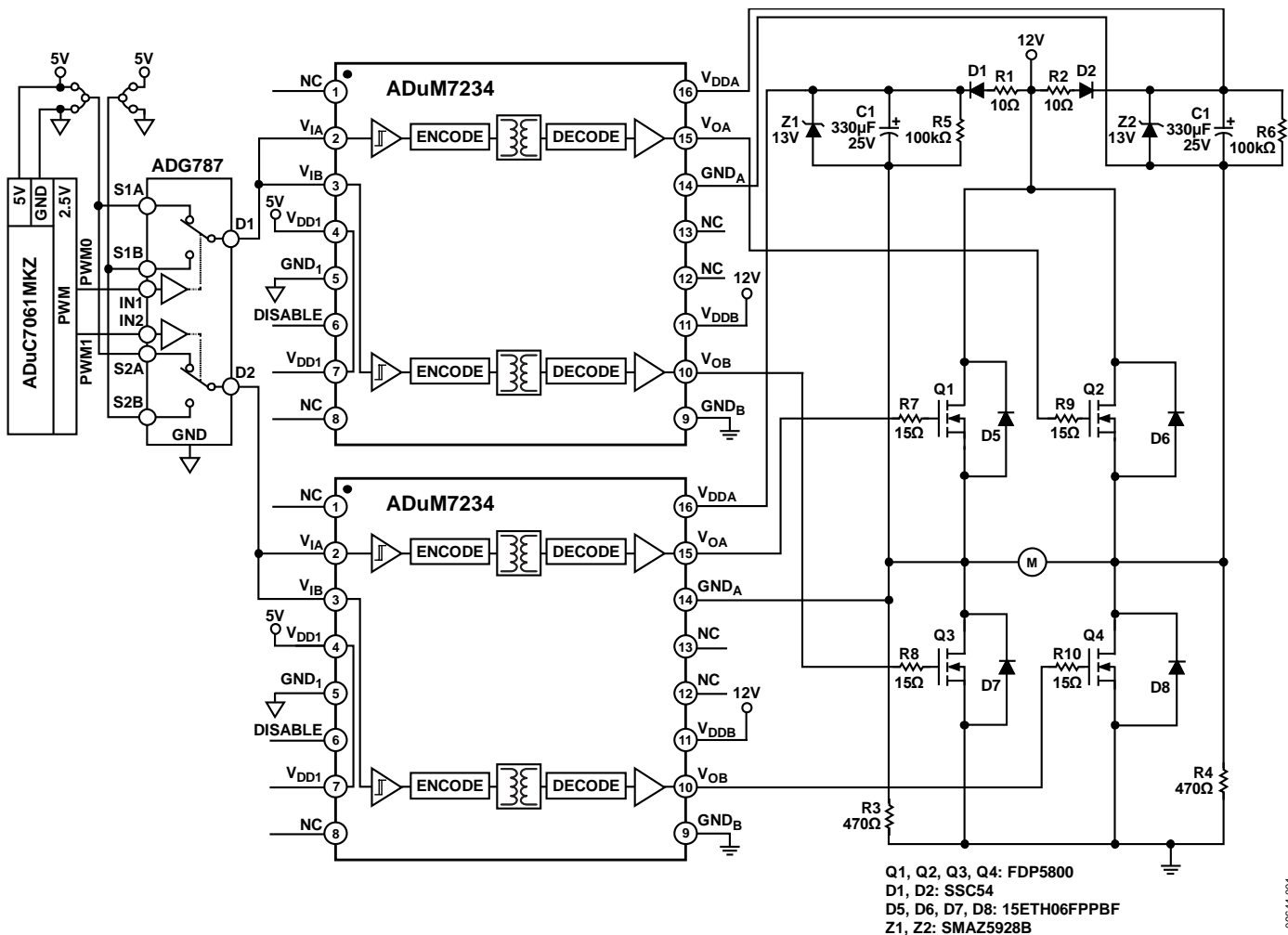
Figure 1. H-Bridge Using ADuM7234 Isolated Half-bridge Driver (Simplified Schematic: All Connections and Decoupling Not Shown)

input of the of the ADuM7234, which has a 3.5 V threshold. Two jumpers are provided, which makes it easy to configure the polarity of the controlling PWM signal.

H-Bridge Introduction

There are four switching elements in the H-bridge shown in Figure 1 (Q1, Q2, Q3, Q4). The switches are turned on in pairs, either high left side (Q1) and low right side (Q4) or low left side (Q3) and high right side (Q2). Keep in mind that the switches on the same side of the bridge are never on at the same time. The switches can be implemented using MOSFETs or IGBTs (insulated gate bipolar transistors) and use pulse width modulation (PWM) or other control signals from the controller to turn the switches on and off, thereby changing the polarity of the load voltage.

The sources of the low side MOSFETs (Q3, Q4) are connected to ground, therefore, their gate drive signal is also referenced to

ground. On the other hand, the source voltages of the high side MOSFETs (Q1, Q2) switch as the pairs of MOSFETs are turned on and off. Therefore the optimum gate drive signals should be referenced or "bootstrapped" to this floating voltage.

The gate drive signals from the ADuM7234 offer the benefit of true galvanic isolation between each input and each output. Each output may be operated up to ±350 V peak relative to the input, thereby supporting low-side switching to negative voltages. As a result, the ADuM7234 provides reliable control of the switching characteristics of various MOSFET configurations over a wide range of positive or negative switching voltages. For safety and ease of testing, a 12 V dc supply was chosen as the power supply for this design.

Bootstrapped Gate Drive Circuit

The power supplies to the gate drivers for the high-side and low-side are different. The low-side gate drive voltage is

ground-referenced, so it is developed directly from the ground-referenced dc supply. However, the high-side is floating, so a bootstrap drive circuit is useful and operates as follows.

Let us look at the left side of the H-bridge circuit shown in Figure 1. The bootstrap drive circuit is implemented with the capacitor C1, the resistors R1 and R3, and the diode D1. Immediately after power on, the PWM does not come instantly, and all the MOSFETs are in the high impedance state until all dc voltages are settled. During this time capacitor C1 is charged by the dc supply through the path R1, D1, C1, and R3. The charged capacitor C1 provides the voltage for high-side gate drive. The time constant for C1 charging is τ = (R1 + R3) C1.

When the MOSFETs switch due to the PWM signal, the low-side switch Q3 is turned on, and the high-side switch Q1 is turned off. The GNDA of the high-side is pulled down to ground, and the capacitor C1 is charged. When Q1 is turned on, and Q3 is turned off, the GNDA is pulled up to the dc supply voltage. The diode D1 is reversed biased, and the C1 voltage forces the VDDA voltage of the ADuM7234 to approximately 24 V. The capacitor C1, therefore, maintains a voltage of approximately 12 V between the VDDA and GNDA terminals of the ADuM7234. In this manner, the gate drive voltage to the high-side MOSFET Q1 is always referenced to the floating source voltage of Q1.

Voltage Spikes on the Source of the High-Side MOSFET

When Q1 and Q4 are on, the load current flows from Q1 through the load to Q4 and to ground. When Q1 and Q4 are turned off, the current still flows in the same direction through the free-wheeling diodes D6 and D7, producing a negative spike on the source of Q1. This can damage some gate drivers employing other topologies but has no effect on the ADuM7234, which supports low-side switching to negative voltages.

Bootstrap Capacitors (C1, C2)

The bootstrap capacitor is charged every time the low-side driver is on, and it is discharged only when the high-side switch is turned on. Therefore, the first parameter to consider in selecting the value of the bootstrap capacitor is the maximum allowable voltage drop when the high-side switch is turned on and the capacitor is used as the dc supply for the high-side of the gate driver ADuM7234. When the high-side switch is turned on, the dc supply current of ADuM7234 is typically 22 mA. Assume that the on-time of high-side switch is 10 ms (50 Hz, 50% duty cycle). Using the equation C = I × ΔT/ΔV, the capacitor should be larger than 220 μF if the allowable voltage drop ΔV = 1 V, I = 22 mA, and ΔT = 10 ms. In this design, a value of 330 μF was chosen. The resistor R5 discharges the

bootstrap capacitor after the circuit is powered off and serves no function when the circuit is switching.

Bootstrap Current Limit Resistors (R1, R2)

The series resistor R1 provides the current limit when charging the bootstrap capacitor. If R1 is too high, the dc quiescent current from the high-side driver supply of the ADuM7234 will cause too much voltage drop across R1, and the ADuM7234 may go into undervoltage lockout. The maximum dc supply current for the ADuM7234 is I_{MAX} = 30 mA. If the voltage dropped across R1 due to this current is limited to V_{DROP} = 1 V, then R1 should be less than V_{DROP}/I_{MAX}, or 33 Ω. Therefore, a resistor of 10 Ω was selected as the bootstrap resistor.

Bootstrap Start-Up Resistors (R3, R4)

The resistor R3 starts up the bootstrap circuit. Immediately after power-on, dc voltages are not established, and the MOSFETs are off. Under these conditions C1 is charged through the path R1, R3, D1, V_S, described by the following equation:

$$v_C(t) = (V_S - V_D)(1 - e^{-t/\tau}), \tag{1}$$

where $v_C(t)$ is the capacitor voltage, V_S is the supply voltage, V_D is the diode voltage drop, and τ is the time constant, τ = (R1 + R3) C1. The circuit values are R1 = 10 Ω, C1 = 330 μF, V_D = 0.5 V, and V_S = 12 V. From the equation, it takes one time constant (158 ms) to charge the capacitor to 67% of its final value for R3 = 470 Ω. A larger value resistor will increase the charging time of the capacitor. However, when the high-side MOSFET Q1 is turned on, there will be 12 V across resistor R1, so if the value of the resistor is too low, it will dissipate considerable power. For R3 = 470 Ω, the power dissipation in the resistor at 12 V is 306 mW.

Overvoltage Protection for the Bootstrap Capacitors (Z1, Z2)

As mentioned above, with inductive load, when the high side MOSFET turns off, the current will flow through the free-wheeling diodes. Due to the resonance between the inductance and parasitic capacitance, the charging energy to the bootstrap capacitor may be higher than the dissipated energy of the ADuM7234, and the voltage on the capacitor may rise to an overvoltage condition. The 13 V Zener diode clamps the voltage on the capacitor, thereby avoiding the overvoltage situation.

Gate Drive Resistors (R7, R8, R9, R10)

The gate resistors (R7, R8, R9, R10) are selected based on the desired switching time, t_{SW}. The switching time is the time required to charge C_{gd} and C_{gs} and to charge the switching MOSFETs to the required charge, Q_{gd} and Q_{gs}.
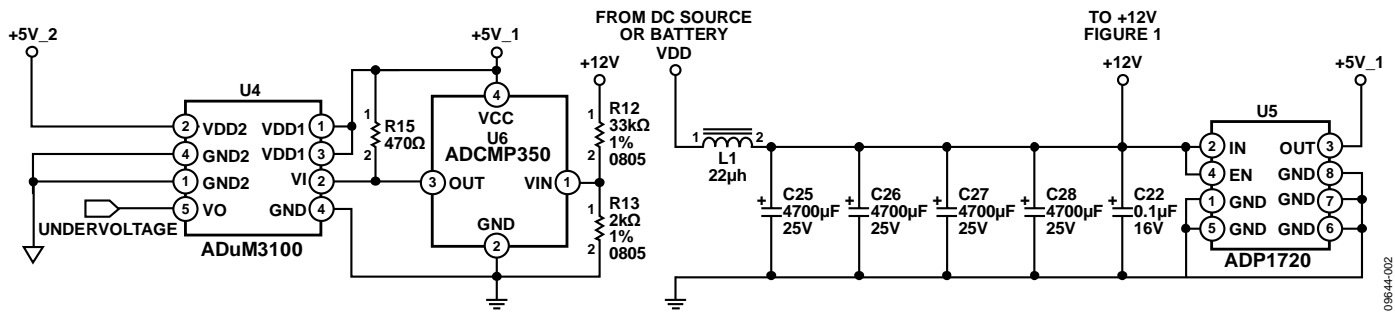
Figure 2. Power Rail Filtering and Undervoltage Lockout Protection for ADuM7234

The following equation describes the gate drive current, I_g:

$$I_g = \frac{Q_{gd} + Q_{gs}}{t_{SW}} = \frac{V_{DD} - V_{gs(th)}}{R_g + R_{DRV}} \quad (2)$$

where V_{DD} is the supply voltage and R_{DRV} is the equivalent resistance of the gate driver ADuM7234, $V_{gs(th)}$ is the threshold voltage, R_g is the external gate drive resistor, Q_{gd} and Q_{gs} are the required MOSFET charge, and t_{SW} is the required switching time.

The equivalent resistance of the ADuM7234 gate driver is calculated from:

$$R_{DRV} = \frac{V_{DDA}}{I_{OA(SC)}} \quad (3)$$

According to the ADuM7234 data sheet, for V_{DDA} = 15 V and the output short circuit pulsed current $I_{OA(SC)}$ = 4 A. Therefore, R_{DRV} is about 4 Ω from Equation 3.

From the FDP5800 MOSFET data sheet, Q_{gd} = 18 nC; Q_{gs} = 23 nC; $V_{gs(th)}$ = 1 V.

If the desired switching time, t_{SW}, is 100 ns, Equation 2 is solved for R_g, yielding R_g ~ 22 Ω. In the actual design, 15 Ω resistors were chosen to allow for some margin.

Power Rail Filtering and Undervoltage Protection

Because of the high peak load current, the dc source voltage (VDD) must be properly filtered to prevent the ADuM7234 from going into undervoltage lockout and also to prevent possible damage to the supply. The filter chosen consists of four parallel 4700 μF, 25 V capacitors in series with a 22 μH power inductor, as shown in Figure 2. The specified maximum rms ripple current of the capacitors at 100 kHz is 3.68 A. Since four of these capacitors are in parallel, the largest allowable rms ripple is 14.72 A. Therefore, $I_{PEAK} = 2\sqrt{2} \times I_{RMS}$ = 41.63 A.

The filtered +12 V also drives the circuit shown in Figure 1.

The ADuM7234 undervoltage lockout is prevented by disabling the input to the ADuM7234 when the power supply voltage is less than 10 V using the circuit shown in Figure 2. The circuit is disabled by applying a logic high to the DISABLE pin of the ADuM7234.

The open-drain, active low ADCMP350 comparator is used to monitor the dc supply voltage. The ratio of the resistor divider (R12, R13) is chosen such that when the supply voltage is 10.5 V, the divider output is 0.6 V, which is equal to the 0.6 V on-chip reference of the comparator. When the supply voltage drops below 10.5 V, the output of the comparator goes high. Because the input and output side of the ADuM7234 are galvanically isolated, the DISABLE signal from the output side must be transferred to the input side through an isolator. The ADuM3100 is a digital isolator based on the iCoupler technology. The ADuM3100 is compatible with 3.3 V and 5 V operation. The 12 V filtered supply drives the ADP1720 linear regulator, which supplies the 5 V (+5V_1) for the right-hand isolated side of ADuM3100, as shown in Figure 2.

The Load and the PWM Signal

If we use an inductor as the load, the current flowing through the inductor will change linearly if a constant voltage is applied. The voltage, U, is 12 V, and if we ignore the voltage drop across the MOSFETs due to the on–resistance, the following equation is true:

$$U = L\frac{di}{dt} \quad (4)$$

With a 50 kHz, 8% duty cycle PWM signal and a 4 μH Coilcraft power inductor (SER2014-402) as the load, the load current waveform is as shown in Figure 3. A current probe is used to measure the inductor current.

For a 12 V supply voltage and a 4 μH inductor, Equation 4 predicts a slope of 3 A/μs. The actual slope was measured to be 2.8 A/μs, and the reduction is due to the voltage dropped across the on resistance of the MOSFETs.
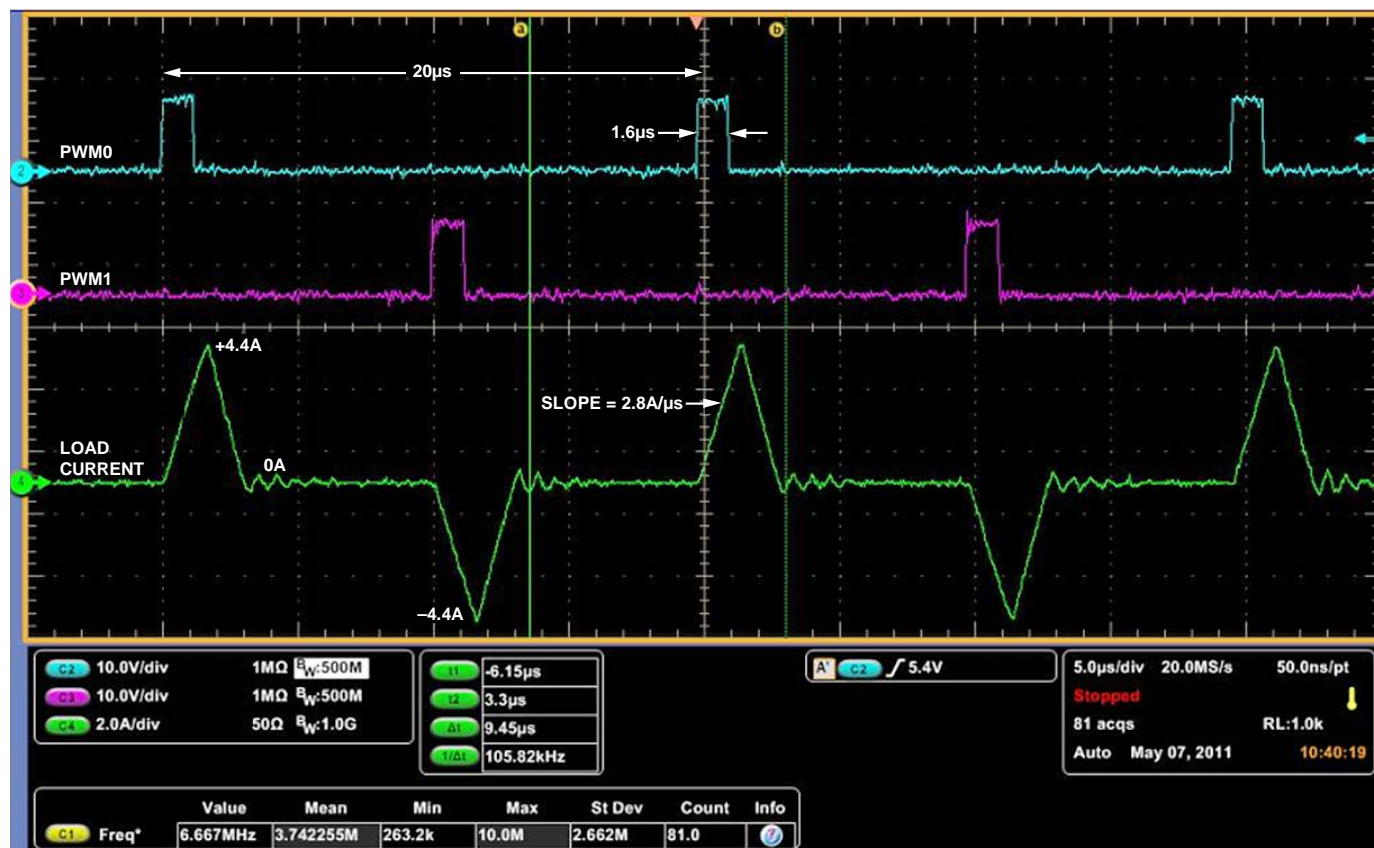
Figure 3. Load Current as a Function of the PWM Pulses with a 4 µH Load

Note that there is a small amount of ringing on the waveform immediately after the current turns off. This is due to the resonance between the inductive load and the parasitic capacitance of the free-wheeling diodes and the MOSFETs.

It is important that the maximum rated current of the inductor is not exceeded in the circuit. If this occurs, the inductor goes into saturation, and the current will increase rapidly, which can damage the circuit and the power supply. The Coilcraft SER2014-402 inductor used as a load in the circuit has a rated saturation current of 25 A.

COMMON VARIATIONS

The circuit can easily be expanded to a 3-phase control application with some additional components. The circuit can also be used in applications requiring higher supply voltages, but care must be taken to ensure the ratings of the MOSFETS and filter capacitors are not exceeded.

Equipment Needed

- PC with a USB port and Windows XP, Windows Vista (32-bit), or Windows 7 (32-bit)

- EVAL-CN0196-EB1Z circuit evaluation board
- EVAL-ADuC7061MKZ evaluation board
- DC supply or battery: +12 V, 10 A
- Load, such as Coilcraft SER2014-402 power inductor
- Oscilloscope with current probe

Getting Started

Load the evaluation software by placing the CN0196 evaluation software disc in the CD drive of the PC. Locate the drive that contains the evaluation software disc and open the Readme file. Follow the instructions contained in the Readme file for installing and using the evaluation software.

Setup and Test

Download the firmware code to EVAL-ADuC7061-MKZ, install CN-0196 evaluation software, and connect the controlling signal from EVAL-ADuC7061-MKZ and EVAL-CN0196-EB1Z according to jumper configuration in the Readme file.
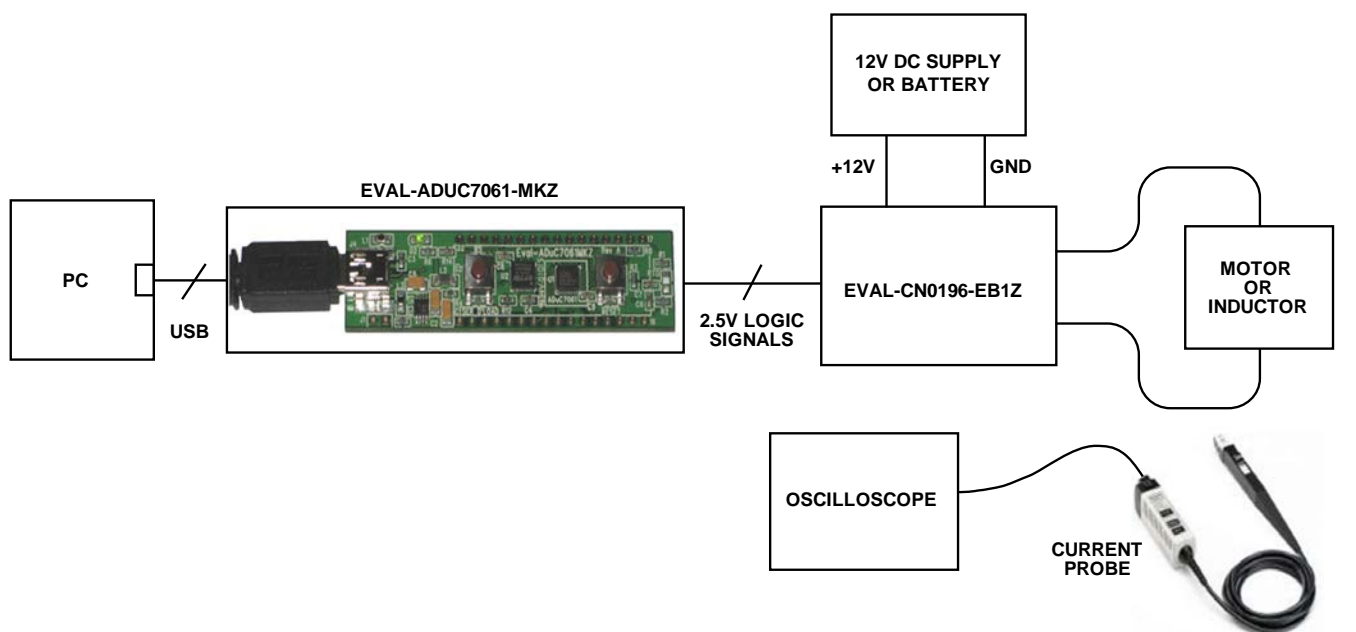
Figure 4. Functional Block Diagram of Test Setup

Connect the jumper LK1, apply +12 V power to CN2, launch the software, and connect the USB cable from the PC to the USB mini-connector on the EVAL-ADuC7061-MKZ board. Using an inductor as the load, run the software and use a current probe to measure the current of the inductor.

Information and details regarding to how to use the evaluation software for proper PWM signals can be found in the CN0196 Evaluation Software Readme file.

LEARN MORE

CN-0196 Design Support Package:
www.analog.com/CN0196-DesignSupport

Ardizzoni, John. "A Practical Guide to High-Speed Printed-Circuit-Board Layout." *Analog Dialogue.* 39-09, September 2005.

MT-101 Tutorial, *Decoupling Techniques*, Analog Devices.

Data Sheets and Evaluation Boards

CN-0196 Circuit Evaluation Board (EVAL-CN0196-EB1Z)

ADuM7234 Data Sheet

ADuM7234 Evaluation Board

ADuC7061 Data Sheet

ADuC7061 Evaluation Board

ADG787 Data Sheet

ADuM3100 Data Sheet

ADP1720 Data Sheet

ADCMP350 Data Sheet

REVISION HISTORY

9/11—Revision 0: Initial Version

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