

## LTC4316 EasySMU: I<sup>2</sup>C Address Translator and Simple Multichannel Source Measurement Unit

### DESCRIPTION

EasySMU is a single-channel  $\pm 12\text{V}/\pm 40\text{mA}$  programmable-voltage/programmable-current source with accurate voltage/current measurement capability. The LTC<sup>®</sup>4316 I<sup>2</sup>C address translator enables up to eight independent EasySMUs to be controlled by a single I<sup>2</sup>C master.

In this demonstration, each EasySMU board contains four I<sup>2</sup>C slaves and the associated components to implement a single-channel  $\pm 12\text{V}/\pm 40\text{mA}$  programmable-voltage/programmable-current source. The LTC4316 translates the I<sup>2</sup>C addresses of each EasySMU to a unique set of addresses, enabling up to eight EasySMU boards to be stacked on a single Linduino<sup>®</sup> (I<sup>2</sup>C master). In this form, it resembles a multichannel automated test system. Alternatively, an optional touchscreen allows the user to interactively control up to four channels, forming a compact multichannel programmable-voltage/programmable-current

bench source for lab testing, powered from a single 12V AC/DC wall adapter.

The primary purpose of the EasySMU is to demonstrate the LTC4316 I<sup>2</sup>C address translator. The programmable-voltage/programmable-current source and meter also provide a convenient demonstration of the associated components: LT<sup>®</sup>1970A, LT5400-3, LTC2655-H, LTC3265, LTC2051, LT3010, LT1991, LTC6655, and LTC2485.

While the EasySMU is not designed to demonstrate the ultimate performance that can be obtained from each of those components, the EasySMU does provide impressive results from a reasonably simple circuit.

**Design files for this circuit board are available at <http://www.linear.com/demo/DC2591A>**

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### PERFORMANCE SUMMARY

Specifications are at T<sub>A</sub> = 25°C

EasySMU SET VOLTAGE	EasySMU VOLTAGE MEASUREMENT ERROR <sup>1</sup>
-5V to 5V	±0.25mV
-12V to -5V, 5V to 12V	±0.5mV
EasySMU SET CURRENT	EasySMU CURRENT MEASUREMENT ERROR <sup>2</sup>
40mA	±10μA
10mA	±2μA
5mA	±2μA
1mA	±1μA

<sup>1</sup> The EasySMU voltage measurement is tested at -12V, -5V, 0V, 5V, and 12V. The measurement error is tested with an Agilent HP34401A 6.5 digit voltmeter. Although the output voltage setting is configurable with <1mV step sizes, it is recommended to use the voltage measurement to accurately determine the actual output voltage.

<sup>2</sup> The current can be measured accurately to the microamp level, but the current limit setting is only configurable between 1mA to 40mA. The current measurement is tested with output voltage settings of 12V and -12V while the output is shorted to ground through the Agilent HP34401A current meter.

## QUICK START PROCEDURE

The simplest way to use the EasySMU is to provide power through the Linduino's 12V input and control it with an Adafruit Capacitive Touchscreen (<https://www.adafruit.com/products/1947>) as shown in the photo below. Up to eight EasySMUs can be powered from a single 12V/1A

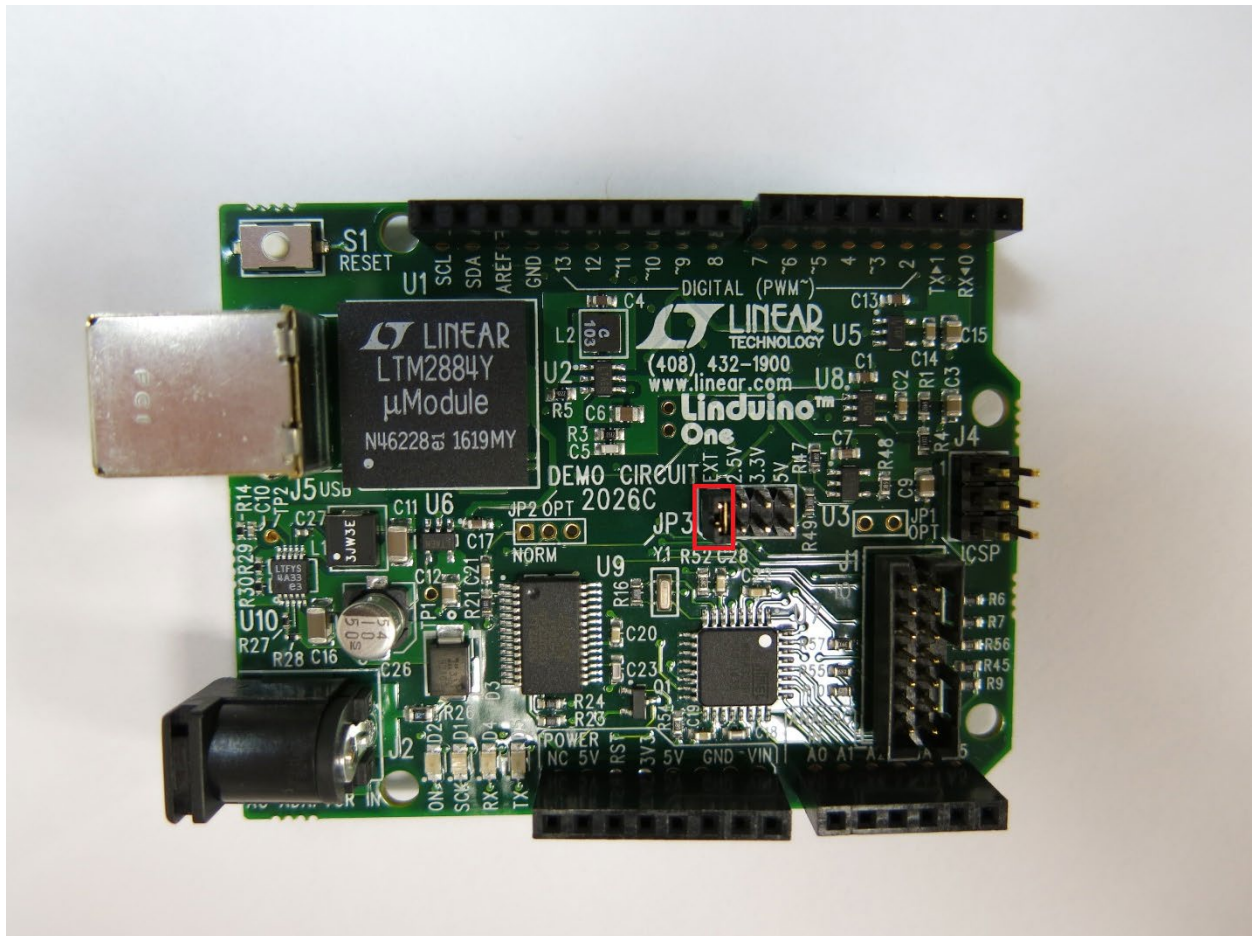
wall adapter. Good choices for the AC/DC wall adapter are a Jameco ReliaPro 100870 or a CUI Inc. SW12-12-N-P5. When adding or removing EasySMUs from the Linduino, it is recommended to first remove power by disconnecting the AC/DC wall adapter and USB cable from the Linduino.



## QUICK START PROCEDURE

It is recommended to set the Linduino JP3 jumper to the EXT position when using the EasySMU shield. The QuikEval™ connector is not used by the EasySMU, so

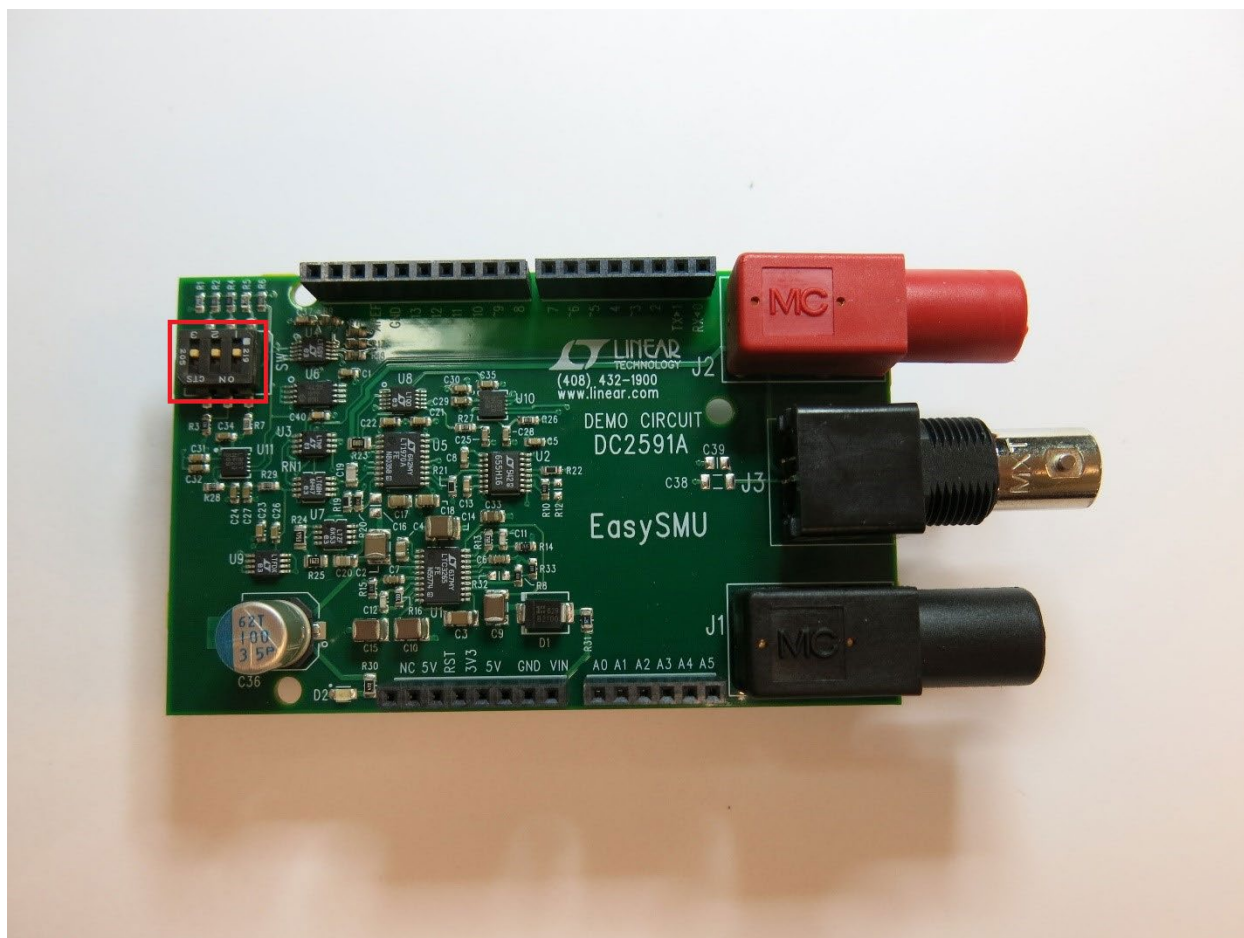
eliminating the fast edges generated by the Linduino's I<sup>2</sup>C and SPI digital buffers reduces noise that could be coupled from the fast signal edges.



## QUICK START PROCEDURE

Up to four EasySMU channels (CH0-CH3) can be controlled directly from the touchscreen, and up to eight (CH0-CH7) can be controlled through the USB port. When multiple channels are present, configure the DIP switches to assign a unique number to each EasySMU. Since the optional touchscreen displays channels CH0-CH3, it is easiest to assign channel numbers starting with 0 at the

bottom and increasing by one for each additional channel. The DIP switch setting is only checked when power is first applied to the EasySMU. Therefore, if a DIP switch setting is changed while the EasySMU is powered it will not be updated until the 12V power input and USB cable have been removed and power is reapplied.

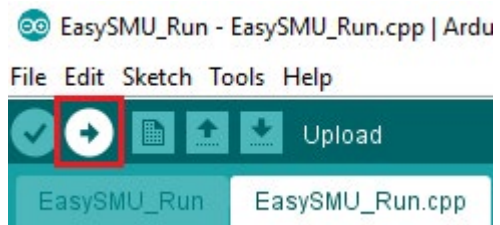
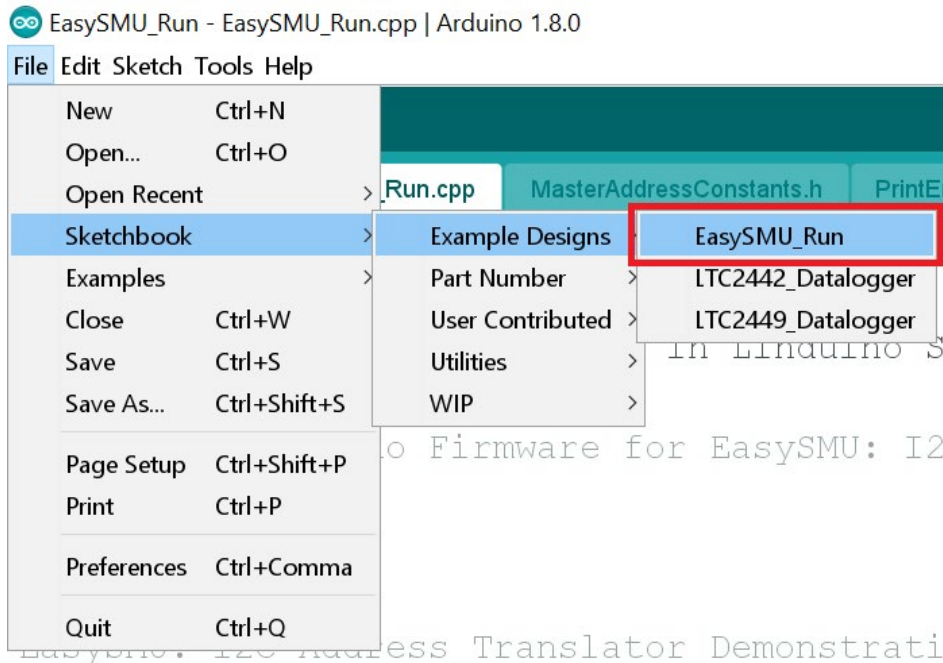




## QUICK START PROCEDURE

If this is your first time using a Linduino, see the Quick Start instructions at <http://www.linear.com/solutions/Linduino> to install the Arduino IDE and download the

LTsketchbook. Use the Arduino IDE to upload the EasySMU\_Run sketch. This is required before using the EasySMU for the first time.

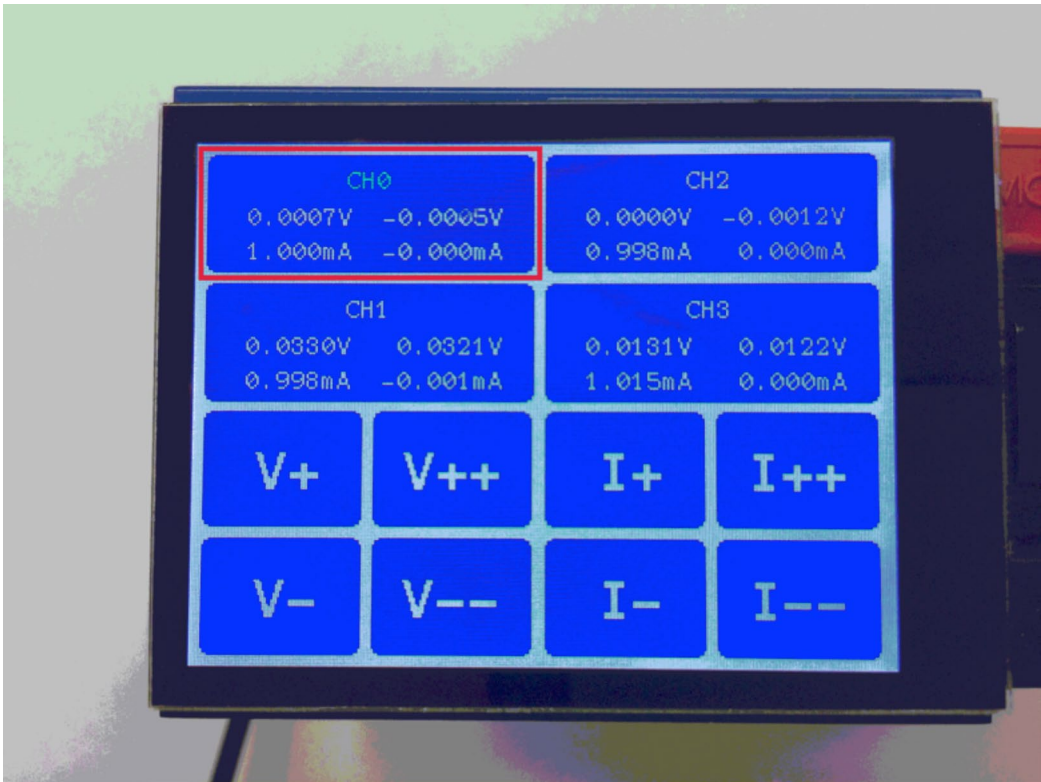


QUICK START PROCEDURE

If the touchscreen is not used, skip ahead to the section entitled USB operation.

When the touchscreen is present, press a measurement box to select the corresponding channel. The label of

the selected channel is displayed in green. The labels of unselected channels are white.

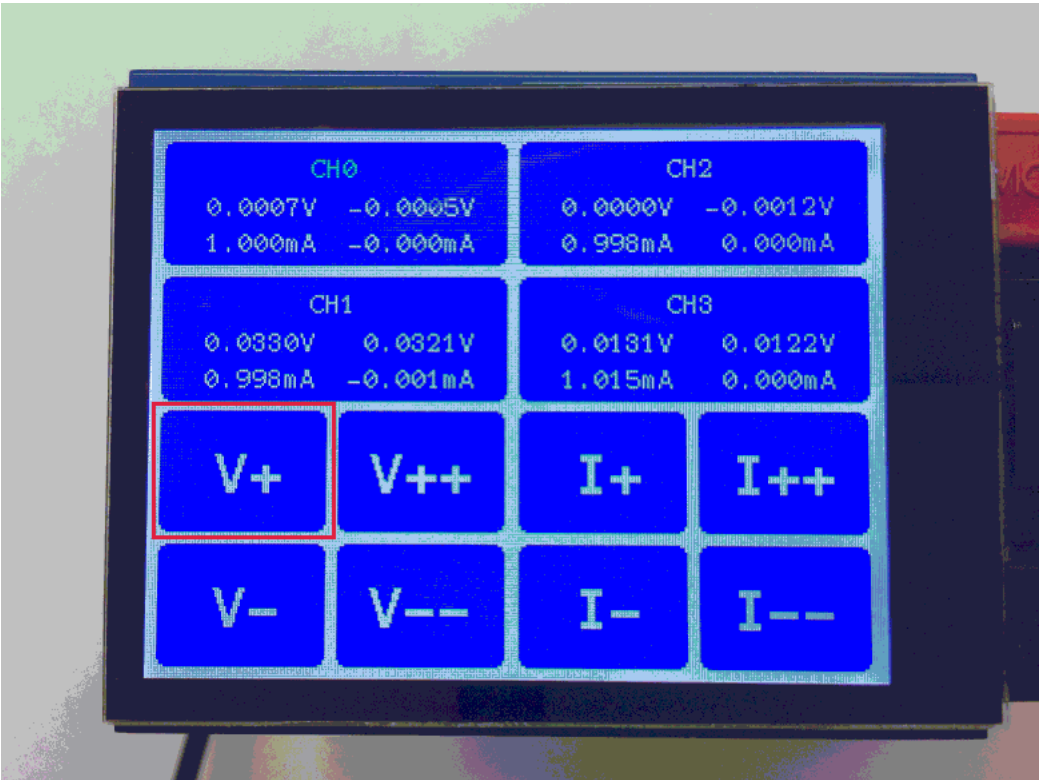


QUICK START PROCEDURE

The V+, V++, V-, V--, I+, I++, I-, and I-- buttons adjust the output voltage and current of the selected channel.

The values on the left side of the measurement box are the voltage and current source settings. In other words,

the left side shows the voltage limit and current limit configurations. The values on the right side of the box are the actual measured values at the output.



# DEMO MANUAL DC2591A

## USB OPERATION

The USB port on the Linduino appears as a virtual COM port on the PC, allowing an EasySMU to be controlled with the serial commands listed below. The baud rate is 9600bps, and the serial port configuration is 8-N-1 (data bits: 8, parity: none, stop bit: 1).

(If you have a Windows version of Excel, the EasySMU.xls spreadsheet available for download at [www.linear.com/demo/DC2591A](http://www.linear.com/demo/DC2591A) provides another simple way to set and measure the voltage and current of EasySMUs.)

In the commands below, x is substituted with 0-7, a number corresponding to the appropriate channel.

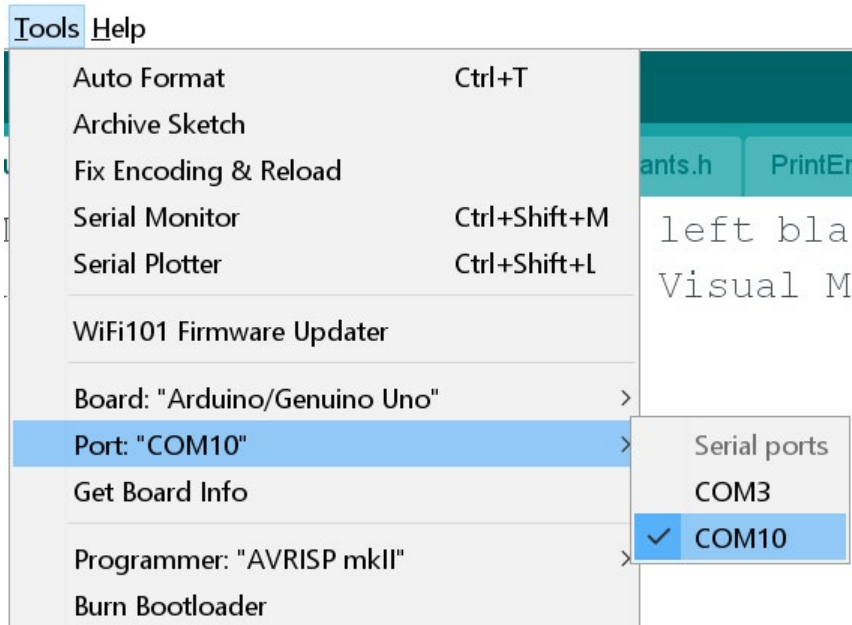
COMMAND	DESCRIPTION
CHx:VOL value	Set the output voltage to value in volts
CHx:CUR value	Set the output current to value in amps. (If value is preceded by + or – it will force source or sink only operation.)
CHx:MEA:VOL	Returns the measured output voltage in volts.
CHx:MEA:CUR	Returns the measured output current in amps.
*RST	Reset to power-up state
*IDN or *IDN?	Return ID string that includes revision, channels that are present, serial number of each channel, etc.
LCD:ENA	Enable the LCD/TFT display (default)
LCD:DIS	Disable the LCD/TFT display. This is sometimes useful to reduce noise at the output caused by SPI communication with the screen.
CHx:DIS	Disable the output. This configures the output to a relatively high impedance state.
CHx:ENA	Enable the channel. (Default state)
CHx:CAL:SET	Calibration routine. (Factory use only. Disabled by default.)
CHx:CAL:RES	Restore factory calibration. (Only useful if the user has overwritten the calibration, which is not possible without editing the firmware.)



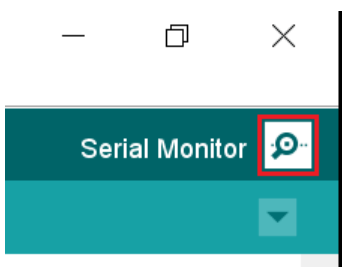
## USB OPERATION

Any terminal software may be used to communicate with the EasySMU. The following example uses the Arduino IDE's serial monitor. Start by configuring the terminal for

the appropriate serial port from the Tools→Port menu. In the example below, COM10 is selected.

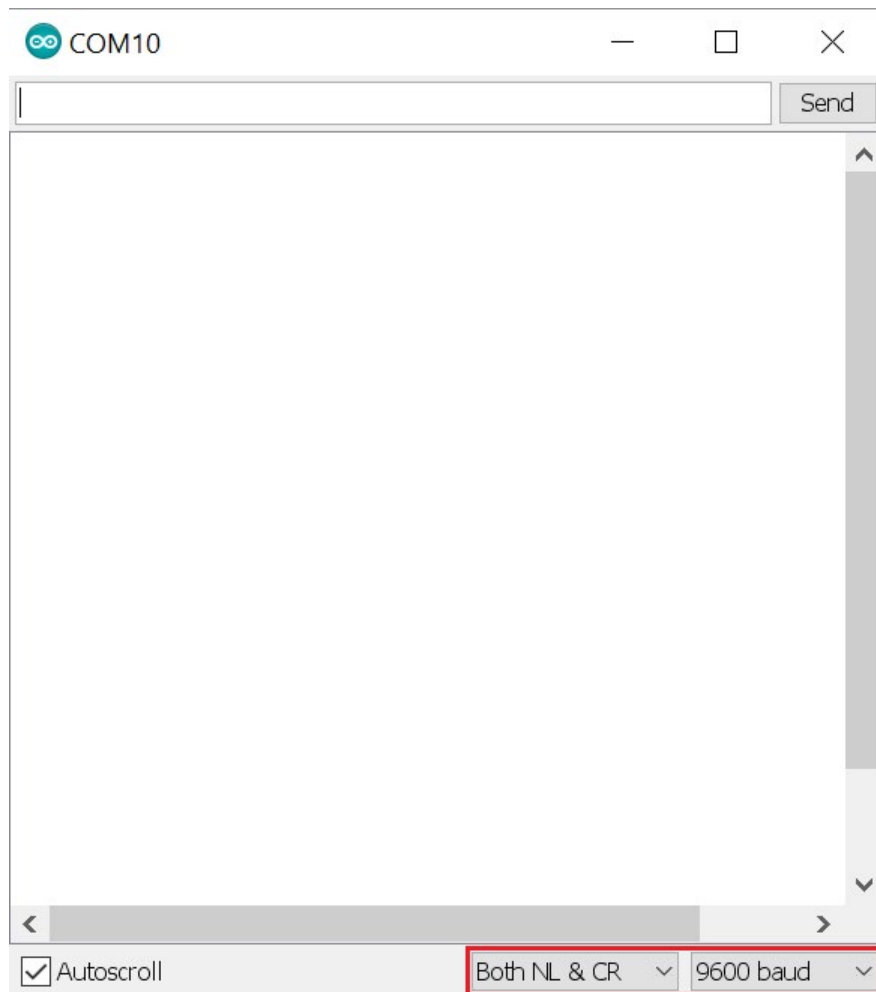


Open the serial monitor by clicking on the magnifying glass icon in the upper right corner of the Arduino IDE.



## USB OPERATION

Then, when the serial monitor window opens, be sure the drop-down menus in the bottom right corner are configured to a baud rate of 9600 and the line terminator is set to Both NL & CR.



## USB OPERATION

Now, if you would like to set CH0's output to 1.00V, type:

CH0:VOL 1

and press Send.



The terminal responds with the voltage value that has been set, and the voltage on the output changes. In this case, CH0's output will be configured to 1.0000V.

The actual voltage measured at the output can be read with the CH0:MEA:VOL command.



On this EasySMU, the response is 0.9977. The voltage measurement is more accurate than the setting value, so it can be concluded that the output voltage is 0.9977V.

The current limit can be configured in a similar manner by sending:

CH0:CUR 0.005

This example sets the output current limit to 5mA. With this configuration, the EasySMU sources or sinks a maximum of 5mA. (If the load on the EasySMU output sinks or sources less than 5mA, the output will be driven to the configured output voltage.) Note that the minimum current limit is 1mA. Current limit values below 1mA will exhibit a significant error. In fact, when the current limit is configured to a value less than 0.6mA, the EasySMU will instead current limit to a value between 0.4mA and 0.6mA.

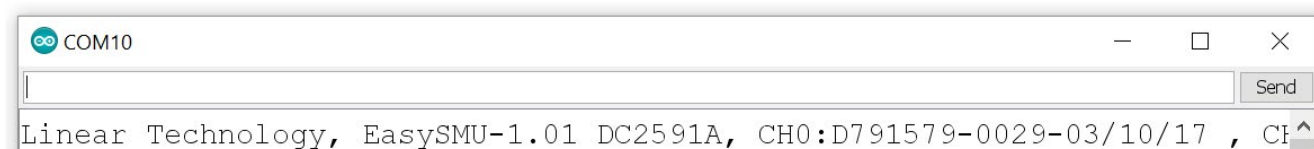
The actual current at the output of CH0 may be read using the following command:

CH0:MEA:CUR

## USB OPERATION

The measurement value is accurate to the microamp level, and the minimum current limit value of 1mA does not influence the measurement accuracy.

The \*IDN? Command is useful for determining information about the EasySMUs that are connected, including the serial number of each channel which matches a sticker affixed to the bottom of the EasySMU.



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## LTC4316 I<sup>2</sup>C ADDRESS TRANSLATOR

The EasySMU demonstrates how the LTC4316 I<sup>2</sup>C address translator solves addressing problems in complex I<sup>2</sup>C systems. Each EasySMU channel (shield) contains four I<sup>2</sup>C components: two LTC2485 analog-to-digital converters, an LTC2655 quad digital-to-analog converter, and a 24LC025 I<sup>2</sup>C serial EEPROM memory. Communicating with eight EasySMU channels using one I<sup>2</sup>C bus would be impossible without the LTC4316 address translator (or an I<sup>2</sup>C addressable multiplexer). Consider that an eight channel EasySMU configuration has 16 LTC2485's. Without the LTC4316, each LTC2485 can be configured to one of only six I<sup>2</sup>C addresses, far fewer than the 16 addresses required.

In this demonstration, all EasySMUs are identical except for the setting of a user configurable DIP switch. Each EasySMU contains an LTC4316 address translator, and

based on the DIP switch setting, the I<sup>2</sup>C addresses are translated to new addresses in real-time before they are received by the EasySMU's I<sup>2</sup>C components. As a result, the I<sup>2</sup>C master (in this case a Linduino) communicates with every I<sup>2</sup>C component in the system using a unique I<sup>2</sup>C address.

Although this demonstration relies on the user to configure a unique DIP switch setting for each EasySMU, a typical system does not require any user intervention. In systems with backplane connectors, one or two pins of each connector are dedicated to resistive dividers that reside on the backplane and configure the XORL and XORH pins of the LTC4316. As a result, each card inserted in the backplane responds to unique I<sup>2</sup>C addresses based on the slot location (and a resistive divider).

## VOLTAGE SOURCE

At its core, the EasySMU is built around the LT1970A power op amp with adjustable precision current limit. When it is not current limiting, the LT1970A behaves as a power op amp with its output voltage configured by feedback resistors and an input source. In the EasySMU, the input source is provided by an LTC2655B-H16 quad I<sup>2</sup>C 16-bit digital-to-analog converter which has a full-scale output voltage of 4.096V. The DAC output drives the noninverting input of the LT1970A directly. An LT5400-3 matched 10k/100k resistor network provides the feedback to the inverting terminal of the LT1970A with one end of the divider tied to the LT1970A's output and the other end tied to the 2.048V output reference voltage of the

LTC2655B-H16, buffered by an LTC2051 op amp. The resulting circuit drives 2.048V at the output when the DAC output is 2.048V, or mid-scale. As the DAC output increases or decreases, the output moves with a gain of 10, as configured by the LT5400-3's 100k/10k resistive divider.

Since the LT1970A power dissipation varies based on loading and output settings, most discrete resistors would exhibit mismatch as the PCB temperature gradients change. The LT5400-3 matched resistor network eliminates this mismatch.

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## CURRENT LIMIT

The LT1970A's stand out feature is the simple manner in which its current limit can be adjusted on the fly. The voltages at the LT1970A VCSRC and VCSNK pins configure the output source and sink current limits respectively, in conjunction with an external current sense resistor. The LT1970A divides the voltage at the VCSRC and VCSNK pins by 10 to configure the maximum voltage across the sense resistor before current limit is invoked.

Two channels of the quad LTC2655B-H16 digital-to-analog converter configure the EasySMU source and sink

current. Because the LTC2655B-H16 has a full-scale voltage of 4.096V, the maximum configurable voltage across the current sense resistor is 4.096V/10 or 409.6mV. The EasySMU's current sense resistor value of 10 $\Omega$  results in a full-scale current limit of roughly 40mA. The LT1970A's minimum configurable voltage across the sense resistor is guaranteed to be at least 10mV, setting the lower end of the current limit range. As a result, a 1mA current limit is guaranteed, but the EasySMU allows the current limit setting to be configured as low as 0.6mA.



## VOLTAGE MEASUREMENT

The EasySMU provides an accurate measurement of the output voltage using an LTC2485  $I^2C$   $\Delta\Sigma$  analog-to-digital converter. In this circuit, the LTC2485's  $REF^-$  pin is tied to GND, and the  $REF^+$  pin is set at 3.3V by an LTC6655-3.3 low noise, low drift precision reference. A 10k/100k resistive divider in the LT5400-3 quad matched resistor network is connected between the output of the LT1970A and the 3.3V reference, with the middle of the divider tied to the  $IN^+$  pin of the LTC2485. The  $IN^-$  pin of the LTC2485 is connected to the 3.3V reference. The result is that the LTC2485's differential voltage measurement between  $IN^+$  and  $IN^-$  pins remains inside of the GND and

$V_{CC} = 5V$  power supply range, while measuring voltages that range between 12V and  $-12V$ . To understand the operation intuitively, consider when the output voltage is 3.3V. The  $IN^+$  and  $IN^-$  pins are equal to 3.3V, and the LTC2485 measures 0V differential voltage. When the output moves away from 3.3V, the differential measurement reflects the output voltage divided by  $10k/(100k+10k) = 1/11$ . To reduce errors caused by the input sampling current of the LTC2485 interacting with the high impedance of the resistive divider, an LTC2051 op amp in a unity gain configuration buffers the  $IN^+$  input of the LTC2485.

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## CURRENT MEASUREMENT

The output current measurement is implemented with an LT1991 precision gain selectable amplifier and another LTC2485 analog-to-digital converter. The LT1991 is configured so that its accurate internal matched resistors produce a gain of 3V/V from the differential voltage across the  $10\Omega$  current sense resistor to the output voltage of the amplifier. Because the LT1991's  $REF$  pin is tied to the 3.3V reference, the output voltage of the LT1991 is at 3.3V when there is no current through the current sense

resistor. When voltage is present across the current sense resistor, the LT1991's output moves above or below 3.3V with a gain of 3V/V. The output of the LT1991 is connected to  $IN^+$  of the LTC2485 analog-to-digital converter while  $IN^-$  pin is connected to the 3.3V reference. As a result, the differential voltage sensed across the  $IN^+$  and  $IN^-$  pins of the LTC2485 is zero when the voltage across the sense resistor is zero.

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## POWER SUPPLIES

An LTC3265 creates 15V and  $-15V$  supplies from the single 12V AC adapter input. The LTC3265 creates the positive and negative supplies using capacitive charge pumps, which it then post regulates using positive and negative low dropout regulators. The post regulation removes the

ripple voltage present on the charge pump outputs, and as a result the output supplies are very low noise.

The 5V supplies used throughout the EasySMU are generated by an LT3010 low dropout linear regulator whose input supply is generated directly from the 12V input.

## CALIBRATION

A 24LC025 I<sup>2</sup>C serial EEPROM on each EasySMU board stores calibration information.

As you might have noticed in the above description of the current measurement, the feedback resistors and the voltage sensing resistive divider create a small current in the 10 $\Omega$  current sense resistor even when no current is delivered to the output. This current is measured during

the factory calibration routine and is compensated for in the EasySMU firmware as a function of the output voltage.

In addition, the voltage sense and current sense LSB weight and offset are measured during this calibration, and are used by the EasySMU firmware on the Linduino.

The EEPROM is also programmed with a unique serial number returned by the \*IDN? serial command.

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## TROUBLESHOOTING

*The EasySMU resets every 15 seconds when the USB cable is connected.*

If you have Keysight IO Libraries Suite version 16.4 or later, it autoscans all available ports every 15 seconds, resetting the connected equipment. As of the time of this was written, there is not an option to disable this feature. It also causes the similar problems with other commercial lab equipment. If it is necessary to install the Keysight IO Libraries Suite, downgrade to version 16.3 which is available from the following link:

<http://www.keysight.com/main/software.jsp?cc=US&lc=eng&nid=-33330.977662&id=2175637&pageMode=Pv>

*EasySMU does not respond to serial commands.*

Begin by confirming that you are communicating with the correct COM port. Connect the Linduino beneath the EasySMU shield to the PC using a USB cable. Open the Arduino IDE, and look at the list of COM ports under the Tools→Ports menu. Unplug the USB cable, and again

select Tools→Ports. The port that is now missing from the list is the COM port assigned to the EasySMU on your PC. Plug the USB cable in once more, and select the COM port in the Tools→Ports menu. Then, open the serial terminal by selecting Tools→Serial Monitor. Type \*IDN? into the terminal and you should see a response string similar to the following.

LinearTechnology, EasySMU-1.01 DC2591A, CH0:D727578-0002, CH1:D727578-0007, CH2:SD727578-0004, CH3:D727578-0020

(There are four EasySMU channels in this example, configured as CH0-CH3 with the DIP switches.)

If you do not receive this response, you have probably forgotten to upload the EasySMU firmware into the Linduino. From the Arduino IDE select File→Sketchbook→Example Designs→EasySMU\_Run. Then, select Sketch→Upload to upload the firmware. You only need to do this the first time you use the EasySMU.

# DEMO MANUAL DC2591A

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