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Preliminary Technical Data

Current Sensing Board with ADSP-CM419F

FEATURES

Isolated current sensing
4 channels measure 1 phase of voltage and 3 phases of current
Measure up to ±30 A
Measure up to ±500 V
Voltage error: 0.15% maximum
Current error: 0.2% maximum

EQUIPMENT NEEDED

AD7401A, isolated Σ-Δ modulator
AD7403, 16-bit isolated Σ-Δ modulator
ADP7104, 20 V, 500 mA, low noise, CMOS low dropout (LDO) linear regulator
ADuM6202 isolated, 5 kV, dc-to-dc converter
ADSP-CM419F, dual-core 240 MHz ARM® Cortex®-M4 and Cortex-M0 with >13 effective number of bits (ENOB) analog-to-digital converter (ADC), 210-ball CSP_BGA

DOCUMENTS NEEDED

AD7401A data sheet
AD7403 data sheet
ADP7104 data sheet
ADuM6202 data sheet
ADSP-CM419F data sheet

GENERAL DESCRIPTION

This user guide describes the use of the current sensing board in conjunction with the EVAL-ADSP-CM419F-EZKIT.

This user guide explains how to build and run the current sensing board when attached to the EVAL-ADSP-CM419F-EZKIT. The current sensing board measures one phase of voltage and three phases of current. This user guide describes the typical performance of a current measurement module designed by Analog Devices, Inc., using the AD7403 and the ADuM6202 devices. This user guide assumes prior knowledge of the Analog Devices series of mixed-signal control processors (see www.analog.com/CM4xx).

For more information on the latest Analog Devices processors, silicon errata, code examples, development tools, system services and devices drivers, technical support, and any other additional information, visit www.analog.com/processors.

For full details on the ADSP-CM419F, see the ADSP-CM419F data sheet, which should be consulted in conjunction with this user guide when using the current sensing board.

EVALUATION BOARD CONNECTION DIAGRAM

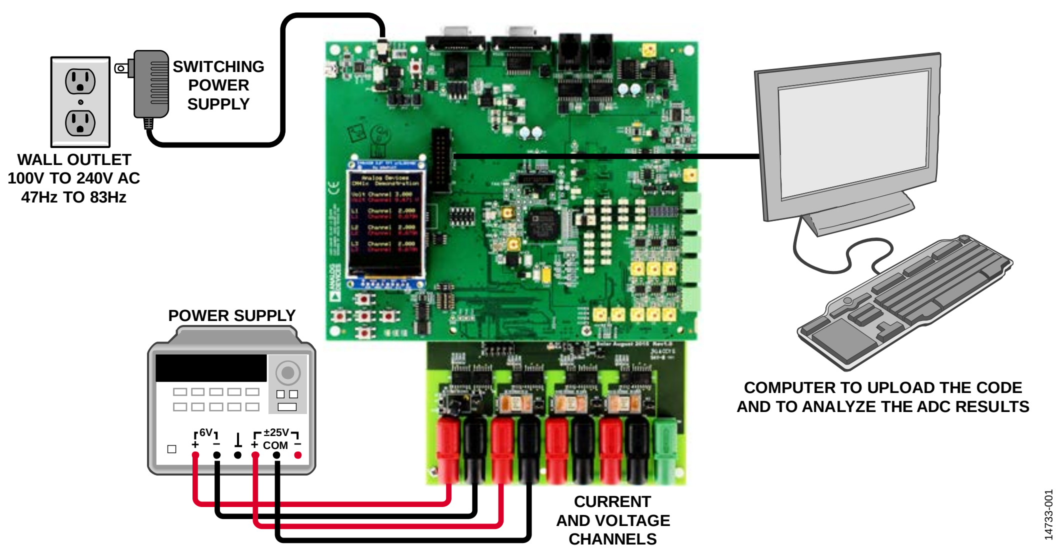

Figure 1.

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CURRENT SENSING BOARD

CURRENT SENSING BOARD FUNCTION AND BENEFITS

The purpose of this current sensing board is to measure one phase of voltage and three phases of current. The circuit of a completely isolated current sensor is shown in Figure 2. This circuit is highly robust and can be mounted close to the sense resistor for accurate measurements and minimum noise pickup. The output is a single bit stream from a Σ-Δ modulator that is processed by a digital signal processor (DSP) using a $sinc^3$ digital filter.

Current can be measured in several ways. Table 1 shows various methods to measure current and their performance in certain areas. Each method of measurement has its benefits and drawbacks. This application uses a shunt or sense resistor to measure current.

CIRCUIT DESCRIPTION

A 1 mΩ shunt resistor, R_{SENSE}, measures up to ±30 A. The ±30 A current through the 1 mΩ resistor creates a voltage of up to ±30 mV. This voltage is then input to the AD7403. A jumper is connected on the current measurement circuit to connect to the negative rail. A guard ring is used around the inputs of the current measurement circuit to prevent any leakage from entering this sensitive, low voltage area.

The current sensing board is connected to the EVAL-ADSP-CM419F-EZKIT board. The 5 V power supply is taken from Pin J4-172 and Pin J4-174 of the EVAL-ADSP-CM419F-EZKIT board. Visit www.analog.com/CM419F-EZ for the full schematics.

This supply feeds through the ADuM6202 isolators to provide power for the isolated side to the ADC.

The 5 V supply is also fed into a regulator, which converts the 5 V supply into 3.3 V. The regulated 3.3 V output of the ADP7104 serves as the input supply to the Σ-Δ modulators. An orange LED indicates that power is being supplied from the EVAL-ADSP-CM419F-EZKIT board to the current sensing board.

The Σ-Δ modulator requires a clock input from an external source such as a DSP. The clock frequency can range from 5 MHz to 20 MHz. The highly robust single bit stream output of the modulator can be processed directly by a $sinc^3$ filter, where the data can be converted to an ADC word. The clock can be aligned with the pulse-width modulation (PWM) signal.

A transient voltage suppressor (TVS) clamps any voltage transients that may damage the circuit. The TVS was designed to protect the ADC. Because coupling can be a problem with the 8-lead package of the ADP7104, 0.22 µF and 22 µF capacitors were placed in parallel with each other between the input to V_{DD2} and ground (see Figure 2). An antialiasing filter was also added to each of the inputs (positive and negative).

Table 1. Comparison of Current Measurement Methods

Measurement Method	Accuracy	Isolation	EMI (Tamper Resistance)	Robust	Size	Cost
Resistive (Direct)						
Sense Resistor	High	No	High	High	Small	Low
Transistor (Direct)	Low	No	Moderate	Moderate	Small	Low
Ratiometric	Moderate	No	Moderate	Moderate	Small	Moderate
Magnetic (Indirect)						
Current Transformer	High	Yes	Moderate	High	Large	Moderate
Rogowski coil	High	Yes	Moderate	High	Large	Moderate
Hall Effect	High	Yes	High	Moderate	Moderate	High

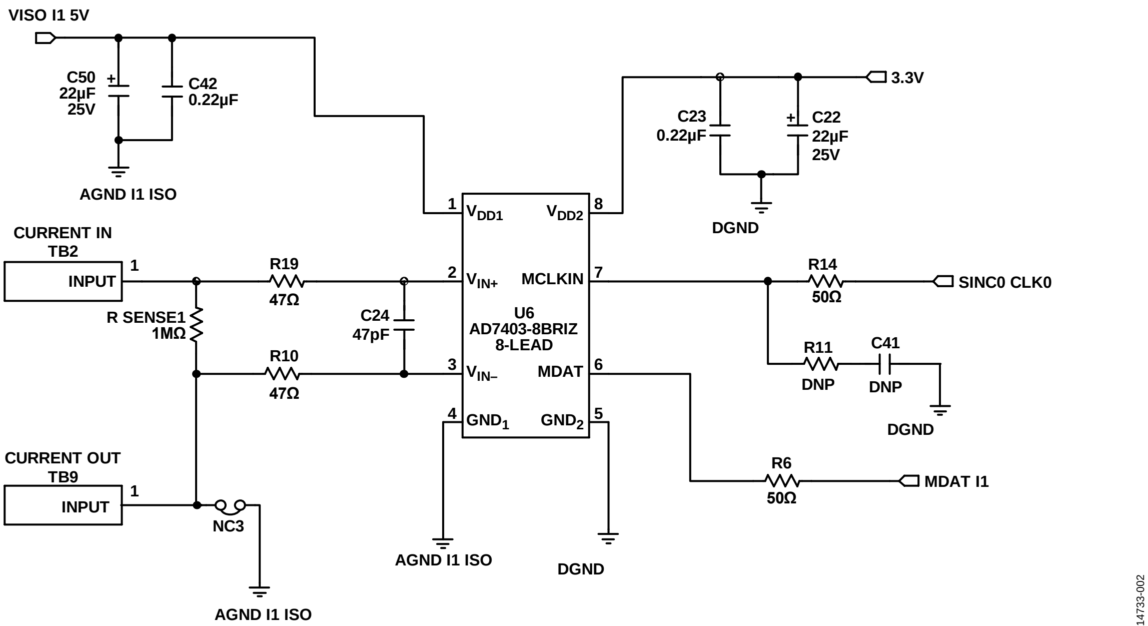

Figure 2. Circuit Diagram of AD7403 on the Current Sensing Board

OVERVIEW

The AD7401A is a second-order, Σ-Δ modulator that converts an analog input signal into a high speed, 1-bit data stream with on-chip digital isolation based on Analog Devices, iCoupler® technology. The AD7401A and the AD7403 operate from a 5 V power supply and accept a differential input signal of ±30 mV (±250 mV maximum). The analog modulator, eliminating the need for external sample-and-hold circuitry, continuously samples the analog input. The input information is contained in the output stream as a density of ones with a data rate of up to 20 MHz. The original information is reconstructed with an appropriate digital filter. The processor side (nonisolated) can use a 5 V or a 3 V supply (V_{DD2}). Current measurement in solar applications requires isolated measurement techniques. The AD7403 is one of many Analog Devices products that offer such isolation applications in ac measurements. This type of isolation is based on *i*Coupler technology.

SINC FILTER

A Σ-Δ front-end modulator outputs a bit stream. This stream is fed into a sinc filter where it is output as a digital word. The digital word represents the signal level presented to the modulator. The sinc filter is composed of integration and decimation stages. It can help capture feedback signals coming from an ADC. The modulator is connected to two sinc filters: a primary filter for controlling feedback and a secondary filter to detect overcurrent. This sinc also has two modulator clock generators and four filter channels.

Figure 3 displays a block diagram of the sinc filters. The block diagram shows four sinc filter pairs (Sinc Pair 0 to Sinc Pair 3), two modulator clock sources, and two banks of control registers (units). The module accepts four Σ-Δ bit streams from the PA_xx to PF_xx general-purpose input/output (GPIO) pins (configured as input pins) and directs the modulator clock source of Group 0 to the PA_xx to PF_xx pin configured as an output. A PWM signal synchronizes the modulator clocks to optimize system performance. Each sinc filter pair includes the primary filter, secondary filter, direct memory access (DMA) interface, and overload limit detection functions.

The primary and secondary filters have programmable order and decimation rates. The PORD and SORD bits in the SINC_LEVEL0 sinc registers determine the order of the primary and secondary filters, respectively. Set these bits to 0 for a third-order filter or 1 for a fourth-order filter. The PDEC and SDEC bits in the SINC0_RATE0 sinc registers determine the decimation rate of the primary and secondary filters, respectively. The valid rate of the primary filters is 4 to 256. If the secondary filters are third-order filters, the valid rate is 4 to 40. If they are fourth-order filters, the valid rate is 4 to 16.

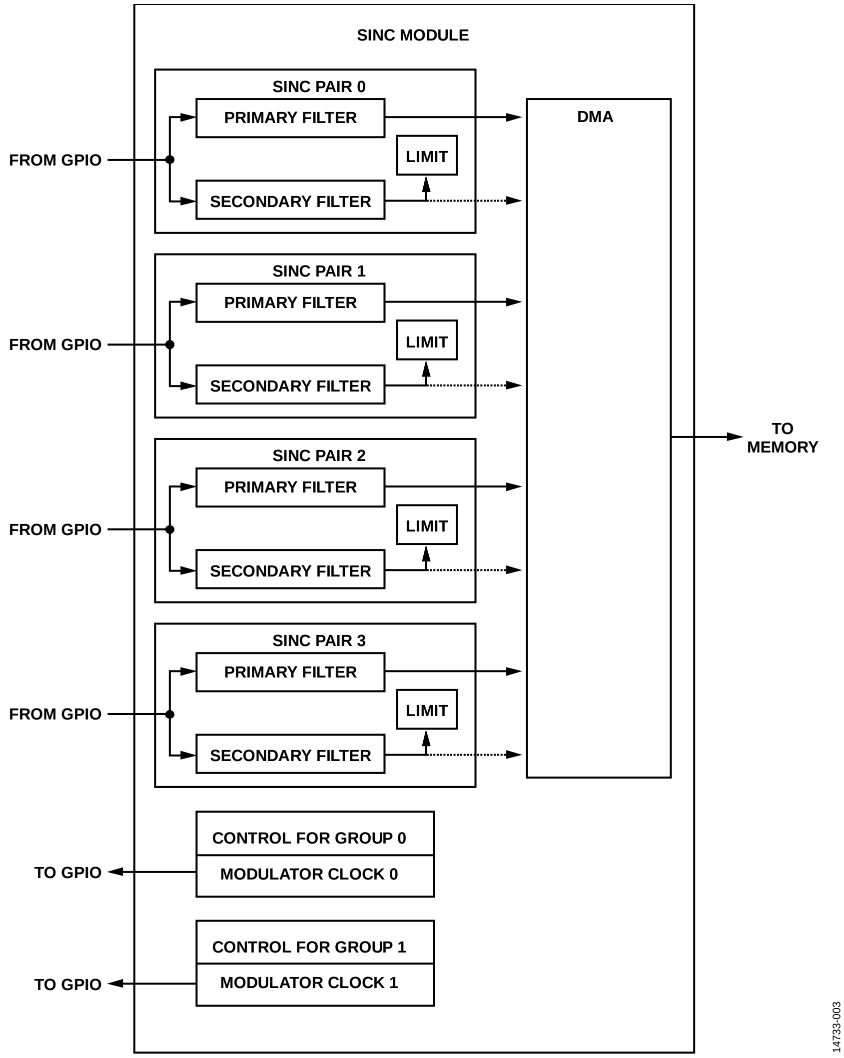

Figure 3. Sinc Module

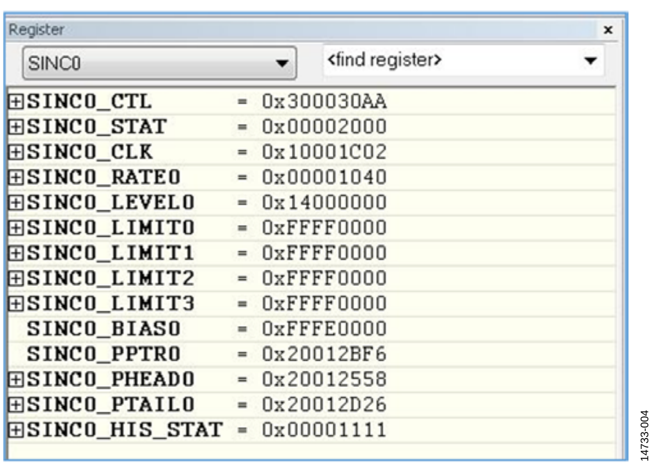

Figure 4. Sinc Register Values

OVERLOAD DETECTION

The function of the secondary sinc filter is to detect ac current overload conditions. An overload condition is detected when the secondary filter output exceeds a programmable overload limit threshold for a minimum number of counts (LCNT) within the detection window (LWIN).

The overload thresholds are defined in four 32-bit registers SINC0_LIMIT0 to SINC0_LIMIT3, according to the channel number. Each register contains two 16-bit LMAX and LMIN overload threshold values. These programmable threshold values can be changed by editing the variables defined in Figure 5. For example, **MaxL1Limit** defines the maximum threshold limit, or LMAX, of the secondary sinc filter for the L1/R current channel, the first current input channel on the current sensing board. The threshold limit is initially defined to 4.3 A rms. **MinL1Limit** defines the minimum threshold limit, or LMIN, of the L1/R current channel. The threshold limit is initially disabled. The overload threshold values are also influenced by LCNT and LWIN.

```
#define MaxVoltLimit 0x01050000
#define MaxL1Limit   0x01050000
#define MaxL2Limit   0x01050000
#define MaxL3Limit   0x01050000

#define MinVoltLimit     0x0000
#define MinL1Limit       0x0000
#define MinL2Limit       0x0000
#define MinL3Limit       0x0000
```

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Figure 5. Defining Threshold Limits

The LCNT bits in the SINC0_LEVEL0 register specify the number of output excursions beyond the threshold limit for the Group 0 secondary filters. The number of excursions greater than specified by the SINC0_LIMIT3, SINC0_LIMIT2, SINC0_LIMIT1, and SINC0_LIMIT0 registers is perceived as an overload and sets a corresponding MAXx or MINx bit (MAXx or MINx = 1) in the SINC0_STAT register. The valid count is between 1 and 8. If the count is greater than the LWIN bits in the SINC0_LEVEL0 register, the bit behaves the same as when it is equal to LWIN. The valid count must be one less than a desired count. The LWIN bits specify the window size for excursion checking for the Group 0 secondary filters. The window size is the number of the most recent outputs to be included in a measurement specified by the LCNT bits the SINC0_LEVEL0 register. The valid value must be one less than a desired count (1 to 8), meaning the valid value is 0 to 7.

Various status bit registers indicate in which channel the secondary filter detected an overload condition. The GLIM0 status bit in the SINC0_STAT register indicates the control group of the secondary filter that detected the overload. The MAX0 to MAX3 status bits in the SINC0_STAT register indicate when a maximum limit on one of the secondary filter channels has been passed. The MIN0 through MIN3 status bits in the SINC0_STAT register indicate when a minimum limit on one of the secondary filter channels is passed.

When the sinc filter module detects an overload condition, GLIM0 in the SINC0_STAT register is set to 1 and triggers an interrupt. The interrupt service routine (ISR) resets the SINC0_STAT register, displays **OVERLOAD DETECTED** on the liquid crystyal display (LCD) and sets Pin JP4 on the evaluation board to high.

Figure 6 shows a screenshot of an oscilloscope. The green signal is the analog ac input signal with a frequency of 60 Hz. This signal is fed into the L1/R channel. The yellow signal is the output of JP4 and goes high or low according to the overload detection. The maximum threshold value of the secondary sinc filter for this channel was set to 6.3 A.

To verify the detection delay, Cursor A is placed at the point where the input signal first reached the threshold limit, and the Cursor B is placed at the point where JP4 first went high due to an overload detection. Therefore, the overload detection time can be calculated by measuring the difference between Cursor A and Cursor B. The time between Cursor A and Cursor B is 830 μs. However, this delay can increase to over 1 ms.

Idealy, the overload detection is instantaneously triggered when an overload current is detected. However, it appears to have a random delay before being triggered by the overload current. The width of the trigger pulse is also random and not symmetrical.

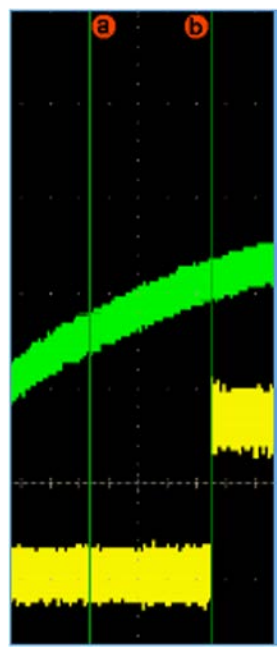

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Figure 6. Overload Detection Example

EVALUATION BOARD HARDWARE

HARDWARE SETUP

To set up the hardware, follow these steps:

1. Attach the LCD to Connector J20 on the EVAL-ADSP-CM419F-EZKIT.
2. Attach the current sensing board to Connector J4 on the EVAL-ADSP-CM419F-EZKIT.
3. Power up EVAL-ADSP-CM419F-EZKIT by connecting a 5 V power supply to Connector P19.
4. When the current sensing board is powered on, there must be no input to the four channels on the current sensing board to ensure an accurate offset value for each channel is calculated.

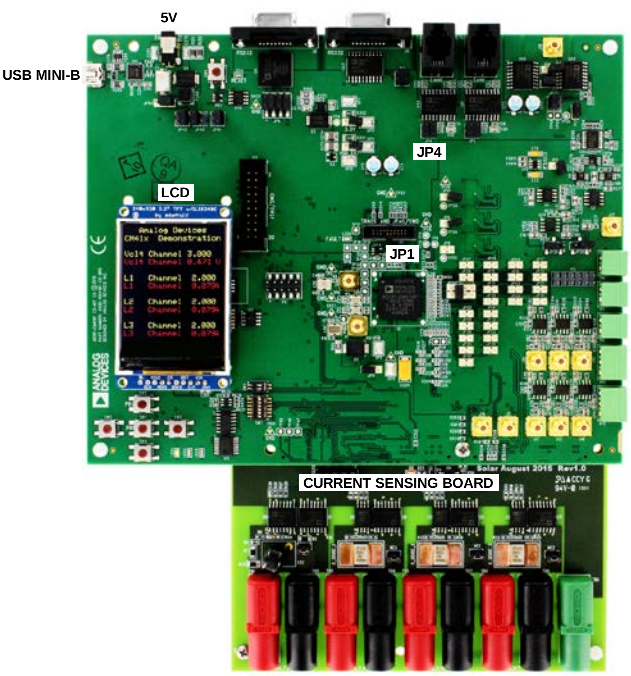

Figure 7. EVAL-ADSP-CM419F-EZKIT, Current Sensing Board and LCD

INSTRUCTIONS FOR PROGRAMMING THE FLASH MEMORY IN THE APPLICATION

To program the flash memory in the application, follow these steps:

1. Connect the EVAL-ADSP-CM419F-EZKIT to a PC using a USB Mini B cable through Connector P3.
2. Install Jumper JP1 to enable UART boot mode and power up the EVAL-ADSP-CM419F-EZKIT.
3. When the EVAL-ADSP-CM419F-EZKIT is connected to PC for the first time, the operational system automatically downloads and installs the necessary drivers for the on-board USB to UART interface.
4. Open the flash programmer application, ccsfp.exe, located at \tools\ccsfp in the installation directory.
5. In the **CrossCore Serial Flash Programmer** window, configure the following parameters (see Figure 8):
   a. Select **ADSP-CM41x** from the **Target** dropdown menu.
   b. Select the COMx port (COM7 shown as an example in Figure 8) that has been assigned to the EVAL-ADSP-CM419F-EZKIT from the **Serial Port** dropdown menu.
   c. Select **115200** from the **Baudrate** dropdown menu.
6. If flashing the board for first time, select **Erase and initialize** from the **Action** dropdown menu and click **Start**. Power cycle the board after initialization is complete.
7. Click **Browse** and select CurrentSensing.hex located in the \iar\pv_inverter_ezcm419f_m4\Debug\Exe directory, or any other .HEX file to be flashed.
8. Select **Program** from the **Action** dropdown menu and click **Start** button to start programming the flash memory. If the application reports any error, ensure that EVAL-ADSP-CM419F-EZKIT is powered and the correct COMx port is selected in the application, and verify that Jumper JP1 is installed on EVAL-ADSP-CM419F-EZKIT.
9. After programming is complete, remove Jumper JP1 and reset the board by pressing Switch SW6 to boot the application from flash memory.

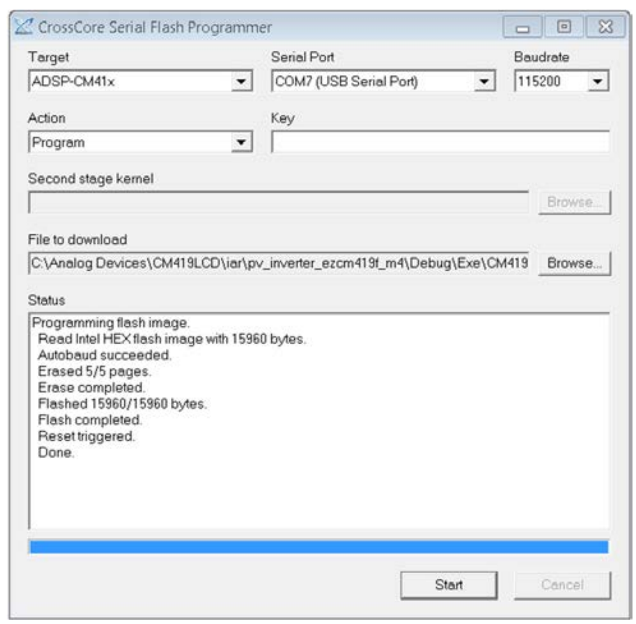

*Figure 8. **CrossCore Serial Flash Programmer** Application to Program the Flash Memory*

INSTRUCTIONS FOR BUILDING THE APPLICATION

The complete project for rebuilding the application is included in the software package that contains this project. This application was built and tested with the IAR Version 7.2 tool chain on a Windows® 7-based host machine.

Follow these instructions to open and build the projects:

1. Open the IAR™ integrated development environment (IDE).
2. Click **File** > **Open** > **Workspace**.
3. Browse and select the /iar/CurrentSensing.eww workspace.
4. Build the project by clicking **Project** > **Make** to update the output .HEX file.
5. Flash the new .HEX file by following the steps in the Instructions for Programming the Flash Memory in the Application section.

The firmware can also be downloaded and debugged onto the board. Attach a J-Link® debug probe to Pin P2 on the current sensing board. Click the **Download and Debug** icon in the IAR IDE to begin downloading and debugging.

LCD INFORMATION

In Figure 9, the LCD displays the analog value in red and the corresponding sampled value in yellow. The channels labeled L1, L2, and L3 represent each current channel on the current sensing board. When an overload is detected by the secondary sinc filters, **OVERLAOD DETECTED** is displayed on the bottom of the LCD. When SW4 is pressed, the LCD freezes, allowing the LCD to be easily read. The LCD displays the highest value of any input ac signal.

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Figure 9. LCD

EVALUATION BOARD SOFTWARE

The software comprises the following functions:

- Configure_pinmux(), Config_Sinc(void)
- Get_ADC_Data_PWM(void)
- Set_Offset(void)
- SetUpDisplay()
- Display()

CONFIGURE_PINMUX(), CONFIG_SINC(VOID)

These two functions set the values of the multiplexer registers and the sinc registers to establish a connection from the ADSP-CM419F to the current sensing board and the LCD. Figure 10 displays these functions. The SINC0_PHEAD0 sinc register is set to the first element of the SINC_circBuffer array, and the SINC0_PTAIL0 sinc register is set to the last element of the SINC_circBuffer array. These settings of the SINC0_PHEAD0 and PTAIL0 registers allow the SINC_circBuffer array to be composed of one period of an input ac signal at 50 Hz to 60 Hz.

```
void Config_Sinc(void) // Config SINC registers
{
  pBuffer = (uint32_t) &SINC_circBuffer[0];

  *pREG_SINC0_PHEAD0 = pBuffer;     // Primary Filters Head for Group 0 :
  *pREG_SINC0_CLK = 0x10001C02;     // Clock Control Register
  *pREG_SINC0_RATE0 = 0x00001040;   // Rate Control for Group 0 Register.
  *pREG_SINC0_LEVEL0 = 0x14002C00;  // Level Control for Group 0 Registe:

  *pREG_SINC0_LIMIT0 = MaxVoltLimit + MinVoltLimit; // Amplitude Limits
  *pREG_SINC0_LIMIT1 = MaxL1Limit   + MinL1Limit; // Amplitude Limits fe
  *pREG_SINC0_LIMIT2 = MaxL2Limit   + MinL2Limit; // Amplitude Limits fe
  *pREG_SINC0_LIMIT3 = MaxL3Limit   + MinL3Limit; // Amplitude Limits fe

  *pREG_SINC0_BIAS0 = 0xFFFE0000;   // Bias for Group 0 Register
  *pREG_SINC0_PTAIL0 = (uint32_t) &SINC_circBuffer[CIRC_BUFF_SIZE - 1];
  *pREG_SINC0_CTL = 0x3000B0AA;     // Control Register

  *pREG_PORTA_FER = 0x00000F00;
  *pREG_PORTA_DIR = 0x000000C0; // Sets Direction to Output
}

void Configure_pinmux() // Config pinmux
{
  *pREG_PORTB_MUX = 0;
  *pREG_PORTB_FER_SET = 0x8004;

  *pREG_PORTC_MUX = 0;
  *pREG_PORTC_FER_SET = 0xFE60;

  *pREG_PORTF_MUX = 0;
  *pREG_PORTF_FER_SET = 0x013F;
}
```

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Figure 10. Configure_pinmux(), Config_Sinc(void)

GET_ADC_DATA_PWM(VOID)

This function obtains the sampled data from each channel of the current sensing board and stores each value in four arrays, one for each channel. Each array stores 1000 samples. At an input frequency of 50 Hz to 60 Hz, one period of an input ac signal is sampled 1000 times. When one period of the wave is sampled, the array of one channel is full.

SET_OFFSET(VOID)

Set_Offset() calculates the input offset for each channel. Before this function is executed, Get_ADC_Data_PWM() is called 50 times to obtain 50 samples. There must be no input at this point to ensure the offset is calculated correctly. Set_Offset() is then called and calculates the average of the last 20 samples of each channel. This average is set equal to the offset of the channel and is subtracted from any further input value to improve accuracy.

SETUPDISPLAY()

The SetUpDisplay() function initializes the LCD.

DISPLAY()

```
for (int h = 0; h <= PWM_Sinc_loop; h++) // S
{
  if (Sinc_Voltage_Data[h] > CheckVPeak)
    CheckVPeak = Sinc_Voltage_Data[h]; // Set

  if (Sinc_L1R_Data[h] > CheckL1Peak)
    CheckL1Peak = Sinc_L1R_Data[h]; // Sets C

  if (Sinc_L2S_Data[h] > CheckL2Peak)
    CheckL2Peak = Sinc_L2S_Data[h]; // Sets C

  if (Sinc_L3T_Data[h] > CheckL3Peak)
    CheckL3Peak = Sinc_L3T_Data[h]; // Sets C
}
  CheckVPeak = CheckVPeak - OffsetVolt;
  CheckL1Peak = CheckL1Peak - OffsetL1;
  CheckL2Peak = CheckL2Peak - OffsetL2;
  CheckL3Peak = CheckL3Peak - OffsetL3;
```

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Figure 11. Sample Code

The Display() function calculates the analog value of the input signal and displays it on the LCD. This sample code, shown in Figure 11, located in the Display() function, finds the positive peak value of an ac signal inputted into each channel and displays it on the LCD.

When the arrays of each channel become full, a for loop searches these arrays for the highest value. This value is then subtracted by the previously calculated offset value. The analog value is then calculated for each channel. These values then display on the LCD.

MEASUREMENTS

Figure 12 and Figure 13 display the accuracy of the voltage and L1/R current channels. For the voltage channel, this accuracy was measured over an input range of 0 V ac to 424.4 V ac. For the L1/R channel, the input range was 0 A ac to 17 A ac.

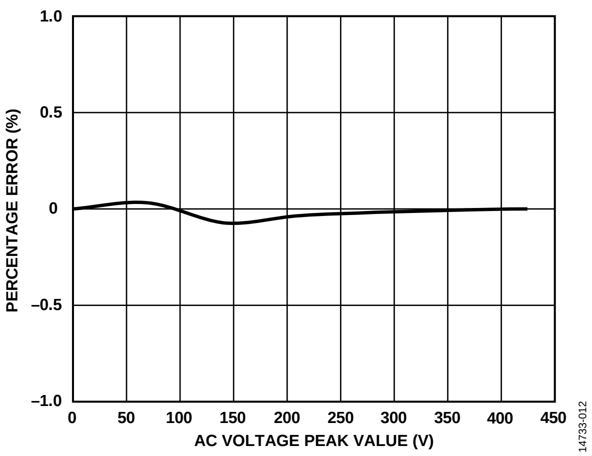

Figure 12. Voltage Channel

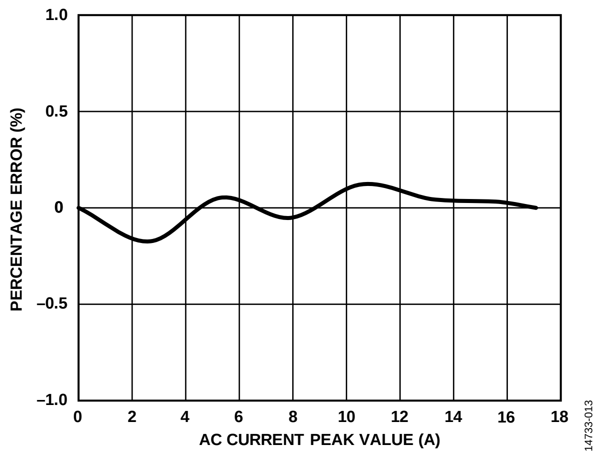

Figure 13. L1/R Current Channel

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