Application Note

Using Z8 Encore! XP® Microcontroller for Current Measurement

AN019303-0508

Z8 Encore! XP® Flash Microcontrollers

Abstract

This application note describes the process of measuring current using the transimpedance amplifier of ZiLOG's Z8 Encore! XP® microcontroller.

The source code associated with this application note is available on www.zilog.com.

Z8 Encore! XP® 4K Series Flash Microcontrollers

ZiLOG's Z8 Encore! products are based on ZiLOG's eZ8 CPU and introduce Flash memory to ZiLOG's extensive line of 8-bit microcontrollers. Flash memory in-circuit programming capability allows faster development time and program changes in the field. The high-performance register-to-register based architecture of the eZ8 core maintains backward compatibility with ZiLOG's popular Z8® MCU. Z8 Encore! MCUs combine a 20 MHz core with Flash memory, linear-register SRAM, and an extensive array of on-chip peripherals.

Z8 Encore! 4K Series of devices support up to 4 KB of Flash program memory and 1 KB register RAM. An on-chip temperature sensor allows temperature measurement over a range of –40 ºC to +105 ºC. These devices include two enhanced 16-bit timer blocks featuring PWM and Capture and Compare capabilities. An on-chip Internal Precision Oscillator (5 MHz/32 kHz) can be used as a trimmable clock source requiring no external components. The Z8 Encore! XP® devices include 128 bytes of Non-Volatile Data Storage (NVDS) memory where individual bytes can be written or read. A full-duplex UART provides serial communications and IrDA encoding and decoding capability, and also supports multidrop address processing in hardware.

The rich set of on-chip peripherals make the Z8 Encore! XP MCUs suitable for a variety of applications including motor control, security systems, home appliances, personal electronic devices, and sensors.

Discussion

In most electronic applications circuit responses and signals are measured in terms of voltage (V_{OUT} versus V_{IN}). However, a large number of sensors produce current variations that must be evaluated or processed. Unlike voltage measurement, current measurement is not an easy task. Therefore, current-to-voltage conversion becomes necessary for measuring small signal current.

According to Ohm's law, current is directly proportional to voltage, and therefore, the variation of current reflects as voltage variation.

A low-noise amplifier (LNA) amplifies small voltage variations and converts current to voltage with better accuracy. LNAs must be highly sensitive to detect small variations in current. A transimpedance amplifier accomplishes both the tasks of amplifying small voltage variations and converting current to voltage. The output of a transimpedance amplifier is a voltage that is directly proportional to the input current.

Theory of Operation

This section describes the basic working principle of a transimpedence amplifier.

A transimpedance amplifier is a high accuracy, high gain, and a buffer amplifier that converts small currents to large voltages for further processing.

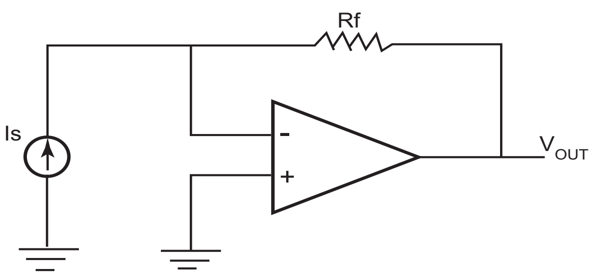


Figure 1. Transimpedance Amplifier

Figure 1 displays a transimpedance amplifier. The operation of a transimpedance amplifier depends on the following:

- I_S, the source current flowing through the feedback resistor, R_f (no current flows into the op-amp itself)
- C_S, the capacitance of the source (in the application described in this document, the source is a photodiode)

The output voltage (V_{OUT}) of a transimpedance amplifier is V_{Rf} (the voltage across R_f), and is calculated using the following equation:

$$V_{OUT} = V_{Rf} = - I_S \times R_f$$

The above equation is applicable for amplifiers which have dual-ended biasing. From this equation, it is evident that the accuracy of R_f is crucial for accurate current measurement. The design of transimpedance amplifier using single-ended power supply is a little different. The primary issue with this is to provide a properly biased current source at the input of transimpedance amplifier.

In the configuration displayed in Figure 2, the variation of current from the current source changes the output to positive voltage.

$$V_{OUT} = I_S \times R_f$$

Z8 Encore! XP® MCU contains an embedded transimpedance amplifier, which can be used for current measurement. When the transimpedance amplifier is used for current measurement, the offset value of the operational amplifier must be taken into consideration, and external circuitry must be added to prevent the input pin of the operational amplifier from being overdriven. The output of the amplifier is connected to ADC.

Developing the Application Using the Z8 Encore! XP® MCU

This section describes the hardware architecture and software implementation for the current measurement application, which uses the transimpedance amplifier of Z8 Encore! MCU.

Hardware Architecture

Figure 2 illustrates a basic block diagram of the setup used to measure current using the transimpedance amplifier of Z8 Encore! XP MCU. Two main built-in peripherals of Z8 Encore! XP MCU: the transimpedance amplifier and the ADC, which function together to constitute a simple circuit for measuring current.

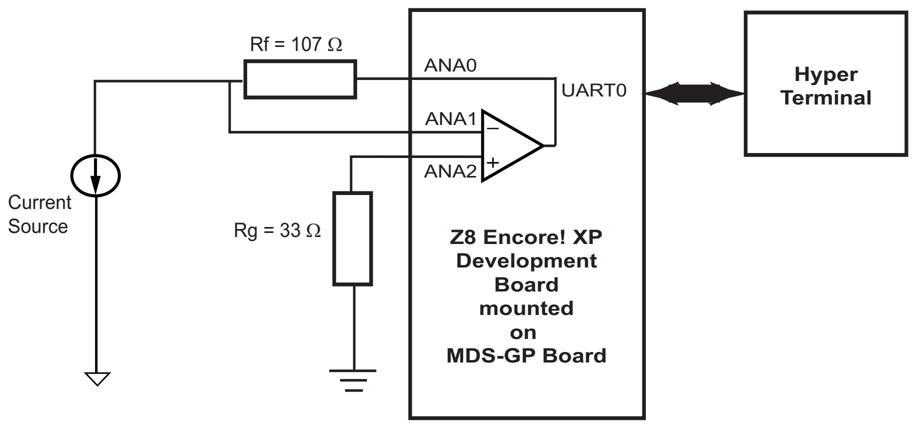


Figure 2. Block Diagram for Measuring Current

Figure 2 displays the feedback resistor, R_f, a critical component of the external circuitry added to the transimpedance amplifier of Z8 Encore! XP® MCU to facilitate the measurement of current. The application described in this document uses the internal oscillator of Z8 Encore! XP MCU as the system clock.

The pin ANA1 of the ADC peripheral is connected to the non-inverting input node and pin ANA0 is connected to the output node of the transimpedance amplifier (see Figure 2). The voltage drop across the feedback resistor R_f, is obtained by subtracting the measured voltage at the output node of the transimpedance amplifier from that at the input node. This voltage drop across R_f is used to calculate the current across the transimpedance amplifier.

The biasing voltage of low-power amplifier is +3.3 V. The output of the amplifier cannot be negative. This output generally ranges from 0 to +1023 at 10 bit ADC after conversion, but offset errors can cause small negative values. The output voltage equation for Z8 Encore! XP transimpedance amplifier is given below:

$$V_{OUT} = V_{Rf} = I_S \times R_f$$

The selection of feedback resistance (R_f) and maximum current flow through this resistance can be calculated using the equation below:

$$R_f = V_{OUT}/Current$$

where

- R_f is the feedback resistance
- V_{OUT} is the transimpedance amplifier output voltage (equal to reference voltage)
- `Current` is the current flow through feedback resistance.

Selecting the Feedback Resistor

Assuming that the maximum source current is 20.5 mA and the reference voltage is 2.2 V.

$$R_f = V_{OUT}/I_S$$

$$= 2.2\ V/20.5\ mA$$

$$= 107\ \Omega$$

Hence the required feedback resistance (R_f) is 107 Ω.

> **Note:** *Determining the feedback resistor required for your application is an important task. If the value of feedback resistance is high then the transimpedance output is also too high for the provided reference voltage. Therefore, it is important to choose a resistor that is appropriate for the range of current measured.*

Software Implementation

In the application described in this document, the process of measuring the voltage drop and calculating the current across the feedback resistor of the transimpedance amplifier is implemented using the software. The calculated current is displayed in milliamperes using the LCD on the MDS-GP Board, and the HyperTerminal application, both of which function as I/O devices that facilitate effective communication. You can choose any I/O device depending on their requirement. The source code available for this Application Note is implemented only for current measurement in the microamperes range.

The keypad matrix on the MDS-GP Board functions as an input interface to the user. Only three keys of the keypad matrix are used in this application. The following two modes of current measurement are implemented using the software:

1. **Auto Measurement Mode**—In this mode, current is measured continuously at specific intervals defined by the user. In this application, Timer0 is used to define the intervals at which current is measured. By default, the minimum time interval is 1 second. The minimum time interval can be changed by modifying the following definition listed in the `transimpedance_demo.h` header file.

   ```
   #define timeout 1
   ```

2. **Measure Current Mode**—In this mode, current is measured at an instance at which a key on the MDS-GP Board keypad matrix is held.

For a visual representation of the two current measurement modes, see screenshots provided in Demonstrating the Application on page 5.

To measure current accurately, it is necessary to measure the ADC offset value and add it to each ADC sample.

Current is measured accurately using the following equation:

$$ADC_{comp} = (ADC_{uncomp} - OFFCAL) + ((ADC_{uncomp} - OFFCAL)*GAINCAL)/2^{16}$$

where

- ADC_{uncomp} is the measured ADC value
- `GAINCAL` is a 12-bit gain calibration value. This is factory set value which comes embedded with MCU.
- `OFFCAL` is an 8-bit, sign-extended offset calibration value. This is factory set value which is embedded with MCU.

Calibration is carried out during testing of the Z8 Encore! XP® MCU. `GAINCAL` and `OFFCAL` are values contained in the information page, which is the last page of the Flash memory, and vary from one chip to another depending on the response obtained during calibration. In the current measurement application described in this document, the software program automatically reads the `GAINCAL` and `OFFCAL` values, and therefore you are not required to measure or calculate these values. For detailed information about the calibration process, and the information page of the Flash memory, refer to the *Z8 Encore! XP 8K and 4K Series Product Specification* (PS0228).

The following define statement allows the choice of either the internal reference voltage or the external reference voltage for the transimpedance amplifier.

```
#define INTERNAL_REFERENCE    1
```

A value other than 1 in the above statement indicates that the external reference voltage of the Z8 Encore! XP® MCU is enabled.

The external reference voltage value can be chosen using the following define statement.

```
#define EXTERNAL_REFERENCE    2000
```

The internal reference voltage value can be chosen using the following define statement.

```
#define REFERENCE_VOLTAGE     2
```

For example, values 1, 2, and 2.2, in the above statement selects 1 V, 2 V, and 2.2 V, respectively as internal reference voltages. The source code also accommodates the choice of an appropriate feedback resistor.

Demonstrating the Application

This section lists the equipment used and the procedure followed to demonstrate the current measurement application.

Setup

A basic setup to demonstrate the measurement of current using the Z8 Encore! XP® MCU, is illustrated in Figure 3. The setup comprises of the MDS-GP Board, a current source, a current measurement interface, and a HyperTerminal application. For details about the MDS-GP Board, refer to the *Modular Development System General Purpose Board User Manual* (UM0169).

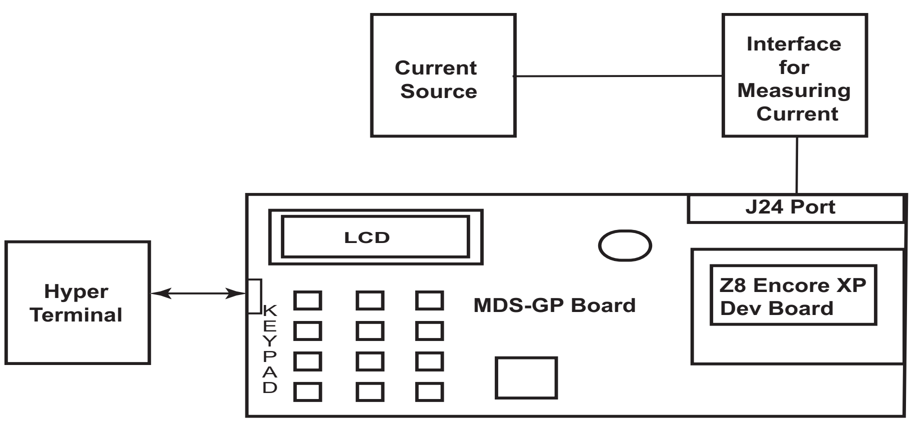


Figure 3. Setup for Current Measurement

Equipment Used

The test setup consists of the following:

- Modular Development System General Purpose Kit (ZGENPRP0100MDS)
- Z8 Encore! XP® 4K Series Development Kit (28-pin) with full ANSI C Compiler (Z8F04A28100KIT)
- Zilog Developer Studio II—Z8 Encore!® (ZDS ll-IDE)
- A PC equipped with the HyperTerminal application configured to the following settings:
  - 38000 bps baud rate
  - 8 data bits
  - No parity
  - One stop bit
  - No flow control

Procedure

To demonstrate the current measurement application, perform the following steps:

1. Install the Z8 Encore! XP Applications Library available under Application Sample Libraries on www.zilog.com.
2. Launch ZDS II for Z8 Encore!, and open the `.zdsproj` file located in the source folder.
3. Recompile and build the project. Download the `.lod` output file to the target board and execute the program.
4. Configure the HyperTerminal application according to the settings provided in the section Equipment Used on page 6.
5. Insert a jumper into J2 to enable RS232-1 port of MDS_GP development board.

Note: *The current measurement application uses the Reset pin of Z8 Encore! XP® MCU as a GPIO pin to drive the LCD on the MDS-GP Board.*

To reset the device, the power supply to the Z8 Encore! XP MCU Development Kit must be turned off.

Results

Table 1 lists the current readings measured using the Z8 Encore! XP MCU against those measured using a calibrated Fluke 8012A ammeter which has an accuracy of 0.3% (DC current readings). The current readings measured using Z8 Encore! XP MCU are nearly same as those measured using the Fluke 8012A Ammeter.

The percentage accuracy of the Z8 Encore! XP MCU is computed using the formula provided below. These percentage accuracy values are listed in Table 1.

```
Percent (%) Accuracy = (IXP –
ISTD)/ISTD * 100%
```

where,

- `IXP` is the current measured using the Z8 Encore! XP MCU, and
- `ISTD` is the current measured using the Fluke 8012A ammeter

Table 1. Ammeter Versus Z8 Encore! XP MCU Current Readings

Fluke 8012A Ammeter Current Readings in μA	Z8 Encore! XP® MCU Current Readings in μA	Z8 Encore! XP® MCU Accuracy (%)
20	20.5	2.50
43	42.8	-0.47
280	278.5	-0.54
543	560.7	3.26

Figure 4 displays the menu displayed in the HyperTerminal application either on power-up of the Z8 Encore! XP® MCU or on execution of the H command.

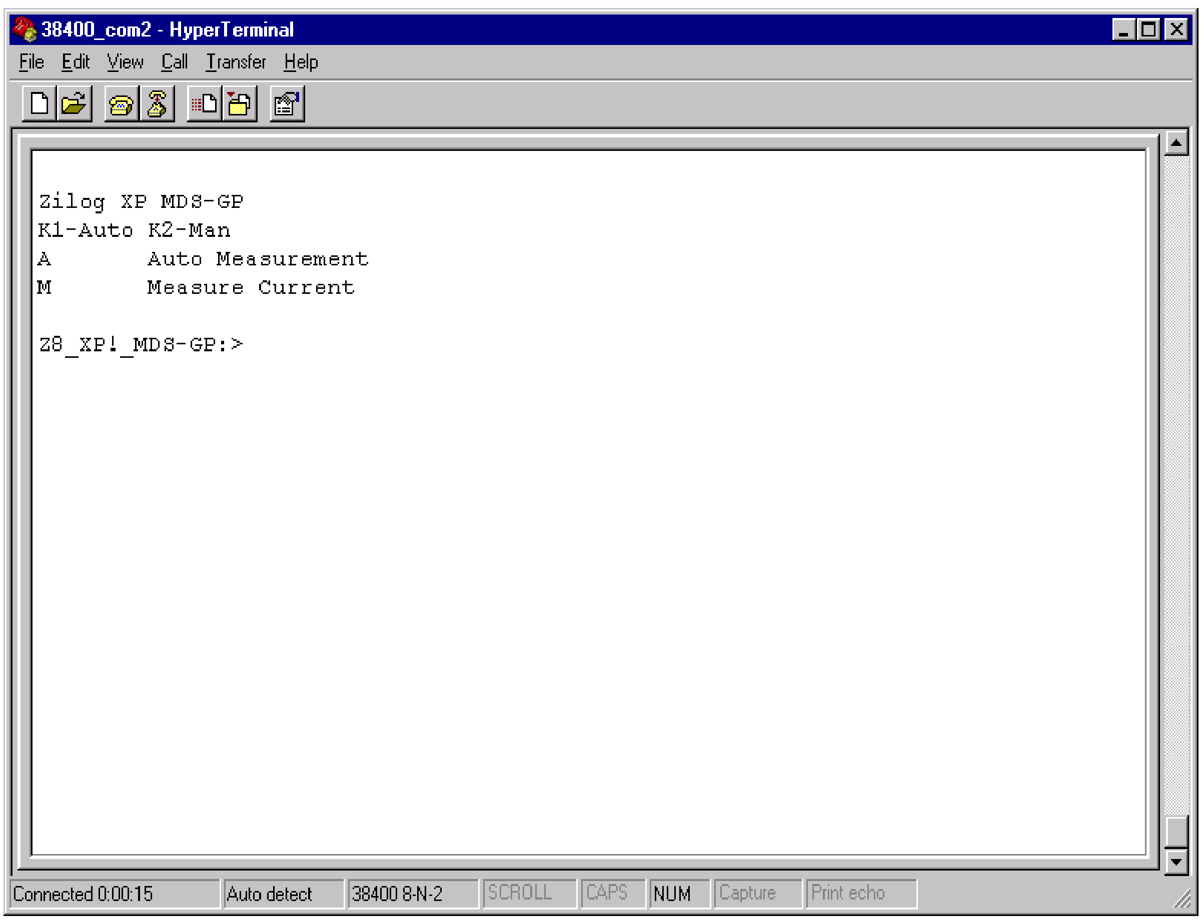


Figure 4. HyperTerminal View of Transimpedance Help Menu

Figure 5 and Figure 6 illustrate the Auto Measurement and Measure Current modes of Z8 Encore! XP® MCU, respectively.

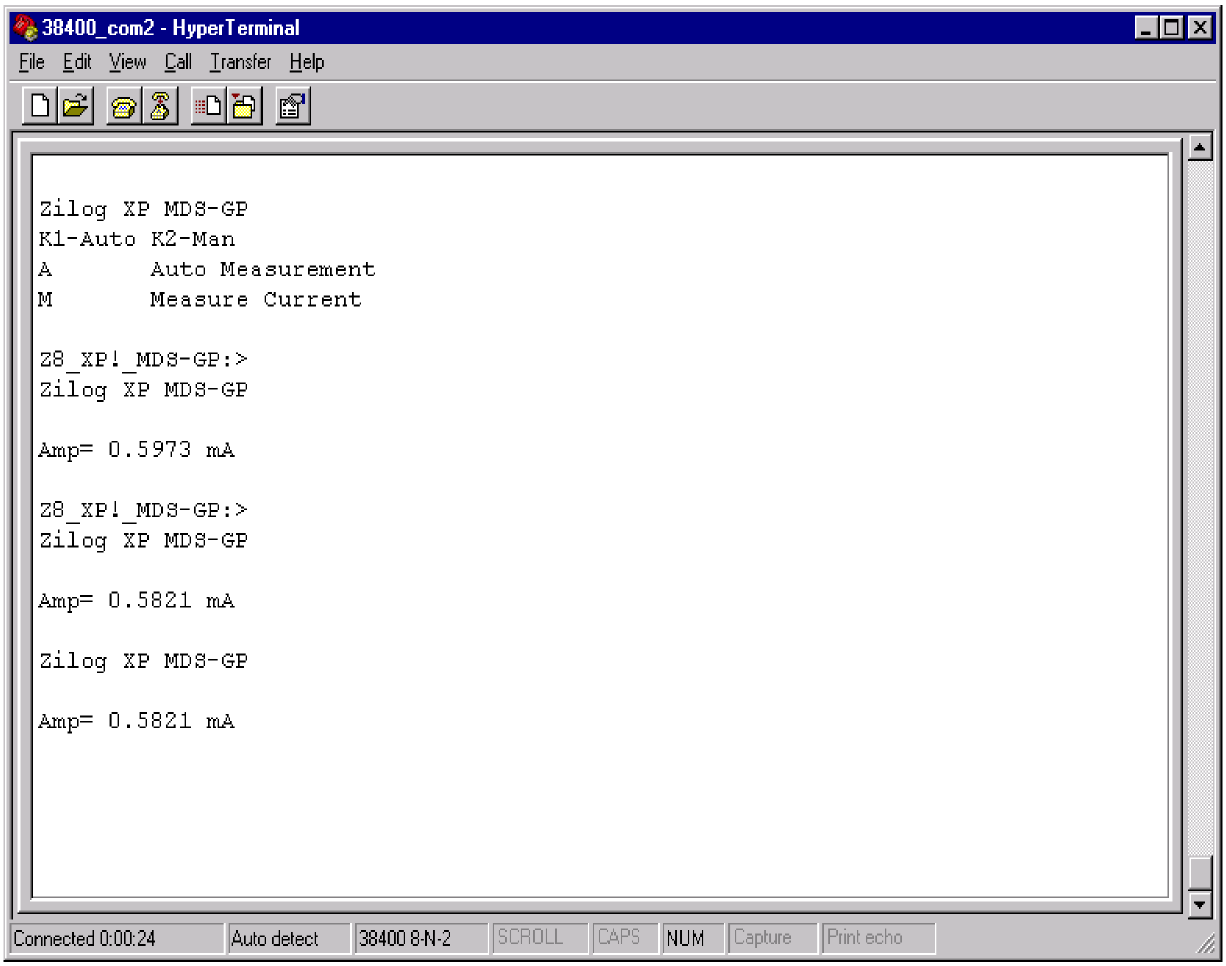


Figure 5. HyperTerminal View of Auto Measurement Mode

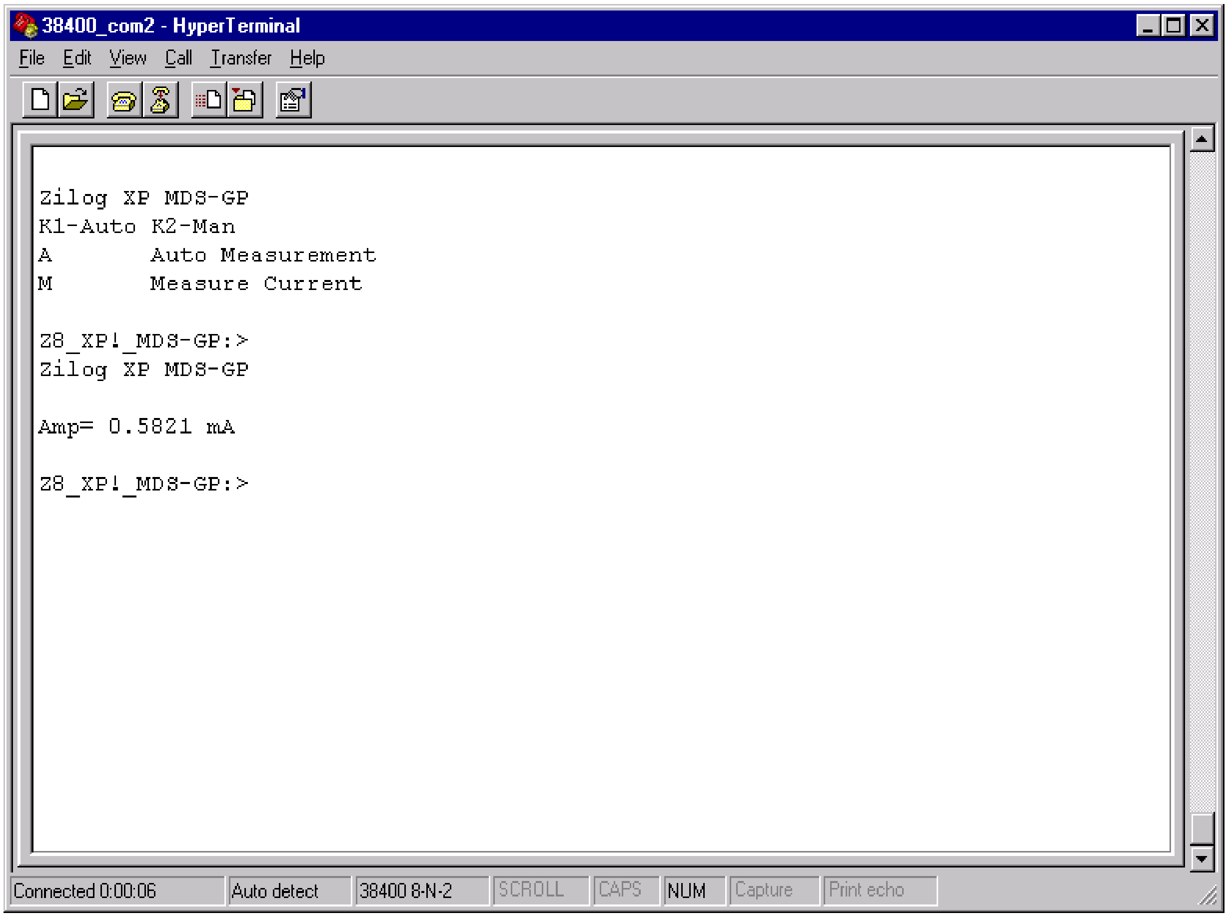


Figure 6. HyperTerminal View of Measure Current Mode

Summary

This application note described the process of measuring current using two peripherals of the Z8 Encore! XP® MCU. A combination of transimpedance amplifier and ADC resulted in a simple circuit that is used to measure current directly. To use transimpedance amplifier as a sensor interface, a capacitor must be added to the external circuitry in addition to the feedback resistor.

The application described in this document is demonstrated only for a single range of current. You can modify the application for multiple current ranges. The feedback resistor used must feature a low resistance deviation to withstand sudden temperature changes.

Appendix A—References

Further details about the Z8 Encore!® products can be found in the references listed in Table 1.

Table 1. List of References

Topic	Document Name
eZ8 CPU	eZ8 CPU User Manual (UM0128)
Z8 Encore! XP® 4K Series Microcontrollers	Z8 Encore! XP® 4K Series Product Specification (PS0228)
	Z8 Encore! XP® 4K Series Development Kit User Manual (UM0166)
MDS-GP Board	MDS General Purpose Board Product Brief (PB0146)
	MDS General Purpose Board Quick Start Guide (QS0045)
	Modular Development System General Purpose Board User Manual (UM0169)
ZDSII-IDE	Zilog Developer Studio II-Z8 Encore!® User Manual (UM0130)
Current-to-Voltage Amplifier	For general information about current-to-voltage amplifiers, visit www.ecircuitcenter.com.

Appendix B—Flowcharts

This appendix provides flowcharts for the current measurement application described in this document. Figure 7 illustrates the process of measuring current using the Transimpedance Amplifier of Z8 Encore! XP® MCU.

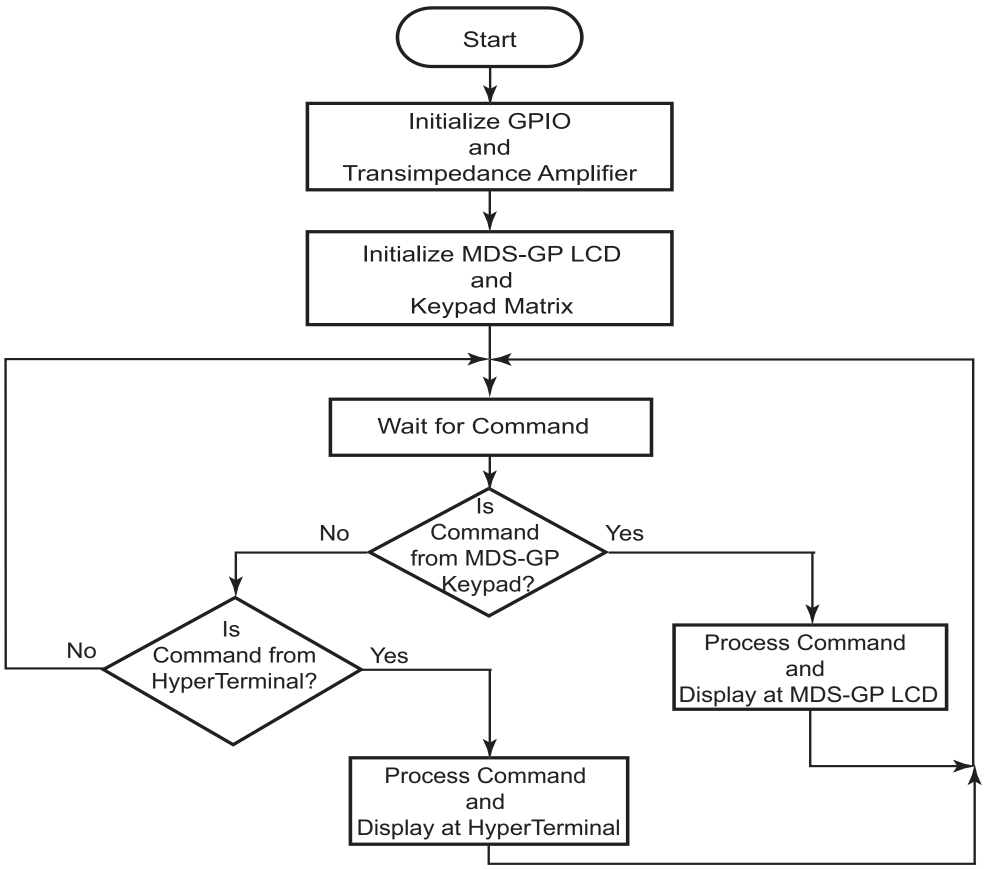


Figure 7. Main Program for Measuring Current

Figure 8 and Figure 9 illustrate the initialization of the GPIO, the Transimpedance Amplifier, the MDS-GP LCD, and the Keypad Matrix of the MDS-GP Board.

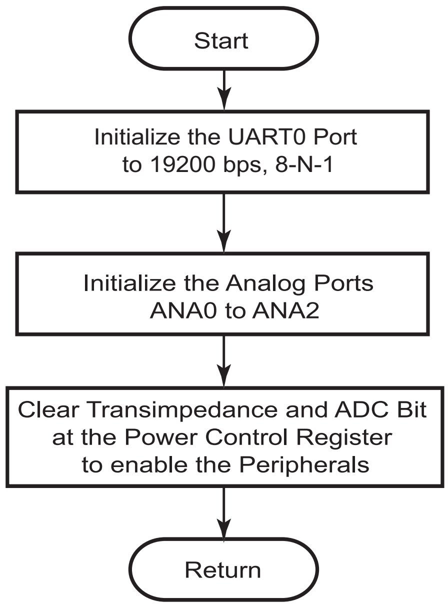


Figure 8. Routine to Initialize GPIO and Transimpedance Amplifier

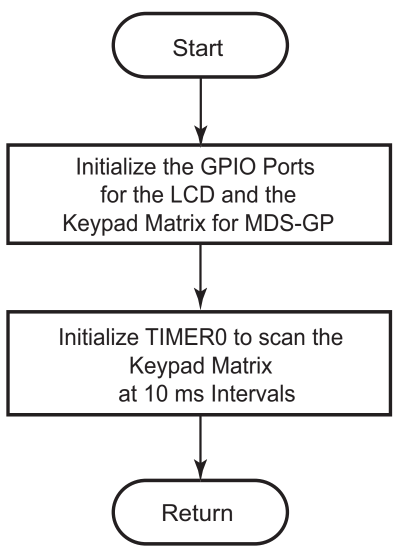


Figure 9. Routine to Initialize the MDS-GP LCD and Keypad Matrix

Figure 10 and Figure 11 illustrate the keyscan and process command routines, respectively

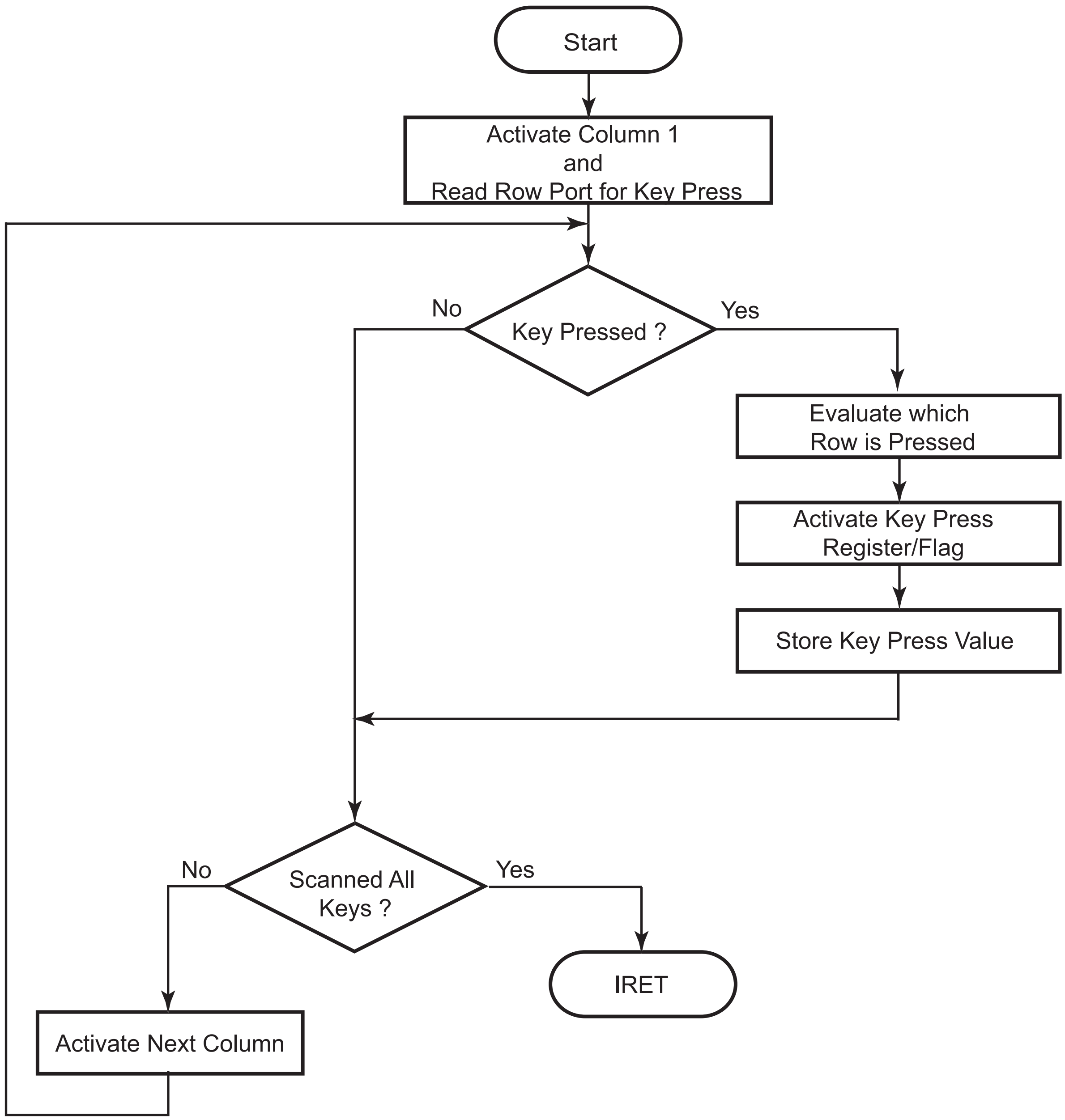
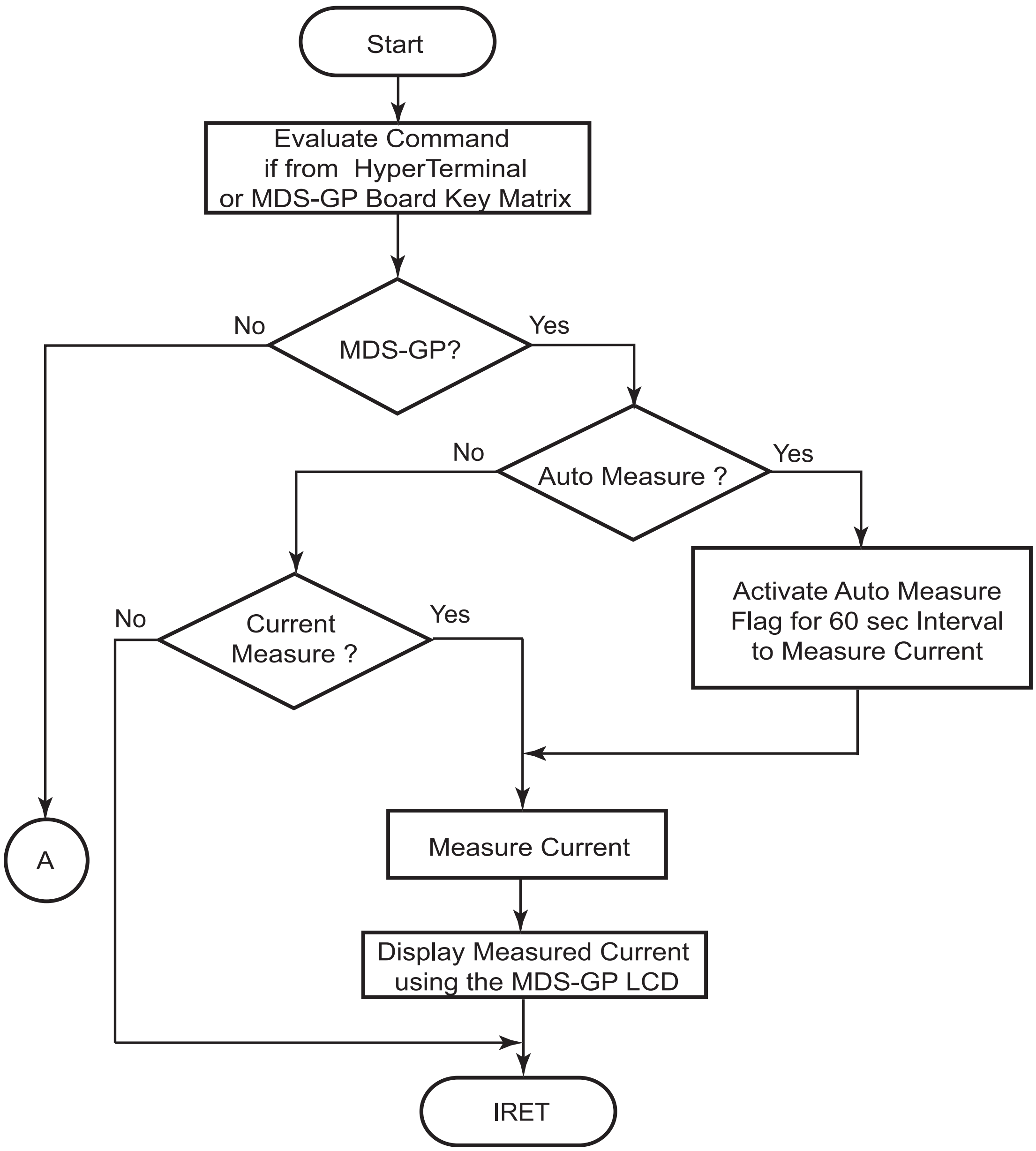


Figure 10. Keyscan Interrupt Routine


Start
Evaluate Command
if from HyperTerminal
or MDS-GP Board Key Matrix
MDS-GP?
No
Yes
Auto Measure ?
No
Yes
Activate Auto Measure
Flag for 60 sec Interval
to Measure Current
Current
Measure ?
No
Yes
A
Measure Current
Display Measured Current
using the MDS-GP LCD
IRET

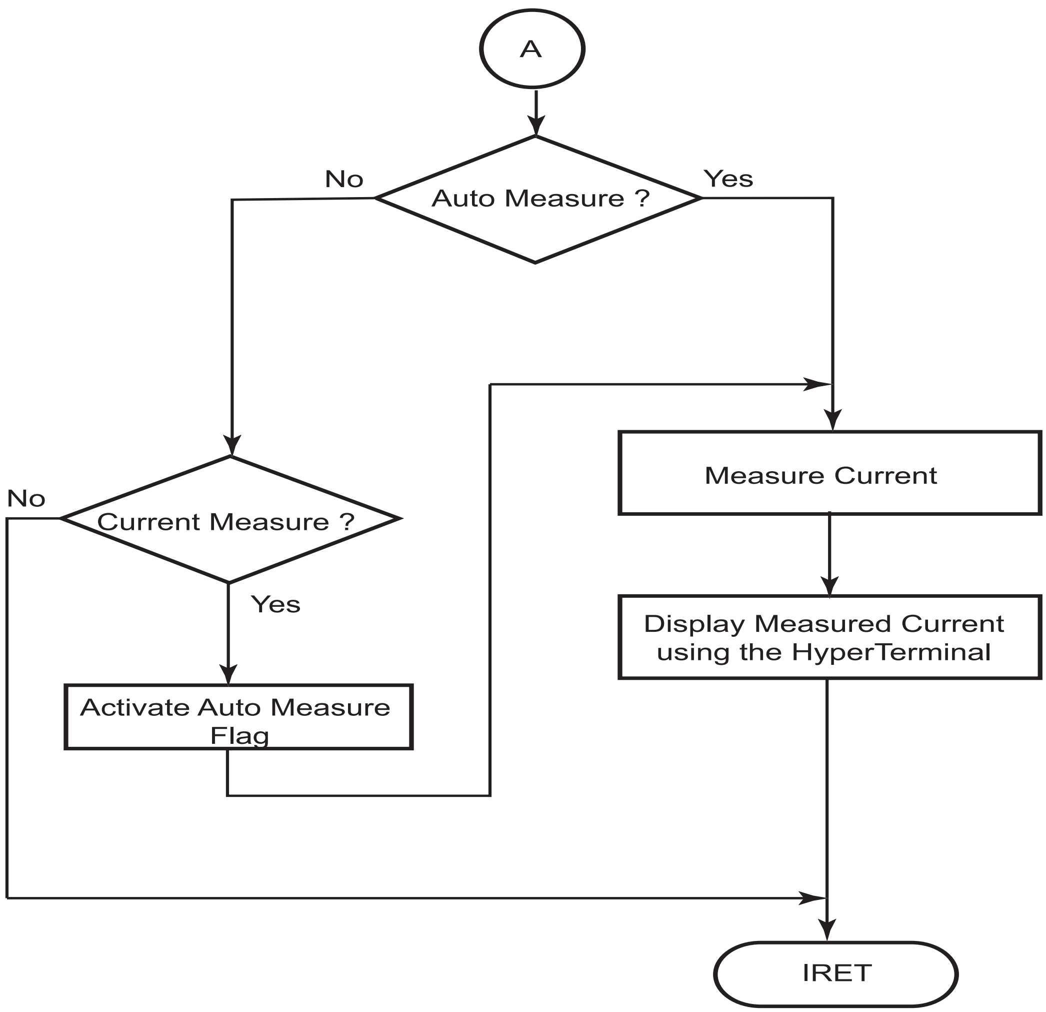


Figure 11. Process Command Routine

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