Application Report
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Data Flash Programming and Calibrating the bq20zxx Family of Gas Gauges

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ABSTRACT

This application report presents a strategy for high-speed, economical calibration and data flash programming of the bq20zxx advanced gas gauge chipset family. VB6 code examples are provided, along with step-by-step instructions for preparing a golden battery pack.

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1 Introduction

The latest TI family of advanced gas gauges is built with new technology and a new architecture for data flash access and calibration. With this new architecture, unit production cost and capital equipment investment can be minimized, as there is no longer a need to perform a learning cycle on each pack. A single “golden pack” can become the source of data for all other packs. A method is shown to quickly read and write the golden image. Also, the calibration method is quick and simple because most of the calibration routines are built into the firmware of the target device.

The methods in this document are presented as VB6 (Visual Basic 6) functions. These functions were copied directly from working code. In order to read from and write to the data flash, they use five types of SMBus read and write functions. These can be duplicated in any software environment that has SMBus communication capabilities. As used herein, each Read/Write function is designed for communication with a gas gauge, so the device address (0x16) is omitted for clarity.

1. *WriteSMBusInteger()* has two arguments—the SMBus command and a signed integer. Internally, this function separates the integer into two bytes for transmission by the SMBus write-word protocol.
2. *WriteSMBusByteArray()* has three arguments—the SMBus command, the array of bytes, and an integer specifying the length of the byte array. Internally, this function separates the byte array into separate bytes for transmission by the SMBus write-block protocol.
3. *WriteSMBusCommand()* has only one argument—the SMBus command.

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4. *ReadSMBusUnsignedInteger* has two arguments—the SMBus command and the returned integer.
5. *ReadSMBusByteArray()* has three arguments—the SMBus command, the returned array of bytes, and the returned length of the byte array. It is internally implemented with the SMBus read-block protocol.

Also used in these functions is a simple delay routine called DoDelay. VB6 code for this procedure is provided at the end of the document.

Error handling is not implemented in this sample code, because requirements are unique and varied. Also, constants are hard-coded into the functions to improve clarity rather than documenting them in code elsewhere as would normally be good coding practice.

A good strategy for production is a seven-step process flow:

1. Write the data flash image to each device. This image was read from a *golden* pack.
2. Calibrate the device.
3. Update any individual flash locations, such as serial number, lot code, and date.
4. Perform any desired protection tests.
5. Connect the cells.
6. Initiate the Impedance Track™ algorithm.
7. Seal the pack.

In this document, the first three steps are examined in detail.

2 Preparing the Golden Pack

Impedance Track technology allows the bq20zxx gas gauge to automatically acquire and maintain parameters for battery modeling needed for continuous accuracy, regardless of battery model or manufacturer. The ICs are shipped preprogrammed with default values for these parameters. In the course of daily use (charge, discharge, unused), the algorithm collects new parameters. Parameter acquisition is complete after one full discharge cycle and subsequent relaxation takes place.

The default parameters that are used for fuel gauging prior to discharge activity are less accurate than parameters acquired during such activity. Therefore, the error of the gas gauge is more than the 1% that is achieved after parameter acquisition. It is desirable to have optimal accuracy in the battery packs coming from the production line even before any discharge activity occurs. This can be accomplished by performing a discharge cycle on one battery pack (let it acquire optimized parameters), save its data flash in a file, and then program the golden data into all battery packs coming from the production line.

Section 2.1 describes the steps in this process. However, this procedure can also be completed using the bqEASY™ software. More information about this tool can be found in the user guide *bqEASY (bq20z70. bq20z80, bq20z90)* (SLUU278).

2.1 Creating Pre-Learned Defaults

1. Assemble a battery pack with the bq20z80 solution, which includes setting basic flash constants for a given pack configuration, calibrating the pack, connecting *System Present* to ground, and enabling IT. This is described in detail in the application report *Pack Assembly and the bq20z80* (SLUA335), which also applies to the bq20zxx.
2. In particular, it is important to set parameters specific to the number of serial cells used. This is described in application report *bq20z80 EVM Data Flash Settings for Number of Serial Cells and Pack Capacity* (SLVA208), which also applies to the rest of the bq20zxx family.
3. To achieve maximum accuracy of first cycle parameter acquisition, set an initial guess for Qmax Cell 0, Qmax Cell 1, Qmax Cell 2, Qmax Cell 3, and Qmax Pack. These values are in mAh as specified in the battery manufacturer data sheet. For example, if single-cell data-sheet capacity is 2400 mAh and 3 parallel cells are used, set each value to 2400 × 3 = 7200 mAh.
4. Charge the pack to full.
5. Let it relax for 2 hours.
6. Discharge the pack to the minimum system-acceptable voltage (should be the same as DF.Gas Gauging.IT Cfg.Term Voltage) at the typical application rate. The exact rate is not critical.
7. Let it relax for 5 hours.

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8. Repeat Steps 4 through 7 to achieve maximum impedance table accuracy. Verify that DF.Gas Gauging.State.Update Status reads 06. If not, repeat the cycle. Its normal value should be 06.
9. Use the EVSW to export the .gg File. Open the .gg file with Notepad to change DF.Gas Gauging.State.UpdateStatus to 02. Change DF.SBS Configuration.Data.Cycle Count to 0.
10. Reprogram the pack with a fresh .senc to clear all hidden constants.
11. Use the EVSW to import the modified .gg file as saved in Step 9. Write All.
12. Send reset command (0x0041).

The *golden pack* is now ready to have its data flash read into a binary file as described in the function listed in Section 3.

3 Reading and Saving the Data Flash Image From the Golden Pack

Two types of files are associated with a golden image file: a ROM file and a DFI file. Both are binary files with data flash information, but a ROM file contains additional headers. The sample code that follows is an example of how to save the golden image in a DFI file. If saving the golden image in a ROM file is desired, see Appendix A. Note that this step only needs to be done once for a given project.

```
Function SaveDataFlashImageToFile(sFileName As String) As Long

  Dim iNumberOfRows As Integer
  Dim lError As Long
  Dim yRowData(32) As Byte
  Dim yDataFlashImage(&H700) As Byte
  Dim iRow As Integer
  Dim iIndex As Integer
  Dim iLen As Integer
  Dim iFileNumber As Integer

  '// FOR CLARITY, WITHOUT USING CONSTANTS
  '// 0x700 is the data flash size.
      0x700 \ 32 = 56 rows

  iNumberOfRows = &H700 \ 32

  '// PUT DEVICE INTO ROM MODE
  lError = WriteSMBusInteger(&H0, &HF00)
  DoDelay 0.01

  '// READ THE DATA FLASH, ROW BY ROW
   For iRow = 0 To iNumberOfRows - 1

     '// Set the address for the row. &H9 (0x09) is the ROM mode command.
     '// 0x200 is the row number where data flash starts.
     '// Multiplication by 32 gives us the actual physical address where each row starts
     lError = WriteSMBusInteger(&H9, (&H200 + iRow) * 32)

     '// Read the row. &HC (0x0c) is the ROM mode command.
     lError = ReadSMBusByteArray(&HC, yRowData, iLen)

     '//Copy this row into its place in a big byte array

     For iIndex = 0 To 32 - 1

     yDataFlashImage((iRow * 32) + iIndex) = yRowData(iIndex)

     Next iIndex

  Next iRow

  '// WRITE DATA FLASH IMAGE TO FILE

  iFileNumber = FreeFile

  Open sFileName For Binary Access Write As #iFileNumber

  Put #iFileNumber, , yDataFlashImage

  Close #iFileNumber

  '// EXECUTE GAS GAUGE PROGRAM

  lError = WriteSMBusCommand(&H8)

End Function
```


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4 Writing the Data Flash Image to Each Target Device

The sample code that follows is an example of how to write a DFI file to the target device. To write with a ROM file, see Appendix A. The following method is fast. It only takes about 2 seconds to write the entire data flash in this manner.

CAUTION

If power is interrupted during this process, the device may become unusable.

```
Function WriteDataFlashImageFromFile(sFileName As String) As Long
   Dim lError As Long
   Dim iFileNumber As Integer
   Dim iNumberOfRows As Integer
   Dim iRow As Integer
   Dim iIndex As Integer
   Dim yRowData(32) As Byte
   Dim yDataFlashImage(&H700) As Byte
   '// READ THE FLASH IMAGE FROM THE FILE INTO A BYTE ARRAY
   iFileNumber = FreeFile
   Open sFileName For Binary Access Read As #iFileNumber
   Get #iFileNumber, , yDataFlashImage
   Close #iFileNumber
   '// FOR CLARITY, WITHOUT USING CONSTANTS
   iNumberOfRows = &H60 \ 32    '54 Rows
   '// PUT DEVICE INTO ROM MODE
   lError = WriteSMBusInteger(&H0, &HF00)
   DoDelay 0.01
   '// ERASE DATA FLASH, ROWS ARE ERASED IN PAIRS
   For iRow = 0 To iNumberOfRows - 1  Step 2
       1Error = WriteSMBusInteger (&H11, iRow)
       DoDelay 0.04
   Next iRow
   '// WRITE EACH ROW
   For iRow = 0 To iNumberOfRows - 1
      '// Set the row to program into the first element of the 33 byte array
      yRowData(0) = iRow
      '// Copy data from the full array to the row array
      For iIndex = 0 To 31
         yRowData(iIndex + 1) = yDataFlashImage((iRow * 32) = iIndex)
      Next iIndex
      "// Write the row. Length is 33 because the first byte is the row number
      lError = WriteSMBusArray(&H10, yRowData, 32 + 1)
      DoDelay 0.02
   Next iRow
   '// EXECUTE GAS GAUGE PROGRAM
   lError = WriteSMBusCommand(&H8)
End Function
```


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5 Calibration

Devices in the latest TI family of advanced gas gauges are quick and easy to calibrate. It only takes about 5 seconds to accurately calibrate current offset, voltage, temperature, and board offset. With the Impedance Track devices, most calibration routines have been incorporated into firmware algorithms, which can be initiated with SMBus commands. The hardware for calibration is also simple. One current source, one voltage source, and one temperature sensor are all that is required. The accuracy of the sources is not important, only their stability. However, accurately calibrated reference measurement equipment should be used for determining the actual arguments to the function. For periodic voltage measurement, a DVM with better than 1-mV accuracy is required.

The elapsed time for calibration can be changed by modifying values in the data flash, but this is not recommended. Use the default values for the times in DF.Calibration.Config.

In the *CalibrateAll()* function, command 0x51 is used to setup a current offset, voltage, current , and temperature calibration of the device. Pack voltage calibration is generally not performed because its accuracy is not required for standard applications. In this case, Pack Voltage refers to a separate measurement of the voltage at the pack terminal and is unrelated to the *SBS.Voltage()* measurement.

The definition of the bits in command 0x51 are:

Bit 0	Coulomb Counter Offset	Bit 8	Pack Gain
Bit 1	Reserved	Bit 9	Pack Voltage
Bit 2	ADC Offset	Bit 10	AFE Error
Bit 3	Temperature, Internal	Bit 11	Reserved
Bit 4	Temperature, External 1	Bit 12	Reserved
Bit 5	Temperature, External 2	Bit 13	Reserved
Bit 6	Current	Bit 14	Run ADC Task Continuously
Bit 7	Voltage	Bit 15	Run CC Task Continuously

Bits 14 and 15 must always be set. These cause the Coulomb Counter and ADC tasks to run continuously, just as they do in normal operation. This has been found to increase the accuracy of the calibration.

After command 0x51 is issued, the calibration sequence is started in the firmware of the gas gauge. The calibrations are run in sequence starting from the least significant bit. Then, command 0x52 is used to poll these bits, which change from high to low as the tasks are completed. However, bits 14 and 15 do not change; hence, the masking of them in the polling loop

It can be seen from this code that a simple modification to command 0x51 would allow it to work as a single function calibration. For example, to only calibrate voltage, only bit 7 could be set.

```
Function CalibrateAll(iVoltage As Integer, iCurrent As Integer, iTemperature As Integer, iCells
As Integer) As Long
'// iVoltage is in millivolts
'// iCurrent is in milliamps (normally negative, such as -2000)
'// iTemperature is in Kelvin/10 units, so the argument is: 10 * (Celsius + 273.15)
    Dim lError As Long
    Dim bDoingCal As Boolean
    Dim iValue As Long
    '// GO TO CALIB MODE
    IError = WriteSMBusInteger(&H0, &H40)
    '// WRITE THE NUMBER OF CELLS
    IError = WriteSMBusInteger(&H63, iCells)
    '// WRITE THE ACTUAL VOLTAGE, CURRENT & TEMPERATURE
    IError = WriteSMBusInteger(&H60, iCurrent)
    IError = WriteSMBusInteger(&H61, iVoltage)
    IError = WriteSMBusInteger(&H62, iTemperature)
```


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```
  '// START CALIBRATION
  '// Useful cal lo byte &HD5 - External temperature sensor 1
  '//                    &HF5 - External temperature sensor 1 and 2
  '//                    &HCD - Internal temperature sensor
  IError = WriteSMBusInteger(&H51, &HC0D5)
  '// POLL CALIBRATION STATUS - WAIT FOR LOWER 14 BITS TO ALL CLEAR
  bDoingCal = True
  While bDoingCal
     IError = ReadSMBusUnsignedInteger(&H52, IValue)
     bDoingCal = IValue And &H3FFF
     DoDelay 0.2 '// check every 200 millisecond
Wend
  '// TRANSFER RESULTS TO DATAFLASH
  IError = WriteSMBusCommand(&H72)
  DoDelay 0.1
  '// Insure write process is finished
  '// EXIT CALIB MODE
  IError = WriteSMBusCommand(&H73)
End Function
```

Because of the simplified single ground system in the bq20zxx family, each unit should be calibrated for board offset. Use the following function in normal mode to calibrate the board offset. During this procedure, the device under test must be powered from the cells only and no external load or charge current may be applied. Note that the function requires the sense resistor value in mΩ as an argument.

```
Function CalibrateBoardOffset(nSenseResuOhm As Integer) As Long
 '// Device under test must be powered from the Cell side, which
 '// allows the device current to flow through the sense resistor.
 '// Insure no other current is flowing through the sense resistor.
  Dim 1Error As Long
  Dim lValue As Long
  Dim I As Integer
  Dim iExternalOffset As Integer
  Dim iInternalOffset As Integer
  Dim iBoardOffset As Long
  Dim yData(32) As Byte
  Dim iLen As Integer
  '// READ EXTERNAL OFFSET CURRENT
  1Error = WriteSMBusInteger(&H40, &H8042)  '//Set address of coulomb counter
  DoDelay 0.2 '// Extra settling time to clear the decimation filter
  For I = 1 To 4
       DoDelay 0.3 '// take 4 samples at 300 ms intervals
       1Error = ReadSMBusUnsignedInteger(&H42, 1Value) '// Peek Coulomb Counter
       iExternalOffset = iExternalOffset + 1Value
  Next I
  '// READ INTERNAL OFFSET CURRENT
  1Error = WriteSMBusInteger(&H40, &H8040) '//Set address of coulomb counter config register
  1Error = WriteSMBusInteger(&H41, &H43) '//Change configuration to internal mode
  1Error = WriteSMBusInteger(&H40, &H8042) '//Set address of Coulomb Counter
  DoDelay 0.2 '// Extra settling time to clear the decimation filter
  For I = 1 To 4
       DoDelay 0.3
```


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```
         lError = ReadSMBusUnsignedInteger(&H42, lValue) '// Read Coulomb Count
iInternalOffset = iInternalOffset + lValue
    Nexti
    lError = WriteSMBusInteger(&H40, &H8040) '//Set address of coulomb counter config register
    lError = WriteSMBusInteger(&41, &H2) '//Return configuration to external mode
    '// CALCULATE BOARD OFFSET
    iBoardOffset = (16 * (iExternalOffset - iInternalOffset)) + 64 * 0.6 * nSenseResuOhm / 9419
    If iBoardOffset < Then iBoardOffset = 65536 + iBoardOffset '// fix negative case
    '// WRITE BOARD OFFSET TO DATA FLASH. FROM DATA MANUAL, SUBCLASS=104, OFSET=16
    lError = WriteSMBusInteger(&H77, 104) '//Set subclass to 104
    lError = ReadSMBusByteArray(&H78, yData(), iLen) '// Read the page
    yData(16) = (iBoardOffset And &HFF00) \ 256 '// Modify MS byte
    yData(17) = iBoardOffset And &HFF '// Modify LS byte
    lError = WriteSMBusByteArray(&H78, yData(), iLen) '//Write page back to flash
    DoDelay 0.1 '// Insure flash write is finished
End Function
```

5.1 Optimizing Current Calibration Accuracy

In CALIBRATION mode (as described above), the CPU utilization is slightly different resulting in a calibration constant that may introduce a small error when the gauge is returned to NORMAL operating mode. The following alternate manual or automated method may be performed to achieve a more accurate calibration:

1. Read the Reported Current from the *SBS.Current()* function in the gauge.
2. Read the Actual Current from the government standard traceable DMM.
3. Modify the CC Gain according to the formula:

   New CC Gain = Existing CC Gain × Reported Current/Actual Current
4. Replace CC Gain in the data flash with the New CC Gain obtained above.
5. Repeat for CC Delta. Use Existing CC Delta in place of Existing CC Gain in the formula above.

6 Writing Pack-Specific Data Flash Locations

The third step is to fine-tune the data flash a little for each pack, to give it a unique identity. In the following example, the pack Serial Number is written using subclass and offset information found in the gas gauge product data sheet. Modifications to single data flash locations normally require a block read of the 32-byte data flash page, then updating the desired element of the block, and writing it back to the device. This procedure is documented in the product data sheet.

```
Function WritePackSerialNumber(iSerialNumber As Integer) As Long
   Dim lError As Long
   Dim yData(32) As Byte
   Dim iLen As Integer
   '// SET THE SUBCLASS TO 48 (FOUND IN PRODUCT DATASHEET)
   lError = WriteSMBusInteger(&H77, 48)
   '// READ THE PAGE
   lError = ReadSMBusByteArray(&H78, yData(), iLen)
   '// REPLACE THE TWO BYTES AT OFFSET 12 (FOUND IN DATASHEET) WITH NEW S/N
   yData(12) = (iSerialNumber And &HFF00) \ 256 '// modify MS byte
   yData(13) = iSerialNumber And &HFF '// modify LS byte
   '// WRITE THE PAGE BACK TO FLASH
   lError = WriteSMBusByteArray(&H78, yData(), iLen)
   '// FLASH WRITES ARE SLOW
```


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```
   DoDelay 0.1
End Function
Sub DoDelay(fWaitTime As Single)
   Dim vTime As Variant
   vTime = Timer
   While Timer < (vTime + fWaitTime)
        '// fix midnight problem
        If Timer < vTime Then Exit Sub
        '// Yield to various Windows events while the delay is in progress
        DoEvents
   Wend
End Sub
```


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Appendix A How to Convert Between .DFI and .ROM File Types Using bqEASY Software

A.1 Introduction

Two file types are associated with a data flash image, a .ROM file and a .DFI file. A .ROM file contains data flash information in binary format, plus some headers related to the target device. This file is used by the bqMTester, a TI production tool. A .DFI file is also a binary file, but with only the data flash information. This file is produced by the TI evaluation design tool—bqEASY. The data flash read/write sample codes in this application report are used to handle .DFI file types. Although both files are similar, ROM and DFI files are not interchangeable.

From the bqEASY v1.85 (or later) software, the ability to read a ROM file into a target device, or to write the data flash image from a target device to a ROM file, was added. By having the related EVM in hand, a user can apply this new feature to convert between DFI and ROM file types to fit into their production/evaluation setting.

A.2 Create a .ROM File From a .DFI File

The read and write data flash image features are available in the bqEASY 1B. Load/Read .DFI or .ROM File page (under 1. Setup), as shown in Figure 1.

Figure 1. bqEASY 1B Load/Read .DFI or .ROM File Page

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1. **To Create a .ROM File From a .DFI File.**
   (a) Connect to the target device before starting the bqEASY software. (For example, to convert a bq20z90-v150 ROM file to a .DFI file, connect the bq20z90EVM to the PC before starting the software.)
   (b) Start the EVSW, and go to the bqEASY selection. Click on 1. Setup tab and go to the 1B. Load/Read .DFI or .ROM File page. (see Figure 1)
   (c) Choose the "Select DFI file manually" radio button; a “Browse…” button appears. Click on the "Browse…" button to select the .DFI file from the local computer.

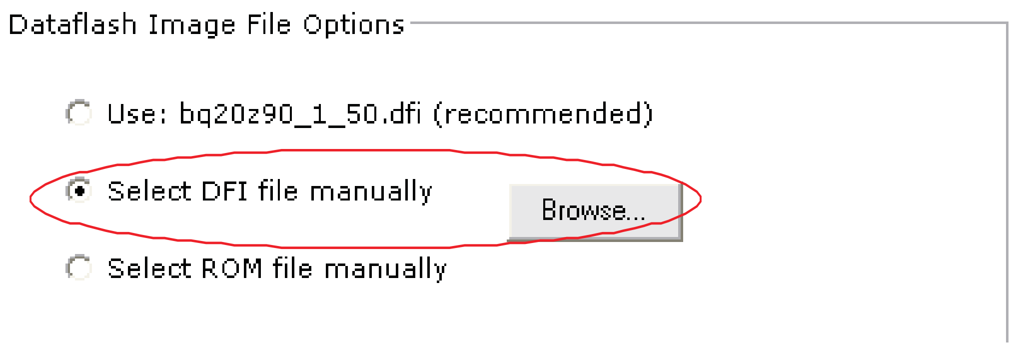

Figure 2. Select DFI File Manually Option

   (d) Click Program Dataflash Image button to program the selected .DFI file to the target device.

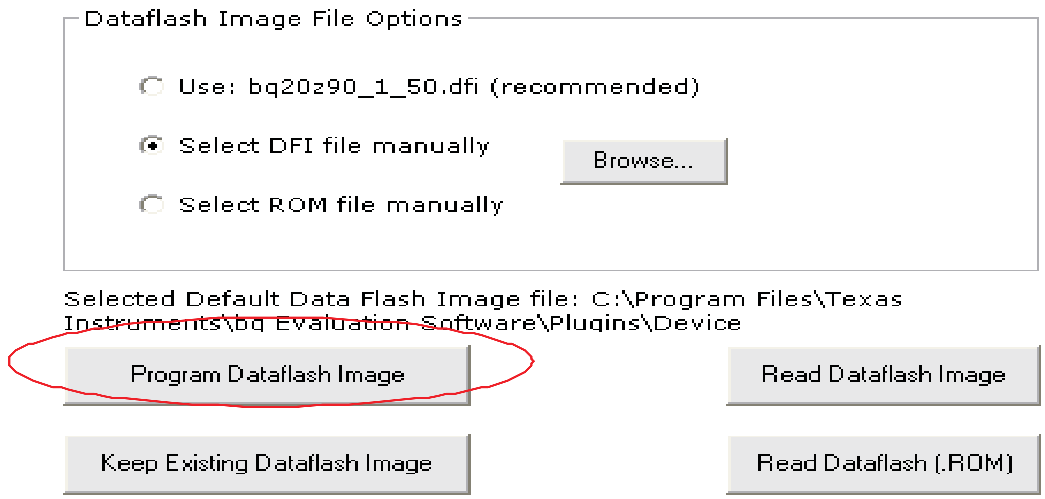

Figure 3. Click Program Dataflash Image

   (e) The target device contains the dataflash image of the .DFI file on completion of the programming. Click Read Dataflash (.ROM) button to read the image out in ROM format. A save-dialog box appears; select the desired directory and filename. A ROM format of the dataflash image will be saved to the computer.

A.3 Create a .DFI File From a .ROM File

Creating a .DFI file from a .ROM file is basically performed in the same manner as described in Section A.2.

1. **To Create a .DFI File From a .ROM File**
   (a) Connect the target device to the PC before starting EVSW.
   (b) Go to the bqEASY 1B. Load/Read .DFI or .ROM File page (see Figure 1)
   (c) Choose the “Select ROM file manually” radio button, and click on “Browse…” to select the .ROM file from the local computer.

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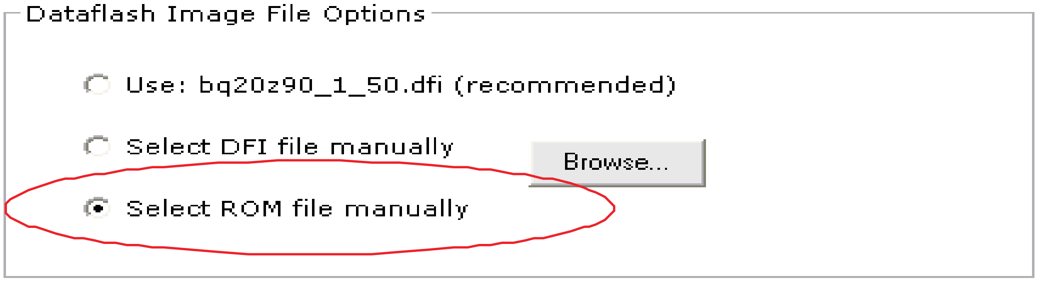

Figure 4. Select ROM File Manually Option

(d) Click the Program Dataflash Image button to program the selected .ROM file to the target device.

(e) On completion of data flash programming, click Read Dataflash (.DFI) button to read the data flash out in .DFI format.

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