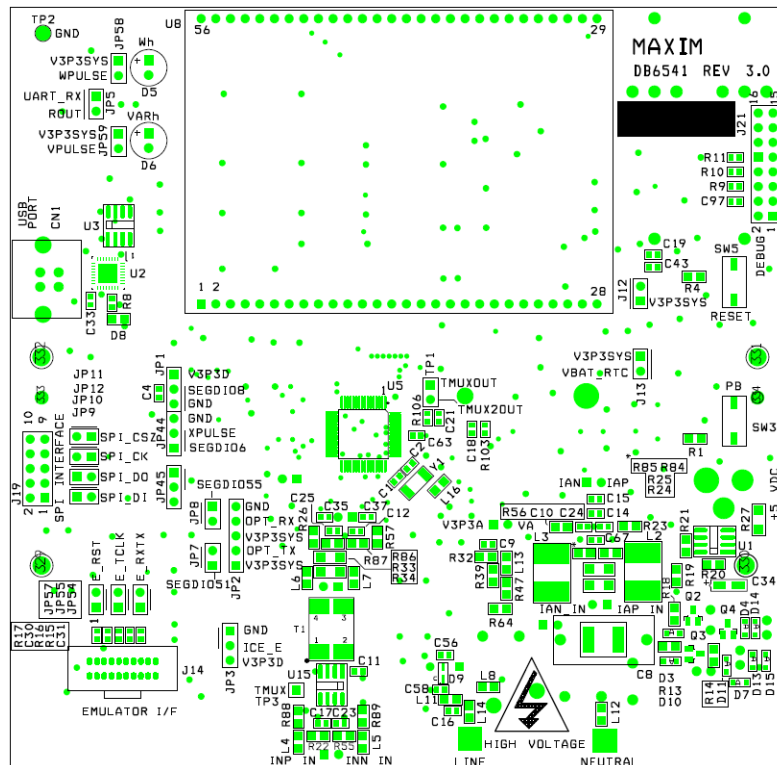


71M6541 Demo Board REV 3.0 User's Manual

Rev 4.0; 12/12



Maxim Integrated cannot assume responsibility for use of any circuitry other than circuitry entirely embodied in a Maxim Integrated product. No circuit patent licenses are implied. Maxim Integrated reserves the right to change the circuitry and specifications without notice at any time.

Maxim Integrated 160 Rio Robles, San Jose, CA 95134 USA 1-408-601-1000

© 2012 Maxim Integrated Products, Inc. Maxim Integrated and the Maxim Integrated logo are trademarks of Maxim Integrated Products, Inc.

Table of Contents

1	GETTING STARTED.....	5
1.1	General	5
1.2	Safety and ESD Notes	5
1.3	Demo Kit Contents	6
1.4	Demo Board Versions	6
1.5	Compatibility.....	6
1.6	Suggested Equipment not Included	6
1.7	Demo Board Test Setup.....	7
1.7.1	Power Supply Setup.....	8
1.7.2	Cables for Serial Communication	8
1.7.3	Checking Operation.....	9
1.7.4	Serial Connection Setup.....	9
1.8	Using the Demo Board.....	10
1.8.1	Serial Command Language.....	11
1.8.2	Using the Demo Board for Energy Measurements	17
1.8.3	Adjusting the Kh Factor for the Demo Board.....	17
1.8.4	Adjusting the Demo Boards to Different SHUNT Resistors	17
1.8.5	Using the Pre-Amplifier	17
1.8.6	Using Current Transformers (CTs).....	17
1.8.7	Implementing a Single-Phase 3-Wire Meter (EQU 1).....	17
1.8.8	Adjusting the Demo Boards to Different Voltage-Dividers	17
1.9	Calibration Parameters	18
1.9.1	General Calibration Procedure	18
1.9.2	Calibration Macro File	19
1.9.3	Updating the Demo Code (hex file)	19
1.9.4	Updating Calibration Data in Flash or EEPROM	20
1.9.5	Loading the Code for the 71M6541 into the Demo Board	20
1.9.6	The Programming Interface of the 71M6541.....	22
1.10	Demo Code.....	23
1.10.1	Demo Code Description.....	23
1.10.2	Important MPU Addresses.....	23
1.10.3	LSB Values in CE Registers	30
1.10.4	Calculating I _{MAX} and K _h	30
1.10.5	Determining the Type of 71M6x0x.....	31
1.10.6	Communicating with the 71M6X0X.....	32
1.10.7	Bootloader Feature	32
2	APPLICATION INFORMATION.....	34
2.1	Sensor Connections and Equations	34
2.1.1	Sensor Wiring.....	34
2.1.2	Single-phase two-wire (EQU 0)	35
2.1.3	Single-phase three-wire (EQU 1)	36
2.2	Calibration Theory.....	37
2.2.1	Calibration with Three Measurements.....	37
2.2.2	Calibration with Five Measurements	38
2.3	Calibration Procedures	40
2.3.1	Calibration Equipment	40
2.3.2	Phase-by-Phase Calibration.....	40
2.3.3	Detailed Calibration Procedures.....	40
2.3.4	Calibration Procedure with Three Measurements	41

2.3.5	Calibration Procedure with Five Measurements	42
2.3.6	Calibration Spreadsheets	42
2.3.7	Compensating for Non-Linearities	45
2.4	Temperature Compensation	46
2.4.1	Error Sources	46
2.4.2	Software Features for Temperature Compensation	47
2.4.3	Calculating Parameters for Compensation	48
2.5	Testing the Demo Board	51
2.5.1	Functional Meter Test	51
2.6	Sensors and Sensor Placement	53
2.6.1	Self-Heating	53
2.6.2	Placement of Sensors (ANSI)	54
2.6.3	Placement of Sensors (IEC)	55
2.6.4	Other Techniques for Avoiding Magnetic Crosstalk	56
3	HARDWARE DESCRIPTION	58
3.1	71M6541-DB Description: Jumpers, Switches and Test Points	58
3.2	Board Hardware Specifications	62
4	APPENDIX	64
4.1	71M6541-DB Electrical Schematic	65
4.2	71M6541-DB Bill of Material	67
4.3	71M6541-DB PCB Layout	69
4.4	71M6541 Pinout Information	73
4.5	Revision History	76

List of Figures

Figure 1-1:	D6541 REV2.0 Demo Board with Debug Board: Basic Connections	7
Figure 1-2:	HyperTerminal Sample Window with Disconnect Button (Arrow)	10
Figure 1-3:	Port Speed and Handshake Setup (left) and Port Bit setup (right)	10
Figure 1-4:	Typical Calibration Macro File	19
Figure 1-5:	Emulator Window Showing Reset and Erase Buttons (see Arrows)	21
Figure 1-6:	Emulator Window Showing Erased Flash Memory and File Load Menu	21
Figure 2-1:	Shunt Connections	34
Figure 2-2:	Single-Phase Two-Wire Meter with Shunt Sensor	35
Figure 2-3:	Single-Phase Two-Wire Meter with two Shunt Sensors	35
Figure 2-4:	Single-Phase Three-Wire Meter with two Shunt Sensors	36
Figure 2-4:	Watt Meter with Gain and Phase Errors	37
Figure 2-5:	Phase Angle Definitions	40
Figure 2-7:	Calibration Spreadsheet for Three Measurements	43
Figure 2-8:	Calibration Spreadsheet for Five Measurements	44
Figure 2-9:	Non-Linearity Caused by Quantification Noise	45
Figure 2-10:	<i>GAIN_ADJ</i> over Temperature	49
Figure 2-11:	<i>GAIN_ADJ</i> and <i>GAIN_ADJ'</i> over Temperature	49
Figure 2-12:	Meter with Calibration System	52
Figure 2-13:	Calibration System Screen	52
Figure 2-14:	Wh Load Lines at Room Temperature with 71M6201 and 50 $\mu\Omega$ Shunts	53
Figure 2-15:	Typical Sensor Arrangement (left), Recommended Arrangement (right)	55
Figure 2-16:	Improved Sensor Arrangement	55
Figure 2-17:	Loop Formed by Shunt and Sensor Wire	56
Figure 2-18:	Shunt with Compensation Loop	56

Figure 2-19: Shunt with Center Drill Holes	56
Figure 3-1: 71M6541-DB REV 3.0 - Board Description	61
Figure 4-1: 71M6541-DB REV 3.0 Demo Board: Electrical Schematic 1/2	65
Figure 4-2: 71M6541-DB REV 3.0 Demo Board: Electrical Schematic 2/2	66
Figure 4-3: 71M6541-DB REV 3.0: Top View	69
Figure 4-4: 71M6541-DB REV 3.0: Top Copper	70
Figure 4-5: 71M6541-DB REV 3.0: Bottom View	71
Figure 4-6: 71M6541-DB REV 3.0: Bottom Copper	72
Figure 4-14: 71M6541, LQFP64: Pinout (Top View)	75

List of Tables

Table 1-1: Jumper Settings on Debug Board	8
Table 1-2: Straight Cable Connections	8
Table 1-3: Null-modem Cable Connections	8
Table 1-4: CE RAM Locations for Calibration Constants	19
Table 1-5: Flash Programming Interface Signals	22
Table 1-6: MPU XRAM Locations	24
Table 1-7: Bits in the MPU Status Word.....	29
Table 1-8: CE Registers and Associated LSB Values	30
Table 1-9: IMAX for Various Shunt Resistance Values and Remote Sensor Types.....	31
Table 1-10: Identification of 71M6X0X Remote Sensor Types.....	32
Table 2-1: Temperature-Related Error Sources	46
Table 2-2: Temperature-Related Error Sources	50
Table 3-1: 71M6541-DB REV 3.0 Description.....	60
Table 4-1: 71M6541-DB REV 3.0: Bill of Material	67
Table 4-3: 71M6541 Pin Description Table 1/3	73
Table 4-4: 71M6541 Pin Description Table 2/3	73
Table 4-5: 71M6541 Pin Description Table 3/3	74

1

1 GETTING STARTED

1.1 GENERAL

The Maxim Integrated 71M6541-DB REV 3.0 Demo Board is a demonstration board for evaluating the 71M6541 device for single-phase electronic energy metering applications in conjunction with the Remote Sensor Interface. It incorporates a 71M6541 integrated circuit, a 71M6601 Remote Interface IC, peripheral circuitry such as a serial EEPROM, emulator port, and on-board power supply. A serial to USB converter allows communication to a PC through a USB port. The Demo Board allows the evaluation of the 71M6541 energy meter chip for measurement accuracy and overall system use.

The board is pre-programmed with a Demo Program (Demo Code) in the FLASH memory of the 71M6541F IC. This embedded application is developed to exercise all low-level function calls to directly manage the peripherals, flash programming, and CPU (clock, timing, power savings, etc.).

The 71M6541F IC on the Demo Board is pre-programmed and pre-calibrated for the 50 $\mu\Omega$ or 120 $\mu\Omega$ shunt shipped with the board. The Demo Board may also be used for operation with a CT after hardware modifications that can be easily performed by the user. This configuration will require a different version of the Demo Code.

1.2 SAFETY AND ESD NOTES

Connecting live voltages to the demo board system will result in potentially hazardous voltages on the demo board.



THE DEMO SYSTEM IS ESD SENSITIVE! ESD PRECAUTIONS SHOULD BE TAKEN WHEN HANDLING THE DEMO BOARD!



EXTREME CAUTION SHOULD BE TAKEN WHEN HANDLING THE DEMO BOARD ONCE IT IS CONNECTED TO LIVE VOLTAGES! BOARD GROUND IS CLOSE TO LIVE VOLTAGE!



CAUTION: THE PHASE A CONNECTION OF THE DEMO BOARD IS CONNECTED TO THE LIVE VOLTAGE SHUNT. THE NEUTRAL SHUNT IS ISOLATED VIA THE 71M6X0X REMOTE SENSOR INTERFACE AND CONNECTED TO THE PHASE B INPUT. EXTREME CARE MUST BE TAKEN WHEN CHANGING SHUNT AND VOLTAGE CONNECTIONS!

1.3 DEMO KIT CONTENTS

- Demo Board D6541 REV 3.0 containing one 71M6601 or 71M6201 Remote Sensor Interface and one 71M6541F IC with pre-loaded demo program
- 5VDC/1,000mA universal wall transformer with 2.5mm plug (Switchcraft 712A compatible)
- Serial-USB converter
- USB cable
- ANSI base with 50 $\mu\Omega$ shunt resistor (optional, for ANSI kits only) or two 120 $\mu\Omega$ shunt resistors

1.4 DEMO BOARD VERSIONS

This manual applies to **D6541 REV 3.0** only.

1.5 COMPATIBILITY

This manual applies to the following hardware and software revisions:

- 71M6541 chip revision B02
- Demo Kit firmware revision 5.4G or later
- Demo Board D6541 REV 3.0

1.6 SUGGESTED EQUIPMENT NOT INCLUDED

For functional demonstration:

- PC with Windows® 2000, Windows XP®, or Windows 7 operating system, equipped with USB port.
For the use of the optional Debug Board, a serial interface (COM port) is required.

For software development (MPU code):

- Signum Systems In-Circuit Emulator (ICE): ADM-51
 - o Signum WEMU51 version 3.11.09 or later should be used.
- Keil 8051 “C” Compiler Kit: CA51

Windows and Windows XP are registered trademarks of Microsoft Corp.

1.7 DEMO BOARD TEST SETUP

Figure 1-1 shows the basic connections of the Demo Board plus optional Debug Board with the external equipment. The PC can be connected via the USB Interface (CN1). For stand-alone testing (without AC voltage) the Demo Board maybe powered via the 5.0 VDC input (J20). The optional Debug Board must be powered with its own 5 VDC power supply.

DEMONSTRATION METER

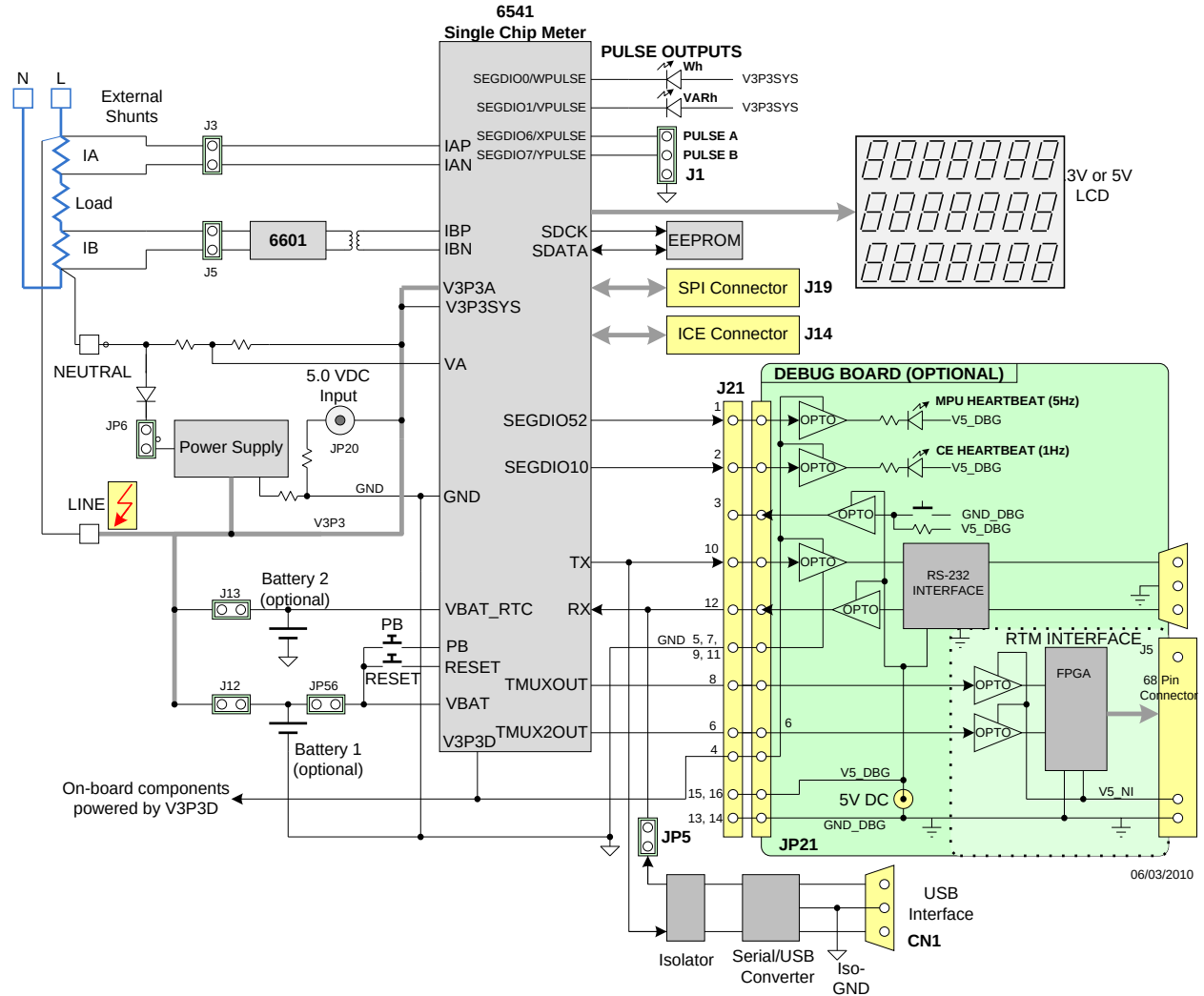


Figure 1-1: 71M6541-DB REV3.0 Demo Board with optional Debug Board: Basic Connections

The Demo Board contains all circuits necessary for operation as a meter, including display, calibration LEDs, and internal power supply. Communication with a PC USB port is provided via connector CN1. The optional Debug Board uses a separate power supply, and is optically isolated from the Demo Board. It interfaces to a PC through the USB connector.



It is recommended to set up the demo board with no live AC voltage connected, and to connect live AC voltages only after the user is familiar with the demo system.



All input signals are referenced to the V3P3A (3.3V power supply to the chip).

1.7.1 POWER SUPPLY SETUP

There are several choices for the meter power supply:

- o Internal (using the AC line voltage). The internal power supply is only suitable when the voltage exceeds 100V RMS. To enable the internal supply, a jumper needs to be installed across JP6 on the top of the board.
- o External 5.0VDC connector (J20) on the Demo Board.

1.7.2 CABLES FOR SERIAL COMMUNICATION

1.7.2.1 USB Connection (Recommended)

A standard USB cable can be used to connect the Demo Board to a PC running HyperTerminal or a similar serial interface program. A suitable driver, e.g., the FTDI CDM Driver Package, must be installed on the PC to enable the USB port to be mapped as a virtual COM port. The driver can be found on the FTDI web site (www.ftdichip.com).

See Table 3-1 for correct placement of jumper JP5 depending on whether the USB connection or the serial connection via the Debug Board is used.

1.7.2.2 Serial Connection (via Optional Debug Board)

For connection of the DB9 serial port of the Debug Board to a PC serial port (COM port), either a straight or a so-called "null-modem" cable may be used. JP1 and JP2 are plugged in for the straight cable, and JP3/JP4 are empty. The jumper configuration is reversed for the null-modem cable, as shown in Table 1-1.

Cable Configuration	Mode	Jumpers on Debug Board			
		JP1	JP2	JP3	JP4
Straight Cable	Default	Installed	Installed	--	--
Null-Modem Cable	Alternative	--	--	Installed	Installed

Table 1-1: Jumper Settings on Debug Board

JP1 through JP4 can also be used to alter the connection when the PC is not configured as a DCE device. Table 1-2 shows the connections necessary for the straight DB9 cable and the pin definitions.

PC Pin	Function	Demo Board Pin
2	TX	2
3	RX	3
5	Signal Ground	5

Table 1-2: Straight Cable Connections

Table 1-3 shows the connections necessary for the null-modem DB9 cable and the pin definitions.

PC Pin	Function	Demo Board Pin
2	TX	3
3	RX	2
5	Signal Ground	5

Table 1-3: Null-modem Cable Connections

See Table 3-1 for correct placement of jumper JP5 on the Demo Board depending on whether the USB connection or the serial connection via the Debug Board is used.

1.7.3 CHECKING OPERATION

A few seconds after power up, the LCD display on the Demo Board should display a brief greeting in the top row and the demo code revision in the bottom row:

		H	E	L	L	O	
			5.	4	G		

The "HELLO" message should be followed by the display of accumulated energy:

					0.	0	0	Wh	SYS
	0	3							

The "SYS" symbol will be blinking, indicating activity of the MPU inside the 71M6541.

In general, the fields of the LCD are used as shown below:

			Measured value				Unit
	Command number						
					(Phase)		

1.7.4 SERIAL CONNECTION SETUP

After connecting the USB cable from the Demo Board to the PC, or after connecting the serial cable from the optional Debug Board to the PC, start the HyperTerminal application and create a session using the following parameters:

Port Speed: 9600 bd

Data Bits: 8

Parity: None

Stop Bits: 1

Flow Control: XON/XOFF

When using the USB connection, you may have to define a new port in HyperTerminal after selecting File → Properties and then clicking on the "Connect Using" dialog box. If the USB-to-serial driver is installed (see section 1.7.2.1) a port with a number not corresponding to an actual serial port, e.g., COM5, will appear in the dialog box. This port should be selected for the USB connection.

HyperTerminal can be found by selecting Programs → Accessories → Communications from the Windows® start menu. The connection parameters are configured by selecting File → Properties and then by pressing the Configure button. Port speed and flow control are configured under the General tab (Figure 1-3, left), bit settings are configured by pressing the Configure button (Figure 1-3, right), as shown below. A setup file (file name "Demo Board Connection.ht") for HyperTerminal that can be loaded with File → Open is also provided with the tools and utilities.



Port parameters can only be adjusted when the connection is not active. The disconnect button, as shown in Figure 1-2 must be clicked in order to disconnect the port.

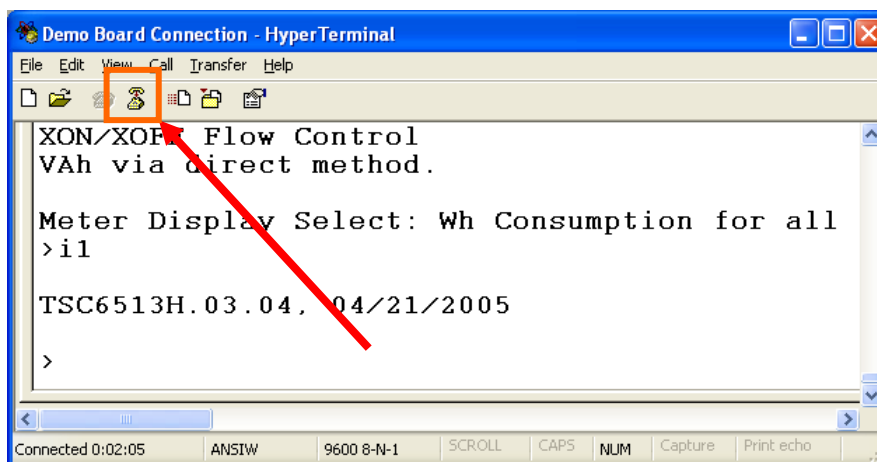


Figure 1-2: HyperTerminal Sample Window with Disconnect Button (Arrow)

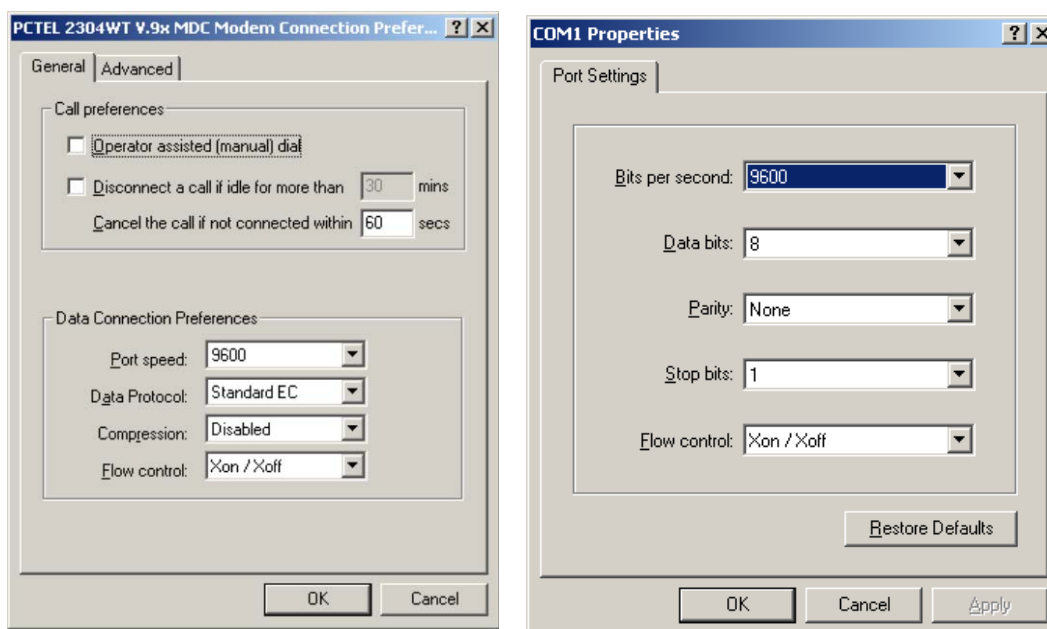


Figure 1-3: Port Speed and Handshake Setup (left) and Port Bit setup (right)

Once, the connection to the demo board is established, press <CR> and the command prompt, >, should appear. Type >? to see the **Demo Code** help menu. Type >i to verify the demo code revision.

1.8 USING THE DEMO BOARD

The 71M6541 Demo Board is a ready-to-use meter prepared for use with external shunt resistors.

Demo Code versions for single-phase two-wire operation (EQU 0, with secondary tamper sensor) and for single-phase three-wire operation (ANSI configuration, EQU 1) are provided by Maxim Integrated. Demo Boards in ANSI configuration are preloaded with Demo Code for EQU 1, Demo Boards in IEC configuration are preloaded with Demo Code for EQU 0.

Using the Demo Board involves communicating with the Demo Code via the command line interface (CLI). The CLI allows all sorts of manipulations to the metering parameters, access to the EEPROM, selection of the displayed parameters, changing calibration factors and many more operations.

Before evaluating the 71M6541 on the Demo Board, users should get familiar with the commands and responses of the CLI. A complete description of the CLI is provided in section 1.8.1.

1.8.1 SERIAL COMMAND LANGUAGE

The Demo Code residing in the flash memory of the 71M6541 provides a convenient way of examining and modifying key meter parameters via its command line interface (CLI).

The tables in this chapter describe the commands in detail.

Commands for CE Data Access:

]	CE DATA ACCESS	Comment
Description:	Allows user to read from and write to CE data space.	
Usage:	] [Starting CE Data Address] [option]...[option]	
Command combinations:	]A???	Read consecutive 16-bit words in Decimal, starting at address A
	]A\$\$\$	Read consecutive 16-bit words in Hex, starting at address A
	]A=n=n	Write consecutive memory values, starting at address A
Example:	]40\$\$\$	Reads CE data words 0x40, 0x41 and 0x42.
	]7E=1AD2=9A23	Writes two hexadecimal words starting @ 0x7E
	]10=+16384	Writes one decimal word starting @ 0x10

All CE data words are in 4-byte (32-bit) format. Typing]A? will access the 32-bit word located at the byte address $0x0000 + 4 * A = 0x1028$.

Commands for MPU/XDATA Access:

)	MPU DATA ACCESS	Comment
Description:	Allows user to read from and write to MPU data space.	
Usage:	) [Starting MPU Data Address] [option]...[option]	
Command combinations:	)A???	Read three consecutive 32-bit words in Decimal, starting at address A
	)A\$\$\$	Read three consecutive 32-bit words in Hex, starting at address A
	)A=n=m	Write the values n and m to two consecutive addresses starting at address A
	?)	Display useful RAM addresses.
Example:	)08\$\$\$\$	Reads data words 0x08, 0x0C, 0x10, 0x14
	)04=FFFFAD2=9A23	Writes two hexadecimal words starting @ 0x04
	)04=+1000	Writes decimal 1,000 to address 0x04
	)04=-1000	Writes decimal -1,000 to address 0x04

MPU or XDATA space is the address range for the MPU XRAM (0x0000 to 0xFFFF). All MPU data words are in 4-byte (32-bit) format. Typing)A? will access the 32-bit word located at the byte address $4 * A = 0x28$. The energy accumulation registers of the Demo Code can be accessed by typing two Dollar signs ("\$\$"), typing question marks will display negative decimal values if the most significant bit is set.

Commands for I/O RAM (Configuration RAM) and SFR Control:

R	I/O RAM AND SFR CONTROL	Comment
Description:	Allows the user to read from and write to DIO RAM and special function registers (SFRs).	
Usage:	R [option] [register] ... [option]	
Command combinations:	Rlx...	Select I/O RAM location x (0x2000 offset is automatically added)
	Rx...	Select internal SFR at address x
	Ra???...	Read consecutive SFR registers in Decimal, starting at address a
	Ra\$\$\$...	Read consecutive registers in Hex, starting at address a
	Ra=n=m...	Set values of consecutive registers to n and m starting at address a
Example:	RI2\$\$\$	Read DIO RAM registers 2, 3, and 4 in Hex.

The SFRs (special function registers) are located in internal RAM of the 80515 core, starting at address 0x80.

Commands for EEPROM Control:

EE	EEPROM CONTROL	Comment
Description:	Allows user to enable read from and write to EEPROM.	
Usage:	EE [option] [arguments]	
Command combinations:	EECn	EEPROM Access (1 → Enable, 0 → Disable)
	EERa.b	Read EEPROM at address 'a' for 'b' bytes.
	EESabc..xyz	Write characters to buffer (sets Write length)
	EETa	Transmit buffer to EEPROM at address 'a'.
	EEWa.b...z	Write values to buffer
	CLS	Saves calibration to EEPROM
Example:	EEShello EET\$0210	Writes 'hello' to buffer, then transmits buffer to EEPROM starting at address 0x210.



Due to buffer size restrictions, the maximum number of bytes handled by the EEPROM command is 0x40.

Commands for Flash Memory Control:

F	FLASH CONTROL	Comment
Description:	Allows user to enable read from and write to Flash memory.	
Usage:	F [option] [arguments]	
Command combinations:	FRa.b	Read Flash at address 'a' for 'b' bytes.
	FSabc..xyz	Write characters to buffer (sets Write length)
	FTa	Transmit buffer to Flash memory at address 'a'.
	FWa.b...z	Write string of bytes to buffer
	FShello FT\$FE10	Writes 'hello' to buffer, then transmits buffer to EEPROM starting at address 0xFE10.

Auxiliary Commands:

Typing a comma (",") repeats the command issued from the previous command line. This is very helpful when examining the value at a certain address over time, such as the CE DRAM address for the temperature (0x40).

The slash ("/") is useful to separate comments from commands when sending macro text files via the serial interface. All characters in a line after the slash are ignored.

Commands controlling the CE, TMUX and the RTM:

C	COMPUTE ENGINE, MEMORY, AND CALIBRATION CONTROL	Comment
Description:	Allows the user to enable and configure the compute engine, store and recall configurations, and initiate calibration.	
Usage:	C [option] [argument]	
Command combinations:	CEn	Compute Engine Enable (1 → Enable, 0 → Disable)
	CTn.m	Selects the signal for the TMUX output pins (n = 1 for TMUXOUT, n = 2 for TMUX2OUT). m is interpreted as a decimal number.
	CREn	RTM output control (1 → Enable, 0 → Disable)
	CRSa.b.c.d	Selects CE addresses for RTM output
	CLS	Stores calibration and other settings to EEPROM.
	CLR	Restores calibration and other settings from EEPROM.
	CLD	Restores calibration and other settings to defaults.
	CLB	Start auto-calibration based on voltage (MPU address 0x17, current (MPU 0x18), and duration (MPU 0x16) in seconds.
	CLC	Apply machine-readable calibration control (Intel Hex-Records).
	CPA	Start the accumulating periodic pulse counters.
	CPC	Clear the pulse counters
	CPDn	Activate pulse counters for n seconds
Example:	CE0	Disables CE, ("SYS will stop blinking on the LCD).
	CT1.3	Selects the VBIAS signal for the TMUX output pin

Commands for Identification and Information:

I	INFORMATION MESSAGES	Comment
Description:	Allows the user to read information messages.	
Usage:	I	Sends complete demo code version information on serial interface.
	M0	Displays meter ID on LCD.

The I command is mainly used to identify the revisions of Demo Code and the contained CE code.

Commands for Battery Mode Control and Battery Test:

B	INFORMATION MESSAGES	Comment
Description:	Allows the user to control battery modes and to test the battery.	
Usage:	BL	Enters LCD mode when in brownout mode (B> prompt).
	BS	Enters sleep mode when in brownout mode (B> prompt).
	BT	Starts a battery test – when in mission mode (> prompt).
	BWSn	Set wake timer to n seconds for automatic return to brownout mode.
	BWMn	Set wake timer to n minutes for automatic return to brownout mode.

Commands for Controlling the RTC:

RT	REAL-TIME CLOCK CONTROL	Comment
Description:	Allows the user to read and set the real time clock.	
Usage:	RT [option] [value] ... [value]	
Command combinations:	RTDy.m.d.w: Day of week	(year, month, day, weekday [1 = Sunday]). If the weekday is omitted it is set automatically.
	RTR	Read Real Time Clock.
	RTTh.m.s	Time of day: (hr, min, sec).
	RTAs.t	Real Time Adjust: (start, trim). Allows trimming of the RTC. If s > 0, the speed of the clock will be adjusted by 't' parts per billion (PPB). If the CE is on, the value entered with 't' will be changing with temperature, based on Y_CAL, Y_CALC and Y_CALC2.
	>	Access look-up table for RTC compensation.
Example:	RTD05.03.17.5	Programs the RTC to Thursday, 3/17/2005
	RTA1.+1234	Speeds up the RTC by 1234 PPB.
	>0????	Read the first four bytes in the look-up table.



The "Military Time Format" is used for the RTC, i.e., 15:00 is 3:00 PM.

Commands for Accessing the Trim Control Registers:

T	TRIM CONTROL	Comment
Description:	Allows user to read trim and fuse values.	
Usage:	T [option]	
Command combinations:	T4	Read fuse 4 (TRIMM).
	T5	Read fuse 5 (TRIMBGA)
	T6	Read fuse 6 (TRIMBGB).
Example:	T4	Reads the TRIMM fuse.



These commands are only accessible for the 71M6541H (0.1%) parts. When used on a 71M6541 (0.5%) part, the results will be displayed as zero.

Reset Commands:

W	RESET	Comment
Description:	Watchdog control	
Usage:	W	Halts the Demo Code program, thus suppressing the triggering of the hardware watchdog timer. This will cause a reset, if the watchdog timer is enabled.

Commands for the 71M6X0X Remote Sensor Interface:

6	71M6X0X Interface	Comment
Description:	Commands for control of the Remote Sensor Interface IC.	
Usage:	6En	Remote sensor Enable (1 → Enable, 0 → Disable)
	6Ra.b	Read Remote Sensor IC number a with command b.
	6Ca.b	Write command b to Remote Sensor IC number a.
	6Ta.b	Send command b to Remote Sensor IC number a in a loop forever.
	6T2	Send temp command to 6000 number 2 in a loop forever.
	6R1.20	Reads the temperature from Remote Sensor IC number 1.

Commands for Controlling the Metering Values Shown on the LCD Display:

Step	Text or Numerical Display	CLI command	Displayed Parameter(s)
0	10000 00	M0	Meter ID
1	24.5 °C 01	M1	Temperature difference from calibration temperature.
2	59.9 02	M2	Frequency at the VA_IN input [Hz]
3	3.27 Whr 03	M3	Accumulated imported real energy [Wh]. The default display setting after power-up or reset.
4	1.04 Whr 04	M4	Accumulated exported real energy [Wh].
5	2.21 VARhr 05	M5	Accumulated reactive energy [VARh].
6	0.95 VARhr 06	M6	Accumulated exported reactive energy [VARh].
7	4.11 VAhr 07	M7	Accumulated apparent energy [VAh].
8	0.7 hr 08	M8	Elapsed time since last reset or power up.
9	01:43:59 09	M9	Time of day (hh.mm.ss)
10	01.01.01 10	M10	Date (yy.mm.dd)
11	0.62 11 1	M11.P	Power factor (P = phase)
12	0	M12	Not used in the 71M6541
13	120 13	M13	Zero crossings of the mains voltage
14	48 14	M14	Duration of sag or neutral current [s]
15	24.10 A 15	M15.P	RMS current (P = phase)
16	241.27 V 16	M16	RMS voltage
17	3.34 V 17	M17	Battery voltage
18	241.34 W 18 1	M18	Momentary power in W (P = phase)
19	50400 W 19	M19	Demand
20	88.88.88 88.88.88 88.88.88	M20	LCD Test



Displays for total consumption wrap around at 999.999Wh (or VARh, VAh) due to the limited number of available display digits. Internal registers (counters) of the Demo Code are 64 bits wide and do not wrap around.

1.8.2 USING THE DEMO BOARD FOR ENERGY MEASUREMENTS

The 71M6541 Demo Board was designed for use with shunt resistors connected directly to the IAP/IAN pins of the 71M6541 and via the Remote Sensor Interface and it is shipped in this configuration.

The Demo Board may immediately be used with a 50 $\mu\Omega$ shunt resistor (ANSI) or a 120 $\mu\Omega$ shunt resistor (IEC). It is programmed for a kh factor of 1.0 (see Section 1.8.4 for adjusting the Demo Board for shunts with different resistance).

Once, voltage is applied and load current is flowing, the red LED D5 will flash each time an energy sum of 1.0 Wh is collected. The LCD display will show the accumulated energy in Wh when set to display mode 3 (command >M3 via the serial interface).

Similarly, the red LED D6 will flash each time an energy sum of 1.0 VARh is collected. The LCD display will show the accumulated energy in VARh when set to display mode 5 (command >M5 via the serial interface).

1.8.3 ADJUSTING THE KH FACTOR FOR THE DEMO BOARD

The 71M6541F Demo Board is shipped with a pre-programmed scaling factor Kh of 1.0, i.e., 1.0 Wh per pulse. In order to be used with a calibrated load or a meter calibration system, the board should be connected to the AC power source using the spade terminals on the bottom of the board. The shunt resistor should be connected to the dual-pin header labeled J3 on the bottom of the board.

The Kh value can be derived by reading the values for *IMAX* and *VMAX* (i.e., the RMS current and voltage values that correspond to the 250mV maximum input signal to the IC), and inserting them in the following equation for Kh:

$$Kh = 109.1587 * VMAX * IMAX / (SUM_SAMPS * WRATE * X),$$

See the explanation in section 1.10.4 for an exact definition of the constants and variables involved in the equation above.

1.8.4 ADJUSTING THE DEMO BOARDS TO DIFFERENT SHUNT RESISTORS

The Demo Board is prepared for use with 120 $\mu\Omega$ or 50 $\mu\Omega$ (ANSI option) shunt resistors in both current channels. For the Demo Board, a certain current flowing through the 120 $\mu\Omega$ shunt resistor will result in the maximum voltage drop at the ADC of the 71M6541. This current is defined as *IMAX*.

IMAX will change when different values are used for the shunt resistor(s) which will require that *WRATE* has to be updated as shown in section 1.10.4.

1.8.5 USING THE PRE-AMPLIFIER

In its default setting, the 71M6541 applies a gain of 1 to the current input for phase A (IAP/IAN pins). This gain is controlled with the *PRE_E* bit in I/O RAM (refer to the IC data sheet). The command line interface (RI command) can be used to set or reset this bit. It is recommended to maintain the gain of setting of 1 (RI2704=0x90).

1.8.6 USING CURRENT TRANSFORMERS (CTs)

Phase B of the 71M6541 Demo Board can be equipped with a CT that may be connected at header J8. A burden resistor of 1.7 Ω , or any other value may be installed at the R33 and R34 locations. With a 2000:1 ratio CT, the maximum current for phase B will be 208 A.

Note: The CT configuration will require a different version of the Demo Code.

Current measurements can be displayed for phase B by the demo code, and the corresponding currents can be extracted by the MPU from the CE registers for tamper detection when using the Demo Code for EQU 0.

1.8.7 IMPLEMENTING A SINGLE-PHASE 3-WIRE METER (EQU 1)

This application will require two identical current sensors for each phase. The simplest approach is to use identical shunt resistors for each channel.

1.8.8 ADJUSTING THE DEMO BOARDS TO DIFFERENT VOLTAGE-DIVIDERS

The 71M6541 Demo Board comes equipped with its own network of resistor dividers for voltage measurement mounted on the PCB. The resistor values (for the D6541 REV 3.0 Demo Board) are 2.5477M Ω (R15-R21, R26-R31 combined) and 750 Ω (R32), resulting in a ratio of 1:3,393.933. This means that *VMAX* equals 176.78mV*3,393.933 = 600V. A large value for *VMAX* has been selected in order to have headroom for

overvoltages. This choice need not be of concern, since the ADC in the 71M6541 has enough resolution, even when operating at 120Vrms or 240Vrms.

If a **different set of voltage-dividers** or an external voltage transformer (potential transformer) is to be used, scaling techniques should be used.

In the following example we assume that the line voltage is not applied to the resistor divider for VA formed by R15-R21, R26-R31, and R32, but to a voltage transformer with a ratio N of 20:1, followed by a simple resistor divider. We also assume that we want to maintain the value for VMAX at 600V to provide headroom for large voltage excursions.

When applying VMAX at the primary side of the transformer, the secondary voltage V_s is:

$$V_s = V_{MAX} / N$$

V_s is scaled by the resistor divider ratio R_R . When the input voltage to the voltage channel of the 71M6541 is the desired 177mV, V_s is then given by:

$$V_s = R_R * 177\text{mV}$$

Resolving for R_R , we get:

$$R_R = (V_{MAX} / N) / 177\text{mV} = (600\text{V} / 20) / 177\text{mV} = 170.45$$

This divider ratio can be implemented, for example, with a combination of one 16.95 k Ω and one 100 Ω resistor.

If potential transformers (PTs) are used instead of resistor dividers, phase shifts will be introduced that will require negative phase angle compensation. Maxim Integrated Demo Code accepts negative calibration factors for phase.

1.9 CALIBRATION PARAMETERS

1.9.1 GENERAL CALIBRATION PROCEDURE

Any calibration method can be used with the 71M6541F chips. This Demo Board User's Manual presents calibration methods with three or five measurements as recommended methods, because they work with most manual calibration systems based on counting "pulses" (emitted by LEDs on the meter).

Naturally, a meter in mass production will be equipped with special calibration code offering capabilities beyond those of the 71M6541 Demo Code. It is basically possible to calibrate using voltage and current readings, with or without pulses involved. For this purpose, the MPU Demo Code can be modified to display averaged voltage and current values (as opposed to momentary values). Also, automated calibration equipment can communicate with the Demo Boards via the serial interface and extract voltage and current readings. This is possible even with the unmodified Demo Code.

Complete calibration procedures are given in section 2.3 of this manual.

Regardless of the calibration procedure used, parameters (calibration factors) will result that will have to be applied to the 71M6541F chip in order to make the chip apply the modified gains and phase shifts necessary for accurate operation. Table 1-4 shows the names of the calibration factors, their function, and their location in the CE RAM.

Again, the command line interface can be used to store the calibration factors in their respective CE RAM addresses. For example, the command

```
>J10=+16302
```

stores the decimal value 16302 in the CE RAM location controlling the gain of the current channel (CAL_IA).

The command

```
>J11=4005
```

stores the hexadecimal value 0x4005 (decimal 16389) in the CE RAM location controlling the gain of the voltage channel (CAL_VA).

The internal power supply generates a ripple on the supply and ground nets that is 90° phase shifted with respect to the AC supply voltage. This affects the accuracy of the VARh measurements. If optimization of the VARh accuracy is required, this can be done by writing a value into the QUANT_VAR register of the CE (see section 2.3.7).

Table 1-4: CE RAM Locations for Calibration Constants

Coefficient	CE Address (hex)	Description
<i>CAL_VA</i>	0x11	Adjusts the gain of the voltage channels. +16384 is the typical value. The gain is directly proportional to the CAL parameter. Allowed range is 0 to 32767. If the gain is 1% slow, CAL should be increased by 1%.
<i>CAL_IA</i> <i>CAL_IB</i>	0x10 0x13	Adjusts the gain of the current channels. +16384 is the typical value. The gain is directly proportional to the CAL parameter. Allowed range is 0 to 32767. If the gain is 1% slow, CAL should be increased by 1%.
<i>PHADJ_A</i> <i>LCOMP2_B</i>	0x12 0x15	This constant controls the phase compensation. No compensation occurs in a phase when <i>PHADJ_A</i> = 0 or when <i>LCOMP2_n</i> = 16384. As <i>LCOMP2_n</i> is increased, more compensation is introduced. CE codes for CT configuration do not use delay adjustment. These codes use phase adjustment (<i>PHADJ_n</i>).

1.9.2 CALIBRATION MACRO FILE

The macro file in Figure 1-4 contains a sequence of the serial interface commands. It is a simple text file and can be created with Notepad or an equivalent ASCII editor program. The file is executed with HyperTerminal's *Transfer->Send Text File* command.

```
CE0      /disable CE
]10=+16022 /CAL_IA (gain=CAL_IA/16384)
]11=+16381 /CAL_VA (gain=CAL_VA/16384)
]12=+115   /PHADJ_A (default 0)
CE1      /enable CE
```

Figure 1-4: Typical Calibration Macro File

It is possible to send the calibration macro file to the 71M6541F for “temporary” calibration. This will temporarily change the CE data values. Upon power up, these values are refreshed back to the default values stored in flash memory. Thus, until the flash memory is updated, the macro file must be loaded each time the part is powered up. The macro file is run by sending it with the *transfer → send text file* procedure of HyperTerminal.



Use the *Transfer → Send Text File* command!

1.9.3 UPDATING THE DEMO CODE (HEX FILE)

The *d_merge* program updates the hex file (usually named *6541_1p2b_19jan09.hex* or similar) with the values contained in the macro file. This program is executed from a DOS command line window. Executing the *d_merge* program with no arguments will display the syntax description. To merge *macro.txt* and *old_6541_demo.hex* into *new_6541_demo.hex*, use the command:

d_merge old_6541_demo.hex macro.txt new_6541_demo.hex

The new hex file can be written to the 71M6541F/71M6541H through the ICE port using the ADM-51 in-circuit emulator or the TFP-2 flash programmer.

1.9.4 UPDATING CALIBRATION DATA IN FLASH OR EEPROM

It is possible to make data permanent that had been entered temporarily into the CE RAM. The transfer to EEPROM memory is done using the following serial interface command:

>]CLS

Thus, after transferring calibration data with manual serial interface commands or with a macro file, all that has to be done is invoking the U command.

Similarly, calibration data can be restored to default values using the CLD command.



After reset, calibration data is copied from the EEPROM, if present. Otherwise, calibration data is copied from the flash memory. Writing 0xFF into the first few bytes of the EEPROM deactivates any calibration data previously stored to the EEPROM.

1.9.5 LOADING THE CODE FOR THE 71M6541 INTO THE DEMO BOARD

Hardware Interface for Programming: The 71M6541F IC provides an interface for loading code into the internal flash memory. This interface consists of the following signals:

E_RXTX (data), E_TCLK (clock), E_RST (reset), ICE_E (ICE enable)

These signals, along with V3P3D and GND are available on the emulator headers J14.

Programming of the flash memory requires a specific in-circuit emulator, the ADM-51 by Signum Systems (www.signum.com) or the Flash Programmer (TFP2) available through Digi-Key (www.digikey.com) or Mouser Electronics (www.mouser.com).

Chips may also be programmed before they are soldered to the board. Gang programmers suitable for high-volume production are available from BPM Microsystems (www.bpmmicro.com).

In-Circuit Emulator: If firmware exists in the 71M6541F flash memory; it has to be erased before loading a new file into memory. Figure 1-5 and Figure 1-6 show the emulator software active. In order to erase the flash memory, the RESET button of the emulator software has to be clicked followed by the ERASE button.

To successfully erase the flash memory, the following steps have to be taken:

- 1) Disable the CE by writing 0x00 to address 0x2000
- 2) Write 0x20 to address 0x2702 (*FLSH_UNLOCK[]* register in I/O RAM)
- 3) Reset the demo board (RESET button or power cycle)
- 4) Activate the ERASE button in the WEMU51 user interface
- 5) Now, new code can be loaded into the flash memory

Once the flash memory is erased, the new file can be loaded using the commands File followed by Load. The dialog box shown in Figure 1-6 will then appear making it possible to select the file to be loaded by clicking the Browse button. Once the file is selected, pressing the OK button will load the file into the flash memory of the 71M6541F IC.

At this point, the emulator probe (cable) can be removed. Once the 71M6541F IC is reset using the reset button on the Demo Board, the new code starts executing.

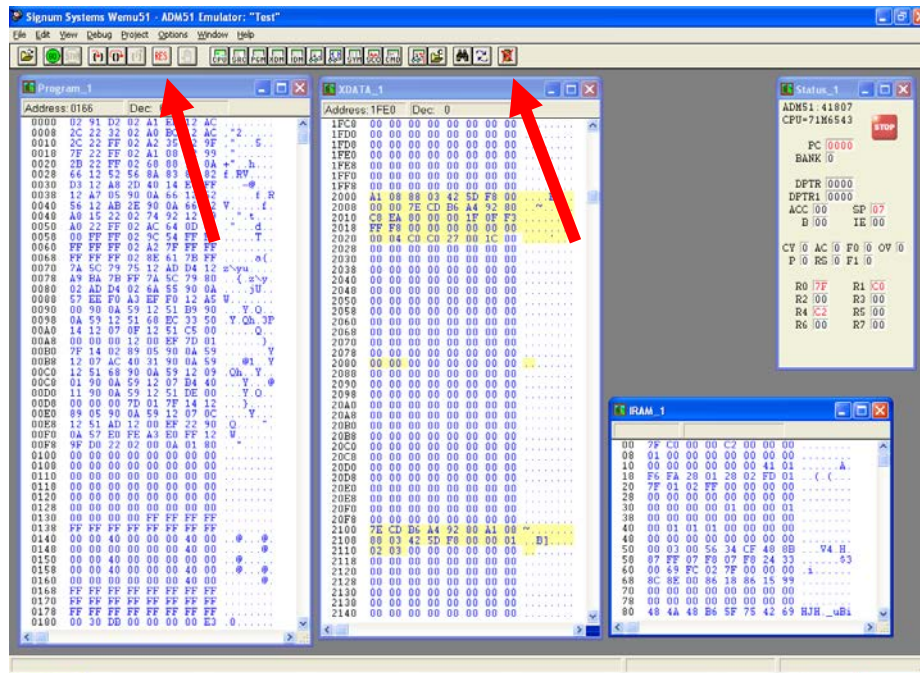


Figure 1-5: Emulator Window Showing Reset and Erase Buttons (see Arrows)

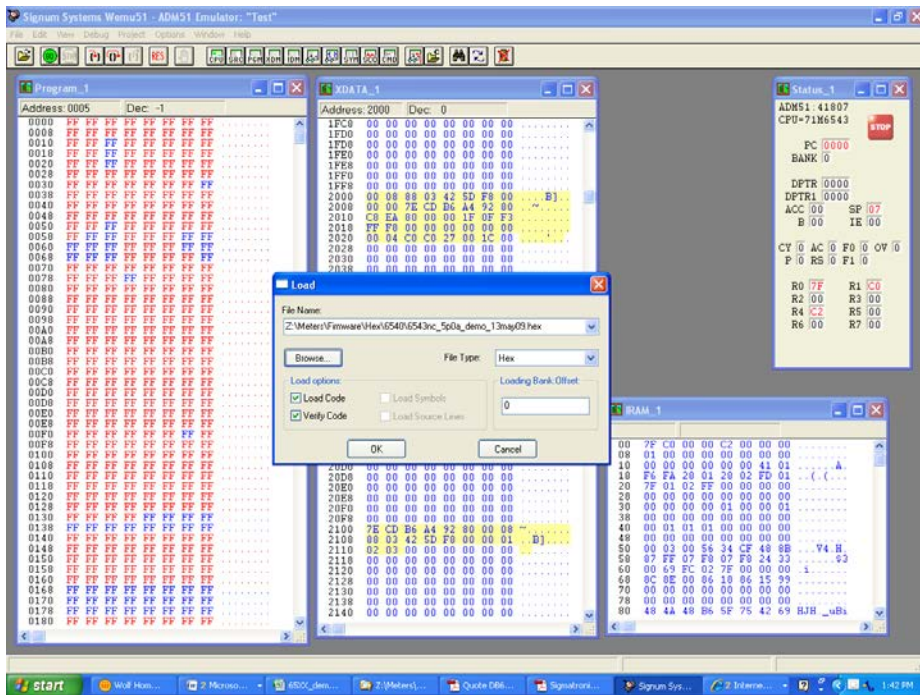


Figure 1-6: Emulator Window Showing Erased Flash Memory and File Load Menu

Flash Programmer Module (TFP-2): The operational firmware of the TFP2 will have to be upgraded to revision 1.53. Follow the instructions given in the User Manual for the TFP-2.

1.9.6 THE PROGRAMMING INTERFACE OF THE 71M6541

Flash Downloader/ICE Interface Signals

The signals listed in Table 1-5 are necessary for communication between the Flash Downloader or ICE and the 71M6541.

Signal	Direction	Function
ICE_E	Input to the 71M6541	ICE interface is enabled when ICE_E is pulled high
E_TCLK	Output from 71M6541	Data clock
E_RTX	Bi-directional	Data input/output
E_RST	Bi-directional	Flash Downloader Reset (active low)

Table 1-5: Flash Programming Interface Signals



The E_RST signal should only be driven by the Flash Downloader when enabling these interface signals. The Flash Downloader must release E_RST at all other times.

1.10 DEMO CODE

1.10.1 DEMO CODE DESCRIPTION

The Demo Board is shipped preloaded with Demo Code in the 71M6541F chip. The code revision can easily be verified by entering the command `>i` via the serial interface (see section 1.8.1). Check with your local Maxim Integrated representative or FAE for the latest revision.

The Demo Code is provided in two different versions:

- Single-phase two-wire operation (EQU 0, with secondary tamper sensor). Energy measurement and Wh/VARh pulses are based solely on VA (phase A voltage) and IA (phase A current). Energy and current values for IB (secondary phase) are available as CE outputs to the MPU for processing of tampering events.
- Single-phase three-wire operation (ANSI configuration, EQU 1). Energy measurements and Wh/VARh pulses are based on $VA (IA - IB) / 2$.

Both Demo Code versions use the same CE code, but with different settings of the *EQU* register.

The Demo Code offers the following features:

- It provides basic metering functions such as pulse generation, display of accumulated energy, frequency, date/time, and enables the user to evaluate the parameters of the metering IC such as accuracy, harmonic performance, etc.
- It maintains and provides access to basic household functions such as the real-time clock (RTC).
- It provides access to control and display functions via the serial interface, enabling the user to view and modify a variety of meter parameters such as Kh, calibration coefficients, temperature compensation etc.
- It provides libraries for access of low-level IC functions to serve as building blocks for code development.

A detailed description of the Demo Code can be found in the Software User's Guide (SUG). In addition, the comments contained in the library provided with the Demo Kit can serve as useful documentation.

The Software User's Guide contains the following information:

- Design guide
- Design reference for routines
- Tool Installation Guide
- List of library functions
- 80515 MPU Reference (hardware, instruction set, memory, registers)

1.10.2 IMPORTANT MPU ADDRESSES

In the demo code, certain MPU XRAM parameters have been given addresses in order to permit easy external access. These variables can be read via the command line interface (if available), with the `)n$` command and written with the `)n=xx` command where *n* is the word address. Note that accumulation variables are 64 bits long and are accessed with `)n$$` (read) and `)n=hh=ll` (write) in the case of accumulation variables.

The first part of the table, the addresses)00..)1F, contains adjustments, i.e., numbers that may need adjustment in a demonstration meter, and so are part of the calibration for demo code. In a reference meter, these may be in an unchanging table in code space.

The second part,)20..)2F, pertains to calibration, i.e., variables that are likely to need individual adjustments for quality production meters.

The third part,)30..., pertains to measurements, i.e., variables and registers that may need to be read in a demonstration meter.

Table 1-6: MPU XRAM Locations

Name	Purpose	LSB	Default	)?	Signed?	Bits
i_min	Metering element enters creep mode if current is below this value. If 0, creep logic is disabled. In creep mode, on each metering element, Wh, VARh, i0sqsum, and other items are zeroed.	Same units as CE's i0sqsum.	0.08A	)0	signed	32
cfg	Configure meter operation on the fly.	bit0: 1=Display KWh. bit1: 1=clear accumulators, errors, etc. (e.g., "1=2") bit2: 1=Reset demand. (e.g., "1=4") bit3: 1=CE Raw mode. MPU does not change CE values with creep or small current calculations. bit5: 1= Send a message once per second for IEC 62056-217 Mode D on UART 1, at 2400 BAUD, even parity. The meter's serial number and current Wh display are sent as data. UART 1 is routed to an IR LED if possible. Mode D data fields are prefaced with OBIS codes in legacy format. ^{7,1} bit6: 1=Auto calibration mode ¹ bit7: 1=Enable Tamper Detect ^{2,1}	0 Do nothing special.	)1	N/A	8
v_min	error if below. Also creep.* Below this, low voltage seconds are counted. Voltage, Wh, VARh, Frequency, and other voltage-dependent items are zeroed.	Same units as CE's v0sqsum.	40V	)2	signed	32
i_max	Scaling Maximum Amps for standard sensor.	0.1A	110.5 for 200 $\mu\Omega$ shunt with 8x preamp. 884.0 A for 200 $\mu\Omega$ shunt, 442.0A for 400 $\mu\Omega$ shunt.	)3	signed	16
v_max	Scaling Maximum Volts for PCB	0.1V	600 V, for the 6541 REV 3.0 Demo Board.	)4	signed	16
i_limit	Error if exceeded.	Same units as CE's i0sqsum.	50.9A = $30A \cdot \sqrt{2}$ *120%	)5	signed	32

v_limit	Error if exceeded.*	Same units as CE's v0sqsum.	407.3V = $240V \cdot \sqrt{2} \cdot 120\%$	)6	signed	32
wrate_mpu	Convert from CE counts to pulses.	CE's w0sum units per pulse, rounded up to next largest CE count so Wh accumulation and display is always rounded down.	3.2 Wh for 3-phase 1.0 Wh for 1-phase	)7	signed	32
interval	The number of minutes of a demand interval.	Count of minutes. $(60/\text{interval}) \cdot \text{interval} = 60$.	2 minutes.	)8	unsigned	8
mains_hz	Expected number of cycles per second of mains. 0 disables the software RTC run from mains.	Hz	0	)9	unsigned	8
temp_cal1	Machine-readable units per 0.1C	Refer to the IC data sheet. Temperature is calculated as $\text{temp} = (\text{measured_temp} - \text{temp_datum}) / \text{temp_cal1} + \text{temp_cal0}$	Refer to the IC data sheet.	)A	signed	32
mtr_cal1 [0..3] ⁹	Linear temperature calibration for meter elements A..D.	$\text{ppm} \cdot (T - \text{mtr_datum})$, in 0.1°C	150	)B..E	signed	16
mtr_cal2 [0..3] ⁹	Squared temperature calibration for meter elements A..D.	$\text{ppm}^2 \cdot (T - \text{mtr_datum})^2$, in 0.1°C	-392	)F..1 2	signed	16
y_datum	Center temperature of the crystal.	0.1C	25C	)13	signed	16
y_cal1 ⁵	RTC adjust, linear by temp.	$10\text{ppb} \cdot (T - y_datum)$, in 0.1°C	0	)14	signed	16
y_cal2 ⁵	RTC adjust, squared by temp.	$1\text{ppb} \cdot (T - y_datum)^2$, in 0.1°C	38	)15	signed	16
s_cal ¹	Accumulation intervals of Autocalibration	Count of accumulation intervals of calibration.	accumulation intervals cover both chop polarities.	)16	signed	16
v_cal ¹	Volts of Autocalibration	0.1V rms of AC signal applied to all elements during calibration.	2400 240 V is a standard full-scale setup for meter test.	)17	signed	16
i_cal ¹	Amps of Autocalibration	0.1A rms of AC signal applied to all elements during calibration. Power factor of calibration signal must be 1.	300 30 A is a standard full-scale setup for meter test.	)18	signed	16

lcd_idx	Selects LCD's current display.	0: Meter identification. ("##") 1: Display variation from calibration temperature, 0.1C 2: Display mains Hz, 0.1 Hz 3: mWh, total 4: mWh total exported. 5: mVARh, total. 6: mVARh, total exported. 7:mVAh, total 8: Operating hours. 9: Time of day 10: Calendar date 11: Power factor, total 12: Angle between phase 0 & 1 13: Main edge count, last accumulation. 14: KW, instantaneous total 15: V, instantaneous max of all phases. 16: A, total 17: V, Battery ("VB") 18: Seconds, bad power ("BPS") 19: Seconds, tamper (- = tamper in progress) ("TS") 20: LCD Test Scrolling not standard for these: 111: PF, phase 0 112: Angle, phase 0 & 1 114: KW, phase 0 115: V, phase 0 116: A, phase 0 211: PF, phase 1 212: Angle, phase 0 & 2 214: KW, phase 1 215: V, phase 1 216: A, phase 1 311: PF, phase 2 312: Angle, phase 2.0 314: KW, phase 2 315: V, phase 2 316: A, phase 2 416: A, neutral (measured)	3	)19	signed	16
lcd_bit	Defines sequence of LCD displays.	The value is a bit mask that describes a scrolling display sequence. Each set bit permits a display with an lcd_idx value from 0..31. Each is displayed for 7 seconds. Ordered by increasing bit number. If value is zero, display does not change.	0	)1A	unsigned	32
mfr_id ⁶	Manufacturer's ID text string of the meter	3 ASCII bytes, in MSB of 32-bit number. Least significant byte should be zero. For AMR demonstrations, sent as the manufacturer's ID of the meter.	"TSC", 0x54534300	)1B	unsigned	32

i_max2 ⁴	Like i_max, except for the 2nd current sensor. Currents, Wh etc. using currents from the second sensor are rescaled into the same units as the first current sensor.	0.1 Amps	208 A (2080)	)1C	signed	16
in_limit ³	Maximum valid neutral current.	Same units as CE's i3sqsum.	0.1A	)1D	signed	32
in_wait ³	The time that neutral current can exceed n_max before the neutral error is asserted.	Count of accumulation intervals.	10 secs.	)1E	signed	16
Reserved				)1F		
meter_id ⁸	Identification number of meter.	32 bit unsigned number. For AMR demonstrations, this is sent in decimal as the identification number of the meter.	100000000	)20	signed	32
temp_datum ⁸	Count of temperature sensor at calibration.	Refer to the IC data sheet. Temperature is calculated as temp = (measured_temp – temp_datum)/temp_cal1 + temp_cal0	n/a	)21	signed	32
mtr_datum[0..3] ⁸	Center temperature of a meter element's temperature curve.	0.1C	22C	)22..25	signed	16
rtca_adj ⁸	Default value for RTCA_ADJ, the crystal's capacitor adjustment.	Refer to the IC data sheet. Set from hardware value when hardware is changed.	Hardware default (refer to the IC data sheet).	)26	unsigned	8
y_cal0 ^{5,8}	RTC offset rate adjust	100ppb	0	)27	signed	16
v_bat_min ⁸	Minimum valid battery voltage.	Units of hardware's battery measurement register.	2V on a real PCB; should be adjusted for battery and chip.	)28	signed	32
cal_cnt	Count of calibrations. In demo code, it also checks adjustments.	Counts number of times calibration is saved, to a maximum of 255.	0	)29	unsigned	8
ver_hash	Checked to prevent old calibration data from being used by new code. Value that changes with the banner text, and therefore with the version, date and time.	Uses data_ok() to calculate a value from the string.	n/a	)2A	unsigned	8
data_ok_cal	Checks calibrations. In demo code, it also checks adjustments.	Checked by data_ok() of calibration value.	n/a	)2B	unsigned	16
Reserved				)2C..2F		

state_bit_ar_y	Status of meter. Nonvolatile.	Bits: See table below.	0 = no errors	)30	unsigned	32
wh_im	Wh energy register. Nonvolatile.	First 32-bit number is a count of pulses, ≈ 3.2 Wh in 3-phase meters, or 1 in 1-phase. A fractional pulse is present in the CE data, but not preserved.	n/a	)31		64
wh_ex	Wh exported energy register. Nonvolatile.	Like wh_im	n/a	)32		64
varh_im	VARh register. Nonvolatile.	Like wh_im	n/a	)33		64
varh_ex	VARh exported register. Nonvolatile.	Like wh_im	n/a	)34		64
dmd_max	Maximum demand, W	Units of w0sum	n/a	)35	signed	32
dmd_max_rtc	Time of maximum demand.	Standard time and date structure.	year, month, date, hour, min	)36.. 3A	unsigned	7x8
v_bat	Battery voltage at last measurement. Volatile; not saved on power failure.	0.1V	n/a	)3B	signed	8
acc_cnt	Count of accumulation intervals since reset, or last clear. Cleared with)1=2 or meter read. Volatile; not saved on power failure.	count	n/a	)3C	signed	32
tamper_sec	Counts seconds that tamper errors were asserted. Cleared with)1=2 or meter read. Nonvolatile.	This is a tamper measurement.	n/a	)3D	signed	32
sag_sec	Counts seconds that voltage low error occurred. or meter read. Nonvolatile.	This is a power quality measurement.	n/a	)3E	signed	32
in_sec ³	Counts seconds that neutral current error was asserted. Cleared with)1=2 or meter read. Nonvolatile.	This is a power quality measurement.	n/a	)3F	signed	32
rtc_copy	Clock time and date when data was last read from the RTC.	Standard time and date structure. year, month, date, hour, min, sec	n/a	)40.. 45	unsigned	8*7
save_cnt	Number of power register saves.	n/a	n/a	)46	unsigned	16
data_ok_reg	Checks data.	n/a	n/a	)47	unsigned	16

¹ Valid only when autocalibration is integrated. Meters with metering equations with differential currents or voltages do not normally support autocalibration.

² Requires features not in some demo PCBs.

³ Three-phase ICs only. Some CE codes calculate neutral current rather than measuring it. Consult the CE documentation.

⁴ Only in systems with two current sensors.

⁵ High accuracy use of this feature may require a calibrated clock.

⁶ IEC 62056 Manufacturers' IDs are allocated by the FLAG Association Limited. Maxim Integrated does not own or profit from the FLAG association. Maxim Integrated's default id may not conform, and is for demonstration purposes only.

⁷ Nothing in the document should be interpreted as a guarantee of conformance to a third-party software specification. Conformance testing is the responsibility of a meter manufacturer.

⁸ May require calibration for best accuracy.

⁹ Calibration item in high-precision "H" series meters (71M6541H only).

Table 1-7: Bits in the MPU Status Word

Name	Bit No.	Explanation
<i>MINIA</i>	0	IA is below IThrshld. Current for this phase is in creep.
<i>MINIB</i>	1	IB is below IThrshld. Current for this phase is in creep.
<i>MINIC</i>	2	IC is below IThrshld. Current for this phase is in creep.
<i>MINVA</i>	3	VA is below VThrshld. Voltage for this phase is in creep.
<i>MINVB</i>	4	VB is below VThrshld. Voltage for this phase is in creep.
<i>MINVC</i>	5	VC is below VThrshld. Voltage for this phase is in creep.
<i>CREEPV</i>	6	All voltages are below VThrshld.
<i>CREEP</i>	7	There is no combination of current and voltage on any phase.
<i>SOFTWARE</i>	8	A software defect was detected. error_software() was called. For example: An impossible value occurred in a selection, or the timers ran out.
<i>NEUTRAL</i>	9	Neutral current was above in_limit for more than in_wait seconds.
<i>SPURIOUS</i>	10	An unexpected interrupt was detected.
<i>SAG</i>	11	Voltage was below VThrshld for more than in_wait seconds
<i>DEMAND</i>	12	Demand was too big (too many watts) to be credible.
<i>CALIBRATION</i>	13	Set after reset if the read of the calibration data has a bad checksum, or is from an earlier version of software. The default values should be present.
<i>RTC_UNSET</i>	14	Set when the clock's current reading is A) Obtained after a cold start, indicating that there was no battery power, and therefore the clock has to be invalid. B) More than a year after the previously saved reading, or C) Earlier than the previously saved reading. In this case, the clock's time is preserved, but the clock can't be trusted.
<i>HARDWARE</i>	15	An impossible hardware condition was detected. For example, the software times out waiting for RTC_RD to become zero.
<i>BATTERY_BAD</i>	16	Just after midnight, the demo code sets this bit if VBat < VBatMin. The read is infrequent to reduce battery loading to very low values. When the battery voltage is being displayed, the read occurs every second, for up to 20 seconds.
<i>REGISTER_BAD</i>	17	Set after reset when the read of the power register data has a bad longitudinal redundancy check or bad software version in all 5 copies. Unlikely to be an accident.
<i>RTC_TAMPER</i>	18	Clock set to a new value more than two hours from the previous value.
<i>TAMPER</i>	19	Tamper was detected. Normally this is a power tamper detected in the creep logic. For example, current detected with no voltage.

Table 1-8 contains LSB values for the CE registers used in the CE code for EQU 0 and EQU 1. All values are based on the following settings:

- Gain in amplifier for IAP/IAN pins selected to 1.
- 71M6103 or 71M6113 Remote Sensor Interface is used.

Note that some of the register contents can be zeroed out by the MPU when it applies functions contained in its creep logic.

1.10.3 LSB VALUES IN CE REGISTERS

Table 1-8: CE Registers and Associated LSB Values

Register Name	LSB Value	Comment
<i>W0SUM_X</i>	$1.55124 \times 10^{-12} \times I_{MAX} \times V_{MAX}$	The real energy for element 1 (IA, VA), measured in Wh per accumulation interval
<i>VAR0SUM_X</i>	$1.55124 \times 10^{-12} \times I_{MAX} \times V_{MAX}$	The reactive energy for element 1 (IA, VA), measured in VARh per accumulation interval
<i>W1SUM_X</i>	$1.55124 \times 10^{-12} \times I_{MAX} \times V_{MAX}$	The real energy for element 2 (IB, VA), measured in Wh per accumulation interval
<i>VAR1SUM_X</i>	$1.55124 \times 10^{-12} \times I_{MAX} \times V_{MAX}$	The reactive energy for element 2 (IB, VA), measured in VARh per accumulation interval
<i>I0SQSUM_X</i>	$2.55872 \times 10^{-12} \times I_{MAX} \times V_{MAX}$	The sum of squared current samples in element 1 (IA). This value is the basis for the I_{RMS} calculation performed in the MPU.
<i>I1SQSUM_X</i>	$2.5587 \times 10^{-12} \times I_{MAX} \times V_{MAX}$	The sum of squared current samples in element 2 (IB). This value is the basis for the I_{RMS} calculation performed in the MPU.
<i>V0SQSUM_X</i>	$9.40448 \times 10^{-13} \times I_{MAX} \times V_{MAX}$	The sum of squared voltage samples in element 1 (VA).
<i>V1SQSUM_X</i>	$9.40448 \times 10^{-13} \times I_{MAX} \times V_{MAX}$	The sum of squared voltage samples in element 1 (VA). This value is not used for EQU 0 or EQU 1.

1.10.4 CALCULATING I_{MAX} AND K_H

The relationship between the resistance of the shunt resistors and the system variable *I_{MAX}* is determined by the type of Remote Sensor Interface used, and is as follows:

$$I_{MAX} = 0.044194 / R_S \text{ for the 71M6601}$$

$$I_{MAX} = 0.012627 / R_S \text{ for the 71M6201}$$

Where:

R_S = Shunt resistance in Ω

Table 1-9 shows *I_{MAX}* values resulting from possible combinations of the shunt resistance value and the type of 71M6X0X Remote Sensor Interface used for the application. All values are for *PRE_E* = 0 (I/O RAM register 2704 = 0x90), *PULSE_FAST* = 0, and *PULSE_SLOW* = 0. The CE register at address 0x30 has to be adjusted as shown in the rightmost column of the table.

Table 1-9: IMAX for Various Shunt Resistance Values and Remote Sensor Types

Remote Sensor Interface	Rated Current [A]	Max. Voltage at IAP/IAN [mV]	Shunt Resistor Value [$\mu\Omega$]	IMAX [A]	IMAX Entry at MPU 0x03	WRATE for $kH = 1.0$ and $VMAX = 600$ V	CE address 0x30
71M6601	60	62.5	500	88.39	+884	383	2483
			400	110.49	+1105	497	2483
			300	147.31	+1473	638	2483
			250	176.78	+1768	766	2483
			200	220.97	+2209	957	2483
			160	276.21	+2762	1196	2483
			120	368.28	+3683	1595	2483
71M6201	200	17.86	75	168.4	+1684	729	8691
			50	252.6	+2526	1094	8691
			25	505.1	+5051	2188	8691

The meter constant k_h (Wh per pulse) is calculated as follows:

$$k_h = 109.1587 \cdot VMAX \cdot IMAX / (SUM_SAMPS \cdot WRATE \cdot X),$$

where

$VMAX$ = RMS voltage at the meter input corresponding to 176.8 mV RMS at the VA pin of the 71M6541. This value is determined by the divider ratio of the voltage-divider resistors. For the 71M6541 Demo Board, this value is 600.

$IMAX$ = RMS current through one current sensor corresponding to 176.8 mV RMS at the IAP/IAN or IBP/IBN pins of the 71M6541, as determined by the formula above.

Note: For the IBP/IBN pins, no physical analog voltage exists due to the digital nature of the current measurement via the remote interface.

SUM_SAMPS = The value in the SUM_SAMPS register in I/O RAM (2520 for this version of the Demo Code).

$WRATE$ = The value in the pulse rate adjustment register of the CE.

X = The pulse rate adjustment modifier, determined by the $PULSE_FAST$ and $PULSE_SLOW$ bits in the $CECONFIG$ register.

A k_h of 1 (1.00 Wh per pulse) is achieved by the following combination of system settings:

$VMAX = 600$ V

$IMAX = 368.3$ A, based on $R_S = 120 \mu\Omega$

$SUM_SAMPS = 2520$

$WRATE = 1595$, based on $X = 6$, and $PULSE_FAST = 0$ and $PULSE_SLOW = 0$

1.10.5 DETERMINING THE TYPE OF 71M6X0X

Sometimes it is useful to be able to determine the type of 71M6X0X Remote Sensor Interface that is mounted on the Demo Board. The CLI can be used to find out which 71M6X0X Remote Sensor Interface is present, using the following steps:

- 1) Type 6R1.14 at the command prompt (>).
- 2) The CLI will respond with a two-byte hex value, e.g., E9DB.
- 3) Write the hex value out as binary sequence, e.g., 1110 1001 1101 1011. Bits 4 and 5 determine the type of the 71M6X0X Remote Sensor Interface, as shown in Table 1-10.

Table 1-10: Identification of 71M6X0X Remote Sensor Types

Bit 5/Bit 4	71M6X0X Remote Interface	Current Range [A]
00	71M6601 or 71M6603	60
01	71M6103 or 71M6113 (Poly-Phase)	100
10	71M6201 or 71M6203	200
11	Invalid	--

1.10.6 COMMUNICATING WITH THE 71M6X0X

Some commands are useful to communicate with the 71M6X0X Remote Sensor Interface for the purpose of test and diagnosis. Some useful commands are:

- 1) 6C1.42 – this command causes the 71M6X0X Remote Sensor Interface to output its reference voltage on the TMUX pin (pin 5).
- 2) 6R1.20 – this command returns the reading from the temperature sensor (STEMP) of the 71M6X0X Remote Sensor Interface in a two-byte hexadecimal format (e.g., FFDF). Negative readings are signaled by the MSB being 1.
 $T = 22^{\circ}\text{C} + (\text{STEMP} * 0.337 - (\text{STEMP}^2) * 0.00015)^{\circ}\text{C}$
 Example: For STEMP = 0xFFDF the decimal equivalent is -32. The temperature calculates to $22^{\circ}\text{C} - 10.9^{\circ}\text{C} = 11.1^{\circ}\text{C}$.
 Note that the IC temperature is averaged and displayed more accurately with the M1 command.

1.10.7 BOOTLOADER FEATURE

Demo Codes 5.4F and later are equipped with a bootloader feature. This feature allows the loading of code via the serial interface (USB connector CN1) when a Signum ADM-51 emulator or the Maxim Integrated TFP2 Flash Loader is not available.

The bootloader functions as follows:

- 1) Meter code must be modified in order to be loaded by the bootloader. The meter code must start at address 0x0400, and its interrupt vector table must also start at 0x400. The bootloader itself is located at address 0x0000 and must be loaded into the IC by some method if the flash memory of the 71M6543 is empty or if code of a previous revision is loaded. The bootloader is part of Demo Code 5.4F.
- 2) The bootloader loads Intel hex-86 files at 38,400 baud 8 bits, no parity. It will only accept record types 0, 4 and 1, which are the types produced by Maxim Integrated's bank_merge program or checksum program, and the Keil compiler (PK51). No records may overlap. (Keil, bank_merge and checksum produce this style of hex file by default.)
 The records from 0x00000 to 0x00400 are ignored, so that the bootloader can't overwrite itself.
- 3) If the bootloader load process is not invoked, the bootloader jumps to address 0x0400 and executes the code found there.
- 4) A detailed description of the bootloader can be found in the _readme.txt file contained in the source code ZIP package.

For a 71M6541-DB containing code with the bootloader, instructions for loading new code are as follows:

- 1) Connect a PC running HyperTerminal or a similar terminal program to the DB6543. Set the program to 38,400 baud 8 bits, no parity, XON/XOFF flow control.
- 2) Turn off the power to the 71M6541-DB.
- 3) Install a jumper from board ground to the VARh pulse output (JP59, right pin), which is also SEGDI01. A low voltage on this pin signals to the bootloader that new code should be loaded via the UART.
- 4) Apply power to the meter.
- 5) After a brief delay, the Wh pulse LED (D5) will light up (SEGDI00). The bootloader should send a ":" on the UART to the PC. If this occurs, the flash is erased, and the 71M6541-DB is ready to load code.
 - If this does not occur, check the jumper, and reset or repower the unit
 - If the Wh LED still does not light up, then the boot code is not installed.
 - If the Wh LED lights up, but the ":" does not appear, debug the RS-232 wiring. Possible issues are that the baud rate is not 38400 baud, or that the wiring is wrong, (debug using a known-good meter), or that the terminal program in the PC is not working.

- 6) Send the Intel hex file built for operation with the bootloader (e.g., 6541eq0_5p4g_07feb12.hex) using the 'Send Text File' command of HyperTerminal.
- 7) During the load procedure, the Wh LED will blink. Once the load process is completed it stops blinking. The Wh LED should remain on solidly at the completion of the load procedure, which indicates an error-free load. If the LED turns off at the end, an error must have occurred. In this case the load should be repeated. The bootloader sends a "1" on the UART if the load succeeded, and "0" if it failed.
- 8) Check the display of terminal program (e.g., the PC running Hyperterminal). If no checksum error has occurred, the bootloader sends a 1 on the UART. In case of an error, reset the DB6543, or turn it off and on, and reload the code.
- 9) Remove the jumper on JP7. This will cause the loaded Demo Code to start.

2

2 APPLICATION INFORMATION

2.1 SENSOR CONNECTIONS AND EQUATIONS

The 71M6541 Demo Board supports the following meter configurations and equations:

- Single-phase two-wire (EQU 0)
- Single-phase three-wire (EQU 1)

Note: Support of EQU 2 requires the 71M6542 IC, which will be available on a separate Demo Board.



CAUTION: THE DIAGRAMS SHOWN IN THIS SECTION ARE SYMBOLIC AND DO NOT REFLECT THE PHYSICAL CONNECTIONS OF THE DEMO BOARD!



THE GROUND OF THE DEMO BOARD IS AT LINE (LIVE) VOLTAGE!

2.1.1 SENSOR WIRING

The Demo Board is referenced to LINE voltage. This means that the sensor wires have to be connected as shown in Figure 2-1.

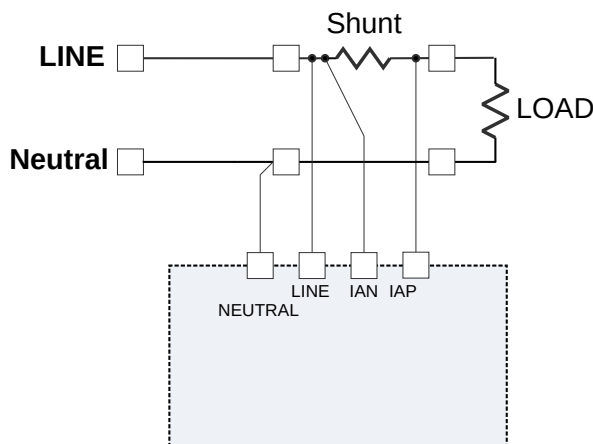


Figure 2-1: Shunt Connections

2.1.2 SINGLE-PHASE TWO-WIRE (EQU 0)

This is the most basic configuration for this Demo Board. The current sensor is connected directly to the IAP/IAN inputs of the 71M6541 (see Figure 2-2). The energy measurement is based on the following equation:

$$P = VA * IA$$

See the explanation below Table 1-8 for the calculation of *IMAX*.

A second current sensor can be connected to the IBP/IBN inputs of the 71M6541, for example to detect tampering (see Figure 2-3). The second current sensor can be another shunt resistor that is isolated using the on-board 71M6X0X Remote Sensor Interface. The Demo Board has provisions for connecting either a shunt or a CT sensor, but the default configuration is the shunt sensor connected via on-board 71M6X0X Remote Sensor Interface. See section 3.1 for details.

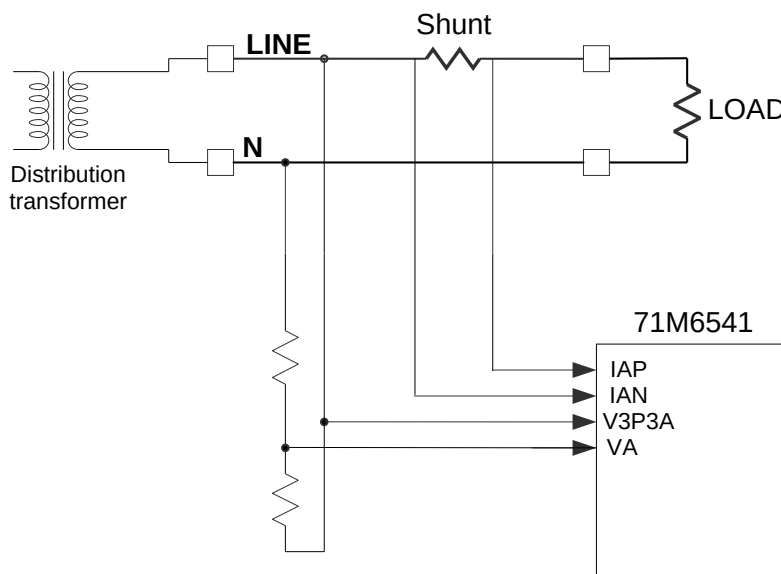


Figure 2-2: Single-Phase Two-Wire Meter with Shunt Sensor

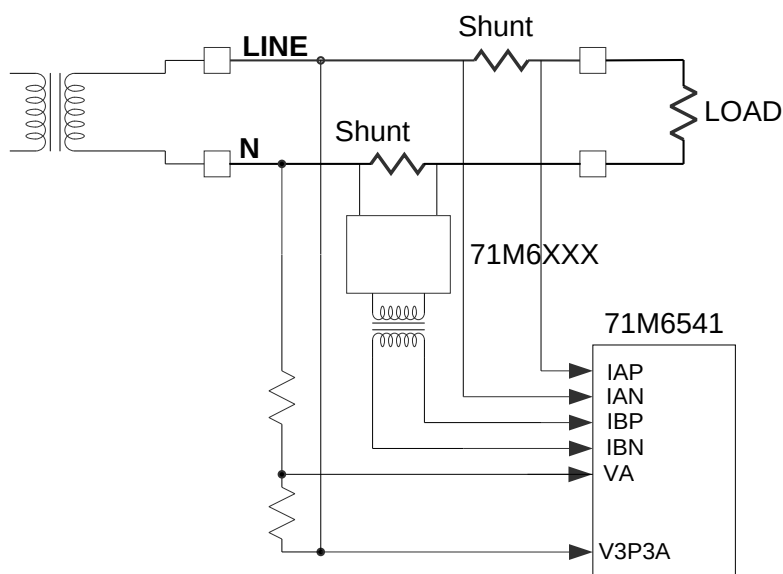


Figure 2-3: Single-Phase Two-Wire Meter with two Shunt Sensors

When the Demo Code is using equation 0, the energy calculation and pulse generation is solely based on the primary shunt (IAP/IAN). The readings from the second shunt can be obtained by the MPU in CE registers and used for tamper detection. Since the shunt in the second current channel may be different from the shunt used

in the primary channel, the CE code allows scaling between the two channels so that all energy calculations can be based on *IMAX*.

2.1.3 SINGLE-PHASE THREE-WIRE (EQU 1)

This meter configuration (see Figure 2-4) is used in North America (ANSI market) and parts of South America. The energy measurement is based on the following equation:

$$P = VA/2 * (IA - IB)$$

Both current sensors can be shunt sensors. The second current sensor may also be a CT. The Demo Board has provisions for connecting either sensor type, but the default configuration for the second current sensor is the connection via on-board 71M6X0X Remote Sensor Interface.

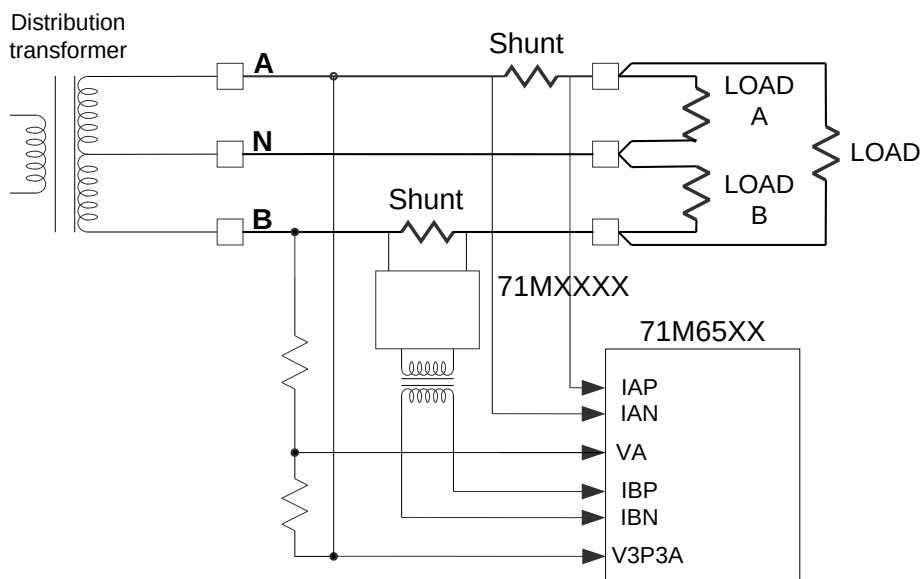


Figure 2-4: Single-Phase Three-Wire Meter with two Shunt Sensors

By default, the gain of the amplifier for the IAP/IAN inputs is set to 1. See the explanation below Table 1-8 for the calculation of *IMAX*.

As for the single-phase two-wire configuration, the CE code allows for scaling of differences between the currents in both phases so that all energy calculations can be based on *IMAX*.

2.2 CALIBRATION THEORY

A typical meter has phase and gain errors as shown by ϕ_S , A_{XI} , and A_{XV} in Figure 2-5. Following the typical meter convention of current phase being in the lag direction, the small amount of phase lead in a typical current sensor is represented as $-\phi_S$. The errors shown in Figure 2-5 represent the sum of all gain and phase errors. They include errors in voltage attenuators, current sensors, and in ADC gains. In other words, no errors are made in the 'input' or 'meter' boxes.

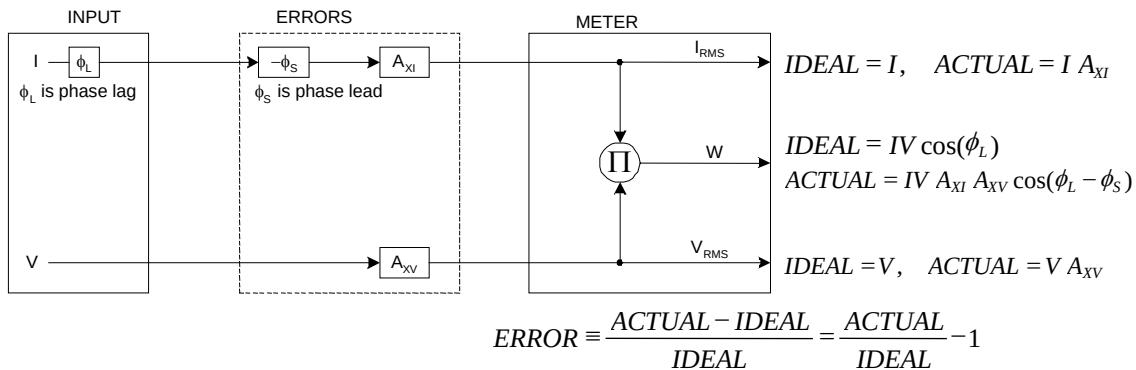


Figure 2-5: Watt Meter with Gain and Phase Errors.

During the calibration phase, we measure errors and then introduce correction factors to nullify their effect. With three unknowns to determine, we must make at least three measurements. If we make more measurements, we can average the results and get better accuracy.

2.2.1 CALIBRATION WITH THREE MEASUREMENTS

The simplest calibration method is to make three measurements. Typically, a voltage measurement and two Watt-hour (Wh) measurements are made. A voltage display can be obtained for test purposes via the command `>MR2.1` in the serial interface.

Let's say the voltage measurement has the error E_V and the two Wh measurements have errors E_0 and E_{60} , where E_0 is measured with $\phi_L = 0$ and E_{60} is measured with $\phi_L = 60$. These values should be simple ratios—not percentage values. They should be zero when the meter is accurate and negative when the meter runs slow. The fundamental frequency is f_0 . T is equal to $1/f_s$, where f_s is the sample frequency (2560.62Hz). Set all calibration factors to nominal: $CAL_IA = 16384$, $CAL_VA = 16384$, $PHADJA = 0$.

Note: In the formulae used in this section, the register /variable name **PHADJA** is used. The CE code for the 71M6541 in reality uses a more advanced type of compensation that results in a delay adjust. The register name for this compensation factor is **DLYADJ_A**. For the purpose of the calculation, the two names are interchangeable.

From the voltage measurement, we determine that

$$1. \rightarrow A_{XV} = E_V + 1$$

We use the other two measurements to determine ϕ_S and A_{XI} .

$$2. E_0 = \frac{IV A_{XV} A_{XI} \cos(0 - \phi_S)}{IV \cos(0)} - 1 = A_{XV} A_{XI} \cos(\phi_S) - 1$$

$$2a. A_{XV} A_{XI} = \frac{E_0 + 1}{\cos(\phi_S)}$$

$$3. E_{60} = \frac{IV A_{XV} A_{XI} \cos(60 - \phi_S)}{IV \cos(60)} - 1 = A_{XV} A_{XI} \frac{\cos(60 - \phi_S)}{\cos(60)} - 1$$

$$\begin{aligned}
 3a. \quad E_{60} &= \frac{A_{XV} A_{XI} [\cos(60) \cos(\phi_s) + \sin(60) \sin(\phi_s)]}{\cos(60)} - 1 \\
 &= A_{XV} A_{XI} \cos(\phi_s) + A_{XV} A_{XI} \tan(60) \sin(\phi_s) - 1
 \end{aligned}$$

Combining 2a and 3a:

$$4. \quad E_{60} = E_0 + (E_0 + 1) \tan(60) \tan(\phi_s)$$

$$5. \quad \tan(\phi_s) = \frac{E_{60} - E_0}{(E_0 + 1) \tan(60)}$$

$$6. \rightarrow \quad \phi_s = \tan^{-1} \left(\frac{E_{60} - E_0}{(E_0 + 1) \tan(60)} \right)$$

and from 2a:

$$7. \rightarrow \quad A_{XI} = \frac{E_0 + 1}{A_{XV} \cos(\phi_s)}$$

Now that we know the A_{XV} , A_{XI} , and ϕ_s errors, we calculate the new calibration voltage gain coefficient from the previous ones:

$$CAL_V_{NEW} = \frac{CAL_V}{A_{XV}}$$

We calculate PHADJ from ϕ_s , the desired phase lag:

$$PHADJ = 2^{20} \left[\frac{\tan(\phi_s) [1 + (1 - 2^{-9})^2 - 2(1 - 2^{-9}) \cos(2\pi f_0 T)]}{(1 - 2^{-9}) \sin(2\pi f_0 T) - \tan(\phi_s) [1 - (1 - 2^{-9}) \cos(2\pi f_0 T)]} \right]$$

And we calculate the new calibration current gain coefficient, including compensation for a slight gain increase in the phase calibration circuit.

$$CAL_I_{NEW} = \frac{CAL_I}{A_{XI}} \frac{1}{\sqrt{1 + \frac{2^{-20} PHADJ (2 + 2^{-20} PHADJ - 2(1 - 2^{-9}) \cos(2\pi f_0 T))}{1 - 2(1 - 2^{-9}) \cos(2\pi f_0 T) + (1 - 2^{-9})^2}}}}$$

2.2.2 CALIBRATION WITH FIVE MEASUREMENTS

The five measurement method provides more orthogonality between the gain and phase error derivations. This method involves measuring E_V , E_0 , E_{180} , E_{60} , and E_{300} . Again, set all calibration factors to nominal, i.e., $CAL_IA = 16384$, $CAL_VA = 16384$, $PHADJA = 0$.

First, calculate A_{XV} from E_V :

$$1. \rightarrow \quad A_{XV} = E_V + 1$$

Calculate A_{XI} from E_0 and E_{180} :

$$2. \quad E_0 = \frac{IV A_{XV} A_{XI} \cos(0 - \phi_s)}{IV \cos(0)} - 1 = A_{XV} A_{XI} \cos(\phi_s) - 1$$

$$3. \quad E_{180} = \frac{IV A_{XV} A_{XI} \cos(180 - \phi_s)}{IV \cos(180)} - 1 = A_{XV} A_{XI} \cos(\phi_s) - 1$$

$$4. \quad E_0 + E_{180} = 2 A_{XV} A_{XI} \cos(\phi_s) - 2$$

$$5. \quad A_{XV} A_{XI} = \frac{E_0 + E_{180} + 2}{2 \cos(\phi_S)}$$

$$6. \rightarrow \quad A_{XI} = \frac{(E_0 + E_{180})/2 + 1}{A_{XV} \cos(\phi_S)}$$

Use above results along with E_{60} and E_{300} to calculate ϕ_S .

$$7. \quad E_{60} = \frac{IV A_{XV} A_{XI} \cos(60 - \phi_S)}{IV \cos(60)} - 1$$

$$= A_{XV} A_{XI} \cos(\phi_S) + A_{XV} A_{XI} \tan(60) \sin(\phi_S) - 1$$

$$8. \quad E_{300} = \frac{IV A_{XV} A_{XI} \cos(-60 - \phi_S)}{IV \cos(-60)} - 1$$

$$= A_{XV} A_{XI} \cos(\phi_S) - A_{XV} A_{XI} \tan(60) \sin(\phi_S) - 1$$

Subtract 8 from 7

$$9. \quad E_{60} - E_{300} = 2 A_{XV} A_{XI} \tan(60) \sin(\phi_S)$$

use equation 5:

$$10. \quad E_{60} - E_{300} = \frac{E_0 + E_{180} + 2}{\cos(\phi_S)} \tan(60) \sin(\phi_S)$$

$$11. \quad E_{60} - E_{300} = (E_0 + E_{180} + 2) \tan(60) \tan(\phi_S)$$

$$12. \rightarrow \quad \phi_S = \tan^{-1} \left(\frac{(E_{60} - E_{300})}{\tan(60)(E_0 + E_{180} + 2)} \right)$$

Now that we know the A_{XV} , A_{XI} , and ϕ_S errors, we calculate the new calibration voltage gain coefficient from the previous ones:

$$CAL_V_{NEW} = \frac{CAL_V}{A_{XV}}$$

We calculate PHADJ from ϕ_S , the desired phase lag:

$$PHADJ = 2^{20} \left[\frac{\tan(\phi_S) [1 + (1 - 2^{-9})^2 - 2(1 - 2^{-9}) \cos(2\pi f_0 T)]}{(1 - 2^{-9}) \sin(2\pi f_0 T) - \tan(\phi_S) [1 - (1 - 2^{-9}) \cos(2\pi f_0 T)]} \right]$$

And we calculate the new calibration current gain coefficient, including compensation for a slight gain increase in the phase calibration circuit.

$$CAL_I_{NEW} = \frac{CAL_I}{A_{XI}} \frac{1}{\sqrt{1 + \frac{2^{-20} PHADJ (2 + 2^{-20} PHADJ - 2(1 - 2^{-9}) \cos(2\pi f_0 T))}{1 - 2(1 - 2^{-9}) \cos(2\pi f_0 T) + (1 - 2^{-9})^2}}}}$$

2.3 CALIBRATION PROCEDURES

2.3.1 CALIBRATION EQUIPMENT

Calibration requires that a calibration system is used, i.e., equipment that applies accurate voltage, load current and load angle to the unit being calibrated, while measuring the response from the unit being calibrated in a repeatable way. By repeatable we mean that the calibration system is synchronized to the meter being calibrated. Best results are achieved when the first pulse from the meter opens the measurement window of the calibration system. This mode of operation is opposed to a calibrator that opens the measurement window at random time and that therefore may or may not catch certain pulses emitted by the meter.



It is essential for a valid meter calibration to have the voltage stabilized a few seconds before the current is applied. This enables the Demo Code to initialize the 71M6541F and to stabilize the PLLs and filters in the CE. This method of operation is consistent with meter applications in the field as well as with metering standards.



During calibration of any phase, a stable mains voltage has to be present on phase A. This enables the CE processing mechanism of the 71M6541F necessary to obtain a stable calibration.

2.3.2 PHASE-BY-PHASE CALIBRATION

Each meter phase must be calibrated individually. Some calibration systems do not allow selective control of currents in each phase. Each phase can still be individually calibrated using the following sequence:

- When calibrating phase A, the calibration coefficient for the current in phase B is set to zero. This way, the pulses are generated solely based on phase A. The kWh factor of the calibration system must be adjusted by -50% to account for the suppression of 50% of the energy.
- When calibrating phase B, the calibration coefficient for the current in phase A is set to zero. This way, the pulses are generated solely based on phase B. The kWh factor of the calibration system must be adjusted by -50% to account for the suppression of 50% of the energy.
- For the final step, both current calibration coefficients are set to their calibration values and the meter can be tested at the original kWh setting.

2.3.3 DETAILED CALIBRATION PROCEDURES

The procedures below show how to calibrate a meter phase with either three or five measurements. The PHADJ equations apply only when a current transformer is used for the phase in question. Note that positive load angles correspond to lagging current (see Figure 2-6).

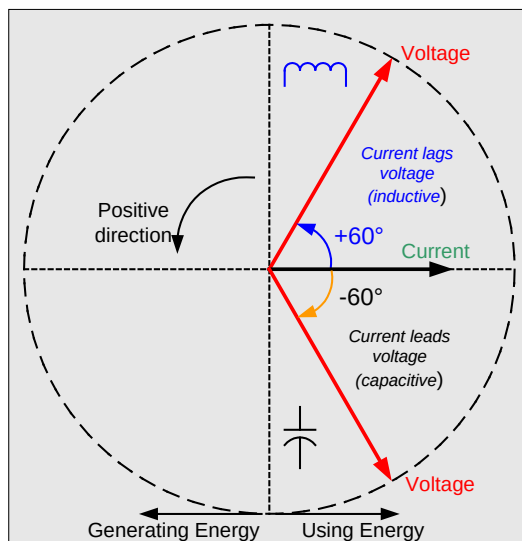


Figure 2-6: Phase Angle Definitions

The calibration procedures described below should be followed after interfacing the voltage and current sensors to the 71M6541F chip. When properly interfaced, the V3P3 power supply is connected to the meter neutral and is the DC reference for each input. Each voltage and current waveform, as seen by the 71M6541F, is scaled to be less than 250mV (peak).

2.3.4 CALIBRATION PROCEDURE WITH THREE MEASUREMENTS

Each phase is calibrated individually. The calibration procedure is as follows:

- 1) The calibration factors for all phases are reset to their default values, i.e., $CAL_In = CAL_Vn = 16384$, and $PHADJ_n = 0$.
- 2) An RMS voltage V_{ideal} consistent with the meter's nominal voltage is applied, and the RMS reading V_{actual} of the meter is recorded. The voltage reading error Axv is determined as

$$Axv = (V_{actual} - V_{ideal}) / V_{ideal}$$
- 3) Apply the nominal load current at phase angles 0° and 60° , measure the Wh energy and record the errors E_0 AND E_{60} .
- 4) Calculate the new calibration factors CAL_In , CAL_Vn , and $PHADJ_n$, using the formulae presented in section 2.2.1 or using the spreadsheet presented in section 2.3.6.
- 5) Apply the new calibration factors CAL_In , CAL_Vn , and $PHADJ_n$ to the meter. The memory locations for these factors are given in section 1.9.1.
- 6) Test the meter at nominal current and, if desired, at lower and higher currents and various phase angles to confirm the desired accuracy.
- 7) Store the new calibration factors CAL_In , CAL_Vn , and $PHADJ_n$ in the EEPROM or FLASH memory of the meter. If the calibration is performed on a Maxim Integrated Demo Board, the methods involving the command line interface, as shown in sections 1.9.3 and 1.9.4, can be used.
- 8) Repeat the steps 1 through 7 for each phase.
- 9) For added temperature compensation, read the value $TEMP_RAW$ (CE RAM) and write it to $TEMP_NOM$ (CE RAM). If Demo Code 4.6n or later is used, this will automatically calculate the correction coefficients PPMC and PPMC2 from the nominal temperature and from the characterization data contained in the on-chip fuses.



Tip: Step 2 and the energy measurement at 0° of step 3 can be combined into one step.

2.3.5 CALIBRATION PROCEDURE WITH FIVE MEASUREMENTS

Each phase is calibrated individually. The calibration procedure is as follows:

- 1) The calibration factors for all phases are reset to their default values, i.e., $CAL_In = CAL_Vn = 16384$, and $PHADJ_n = 0$.
- 2) An RMS voltage V_{ideal} consistent with the meter's nominal voltage is applied, and the RMS reading V_{actual} of the meter is recorded. The voltage reading error Axv is determined as

$$Axv = (V_{actual} - V_{ideal}) / V_{ideal}$$
- 3) Apply the nominal load current at phase angles 0° , 60° , 180° and -60° (-300°). Measure the Wh energy each time and record the errors E_0 , E_{60} , E_{180} , and E_{300} .
- 4) Calculate the new calibration factors CAL_In , CAL_Vn , and $PHADJ_n$, using the formulae presented in section 2.2.2 or using the spreadsheet presented in section 2.3.6.
- 5) Apply the new calibration factors CAL_In , CAL_Vn , and $PHADJ_n$ to the meter. The memory locations for these factors are given in section 1.9.1.
- 6) Test the meter at nominal current and, if desired, at lower and higher currents and various phase angles to confirm the desired accuracy.
- 7) Store the new calibration factors CAL_In , CAL_Vn , and $PHADJ_n$ in the EEPROM or FLASH memory of the meter. If a Demo Board is calibrated, the methods involving the command line interface shown in sections 1.9.3 and 1.9.4 can be used.
- 8) Repeat the steps 1 through 7 for each phase.
- 9) For added temperature compensation, read the value $TEMP_RAW$ (CE RAM) and write it to $TEMP_NOM$ (CE RAM). If Demo Code 4.6n or later is used, this will automatically calculate the correction coefficients PPMC and PPMC2 from the nominal temperature and from the characterization data contained in the on-chip fuses.



Tip: Step 2 and the energy measurement at 0° of step 3 can be combined into one step.

2.3.6 CALIBRATION SPREADSHEETS

Calibration spreadsheets are available from Maxim Integrated. Figure 2-7 shows the spreadsheet for three measurements. Figure 2-8 shows the spreadsheet for five measurements with three phases.

Different tabs are to be used for equation 0/2 and equation 1.

For the calibration, data should be entered into the calibration spreadsheets as follows:

1. Calibration is performed one phase at a time.
2. Results from measurements are generally entered in the yellow fields. Intermediate results and calibration factors will show in the green fields.
3. The line frequency used (50 or 60Hz) is entered in the yellow field labeled AC frequency.
4. After the voltage measurement, measured (observed) and expected (actually applied) voltages are entered in the yellow fields labeled "Expected Voltage" and "Measured Voltage". The error for the voltage measurement will then show in the green field above the two voltage entries.
5. The relative error from the energy measurements at 0° and 60° are entered in the yellow fields labeled "Energy reading at 0° " and "Energy reading at 60° ". The corresponding error, expressed as a fraction will then show in the two green fields to the right of the energy reading fields.
6. The spreadsheet will calculate the calibration factors CAL_IA , CAL_VA , and $PHADJ_A$ from the information entered so far and display them in the green fields in the column underneath the label "new".
7. If the calibration was performed on a meter with non-default calibration factors, these factors can be entered in the yellow fields in the column underneath the label "old". For a meter with default calibration factors, the entries in the column underneath "old" should be at the default value (16384).



**maxim
integrated™**

71M6541/42 Calibration Worksheet
Three Measurements

AC frequency: 60 [Hz]
(click on yellow field to select from pull-down list)

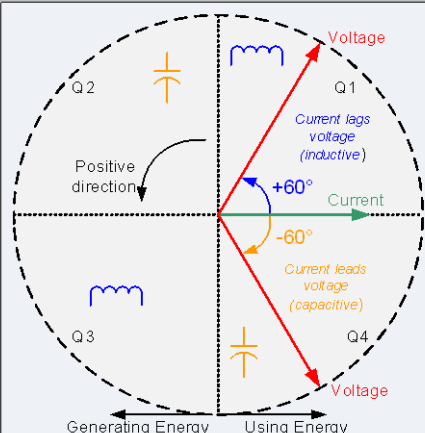
Sample Frequency 2520.615 [Hz]
 FOT 0.023804

Enter values in yellow fields
 Results will show in green fields...

REV 7.2
 Date: 5/4/2011
 Author: JPJ

PHASE A				
	%	fraction	old	new
Energy reading at 0°	-6.158	-0.06158	CAL_IA	16384
Energy reading at +60°	-5.423	-0.05423	CAL_VA	16384
Voltage error at 0°	0	0	L_COMP2_A	15912
Expected voltage	240	[V]		
Measured voltage	240	[V]		

PHASE B				
	%	fraction	old	new
Energy reading at 0°	-6.158	-0.06158	CAL_IB	16384
Energy reading at +60°	-5.423	-0.05423	CAL_VB	16384
Voltage error at 0°	0	0	L_COMP2_B	15912
Expected voltage	240	[V]		
Measured voltage	240	[V]		



Readings: Enter 0 if the error is 0%,
 enter -3 if meter runs 3% slow.

Figure 2-7: Calibration Spreadsheet for Three Measurements



**maxim
integrated™**

71M6541/42 Calibration Worksheet

Five Measurements

Results will show in green fields...

Enter values in yellow fields!

AC frequency: 60 [Hz]
(click on yellow field to select from pull-down list)

Sample Frequency 2520.615

F0T 0.023804

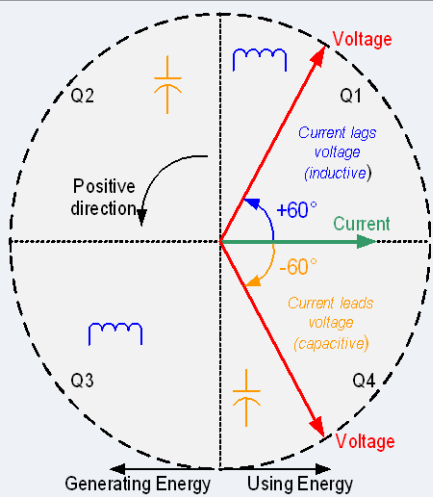
REV 7.2

Date: 5/4/2011

Author: JPJ

PHASE A				old	new
Energy reading at 0°	-6.015	-0.06015	CAL_IA	16384	17331
Energy reading at +60°	-5.058	-0.05058	CAL_VA	16384	16487
Energy reading at -60°	-6.971	-0.06971	L_COMP2_A		15776
Energy reading at 180°	-6.01	-0.0601			
Voltage error at 0°	-0.625	-0.00625			
Expected voltage [V]	240	238.5	Measured voltage [V]		

PHASE B				old	new
Energy reading at 0°	-6.015	-0.06015	CAL_IB	16384	17331
Energy reading at +60°	-5.058	-0.05058	CAL_VB	16384	16487
Energy reading at -60°	-6.971	-0.06971	L_COMP2_B		15776
Energy reading at 180°	-6.01	-0.0601			
Voltage error at 0°	-0.625	-0.00625			
Expected voltage [V]	240	238.5	Measured voltage [V]		



Readings: Enter 0 if the error is 0%,
 enter +5 if meter runs 5% fast,
 enter -3 if meter runs 3% slow.

Figure 2-8: Calibration Spreadsheet for Five Measurements

2.3.7 COMPENSATING FOR NON-LINEARITIES

Nonlinearity is most noticeable at low currents, as shown in Figure 2-9, and can result from input noise and truncation. Nonlinearities can be eliminated using the *QUANT* variable.

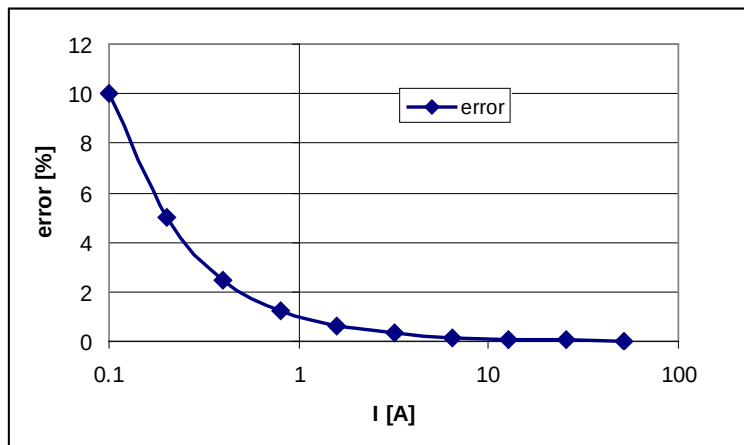


Figure 2-9: Non-Linearity Caused by Quantification Noise

The error can be seen as the presence of a virtual constant noise current. While 10mA hardly contribute any error at currents of 10A and above, the noise becomes dominant at small currents.

The value to be used for *QUANT* can be determined by the following formula:

$$QUANT = - \frac{\frac{error}{100} V \cdot I}{V_{MAX} \cdot I_{MAX} \cdot LSB}$$

Where error = observed error at a given voltage (V) and current (I),
 VMAX = voltage scaling factor, as described in section 1.8.3,
 IMAX = current scaling factor, as described in section 1.8.3,
 LSB = QUANT LSB value = $7.4162 \cdot 10^{-10} W$

Note that different values for the LSB of *QUANT* apply, depending on which type of code is used. The LSB values are listed in the IC data sheet for standard CE codes.

Example: Assuming an observed error for a meter with local sensors as in Figure 2-9, we determine the error at 1A to be +0.5%. If VMAX is 600V and IMAX = 208A, and if the measurement was taken at 240V, we determine QUANT as follows:

$$QUANT \text{ LSB} = 1.04173 \cdot 10^{-9} \quad V_{MAX} \cdot I_{MAX} = 1.3 \cdot 10^{-4}$$

$$QUANT = - \frac{\frac{0.5}{100} 240 \cdot 1}{QUANT_LSB} = -9230$$

QUANT is to be written to the CE location given by the IC data sheet. It does not matter which current value is chosen as long as the corresponding error value is significant (1% error at 1.0 A used in the above equation will produce the same result for *QUANT*).

Input noise and truncation can cause similar errors in the VAR calculation that can be eliminated using the *QUANT_VAR* variable. *QUANT_VAR* is determined using the same formula as *QUANT*.

The internal power supply generates a ripple on the supply and ground nets that is 90° phase shifted with respect to the AC supply voltage. This affects the accuracy of the VARh measurements. If optimization of the VARh accuracy is required, this can be done by writing a value into the *QUANT_VAR* register of the CE

2.4 TEMPERATURE COMPENSATION

2.4.1 ERROR SOURCES

For a meter to be accurate over temperature, the following major sources of error have to be addressed:

- 1) The resistance of the shunt sensor(s) over temperature. The temperature coefficient (TC) of a shunt resistor is typically positive (PTC) and can be far higher than the TC of the pure Manganin material used in the shunt. TCs of several hundred PPM/°C have been observed for certain shunt resistors. A shunt resistor with +100 PPM/°C will increase its resistance by $60^{\circ}\text{C} * 100 * 10^{-6} \text{ PPM/}^{\circ}\text{C}$, or +0.6% when heated up from room temperature to +85°C, causing a relative error of +0.6% in the current reading. This makes the shunt the most pronounced influence on the temperature characteristics of the meter.
Typically, the TC of shunt resistors is linear over the industrial temperature range and can be compensated granted the shunt resistor is at the same temperature as the on-chip temperature sensors on the 71M6X0X Remote Sensor Interface IC or the 71M6541.
Generally, the lower the TC of a shunt resistor, the better it can be compensated. Shunts with high TCs require more accurate temperature measurements than those with low TCs. For example, if a shunt with 200 PPM/°C is used, and the temperature sensor available to the 71M6543 is only accurate to $\pm 3^{\circ}\text{C}$, the compensation can be inaccurate by as much as $3^{\circ}\text{C} * 200 \text{ PPM/}^{\circ}\text{C} = 600 \text{ PPM}$, or 0.06%.
- 2) The reference voltage of the 71M6X0X Remote Sensor Interface IC. At the temperature extremes, this voltage can deviate by a few mV from the room temperature voltage and can therefore contribute to some temperature-related error. The TC of the reference voltage has both linear and quadratic components (TC_1 and TC_2). Since the 71M6X0X Remote Interface IC has an on-chip temperature sensor, and since the development of the reference voltage over temperature is predictable to within $\pm 40 \text{ PPM/}^{\circ}\text{C}$, compensation of the current reading is possible to within $\pm 60^{\circ}\text{C} * 40 * 10^{-6} \text{ PPM/}^{\circ}\text{C}$, or $\pm 0.24\%$. The reference voltage can be approached by the nominal reference voltage:

$$\text{VNOM}(T) = \text{VNOM}(22) + (T - 22) * \text{TC}_1 + (T - 22)^2 * \text{TC}_2$$

Actual values for TC_1 and TC_2 can be obtained as follows:

$$\text{TC}_1 = 3.50 * 10^{-4} - 6.04 * 10^{-6} * \text{TRIMT} \text{ and } \text{TC}_2 = -8.11 * 10^{-7} + 4.19 * 10^{-9} * \text{TRIMT}$$

The *TRIMT* value can be read from the 71M6X0X Remote Sensor Interface IC.

- 3) The reference voltage of the 71M6541 IC. At the temperature extremes, this voltage can deviate by a few mV from the room temperature voltage and can therefore contribute to some temperature-related error, both for the current measurement (pins IAP and IAN) of the secondary shunt sensor and for the voltage measurement (pin VA). As with the Remote Sensor Interface IC, the TC of the 71M6541 reference voltage has both linear and quadratic components. The reference voltage of the 71M6541 over temperature is predictable within $\pm 40 \text{ PPM/}^{\circ}\text{C}$, which means that compensation of the current and voltage reading is possible to within $\pm 0.24\%$.

The temperature coefficients of the reference voltage are published in the IC data sheet.

- 4) The voltage-divider network (resistor ladder) on the Demo Board will also have a TC. Ideally, all resistors of this network are of the same type so that temperature deviations are balanced out. However, even in the best circumstances, there will be a residual TC from these components.

The error sources for a meter are summed up in Table 2-1.

Table 2-1: Temperature-Related Error Sources

Measured Item	Error Sources for Current	Error Sources for Voltage
Energy reading in direct channel VA and (IAP/IAN)	71M6541 VREF	71M6541 VREF
	Shunt resistor at IAP/IAN	Voltage-divider for VA
Energy Reading in remote channel VA and (IBP/IBN)	VREF of 71M6XX1 Remote Sensor IC	71M6541 VREF
	Shunt resistor at Remote Interface IC	Voltage-divider for VA

When analyzing the contribution of thermal errors for power equation 1 for single-phase 3-wire systems, we can write the equation as follows:

$$P = VA \frac{(IA - IB)}{2} = \frac{VA \cdot C_{VD} \cdot C_{4X} \cdot IA \cdot C_{S1} \cdot C_{4X}}{2} - \frac{VA \cdot C_{VD} \cdot C_{4X} \cdot IB \cdot C_{S2} \cdot C_{6X}}{2}$$

The terms used in the above equation are defined as follows:

- VA = voltage applied to the meter
- IA = current applied to the shunt S1 that is connected to the IAP/IAN pins of the 71M6541
- IB = current applied to the shunt S2 that is connected via the Remote Interface IC
- C_{VD} = error contribution from the voltage-divider
- C_{4X} = error contribution from the voltage reference of the 71M6541
- C_{S1} = error from the shunt resistor that is connected to the IAP/IAN pins of the 71M6541
- C_{S2} = error from the shunt resistor that is connected via the Remote Interface IC
- C_{6X} = error contribution from the voltage reference of the Remote Interface IC

The equation can be simplified as follows:

$$P = \left\{ \frac{VA \cdot C_{VD} \cdot IA \cdot C_{S1} \cdot C_{4X}^2}{2} - \frac{VA \cdot C_{VD} \cdot C_{4X} \cdot IB \cdot C_{S2} \cdot C_{6X}}{2} \right\}$$

Or:

$$P = VA \frac{C_{VD} \cdot C_{4X}}{2} \{ IA \cdot C_{S1} \cdot C_{4X} - IB \cdot C_{S2} \cdot C_{6X} \}$$

2.4.2 SOFTWARE FEATURES FOR TEMPERATURE COMPENSATION

In the default settings for the Demo Code, the *CECONFIG* register has its *EXT_TEMP* bit (bit 22) set, which means that temperature compensation is performed by the MPU by controlling the *GAIN_ADJA* and *GAIN_ADJB* registers. In this context, *GAIN_ADJA* controls both current and voltage readings for phase A (i.e., the VA and IAP/IAN pins) whereas *GAIN_ADJB* controls both current and voltage readings for phase B (i.e., the VA and the 71M6X0X Remote Sensor Interface IC).

In general, the *GAIN_ADJA* and *GAIN_ADJB* registers offer a way of controlling the magnitude of the voltage and current signals in the data flow of the CE code. A value of 16385 means that no adjustment is performed (unity gain), which means that the output of the gain adjust function is the same as the input. A value of 99% of 16385, or 16222, means that the signal is attenuated by 1%.

The Demo Code bases its adjustment on the deviation from calibration (room) temperature *DELTA_T* and the coefficients *PPMC* and *PPMC2* to implement the equation below:

$$GAIN_ADJ = 16385 + \frac{DELTA_T \cdot PPMC}{2^{14}} + \frac{DELTA_T^2 \cdot PPMC2}{2^{23}}$$

It can be seen easily that the gain will remain at 16385 (0x4001), or unity gain, when *DELTA_T* is zero.

For complete compensation, the error sources for each channel have to be combined and curve fit to generate the *PPMC* and *PPMC2* coefficients, as we will see in the following section.

The *PPMC* and *PPMC2* coefficients are in the following MPU RAM locations:

- Phase A (IAP/IAN pins): *PPMCA* -- 0x0B, *PPMC2A* -- 0x0F
- Phase B (IBP/IBN pins): *PPMCB* -- 0x0C, *PPMC2B* -- 0x10

2.4.3 CALCULATING PARAMETERS FOR COMPENSATION

2.4.3.1 Shunt Resistors

The TC of the shunt resistors can be characterized using a temperature chamber, a calibrated current, and a voltmeter with filtering capabilities. A few shunt resistors should be measured and their TC should be compared. This type of information can also be obtained from the manufacturer. For sufficient compensation, the TC of the shunt resistors must be repeatable. If the shunts are the only temperature-dependent components in a meter, and the accuracy is required to be within 0.5% over the industrial temperature range, the repeatability must be better than:

$$R = (5000 \text{ PPM}/^{\circ}\text{C}) / (60^{\circ}\text{C}) = 83.3 \text{ PPM}/^{\circ}\text{C}$$

This means that for a shunt resistor with +200 PPM/ $^{\circ}\text{C}$, the individual samples must be within +116.7 PPM/ $^{\circ}\text{C}$ and 283.3 PPM/ $^{\circ}\text{C}$.

Let us assume a shunt resistor of 55 $\mu\Omega$. This resistor is 10% above the nominal value of 50 $\mu\Omega$, but this is of minor importance, since this deviation will be compensated by calibration. In a temperature chamber, this resistor generates a voltage drop of 5.4559 mV at -40°C and 5.541 mV at $+85^{\circ}\text{C}$ with 100 A applied. This is equivalent to a resistance deviation of 0.851 $\mu\Omega$, or 15,473 PPM. With a temperature difference between hottest and coldest measurement of 125°C , this results in +124 PPM/ $^{\circ}\text{C}$. At high temperatures, this resistor will read the current $60^{\circ}\text{C} * 124 \text{ PPM}/^{\circ}\text{C}$, or 0.744% too high. This means that the *GAIN_ADJA* and *GAIN_ADJB* registers have to be adjusted by -0.744% at the same temperature to compensate for the TC of the shunt resistor.

Let us assume that only linear components appear in the formula below, i.e., *PPMC2* is zero.

$$GAIN_ADJ = 16385 + \frac{DELTA_T \cdot PPMC}{2^{14}} + \frac{DELTA_T^2 \cdot PPMC2}{2^{23}}$$

We must now find the PPMC value that decreases *GAIN_ADJ* by 0.744% when *DELTA_T* is +600 (*DELTA_T* is measured in tens of $^{\circ}\text{C}$). We find *PPMC_S* to be:

$$PPMC_S = 2^{14} * (16263 - 16385) / 600 = -3331$$

2.4.3.2 Remote Sensor Reference Voltage

Above the contribution of the TC from the shunt resistor, we will have to take into account the linear and quadratic deviation of the reference voltage of the Remote Sensor Interface IC.

As mentioned above, we have to read the *TRIMT* register of the Remote Sensor Interface IC. This can be done with the CLI command >6R1.10.

Let us assume, the command >6R1.10 returns the value 9082 which we can interpret as the binary sequence 1001 – 0000 – 1000 – 0010. The value of *TRIMT* is contained in the bits 1 through 8, i.e., 0100 – 0001, or 65 decimal.

We can now calculate the TCs of the reference voltage (VREF) for the Remote Sensor Interface IC:

$$TC_1 = 3.50 * 10^{-4} - 6.04 * 10^{-6} * TRIMT = 3.50 * 10^{-4} - 6.04 * 10^{-6} * 65 = -42.6 * 10^{-5}$$

$$TC_2 = -8.11 * 10^{-7} + 4.19 * 10^{-9} * TRIMT = -8.11 * 10^{-7} + 4.19 * 10^{-9} * 65 = -5.39 * 10^{-7}$$

These coefficients are in V/ $^{\circ}\text{C}$, somewhat different from the $\mu\text{V}/^{\circ}\text{C}$ given in other data sheets. Using these coefficients, we obtain 1.19557 V at -40°C and 1.19018 V at $+85^{\circ}\text{C}$, assuming VREF was trimmed to 1.195 V at room temperature.

If we had to compensate only for VREF, *GAIN_ADJ* would have to follow the curve of VREF that is shown in Figure 2-10.

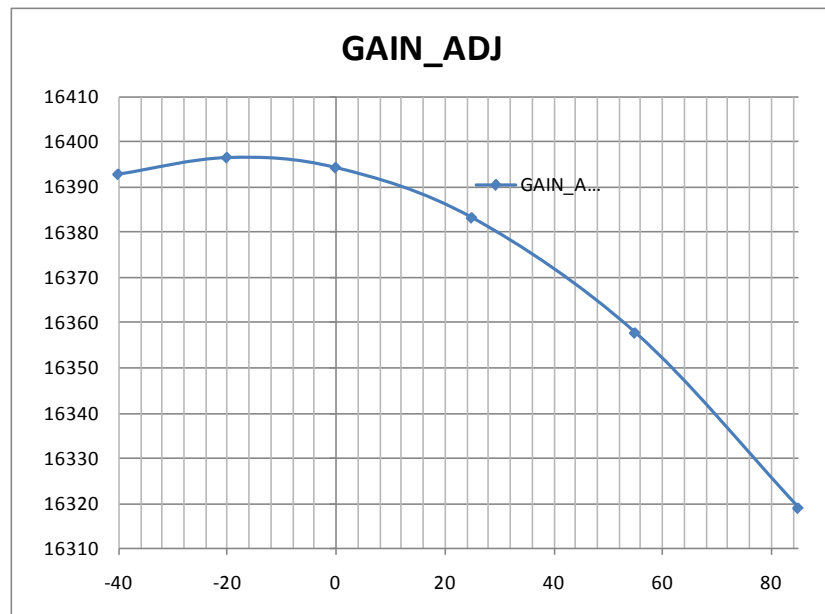


Figure 2-10: *GAIN_ADJ* over Temperature

Some curve-fitting is required to find $PPMC_{6X}$ and $PPMC2_{6X}$ coefficients that will generate the desired behavior of the *GAIN_ADJ* register. For this case, $PPMC_{6X} = -960$ and $PPMC2_{6X} = -610$ approach the curve very accurately. The maximum deviation between *GAIN_ADJ* and the *GAIN_ADJ'* synthesized by *PPMC* and *PPMC2* coefficients is 0.00435%. Figure 2-11 shows how both functions almost overlap.

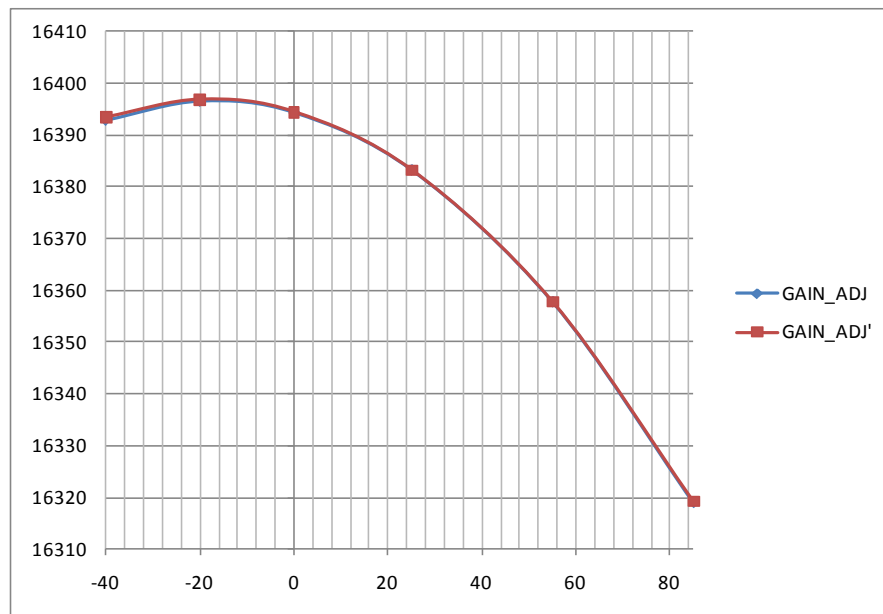


Figure 2-11: *GAIN_ADJ* and *GAIN_ADJ'* over Temperature

2.4.3.3 Reference Voltage of the 71M6541

At a later time, it will be shown how the compensation coefficients for the reference voltage of the 71M6541 can be derived. For the moment, let us assume that we know these coefficients, and that they are $PPMC_{4X} = -820$ and $PPMC_{2_{4X}} = -680$.

2.4.3.4 Voltage-Divider

In most cases, especially when identical resistor types are used for all resistors of the voltage-divider ladder, the TC of the voltage-divider will be of minor influence on the TC of the meter.

If desired, the voltage-divider can be characterized similar to the shunt resistor as shown above. Let us assume, applying 240 Vrms to a meter and recording the RMS voltage displayed by the meter at -40°C, room temperature, +55°C, and at +85°C, we obtain the values in the center column of Table 2-2.

Table 2-2: Temperature-Related Error Sources

Temperature [°C]	Displayed Voltage	Normalized Voltage
-40	246.48	240.458
25	246.01	240.0
55	245.78	239.78
85	245.56	239.57

After normalizing with the factor 240/246.01 to accommodate for the initial error, we obtain the values in the third column. We determine the voltage deviation between highest and lowest temperature to be -0.88 V, which is equivalent to -3671 PPM, or -29.4 PPM/°C.

Finally, we obtain a $PPMC_{VD}$ value of 788.

2.4.3.5 Combining the Coefficients for Temperature Compensation

The TC formula for equation 2 is restated below:

$$P = \left\{ \frac{VA \cdot C_{VD} \cdot IA \cdot C_{S1} \cdot C_{4X}^2}{2} - \frac{VA \cdot C_{VD} \cdot C_{4X} \cdot IB \cdot C_{S2} \cdot C_{6X}}{2} \right\}$$

After characterizing all major contributors to the TC of the meter, we have all components at hand to design the overall compensation.

For simplification purposes, we have decided to ignore C_{VD} . For the control of $GAIN_ADJA$, we will need the following coefficients:

C_{S1} : The $PPMC_S = -3331$ determined for the shunt resistor. $PPMC_{2_S}$ for the shunt resistor is 0.

C_{VD} : The $PPMC_{VD}$ value of 788 determined for the voltage-divider.

C_{4X} : $PPMC_{4X} = -820$ and $PPMC_{2_{4X}} = -680$

We will find that coefficients can simply be added to combine the effects from several sources of temperature dependence. Before we do that, we must consider that the equations for temperature compensation are structured in a special way, i.e.,:

- If an error source affects both current and voltage measurements, the original $PPMC$ and $PPMC2$ coefficients are used.
- If an error source affects only one measurement, the original $PPMC$ and $PPMC2$ coefficients are divided by 2.

Following this procedure, we obtain the coefficients for $GAIN_ADJA$ as follows:

- $PPMC_A = PPMC_S/2 + PPMC_{4X} + PPMC_{VD}/2 = -3331/2 - 820 + 788/2 = -2092$
- $PPMC_{2_A} = PPMC_{2_S} + PPMC_{2_{4X}} = -680$

For the control of $GAIN_ADJB$, we will need the following coefficients:

C_{S2} : Since we assume that the shunt resistors are very similar with respect to their TC, we use the value found for the shunt connected at phase B ($PPMC_S = -3331$). Again, $PPMC2_S$ for the shunt resistor is 0. Since this coefficient applies to the current measurement only, we will have to apply the $\frac{1}{2}$ factor mentioned above.

C_{4X} : $PPMC_{4X} = -820$ and $PPMC2_{4X} = -680$, as already stated above. Since these coefficients apply to the voltage measurement only, we will have to apply the $\frac{1}{2}$ factor mentioned above.

C_{6X} : $PPMC_{6X} = -960$ and $PPMC2_{6X} = -610$. Since these coefficients apply to the current measurement only, we will have to apply the factor of $\frac{1}{2}$ that was mentioned above.

C_{VD} : The $PPMC_{VD}$ value of 788 determined for the voltage-divider.

We obtain the coefficients for $GAIN_ADJB$ as follows:

- $PPMC_B = PPMC_S/2 + PPMC_{4X}/2 + PPMC_{6X}/2 + PPMC_{VD}/2 = -3331/2 - 820/2 - 960/2 + 788/2 = -2162$
- $PPMC2_B = PPMC2_S/2 + PPMC2_{4X}/2 + PPMC2_{6X}/2 = 0 - 680/2 - 610/2 = -985$

2.5 TESTING THE DEMO BOARD

This section will explain how the 71M6541F IC and the peripherals can be tested. Hints given in this section will help evaluating the features of the Demo Board and understanding the IC and its peripherals.

Demo Board. It interfaces to a PC through a 9 pin serial port connector.



It is recommended to set up the demo board with no live AC voltage connected, and to connect live AC voltages only after the user is familiar with the demo system.



BEFORE CONNECTING THE DEMO BOARD TO A CALIBRATION SYSTEM OR OTHER HIGH-VOLTAGE SOURCE IT IS RECOMMENDED TO MEASURE THE RESISTANCE BETWEEN THE LINE AND THE NEUTRAL TERMINALS OF THE DEMO BOARD WITH A MULTIMETER. ANY RESISTANCE BELOW THE 1 MΩ RANGE INDICATES A FAULTY CONNECTION RESULTING IN DESTRUCTION OF THE 71M6541.

2.5.1 FUNCTIONAL METER TEST

This is the test that every Demo Board has to pass before being integrated into a Demo Kit. Before going into the functional meter test, the Demo Board has already passed a series of bench-top tests, but the functional meter test is the first test that applies realistic high voltages (and current signals from current transformers) to the Demo Board.

Figure 2-12 shows a meter connected to a typical calibration system. The calibrator supplies calibrated voltage and current signals to the meter. It should be noted that the current flows through the shunts or CTs that are not part of the Demo Board. The Demo Board rather receives the voltage output signals from the current sensor. An optical pickup senses the pulses emitted by the meter and reports them to the calibrator. Some calibration systems have electrical pickups. The calibrator measures the time between the pulses and compares it to the expected time, based on the meter Kh and the applied power.

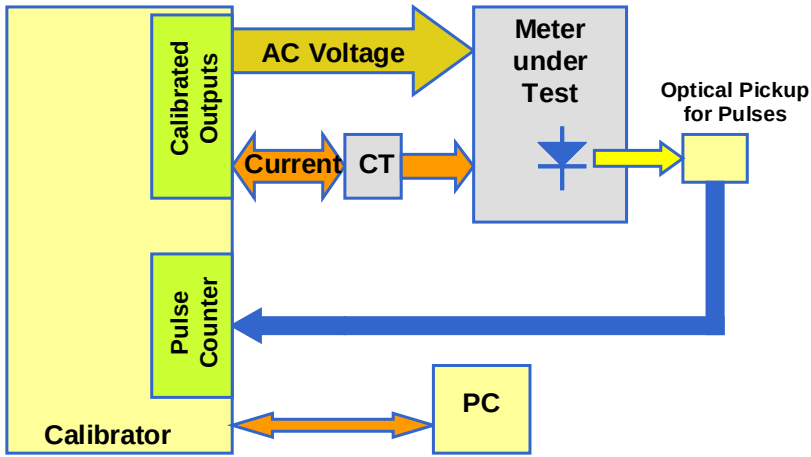


Figure 2-12: Meter with Calibration System

Figure 2-13 shows the screen on the controlling PC for a typical Demo Board. The error numbers are given in percent. This means that for the measured Demo Board, the sum of all errors resulting from tolerances of PCB components, current sensors, and 71M6541F tolerances was -3.41% , a range that can easily be compensated by calibration.

Figure 2-14 shows a load-line obtained with a 71M6541 in differential mode. As can be seen, dynamic ranges of 2,000:1 for current can be achieved with good circuit design, layout, cabling, and, of course, good current sensors.

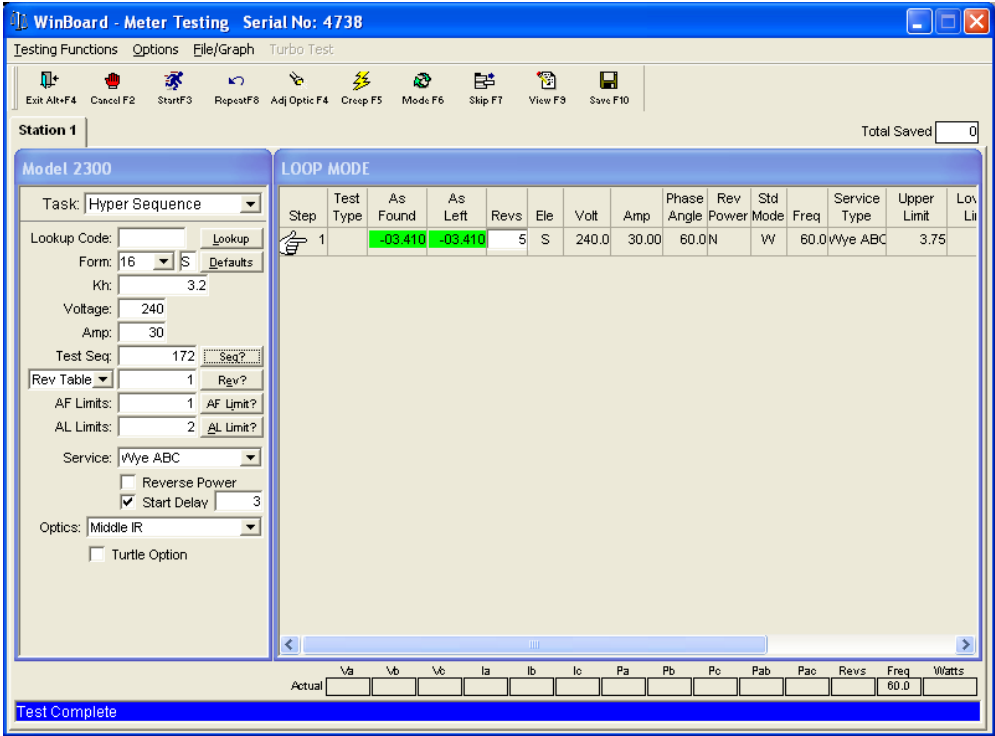


Figure 2-13: Calibration System Screen

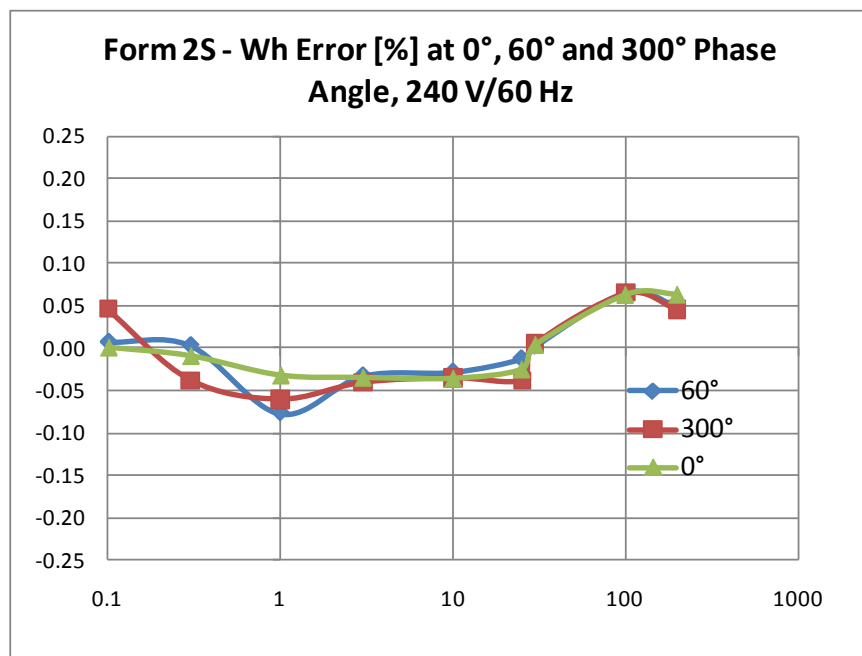


Figure 2-14: Wh Load Lines at Room Temperature with 71M6201 and 50 $\mu\Omega$ Shunts

2.6 SENSORS AND SENSOR PLACEMENT

Both sensor self-heating and sensor placement has to be considered in order to avoid side effects that can affect measurement accuracy. These considerations apply in general to both ANSI meters and IEC meters.

Both meter variations will be discussed below.

2.6.1 SELF-HEATING

The effect of self-heating will be most pronounced at maximum current and depends on the following parameters:

- Nominal shunt resistance
- Current through the shunt resistor
- Thermal mass
- Heat conduction away from the shunt (thermal resistance towards the environment)
- Temperature coefficient of copper and resistive material.

It is quite obvious that the nominal resistance of the shunt resistor should be kept as low as possible. Table 1-9 shows a few combinations of shunt resistance and 71M6X0X part number. The parts with part numbers corresponding to higher current capacity are designed to work with low shunt resistance. Lowering the shunt resistance below the recommended limits decreases accuracy and repeatability.

Good heat conduction can help to maintain the shunt temperature. Attaching the shunt to solid metallic structures such as meter terminal blocks helps decreasing the thermal resistance. This, of course, applies to meters where the terminals and other mechanical parts can be considered heat sinks, i.e., they do not heat up due to other effects.

The thermal mass will control how long it takes the sensor to reach its maximum temperature. Meters, for which only short-time maximum currents are applied, can benefit from a large thermal mass, since it will increase the time constant of the temperature rise.

The temperature coefficient (TC) of the shunt is a very important factor for the self-heating effect. Shunts with a TC of just a few PPM/°C can maintain good shunt accuracy even in the presence of significant self-heating.

There are several methods that can be applied in the meter code that can minimize the effects of self-heating.

The effect of shunt self-heating can be described by the following formulae. First, the relative output of a shunt resistor is:

$$\Delta V/V = \Delta R/R$$

ΔR is a function of the change in temperature, the temperature coefficient, the thermal resistance, and, of course, the applied power, which is proportional to the square of the current:

$$\frac{\Delta V}{V} = \frac{\Delta R}{R} = \frac{R \cdot \Delta T \cdot TC_R}{R} = I^2 R \cdot R_{TH} \cdot TC_R$$

Ultimately, it is up to the meter designer to select the best combination of shunt resistance, TC, shunt geometry and potential software algorithms for the given application.

2.6.2 PLACEMENT OF SENSORS (ANSI)

The arrangement of the current terminals in an ANSI meter enclosure predetermines shunt orientation, but it also allows for ample space in between the sensors, which helps to minimize cross-talk between phases.

A good practice is to shape the shunts like blades and to place them upright so their surfaces are parallel. In a 16S meter, the distance between the phase A sensor and the phase B sensor is roughly 1", which makes these two phases most critical for cross-talk. For the form 2S meter, which is a very frequently used single-phase configuration, the distance between the sensors is in the range of 2.75", which makes this configuration much less critical. However, even for this case, good sensor placement is essential to avoid cross-talk.

Sensor wires should be tightly twisted to avoid loops that can be penetrated by the magnetic fields of the sensors or conductors.

2.6.3 PLACEMENT OF SENSORS (IEC)

The arrangement of the current terminals in a typical IEC meter enclosure predetermines the spacing of the shunts, and usually allows for only 20 to 22 mm center-to-center spacing between the shunts. This means that the clearance between adjacent shunts is typically only 10 mm or less. A typical arrangement is shown in Figure 2-15, left side. This arrangement is not optimized for suppression of cross-talk.

In order to minimize cross-talk between phases, the shunts should be turned by 90 degrees as shown in Figure 2-15, right side. In this arrangement, the sensitive areas of the shunts are kept away from the adjacent currents.

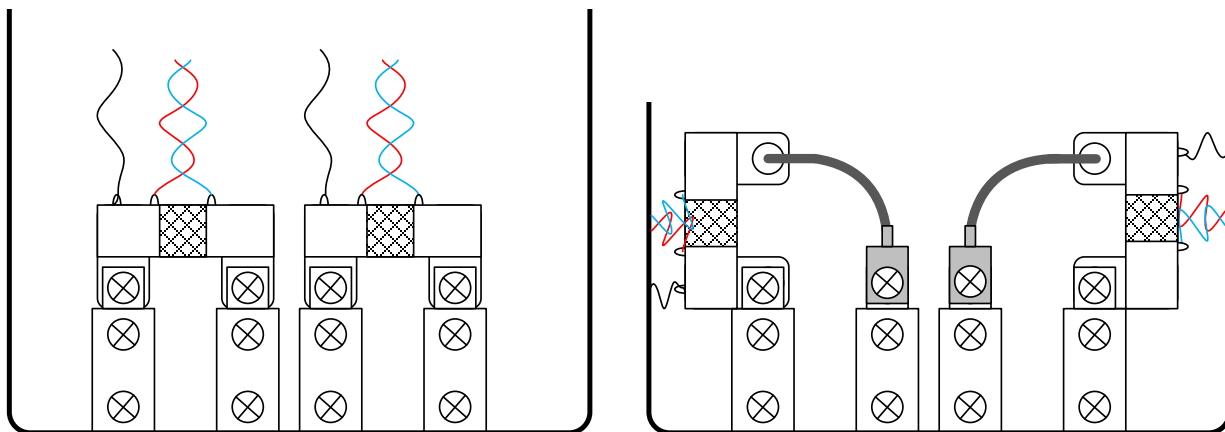


Figure 2-15: Typical Sensor Arrangement (left), Recommended Arrangement (right)

Other arrangements are shown in Figure 2-16. In the left figure, the shunts are shown swiveled by 90 degrees towards the terminals. In the right figure, the shunts are shown staggered in height, for example by using spacers.

It is useful to minimize the loop area formed by the Manganin zone of the shunts and the wires. As with the ANSI sensors, it is recommended that sensor wires are tightly twisted to avoid loops that can be penetrated by the magnetic fields of the sensors or conductors.

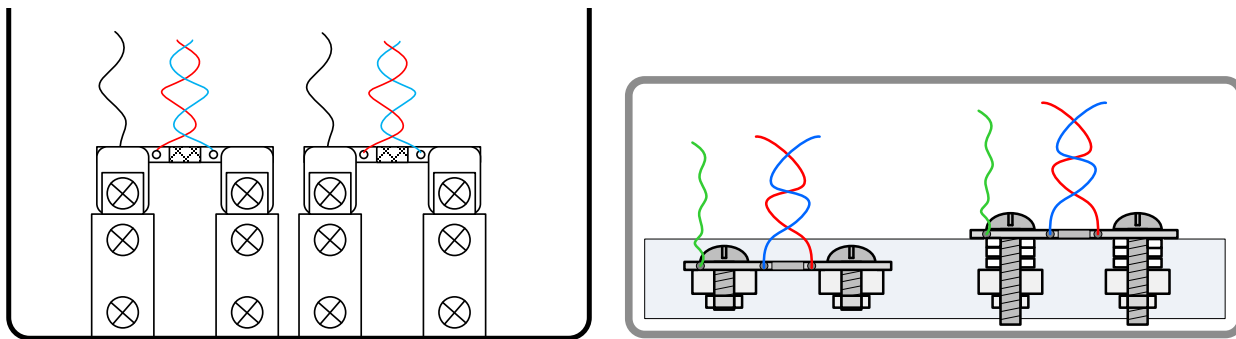


Figure 2-16: Improved Sensor Arrangement

2.6.4 OTHER TECHNIQUES FOR AVOIDING MAGNETIC CROSSTALK

With very high currents or close distances between shunt sensors, magnetic pickup or cross-talk will sometimes occur even if good placement practices are followed.

One mechanism for cross-talk is shown in Figure 2-17, where the Manganin zone and the sensor wire act as a loop that will generate an output voltage similar to that generated by a Rogowski coil.

The effect of this loop can be compensated by adding a second loop on the opposite side of the shunt resistors, as shown in Figure 2-18.

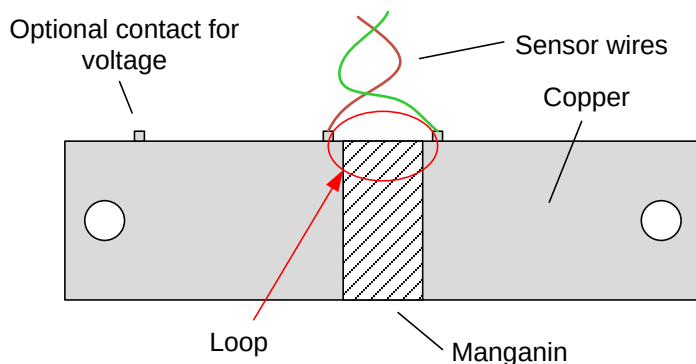


Figure 2-17: Loop Formed by Shunt and Sensor Wire

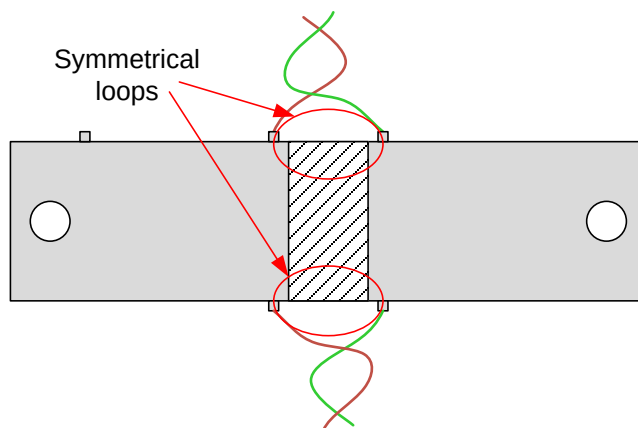


Figure 2-18: Shunt with Compensation Loop

Since the compensation loop is impractical, a similar compensation effect can be achieved by attaching the sensor wires in the center, as shown in Figure 2-19. An economical approach to this technique is to drill holes in the center of the shunt resistor for attachment of the sensor wires¹.

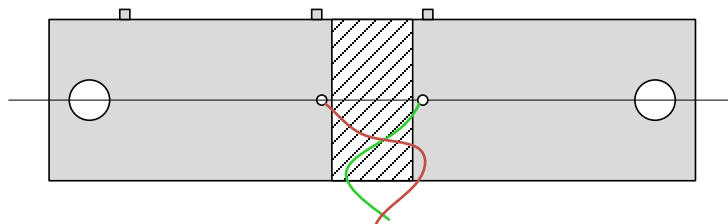


Figure 2-19: Shunt with Center Drill Holes

¹ Patent pending

3 HARDWARE DESCRIPTION

3.1 71M6541-DB DESCRIPTION: JUMPERS, SWITCHES AND TEST POINTS

The items described in the following tables refer to the flags in Figure 3-1.

Item #	Reference Designator	Name	Use
1	TP2	GND	GND test point.
2	JP58	WPULSE	2-pin header connected to the Wh pulse LED
3	D5	Wh	Wh pulse LED.
4	D6	VARh	VARh pulse LED.
5	JP1	BAT MODE	Selector for the operation of the IC when main power is removed. A jumper across pins 2-3 (default) indicates that no external battery is available. The IC will stay in brownout mode when the system power is down and it will communicate at 9600bd. A jumper across pins 1-2 indicates that an external battery is available. The IC will be able to transition from brownout mode to sleep and LCD modes when the system power is down and it will communicate at 300bd.
6	JP44	XPULSE	3-pin header that connects XPULSE pin to the LCD. The XPULSE pin should be configured as an LCD pin when a jumper is placed in the 1-2 position.
7	JP45	YPULSE	3-pin header that connects YPULSE pin to the LCD. The YPULSE pin should be configured as an LCD pin when a jumper is placed in the 1-2 position.
8	JP53	V3P3D	2-pin header that connects the V3P3D pin to parts on the board that use the V3P3D net for their power supply. For supply current measurements in brownout mode, the jumper on JP53 may be removed.
9	U5	--	The IC 71M6541 soldered to the PCB.
10	TP1	TMUXOUT, TMUX2OUT	Test points for access to the TMUXOUT and TMUX2OUT pins on the 71M6541.
11	BT1	--	Location of optional battery for the support of battery modes. (Located on the bottom)
12	BT2	--	Location of optional battery for the support of RTC and non-volatile RAM. BT2 has an alternate circular footprint at location BT3.

Item #	Reference Designator	Name	Use
13	J21	DEBUG	Connector for Debug Board. 2x8 pin male header.
14	SW5	RESET	Chip reset switch: When the switch is pressed, the RESET pin of the IC is pulled high which resets the IC into a known state.
15	J12	--	2-pin header. If a jumper installed, the battery BT1 will be connected to the V3P3SYS net.
16	J13	--	2-pin pin header. If a jumper installed, the battery BT2/BT3 will be connected to the V3P3SYS net.
17	BT3	--	Alternate footprint for BT2. A circular battery may be mounted in this location (on the bottom of the board).
18	SW3	PB	Pushbutton connected to the PB pin on the IC. This push-button can be used in conjunction with the Demo Code to wake the IC from sleep mode or LCD mode to brown-out mode.
19	JP20	5.0 VDC	Circular connector for supplying the board with DC power. Do not exceed 5.0 VDC at this connector!
20	J7	IAP/IAN	2-pin header connected to pins IAP and IAN on the IC.
21	J6	VA	2-pin header connected to pins VA and V3P3A on the IC
22	J3	IAN_IN, IAP_IN 	2-pin header for the connection of the primary (non-isolated) shunt. This header is on the bottom of the board. Since the board is at line voltage, the shunt corresponding to the line side of the meter should be connected here. Caution: Connecting the shunt corresponding to the neutral voltage will result in board damage!
23	JP6		A jumper is placed across JP6 to activate the internal AC power supply. Caution: High Voltage! Do not touch!
24	J11	NEUTRAL	The NEUTRAL voltage input connected to V3P3. This input is a spade terminal mounted on the bottom of the board.
25	J4	LINE 	LINE is the line voltage input to the board. It has a resistor divider that leads to the pin on the IC associated with the voltage input to the ADC. This input is a spade terminal mounted on the bottom of the board. Caution: High Voltage! Do not touch this pin!
26	J10	IBP, IBN	2-pin header connected to pins IBP and IBN on the IC
27	J8	--	2-pin header on the bottom of the board for optional connection of a CT. When using a CT, the burden resistor locations R33/R34 have to be populated. Also, the resistors and capacitors for filtering (R26/C25, R57/C12) and for biasing the IBP/IBN inputs (R86, R87) must be populated.
28	J5	IBP_IN, IBN_IN	2-pin header for the connection of the secondary (remote) shunt. This header is on the bottom of the board. The shunt connected here should be the one corresponding to the neutral side of the meter.
29	JP2		5-pin header for access to OPT_TX and OPT_RX signals.
30	JP3	ICE_E	3-pin header for the control of the ICE_E signal. A jumper across pins 1-2 disables the ICE interface; a jumper across pins 2-3 enables it.
31	JP7	SEGDI051	2-pin header that allows connecting the

Item #	Reference Designator	Name	Use
			SEGDI051/OPT_TX pin to the LCD. If the second UART is used, the jumper should be removed from the header.
32	J14	EMULATOR I/F	2x10 emulator connector port for the Signum ICE ADM-51 or for the TFP2 Flash Programmer.
33	JP54	E_RXTX	Three 2-pin headers that connects the E_RXTX, E_RXTX, and E_TCLK pins to the LCD. The emulator pins should be configured as LCD pins when this jumper is inserted.
34	JP8	SEGDI055	2-pin header that allows connecting the SEGDI051/OPT_RX pin to the LCD. If the second UART is used, the jumper should be removed from the header.
35	J19	SPI	2X5 header providing access to the SPI slave interface.
36	JP9, JP10, JP11, JP12	SPI_DO, SPI_DI, SPI_CK, SPI_CSZ	Four 2-pin headers that connect the SPI_DI, SPI_DO, SPI_CK, and SPI_CSZ pins to the LCD. The SPI pins should be configured as LCD pins when these jumpers are inserted
37	CN1	USB PORT	This connector is an isolated USB port for serial communication with the 71M6541.
38	U8	LCD	3-row LCD with 6 7-segment digits per row and special metering symbols.
39	JP59	VPULSE	2-pin header connected to the VARh pulse LED
40	JP5	UART_RX, ROUT	2-pin header for connection of the RX output of the isolated USB port to the RX pin of the 71M6541. When the Demo Board is communicating via the USB port, a jumper should be installed on JP5. When the Demo Board is communicating via the Debug Board plugged into J21, the jumper should be removed.

Table 3-1: 71M6541-DB REV 3.0 Description

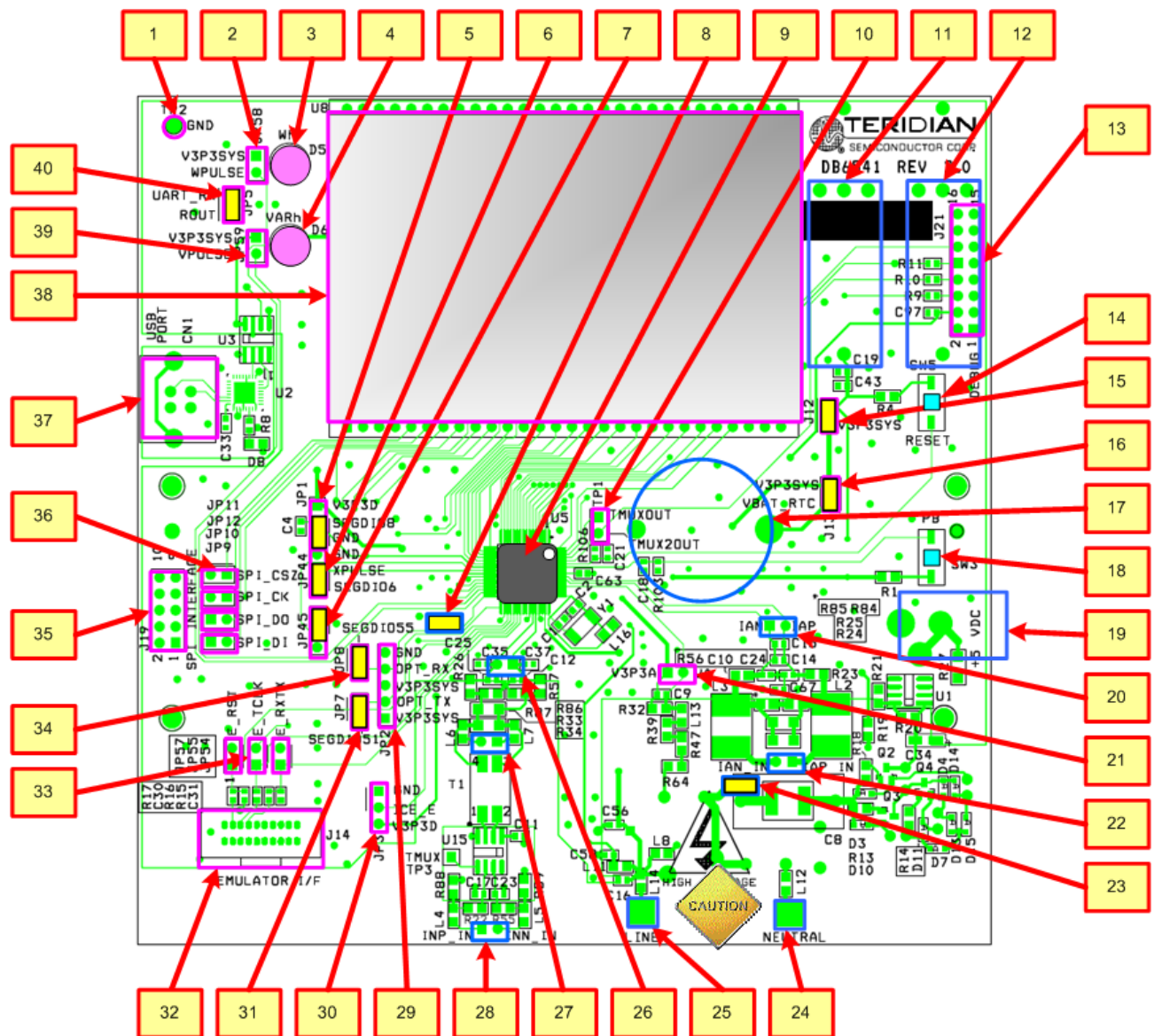


Figure 3-1: 71M6541-DB REV 3.0 - Board Description

(Default jumper settings are indicated in yellow)

3.2 BOARD HARDWARE SPECIFICATIONS

PCB Dimensions

Width, length	134 mm x 131 mm (5.276" x 5.157")
Thickness	1.6mm (0.062")
Height w/ components	40 mm (1.57")

Environmental

Operating Temperature	-40°...+85°C
Storage Temperature	-40°C...+100°C

Power Supply

Using internal AC supply	100 V...240 V RMS
DC Input Voltage (powered from DC supply)	5.0 VDC $\pm$ 0.3 V
Supply Current	< 10 mA typical

Input Signal Range

AC Voltage Signal(VA)	0...240 V RMS
AC Current Signals (IA) from Shunt/CT	0...27.8 mV peak for Remote Sensor Input 0...31.5 mV peak for direct input (IAP/IAN)

Interface Connectors

DC Supply (J20)	2.5 mm circular (Switchcraft RAPC712X)
Emulator (J14)	10x2 header, 0.05" pitch
Voltage Input Signals	Spade terminals on PCB bottom
Current Input Signals	0.1" 1X2 headers on PCB bottom
USB port (PC Interface)	USB connector
Optional Debug Board (J2)	8x2 header, 0.1" pitch
SPI Interface	5x2 header, 0.1" pitch

Functional Specification

Program Memory	64 KB FLASH memory
NV memory	1Mbit serial EEPROM
Time Base Frequency	32.768kHz, $\pm$ 20PPM at 25°C

Controls and Displays

RESET	Push-button (SW5)
PB	Push-button (SW3)
Numeric Display	3X8-digit LCD, 7 segments per digit, plus meter symbols
"Wh"	red LED (D5)
"VARh"	red LED (D6)

Measurement Range

Voltage	120...600 V rms (resistor division ratio 1:3,398)
Current	Dependent on shunt resistance or CT ratio/burden resistor

4 APPENDIX

This appendix includes the following documentation, tables, and drawings:

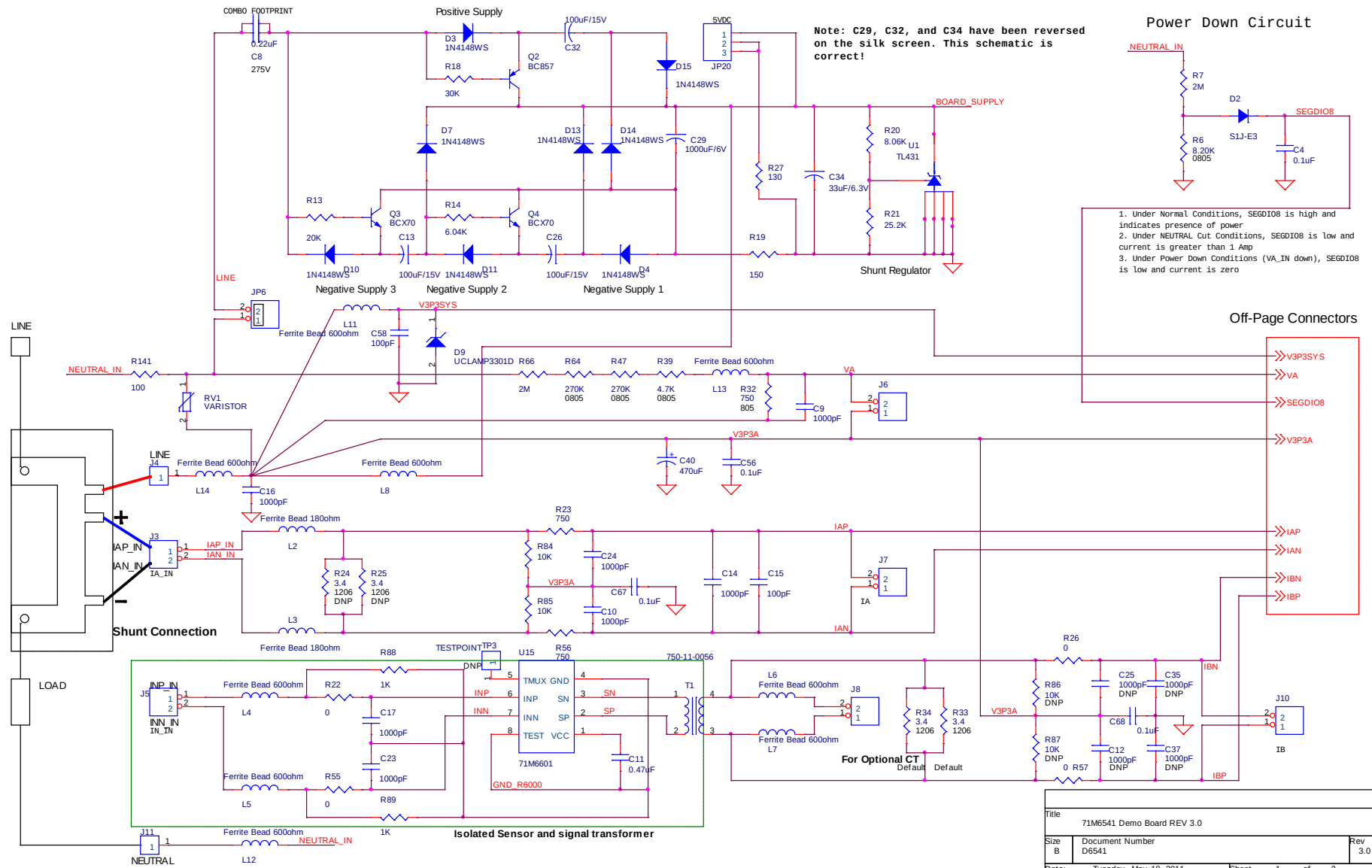
71M6541 Demo Board Description

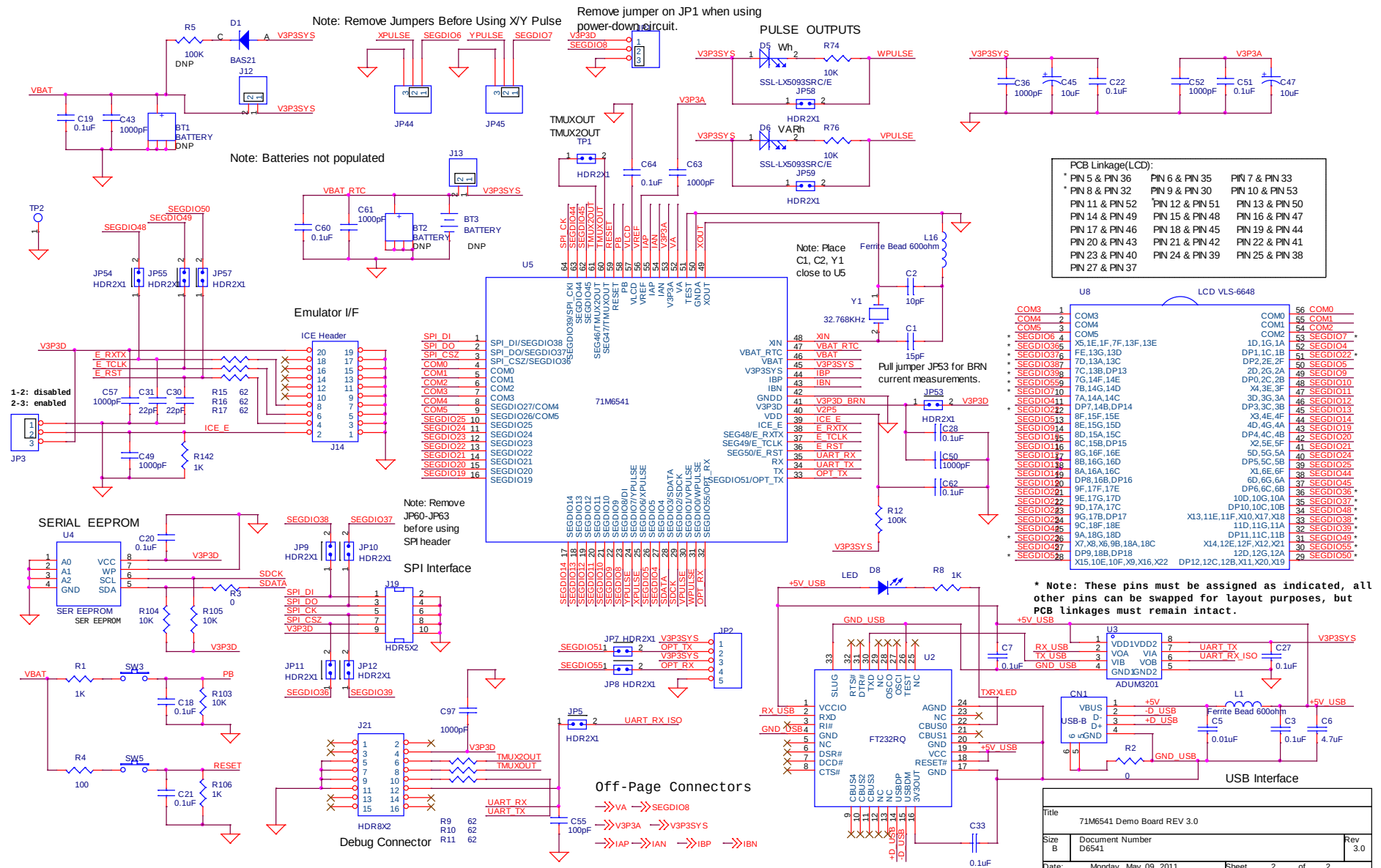
- D6541 REV 3.0 Demo Board Electrical Schematic
- D6541 REV 3.0 Demo Board Bill of Materials
- D6541 REV 3.0 Demo Board PCB layers (copper, silkscreen, top and bottom side)

71M6541 IC Description

- 71M6541 Pin Description
- 71M6541 Pinout

4.1 71M6541-DB ELECTRICAL SCHEMATIC





4.2 71M6541-DB BILL OF MATERIAL

Table 4-1: 71M6541-DB REV 3.0: Bill of Material

Item	Q	Reference	Part	Footprint	Digi-Key P/N	Mouser P/N	Manufacturer	Manufacturer P/N	Tol	Rating	HDR	DNP
1	2	BT1,BT2	BATTERY	BAT 3 PIN BARREL COMBO								DNP
2	1	BT3	BATTERY	BAT CR2032 MAX								DNP
3	1	CN1	USB-B	USBV	609-3657-ND		FCI	806-KUSBVX-BS1N-W				
4	1	C1	15pF	603	445-1237-1-ND		TDK	C1005C0G1H150J	±5%	50V		
5	1	C2	10pF	603	445-1269-1-ND		TDK	C1608C0G1H100D	±5%	50V		
6	3	C3,C7,C27	0.1uF	805	478-3351-1-ND		AVX Corporatic	08055C104MAT2A				
7	15	C4,C18,C19,C20,C21,C22, C28,C33,C51,C56,C60,C62, C64,C67,C68	0.1uF	603	445-1314-1-ND		TDK	C1608X7R1H104K	±10%	50V		
8	1	C5	0.01uF	603	478-1383-1-ND		AVX Corporatic	08055C103KAT2A				
9	1	C6	4.7uF	805	587-1782-1-ND		Taiyo Yuden	TMK212BJ475KG-T				
10	1	C8	0.22uF	Block	BC1609-ND	594-2222-338- 20224	Vishay	BFC233820224	±10%	275V		
11	16	C9,C10,C14,C16,C17,C23, C24,C36,C43,C49,C50,C52, C57,C61,C63,C97	1000pF	603	445-1298-1-ND		TDK	C1608X7R2A102K	±10%	100V		
12	1	C11	0.47uF	603	445-1314-1-ND		TDK	C1608X7R1H104K	±10%	50V		
13	4	C12,C25,C35,C37	1000pF	603	445-1298-1-ND		TDK	C1608X7R2A102K	±10%	100V		DNP
14	3	C13,C26,C32	100uF/15V	CAP P833-ND	P833-ND		Panasonic	ECE-A1CKA101	±20%	16V		
15	3	C15,C55,C58	100pF	603	445-1281-1-ND		TDK	C1608C0G1H101J	±5%	100V		
16	1	C29	1000uF/6V	CAP P5115-ND	P5115-ND		Panasonic	ECA-0JM102	±20%	6.3V		
17	2	C30,C31	22pF	603	445-1273-1-ND		TDK	C1608C0G1H220J	±5%	50V		
18	1	C34	33uF/6.3V	A SIZE_3216_CAP	478-1666-1-ND		Panasonic	TAJA336K006RNJ	±20%	6.3V		
19	1	C40	470uF	CYL/D.400/LS. 200/.034	P963-ND		Panasonic	ECE-A1AKS101	±20%	10V		
20	2	C45,C47	10uF	SM/CT_3216	478-1672-1-ND		AVX	TAJB106K010R	±10%	10V		
21	1	D1	BAS21	SOT-23 AC	BAS21FSCT-ND		Fairchild	BAS21				
22	1	D2	S1J-E3	SMA/DIODE	S1J-E3/61TGICT-ND		Vishay/Genera	S1J-E3/61T				
23	8	D3,D4,D7,D10,D11,D13,D14, D15	1N4148WS		1N4148WSFSCT-ND		Fairchild	1N4148WS				
24	2	D5,D6	SSL-LX5093SRC/E	LED6513	67-1612-ND		Lumex	SSL-LX5093SRC/E				
25	1	D8	LED	805	L62415CT-ND		CML	CMD17-21UGC/TR8				
26	1	D9	UCLAMP3301D	SOD-323	UCLAMP3301DCT-ND		Semtech	UCLAMP3301D.TCT				
27	4	JP1,JP3,JP44,JP45	HDR3X1	BLKCON.100/V H/TM1SQ/W.1 00/3	S1011E-36-ND		Sullins	PBC36SAAN			0.1	
28	1	JP2	HDR5X1	BLKCON.100/V H/TM1SQ/W.1 00/5	S1011E-36-ND		Sullins	PBC36SAAN			0.2	
29	23	TP1,J3,JP5,J5,JP6,J6,JP7, J7,JP8,J8,JP9,JP10,J10, JP11,JP12,J12,J13,JP53, JP54,JP55,JP57,JP58,JP59	HDR2X1	BLKCON.100/V H/TM1SQ/W.1 00/2	S1011E-36-ND		Sullins	PBC36SAAN			0.1	
30	1	JP20	SWITCHCRAFT	SWITCHCRAFT	SC237-ND		Switchcraft Inc	RAPC712X				
31	2	J4,J11	Spade Terminal	Faston	A24747CT-ND		Tyco/AMP	62395-1				
32	1	J14	ICE Header	RIBBON65130 UTLINE	A33555-ND		Tyco/AMP	5-104068-1				
33	1	J19	HDR5X2	BLKCON.100/V H/TM2OE/W.2 00/10	S2011E-36-ND		Sullins	PBC36DAAN			0.2	
34	1	J21	HDR8X2	BLKCON.100/V H/TM2OE/W.2 00/16	S2011E-36-ND		Sullins	PBC36DAAN			0.3	
35	11	L1,L4,L5,L6,L7,L8,L11, L12,L13,L14,L16	Ferrite Bead 600ohm	805	445-1556-1-ND		TDK	MMZ2012S601A				
36	2	L2,L3	Ferrite Bead 180ohm	HI2220R181R- 10	240-2546-1-ND		Steward	HI2220R181R-10		5A		
37	1	Q2	BC857	SOT-23 BCE	BC857CINCT-ND		Infineon Techn	BC857CE6327				
38	2	Q3,Q4	BCX70	SOT-23 BCE	BCX70KINCT-ND		Infineon	BCX70KE6327XT				
39	1	RV1	VARISTOR	MOV CPS 2381594		594-2381-594- 55116	AVX	2381 594 55116				
40	3	R1,R88,R89	1K	805	541-1.0KACT-ND		Vishay/Dale	CRCW08051K00JNEA	5%			
41	1	R2	0	1206	RHMO.0ECT-ND		Rohm Semicon	MCR18EZHJ000				
42	1	R3	0	603	541-0R0GCT-ND		Vishay/Dale	CRCW06030000Z0EA	5%			
43	1	R4	100	805	541-100KACT-ND		Vishay/Dale	CRCW08051K00JNEA	5%			
44	1	R5	100K	603	P100KGCT-ND		Panasonic	ERJ-3GEYJ104V	5%			DNP

45	1	R6	8.20K	805	P8.20KCCT-ND	Panasonic	ERJ-6ENF8201V	1%	0.125W		
46	2	R7,R66	2M	AXLE FLAME UPRIGHT	CMF2.00MHFCT-ND	Vishay/Dale	CMF552M0000FHEB	1%	0.5W		
47	3	R8,R106,R142	1K	603	P1.00KHCT-ND	Vishay/Dale	ERJ-3EKF1001V	1%			
48	3	R9,R10,R11	62	603	P62GCT-ND	Panasonic	ERJ-3GEYJ620V	5%			
49	1	R12	100K	603	P62GCT-ND	Panasonic		5%			
50	1	R13	20K	805	P20.0KCCT-ND	Panasonic	ERJ-6ENF2002V	±1%	25W, 1/8W		
51	1	R14	6.04K	805	541-6.04KCCT-ND	Vishay/Dale	CRCW08056K04FKEA	±1%	25W, 1/8W		
52	3	R15,R16,R17	62	603	P62GCT-ND	Panasonic	ERJ-3GEYJ620V	5%	1W, 1/10W		
53	1	R18	30K	805	311-30KARCT-ND	Yageo	RC0805JR-0730KL	±5%	25W, 1/8W		
54	1	R19	150	805	RHM150CCT-ND	Rohm	MCR10EZHF1500	±1%	25W, 1/8W		
55	1	R20	8.06K	805	RHM8.06KCCT-ND	Rohm	MCR10EZHF8061	±1%	25W, 1/8W		
56	1	R21	25.2K	805	P25.5KCCT-ND	Panasonic	ERJ-6ENF2552V	±1%	25W, 1/8W		
57	4	R22,R26,R55,R57	0	805	RR12P750DCT-ND	Susumu	RR1220P-751-D	1%			
58	3	R23,R32,R56	750	805	RR12P750DCT-ND	Susumu	RR1220P-751-D	0.5%			
59	4	R24,R25,R33,R34	3.4	1206	541-3.40CCT-ND	Vishay/Dale	CRCW08053R40FNEA	1%			DNP
60	1	R27	130	1206	541-130FCT-ND	Rohm	CRCW1206130RFKEA	±1%	0.25W		
61	1	R39	4.7K	805	RG20P4.7KBCT-ND	TDK	RG2012P-472-B-T5	0%			
62	2	R47,R64	270K	805	RG20P270KBCT-ND	Susumu	RG2012P-274-B-T5	0%			
63	5	R74,R76,R103,R104,R105	10K	603	P10.0KHCT-ND	Panasonic	ERJ-3EKF1002V	1%			
64	2	R84,R85	10K	805	541-10KACT-ND	Vishay/Dale	CRCW080510K0JNEA	5%			
65	2	R86,R87	10K	805	541-10KACT-ND	Vishay/Dale	CRCW080510K0JNEA	5%			DNP
66	1	R141	100	AXLE FLAME UPRIGHT	100W-2-ND	Yageo	RSF200JB-100R	5%	2W		
67	2	SW3,SW5	PB	PB	P13598SCT-ND	Panasonic	EVQ-PNF05M				
68	1	TP2	TESTPOINT	TESTPOINTSMA LL	5011K-ND	KEystone	5011				
69	1	TP3	TESTPOINT	BLKCON.100/V H/TM1SQ/W.1 00/1	5011K-ND	KEystone	5011				DNP
70	1	T1	750-11-0056	XFORM/COMB O MID		Midcom	750-11-0056				
71	1	U1	TL431	SO8-NARROW	296-1288-5-ND	Texas Instrume	TL431AIDR				
72	1	U2	FT232RQ	32QFNW/GND	768-1008-1-ND	FTDI	FT232RQ.R				
73	1	U3	ADUM3201	SO8-NARROW	ADUM3201ARZ-ND	Analog Devices	ADUM3201ARZ				
74	1	U4	SER EEPROM	SO8-NARROW	AT24C1024BW-SH25-B-ND	ATMEL	AT24C1024BN-SH25-B				
75	1	U5	71M6541	LQFP-64		Teridian					
76	1	U8	LCD VLS-6648	LCD VLS-6648		VARITRONIX	VL_6648_V00				
77	1	U15	71M6601	SOIC-8		Teridian	71M6601				
78	1	Y1	32.768KHz	XTAL-ECS-39	XC1658CT-ND	ECS	ECS-.327-12.5-39-TR				

4.3 71M6541-DB PCB LAYOUT

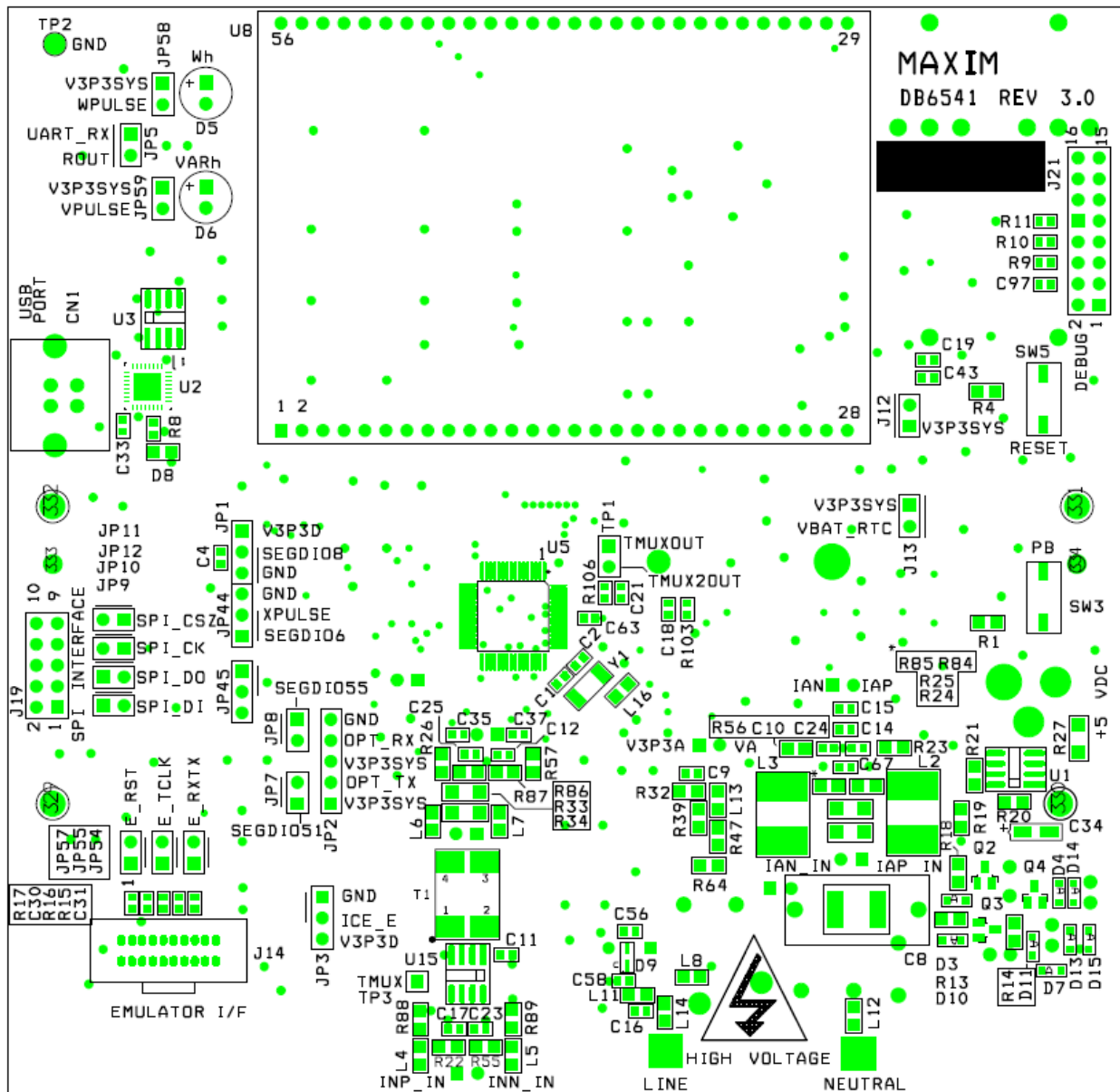


Figure 4-3: 71M6541-DB REV 3.0: Top View

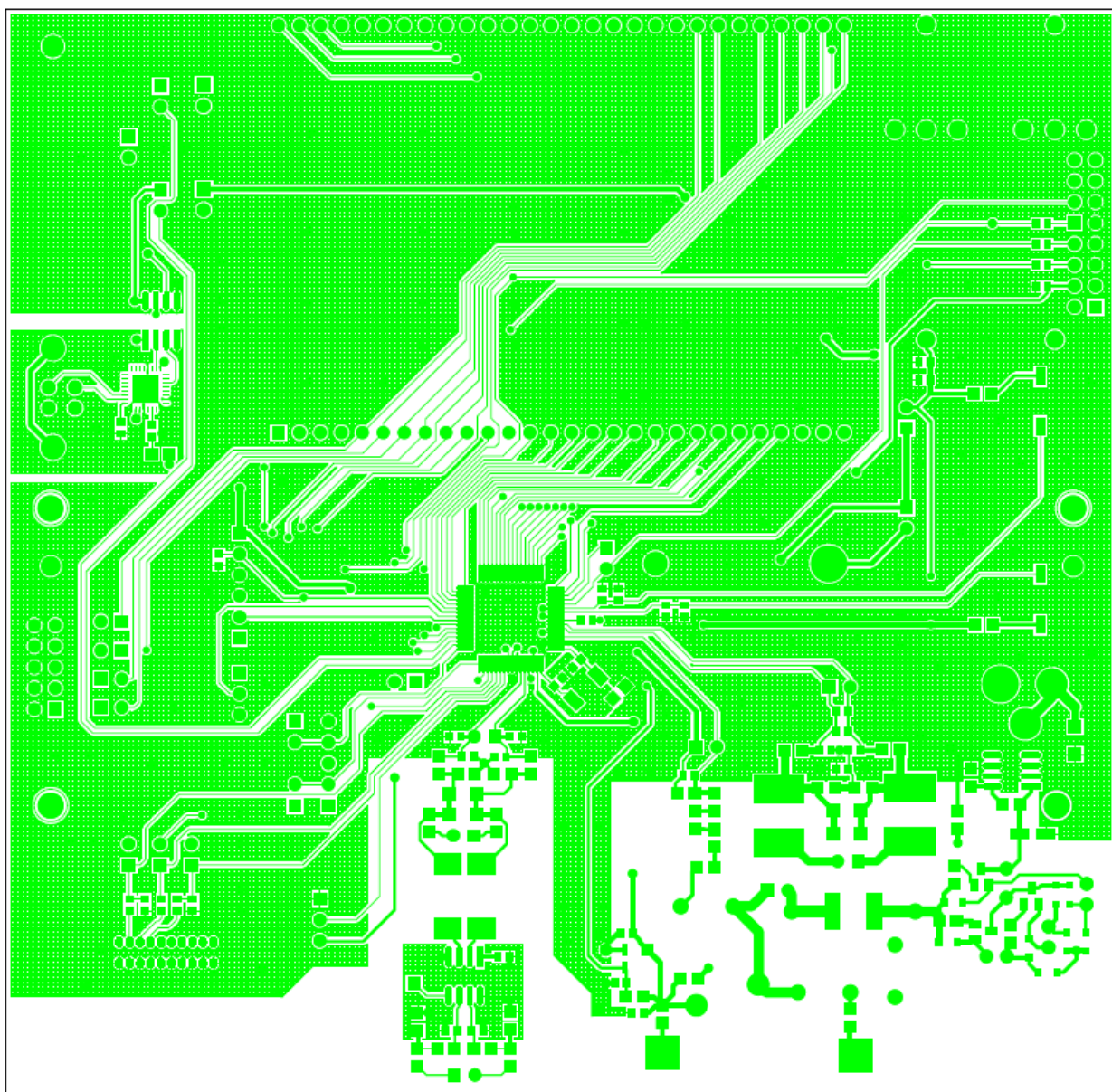


Figure 4-4: 71M6541-DB REV 3.0: Top Copper

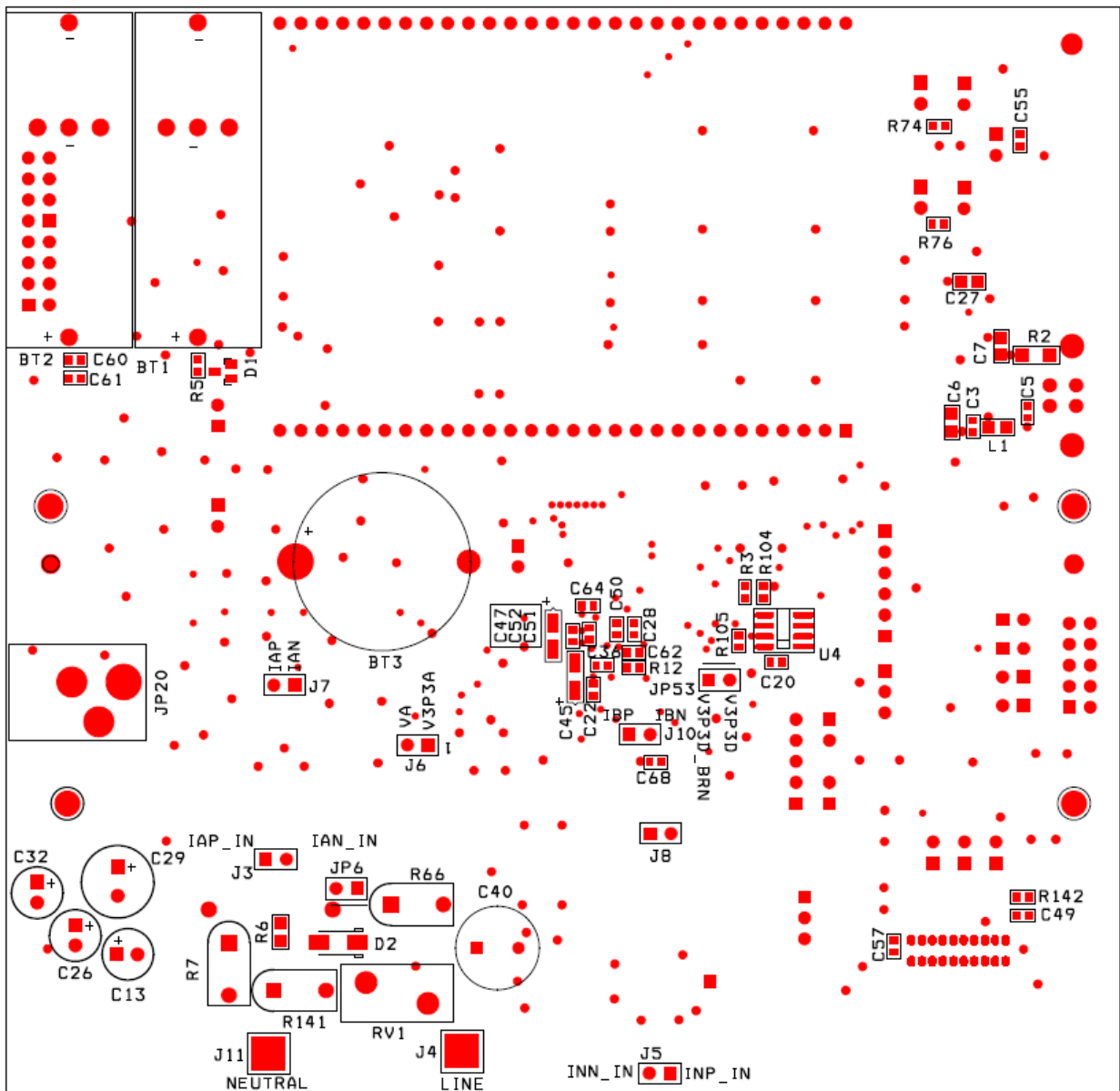


Figure 4-5: 71M6541-DB REV 3.0: Bottom View

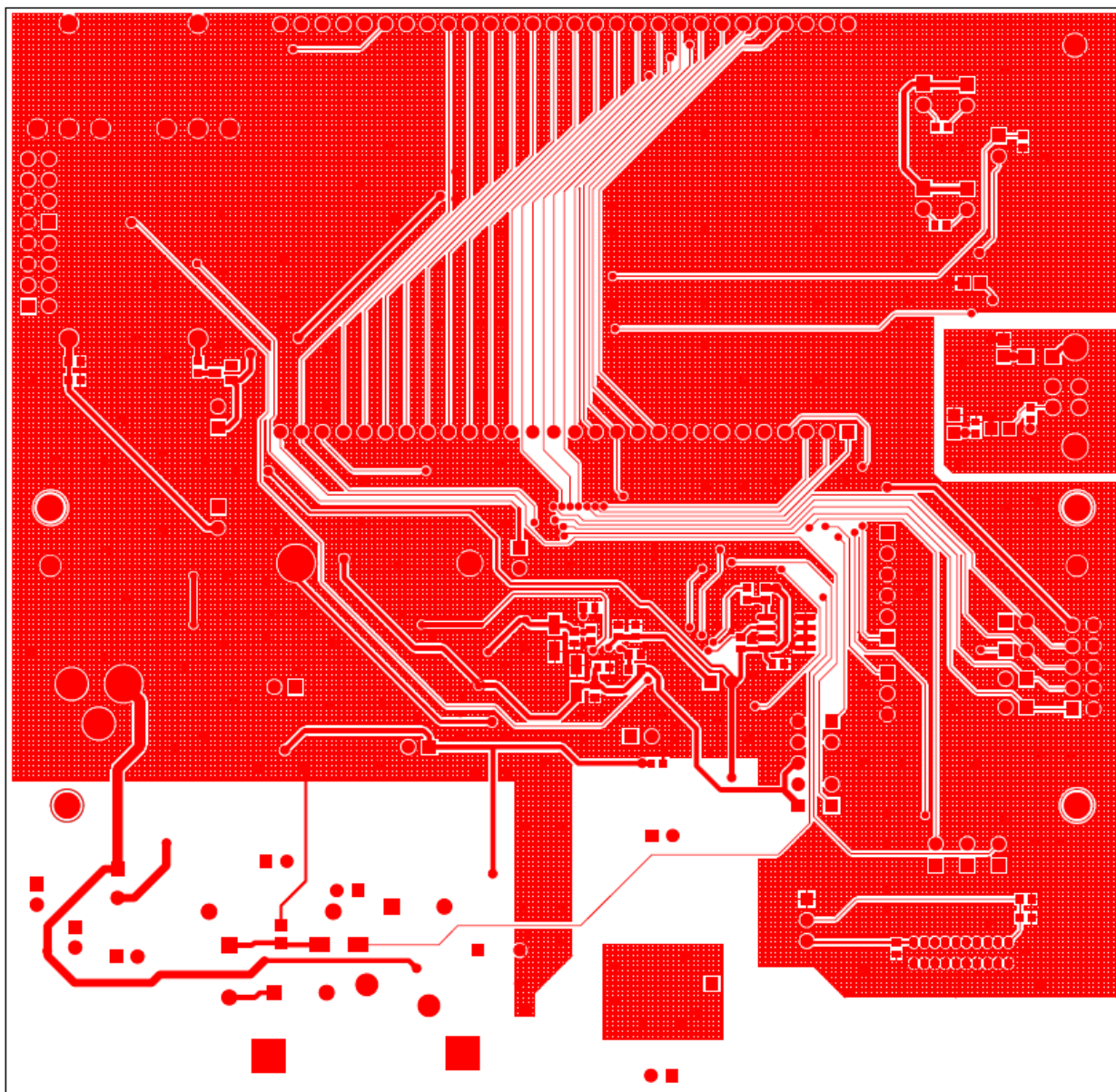


Figure 4-6: 71M6541-DB REV 3.0: Bottom Copper

4.4 71M6541 PINOUT INFORMATION

Power/Ground/NC Pins:

Table 4-2: 71M6541 Pin Description Table 1/3

Name	Type	Description
GNDA	P	Analog ground: This pin should be connected directly to the ground plane.
GNDD	P	Digital ground: This pin should be connected directly to the ground plane.
V3P3A	P	Analog power supply: A 3.3 V power supply should be connected to this pin. V3P3A must be the same voltage as V3P3SYS.
V3P3SYS	P	System 3.3 V supply. This pin should be connected to a 3.3 V power supply.
V3P3D	O	Auxiliary voltage output of the chip. In mission mode, this pin is connected to V3P3SYS by the internal selection switch. In BRN mode, it is internally connected to VBAT. V3P3D is floating in LCD and sleep mode. A bypass capacitor to ground should not exceed 0.1 μ F.
VDD	O	The output of the 2.5V regulator. This pin is powered in MSN and BRN modes. A 0.1 μ F bypass capacitor to ground should be connected to this pin.
VLCD	O	The output of the LCD DAC. A 0.1 μ F bypass capacitor to ground should be connected to this pin.
VBAT	P	Battery backup pin to support the battery modes (BRN, LCD). A battery or super-capacitor is to be connected between VBAT and GNDD. If no battery is used, connect VBAT to V3P3SYS.
VBAT_RTC	P	RTC and oscillator power supply. A battery or super-capacitor is to be connected between VBAT and GNDD. If no battery is used, connect VBAT_RTC to V3P3SYS.

Analog Pins:

Table 4-3: 71M6541 Pin Description Table 2/3

Name	Type	Description
IAP/IAN, IBP/IBN,	I	Differential or single-ended Line Current Sense Inputs: These pins are voltage inputs to the internal A/D converter. Typically, they are connected to the outputs of current sensors. Unused pins must be tied to V3P3A. Pins IBP/IBN may be configured for communication with the remote sensor interface (71M6X0X).
VA	I	Line Voltage Sense Input: This pin is a voltage input to the internal A/D converter. Typically, it is connected to the output of a resistor divider. Unused pins must be tied to V3P3A.
VREF	O	Voltage Reference for the ADC. This pin should be left unconnected (floating).
XIN XOUT	I O	Crystal Inputs: A 32 kHz crystal should be connected across these pins. Typically, a 15 pF capacitor is also connected from XIN to GNDA and a 10 pF capacitor is connected from XOUT to GNDA. It is important to minimize the capacitance between these pins. See the crystal manufacturer datasheet for details. If an external clock is used, a 150 mV (p-p) clock signal should be applied to XIN, and XOUT should be left unconnected.

Pin types: P = Power, O = Output, I = Input, I/O = Input/Output

Digital Pins:**Table 4-4: 71M6541 Pin Description Table 3/3**

Name	Type	Description
COM3,COM2, COM1,COM0	O	LCD Common Outputs: These 4 pins provide the select signals for the LCD display.
SEGDI00 ... SEGDI014, SEGDI019 ... SEGDI025, SEGDI044, SEGDI045,	I/O	Multi-use pins, configurable as either LCD segment driver or DIO. Alternative functions with proper selection of associated I/O RAM registers are: SEGDI00 = WPULSE SEGDI01 = VPULSE SEGDI02 = SDCK SEGDI03 = SDATA SEGDI06 = XPULSE SEGDI07 = YPULSE Unused pins must be configured as outputs or terminated to V3P3/GNDD.
SEGDI026/ COM5, SEGDI027/ COM4	I/O	Multi-use pins, configurable as either LCD segment driver or DIO with alternative function (LCD common drivers).
SEGDI036/ SPI_CSZ, SEGDI037/ SPI_DO, SEGDI038/ SPI_DI, SEGDI039/ SPI_CK1	I/O	Multi-use pins, configurable as either LCD segment driver or DIO with alternative function (SPI interface).
SEGDI051/ OPT_TX, SEGDI055/ OPT_RX	I/O	Multi-use pins, configurable as either LCD segment driver or DIO with alternative function (optical port/UART1)
E_RXTX/SEG48	I/O	Multi-use pins, configurable as either emulator port pins (when ICE_E pulled high) or LCD segment drivers (when ICE_E tied to GND).
E_RST/SEG50	I/O	
E_TCLK/SEG49	O	
ICE_E	I	ICE enable. When zero, E_RST, E_TCLK, and E_RXTX become SEG50, SEG49, and SEG48 respectively. For production units, this pin should be pulled to GND to disable the emulator port.
TMUXOUT/ SEG47, TMUX2OUT/ SEG46	O	Multi-use pins, configurable as either multiplexer/clock output or LCD segment driver using the I/O RAM registers.
RESET	I	Chip reset: This input pin is used to reset the chip into a known state. For normal operation, this pin is pulled low. To reset the chip, this pin should be pulled high. This pin has an internal 30 μ A (nominal) current source pulldown. No external reset circuitry is necessary.
RX	I	UART input. If this pin is unused it must be terminated to V3P3D or GNDD.
TX	O	UART output.
TEST	I	Enables Production Test. This pin must be grounded in normal operation.
PB	I	Push button input. This pin must be at GNDD when not active or unused. A rising edge sets the <i>IE_PB</i> flag. It also causes the part to wake up if it is in SLP or LCD mode. PB does not have an internal pullup or pulldown resistor.

Pin types: P = Power, O = Output, I = Input, I/O = Input/Output,

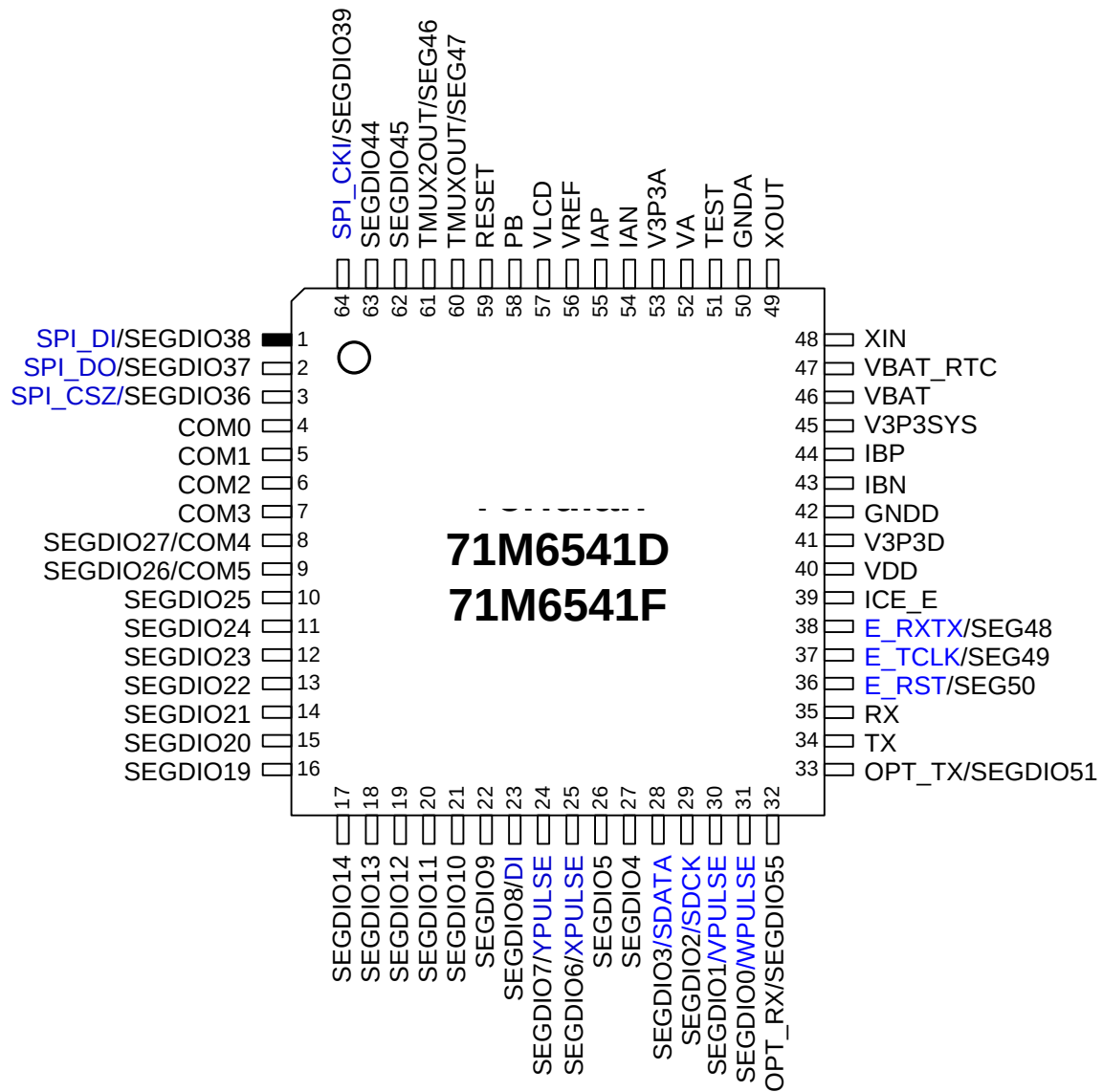


Figure 4-7: 71M6541, LQFP64: Pinout (Top View)

4.5 REVISION HISTORY

REVISION	DATE	DESCRIPTION
2.0	1-14-2010	Initial release based on DBUM revision 1.1 for 6541 REV 1.0 Demo Board.
2.1	1-16-2010	Added Table 1-8 and explanation of scaling in CE and MPU codes. Added cautionary notes for connection of Line and Neutral. Updated formulae for WRATE and kh calculation.
2.2	1-29-2010	Updated Figures 2-1, 2-2, and 2-3. Updated CLI tables and Bill of Material. Added chapter on temperature compensation. Removed most text referencing CTs and added notes stating that different Demo Code versions will be required for a CT configuration.
2.3	2-16-2010	Updated Demo Kit contents list. Updated Table 1-9. Added chapters on shunt self-heating and shunt placement.
2.4	3-5-2010	Corrected description of IMAX calculation. Added more information on self-heating.
2.5	6-3-2010	Added description of test and control commands for 71M6X0X Remote Sensor. Updated Demo Board schematics. Updated Demo Board top-level diagram (Figure 1.1).
2.6	8-16-2010	Added Figure 2.1 showing proper shunt connections. Corrected Figure 2.2. Added text in Application Section explaining the change from <i>PHADJ_A</i> to <i>DLAYADJ_A</i> compensation coefficients. Updated Calibration Spreadsheets.
3.0	5-10-2011	Updated schematics, PCB layout and BOM information to Demo Board Revision 3.0. Removed references to Debug Board. Added information on avoiding cross-talk between shunt resistors. Corrected equation for <i>QUANT</i> .
4.0	12/12	Removed text stating that the Demo Code and documents/tools are delivered on a CD-ROM in the kit. Added attribute 'optional' for all references to the 'Debug Board'. Added USB Interface Module as part of Demo Kit Contents. Updated sample images of calibration spreadsheets and added text stating that spreadsheets are available on the Maxim Integrated web site. Corrected part number for remote sensor IC (71M6601). Added sources for TPF2 Flash Programmer. Updated company logo. Replaced <i>Teridian Semiconductor</i> with <i>Maxim Integrated</i> where applicable.