HIGH-PRECISION COULOMB COUNTER

George Sandler, UNCC ECE

Abstract: For the purpose of monitoring current consumption of wireless communication in different modes a coulomb counter board has been designed. The coulomb counter is based on DS2740 high-precision chip for current-flow measurements. Current is measured bidirectionally over a dynamic range of 13 bits (DS2740UB), with the net flow accumulated in a separate 16-bit register. Through its Dallas 1-Wire interface, the DS2740 allows the host system access to real-time current and accumulated data.

INTRODUCTION.

Thanks to the science and technology, modern electronics becomes less power dependable and more mobile. Simple inexpensive wireless solutions are now available for virtually any home and office device. Therefore, power consumption of wireless communicators and careful monitoring and regulation of transmitting radio power becomes a major issue. This paper addresses the issues associated with power consumption measurements in the low-cost wireless systems and covers some aspects of using coulomb counters. The DS2740 – high precision coulomb counter with 65µA/1µA current consumption in active/sleep modes respectively was initially designed for battery monitoring, but can be used to monitor consumption of any device.

CURRENT MEASUREMENT.

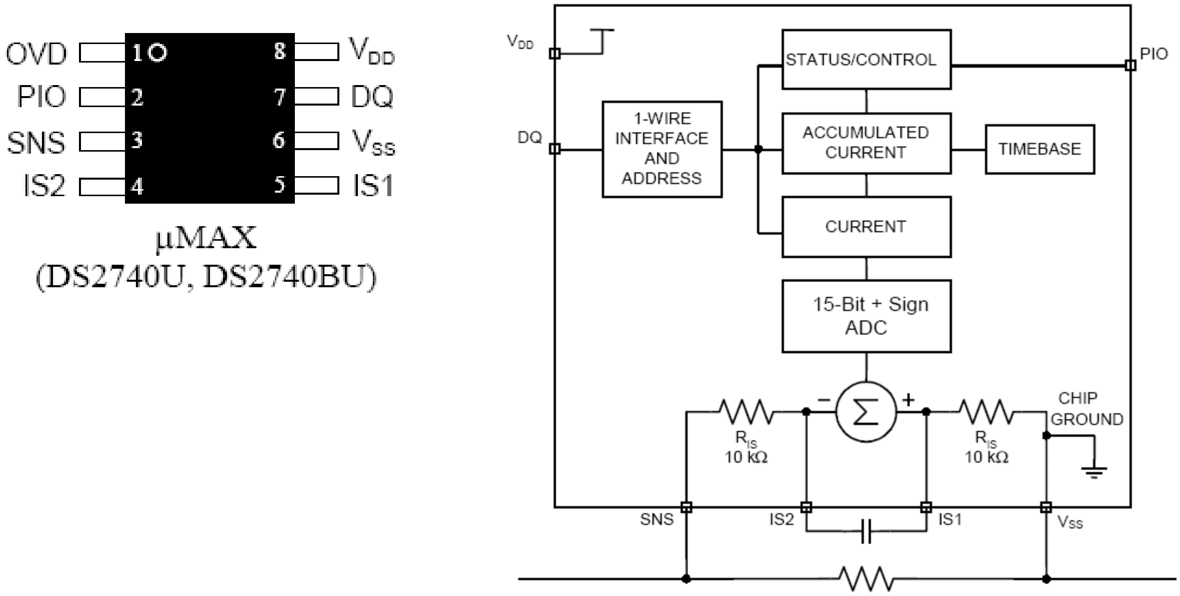

Figure 1. Pin discription and block diagram

In the active mode of operation, the DS2740 continually measures the current flow into and out of the battery by measuring the voltage drop across a low-value current-sense resistor, R_{SNS} [1]. The voltage-sense range is ±51.2mV. To extend the input range for pulse-type load currents, the voltage signal can be filtered by adding a capacitor between the IS1 and IS2 pins (Figure 1). The external capacitor and two internal 10kΩ resistors form a lowpass filter at the input of the ADC. The input converts peak signal amplitudes up to 75mV as long as the continuous or average signal level (post filter) does not exceed ±51.2mV over the conversion cycle period. The ADC samples the input differentially and updates the current register (CR) at the completion of each conversion cycle. There are two versions of DS2740 available: 15- and 13- bit A/Ds. With identical analog circuits the 15-bit version has a conversion period 4 times longer then the 13-bit version (3.2s versus 0.875s), and hence, 4 times better resolution and dynamic range. For 15-bit (DS2740) and 13-bit (DS2740B) devices, the resolution (LSB) is 1.56µV and 6.25µV respectively. One possible drawback of higher sensitivity is prolonged conversion which may be critical in real-time applications. The range of measuring current depends on a sense resistor R_{SNS} and can be adjusted widely. The value of R_{SNS} is calculated based on maximum consumption I_{max} and is equal to ***R_{SNS}=51.2mV/I_{max}***. Current resolution is ***6.25µV/R_{SNS}*** and

1.56μV/R$_{SNS}$ for 13-bit and 15-bit versions respectively. Thus for the 13-bit device using R_{SNS}=20mΩ, the current resolution is 312μA LSB and dynamic range ±2.56A. For R_{SNS}=0.1Ω, the current resolution and dynamic range are 62.4μA and ±512 mA respectively.

The current measurement offset range is –3 LSBs to +5 LSBs according to datasheet specification [1]. The positive average offset error +1 LSB caused by sharing one sense line with device ground through VSS and can be reduced by an average of 2 LSBs (1.9mAh per day with a 20mΩ sense) by eliminating internal resistors of RC filter and connecting IS1 and IS2 directly to the sense resistor. The loss of the filter will have no impact in most applications. In pulse-load cases with current spikes larger than the dynamic range of the A/D external filter can be used.

Every 1024th conversion (15 minutes in the DS2740B), the ADC measures its input offset to facilitate offset correction. During the offset correction conversion, the ADC does not measure the IS1 to IS2 signal. To reduce the error, the current measurement just prior to the offset conversion is displayed in the Current Register and is substituted for the dropped current measurement in the current accumulation process.

Due to the nature of DS2740's current sensing, special precautions need to be taken in the systems with multiple connections between devices. Electrical connections may create go-round current leaks and may compromise measurement. In order to prevent unwanted current flows bypassing R_{SNS}, all connections to "SmartRF" were made through Coulomb counter.

CURRENT ACCUMULATOR.

Current measurements are internally summed at the completion of each conversion period with the results displayed in the Accumulator Current Register (ACR). The ACR has a range of ±204.8mVh with Current Accumulation Register resolution 6.25μVh (Both DS2740 and DS2740B). For R_{SNS}=20mΩ ACR resolution is 312.5μAh and range is ±10.24Ah.

Read and write access is allowed to the ACR. A write forces the ADC to measure its offset and update the offset correction factor. The current measurement and accumulation begin with the second conversion following a write to the ACR.

MEMORY

The DS2740 has memory space with registers for instrumentation, status, and control. When the MSB of a two-byte register is read, both the MSB and LSB are latched and held for the duration of the read data command to prevent updates during the read and ensure synchronization between the two register bytes.

MEMORY MAP

ADDRESS (HEX)	DESCRIPTION	READ/WRITE
00	Reserved	--
O1	Status Register	R
02 to 07	Reserved	--
08	Special Feature Register	R/W
09 to 0D	Reserved	--
0E	Current Register MSB	R
OF	Current Register LSB	R
10	Accumulated Current Register MSB	R/W
11	Accumulated Current Register LSB	R/W
12 to FF	Reserved	--

SPECIAL BITS

SMOD—SLEEP Mode Enable. Status Register bit. A value of 1 allows the DS2740 to enter sleep mode when DQ is low for 2s. The power-up default of SMOD = 0.

RNAOP—Read Net Address Opcode. Status Register bit. A value of 0 in this bit sets the opcode for the read net address command to 33h, while a 1 sets the opcode to 39h. Addressing different opcodes help save time in multi-slave systems.

PIO—PIO Pin Sense and Control. Special Features Register bit. This bit is read and write enabled. Writing a 0 to the PIO bit enables the PIO open-drain output driver, forcing the PIO pin low. Writing a 1 to the PIO bit disables the output driver, allowing the PIO pin to be pulled high or used as an input. Reading the PIO bit returns the logic level forced on the PIO pin.

1-WIRE BUS SYSTEM.

The Dallas Semiconductor 1-Wire® bus is a simple signaling scheme that performs two-way communications between a single master and peripheral devices over a single connection. There are over 30 different 1-Wire devices Dallas Semiconductor currently produces. The bus master is typically a microprocessor in the host system. Each device has a unique factory-programmed 64-bit net address that allows it to be individually addressed by the host system, supporting multiple connections to 1-Wire bus. The interface can be operated with standard or overdrive timing.

Dallas Semiconductor's 1-Wire communication protocol can easily be implemented on almost any microcontroller:

- Only two bidirectional PIO states are necessary: high impedance and logic low. If a bidirectional pin is not available on the bus master, separate output and input pins can be connected together.
- The 1-Wire timing protocol has specific timing constraints that must be followed in order to achieve successful communication. The DS2740 can operate in two communication speed modes, standard and overdrive. The speed mode is determined by the input logic level of the OVD pin.
- The 1-Wire bus must have a pullup resistor at the bus-master end of the bus. For short line lengths, the value of this resistor should be approximately 5kΩ. The idle state for the 1-Wire bus is high.

The protocol for accessing the DS2740 is as follows:

1. Initialization - Reset.
2. Net Address Command.
3. Function Command followed by Transaction/Data.

1. The start of any 1-Wire transaction begins with a reset pulse from the master device followed by a simultaneous presence detect pulses from the slave devices.
2. Once the bus master has detected the presence of one or more slaves, it can issue one of the Net Address Commands.

   Search Net Address [F0h]. This command allows the bus master to use a process of searching to identify the 1-Wire net addresses of all slave devices on the bus. In multidrop systems this command must be used first, then Match Net Address.

   Match Net Address [55h]. This command allows the bus master to specifically address one DS2740 on the 1-Wire bus. Only the addressed DS2740 responds to any subsequent function command.

   Read Net Address [33h or 39h]. This command allows the bus master to read the DS2740's 1-Wire net address. This command can only be used if there is a single slave with correspondent opcode on the bus. Bit **RNAOP**, responsible for that opcode must be set first in a system of two DS2740s.

Skip Net Address [CCh]. This command saves time when there is only one DS2740 on the bus by allowing the bus master to issue a function command without specifying the address of the slave.

Resume [A5h]. This command increases data throughput in multidrop environments where the DS2740 needs to be accessed several times. After successfully executing a Match Net Address command or Search Net Address command, an internal flag is set in the DS2740. When the flag is set, the DS2740 can be repeatedly accessed through the Resume command function. Accessing another device on the bus clears the flag, thus preventing two or more devices from simultaneously responding to the Resume command function.

3. After successfully completing one of the net address commands, the bus master can access the features of the DS2740 with any of the Function Commands.

   Read Data [69h, XX]. This command reads data from the DS2740 starting at memory address XX. The LSb of the data in address XX is available to be read immediately after the MSb of the address has been entered.

   Write Data [6Ch, XX]. This command writes data to the DS2740 starting at memory address XX. The LSb of the data to be stored at address XX can be written immediately after the MSb of address has been entered. Incomplete bytes are not written.

Figure 2 presents a transaction flowchart of the DS2740 net address commands.

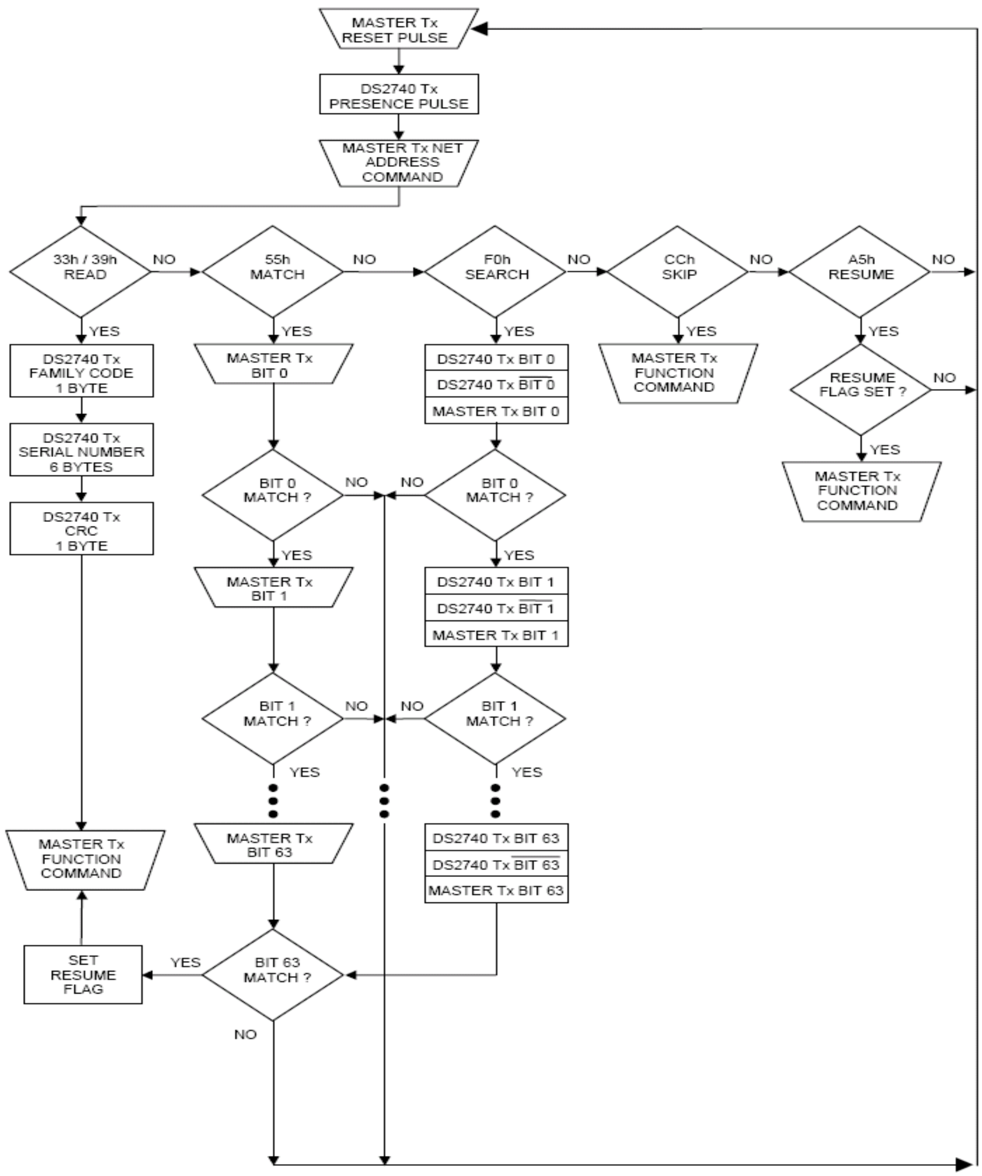

Figure 2. NET ADDRESS COMMAND FLOW CHART

Protocols, diagrams, flow charts, examples of implementations are available on Dallas Semiconductor site [1, 2, 3].

BLOCK SCHEMES.

Figures 3, 4 show single and multiple using of coulomb counters to microcontroller/PC. Necessary connections (controls, communications, etc.) between the device and microcontroller/PC must be made through corresponding coulomb counter.

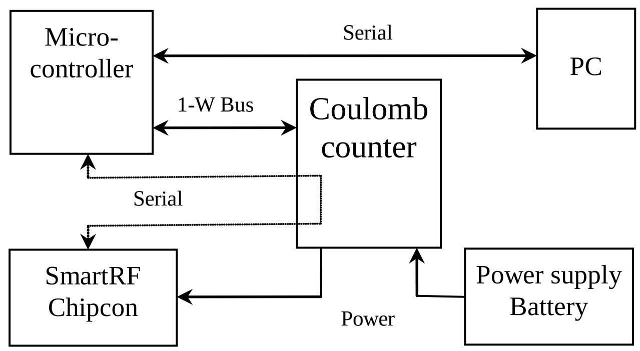

Figure 3. Measuring radio communication only.

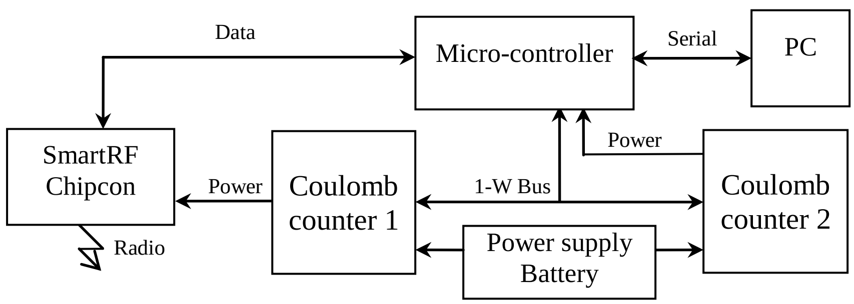

Figure 4. Simultaneous measuring radio communication and microcontroller activity

HIGH-PRECISION COULOMB COUNTER EVALUATION KIT.

For the purpose of performance evaluation, software development, and prototyping, DS2740K evaluation kit has been used [4]. The evaluation board interfaces to a PC running Windows 95 or newer through a DS9123 serial port adapter and RJ-11 cable connection. The DS2740K evaluation software gives the user complete control of all functions of the DS2740. Separate control tabs allow the user access to all memory locations, all status registers, and real-time updates of all monitored parameters. The software also incorporates a data-logging feature to monitor a battery over time.

APLICATION CIRCUIT.

Electrical implementation of DS2740 Coulomb counter is shown on Figure 5. With 20 mΩ Sense Resistor (R_{SNS}) used Current Range is ±2.56A and Current Resolution is 312μA. Current Accumulation Register Resolution and Range are 0.3125mAh and ±10.24Ah respectfully.

The 150Ω resistors are for ESD immunity. The resistors help limit current spikes into the part, and along with zener-diode protect against over-voltage conditions. The pin 2, PIO, an open-drain, general-purpose input/output is used for driving an LED.

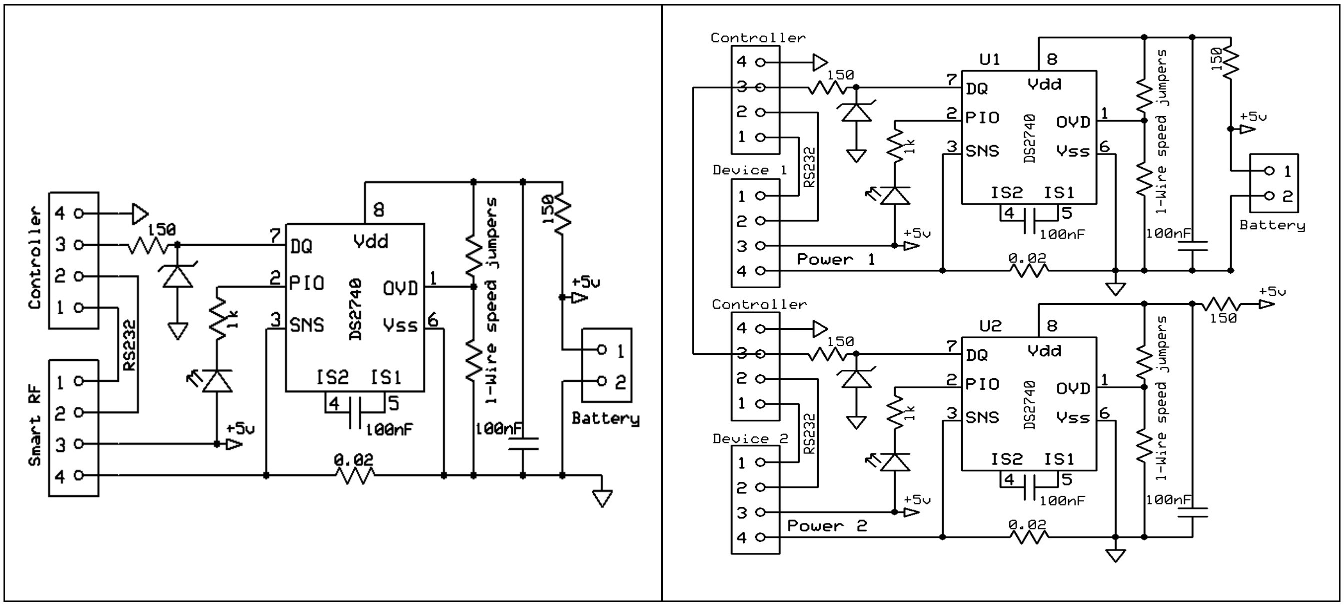

Figure 5 (a, b). Schematics. Single (a) and multiple (b) applications.

CIRCUIT BOARD DESIGN.

CAD software and board manufacturing service from ExpressPCB were used. The CAD software includes ExpressSCH for drawing schematics and ExpressPCB for designing circuit boards [5]. The PCB integrates several in parallel connected coulomb counters which allows multiple monitoring with centralized control over 1-Wire Bus (Figure 6). Any coulomb counter can be cut off for separate using.

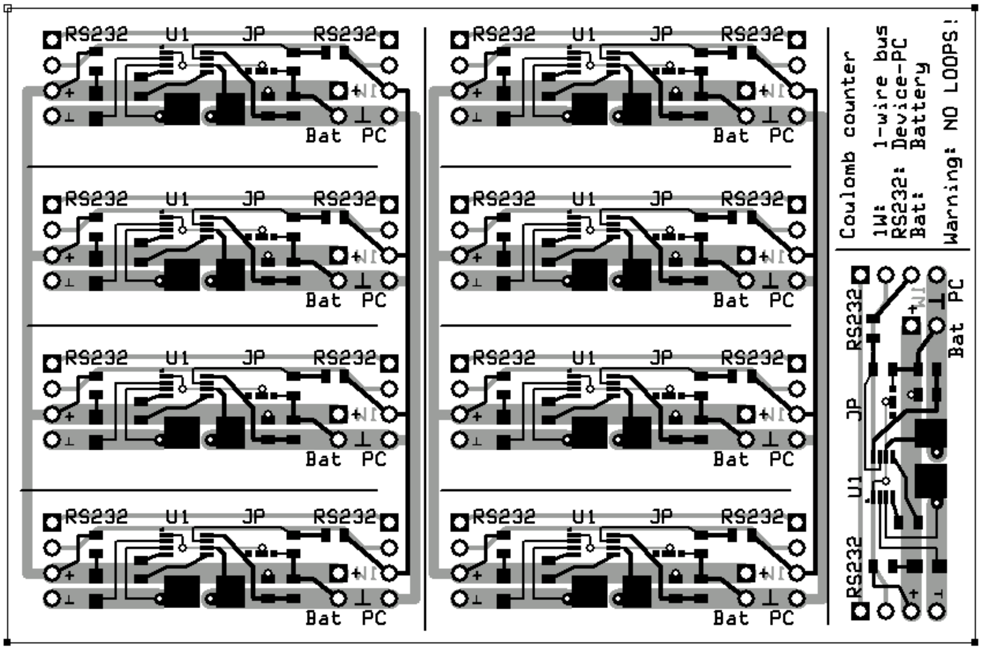

Figure 6. PCB. Black – top layer, gray – bottom layer.

CONCLUSION

The paper suggests a solution for the monitoring power consumption of wireless link based on high precision coulomb counter DS2740. We give overview and implementation of the DS2740 chip for current-flow measurements.

The DS2740 chip has several peculiarities.

First, offset recalibration, which can normally happen any time, can result in losing actual data. In an application with short pulse-like load, simple substituting with the last measurement may create significant error. Overwriting the Current Accumulated Register will force immediate offset correction with 15 minutes measuring time window. This as well is the only way to reset internal registers containing fractions of summations and therefore will increase the precision of the entire measurement.

Second, to reduce experimental error due to the time uncertainty, quasi-stable measurements are required. In other words, in order to measure power load over a short period of time, a series of repetitive pulses must be created with a known number and time parameters. The series must be long enough to overlap several consecutive conversion periods. After the second conversion period the Current Register will contain the correct measurement. In some cases the Current Accumulated Register may be recommended if the duration of experiment can be extended over a significant period of time.

And third, all electrical connections between devices must be made to avoid current leaks over the common ground. The designed PCB contains a number of grounded connectors which must be used to make all necessary connections.

REFERENCES AND LINKS:

1. Dallas Semiconductor. DS2740 High-Precision Coulomb Counter
   http://www.maxim-ic.com/appnotes.cfm/appnote_number/20962
2. Dallas Semiconductor. 1-Wire Search Algorithm
   http://www.maxim-ic.com/appnotes.cfm/appnote_number/950
3. Dallas Semiconductor. Guidelines for Reliable 1-Wire Networks
   http://www.maxim-ic.com/appnotes.cfm/appnote_number/857
4. Dallas Semiconductor. DS2740K High-Precision Coulomb Counter IC Evaluation Kit
   http://www.maxim-ic.com/quick_view2.cfm/qv_pk/3853
5. Software: ExpressPCB Design Tool. www.expressPCB.com