Cheap, Simple and Functional

Presented by Bob Nash at the November 21th, 2009 Forth Day

The Programmer's Dilemma

Speaking to an audience comprised mostly of programmers, I suspect that many of you would prefer not to deal with hardware and user interfaces. I also suspect that, even for those intimately involved with hardware, there is little interest in hearing about "yet another microprocessor."

Nonetheless, I would like to share my recent experiences in building inexpensive, highly functional instruments using Charley Shattuck's MyForth and a simple, cheap and highly functional user interface. I hope you will find at least some of my experiences applicable to your own work.

Cheap and Easy

I often wonder at the number of articles, purportedly aimed at hobbyists, that suggest that a three thousand dollar C compiler and a several hundred dollar development board are needed to program a five dollar chip. Less expensive development environments based on vendor-specific versions of Basic are not much of an improvement, as they are generally tailored to specific microprocessors or development environments.

Of course, Forth provides the ultimate solution for inexpensive embedded software development on a wide variety of processors.

As one approach to the hardware solution, I offer an inexpensive but full-featured development environment assembled from free development tools and inexpensive production facilities. These can produce professional quality results notwithstanding the use of a "poor boy" development philosophy.

Hardware Development Platform

First of all, I would like to discuss the Silicon Laboratories Toolstick modules. Figure 1 provides a brief overview of Toolstick features.

Toolsticks are available for a wide range of processors. An overview of the extensive line of microprocessors from Silicon Laboratories is beyond the scope of this presentation. But, the attached feature summary from the C8051F362 datasheet provides an overview of the features available on the Toolstick 362 module.

This is the module I have recently used in several MyForth projects, some of which can be seen here today.

For an indication of the depth of products available for Silicon Laboratories, I suggest looking in the latest Digikey catalog (or its on-line equivalent). The attached Bill Of Materials provides a part number reference.

Figure 1 – Toolstick Features

Small Size – 1.5" X 2 ¼" (show board)

Inexpensive and Commonly Available – All of the toolstick boards cost only $10.25 and can be purchased from Digikey and Mouser

System on a Board – The development board typically includes a voltage regulator, a chip programming interface, power and test LEDs, a test pushbutton and an on-board, wired, potentiometer for A/D testing (show closeup photo)

Easy Access to I/O – All I/O, including reset and regulated power, is brought out to 0.1 inch-spaced pads. The board can be mounted and wired on standard perf board or easily piggybacked on a motherboard (show motherboard).

Large I/O Count – The 362 Toolstick provides 0.1" pad access to 25 I/O pins in addition to reglated power and reset.

High Functionality and Flexibility – Functions provided include digital outputs that are will sink up to 15 mA, digital inputs that are 5-Volt tolerant, 10 and 12-bit DAC outputs and 8, 10 and 12 bit A/D converters. Other features include an on-board A/D voltage reference and an on-board temperature measurement capability. Most features can be assigned to any I/O pin using a software-configurable crossbar switch.

High Speed, Flexible Clock Sources – Clock options typicall include an internal, software-adjustable 24.5 MHz oscillator, an attached crystal, an external CMOS clock or an RC clock. Many processors, such as the processor on the 362 Toolstick, can operate at 100 MHz using an on-board PLL. Most instructions operate in one cycle (10 ns). A 2-cycle 16X16 MAC engine is also available.

Wide Range of Processors – The Toolstick family encompass most of the Silicon Laboratories microprocessor product line. Typically, the Toolsticks have a top of the line processor mounted on the board but development is targeted for multiple chips within the same family, including very inexpensive OTP chips such as the C8051T60x processors costing about $0.80 and available in SOIC packaging.

Digital Peripherals - Of particular usefulness are features such as hardware comparators with programmable-hysteresis, hardware-based programmable counter chains and software-programmable capture/compare registers. These

allow signal processing that, once set up, is independent of the software application.

Figure 1 – Toolstick Features (Cont.)

8051 Instruction Set – This is perfectly compatible with MyForth, which uses an 8-bit model and is designed for 8051 processors.

Inexpensive Development Tools – A USB-based "base adapter" programs the Toolsticks and costs only $18.18 (show). A free development IDE allows the chips to be easily programmed using any system capable of producing an Intel HEX programming image, such as MyForth. The IDE provides a disassembly view of the downloaded code and is integrated with a full-featured assembler and a very limited Keil C compiler.

Large Flash and RAM Memory – A wide variety of configurations are possible, depending on chip selection. A typical example is the 362 Toolstick processor which has 32K flash, 256 bytes of direct RAM and 1024 bytes of on-board RAM mapped as 8051 "external" RAM.

Interactive Development with MyForth and a Serial Tether – This is a feature of high importance to perhaps as many as three people. Others will probably want to program the Toolsticks with other interactive environments such as SwiftX.

Convenient Packaging – If your target application requires the use of a microprocessor mounted on a custom PCB, a number of package options are available. The One Time Programmable (OTP) chips and the single-port C8051F300 are available in easy to use 14-pin SOIC packages.

User Interface

I have recently found some inexpensive hardware that, along with a Toolstick system, will provide a very inexpensive but highly functional user interface. The interface consists of an 8-character LCD display and an incremental encoder that, together, cost approximately $8.00 (see attached BOM).

The LCD operates from 3.3 Volts and includes a high-brightness white LED backlight. The encoder provides 48 counts per revolution and, more importantly, a pushbutton switch that is operated by pressing the encoder's shaft.

The menu system operates by scrolling the user options across the display as the incremental encoder is turned. Once the user finds the desired option, it is selected by pushing the encoder shaft. Multiple level menus are accommodated by offering a "back" option (a "←" indicator). Direct memory cells are used to

save options as they are selected. This ensures that the user is always offered the most recently selected option on return to each menu level.

User Interface (Cont.)

Additional user indication is provided by creative use of the cursor(s) and by flashing the backlight LED at different rates.

Although the 8-character display may seem somewhat limiting, I have found that, along with creative naming, it fits a wide range of applications. For example, the display can display all of the digits of a MyForth "triple" number (three bytes).

Routines are also available to display the digits of quad numbers by rotating the least significant digits off the right side of the display but allowing decimal point placement and leading zero suppression for smaller numbers.

My Forth Libraries

For those wanting to produce instruments similar to those demonstrated today, MyForth code is available for the following:

- **A multi-level menu system**, as described above
- **Drivers for 9833 and 9850 Direct Digital Synthesizer (DDS) chips**
- **A Variable Frequency Oscillator application** based on the 9833 DDS synthesizer chip (with accurate real-time frequency display up to several megahertz)
- **A 32-bit Pseudo Random (PSR) sequence generator**
- **An Driver for the WIZNet 830 Ethernet module** (< $20, including Ethernet connector) – this application is for the C8051F120 chip which is not available in a Toolstick configuration but is available on a $50 Development board compatible with the SL development environment described here)
- **An Incremental Encoder Driver** (implemented as an ISR) that maintains a four-byte accumulator containing the total incremental encoder count
- **Initialization Examples** for various SL chips such as the C8051F300, C8051F310, C8051F410, C8051F120, C8051F062 and C8051T60x (OTPs).
- **Drivers for various features such as A/D, D/A, temperature measurement, XRAM access, comparators, and timer/counters.**
- **Clock source selection and initialization** for the internal 24.5 MHz oscillator, an external crystal (24.5, 25 MHz) PLL operation at 100 MHz and an external CMOS clock.
- **An LED "blinky" application** for the C8051T600 OTP processor (don't laugh)

Circuit Boards

In previous SVFIG meetings developers have commented on the difficulty in dealing with small surface mount components and producing high quality custom circuit boards. In a previous SVFIG presentation I described methods that I have used to successfully mount very small SMDs, including the tiny 9833 DDS chip.

For the circuit board problem, I have found that ExpressPCB (**www.expresspcb.com**) provides a free, easy to use PCB layout software for producing inexpensive, high quality circuit boards of low to moderate complexity (show boards).

Typical turnaround time is three days. After completing your PCB design, you can order boards via the Internet with a credit card. At the low end, the "miniboard" option produces standard-size bare boards with plated through holes for about $65 (postpaid in CA). For professional quality boards, the miniboard pro option adds a silk screen and a solder mask for about $90 (pp in CA).

For these prices, you get three 2.5" X 3.8" boards. It is easy to put multiple boards on each blank. For example, I was able to fit four PCBs on a blank for a recent Toolstick project (show EPUT layout). This produced a total of 12 boards at a cost of $7.60 each. Each board included a direct connection for an LCD and a 24-pin connecter for interface to peripherals such as an RS-232 level converter, I/O jacks and an incremental encoder (show unmounted assembly).

Using a Toolstick attached as a daughterboard to these boards, they accommodate a suprising amount of circuitry. Motherboard circuitry included conditioning for an analog input, a digital input and two FETs for driving the LCD backlight and an external relay (schematic available here). In addition to the boards shown here, I have several other small and full-size project boards produced for non-toolstick applications. Contact me if you would like templates for any of these boards.

Packaging

Above I have described how to produce professional-quality PC boards that can be mated with commercial Toolstick modules to produce a high quality, professional product.

But, until recently, it was not easy to inexpensively package the hardware while producing the same professional "look and feel."

It is now possible to inexpensively and professionally package your products for your customers, magazine articles or ”bragging rights.” I have discovered Front Panel Express (FPE) which does for panel layout what Express PCB does for PCB production. See **www.frontpanelexpress.com** .

Front Panel Express provides free software to lay out front panels. The finished layout can be printed and used as a punch template for a panel blank. The layout can also be printed out on photo quality heavy duty paper to cover the finished panel (show crystal set transformer box).

For truly professional looking results, you can submit your front panel design via the Internet and have a punched and engraved panel delivered in about 5 days (show Rubidium panel). For a recent project, I produced three, 2U, 19 inch rack mount panels for about $50 each. I mounted these panels on a standard rack mount enclosure (available from Hammond for about $60, see BOM). The custom panels were designed to exactly match the mounting holes on the Hammond assembly so that they could be directly attached in place of the panels supplied with the enclosure. See me if you would like a template.

The FPE software also provides a detailed cost breakdown, which is available as a pulldown option that shows items such as set up costs, material costs and finish and engraving charges. You can order panels in a variety of material thicknesses and sizes, easily comparing the costs of various thicknesses, materials and engraving options to minimize costs.

Conclusion

The Forth community has long provided a wide variety of commercial and low cost software development tools for quickly producing high quality embedded software.

However, the hardware, user interface and packaging aspects of project development have often proven more difficult, typically producing products that appeared somewhat ”home brewed.”

Using a combination of the tools and products described above, it is now possible to produce high quality products that are compatible with the Forth principles of simple, cheap and functional.

Finally, I should note that there are a number of products and services similar to ExpressPCB and Front Panel Express that produce comparable results. But, I have only described tools that I have actually used and like. Another product worthy of mention is Eagle PCB Layout. A free version is available that will

produce professional quality PC boards in the size range noted above. Of particular use is the Eagle schematic drawing facility that is both easy to use and can export schematics as a PDF or JPEG files.

Bill Of Materials

ID	QTY	Description	Vendor.	Part Number	Cost
		ENCODER/LCD			
IEN1	1	incremental encoder, 16mm, no detent, 24 ppm, w/switch	Arrow	PEC16-4020F-S0024	$0.92
LCD1	1	LCD display, 3.3V, 8 char, w/backlight	Mouser	NHD-0108HZ-FSW-GBW	$7.12
		CPU MODULE			
TS1	1	Toolstick Daughter Card, C8051F362 processor	Mouser	634-TOOLSTICK360DC	$10.25
TBA1	1	Toolstick Base Adapter for Daughter Card	Mouser	634-TOOLSTICKBA	$18.18

NOTE: The first page of the C8051F362 datasheet was manually attached to the original presentation. For this information, please go to the Silicon Laboratories web site and download the datasheet.