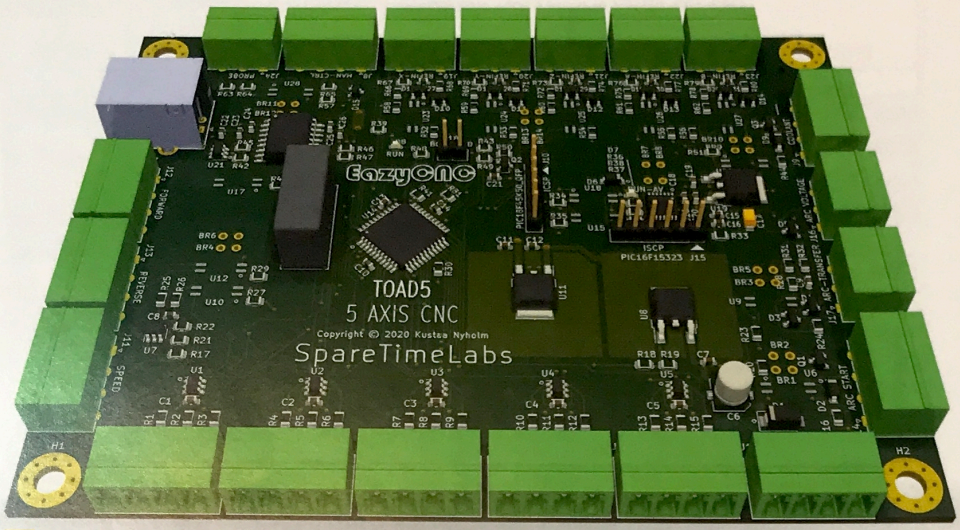
TOAD5 has Arrived

by Kustaa Nyholm

Figures by Author



A rendering of the new TOAD5 board.

My article "EazyCNC – A Different Approach" in *Digital Machinist*, Spring 2020, received a lot of positive feedback. I was and still am pretty happy with the overall design of TOAD4. It is minimalistic, compact, and fit for purpose – a one-board system for a medium sized hobby CNC. I had no real plans to revise it anytime soon.

But then the circumstances conspired against me, and one thing led to another. I got requests for more axes and more oomph for the axes. Some people wanted "standard" screw terminals for all the wiring. One or two people had problems with EMI and the USB. But the real clinching moment was when the Chinese company JLCPCB appeared on my radar.

Modern Product Development

JLCPCB offers free assembly of surface mount components on small quantity PCB prototypes if you buy the components from their selection. Surface Mount Devices (SMD) offer several advantages: They are significantly smaller and cheaper and are specifically designed for mass production, fully automated assembly. The downside is that I don't think they are suitable for the average hobbyist, though some advanced people will have the facilities and skills to use them.

I was skeptical at first, but all the components I needed were available as SMD and, more importantly, available from JLCPCB inventory at acceptable prices for my very small PCB quantities. My initial order was for just five boards!

My old PCB design software was no longer available and the DipTrace free edition that I had dabbled with was too limited, so I decided to take the plunge and learn KiCad. It is very different from most other software, so it has a learning curve, but with the right attitude and motivation it proved to be very good. It can even produce nice renderings of your design, which really helps to visualize component and text placement (***Figure 1***).

I'm still amazed that we are in a point of history where an individual with limited means can design a complex electronic board with *Free* (in every sense of the word) tools while sitting comfortably on their lazy-chair and have it delivered to their doorstep in a week or two.

That is some lockdown activity for you right there!

Introducing TOAD5

There is a complete manual of TOAD5 with a detailed description of all the features and full schematics at my personal website, *eazycnc.com*. In this article I'll discuss some of the design decisions and highlight some interesting technical details of TOAD5.

The main difference compared to TOAD4 is that TOAD5 does not have the stepper motor drivers incorporated on the PCB board. This allows flexibility with your choice of drivers, making it possible to use higher current motors, take advantage of the incredibly cheap Chinese driver offerings, or use servo motors as long as they conform to the STEP and DIR method of control. Servo motors are superior to stepper motors in almost every way, except price!

Outputs

The TOAD5 board has the following outputs:

- 5 x STEP, DIR, and ENABLE outputs for stepper drivers
- COOLANT control output, relay compatible
- FORWARD and REVERSE outputs to control a spindle via a VFD

- Analogue SPEED (0-10V) output to control spindle speed
- ARC START output for controlling a plasma torch, relay compatible
- RUN LED output

Inputs

The following inputs are available on the board:

- 5 x REFIN switch inputs, compatible with proximity switches
- Touch PROBE input
- Analogue ARC VOLTAGE input for torch height control
- ARC TRANSFER input to synchronize cut start with arc start up
- MAN-CTRL connection for Manual Control Panel
- ESTOP input to kill all outputs

Stepper Control Outputs

For each axis/motor, STEP, DIR, and ENABLE signals are provided. These are referenced to ground and protected against electro-static discharge (ESD) but are not optically isolated because most motor driver modules already have opto-isolated inputs.

Isolation

Except for the axis control outputs, everything else is optically isolated. All outputs are completely isolated from everything else.

All inputs are isolated, but are fed from a single on-board DC/DC converter. There are very few use cases where complete isolation is called for. But, if necessary, they can all be isolated from each other by drilling through vias on the PCB provided for that purpose.

The on-board DC/DC is adequate for most applications but if you need to max out every input and output you may run out of juice, in which case an external 12v supply can be used.

All the inputs and outputs are on their own "islands" on the PCB, which can be isolated from each other by simply drilling through conveniently placed and clearly marked through holes.

Powering the Board

The board needs a single DC voltage supply in the range of 24-36 VDC. This allows operation from common 24 VDC switch mode power supplies or from rectified and filtered 24 VAC. In fact, with some additional cooling, up to 60 VDC can be used, which may come in handy if your stepper drivers need that much voltage, saving you the expense and space of a separate PSU for the TOAD5 board.

Careful power balancing allowed me to get away without a heatsink, reducing cost and mechanical complexity.

Screw Terminals

I was reluctant to use screw terminals for the wiring because I think that service and troubleshooting are better served with connectors. But then I realized there are pluggable screw terminals that offer the best of both worlds; no need to solder or crimp wires and yet you can just un-plug a wire when necessary (***Figure 2***).

Isolated USB!

USB is not the best choice for interfacing high current and electrically noisy equipment, so isolation is very attractive, and it should go a long way in reducing EMI (electromagnetic interference) problems.

USB isolation is much more complex than just throwing one or two opto-isolators on the board, however. Luckily, I discovered that a USB isolator was available from the JCLPCB inventory, which allowed me to easily incorporate this feature.

Plasma Cutter Controls

I use one of my TOAD4 boards to run my plasma cutter. One glaring (no pun intended) omission is that it has no torch height control. THC keeps the distance between the workpiece and torch constant, which helps to keep the cut width consistent and is essential if (or when!) the workpiece tends to warp.

To remedy this omission, I included an optically isolated analog to digital converter in the design of TOAD5. There is a direct correlation between the arc length and the arc voltage, so by measuring and keeping the arc voltage constant the torch is kept at the optimum distance.

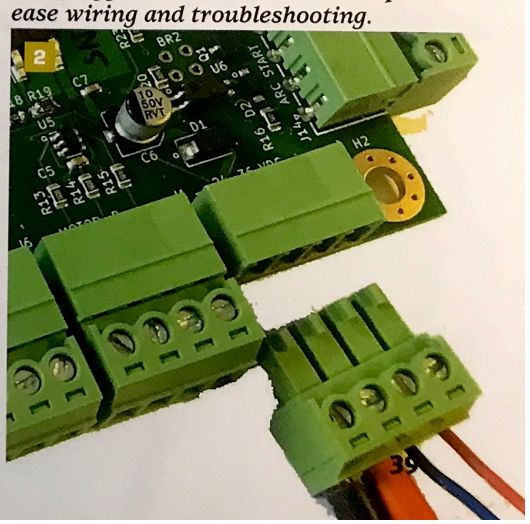
I also added an input for an "arc transfer" signal that is used to signal to the TOAD5 that the initial plasma arc has transferred to the workpiece and thus it is the optimal time to start the torch movement. All plasma power supplies that are aimed at CNC have the arc transfer output.

The hardware for these features works but I still have work to do on the firmware, so as of this writing this is a work in progress feature.

Compatible Inputs

Naturally, the board also has inputs for reference switches for each axis, a digital probe input, and outputs to control a spindle via a variable frequency drive (VFD).

The pluggable screw terminals help ease wiring and troubleshooting.



The reference switch inputs are interesting in that they are compatible with both mechanical switches and PNP- or NPN-style proximity switches and optical forks (***Figure 3***). NPN and PNP refer to the type of output transistor in an electronic switch – in practical terms this indicates whether the transistor pulls the output down against ground (NPN) or up (PNP) towards the supply voltage of the switch, voltage that the board also supplies.

This is implemented by a clever little circuitry that a good friend of mine supplied – thanks Christian (***Figure 4***). This has quite a few components and it was only feasible to include this feature thanks to the SMD technology. I include a schematic snippet here because I think it is an interesting little detail. To make sense of it you can envision that the circuitry treats the input signal as AC (Alternating Current) and rectifies it.

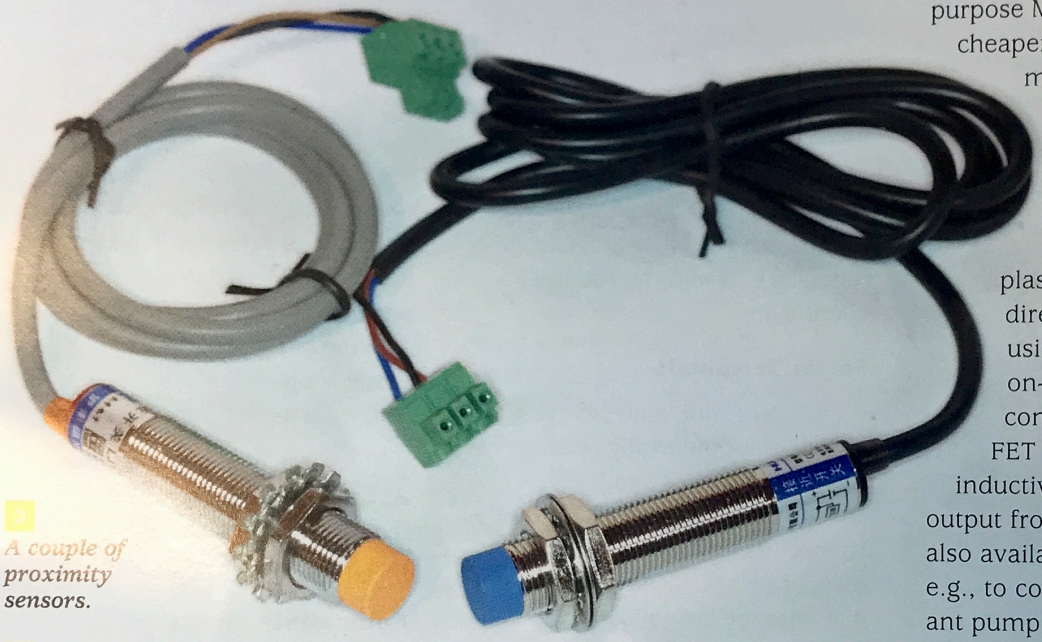
Optically Isolated Analog Input

Another interesting detail is how the isolated analog to digital conversion is implemented. It turned out that the most economical way to implement this was to add a single-chip microcontroller just for that task.

The MCU I chose costs less than 85 cents and includes a 10 bit analog to digital converter and a serial communication port to send the conversion result through an opto-coupler to the main CPU. I find it interesting that a general purpose MCU based solution is cheaper than chips specifically made for the task.

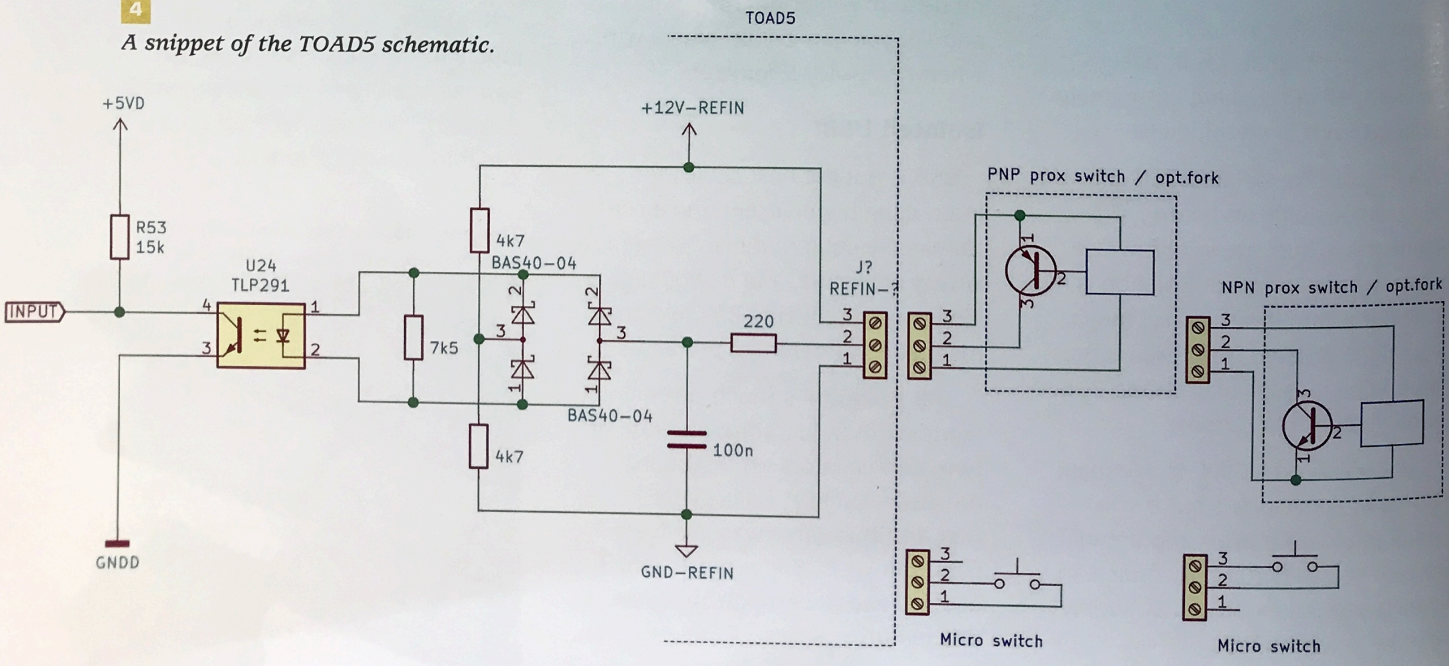
Relay Controls Without External Power

The outputs for coolant pump and plasma power supply can directly control 12v relays using power from the on-board, isolated DC/DC converter. The relay output FET is protected against inductive kickback. The raw output from the opto-coupler is also available, which can be used, e.g., to control a VFD driven coolant pump on and off.



3 *A couple of proximity sensors.*

4 *A snippet of the TOAD5 schematic.*



Variable Frequency Drive Control Outputs

The VFD control outputs are simple opto-isolator outputs compatible with both the pull-up and pull-down style logic inputs of most VFDs. The ratio-metric analog speed output for the VFD speed control is improved compared to TOAD4.

Probe Input

The probe input is compatible with Econo-Probe-style touch probes, or any probe with mechanical switch or NPN-type output.

Econo-Probe is a product that utilizes the famous Renishaw mechanical switch arrangement and has a resistor and an LED in parallel with the switches to indicate a touch (***Figure 5***). This has the convenient property that only two wires are needed, but it does require that the input can supply current for the LED.

Option for Manual Milling

Some CNC milling machines retain the manual axis handles and can thus be used for manual milling. But, if the spindle is wired to a VFD that is controlled by the computer, then it is inconvenient to have to boot up the computer and use a mouse for speed control. For those users, I've added an interface that allows you to control the VFD and coolant pump manually.

For convenience and economy this is a separate PCB board that can be mounted to the front panel and requires only three wires to the TOAD5 board.

Raspberry Pi

This is an article about TOAD5, but I feel I need to mention some breaking news. Since I originally wrote this article, I've been dabbling with Raspberry Pi 4 and touch screens. With just a moderate effort I've got EazyCNC up and running

The Econo-Probe.

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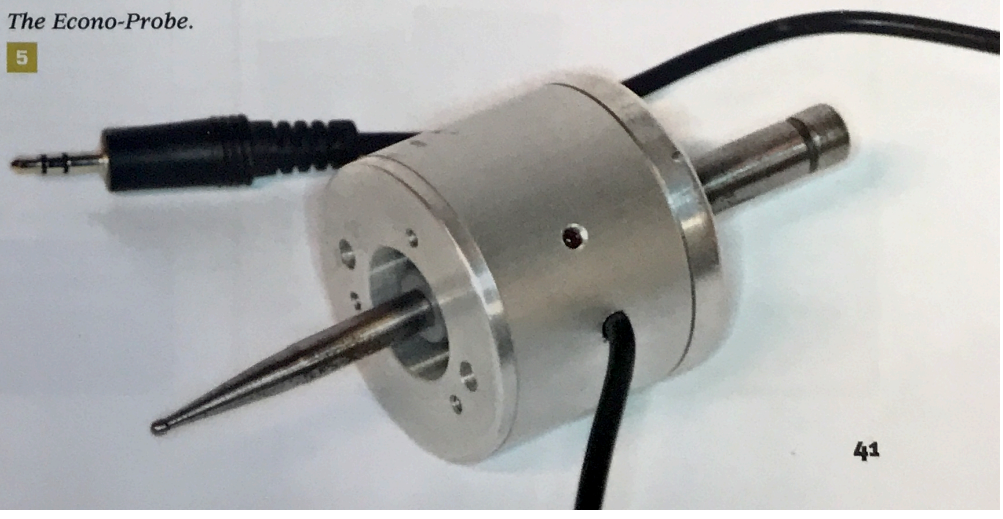

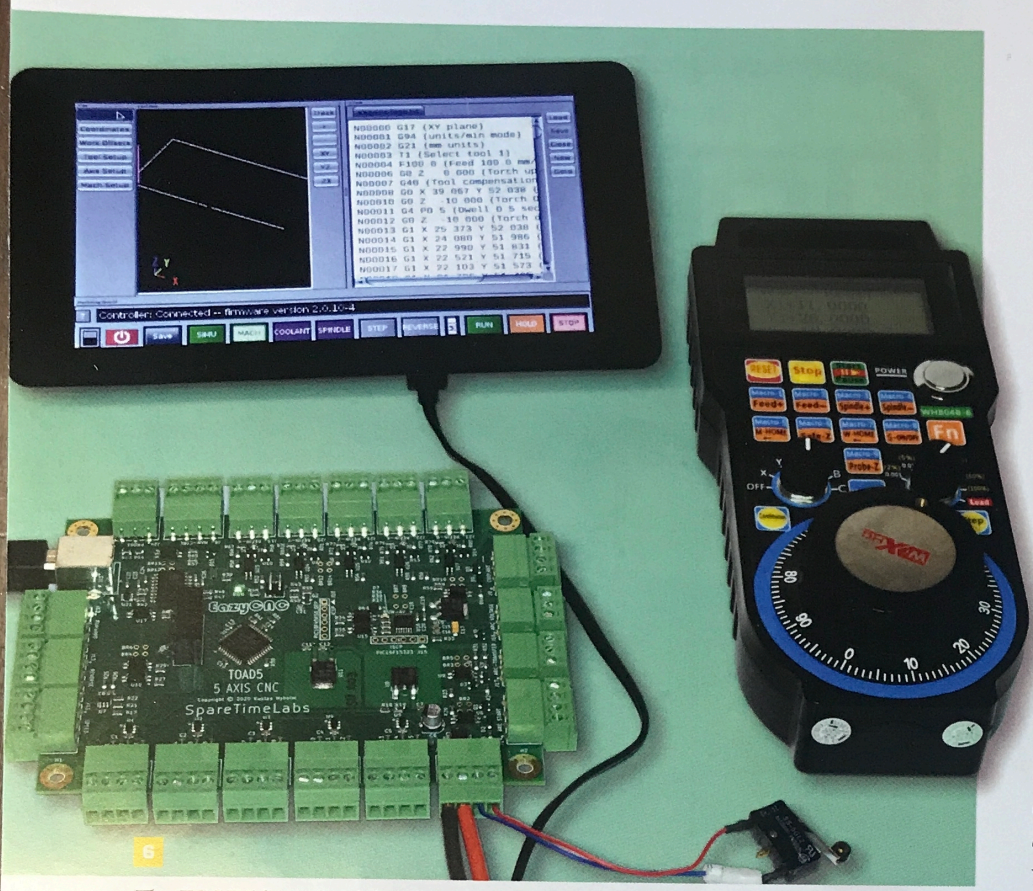

The TOAD5 board, with a Raspberry Pi touch screen and a wireless pendant.

and even with the original, dismally small 7" Raspberry Pi touch screen it can be used without a mouse or keyboard. Together with a TOAD board this would seem to form a good basis for a small and compact CNC control system (***Figure 6***).

Even the wireless MPG pendant worked right out of the box, thanks to Java write once, run everywhere technology. If the editor allows me, I may write an article about that!

Availability

The boards are available from me fully assembled and tested, or the board with just the SMT devices assembled and MCUs preprogrammed, in which case you need to solder the screw terminals and USB connector yourself. As this is not a commercial operation, I'm quite flexible, so don't hesitate to contact me. I can be reached at *eazycnc@eazycnc.com* and you can visit my website at *eazycnc.com* for more information.