Adapting to Technology Advances and End of Life Announcements for Current Measurement Technologies

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***Abstract*—As technology advances and manufacturing processes evolve, electronic components and subassemblies are replaced by updated, generally more capable components and subassemblies. After a period of dwindling supplies of the outdated parts, the component or subassembly is discontinued. The first warning is generally an "End of Life" announcement to permit the clients dependent on the part to make other arrangements. The need to adapt to these changes can present a significant challenge to small companies, making limited runs of product depending on a stable supply of parts and there are several strategies that can be employed to minimize the disruption and maximize the benefit of the upgraded part replacement.**

Keywords—End of life announcement; current meter upgrade; adapting to changing technologies; part replacement; subassembly replacement

I. INTRODUCTION

Current measurement technology has advanced over the last century through the intersection of oceanographic problems and technological solutions. One of the biggest leaps in technology has been in digital electronics, giving rise to the Vector Averaging Current Meter, VACM, in 1969 and the Acoustic Doppler Current Profiler, ADCP, in 1981. The former benefitted from the introduction of CMOS logic circuits providing low-power digital processing in the fashion previously used in business and laboratory computers. The second benefitted from the introduction of signal processing digital circuits. Each current meter development in turn had the pull of an oceanographic problem: need to remove wave and turbulence noise from deep-sea current measurements for the former and need to profile the full water column currents on the shelf for the latter. But one of the biggest technology boosts has been from microprocessors, µP, that permit complex controllers to be included in autonomous instruments.

The higher the order of complexity in the device, the less durable is the continued supply. Resistors, capacitors, and transistors continue to be available albeit in slightly different packages and capabilities; digital logic circuits less so with certain technologies being replaced by more market driven advances, cell phones being a strong driver; and single board controllers using microprocessors at the most complex level being the most ephemeral. This technological EOL (End of Life) issue is not peculiar to current measurement technology but this is where we have experienced it.

II. ISSUES FROM END OF LIFE ANNOUNCEMENT FOR SMALL MANUFACTURERS OF CURRENT METERS

A. Large Batch Assemblies vs. Small Production Runs

Unlike new cell phone releases where all parts are acquired at the time of manufacture, small current meter manufacturers who gradually evolve design for revised models in response to oceanographic problem-pull must adapt to EOL for critical components. Package size is one of the simplest revisions to which one must adapt although it may require a new circuit board layout and revised stuffing guide, supply reels of parts, and production run of boards. Often "wouldn't it be nice" improvements in design can be included in this revised layout. Functional changes in components offer greater opportunities, requiring revised design followed by testing and second order revision. But when a new generation of microprocessor or logic level is forced, a major redesign opportunity is offered with improved code for the controller and extensive testing.

B. Examples Drawn from Current Meter Evolution

Most EOL announcements are for non-essential changes such as new packaging of the components or a change in a temperature rating. In most cases the change is beneficial and offers little trouble to accommodate. However, this is not always the case and a simple color change to the label of a digital cassette tape in a logger of an early current meter, BASS (Benthic Acoustic Stress Sensor) hid a more significant change in the chemical composition of the side plates in the cassette. The side plates in fact had a different drag coefficient causing the tape to wrap around the capstan instead of remaining on the supply reel. Loss of data due to this tape wrapping failure from deep sea deployments affected not only the BASS deployments but VACM deployments using the same Sea Data Digital Cassette Tape Recorder. It became a research project to discover the cause of the failure until a more persistent enquiry to the cassette tape supplier revealed that not

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only the color had been changed but a new material for the side plates had been substituted as well. It wasn't humidity, temperature, or care of the unopened cartons of the cassette tapes but the color that was correlated with failure.

Less subtle changes result from development of manufacturing techniques. Electronics has evolved from discrete leaded components, originally soldered to the contacts of vacuum tube sockets, to printed circuit boards with foil on a single side and then to double sided circuit boards, soon with plated through holes so that only one side needed to be soldered, and then to surface mount components without leads where pick and place machines taking from reels of components reduced the unit cost of both the component and the placing of the component. Each of these transitions required a new layout but the circuit diagram was unchanged (not including the vacuum tube designs) and the tested design did not generally need more than a validation check to be sure the new layout and assembly process was satisfactory. The functioning of the design remained unchanged. Surface mount components, frequently mounted on both sides of a multilayer printed circuit board with vias often to buried layers making repairs and troubleshooting more complex, continued a miniaturization process begun even with leaded components. Quarter watt resistors were superseded by tenth watt resistors but then surface mounted resistors, capacitors, and other discrete components were offered in yet smaller packages and then the larger packages in some cases were discontinued. The solution to reduce the vulnerability to these evolutionary changes was to provide solder pads on the circuit boards that could accommodate several sizes. And when a new production run of circuit boards was needed, it was sufficient to simply revise the pad size without a complete rerouting of the circuit.

Active components presented greater issues. BASS was originally hardwired to perform velocity measurements in a sequence that derived from a counter and parallel to serial shift registers to load words output from an A/D converter into a long buffer. This buffer was shifted by the Sea Data Digital Cassette Tape Recorder to the recording head and stored on cassette tape. The program was the tape recorder and everything else used only CMOS digital counters, flip-flops, serial to parallel shifters, and latches. Then came the microprocessor in 1978 and it was possible to gain the flexibility of a digital program. This change while major was not driven by EOL, it was for increased capability. Many CMOS logic circuits were still used but the RCA COSMAC, 1802 μP was added with memory both RAM and EPROM. Parallel bus connections between circuit boards became necessary with new types of connectors for bus communications. Still none of these evolutions were forced by EOL. But the 1802 didn't last forever and other higher level components began to be replaced by more capable revisions and this became a more worrisome issue. BASS was produced in small numbers; at most about 17 were ever made. Most were identical except for special circuits to measure total acoustic travel time as well as differential acoustic travel time. Such changes were hand made in any case so availability of parts wasn't very troublesome. The discontinuation of the 1802 wasn't a big issue since we had boxes of them exceeding any expected demand. But it was clear that future designs needed to use a μP of greater popularity for safety of continued supply. A few specialized designs were produced for benthic boundary layer studies using the Motorola 6304 μP and eventually the Tattletale single board computer by Onset Computer was chosen to not only provide a stable μP but other components, the glue, to turn it into a user friendly controller that could be programmed in Tattletale BASIC (TTB) so anyone might adapt the program to their needs. TT4 and TT5 were both used in developing designs, again not driven by EOL but by desired capability. For deep-sea deployments, a vast increase in storage capability was provided by the TT6 with a hard drive, 20MB followed by 120MB and 540MB and 1.2MB and then the practical limit of DOS formatting complicated the problem as did the need to start and stop the hard drive to save power. But the TT8 with a Motorola 68332 μP and a separate compact flash logging board removed all of these worries and design proceeded with only the minor adaptations to greater miniaturization causing solder pads to be redrawn.

C. *Ancillary Sensors*

Current meters not only measure flow, they also must determine orientation to convert instrument frame coordinate vector velocities into earth frame coordinate currents. The ancillary sensors to determine orientation are also subject to EOL.

- Precision Navigation provided an excellent magnetic sensor for compass heading. It was a separate board supporting two gimbaled coils and the electronic glue to give a serial peripheral interface word with the two components of magnetic field needed to determine heading of the current meter. Supply of these units was sometimes interrupted for manufacturing difficulties and eventually the V2XG was discontinued. But there was a replacement solution offered with three discrete leaded magnetic sensors and the PIC processor. This required constructing a special board but it performed even better, requiring however, a good tilt sensor. The discrete parts were discontinued and surface mount parts seemed to be called for but a module was supplied instead that combined the three surface mount parts with an orthogonal fixture so the EOL issue was a net gain in performance and simplicity to produce.
- Spectron produced a fluid tilt sensor that output tilt in degrees along two axes up to about 45 degrees. Two versions were made available with a fast sensor replacing a slower sensor, which was a simple plug-in replacement with improved capability. But there were issues with the limited range and dynamic response so when Analog Devices offered a two-axis linear accelerometer that could read gravity along two axes it made that tilt sensor a better choice in a solid state unit. Temperature sensitivity required that every unit be thermally calibrated and shipped with coefficients to correct for temperature. While a nuisance, it was acceptable but a revision provided an equivalent unit that didn't have the temperature sensitivity making this step no longer necessary and that was an improvement in performance with negligible cost increase. The combination of the Analog Devices two-axis linear

accelerometer with the three-axis Precision Navigation magnetometer is a compact package that has served us well. It does everything needed to rotate current measurements made in instrument frame coordinates into earth frame coordinates if there is no acceleration.

- Changes in the two ancillary sensors are of less impact to us because they occupy a small circuit board that can be modified to adapt to different footprints or even moderately different communications protocols without major redesign.
- In waves, the linear accelerometer alone is not able to distinguish linear wave acceleration from real tilt but inertial sensors have been offered over the last several years that include rate gyroscopes that can distinguish tilt from linear acceleration and the VectorNav 100 is a substitute that can be wired into the current meter to convert from instrument frame to earth coordinates even in wave accelerations.

D. *Controller*

The µP controller as a subassembly is more tightly integrated with the rest of the electronics than any component or even ancillary sensor. The conversions from the 1802 to 6304 and later the TT4, TT5, and TT6 were major changes and each took between six months and two years to accomplish. They were done because of increased capability that was needed for adding sensors and for increased data storage. None were caused by EOL although all are now discontinued, just not while the conversion was ongoing. The final controller, the TT8 shown in Fig. 1 is however perfectly satisfactory yet it is now discontinued and many of us are forced to make a conversion that will probably be looked back upon with at least acceptance but which is an inconvenience at the time of conversion.

Fig. 1. TT8 controller board with Persistor CF8 compact flash logging card stacked on top. The MAVS4 mother board is beneath.

III. Strategies for Adapting to a New Controller

Many potential replacement controllers are available but with different purposes, different programming languages, different power and form factors, different capabilities, and different user communities.

A. *Footprint*

The TT8 was plugged onto a single board containing the differential travel-time to voltage circuits for MAVS, the Modular Acoustic Velocity Sensor, that forms the core of the current meter. MAVS was developed through a grant from NSF to Woods Hole Oceanographic Institution and is manufactured and cared for by Nobska Development, Inc. MAVS 1 was a conglomerate of the four essential circuit boards of BASS, the sequencer, the differential travel-time to voltage, the power supply, and the controller interface board. The components were leaded discrete parts and ICs and the board was two sided but components were all on top. A TT4 was plugged onto this board. The MAVS2 used surface mount components but still a TT4 controller. Fig. 2 shows the transition from MAVS 1 to MAVS2 with the benefit that was provided of a built in RAM memory for logging data.

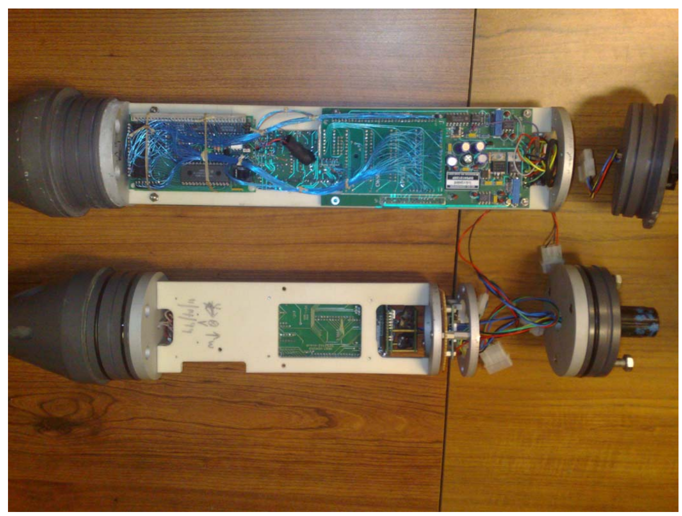

Fig. 2. The MAVS 1 (top) is a single board but with leaded parts. The need to incorporate RAM data logging with the TT4A controller when there was too little space necessitated interconnecting the RAM expansion board to the TT4A board with wire wrap wires in blue. By contrast the MAVS2 (below) with the same circuit but constructed with surface mount components contained the extended RAM without such extraordinary means. The compass and tilt sensors are at the right end of the chassis.

MAVS3 was adapted to the TT8 with its MC 68332 µP allowing a sleep mode that permitted lengthy deployments and this transition was major. The TT8 accepts a Persistor CF8 piggyback board that carries a compact flash with memory up to 2 GB specially made to interface to the TT8. When this board is attached, the stack of boards is three deep. But in an effort to shorten the entire assembly for a particular application, current measurement aboard the McLane Moored Profiler, the MAVS board was re-laid out so that it could be cut and folded in half making a stack of four boards. This became the MAVS4, shown with a test probe in Fig. 3. This stack can be fit inside a 3.5” outside diameter titanium housing good for 6000m depth. To go to a controller with a vastly different footprint would require that the pressure housing and stacking issue be addressed again. So a controller that has a very similar footprint to the TT8 and can interface to a compact flash or other logging device that stacks is desirable.

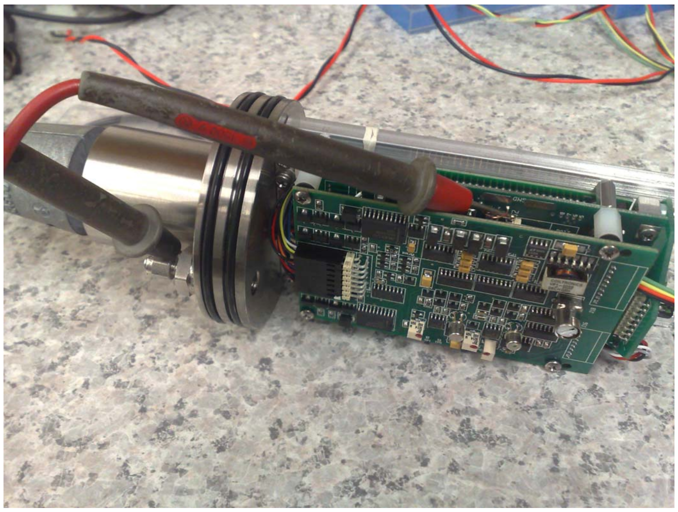

Fig. 3. The MAVS 4 mother board is capable of being cut in half and folded to fit within a 3.5" OD titanium housing for 6000m depth yet occupy a small space within the McLane Moored Profiler. The stack of boards with the TT8 and CF8 is four high. Isolation resistance is being measured in this picture. There is not much room to substitute a controller with a different footprint.

B. Voltage

In the TT8, logic is 5v and the rest of MAVS uses 5v logic with +12v and -12v power for op amps and the voltage comparators. It would be a great convenience to have a controller with this logic level. However, this is not generally available. The common logic level today is 3.3v and there are some that are lower, to 1.8v, for example.

Alternative 1 is to redesign MAVS with 3.3v logic devices. There are about 20 ICs some of which are particular about logic level and others that are able to operate at either 5v or 3.3v. Such changes, however, will require extensive testing for timing, sensitivity to temperature, and long term drift and component degradation.

Alternative 2 is to shift all of the 3.3v lines from the controller to 5v with a level shifter to keep the MAVS board logic at 5v and just make an interface that shifts both ways for the controller. This is a surprisingly frugal use of lines, only about eight being needed. So this is the preferred route for this revised design. Fig. 4 shows where this might be done from a section of the MAVS4 schematic. While this piece of the schematic has the TT8 as the controller, it is assumed that an equivalent set of lines from a Persistor controller would work.

C. Power and Sleep

The sleep mode of the TT8 is important to our clients for long deployments. Not all controllers support this mode. But for now the MC68332 is still supported Power is strongly influenced by operating frequency of the µP and the TT8 allows this frequency to be varied from high–frequency, high-power for fast processing but low-frequency, low-power for slow processing.

IV. SELECTION OF CONTROLLER

The principal short term issue for selection of a new controller to replace the TT8 is minimum rework although it is clear that a new circuit board will have to be laid out. But if the function of the circuit remains essentially as it was, the testing will be reduced. The second most important issue is the amount of programming that must be done. And finally the third issue is the footprint issue since there are external constraints on size and shape that must be met.

A. Persistor

Conversations with several potential logger suppliers narrowed our choice down to the Persistor family of controllers. The CF2 [1] has a long track record among ocean engineers making ocean sampling and logging equipment and the CF8 piggy back board that logs to compact flash, which also connects to the CF2, is familiar to us. We have a concern since this product, the CF2, is older, that it might be slated for EOL like the TT8 was. We have been assured this is not the case. But we learned that there is a CF3 in beta test now with increased capability.

- The CF2 uses the MC68332 µP that the TT8 uses so the assembly language routines programmed for the TT8 can be ported with minor revision to a CF2. It plugs directly to the CF8 with a compact flash card as in the TT8 so there will be no surprises for repeat customers of the MAVS3 and MAVS4. Interfaces to sensors can be by QSPI (queued serial peripheral interface) as in the TT8. The compiler/assembler for the C code, CodeWarrior, is free and a product that we have used although it isn’t our first choice due to its generation of larger assembly code than our preferred compiler/assembler. However this is not an immediate issue since the CF2 has substantially more program memory than the TT8 so larger assembly code will not be a problem in the near term. Perhaps most important is that the footprint is identical to the TT8. However, all of the connections to the CF2 come off a 53 pin connector running the long way on the board, a connector with similar function that existed on the TT8 but that we didn’t routinely use due to the crowding to get signals out across the width of our MAVS circuit board. We were able to get all the signals we needed on the TT8 from two connectors at the short ends of the board that were not crowded. However, not all 53 pins of the CF2 need to be connected to circuits so the crowding issue may be solved with a sort of matrix of vias to spread the circuits to places where they are more accessible.

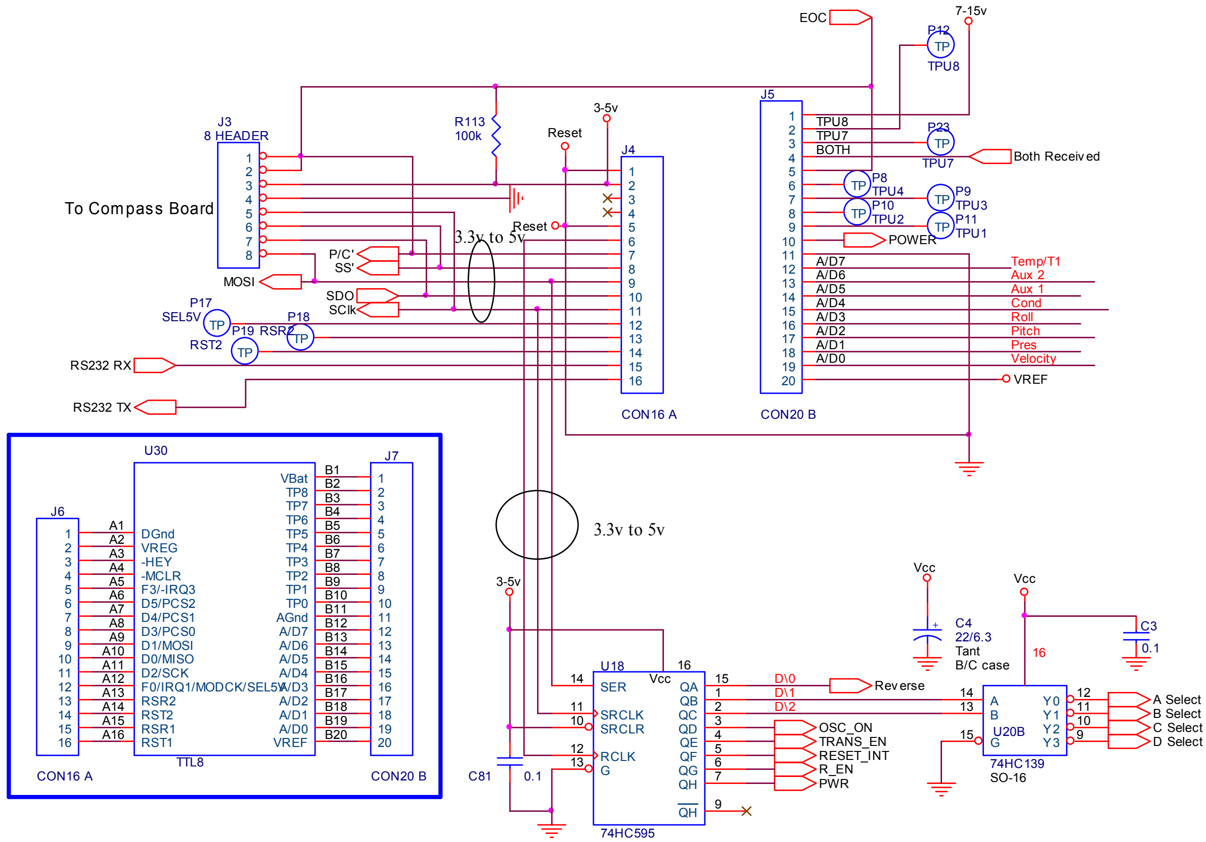

Fig. 4. This section of the MAVS4 schematic with the connections from the TT8 to the MAVS circuit and the compass board shows two places where level shifting could be done if the TT8 were replaced by a 3.3v Persistor controller. The ovals are where the level shifter would be inserted to upshift the logic signals. There are also three lines not yet accounted for: POWER which might need up shifting and EOC and Both Received, which might need down shifting.

- The CF3 uses a new (for us) LPC4357 processor [2] capable of running at 204MHz against the MC68332 running at a maximum of 16MHz in the CF2. The LPC4357 is a 32 bit processor vs. the MC68332 which is a 16 bit processor. Logging is done on an SD card in the CF3 rather than compact flash. The footprint is the same as the CF2 so subsequent migration from a CF2 to a CF3 will impose few mechanical or electrical issues. Programming will, however, be a significant additional project and compiling and assembly requires a new and moderately costly product, LPCXpresso. Perhaps the biggest concern is the beta test condition of the CF3 vs. the long experience with the CF2. Things are yet to be discovered in the CF3 and Persistor is releasing only a partial access to the capabilities of the LPC4357 while they learn more about it. So we elected to put off the CF3 until it is needed but we are happy that there are several compatibility worries that go away such as footprint and electronic compatibility. Fig. 5 shows one configuration of the CF3.

B. Logic Level Conversion

MAVS3 and MAVS4 with the TT8 use 5v logic. Three address lines are needed to select which acoustic axis is being interrogated and whether the measurement is normal or reversed (eight possibilities with four acoustic axes). Then for each measurement cycle the oscillator needs to be turned on, the transmitter enabled, the differential time to voltage integrator reset, the receiver enabled, and power turned on at the beginning of a measurement and off at the end. These eight functions are decoded from a serial peripheral interface word passed from the TT8 as three lines: serial data, serial clock, and latch. It is only those three lines that need to be level shifted and the subsequent decoding can be done at 5v. This takes care of the acoustic differential travel-time measurements in MAVS.

The compass and tilt sensing board uses 5v logic but needs to communicate with the controller by QSPI and this takes another two lines in addition to the serial data and serial clock already level shifted for the MAVS functions.

In addition, there are some TPU (terminal processing unit) pins that communicate directly with the MAVS circuits. Inputs can be accommodated by a simple series resistor and a voltage limit clamp. But there is a final master power switch that needs an upshift converter. In total six lines need upshifting from 3.3v to 5v logic levels. A versatile level converter, [74ALVC164245](), is a satisfactory solution with room for expansion [3]. A total of 16 lines can be level shifted between 3.3v and 5v logic. This device is a ball and grid 48 contact circuit, which is a new technology for Nobska Development so additional research may be needed to select a lower level of circuit board sophistication and one that can be tested and repaired/replaced when there is time to move from design to implementation and layout. The industry standard HEF4104 [4] logic level up shifter is a four bit device that is capable of doing what is required and two or three of these will serve our purposes.

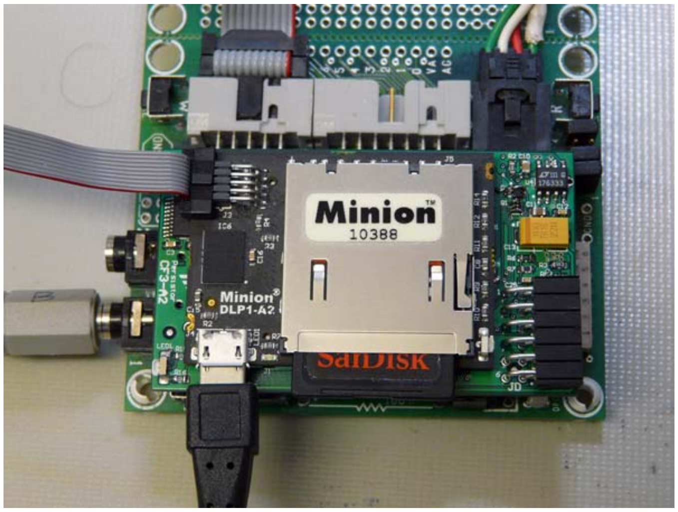

Fig. 5. CF3 is shown with a Minion DLP1 on top. There are a family of piggy back boards for either the CF2 or the CF3 including a USB interface.

With either Persistor board there are some features of the TT8 that are absent. The most significant is that neither the CF2 nor the CF3 have an on board A/D converter. It will therefore be necessary to add a suitable A/D converter to the MAVS mother board. Several options are attractive and can use the 3.3v logic lines. In fact the A/D will probably be a 16 bit A/D in place of the existing 12 bit A/D. However, a nice advantage of the Persistor controller for either CF2 or CF3 is that with a lithium coin cell on the MAVS mother board, a real-time clock can be maintained even when there is no external power. This means that there will no longer be a need to set the clock when a new deployment is started.

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