General Purpose PIC Controller

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Overview

The PIC microcontroller is a wonderful device for radio amateurs, allowing a wide range projects to be built using one underlying basic hardware design. The chip manufacturers, Arizona Microchip [1], offer a range of devices for all sorts of applications, ranging from low pin-count devices for simple pushbutton jobs, right the way up to advanced Digital Signal Processing.

The “mid range” Pic 16Fxxx family of devices are probably the most useful to us, as they come in a variety of packages and pin counts, are straightforward to programme, have the same basic processor core, and come with a variety of different peripherals. Analogue to Digital converters, Timer counters, Serial Interface, EEPROM memory, as well as various numbers of Input / Output pins. Some even have integrated USB interfaces.

To allow widespread adoption by amateurs and give an introduction to the use of PICs I designed the module described here. A few standard applications have been developed in parallel, with ready programmed PICs offered for a plug-and-play solution. BUT... the fully commented source code for these is all available for free download and you are strongly advised to think about obtaining a PIC programmer and tools and try modifying the code to do what ***you*** want it to do, then try writing your own applications. Details of how to obtain programmers and programming tools is given at the end.

But be very very wary. PIC programming is one of the most addictive things ever invented! Once you start writing code, all thoughts of food, drink, bed, exercise stop until the job works. Been there, done that!

Universal PIC Development Platform

The module is a platform designed to run PIC software to control and interface to external hardware. An 18 pin socket is provided for a DIL packaged PIC 16F628 or 16F819 device – these are two mid-range “workhorse” devices with most of the peripherals we will need. They can be either programmed externally , or via the In-Circuit Programming (ICP) interface. The board includes provision for either a four or two line by 16 character Liquid Crystal Display with holes on the board designed for direct installation of either of these. A suitable low cost 4x16 LCD module is available from [2]. The holes can be a convenient way to mount the whole assembly in an enclosure. Alternative LCDs or compatible displays of different dimensions can be used with a flexible jumper connection.

A rotary quadrature encoder with integral push button can be fitted to the right of the LCD for applications that require up/down tuning or entry of variable parameters in conjunction with the display. An alternative would be an off-board encoder with separate pushbutton and it is also possible to use a stepper motor with a differential line-receiver interface as described in *Design Notes* [3]

User Input / Output

The whole purpose of the module is to provide a capability for controlling or reading external hardware. For this, up to five Input/Output lines are made available on an 8-pin header, along with +5V and ground connections. Depending on the choice of PIC, these connections can function as analogue inputs as well as digital I/O. Two more digital only I/O lines as well as the processor reset line are accessible using the 4 way in circuit programming header, making a total of up to seven connections for the most demanding or projects. A LED mounted on the PCB just above the rotary encoder can be allocated to one of these lines.

Example of devices that can be controlled are :

Serially programmed Synthesizer chips – requiring three, or sometimes just two, connections.

Serial D/A converters for generating voltage levels defined by software, like PSUs, test equipment, audio generators

External high resolution A/D converters – more than the 10 bits offered by the integral A/D

Serially programmed expansion chips, like relay drivers for controlling high current external hardware. Or just shift registers like that used for the LCD. A parallel input serial output shift register like the 74HC165 can be used for reading multiple digital inputs or status lines.

All rarely need more than three I/O lines leaving some spare for other enhancements

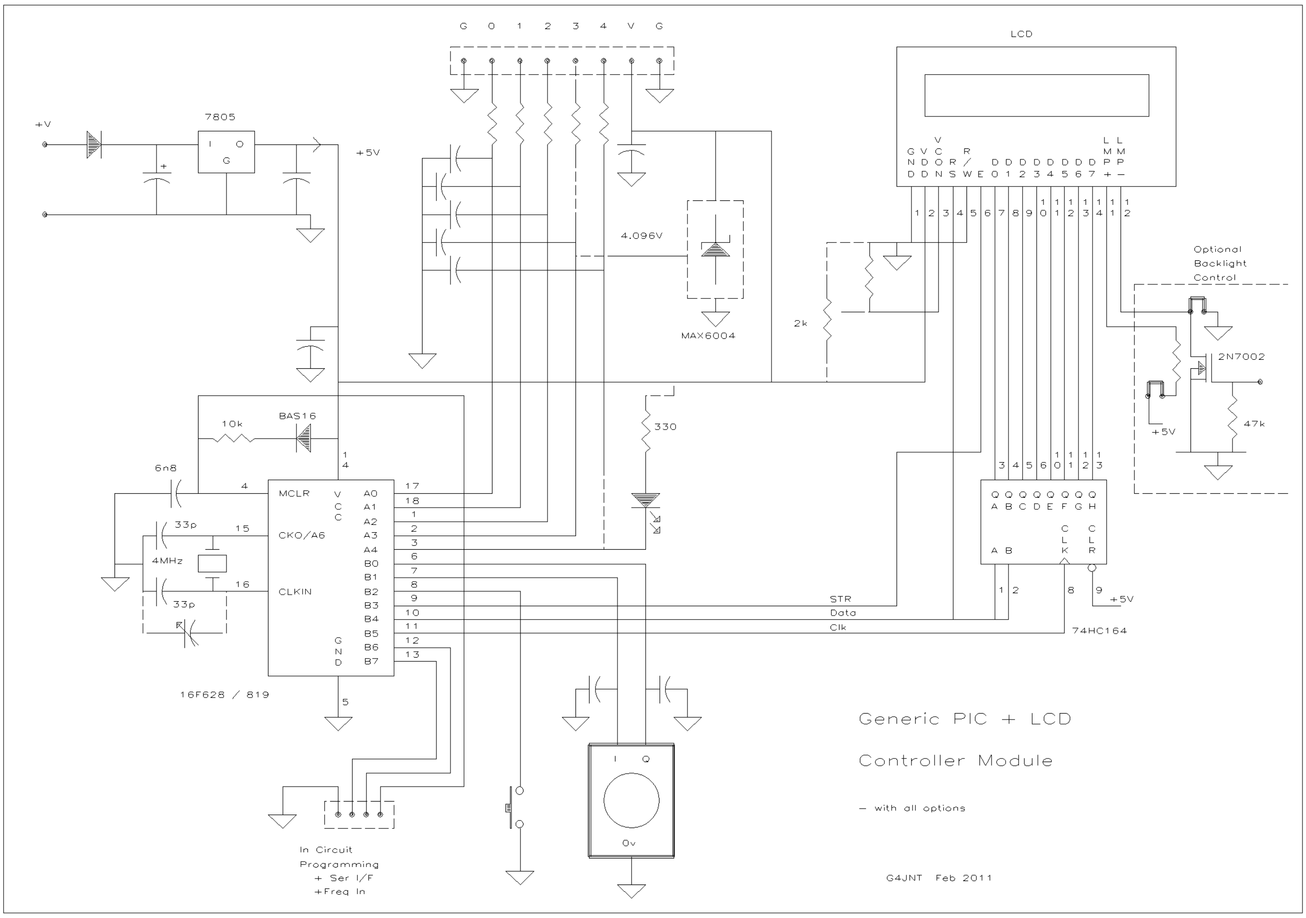
Analogue Inputs

The PIC 16F819 has an internal five channel 10-bit A/D converter and provision has been made on the board for some analogue conditioning circuitry if required. The converter allows use of an external voltage reference for accurate voltage measurement so for maximum flexibility the PCB has been designed to take a MAX6004 4.096 Volt precision voltage reference and feed this to the appropriate pin, reducing the analogue channels to four. For less demanding voltage measurements the internal +5V supply can be defined as a the reference allowing all five analogue inputs channels. Component pads have been included on the PCB on the interface lines so users can install potential divider resistors, or filtering capacitors as needed.

Circuit Description

The full circuit diagram is shown in Figure 1, which includes all the options mentioned above. Note the LCD module interface which needs 8 parallel data lines for sending it the text to display, as well as a register select pin and a strobe signal. The ten interface connections would use up most of the PICs I/O capacity so a 74HC164shift register is used to allow the PIC to output the data serially on two lines. The shift register converts the serial data from the PIC, in conjunction with the *Clock*, into 8 parallel outputs, with the ninth bit of data, the register select remaining on the *Data* line after clocking in the 8 bits. A third *Strobe* signal from the PIC latches the information into the LCD module

The rotary encoder uses two more of the PICs pins for its In-phase and Quadrature connections – two being needed to extract direction of rotation – the pushbutton one more. All of which means just six I/O lines are tied up with module itself, leaving the rest as user I/O. Two pins are allocated to the In-Circuit Programming interface, but are available as two more I/O pins on a separate header. Because of the PICs internal allocation of pins to its various peripheral components, one of these two must be used for the frequency counter to be described later.



A 5V voltage regulator and reverse protection diode provide power for the module. Although the PIC device and LCD only consume a few milliamps, a 1 Amp regulator has been installed with a bit of PCB

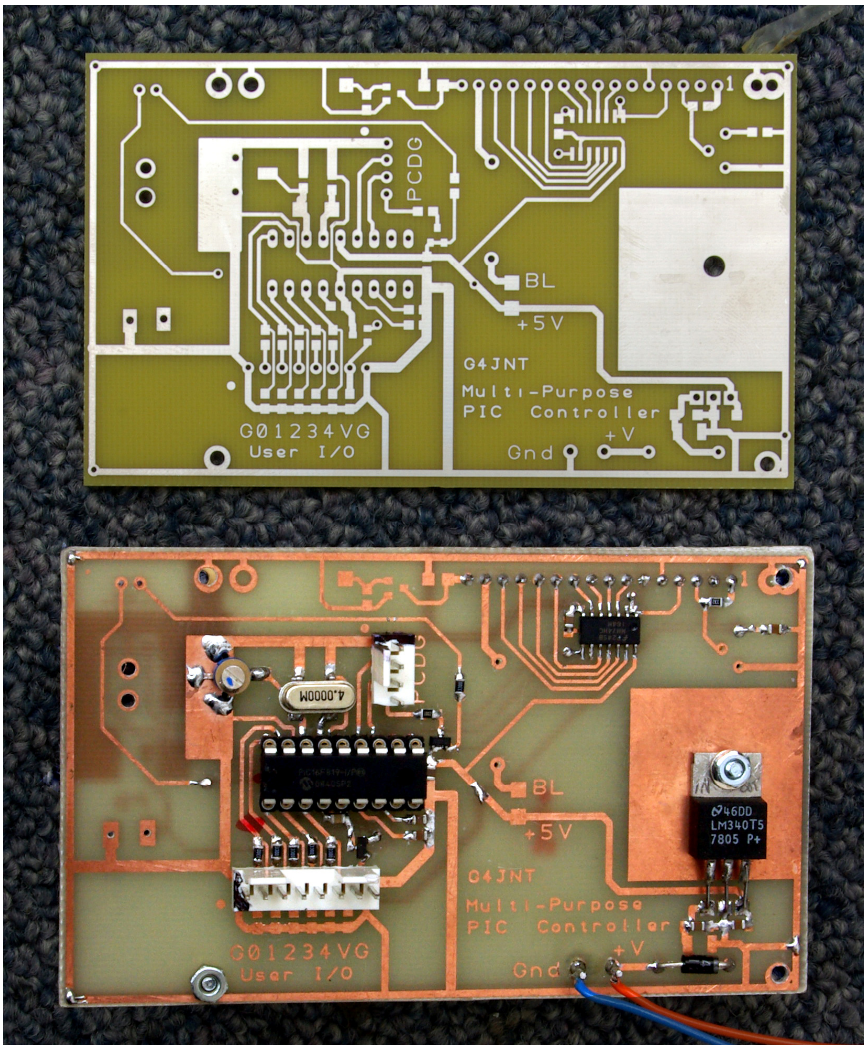
heaksinking to allow powering of additional hardware, and for an LCD backlight to be included. The high current capability allows pin and software compatible vacuum fluorescent display to be used instead. These need several hundred milliamps at 5V, and one is shown in Photo 5. Connections to allow a FET to turn the backlight of the LCD on and off under software control are included on the PCB, but unused at present. The LED, if installed, runs from User I/O line 5.

For analogue applications each of the 5 I/O lines includes a series input resistor and a capacitor to ground filtering. The maximum input voltage is 5V (or lower if the 4.096V reference is used) so these capacitors can be replaced with resistors to give a potential divider for higher input voltages. (If filtering capacitors are still then needed , they can be piggy-backed on top of the respective shunt divider resistors.).

For digital I/O, a small value resistor in the region of 200 ohms in series with each connection is advisable as a current limit in case of short circuits to ground or the supply. Each pin of the PIC can safely source or sink 20mA and internal clamp diodes to Vcc and ground protect against excursions above 5V and below 0V. The PIC is a very robust microcontroller – it has to be – it was designed with applications like washing machine controllers in mind !

Module Hardware and Construction

A rear view of the PCB carrying components and connectors is shown Photo 1 and the front view in Photo 2 . Apart from the DIL IC socket for the PIC device and a couple of other higher-current rated ones, all components are of surface mount type using the comfortably-sized 0805 dimension for resistors and capacitors (dimensions 1.6 x 2mm). The devices are well spaced apart and assembly shouldn't present too many difficulties for the home constructor. Full construction details including board overlay with component placing can be obtained from [4] The two links shown are only applicable to LCD backlighting, as is resistor Rb, and can be left out when this facility is not used.



Component and PCB Availability

See Reference [4] for full details of how to obtain the PCB. As most constructors will have their own requirements and sources of components, and with all the differing functions and configurations possible here, providing a full kits of parts is unrealistic. The PCB was designed to accept the EC11J152 type of rotary encoder with integral pushbutton, available from Farnell [5] - part Number 165-6447. Farnell also stock everything else needed – although their LCD modules aren't particularly cheap! The ready-to-go designs require a 4 line x 16 display, like those from [2] but with changes to PIC software, any other text based LCD with the standard 14 or 16 pin in line connections can be dropped in.

Small SMT components may present a minor problem to some. While these can be **extremely** cheap if you go to the bigger component suppliers, resistors may have to be purchased 50 at a time. Some amateurs have quite successfully recovered SMT components from scrap boards, using a blowlamp or hot air gun to remove the whole lot in one go. I often do this to get at the quite nice ICs that can sometimes be found in junk at rallies.

Ready-to-Go Projects

Several projects described are ready-to-go designs with pre-programmed PICs for plug and play operation. At the time of writing the following are operational, but may yet undergo further enhancement:

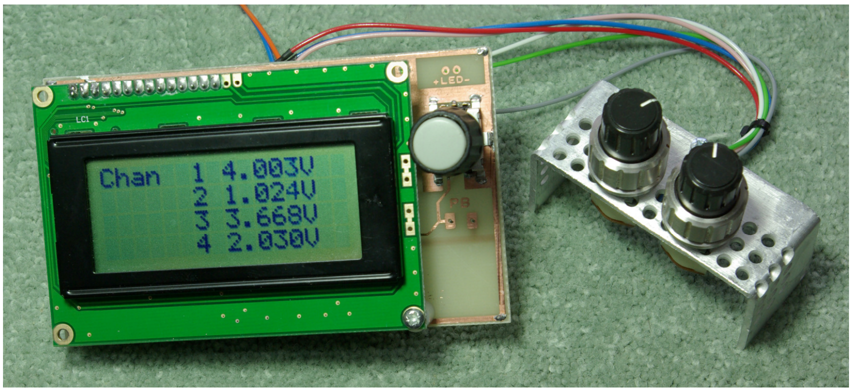
4 Channel Voltmeter

Automatic VSWR and Power indicator (separate RF head hardware needed)

Frequency Counter – up to typically 50MHz, but may go higher

Dual Controller for a pair of I2C programmed synthesizer chips as used in the G1MFG and similar FM TV Tx/Rx modules.

The first, a four-channel voltmeter, gives the display shown in Photo 3. The MAX6004 voltage reference is installed so the four analogue channels go to I/O pins 0, 1, 2, and 4. I/O line 3 is allocated to the reference and connected on the PCB, so its respective resistor R4 and associated capacitor should not be installed unless you need to bring the 4.096V reference out for further use .



The PIC code cycles through each channel and makes 16 successive ten-bit readings of each channel. Every read yields a value from 0 to 1023 which is proportional to Vin/Vref. The 16 readings are added together and divided by four giving a number in the range 0 – 4092 which, provided the specified 4.096V reference is used, is equal to the voltage input in mV. This summation of 16 reading gives some averaging and increases the resolution slightly for noisy signals. Please note, though, that for **steady** DC voltages, the averaging does not increase resolution above the basic 1024 levels possible from 10 bits.

The display shown is from the first version produced at the time of writing, and shows just the voltage on each channel. With a 10 times potential divider on the input [Note 1] the value would indicate up to 40.95V. It is intended to add user-adjustable decimal point placement, or scaling, on an individual channel basis, set using the rotary encoder and/or the pushbutton then stored in the PIC's own non-volatile memory. See [4] for details of the latest version. Further enhancements could include differential readings, AC measurement with true RMS, and relative level in dB.

Automatic SWR Bridge

The two detector diodes in any SWR bridge produce two DC voltages that are related to forward and reverse RF power. Normally these are taken to an analogue meter and the scaling adjusted with a potentiometer to set the Forward reading to full scale, whereupon switching to measure Reflected power indicates the reflected signal fraction. In effect, the meter is being forced to show the ratio V_{FWD} / V_{REFL} . By connecting the two voltage outputs, instead, to two input channels of this voltmeter, then calculating the ratio between them inside the PIC, the SWR can be calculated automatically and made independent of power level. It also becomes possible to add a digital readout of actual forward power.

The Calculation

VSWR can be calculated directly from (V_{FWD} + V_{REFL}) / (V_{FWD} - V_{REFL}). Alternatively, the reflection coefficient, *rho*, can be first calculated : $\rho = V_{fwd} / V_{ref}$ Then VSWR = $(\rho + 1) / (\rho - 1)$. This latter more complex route is chosen here as the reflection coefficient is a convenient value to have on-hand for future applications.

Strictly speaking, these should be the RF voltages (RMS, or peak) but the majority of diode detectors deliver a DC level close to the peak of the RF waveform, minus any forward drop in the diodes. By using Schotky diodes this drop can be made adequately low, in the region of 0.2 to 0.4V, to ignore for practical purposes. So now $V_{DC} = V_{peak}$ and can be used directly in the VSWR calculation.

The PIC makes 16 readings of each of the forward and return DC voltages which are summed to give a pair of 14 bit values . The Forward reading is divided by the Reflected value to obtain the reflection calculation. The VSWR is then calculated as shown above. As the PIC can only work with integer maths, scaling factors of 65536 (16 bits) are liberally sprinkled around the calculation indiscriminately, to raise numbers up to useable values. This is not the time or place to go into the full PIC code for the calculations, but the source code [3] is fully documented and all the important routines are in their own blocks

Power

VSWR calculation is absolute, as it is the ratio between two identically derived quantities. With a properly matched load RF power is given by V_{RMS}^2 / Zo (Zo usually 50Ω), so we now need an absolute voltage level rather than just a ratio. Assume, for example, our RF detector delivers a rectified DC level of $V_{RF(peak)}$ divided by a scaling , or coupling factor, K. For a sinewave, $V_{peak} = V_{RMS} * \surd 2$ so our DC level , $V_{DC} = \surd 2 * V_{RMS} / K$. (again ignoring diode drop), or $V_{RMS} = V_{DC} * K / \surd 2$

Plugging this into the equation for power gives us : $P_{RF} = V_{DC}^2 * K^2 / Zo / 2$

If we know the voltage division ratio K in the detector we can get a reasonably accurate value for the actual RF power delivered to the load by squaring the Forward reading and multiplying by the appropriate values.

RF Detector Head

Figure 2 shows the circuit diagram of a VSWR detector head suitable for the HF range and beyond, typical of that inside many SWR bridges. A current transformer is made up from a high-permeability ferrite torroid with a single turn primary formed by the main conductor passing though the middle of the core. N turns are wound on to form the secondary winding. The result is that a current equal to I_{RF} / N is driven through each of the pair of resistors of value R so that the voltage across each resistor is then $I_{RF} / N * R$. The voltage developed across each of the two resistors is identical in value but shifted in phase by 180° . This current-related voltage is referred to as V_I

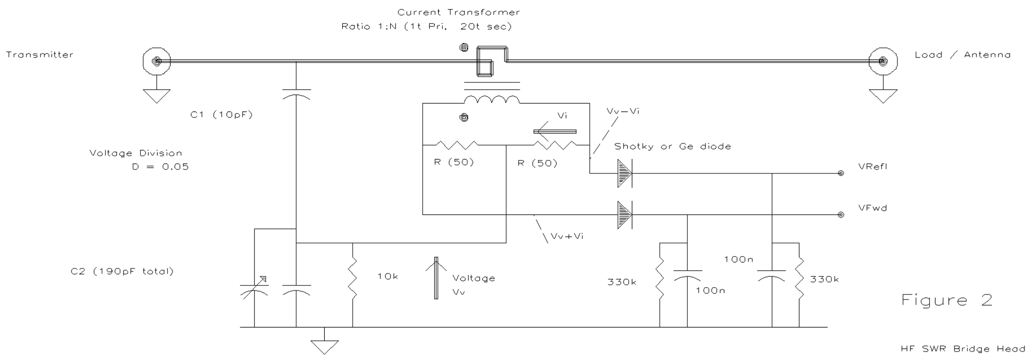


Figure 2

HF SWR Bridge Head

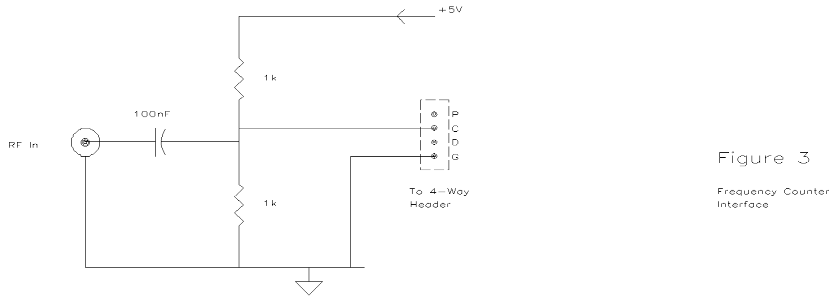


Figure 3

Frequency Counter Interface

A voltage divider is made up from two capacitors C1 and C2. Resistors could be used, but at high power levels they could get hot and the lossless capacitor divider is usually preferred. The 10k resistor just serves as a DC path for the diode current. The voltage division ratio D is equal to C1 / (C1 + C2). In a system with characteristic impedance Zo, we know from Ohm's Law that with a perfectly matched load $V_{RF} = I_{RF} * Zo$, so by choosing D and N appropriately, we can arrange for this tapped down voltage to be equal to that delivered from the current transformer *when the load is terminated with the characteristic impedance Zo*. By adding each of the two out-of-phase current-derived voltages to the tapped down voltage (Shown on Figure 2 as V_V), one will subtract and cancel, the other will double in value the when the bridge is balanced.

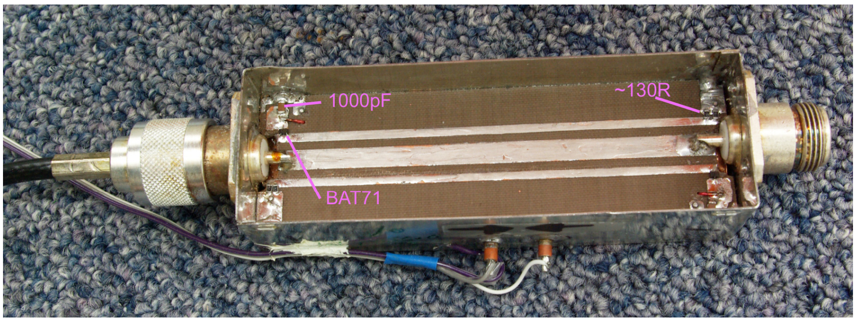
The condition for balance is when $V_{RF} * D = I_{RF} / N * R$. With a load equal to Zo $V_{RF} = I_{RF} * Zo$ so V_{RF} cancels leaving $D = R / (N * Zo)$ D, N and R can now be chosen to satisfy this equation for a particular Zo (lets keep to 50Ω), but they can still be selected over a wide range to suit power level and practicality. The values shown bracketed in Figure 2 show a 'nice' set of values, R = 50Ω, N = 20 and D = 0.05. The balance equation is satisfied since 50 / (20 * 50) = 0.05

For any mismatched load, V_I is no longer equal to V_{RF}/K and a new pair of voltages are generated by the two additions [Note 2] These are the V_{FWD} and V_{REF} we need for the VSWR calculation and can be rectified as shown and fed to the PIC module as analogue Channels 0 and 1 respectively. The result of summing the two voltages means that with a matched load, V_{FWD} is now $2 * V_{RF} * D$, being the sum of both (equal) terms and resulting in the factor K needed for the RF Power calculation.

The values shown have a current sampling transformer ratio of 1:20 (N = 20) and voltage divider D = 0.05 giving a value for K of 10. 10 Watts of RF in a 50Ω load will result in V_{FWD} = 2.23V RMS, supplying about 3.1V rectified DC. For higher power designs, either D, N and K can be altered, or the rectified voltages can be divided down to fit into the 0 - 4.09V range for the A/D converter

UHF and Microwave Detector Heads

At the higher frequencies, transformer based RF heads like that shown become impractical, and transmission line based ones are usually chosen. These are rarely possible to design from first principles, and a certain amount of trial and error (suck-it-and-see) is involved with their setting up, balancing and calibration. In particular, even when balanced, the voltage division K is unknown, and more often than not frequency dependent. So absolute power calculation can become fraught. But with access to a calibrated power meter, measurements can be made and the calibration factors be worked out; DC levels can then be adjusted by potentiometers, For more information on suitable detector heads take a look in the test equipment sections of the various VHF and Microwave publications. As an example, Photo 4 shows a homebrew SWR head built for monitoring a QRO solid state VHF transmitter. This gives a DC output of around 7V for 166 Watts of RF at 70MHz, which has to be reduced in a potential divider before going to the A/D converter.



By the time this appears in print, it intended that the scaling factor for absolute power measurement will be made user-adjustable; a third analogue input being used to inject a 'calibration' voltage which the PIC interprets as a scaling factor. Setting the value this way allows several different RF heads to be used with the same PIC code without reprogramming the PIC itself for different power calibration values – each head can carry its own calibration voltage setting resistor. The 4.096V reference is brought out via R4 on the module to the channel 3 header pin. A single external resistor to ground, specific to each head unit, then sets the correct calibration voltage which is applied the Analogue channel 3. Connections are shown in Figure 2.

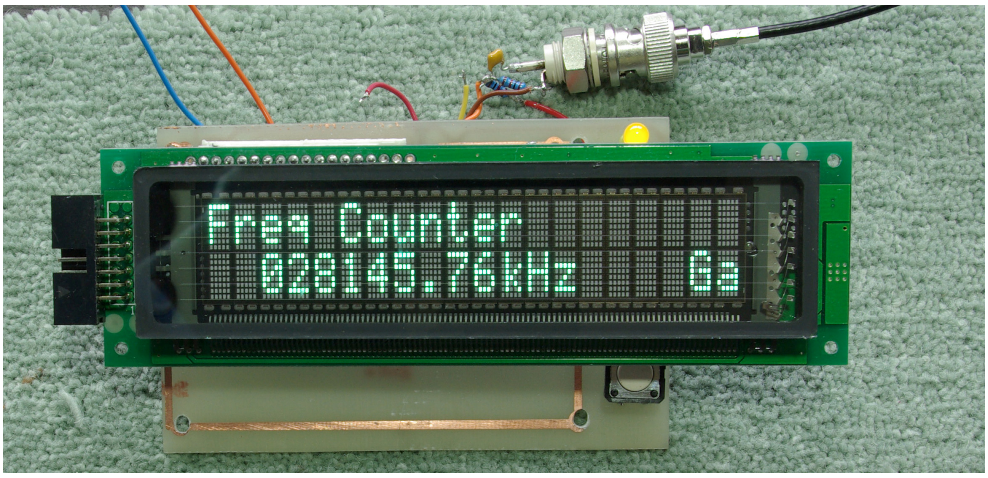
Frequency Counter

Both the 16F628 and 16F819 PIC devices include counter timers that can be used as the basis of a frequency meter; asynchronous counters that can be clocked at high speed. TIMER1 is a 16 bit counter which can be driven from the RB6 input line. This connection is brought out on the 4-way header otherwise used for In-Circuit programming - the pin labelled 'C'. The input goes via a Schmitt trigger buffer within the PIC, so the waveform to be measured does not even have to be converted to true logic levels. All that is required is to bias the input at half supply voltage and AC- couple the RF as shown in Figure 3.

The PIC data sheet specifies an upper limit of 20MHz for the timers, but I have had them running satisfactorily to a bit over 80MHz. Many users report success up to 70MHz, so it can reasonably be assumed full HF band coverage, and most likely up to 50MHz will be possible. An RF input level of +8dBm or greater was needed to ensure reliable operation. Peak-to-peak amplitude must be high enough to traverse the two Schmitt Trigger voltage thresholds.

The PIC software first resets the TIMER1 value to zero and enables the counting. After a precise gate period, defined by the PICs clock and internal instruction loops, the counter is stopped and the total number of counts read out. The 16 bit TIMER1 register is extended by software monitoring its overflow into a 32 bit count. The maximum count of 2^{32}, which is around 4 Billion, is more than enough for a 70MHz signal to be measured in a 10s window if necessary.

Photo 5 Shows the Frequency Counter display.



The gate time – and readout resolution - can be cycled though the values 10ms, 100ms and 1s by repeatedly pressing the pushbutton. An IF offset can be programmed into semi-permanent non-volatile memory by holding the pushbutton down while switching on, or resetting the module. When the IF offset display appears, operate the rotary encoder to choose your desired value, either positive or negative. When selected, press the pushbutton to store into memory and resume normal frequency meter operation. This IF offset will be preserved until it is changed using the same procedure.

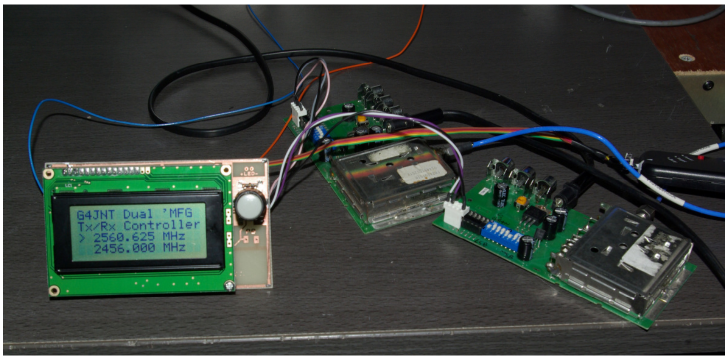
Synthesiser Controller

The last plug-and-play design is of a more specialist nature. It will control two independent synthesiser chips of the TSA5505, SP5505, or U6239 type that use an I2C two-wire bus [6] for programming. Such devices are in widespread use for TV, satellite and cable TV tuners, and many of the 2.4GHz Rx and Tx modules. This design was specifically intended for control of a pair of G1MFG FM TV tuner modules, allowing, for example, independent tuning for transmit and receive. Ports A0-3 are configured for digital operation (use a low value resistor in series with each for protection) and connected to the synthesiser chip SCL and SDA programming lines according to Table 1. On the MFG TV modules, the existing PIC is removed so the connections from the controller can conveniently be made pins 1 and 2 on the now-empty IC socket.

Table 1 - Connections for dual I2C bus synthesizer chip programming

Controller Conn	Synth Unit	I2C Bus Line	G1MFG Module Connection
A0	1	SDA 1	Module A Pin 1
A1	1	SCL 1	Module A Pin 2
A2	2	SDA 2	Module B Pin 1
A3	2	SCL 2	Module B Pin 2

Photo 6 shows the controller in operation



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G4JNT Dual 'MFG
Tx/Rx Controller
> 2560.625 MHz
  2456.000 MHz
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Freq 1 or Freq2 are selected in turn, and may be altered in 125kHz or 4MHz steps. Selection is made by repeated pressing the pushbutton to cycle though each frequency tuning option. IF Offset and upper / lower tuning limits for each module can be set by holding the pushbutton down while powering on or resetting the controller, then following the prompts.

PIC Programming

The ready-to-go projects described are all very well as examples of the power of the PIC microcontroller to do an infinite variety of tasks, but to get the most out of them, and this development module, you really need to be ale to programme your own. This takes two stages :

Programming the device itself

Or actually loading the code into the chip using a hardware programmer. Just being able to do this will enable you to download the latest version of any code and use it, with well as new applications as soon as they are published. Without being able to 'blow' PIC devices, you will be forced to purchase ready programmed chips, which usually cost a lot, are not amenable to upgrades and hardly ever to customisation, and are very tedious for designers to have to supply. And we get unhappy having to do it. And charge a lot for them

All you need is a PIC programmer and software to drive it. There are many home-brew designs out there, several have been mentioned in RadCom over the years, but I advise paying a bit more and getting the Microchip **PicKit 2** programmer. This will handle every PIC they make, is ensured of all upgrades and comes with full support from the chip manufacturers themselves – who better!. Nearly all the component suppliers sell the **PicKit**, and it can often be found at special discount prices. You load in the .HEX file, click the PGM button and get a fully functional chip a few seconds later.

Writing Your Own Code

This is where the fun really starts and all you really need is the MPASM assembler software and the PIC include, or support, files. They can be downloaded from [1], although it may be necessary to download the full MPLAB development suite which can be quite large. Also a text editor to actually write the source code, or .ASM files. At least that is all you need for writing in assembler code – my own personal choice after many years of PIC programming.

Alternatively, there are high level programming languages like Basic and C, which is the route chosen by many especially those coming into programming via an educational route. Having never used high level PIC languages, I can't say how good the code produced is, but I'll bet the frequency counter described here couldn't have been written using one. And certainly not the PIC DDS described in the April *Design Notes*.

I repeat the warning issued above

“ PIC programming is one of the most addictive things ever invented! Once you start writing code, all thoughts of food, drink, bed, exercise stop until the job works. “

References

[1] Arizona Microchip www.microchip.com

[2] Low Cost LCD modules Contact Kevin, G3AAF, at Kevin@avery03.fsnet.co.uk

[3] “*Rotary Encoders on the cheap*” G4JNT, ‘Design Notes’, RadCom, December 2010, pp 38-39

[4] Full construction details of the PIC module, PCBs, PICs, software downloads including source code. www.g4jnt.com/PIC_Controller.htm

[5] Farnell www.farnell.co.uk

[6] I2C Bus http://en.wikipedia.org/wiki/I2c

[Note 1] A 10-times potential divider cannot be made with just two individual standard E24 value resistors. but 9.1kΩ in parallel with 820kΩ at the top (for a total of 9.0001kΩ) and 1kΩ in the bottom is a solution that even with 0.1% close tolerance resistors gives a negligible error.

A 100 times divider can use 3 * 33kΩ in series, working against 1kΩ at the bottom. Having three input resistors in series means that the voltage across each can be reduced – advisable when measuring up to 409 Volts to keep power dissipation down.

[Note 2] It is possible to show mathematically that even for reactive loads, provided V_{FWD} and V_{REF} are treated as complex numbers, the equations hold and the complex load impedance can be calculated from the result – Both phase and amplitude of the output waveforms do have be measured.

Figure 1	PIC_Ctrlr_Circuit.gif	Overall Circuit Diagram of the PIC Controller Module showing all optional components
Figure 2	PicMdl_Figs2&3.gif	Circuit Diagram of SWR Bridge Head for HF and up.
Figure 3	“” “” “”	Interfacing for a Frequency Counter
Photo 1	Pic_Ctrlr_PCB_Comp.jpg	The original breadboard PCB from the rear showing Components and Input/Output Connections and the first batch of properly manufactured boards
Photo 2	Genctrlr_VSWRMon.JPG	Front of the module showing the display and rotary encoder
Photo 3	4ChanVMeter.JPG	4-Channel Voltmeter
Photo 4	VHF_SWR_Head.jpg	VHF High Power SWR bridge head.
Photo 5	FreqCounter.jpg	Frequency Counter Display with a Vacuum Fluorescent display installed. (The PIC code was written for a 4 line display, so part of the text showing the gating interval is missing)
Photo 6	Dual_MFG_Ctrlr.jpg	I2C Synthesizer Controller display.